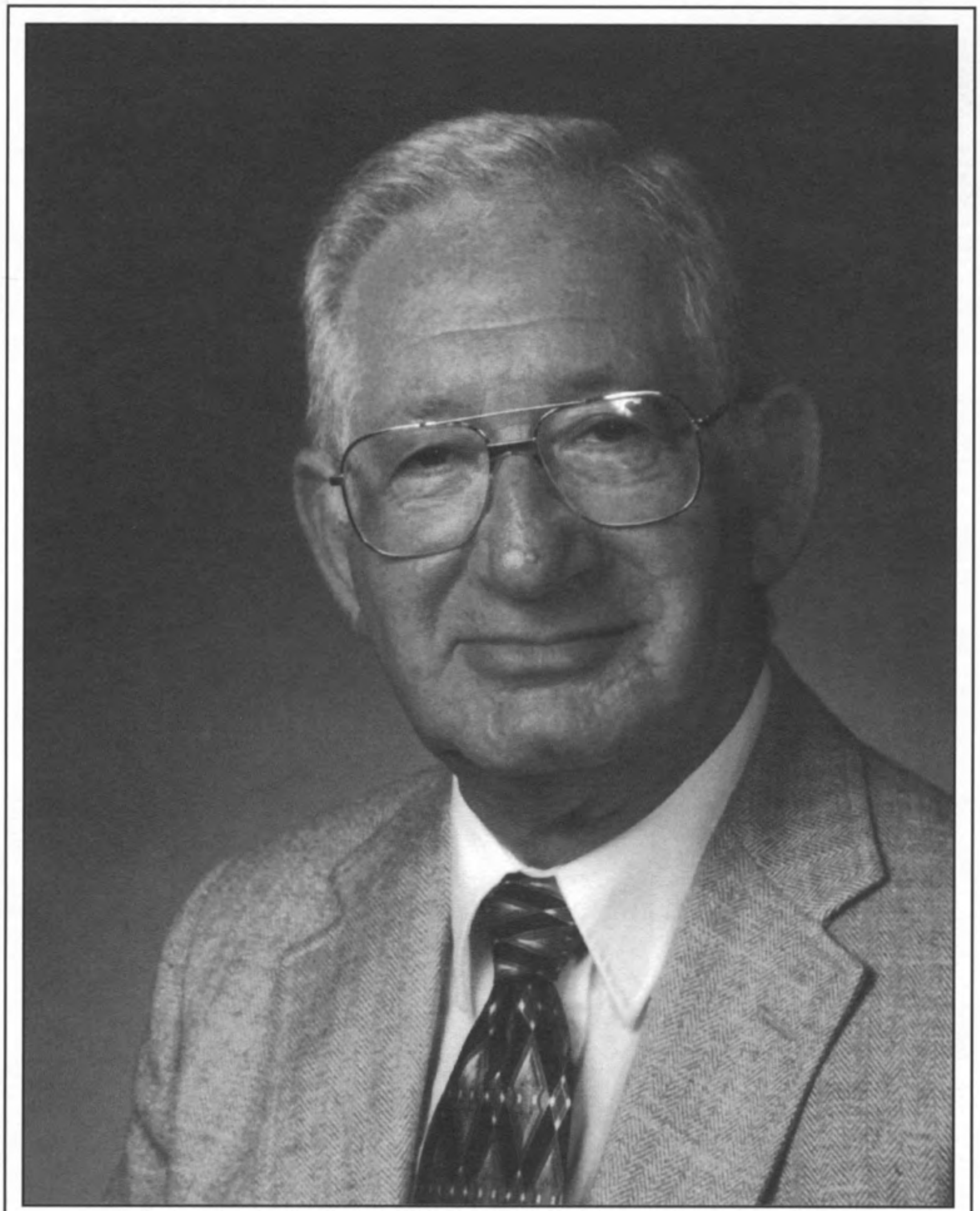
The Genesis of Surgical Anesthesia



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THE GENESIS OF SURGICAL ANESTHESIA

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Dedication

To my wife Betty,
whose constant support and
high tolerance for my prolonged
absences from home and
my protracted periods of
sequestration when other aspects
of life were frequently neglected,
this book is lovingly dedicated.

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Preface

On October 16, 1846 William Morton, a dentist of Boston, administered ether vapor by inhalation to Eban Frost from whom a tumor of the jaw was removed. During the operation the patient remained in a state of obvious unresponsiveness to the grievous pain known to be associated with such a procedure. 1996 saw the 150th anniversary of this date. It is fitting that Morton's achievement and related events should be widely noted and celebrated because this particuar etherization constituted the introduction of anesthesia into clinical practice.

The capability to provide relief from pain during surgery has rightly been hailed as one of the most important advances in the history of the healing arts and sciences. If modern physicians lacked an effective method of preventing pain during surgical operations, our methods of medical practice would be quite different from those with which we are familiar. But when recounting and celebrating the mid 19th century "discovery" of anesthesia, it is quite easy to become so overwhelmed with the significance of the contributions of Morton and others around this time that the accomplishments of earlier workers, some dating back to remote beginnings of civilzation, tend to be glossed over. When examining events before the mid-19th century that can be associated with the development of anesthesia, it becomes possible to discern a pattern of stepwise and incremental gathering of information which in its totality ultimately resulted in the use of clinical anesthesia. It becomes apparent that somebody in every age was concerned with some aspect of pain relief or medical gases and that their total cumulative experience and writings, not simply those of one or a small group of individuals, were essential to the final achievement of pain-free surgery. It becomes futile to try to designate any one individual or group as the discoverer of anesthesia.

Many authors in the past who have related the story of anesthesia have described these early pre-Morton contributions, some in considerable detail. But in spite of this many individuals, ideas, situations, and topics relevant to the development of anesthesia appear to have escaped attention or have not been given an emphasis proportional to their significance or interest. Examples of such persons and topics include the members of the Lunar Society of Birmingham and their individual and collective influence on the unfolding of concepts basic to anesthesia as well as their roles in establishing a society which was receptive to the concept of pain-free surgery when it was finally offered. Another neglected subject is pneumatic medicine including medicinal application of gases destined to become anesthetic agents. This topic is essential to an understanding of the evolution of anesthesia and the limited attention formerly afforded to this topic is extraordinary. Yet another such area is the apparently widespread knowledge prior to 1846 of techniques which could be and on occasion were used to render patients unresponsive before certain surgical and obstetrical manipulations. The concept of surgical anesthesia was apparently not novel in 1846. The material presented in the present volume attempts to emphasize these areas which, although they may have been mentioned in previous works, have not received the attention that they need or deserve.

This volume deals almost exclusively with the foundations of anesthesia before 1846. A brief description of the actual introduction of clinical anesthesia around 1846, a tale told many times previously, is included to make the story complete and also to demonstrate the futility of attempting to designate a "discoverer of anesthesia" from among claimants for the honor.

During the early phases of preparation of this volume, I regarded and designated the various topics from the pre-1846 era as being in the realm of "anesthesia prehistory". But it became apparent that the distinction between "prehistory" and "history" of anesthesia was arbitrary and factitious. Many of the individuals described in this book and the developments and progress associated with them qualify as constituting *bona fide* anesthesia history. The medical writings of Thomas Beddoes were no less significant to the ultimate status of anesthesia than those of J.Y. Simpson. The role of Michael Faraday in popularizing the use of ether in the society of his day was no less important than that of Charles Jackson in directing the attention of Morton to ether a generation later. Developments discussed in this volume are mostly in the main stream of anesthesia history and were essential to the final achievement. The materials and opinions presented are, of course, one individual's interpretation of the early developments.

A few peculiarities of this book deserve comment. Most of the material considered was based on sources written in the English language because all of my research on these topics was undertaken in English-speaking countries, and in addition I am not sufficiently fluent in any foreign language to extend the search further. Interested historians literate in other languages are encouraged to search for early anesthesia related material in foreign sources which may have been so far overlooked. They will probably uncover information which could alter the interpretation of the course of anesthesia history. The current volume is heavily oriented toward narration of details concerning individuals and their contributions to knowledge essential to the employment of anesthesia. Perhaps some will object to the presentation of large amounts of biographical details, personal anecdotes, family life, personality traits etc. But narration of history emphasizing the important individuals involved and presenting developments from their particular standpoints is a recognized biographical approach.(1) Besides, the individuals involved in the narrative were interesting people, and their lives and personalities are worthy of attention. They would have made good companions. At certain places in the text the subject matter may come to resemble a catalog of names, facts, or developments with a minimal amount of correlative material immediately obvious. Examples are descriptions of numerous apparently unrelated medicinal uses of ether or other gaseous substances. The purpose of this type of exposition is to place a number of facts in evidence quickly so that some conclusion or generalizarion can be made relative to the aforementioned facts.

It seems remarkable that certan topics that I have come to regard as being of greatest importance to the subsequent development of anesthesia (such as the field of pneumatic medicine) have been almost completely overlooked by previous commentators on anesthesia history. In these areas I have been particularly compendious, frequently examining content in considerable detail in the hope that it is possible to determine not only what was concluded, but also how those beliefs were rationalized. I trust that the often synoptic presentation of material will not constitute an impediment to an appreciation of the reasoning and behavior of the involved individuals. In recent years there has been great interest by medical historians in Thomas Beddoes. Numerous books and articles have appeared, including those of the Stanfields, of Porter and of Levere. These are writings of authors who are not medically qualified and who have stressed the societal and literary aspects of Beddoes' career. His medical activities have been less extensively covered and very little attention has been given to the content of his medical writings. In the present volume the medical writings of Beddoes are emphasized for two reasons. First, they demonstrate how an important 18th century physician and medical theorist approached disease and its mangagment within the context of his period, knowledge, and understanding of the teachings of his day. Also, the medical writings of Beddoes are a most important example of how gases and vapors came to be used within the framework of 18th century medicine to ultimately become the origin of modern clinical anesthesia.

In medicine, contrary to the often quoted aphorism of Santayana, he who forgets the past is often not neccessarily doomed to relive it. It is possible to become a highly competent and proficient clinical practitioner without knowing very much about the history of anesthesia. Knowledge concerning Humphry Davy, John Snow, or Arthur Guedel is not a prerequisite for administering a creditable anesthetic. But occasional attention to and meditation on the lives, thoughts, contributions, and modes of practice of those who have gone before adds variety, interest, scope and an additional measure of understanding to clinical practice. One particular benefit of historical information derives from knowledge of how and why, in bygone eras, certain modes of medical practice were formulated as well as the principles upon which they were based. Armed with these facts, one can discern many similarities between currently popular "alternative" forms of medical therapy and comparable ideas and systems from the past which simply failed to stand the test of time and then predict a similar fate for these latter day attempts at treatment.

I owe greatest thanks to the various libraries and the many members of their staffs who provided materials and assistance during research to gather the material related in this volume approximately during the period 1982-1993. These include the libraries of Oregon Health Sciences University, the National Library of Medicine, and the Library of Congress in the United States, and in England the British Library and its various divisions, the Wellcome Institute Library, the Royal Society of Medicine Library, the library of the Royal College of Surgeons of England, the Royal Institution of Great Britain, the University of London, the municipal libraries of Bristol and of the Borough of Marylebone, London, the library of Imperial College, London, and others. I am deeply indebted to Nuffield College, Royal College of Surgeons of England, for providing me with a home away from home during several working sessions in London. I also thank Dr. John F. Nunn and his Division of Anaesthesia, Clinical Research Centre, Northwick Park, for being my host during the 1982 sabbatical when this histroical project was launched. I gratefully acknowledge assistance from Oregon Health Sciences University for granting me a sabbatical leave in 1987 permitting a prolonged stay in London for library research and from the Research and Education Society, Department of Anesthesiology, OHSU, for providing financial support for an additional brief period of residence in Washington, D.C. and in London for continuation of library research.

I am greatly indebted to Dr. B. Raymond Fink for his editorial role in the preparation of the manuscript.

This work is intended for both the physician with an interest in the origins of modern anesthesia and also for medically untrained individuals who would like to learn about the foundations and early history of attempts to provide relief of pain during surgery. For the latter, some of the technical medical terms used in the text are explained and important chemical equations are labeled for easier comprehension.

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Chapter I

Anesthetics of the Ancients

Persistent and recurrent legends involving anesthesia history suggest existence and use of effective techniques for anesthesia in past ages.(1,2) The casual reader is likely to accept such suppositions as truth because of the positive, convincing, and confident manner in which such practices were described. Some historians and commentators unequivocally stated that individual practitioners or schools of medical practice in the ancient, medieval, or Renaissance world were accustomed to render their patients comfortable before commencing a surgical procedure. An example of such a statement is in the works of St. Hilary of Poitiers. It was written in the fourth century A.D. and is said to be the first reference to anesthesia in the "modern" era.(3) St. Hilary wrote: "Also when through some grave necessity part of the body must be cut away, the soul can be lulled to sleep by drugs, which overcome the pain and produce in the mind a death-like forgetfulness of its power of sense. Then limbs can be cut off without pain: the flesh is dead to all feeling and does not heed the deep thrust of the knife, because the soul within it is asleep."(4)

Authors in more recent times have suggested availability of both drugs and physical means for anesthesia in bygone eras.(5,6) One modern writer related that:

> "From the earliest times attempts were made to alleviate the pain incidental to surgical operations. Homer mentions nepenthe as employed for this purpose. Indian hemp (cannabis indica) and mandragora were used throughout the Middle Ages and the soporific sponge of Theoderic was in quite general use...."(7)

Some have concluded that knowledge of effective anesthetic drugs from earlier ages has been lost to modern practitioners (8) or, for one reason or another, has fallen into general disuse. The list of anesthetics supposedly used by pre-Columbian surgeons in certain early American civilizations is extensive.(9)

James Moore, writing in 1784, commented on some of the early surgical observations pertaining to pain associated with wounds and surgical procedures. He speculated that perhaps the first discovery in surgery was the propriety of keeping a wounded limb quiet and without motion. Another early observation was probably that cold aggravated pain of various conditions. Therefore the wound would frequently be covered with leaves and these leaves acquired a reputation as healing agents, whereas they actually had nothing to do with healing of lesions. The next observation, wrote Moore, was probably related to invention of cutting instruments. Enlarging a wound to facilitate the removal of arrows or other missiles facilitated healing, and this principle was carried over to other types of lesions such as sinuses where no foreign object was present. Excessively painful devices such as actual cautery and scissors were abandoned.(10) John Snow believed that modern anesthetics did not arise from attempts of the ancients to relieve pain of surgery but rather from practices of inhaling chemical and medicinal substances therapeutically. He described smokes said to be breathed in various rites and ceremonies.(11)

Some of the drugs known in times past, for example opium, cannabis, and mandragora certainly had the capability to compel sleep and alter mental status. In this role they would have been useful for inducing a trance-like state during which mystical-religious healing rites could be performed. An example is the ceremonies practiced in ancient Greece in association with the Cult of Aesculapius, described in this book in the section on Greek medicine. Also, these drugs were undoubtedly used as anodynes (drugs which calmed, soothed, and comforted patients and allayed pain). Crude techniques involving medicinal substances for pain relief are probably ancient and began with notation of the effects of crude plant and mineral substances on the body. An example is the observation by the Incas of effects of coca leaves on pain and bodily discomfort.(12) However, it appears quite unlikely that before the mid 19th century any universally applicable and effective method of mitigating pain during surgery was available to patients and medical practitioners and was actually employed. Reasons for this conclusion will be stated after review of selected writings on anesthesia from bygone ages. Perhaps some of the failure to develop anesthesia during many centuries of the existence of civilized man was related to ideas about the necessity to experience pain as a purification rite or perhaps beliefs about various societal prohibitions regarding attempts to avoid pain.(5) Indifference to physical pain and pleasure was taught by some influential philosophers such as the Stoics in the pre-Christian era.(13)

PHYSICAL MEANS OF ANESTHESIA IN ANCIENT TIMES

Application of physical forces to the body in several ways was reputed to produce effective pain relief for surgery.(5) One such method was compression in the neck of the principal arteries supplying blood to the brain.(14) It is suggested in modern dictionaries that the name of these vessels, the "carotid" arteries, is derived from the Greek word "karoun" meaning "to stupefy" or "to throttle." Related Greek words are "karos" (heavy sleep) and "karotikos" (stupefying).(14a) The maneuver might operate in two ways. First, the supply of blood to the brain might be interrupted by occlusion of the arteries with resulting loss of consciousness. Alternatively, pressure on certain physiological regulatory structures (carotid sinus) closely associated with these arteries often causes impressive slowing of the pulse through a nervous reflex mechanism. The diminution of blood flow to the brain associated with the slow pulse could have caused a brief period of fainting. Whatever mechanism was operative, it is conceivable that performance of short surgical procedures was possible during brief periods of unconsciousness induced by the low brain blood flow. However it is uncertain whether this technique was ever widely used if it was used at all. I have been unable to find any specific account confirming that the method was actually applied during a surgical procedure in ancient times. In manipulating the blood flow to the brain in the fashion described above by individuals totally lacking in physiological concepts, the margin between producing a brief period of unconsciousness on the one hand and permanent brain damage on the other appears unacceptably narrow by modern standards. Recall the punishment prescribed for physicians who obtained unsatisfactory medical results in the Code of Hammurabi, which regulated human conduct in Mesopotamia about 1900 B.C. It was written:

> "If a physician shall make a severe wound with an operating knife and kill him [a patient], or shall open an abscess with an operating knife and destroy an eye, his hands shall be cut off."(15)

If the penalty for an anesthetic death were equally severe, it seems unlikely that an ancient practitioner would choose to risk producing anesthesia by such a hazardous technique as carotid pressure. Tweedy emphasized that restrictions placed upon the practice of medicine in former times, and the liabilities to which medical practitioners were exposed in cases of ill-success or failure, did much to check the progress of medical thought and practice over the ages.(16) But apparently this anesthetic technique has been used with some degree of success in more modern times. Sir James Y. Simpson indicated that in the sixteenth and seventeenth centuries authorities such as Valverdi and Hoffman suggested controlled strangulation by garroting or compression of carotid vessels to produce surgical anesthesia.(17) Dr. L. Steiner indicated that he had done a simple operation in Java using carotid pressure for anesthesia about 1902.(18)

Another archaic physical method for producing anesthesia was thought to be a sharp blow delivered to the jaw or to the skull. This technique was believed to have been practiced in ancient Egypt. It was alleged that the skull would be struck with considerable force using some type of blunt object. Surgery could then have been performed during the ensuing period of concussive loss of consciousness. Such an impact would have involved a considerable risk of inflicting a depressed skull fracture. To obviate this possibility ancient practitioners were said to have fabricated a wooden or ceramic bowl modeled to conform closely to the shape of the skull. This helmet was to be struck with a bludgeon. Delivering the blow in this manner distributed its force over a wide area and minimized the chance of skull fracture. But there is no evidence that this imaginative technique was ever actually applied. Egyptologists who were queried by a previous author were not aware of such a practice. Curators of Egyptian artifacts had no knowledge of these hat-like objects in their collections.(19) An important objective of ancient Egyptian funerary practices involved supplying the material needs of the departed in afterlife. If such important medical objects existed, they would likely have been supplied to the dead and found in tombs. Such has not been the case. The "anesthetic helmet," although intuitively appealing, lacks a factual basis.

Other physical methods for anesthesia proposed in preanesthetic times could have been really effective. Numbness of an extremity produced by prolonged pressure on a major nerve as proposed by Moore(10) and refrigeration of the affected part, as alleged to have been described by Baron Dominique Larrey(20), were both advocated to provide pain relief during amputations. These will be considered subsequently. One wonders why these techniques were not used more often.

ANESTHESIA WITH DRUGS IN BYGONE DAYS

The practice of using drugs for the relief of pain, as mentioned above, is very old.(21) Ability of certain drugs to cause deep sleep and stupor while relieving pain has been known since antiquity.(5) Physicians of the school of Hippocrates on the Island of Cos and surrounding territories classified drugs on the basis of body humors. Some drugs were believed to be cooling and anodyne and were classified as refrigerants. Included in this group were the drugs hyoscyamus and wild lettuce. In the Iliad, Homer described how Helen added "Nepenthes" to wine which made the recipients sleepy and indifferent to their surroundings. The Greek word "pharmakon" occurs sixteen times in the Odyssey to refer to drugs of various types. The designation "pharmakon" as used in Homer means magic plant but by the time of Hesiod (8th Cent. B.C.) the magic implications were gone thanks to secularization of medicine which had occurred in Greece.(22) One use of the word in the Iliad was in reference to the above mentioned "Nepenthes," a sedative or narcotic that Helen put into the wine (book 4, canto 220) which assuaged suffering, dispelled anger and caused forgetfulness of all ills. She had obtained this preparation from Egypt where many potent drugs were said to originate.(23)

Similar sedative and anesthetic drugs were used in China. One legend involved Pien Ch'iao, a physician of note who practiced about 255 B.C. He caused two men to drink of a drugged wine which made them insensible as if dead for three days. During that time, he opened their chests and exchanged their hearts. They awoke and subsequently departed. Hua T'o, born about 150 A.D. used a wine containing a certain effervescent powder which, upon ingestion, caused insensibility to pain.(23)

Surgical operations appear to have been performed in India in ancient times and anesthetic regimens involving psychoanesthesia, alcohol and other drugs were described in ancient Indian medical writings.(24)

In February, 1848, scarcely 14 months after the introduction of clinical anesthesia into England, a paper with a primarily historical orientation was read before the South London Medical Society. The author, Thomas Silvester, was quite certain that since man is surrounded by agents possessing the wonderful property of alleviating pain, it would be surprising if anesthesia had not been practiced before modern times. He believed that "the ample treasury of nature had been ransacked for remedies." He inferred, from terms used in Greek language, that "they [the Greeks] were acquainted with medicaments, now quite unknown, possessing properties of a very singular kind" and cited the activities of Helen, as described in the Iliad and the Odyssey (see above).

Other accounts from bygone eras involving depressant drugs were recounted by Silvester. A medieval practitioner, Johannes Batista Porta, used a soporific inhalant. An English writer named William Bullein commented upon the juice of a certain herb which could produce very deep sleep and anesthesia.(25) Anderson described Bullein as "a celebrated anesthetist, who lived in the reign of Henry VIII," who described "the juices of a certain herb pressed forth and kept in a closed earthen vessel, according to art bringeth deep sleep and casteth man into a trance or deep terrible sleep — until he shall be cut of the stone."(26) Classical literature was replete with passages describing draughts and potions capable of inducing stupor and also suggestions that anesthetic techniques were able to provide painless surgery in past eras (Some of these literary selections will be considered later).

There seemed to Silvester to be ample confirmation that anesthesia had been used in former eras. He then wondered why, if anesthesia had been used so successfully in ancient times, it had fallen out of use and had become unknown in ages closer to his own. He speculated that perhaps this was related to a public perception of a connection between use of sedative and depressant drugs* and

* R. Camerarius. The Living Library, A.D. 1625, translated into English by J. Mole., Chapter 13.

witchcraft in times when black arts preoccupied human thought. He quoted a 17th century document.

This work described how witches would invoke evil spirits by rubbing soporific ointments all over their bodies and then fall into a very deep sleep from which it was impossible to arouse them.(27) Other drugs could be compounded into "flying ointment" that, when rubbed over the body, would permit witches to perform their amazing aerial feats.(28) Camerarius, writing in 1625, also stated that the anesthetic state might be achieved by means of a gas obtained by treating certain drugs in vessels.(26)

EUFAEMIA MACCALYAN

The case history of Eufaemia MacCalyan provides a graphic and anesthetically oriented illustration of the attitude of society towards individuals caught practicing witchcraft in bygone days. This unfortunate woman, together with an accomplice, Agnes Sampson, was burned at the stake in Edinburgh in 1590-1591. Some authors have written that the charge against them consisted of circumventing Divine will by seeking to relieve the pain of childbirth during delivery of MacCalyan's twin sons.(29) Others have speculated that the actual offense for which these two were punished was more likely to have been simply the practice of witchcraft, and that attempts to relieve pain of childbirth would not have been particularly offensive had more conventional methods been used. Perhaps Sampson was perceived as a witch who had been consulted by the naive MacCalyan.(27, 28). But attention to the details of the cases against Sampson and MacCalyan provides evidence that simply seeking pain relief during labor in the Scotland of this era was an indictable capital offense. In the 24th year of the reign of King James VI of Scotland (later also James I of England), on June 9, 1591, a woman was criminally charged and tried for treasonably conspiring against his Majesty's life and practicing witchcraft, sorcery, murder etc.

The defendant was identified as Ewfame Makcalzane ("Eufaemia MacCalyan" "Effie") of Cliftounhall, spouse to Patrick Makcalzane, alias Moscrop. (Apparently Mr. Moscrop took the Makcalzane name to become eligible to receive an inheritance) The portion of the indictment dealing with practicing witchcraft and using her powers against the king: "to haif destroyit oure souverane lordis persoune, and bereft his Maiestie of his lyffe be that schameful and extraordinar meanis:..."(30) refers to an alleged cooperative effort on the part of a number of witches to raise a storm at sea and drown King James as he was returning from Denmark with his bride. (31) The total "dittay" (indictment) against Effie had 28 charges and included bewitching several individuals in various ways, consorting with other witches, consulting other witches about the murder of her husband, bringing harm on other individuals using witchcraft, and promoting and impeding various marriages.(30) Charge 18 of the indictment dealt with the measures to obtain pain relief during labor using witchcraft. The modern reader should have little difficulty with the archaic spelling and vocabulary:

> "(18.) Indytit of consulting and seiking help att the said Anny Sampsoune, ane notorious Wich, for relief of your payne in the tyme of the birth of your twa sonnes; and ressauing (receiving) fra hir to that effect, ane boird stone, (probably a "bored stone — a fairy stone having a natural hole formed by the action of water…") to be layed vnder the bowster (bolster) putt vnder your heid. Inchantit mwildis (mold or soil) and powder put in ane peice paipar, to be vsit (used) and rowit (rolled) in your hair; and att the tyme of your drowis (labor pains) your guidmannis (husband's) sark (shirt) to be presentlie tane of him, and laid woumplit (folded) vnder your bedseit. The quhilk (which) being pradtesit by yow as ye had ressauit (received) the samin fra the said Annie, and informatioun of the vse thairof; your seiknes was cassin of yow, vnnaturallie in the birth of yaure fyrst sone, vpone ane dog; quhilk ranne away and was newir sene agane; and in the birth of yaure last sone, the same prakteis foirsaid was vsit, and your natural and kindlie payne vnnaturallie cassin of yow, vpon the wantoune catt in the hous; quhilk lyke wyis was newer sene their efter."(30)

Effie was found guilty of all these charges, including the attempt at the fantastic means of obstetrical anesthesia described, and was sentenced to be: "takin to the Castel-hill of Edinburghe and thair bund to ane staik and brunt in assis (ashes), quick (alive) to the death."(32) She must have been regarded as a particularly monstrous and vicious witch because of the specific and particularly harsh sentence of being burned alive, as opposed to being granted the customary preliminary strangulation as the flames were lit. All her goods were forfeit to the state. (Perhaps Makcalzane's greatest crime was being Roman Catholic in 16th century Presbyterian Scotland.)

Effie's alleged accomplice, Agnes (Annie) Sampsoun had been tried and convicted on January 27, 1590, for "Conspiring the King's death - Witchcraft - Sorcery - Incantation & c." and subsequently burned at the stake. The indictment against her consisted of 53 charges. Charge 42 related to the above described activities involving Eufamie Makcalzane and described how Sampsoun had placed "mwildis" (mold or soil) or other powder made of mens' joints and other body members taken from Natoun churchyard under Effie's bed ten days before her labor which, together with other measures, were designed to ease birth.

Of particular interest is charge 43 of the indictment against Sampsoun: "(43) Item, convict of the taking of the pane and seiknes of the Lady Hirmestoune, the nycht of hir delyuerie (delivery) of hir birth."(33) This direct and unqualified charge strongly suggests that simply attempting to relieve the pain of childbirth at this time and in this locality, regardless of the means employed, was a criminal offense. This conclusion is contrary to that expressed by some previous authors who have stated that the religious establishment in many times past banned witchcraft and use of obstetrical forceps, but had no particular objections to seeking relief of pain in childbirth if "conventional" methods were used.(34) The world was not yet ready for anesthesia.

DEPRESSANT DRUGS IN FORMER TIMES

Drugs used before modern times for management of pain and to secure sleep were principally poppy, hyoscyamus, mandragora, and cannabis (marijuana). Anesthetic agents and techniques allegedly used before 1846 have been comprehensively reviewed by Bauer.(6) Some ancient drugs could be inhaled when they were volatlized by placing them on a fire or otherwise heating them. Also, gases coming out of certain openings in the earth appeared to have medicinal properties.(5)

POPPY

Opium, extracted from the poppy plant, has been used for millennia. The Sumerians, Assyrians, Egyptians and Babylonians all used opium in various preparations. The drug was used by the Minoan and Mycenian civilizations as well.(35) They all appreciated that the juice of the poppy could induce sleep, relieve cough, stop the bowels, and alleviate pain. The effects of overdose of juice of the plant were known to include stupor and even death. There are references to opium (rosh) in Old Testament . Romans called poppy heads "caputa." "Ophion" is mentioned in the Talmud. The original home of opium was in Asia Minor and it came to Greece later. "Opium" is from the Greek "ophos" meaning juice. Arabic and Chinese cultures adopted similar names. Opium was first introduced into China by the Arabs. Eventually, import of the substance into China, particularly from India, reached staggering quantities and ultimately led to massive addiction and finally to the Opium war.(36)

The deep sleep associated with opium came to be described by many writers using Virgil's word "letheon;" a word which was to assume great significance in more modern times.(21) Based on Greek writings and Egyptian illustrations, it was concluded that the substance used by Helen, as related in the Odyssey and called by the Greek word "nepenthes," must have been dried opium from Egypt.(23) Celsus, who lived and wrote in Rome about the beginning of the Christian era, described directions for preparing pills with "tears of poppy" (juice extracted from the pod of the opium poppy). He recognized its potency and cautioned against its indiscriminate use. Recommended uses included induction of sleep, relief of earache and colic and in inflammations. Tears of poppy were mentioned over the ages by many subsequent writers, including Dioscorides, Galen, physicians of the school of Salerno, Pare, Fabricius and others. Opium may have achieved its greatest popularity in the Arab world because its use was still in accord with the Islamic prohibition against alcoholic beverages.(36) Opium-like substances prepared from Indian poppy were called "bhang."(14) A certain Gilbert of England was said to have prescribed poppy juice for operations in medieval times. It was given in repeated doses until sleep occurred. After the operation, the patient was revived with vinegar. If this drug was indeed used in this manner, heroic doses must have been necessary to produce adequate narcosis and frequently the vinegar must have failed. A recipe for making a soporific sponge is also attributed to Gilbert.(21) Paracelsus and other Renaissance physicians prescribed opium frequently. Paracelsus used laudanum and others used similar preparations. Other opium preparations gradually introduced into medical practice were black drop, paregoric (from Greek meaning "soothing" or "consoling"), opium pills, Dover's powders etc.(36)

In what may have been the earliest attempt at intravenous anesthesia, opium was used by Christopher Wren about 1656.*(37) This practice was described by Thomas Willis writing in 1684:

> "Many years ago I saw about three ounces of the tincture of opium, made very strong in Canary wine, and transfused into the jugular vein of a live dog. When his vein was closed, the dog ran about as he used to do, seeming to be little or not affected with it: but after a quarter of an hour, he began to be a little dozed to nod his head and at last to fall asleep: but we having no mind he should do so when we had hindered him for some time of it by beating, threatening him, and trying to make him run, at last by that means his sleepy inclination was quite off of him, and he became very sound and lively."(38)

(See below in section on early intravenous anesthesia.)

Sertürner isolated morphine, the first alkaloid to be discovered, from opium, in 1805.(36)

Hyocyamus

Hyoscine and hyoscyamine, together with the related drugs atropine and scopolamine, are used in medical practice today, most often for their effects on the autonomic nervous system. These substances, particularly scopolamine, can also produce marked memory loss and delirium. Scopolamine for a time enjoyed some popularity as a component of the combination of drugs used for "twilight sleep"

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* Probably a goose quill would have been introduced into a vein which had been surgically exposed and an animal bladder tied to the quill would have contained the opium solution which could be squeezed into the vein.

when this was a common obstetrical anesthetic technique. In bygone days, this type of drug was regarded as a soporific and was known to be poisonous. There was difficulty in standardizing the preparations from patient to patient. The seeds of the plant were used to prepare the drug for use. It was sometimes used to kill unwanted animals. Celsus suggested its use for toothache. Dioscorides described its toxicity: it caused a kind of insanity or a turbulent counterfeit of sleep; it produced alienation of the mind. In practice it was sometimes used with opium but the synergism between poppy and hyocyamus was apparently unrecognized. (21)

MANDRAGORA

If there were a true "Anesthetic of the Ancients," it would have been mandragora. This drug was prepared from the stems, leaves and bark of mandrake plants. These species were classified as solanaceous plants, that is as belonging to the nightshade family. They were unknown north of the Alps but were plentiful in Greece, the Greek islands, Italy and the near East. Classical mandrakes are different from the American variety which are also called "May Apples."

Over the ages, the mandrake has been endowed with a wondrous and mystical aura. Also, myths and folklore relating to many other plants believed to possess extraordinary properties appear to have been settled on the mandrake. Examples are superstitions regarding harvesting of the plants. Upon being torn from the ground, according to some tales, the mandrake would emit a horrible shriek, hearing of which would be fatal to the harvester. To avoid this fate, the plant could be partially dug with a few remaining roots staying in the ground. Then a starved dog was tied to the mandrake with a rope. The harvester, with plugged ears and from a safe distance, threw a scrap of food to the hungry dog. When the unsuspecting animal lunged for the food, the mandrake was completely uprooted and the ensuing shriek killed the dog while sparing the man. According to different legends, other unspecified dire consequences of taking a mandrake could be avoided by marking circles around the plant on the ground with a sword and then facing west while digging.(39)

The roots of the plant were often bifurcated. The shape and form of the plant suggested the human body to some observers. The mandrake was endowed with some human characteristics, including the peculiarities of sexual differentiation. Male and female plants were alleged to exist and the species enjoyed some popularity as a fetish credited with many remarkable attributes. Major uses of these plants included applications as an aphrodisiac and to enhance fertility.(39)

The various species of the plant were described in great detail. The mandragora described by Theophrastus was identified with belladonna. Leaves, fruit, seeds and bark were used medicinally, both internally and externally. Its soporific effect was its most prominent characteristic and its most wide application was probably in an enormous number of preparations classified as anodynes (i.e.

remedies which relieve pain by causing sleep).(39) Celsus, in the first century A.D. recommended a pillow stuffed with mandragora apples for sleep. (In 1787 this mode of therapy was revived when a Dr. Willis, physician to George III, prescribed a pillow filled with hops for his royal insomniac patient.(40))

Another reputed use for the mandrake was to provide comfort for the condemned. Under the name of "morion" or "death wine," it is said to have been administered to persons subjected to torture or slow and painful death.(26) There is a Jewish tradition that, at the time when death by crucifixion was common, women were accustomed to visit the prisoners on the cross, and to administer morion under the influence of which the sufferers passed into deep sleep. It was also said that after having received morion, when the victim was removed from the cross recovery frequently occurred. Thus, Roman soldiers were instructed to mutilate the bodies before removal from the cross.(41) In medieval times, the drug was allegedly taken by criminals about to undergo torture.(42) Within a historical review of anesthesia included in an 1847 article on chloroform, Simpson cited:

> " ...various authorities to show that the gall and vinegar or myrrhed wine given to our Savior before his crucifixion was probably at that time generally employed with the same effect."[referring to administration of the preparation to criminals about to be tortured].(43)

Use of preparations of mandragora for anesthesia during surgical procedures is described by many different writers of antiquity. The following passages are quoted from the scholarly study of Randolph on "Mandragora in Folklore and Medicine." An early such comment is that of Dioscorides in the first century A.D. relating the use of wine of mandragora:(44)

> "Some persons boil down the roots in wine to a third, strain it, and put it away, using one cyathus* in the case of persons suffering from insomnia or severe pain, or those about to be cut or cauterized, when they wish to produce anaesthesia."

Note particularly the use of the word "anaesthesia" in its modern sense by Dioscorides. He described anesthesia with mandragora twice more in his writings.

Another first century A.D. description of the anesthetic use of mandragora was that of Pliny:

> "..... an average dose is one cyathus. It is drunk..... before incisions and punctures to remove sensation; some persons can be put to sleep merely by the odor."

* One cyathus is equivalent in volume to about one moderate water glass. John Snow indicated that a cyathus was "rather more than an ounce and a half.(45)

Another example is from Serapion, a Syrian whose 9th century A.D. manuscript is said to be the oldest medical treatise in Arabic:

> "If it is necessary to cut or cauterize any member, and we wish that patient not to feel the pain, let him be given more [mandragora] to drink. A measure of four obols is given to drink to a person whom it is necessary to cauterize or cut. He will not feel the cauterizing or cutting because of the stupor which ensues. Surgeons administer it when they wish to cut or burn a member."

Avicenna, the illustrious 11th century Persian physician wrote of mandragora:

> "If anyone wishes any of his members cut, let him first drink three obols of it in wine, and it will produce stupor."

Pliny is said to have written:

> " Mandrake is taken against serpents, and before cutting and puncture, lest they be felt. Sometimes the smell is sufficient."(26)

One fascinating speculation was ventured by Thomas Silvester in 1848. He called attention to the story of Rachel and Leah and mandragora as related in the Old Testament (Genesis, Chapter 30, verse 14) This passage relates how Leah's son, Reuben, had gathered some mandragora plants in the fields and had brought them to his mother. Rachel approached Leah and bargained with her for the plants. She eventually received them in return for relinquishing to Leah some of the favors of their husband, Jacob. It is then stated that Rachel, who had been childless, gave birth to Benjamin. The common interpretation had been that Rachel wanted the mandragora plants as a means to enhance her fertility. However, Silvester wrote: "Is it not more probable, that the mandrake mentioned in Scripture as brought from the field by Reuben to his mother Leah, was sought for by Rachel for the purpose of alleviating the pains of parturition, which she was expecting shortly to undergo?"(25) If this is the true meaning of this passage of scripture it is certainly the first recorded instance of obstetrical anesthesia.

The anesthetic reputation of mandragora persisted among medical writers through the medieval era and into the Renaissance period. According to Giovanni della Porta (1536-1615):

> "Dioscorides says that persons will sleep right on in the position in which they have drunk mandragora, all sensation being destroyed for three or four hours from the time when the draft was administered, and that physicians use this when they wish to cauterize or cut any one."

In England, during the sixteenth century, Williyam Bullein is said to have had an anesthetic formula, the chief ingredient of which was mandragora. Bullein wrote that the preparation was particularly useful in lithotomy.(46) Bullein (also spelled Bulleyn or Bullien) discussed mandragora at great length in his general medical treatise, "Bullein's Bulwark of defence againste all sickness, sores and wounds etc." This work took the form of a dialogue between a physician and a gardener knowledgeable in the lore of plants and reiterates many of the beliefs stated above:

> "Marcellus [a physician]: What is the nature of mandragora? Hillarius [a gardener]: Many superstiticious and foolishe thinges have been devised of this herbe: a verie invention of Witches, and Hypocrites, the sudgestion a motion of the devill, to delute the weake hart of mankind withall for thei do afferme, that this herbe cometh of the sede, of some convicted dedde menne: and also, without the death of some living thing, it can not be drawen out of the yearth, to mannes use. Therefore, thei did teye some Dogge, or other living beaste, unto the roote thereof with a corde: and digged the yearth in copasse round about, and in the mean time, stopped their own eares for feare of the tirrable shrieke, and crie of this Mandrake. In which crie, it dieth not onely die it self, but the feare thereof: killeth the Dogge or beaste, which pulled it out of the yearth. And this herbe is called also anthropomorphos: because it beareth the Image of a man, and that is false, for no herbe have the shape of a man or woman, no truely, it is not natural of his owne growings: but by the craftie invention, of some false man, it is doen by arte. As many rootes maie bee made, in the formes of men, foules, and beastes, and secretly covered in the yearth: whiche when it is found, by the craftie hider thereof, the beholders be driven into no small admiration and wounder. Supposyng there by, that some strange fearfull thing shall quickly followe the same. My frend Marcellus, the discripcion of this Madrake (sic) as I have said, was nothing but the impasterous subtiltie of wicked people. Perhaps of friers, or supersticious Monkes: which have written thereof at legth, but as for Dioscorides, Galen and Plini &c. thei have not written thereof so largely for to have hed, armes, fingers &c. But there is an herbe called Mandrake, whose leaves be large and long, like unto large Lettice: whole apples bee in the forme of Cheries, verie colde, properly given to helpe conception some saie: as it appeareth by the wives of the holie Patriarch Jacob. The one was fruictful, the other did desire helpe, by the meanes of the mandrak: brought out of the fieldes by the handes of Ruben Leas sonne, This herbe have a long large roote, with twoo legges in forme, one wrapped about the other: and fine rootes like heere, growing upon it. But no armes, feete, fingers, handes, hedde, nor stalkes, but the leves crepe out of the grounde: whereof be twoo kindes, male and female, the male greater than the female. This herbe is cold in the third degree, and have vertue, to cause depe slepe: the strengthe is in the apple, and in rinde of the roote. The remnanat, that is in the leaves and inward partes of the roote, be but weake saieth Galen: the Sedes of the apple, saieth Dioscorides, beying drunke, will

> purge the bellie. The juice of the herbe pressed forthe, and kepte in a close yearthen vessel, according to arte: this bringeth slepe, & casteth men into a trans on a depe tirrible dreame, untill he be cutte of the stone &c. This herbe, sodden in wine, unto the third parte, doe purge black choller as well as Elleborus niger will do. The herbe stamped, and applied upon a wound or ulcer...(local uses)...: if the roote bee cutte in sondrie places, there will come forth a worthie juice, to annoint the forehead, to bring slepe...(use in miscarriages)...the roote is unpleasant to smell upon, and pestiferous saieth Plini...(instructions for timing of harvest and preparing wine of mandragora)...All these bee good to coole to cause slepe, moderately used. Two halfpence waight of the powder of the rinde therof, may be drunke in swete water, for the Kynges evill; or lack of slepe. The iuce thereof with oile and Honie, healeth wounds: and thus I ende of Mandrack, whiche in the old tyme, it was called "circram" of Witches, which had the virtue (saied thei) or craft to transforme bothe man, beast and herbe out of kinde: Among all other, thei wrought wounders by this herbe to provoke, be witche, or cast men into madde blind fanatics or frances called Love whiche rather maie be termed, not some beastly luste, and when it is wrought by herbes foolishness."(47)

Thomas Willis, writing in 1684, indicated that he knew of mandragora, but he said that it was rarely used in medical practice in his day.(48)

In the 1870's and 1880's Benjamin Ward Richardson made extensive studies on the effects of mandragora in animals and man and published the results.*(49) The inspiration for these studies on mandragora was a set of experiments using some of the first chloral hydrate brought from Germany to England. The action of the chloral hydrate in animals reminded Richardson to a great extent of the action of mandragora as described in writings from antiquity.(52) A Mr. Hanbury, F.R.S., who supplied the chloral hydrate was also able to secure a "splendid sample" of the root of "Atropa mandragora" plant from the Greek Isles. From this, Richardson prepared (as he said perhaps for the first time since the thirteenth century) "wine of mandragora."

Dioscorides gave directions for preparing wine of mandragora either by boiling the root in wine, reducing its volume to one-third, or, alternatively, for preparation of a tincture of the root with wine.(53) Obtaining a potent preparation apparently required considerable experimentation by Richardson. Eventually he made a

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* Sir Benjamin Ward Richardson (1828-1896) was a remarkably versatile Victorian British physician. He obtained the M.D. degree from the University of St. Andrews and subsequently also received several honorary degrees. He settled in London in 1855 and thereafter taught various subjects in several London medical schools. He had wide interests, including heart disease, surgery, anesthesia, and public health. He founded the medical journal, "Asclepiad," which was issued from 1884 to 1896. Every line of the eleven volumes was written by him personally. He was recognized by his medical colleagues and contemporaries for his role in general improvements in scientific medicine. He is probably best known in anesthesia history as the biographer of Dr. John Snow. (50,51)

tincture by permitting powdered mandragora leaf to steep for several weeks in weak wine. This produced the desired infusion with marked pharmacological action. He concluded that the active ingredients, being water soluble, had to be extracted in a weak wine solution rather than in strong.

Richardson was quite certain of the identity of the plant with which he was working and identified it as the "Anaesthetic of Antiquity," quoting from the writings of Dioscorides, Pliny, and Apuleius. The plant substance that was employed was the root of the Atropa mandragora, a solanaceous* plant growing in the Greek Isles, the Levant, Spain and in Italy. These authorities stated that for anesthesia, it was sufficient for some persons merely to smell the medicine. He was satisfied that the wine of mandragora which he had brewed was the preparation of which "three cyathi are given to those who require to be cut or cauterized." Some patients might die from a considerable draught of the preparation. The juice of the leaf was also vey potent and useful.(53) Richardson identified mandragora as the potion that Juliet drank and stated that Shakespeare's knowledge of this drug was derived from a book republished in Paris in 1528. Perhaps it was a book by Apuleius. Richardson related how mandragora for anesthetic use was gradually lost to the pharacopoea. The gradual abandonment of atropine-like anesthetics was attributed, in a later article by Leake, to the gradual recognition of the superiority of opium and of the introduction of alcoholic tinctures of opium by Paracelsus.(54) By the late Renaissance this drug was rarely used in medical practice, even in the Middle East.

Drugs derived from other belladonna plants gained and retained its place.(52,55)

In birds, Richardson observed that the tincture caused sleep, sometimes interrupted by short episodes of wildness and excitement. Rabbits slept quietly for more than one hour. Sometimes their awakening was stormy. Overdose of the drug caused repiratory arrest.(53) Generally in animals, administration of mandragora, orally or subcutaneously, caused rapid onset of narcotism: pupillary dilitation, paralysis of motion and sensation, and excitement during recovery. The dose required for effect varied considerably among different animal species but death from drug overdose was due to continued narcosis and respiratory paralysis. The heart continued to beat for several minutes after respiration ceased. Richardson believed that the respiratory arrest was not due to muscle failure, but rather to accumulation of secretions because the voluntary muscles responded to direct stimulation. He wondered whether mandragora might be an antidote for opium poisoning. He also questioned whether an alkaloid could be obtained from mandragora and whether it might be identical with atropine.(53,55)

In man, mandragora had a very potent action. The tincture numbed the tongue and left a characteristic taste for many hours. Twenty minims of wine of

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* Solanaceous - a member of the "nightshade" group of plants

mandragora caused a desire for sleep, a sense of fullness in the head, blurred vision, pupillary dilatation, perhaps hallucinations, exaggeration of sounds and restless excitability of a hysterical nature. These symptoms lasted for two days or longer and left residual effects. The prolonged sleep and delirium maintained the reputation of the drug for causing madness.(53,55)

Richardson claimed that mandragora played its part as the "Anaesthetic of Antiquity" uncommonly well even when divested of all its charms and enchantments.(52) He suggested that wine of mandragora was a general anesthetic of the most potent quality and suggested its use to deaden pain of surgery. Experiments using this potent infusion of mandragora never failed to confirm the ancient observations. He also believed that mandragora might be applicable in some situations where atropine was used, such as for producing pupilary dilitation, and also as a local anesthetic.* Other suggested uses were as an antidote in poisoning by opium or strychnine and in tetanus.

Richardson's papers of 1888 were his final communications on mandragora. He acknowledged that further work on the drug was necessary and stated his intention to resume this phase of his investigations but I have been unable to find any subsequent writings by him on the subject. In spite of his confidence in the potential anesthetic use of the drug, he apparently never actually evaluated its anaesthetic properties. John Snow had presumed that mandragora was not used as an anesthetic in bygone days because an authoritative medical botanist, Dr. William Woodville, did not mention its use in this fashion. Mandragora was identified as being anodyne and soporific but no anesthetic use was indicated.(56) But Snow shared the opinion later stated by Richardson that mandragora had the potential to be a useful anesthetic agent because it "is probable, that after ascertaining the right quantity to be administered for the purpose, this medicine (referring to belladonna or mandragora) might be used with considerable success and no great danger, to prevent the pain of operations, if chemistry had not supplied us with agents much more convenient."(45) [Snow had pointed out that overdosages of belladonna very rarely are fatal no matter how large the dose.] Perhaps it was this conjecture by Snow that kindled Richardson's optimistic, though transient, interest in possible clinical application of mandragora for anesthesia. C.J.S. Thompson has provided an extensive discussion of all aspects of mandragora.(57)

CANNABIS

Cannabis is another preparation frequently mentioned as an anesthetic in antiquity. It was concocted from the hemp plant, *Cannabis indica* or *C. sativa*. Fibers obtained from this plant are used in making rope. The dried leaves were burned

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* Local anesthesia was introduced into practice in 1884 by Carl Koller. Richardson must have been doing some studies on mandragora at about this time. His suggestion, while not original, was certainly novel for the time.

and the smoke inhaled. This form of cannabis is marijuana. The resinous extract made from the flowering tops of the plant is hashish and can be smoked, chewed or drunk.(5,46,58) The drug used by Chinese physicians, as described previously above, was identified as "Ma," which was the generic name for hemp.(23) Hemp was used in the Orient for anesthesia when acupuncture was not applicable.(39)

MEMPHITES STONE

Both Dioscorides and Pliny described the Memphites stone. These stones were about the size of pebbles and were described as "gem-like." They were found in the region of Memphis in Egypt and were said to consist of marble. The stone could be powdered and a liniment prepared from the powder and vinegar. This formulation, when applied to the part of the body to be operated upon, was said to abolish perception of pain and to provide a type of local anesthesia.(14) Dioscorides emphasized the safety of this form of pain relief in distinction to others, probably chiefly mandragora, which were designated as being more dangerous.(39,46) Dioscorides wrote concerning the Memphites stone: "The Memphian Stone is found in Egypt near Memphis, of the size of a calculus, fatty and of different colours. They say that this, when bruised, and spread over parts that are to be cut or cauterized, so anaesthetizes these parts that they do not feel pain."(59)

OTHER PREPARATIONS

Other drugs mentioned as possible soporifics and anesthetics in ancient times included monk's hood or wolf's bane, cuckoo-pint, wake-robin, henbane, and others. Some of these may have been sources of belladonna-type alkaloids such as stramonium or hyoscyamus. The precise identity of some of these plants remains in question and further investigation would be required for their characterization.(23) Other drugs included wild lettuce (lacuta) and mulberry (morum), a species of hemp from which cannabis was obtained. Mulberry had many medicinal uses and was only infrequently used as a refrigerant and soporific.(21) Alcohol was widely used and is a genuine depressant of the central nervous system. The problem with its use would have been achieving a depth of unconsciousness sufficient for performance of surgery without endangering the patient's life.(60) A more exotic suggestion was that of Pliny who advocated the ashes of the hide of a crocodile, either locally applied or inhaled, as an anesthetic. (39) A prescription for a preparation useful in painful labor and delivery was presented by Zerobabel Endicott (c1635-1684) of New England in 1677:

> "FOR SHARPE AND DIFFICULT TRAVEL (travail) IN WOMEN WITH CHILD BY J.C.": "Take a lock of Vergin's hair on any Part of ye head, of half the Age of ye Woman in Trauell. Cut it very smale to

> fine Pouder then take 12 Ants Eggs dried in an oven after ye bread is drawne or other wise make them dry and make them to pouder with the haire, giue this with a quarter of a pint of Red Cows' milk or for want of it give it in strong ale wort."(61)

SOPORIFIC SPONGES

Soporific sponges were advocated as a means of administering mixtures of drugs by inhalation to achieve unconsciousness and anesthesia for surgery. The general methods of preparation and use appear comparable for the different formulae advocated. The various drugs and items prescribed were placed in a kettle of fluid together with a sponge or similar object. The whole was evaporated to dryness leaving the sponge impregnated with all the necessary ingredients.

The association of sleep with inhalation of vapors or "humors" was very old. Thomas Willis, in 1683, commented on the mechanism of normal sleep:

> "...it has been for otherways taught by the Opinion of the Vulgar, to wit, that fumes and vapors are raised up from the chyle, or humors growing hot within the viscera of Concoction which cloud the brain, and so cause a Numbness. But this opinion easily falls..."

Willis argued that there were too many physical barriers and impediments in the pathways that would be involved. On the other hand, to prevent sleep and make one watchful he has "...made frequent mention of a certain liquor called coffee..."(62)

There were a large number of recipes for soporific sponges formulated over several centuries and originating from many sources. Among these were the ecclesiastical school of Monte Cassino in the 9th century, the Arabic world, and the school of Salerno of about the twelfth century. Bologna and England in the thirteenth century also provided recipes for soporific sponges. Later recipes were attributed to the school at Avignon in the fourteenth, to a German school in the fifteenth and to Spanish writers in the sixteenth centuries.(63) One representative prescription for the soporific sponge was that offered by Theoderic in the thirteenth century. It was passed down to him from his father, Hugh of Lucca, a renowned practitioner of the day.*(64) Watson related how Theodericus' recipe for

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* Theoderic (Theodericus) entered the church and ultimately became Bishop of Cervia. Although he referred to Hugh of Lucca (Ugone da Lucca) as his "father," it has been suggested that this designation was used as a term of respect and that the true relationship was that of master to disciple. Theodoric enjoys an honored position in the history of surgery because of his enlightened views on the care of wounds. His writings must have been regarded with considerable authority. Those which I consulted were published in Venice at the end of the fifteenth century and appeared bound in the same volume with works of Guy de Chauliac, Roger of Salerno, Guido Lanfranchi and other medieval surgical luminaries. Theoderic also advocated the use of some form of arsenic applied to the skin to produce local anesthesia. Snow tried this suggestion but failed to observe any identifiable change in pain perception.(72)

a soporific sponge was discovered by a trustee of the British Museum while examining an Italian book which had been presented to the museum. Watson concluded: "So the practice of benumbing the sensibility of the patient about to undergo a surgical operation, by causing him to inhale an anesthetic vapour, is as old as the twelfth century."(65)

The formula had been guarded as a secret during Hugh's career and was as follows:

> ". . . . . The recipe for an inhalation to use in surgery as prescribed by Master Ugone [Hugh] is made thus: Take of Opium, of the juice of unripe mulberry, of hyoscyamus, of the juice of hemlock, of the juice of the leaves of mandragora, of the juice of the woody ivy, of the juice of wild mulberry, of half a lettuce, of the seeds of a dock which has hard, round fruit, and of water hemlock, one ounce each. Mix all these in a brazen vessel, then place in it a new sponge; let the whole boil as long as the sun stands on the dog days, until the sponge consumes it all. As oft there shall be need of it place this sponge in hot water for an hour and let it be applied to the nostrils of him who is to be operated on until he has fallen asleep, and so let the surgery be performed, and when this is finished, to wake him up again apply another sponge soaked in vinegar repeatedly to his nostrils."(65,66)

James Y. Simpson indicated that a modern French surgeon, M. Dauriol, stated that he had successfully induced a state of anaesthesia using a sponge prepared according to the directions of Theodoric.(17,67,68) Raper related how a twentieth century anesthesiologist prepared a soporific sponge following Theoderic's instructions and evaluated its anesthetic capabilities. His verdict: "It won't even make a guinea pig nod!"(69) Other recent experiments with attempts to recreate soporific sponges appeared equally unsuccessful.(70) Keys mentioned the fumes of alcohol as a substance that might have been tried for anesthesia.(71)

Silvester described preparation of the "pomum somniferum." This was usually compounded by an old lady in the village who knew how to gather all the ingredients and prepare the material. Silvester believed that when alchemists discovered ether and extracted ingredients from the pomum somniferum with ether the efficacy was greatly improved. A quotation from Johannes Baptiste Porta described the preparation of the ingredients in a leaden flask which was then sealed and as needed was brought to the nostrils of the patient to produce a deep sleep.(27) John Snow suggested that the menstruum, or solvent, in which the various ingredients were dissolved was in fact sulfuric ether and that this agent was responsible for whatever sleep ensued. Many of these concoctions were supposed to be stored in a tightly sealed vessel until they were used.(45) To terminate the action of some sleeping potions, certain types of drugs were instilled into the ear.(26) This type of practice probably inspired Shakespeare to use this route of administration to poison Hamlet's father.(14)

EARLY LITERARY REFERENCES TO DRUG-INDUCED SLEEP AND ANESTHESIA

The impression that, in former times, drugs were known which could induce profound sleep states and provide effective pain relief during surgery is greatly strengthened by numerous early literary quotations. Some of these alluded to the capability of sedative drugs known in those times to produce a predictable period of deep unconsciousness. Included among these were the mandragora and poppy mentioned above. The straightforward manner in which other writings from bygone eras described operations done with complete anesthesia leaves the impression that such procedures must have been relatively commonplace. The earliest anesthetic is universally acknowledged to have occurred when God took a rib from Adam during a deep sleep to create Eve. This method of procedure was recognized as a surgical operation performed under an anesthetic by the French Poet Guillaume Du Bartas in his poem "Les Semaines" first published in 1578:*

> "Even as a Surgion, minding off to cut
> Some cure-lesse limbe; before in use he put
> His violent Engines on the viscious member,
> Bringeth his Patient in a sens-less slumber,
> And Griefe-lesse then (guided by use and Art)
> To save the whole; sawes off th' infected part:
> So, God empal'd our Grandsires lively looks,
> Through all his bones a deadly chilnesse strooke,
> Sield-up his sparkling Eyes with iron bands,
> Led down his feet (almost) to Lethe sands,
> In briefe, so numb'd his Soules and Bodies sense,
> That (without paine) opening his side; from thence
> He tooke a Ribb, which rareley he refined,
> And thereof made the Mother of Mankind:.... (73)

The use of potent medications to provide profound sleep and pain relief during surgery is mentioned in Boccaccio's Decameron written in the 14th century. In the eighth tale of the third day a certain husband is to be temporarily taken out of circulation. An abbot had a medication to do this:

> "He possesed a powder of marvellous virtue which he had received from a great Prince of the Levant, who asserted that this powder was used by the Old Man of the Mountain when he wished to put anyone asleep and

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* In 1857 a reader indicated in a letter to the editor of the "Medical Times and Gazette" (London) that he had read DuBartas' "Les Semaines" and wondered what type of anesthetic the surgeon in the poem might have used. In the published editorial reply to this letter. Thomas Silvester provided a lengthy answer using many of the opinions and facts on the early history of anesthesia discussed in the current chapter.(27)

> send him to Paradise and then bring him back. According to the quantity administered, the person who took it slept a shorter or longer period without any harm, and as long as its virtue lasted everyone would swear the person who took it was dead."

In the tenth tale of the fourth day a gentleman is to have an operation on his leg. For this, the physician:

> ". . . . . had distilled a certain preparation of his which when drunk would put a man to sleep for as long a period as he thought necessary for the operation"(74)

The plays of Shakespeare contain several relevant passages.* One is the conversation between Cleopatra and her maidservant, Charmian, during Antony's absence:

> Cleopatra: Ha! Ha! Give me to drink mandragora.
> Charmian: Why madam?
> Cleo: That I might sleep out this great gap of time My Antony is away.
> (Antony and Cleopatra. I,v,3)

The treacherous Iago, predicting the effects on Othello of his plans to cause the Moor to believe that his wife is unfaithful, says as if he were addressing Othello:

> Not poppy, nor mandragora,
> Nor all the drowsy syrups of the world
> Shall ever medicine thee to that sweet sleep
> Which thou ow'dst yesterday. (Othello, III,iii, 330)

Probably the best known sleeping draught in all literature is that which Friar Lawrence gave Juliet. The tragedy of Romeo and Juliet was classified as a generic 'separation and potion' drama.(76) The basic plot had been used several times, and with each telling of the story additional features and characters were added to culminate in Shakespeare's masterpiece. An earlier example involving Friar Lawrence, Juliet and the sleeping potion is found in the epic poem "The Tragical Hystory of Romeus and Iuliet," by Arthur Broke (Brooke) published in 1562. This poem was the immediate source of Shakespeare's play. Friar Lawrence addressed Juliet thus:

* In more than 60 instances Shakespeare used as few as one or as many as 25 or more lines to denote the nature and quality of sleep and this included sleep due to the action of drugs. The frequency of reference to disturbed sleep has led some authorities to speculate that Shakespeare might have suffered from insomnia.(75)

"Know therefore daughter, that with other gyftes which I
Have well attained to, by grace and favor of the skye,
Long since I did finde out, and yet the way I knowe,
Of certain rootes and savory herbes to make a kynde of dowe,
Which baked hard, and bet into a powder fyne,
And dranke with conduit water, or with any kynde of wine,
It doth in half an howre astone the taker so,
And maketh all his senses, that he feeleth weale not woe:
And so it burieth up the sprite and living breath,
That even the skilful leeche would say, that he is slayne by death,
One vertue more it hath, as marvelous as this:
The taker by receiving it, at all not greeved is;
But painless as a man that thinketh naught at all,
Into a sweet and quiet slepe immediatley doth fall;
From which, according to the quantitie he taketh,
Longer or shorter is the time before the sleper waketh:
And then (the effect once more wrought) again it doth restore Him that received unto the state wherin he was before.
Wherefore, marke well the ende of this my tale begonne,
And thereby learne what is by thee hereafter to be donne.
Cast of from thee at once the weede of womanish dread,
With manly courage arme thyself from heele unto the head;
For onely on the feare or boldness of the brest
The happy happe or yll mishappe of thy affayre doth rest.
Receive this yvoll small and kepe it as thine eye;
And on the mariage day, before the sonne doe cleare the skye,
Fill it with water full up to the very brim
Then drinke it of, and thou shalt feele throughout eche vayn and lym
A pleasant slumber slyde, and quite dispred at length
On all the partes, from evey part reve all thy kindly strength
Withouten moving thus thy ydle partes shall rest,
No pulse shall goe, ne hart once beats within thy hollow brest,
But thou shalt lye as she that dieth in a traunce:
Thy kinsman and thy trusty friends shall wayle the sodayne haunce;
Thy corps then will they bring to grave in the churchyarde,
Where thy forefathers long agoe a costly tombe preparde,
Both for them selfe and eke for those that should come after,
(Both Depe it is, and long and large) where thou shalt rest, my daughter,
Till I to Mantua sende for Romeus thy knight:
Out of the tomb both he and I will take thee forth that night.
And when out of thy slepe thou shalt awake agayne,
Then mayst thou goe with him from hence...."(77)

Broke's commentaries on Friar Lawrence's education and ethics provide an interesting insight into public perceptions of science and medicine in the sixteenth century. Even in that age some qualifications were expected from the practitioner before he prescribed potent medicines:

"For he of Francis' order was a fryer, as I reede.
Not as the most was he, a grosse unlearned foole,
But doctor of divinetee proceeded he in school.
The secrets eke he knew in Nature's woorks that loorke;
By magick's arte most men supposed that he could wonders woorke.
Ne doth it ill beseeme devines whose skills to know,
If on no harmful deede they do such skilfulnes bestow;
For justly of no arte can men condemne the use,
But right and reason's lore crye out agaynst the lewd abuse."(78)

Shakespeare's Friar Lawrence described the profound coma which his potion would produce to Juliet. (As noted above, Richardson identified the active ingredient in this concoction as mandragora):

"Take thou this vial, being then in bed,
And this distilling liquor drink thou off,
When presently through all thy veins shall run
A cold and drowsy humor — for no pulse
Shall keep his native progress, but surcease;
No warmth, no breath shall testify thou livest;
The roses in thy lips and cheeks shall fade
To wanny ashes, thy eyes' windows fall
Like Death when he shuts up the day of life.
Each part, depriv'd of supple government,
Shall stiff and stark and cold appear like death,
And in this borrow's likeness of shrunk death
Thou shalt continue two and forty hours
And then awake as from a pleasant sleep."(79)

Juliet had a transient period of indecision before she finally drank the sleeping potion. As she reviewed in her mind some of the ways in which her plans might go wrong she enunciates some of the superstitions surrounding the mandrake:

"Alack, alack, is it not like that I
So early waking — what with loathsome smells
And shrieks like mandrakes torn out of the earth,
That living mortals hearing them run mad —"(80)

Yet another statement concerning the horror of the cry of the mandrake is in Henry VI, Part II :

Suffolk. . . .
Would curses kill, as doth the mandrake's groan,
I would invent as bitter-searching terms,
As curst, as harsh and horrible to hear, ... (81)

In Cymbeline, the queen had requested a powerful sleeping potion from Cornelius, a physician. He expressed a reluctance to trust her with the medicine:

> "A drug of such damn'd nature. Those she has
> Will stupefy and dull the sense awhile;
> Which first, perchance, she'll prove on cats and dogs,
> Then afterward up higher; but there is
> No danger in what show of death it makes,
> More than the locking up the spirits a time,
> To be more fresh, reviving...."(82)

Another testimonial to the remarkable powers of ancient depressant drugs was provided by Christopher Marlowe in "The Jew of Malta" published in 1633. Calymath, who had besieged Malta, entered and asked Barabas, the Jew of Malta, how he has escaped from the authorities.

> "Did he break prison?"
> "Barabus : No, No! I drank of poppy and cold mandrake juice:
> And being asleep, belike they thought me dead
> And threw me o'er the walls."(83)

Thomas Middleton, an English dramatist of the seventeenth century and a contemporary of Ben Jonson, provided another passage describing use of surgical anesthesia in pre-anesthetic times. This example occurred in his play "Women Beware Women," first printed in 1657. In the play a duke and one of his associates, Hippolito, are formulating plans to dispose of a courtier while showing due consideration for the feelings of the victim's wife:

> 'Hippolito:
> "Yes my lord,
> I make no doubt, as I shall take the course,
> Which she shall never know till it be acted;
> And when she wakes to honour then shall thank me for 't.
> I'll imitate the pities of old surgeons
> To this lost limb; who ere they show their art,
> Cast one asleep, then cut the diseas'd part;
> So out of love to her I pity most,
> She shall not feel him going till he's lost
> Then she'll commend the cure."(84)

A.G. Meissner, a German author, wrote the following account of an operation apparently done with anesthesia in his "Skizzen" (Sketches) published at Karlsruhe in 1782. The translation presented below was said to be a meagre abstract of the original tale, which was worked up by Meissner into dramatic effect.

> "Augustus, King of Poland and Elector of Saxony, suffered from a wound in his foot, which threatened to mortify. The court medical men were opposed to the operation of amputation, but during sleep induced by a certain potion surreptitiously administered, his favorite surgeon, Weiss, a pupil of Petit of Paris, cut off the decaying parts. The Royal patient was disturbed by the proceeding and inquired what was being done, but on receiving a soothing answer he again fell asleep and did not discover till the following morning, after his usual examination, that the operation of amputation had really been preformed."(25)

Elizabeth Barrett Browning was familiar with mandragora. She wrote:

> "Have the pigmies made you drunken, Bathing in mandragora?"(85)

A novel method for homicide involving inhalation of a gas was incorporated by Edgar Allen Poe in his 1845 tale, "The Imp of the Perverse." After rejecting many alternatives, the perpetrator killed the victim by arranging for him to inhale the fumes of a poisoned candle.(86)

DID EFFECTIVE ANESTHESIA EXIST BEFORE THE "MODERN ERA"?

Could the suppositions that effective anesthesia existed before our modern anesthetic era be true? Did our ancestors and predecessors possess and use anesthetic drugs and methods which have subsequently become lost and are now unknown to us? Do the passages quoted above from medical writings and classical literature which describe surgical anesthesia during stuporous, drug-induced sleep have a factual basis?

The answer to all the above questions is probably "no" for several reasons. The identity of many drugs mentioned in old manuscripts cannot be established with any degree of certainty. However other such drugs can be identified. Some are used in our day in anesthetic practice. Others have analogs which are still used as anesthetic adjuvants. Yet others are widely abused in modern society. Experience with these drugs in modern clinical practice clearly shows that, in the absence of technology and physiological knowledge which would far exceed the capability of all practitioners before our time,(87) their use could not have predictably produced a state of serene sleep with insensibility to the pain inflicted by the cutting of the body as described in bygone writings and by historians commenting on these writings. Attempts to use them in this manner would certainly have caused an appalling and unacceptable mortality rate from anesthesia or would have been unsuccessful. In short, anesthetics of the Ancients, as nearly as we can tell, simply did not work!

Individuals writing before or at the beginning of the modern anesthetic era confirmed the ineffectiveness of certain drugs known in antiquity for producing surgical anesthesia. James Moore commented in 1784 that after every improvement of the instruments and of the manner of operating a great deal of pain still remained in surgical operations. He continued:

> "An obvious means of dulling and diminishing this was early tried by giving anodynes internally, some time before he underwent an operation. Opium is the most powerful of this class of drugs, and a moderate dose is highly expedient to abate the smarting of the wound after the operation is over, and to induce sleep; but the strongest dose we dare venture to give has little or no effect in mitigating the suffering of the patient during the operation."(88)

James Wardrop, writing in 1833, stated that large doses of opiates, e.g. more than 40-50 drops of laudanum, were frequently given preoperatively but were often ineffective in providing pain relief.(89)

J.C. Warren, in 1848, commented on how surgeons had always abhorred the inflicting of pain. To avoid this he had tried various agents, including all forms of opium and other narcotics, even in such quantities as really alarmed him, without satisfactory results.(90) Randolph made an interesting observation regarding comparison of old descriptions of anesthesia such as those quoted above with more modern reports. He pointed out that, when the earliest descriptions of genuine modern anesthesia were presented the date and locality of the event, the nature of the operation, and the names of the surgeon and the patient were provided.* Thus we know that on March 30, 1842, at Jefferson, Georgia, U.S.A. Crawford W. Long excised a tumor on the neck of James Venable during anesthesia produced by ether.(91) We know that on October 16, 1846 William T.G. Morton anesthetized Gilbert Abbott with ether for removal of a tumor of the jaw at Boston, Massachusetts, U.S.A.(92) No comparable details are supplied in the old accounts of anesthesia. It was suggested that not too much credence be accorded a passage such as: "We use a certain drug to produce anesthesia......" Randolph believed that this could be an editorial "we" and that this statement does not necessarily confirm the use of anesthesia.(39)

The stories of anesthesia appear to have been passed from generation to generation without anybody having tried the techniques described. Many tales concerning properties of ancient drugs or techniques are obvious fantasy or cannot be factually substantiated. In each era, the consensus appears to be that drugs then available for anesthesia, if they existed, could have endangered patients' lives.(60) Williyam Bullien, writing in 1562, opined: "Opium is made of blacke poppy which is colde, and is in sleaping medicines: but it causeth deep deadly sleapes."(93) and

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* The introduction of Warren's book on "Etherization" suggested that the names of patients were frequently put into case reports from this era to permit confirmation and verification, if desired, of the information presented.(90)

also: "Henbane is called of the Grekes 'hyoscyamus' — it reconciles sleep. Pliny would that none would use more than fower (four) leaves of this herb, the iuce (juice) thereof at ones (once)! For who so useth more will be in danger to slepe without wakening."(94) Such views probably account, in part, for the infrequency of use of depressant drugs in bygone days.(60)

Randolph reviewed 150 passages from world literature in which surgical procedures were mentioned or described. These were not medical writings, but rather fictional, historic, or dramatic works. In many there were descriptions of how the patient bore and tolerated the pain and of the intense suffering endured. In none was there any hint of any form of anesthesia being employed.(39) The pain and suffering described in these archeological and literary sources is almost always that of kings, queens, gods, heroes, aristocrats, etc. The lot of the common man must have been immeasurably worse.(35) Even in ancient times, philosophers were concerned with the nature of pain and formulated theories to explain the phenomenon.(95) Some previous writers have suggested that perhaps people in former eras or in primitive civilizations had a diminished sensitivity to pain as compared to those in modern times: "Civilized man has of will ceased to torture, but in our process of being civilized we have won, I suspect (says Dr. S. Weir Mitchell), intensified capacity to suffer. The savage does not feel pain as we do; nor, as we examine the descending scale of life, do animals seem to have the acuteness of pain-sense at which we have arrived."(96)

Among evidence sometimes presented for a diminished degree of pain perception in bygone times is the appearance of certain people depicted in medieval and renaissance art works who appear to be suffering little in spite of intense physical abuse, e.g. St. Sebastian. But de Moulin reviewed references describing response to pain in the 19th, 18th, 17th, 16th centuries, medieval times, Rome and Greece, other societies of antiquity and ending up with the Trojan War and classical mythology. He concluded that people in former eras perceived and suffered pain with the same sensitivity and behavior as occurs today. Hence, differences in pain perception and response seem not to be a factor in evaluating possible anesthetics of the ancients.(97) John Snow doubted the existence of anesthetics in bygone days. He wrote:

> "it is reasonable also to conclude that if any successful plan of preventing the pain of surgical operations had been introduced after the revival of literature, it would not have fallen into disuse and been forgotten."(45)

I concur in the opinion of Dr. John Snow that before the introduction of ether inhalation into clinical practice in the 1840's there was no generally applicable method for relief of pain during surgery. Perhaps preliminary generous doses of opium and alcohol might somewhat allay apprehension and slightly diminish the impact of pain thus making some surgery possible.(12) But most potentially applicable methods and those few techniques actually used successfully before the mid 19th century (see Anesthesia Before Ether below) usually represented extreme physiological trespass and would have been unsuitable for general use. For most of mankind's history on earth, surgery remained a terrifying ordeal of pain, misery, and intense suffering.

PLATE I—A MONK undergoing surgery in the 16th century appears to be receiving some type of ministration from one of his brothers. This was identified as inhaled alcohol fumes to provide some measure of anesthesia.

Chapter II

The Beginning

Medicine Before 1600

Anesthesia could not have developed until a proper foundation for its introduction had taken place in general medicine, chemistry, physics and physiology. The following description of the beginnings of this foundation generally emphasizes those individuals and events which would eventually bear upon the development of anesthesia.

GREEK MEDICINE

Origins of medicine in ancient Greece are lost in antiquity. Mythological sources relate that the founder of medicine was Chiron, a centaur. The first pupil of Chiron was Aesculapius, son of Apollo. He became the Greek god of medicine and the central theme of a priestly cult of healing. Temples were founded associated with this "Cult of Aesculapius" and dedicated to the treatment of disease. Prospective patients would gather at the temples. They would cleanse and otherwise prepare themselves by participating in the rites under guidance of the priests. At some time a hypnotic trance would occur (possibly aided by alcohol and hallucinogenic drugs) during which a cure was effected.(1) this form of pagan, theistic cult practice remained popular for several centuries. The ultimate cause of cures was believed to be the mercy of Aesculapius.(2) If there were physicians or any type of science involved, it was strictly incidental and the association was minor. Perhaps Chiron and Aesculapius were ordinary mortal men skilled in medical lore and practice who were gradually deified over the ages.(3)

Coexisting with the temples and priests, but quite separate from them, were lay physicians. These practitioners often were associated with specific towns or prominent families. Medical schools to train them were a fixture of Greek civilization for centuries. One such medical school was located on the island of Cos.

Hippocrates (c.460-355 BC) was associated with this locale. This individual (or perhaps group of individuals) formulated a remarkable system of medicine and left a mark on every physician who has subsequently practiced this profession.

Greek medical knowledge and primitive scientific beliefs were intimately interwoven with Greek philosophy. Greeks appear to have been aware of and interested in respiration and the circulatory system from about 600 B.C. A common belief was that arteries contained air and that blood was carried in veins.(4) It has been suggested that this teaching arose because Greeks slaughtered animals by strangulation: an act resulting in extreme venous congestion with relatively little blood remaining in arteries.(5) An association between the physical process of combustion and vital activities had been inferred quite early. Presence of air in arteries could then serve to cool the heart. The Greeks recognized the presence of "pneuma," breath, which was believed to contain some kind of vital component.

Thales (639-544 B.C.), a prominent pre-Socratic philosopher, proposed existence of a substance which was the original principle of everything. He believed that this material might be water. Subsequent philosophers, primarily Pythagoras and his followers, elaborated this theory to include several fundamental constituents of all worldly objects and materials. Empedocles (504-443 B.C.), a disciple of Pythagoras, is probably the best known proponent of the views of this school. He wrote that all matter, including living creatures, is composed of four simple elements combined in various ways. These elements were earth, fire, water and air. Physical attributes were associated with each element: fire was associated with heat, earth with cold, air with dryness and water with moisture. About 400 BC this doctrine was incorporated into a philosophy of medicine where each of the elements was associated with a body "humor " (see medieval medicine). This humoral pathology persisted for centuries as a basis for medical practice. These were important advances because they represented the first time that disease was not explained on a supernatural basis or attributed to presence of spirits which needed to be exorcised or propititaed using priestly rites.(6) Empedocles also inferred the corporeal nature of air and hence the existence of matter in the gaseous state by observing presence of bubbles when "pneuma" was blown through a reed under water.(4) He taught that air penetrates into the lungs and also enters the body through pores in the skin.

Erasistratus of Alexandria (3rd century B.C.) also recorded conclusions and inferences which influenced development of repiratory knowledge. His pneumatic theory encompassed the belief that there was something in air necessary for the sustenance of life. Erasistratus was a leader in the Greek school of "Pneumatist" philosophers who based good health and strength on proper condition of the pneuma.(8) He taught that the right ventricle supplied blood to the lungs, but blood was believed to travel from the liver to the body with relatively little reaching the lungs. The left ventricle supplied pneuma, which had been extracted from the surrounding air to the body. He persisted in the belief that arteries contained air and speculated that an artery bled when cut because a vacuum developed in the arterial circulation. However in order to explain how blood got from veins to arteries Erasistratus had to postulate anastomoses between the two types of vessels. This is perhaps the earliest inference of the presence of a capillary circulation. He recognized and described the heart valves and understood their function in making the heart a unidirectional pump.(4) Another Hellenistic physician of Alexandria was Herophilus (about 300 B.C.). He concluded that every organ had an artery for air, a vein for blood and a nerve for pneuma.(7)

The most important legacy of Greek medicine was the Hippocratic system with its associated methods of thought, practice and ethical approach to medicine. The origin of Greek Hippocratic medicine probably lay in a fusion of the priestly Cult of Aesculapius and empirical folk medicine.(2) The Hippocratic school explained disease on the basis of humoral pathology which involved various imbalances between the humors of the body. But much of Hippocratic medicine, was remarkably sensible and rational. Information was often gathered and conclusions reached on the basis of practical observation, empirical experience and accurate reasoning within limits imposed by the sparse and usually erroneous knowledge of anatomy, physiology and pathology. The therapeutic advice of Hippocrates was sensible for his age. He advocated prescription of substances and measures likely to promote and regulate the work of nature. He taught that therapeutic measures should be based on observation and deduction from bedside experience. The physician was exhorted to cooperate with nature. Great emphasis was placed on diet, exercise, sea bathing, gymnastics and massage.

The greatness of the legacy of Hippocrates resides in several different aspects of medical practice. He dissociated medicine from its former constraining theurgic and philosophic basis. Disease no longer had to be regarded as a supernatural occurrence. Healing could now occur free from priestly influence and spiritual intervention. Hippocrates crystallized and systematized the previous disorganized medical knowledge that was available. He gave physicians a high moral and ethical inspiration which we would hope still influences medical practice in our own age. He was the founder of modern bedside medicine.

ROMAN MEDICINE

In the Roman Empire the practice of medicine was considered to be a demeaning activity not worthy of attention by the average citizen. Medical activities were often entrusted to slaves. Much of medicine remained in the hands of Greeks living in the Roman world. Institutional care of the sick was generally not practiced. Pedacius Dioscorides, a Greco-Roman surgeon of the army who served during the reign of Nero (54-68 A.D.) is credited with compiling the first Western pharmacopoeia. He had a phenomenal familiarity with medicinal plants and his writings remained the authoritative works on botany into the seventeenth century. The Materia Medica of Dioscorides (about 60 A.D.) discussed 600 medicinal plants as compared to 250 in Hippocratic writings.(13) He recommended mandragora wine as a sleeping draught and for surgical operations or cauterizations. Dioscorides used the word "anaesthesia" to describe the desired effect of mandragora in exactly the same sense as it would be used today.(9) (The word "anaesthesia" also occurs in Plato's "Timaeus") The idea of a sleeping potion apparently originated with Dioscorides.(11,12)

The Roman successor to the school of Hippocrates was Claudius Galen (131-201 A.D.). He was renowned in his own lifetime and became personal physician to the emperor Marcus Aurelius. Few individuals in science however have attained the posthumous status of reverence and authority for so many centuries as was achieved by Galen through his writings. These works influenced medicine for the next 1500 years throughout the Western world in Christian, Jewish, Anglo-Saxon, Arabic and other cultural settings. The work and writings of Galen tended to modify the basis of medical practice from the bedside observation and empirical method of Hippocrates to one based on application of abstract theory. Galen believed in prescribing a large number of drugs and preparations. The body could then choose the one that was needed. Galen was also an enthusiast of bloodletting.(13) He was never at a loss to contrive explanations for observed phenomena and was quite confident of the correctness of his conclusions.

The works of Galen became the final authority on medical questions. There was no appeal beyond Galen. Here medicine languished statically for the next 1500 years.(14) Galen's most important service to medicine lay in his transmission of Greek theory and practice to his successors in the medieval world. But in addition he was history's foremost experimental physician until fairly modern times. Important contributions were his numerous direct anatomical observations, particularly of the nervous system. Many of these observations were inaccurate and all were made on species other than man. His experimental conclusions were often flawed by wild speculation in attempts to make the observed structural and functional changes conform to his theories. Some of the subsequent difficulties with his writings arose from attempts to apply these results in human disease.(15) Views of Galen on respiration are sometimes obscure, frequently contradictory and often difficult to interpret. He would on occasion state whatever view was necessary to support or refute the issue under consideration.(5) He too believed in pneuma - some vital essence from inspired air.(7) He disproved the long-standing Greek belief that the left side of the heart and the arteries contained air by showing that blood would escape from an artery cut between two ligatures. Having demonstrated this, he was then obliged to provide an alternative physiology. This led to the postulation of the existence of communications between arteries and veins where they lay in proximity. These invisible pores were termed "synanastomoses;" another early inference of the existence of the capillary circulation. Arteries were then said to carry both blood and pneuma.(5) Galen made several observations on the structure and function of the heart and pulmonary circulation. He concluded that valves conferred unidirectional properties on the heart, except for some slight incompetence of the mitral valve which permitted wastes to return from the left ventricle to the lung.(4) The important function of the pulmonary artery was the nourishment of the lung. "Smoky residues" returned from the left ventricle to the lungs through pulmonary veins. Galen determined that the pulmonary artery was smaller than the vena cava and that the pulmonary veins were smaller than the aorta. He therefore postulated that "invisible pores" must exist in the septum between the right and left hearts to permit passage of a "finer part" of the blood.

The purpose of respiration was fanning and cooling of the heart and also to provide a means to permit outflow of "smoky residue" and conserve "innate heat" derived from some type of burning process occurring primarily in the left ventricle but to a lesser extent in the remainder of the body. This "innate heat" was characteristic of life and had requirements similar to fire. Galen was aware of the difference in color between arterial and venous blood but considered their conditions similar.(5)

Galen's views on the pulmonary circulation (using modern terminology) have been summarized as follows:

1. Blood on entering the right ventricle must pass inward as a result of the tricuspid valve so only a little can go back into the venae cava.
2. Some of the blood passes from right to left through the "invisible pores" in the interventricular septum.
3. Most of the blood moves into the pulmonary artery past the one way valve opening outward from the right ventricle.
4. Blood returns to the left ventricle through the pulmonary veins. Also, inspired air travels by the same route. In addition, by the same route smoky waste is returned from the left ventricle to the lungs. This is made possible by comparative insufficiency of the mitral valve.(16)
5. Blood from the left ventricle passes into the aorta.

These are generally the principles of circulatory physiology which persisted until William Harvey's work in the seventeenth century. Galen probably didn't grasp the principle of the general circulation. One reason which might explain the differences in view between Galen and Harvey was the interim discovery of valves in veins.(17,18) Had Galen known about these he might have considered unidirectional flow in the systemic circulation. But he may have done so anyway. One persistent misinterpretation of Galen's writings involved his ideas on "ebb and flow" of blood in the circulatory system. What has been translated as "ebb and flow" might alternatively refer to flow into an organ and flow away from the organ during alternate stages of the cardiac cycle.(16)

There are several prescient features in Galen's writings on respiration. He inferred that there is something special absorbed from inspired air because of the distress sustained during breath holding. He is quoted as saying that if he could discover why flames are extinguished when covered with an airtight vessel, he might determine the nature of the substance gained by the bodily heat through inspiration.(The Romans must have generally intuitively associated combustion with respiration since they would sometimes lower a lighted lamp into an excavation to determine fitness of the atmosphere before entering). Galen clearly described closure of the ductus arteriosus and foramen ovale after birth.(17)

Aside from the contributions of Galen, the important medical achievement of the Romans was not in scientific areas but rather in hygienic measures such as improved water supply and construction of sewers, drains and public baths. Whatever benefits accrued were obtained without medical intention.

ORIGINS OF EUROPEAN MEDICINE AND PHYSIOLOGY

While Europe floundered through the Dark Ages, medical knowledge was kept alive by Arabic physicians. It should be understood that the word "Arabic" is used here in a cultural rather than an ethnic sense. It signifies the language in which these individuals communicated and the milieu in which they lived rather than their racial origin. "Arabic" physicians of this period could have been of Jewish or European descent. Whatever their origin they were astute practical physicians. Their most important functions, however, were as repositories, collectors and transmitters of ancient Greek and Roman medicine.(7) Through the Arabs many additional Eastern drugs entered the pharmacopaea.(13)

In the early Middle Ages, medical practice was conducted by both lay and ecclesiastical individuals. Then increasing constraints on medical activities by clerics left practice primarily in lay hands. A series of church edicts about 1130-1250 stopped monks, about the only educated people at that time, from engaging in healing activities. A general odium was cast over medical practice. Particularly in disfavor was the shedding of blood by any means. During the Middle Ages medical texts were divorced from practical knowledge and medieval scholastics debated the meaning of words in classical Arabic texts at great length. Practical or empiric knowledge was generally apparently completely disregarded and research and dissection were suppressed.(6)

An early important lay medical institution was the Medical School at Salerno in the 11th and 12th centuries. The "Antidotarium" of Nicholas of Salerno was an early formulary which is said to contain the earliest recipe for the "spongia somnifera." Disciples of this School were Hugh (Ugo) of Lucca (d. 1252) and his son or disciple, Theodoric of Lucca (1205-1298),(19) who are also mentioned in connection with the soporific sponge elsewhere in the present volume. These sponges, however, can be traced back to earlier times. Soon other famous medical schools arose in various cities in Europe.

Hospitals existed throughout the Middle Ages and control gradually passed from the monastaries to municipalities about the 13th or 14th centuries.(20) The science of healing advanced little in the Middle Ages beyond the medicine of Galen.

Humoral pathology was one of the important medical concepts in the ancient and medieval worlds. Humoral pathology and therapeutics began in the Greece of Thales, Empedocles and Hippocrates, developed over the intervening years, and flourished in the Middle Ages. The four elements of Empedocles, fire, earth, water, and air, were endowed with corresponding physical attributes. Thus fire was associated with heat and dryness, earth with dryness and cold, water with cold and moisture, and air with moisture and heat. Each of four body humors was associated with a corresponding element through associated physical characteristics: blood (moist and hot), yellow bile (hot and dry), black bile (dry and cold) and phlegm (cold and moist). Various therapeutic agents were assigned properties of heat, dryness, cold and moisture in varying proportions. Thus, on diagnosis of an excess or deficiency of one or more humors as a basis for a particular illness, appropriate treatment could be prescribed to augment or antagonize the particular humoral imbalance present.(20)

After the fall of Constantinople in 1453 refugees from Byzantium brought back to the West many original manuscripts of the writings of Hippocrates, Galen, Dioscorides, Aristotle and others. A new generation of physicians arose who had the opportunities to study these original writings and they realized how the writing which had been studied in medieval times had been corrupted, partly by serial translation from Latin or Greek to Syraic to Arabic and back again to Latin. At this time reinterest in subjects such as anatomy was awakened and Vesalius and his successors belonged to this era.(20) There was also considerable interest in theories and hygiene of sleep in medieval and Renaissance times.(21)

An important physiological advance was the recognition of the nature of the pulmonary circulation. Discovery of the pulmonary circulation may be regarded as the realization that all blood circulated through the lungs to get from the right side of the heart to the left. This concept is attributed to three men: Ibn An-Nafis (ca 1210-1288), Michael Servetus (1511-1553), and Mattheus Realdus Columbus (?1516-?1559) who reached the conclusion independently but began from the same source: Galen. He had taught that a significant fraction of the blood from the right ventricle reached the left heart through invisible pores in the interventricular septum. Both Servetus and Columbus appear to have based their conclusions on observations made during vivisection. An-Nafis was unable to demonstrate any such pores and realized that the septum was too thick to permit leakage of blood.(7,22,23)

Servetus reasoned that the size of the pulmonary artery and the force of blood issuing from it implied that the pulmonary circulation must subserve some other function in addition to merely nourishing the lung. He postulated that blood mixed with air in the lung and the "sooty vapours" in blood were thereby eliminated.

These conclusions appeared in his book, "Christianismi Restitutio," and the primary motivation for his writings were theological rather than physiological. He was burned as a heretic, together with most of the copies of his book, because of the unconventional religious opinions expressed in the volume.(24)

Columbus deduced the fallacy of Galen's interpretation of the pulmonary circulation by observing that pulmonary veins contained blood and therefore could not be conducting air from the lung to left ventricle.(25) Both Servetus and Columbus were well schooled in anatomy, sharing the same tradition as Vesalius. But all of these discoverers of the pulmonary circulation wrote in the Galenical tradition. They considered only flow of blood related to the heart and lungs and blood was free to ebb and flow through the rest of the body at will until the work of Harvey.

In medieval, Renaissance, and reformation times personalities and discoveries began to emerge which can be specifically associated with the subsequent development of anesthesia. Ramon Lull (ca. 1232-1316) was regarded as an individual with encyclopedic learning. His system of philosophy influenced thinkers for several centuries. He is generally regarded as the first to ever write about sulfuric ether. His place in science was evaluated by Pring-Mill.(26) Lull himself was opposed to alchemy. His methods had obvious applications in the alchemical field, and they were so applied in a host of pseudo-Lullian alchemical works, most of them composed more than fifty years after his death. These works explain the traditional (but false) "scientific view" which made him "Lull the Alchemist."(26)

Paracelsus

Paracelsus (Theophrastus Phillipus Aureolus Bombastus von Hohenheim ca 1493-1541) travelled and practiced widely, offending everyone as he went. He was characterized as an angry man with a "difficult" personality. He rejected organized religion, classical scholarship, custom and authority and also was addicted to drink. His writings were those of a naturalist physician, spiritualist and a symbolic thinker.(27) Paracelsus was instrumental in revising the concept of causation of disease from that involving medieval ideas of humoral pathology to the agency of external causes: specific agents foreign to the body taking possession and altering function of one or more parts. These new ideas led to new modes of therapy directed against these foreign agents. Many of these therapeutic measures involved chemical substances which he was preparing and characterized by using new and refined laboratory techniques. Paracelsus believed that the most important function of chemistry was to use the knowledge to prepare remedies for illness; so-called iatrochemistry.(28) He was the first to demonstrate and write on the narcotic and sedative properties of sulfuric ether. Although a good part of his writings were mystical, metaphysical and spiritual they contain much that constitutes stepping stones to modern science.(29) Paracelsus had an advanced opinion on respiratory gas exchange. He wrote that "as the Stomack concocts Meat, and makes part of it useful to the Body, rejecting the other part, so the Lungs consume part of the Air, and proscribe the rest."(30) The ideas of Paracelsus influenced van Helmont, Boyle, Boerhaave and others who followed.

Gravenstein assessed the position of Paracelsus in anesthesia history thus:

> "Paracelsus deserves to be remembered by all physicians as a devoted and idealistic healer, a magnificent observer, a bold and imaginative innovator in therapeutics, a colorful personality and a religious mystic."(31)

Further definition of the identity and chemistry of sulfuric (diethyl) ether appeared in the writings of Valerius Cordus (1515-1544). Although he was not the first to recognize or describe this substance, he did provide the earliest description of its preparation. Valerius Cordus was born in the Hessian town of Siemershausen to a scholarly father, Euricius Cordus, who later became professor of medicine at the University in Marburg. The elder Cordus, in addition to his scientific pursuits, wrote Latin verse. Valerius obtained his bachelor's degree at Marburg and subsequently a doctorate, perhaps at Wittemburg. His primary field of eminence was in Botany where his objective became "to teach man to cease dependence on prior descriptions of the ancients and to describe plants anew from nature." His writings were modern and free from animism. He is said to have laid the foundations of modern botany. His "Dispensatorium," first published in 1546 was the first European pharmacopoeia and went through many subsequent editions.(12) The roles of Ramon Lull, Paracelsus and Valerius Cordus in the discovery and investigations of sulfuric ether will be discussed in the section on early history of ether. Physiology, hygiene and significance of sleep was an important concern of several Renaissance medical writers. Many of these leaned heavily on authorities of the classical period such as Aristotle and Avicenna.(21)

WILLIAM HARVEY

William Harvey (1578-1657) was the first investigator to deduce and describe the circulation of the blood. The book describing his conclusions, "De Motu Cordus," is a true landmark in the history of medicine and physiology. Harvey was familiar with the works of Galen and held him in high esteem. Neither he, nor any of his predecessors could have understood the true function of respiration because of the primitive state of knowledge concerning microanatomy of the lungs as well as that of physics and chemistry(4,32), He therefore failed to appreciate the function of the pulmonary circulation and fell back on the "cooling of the blood" and similar types of explanations. Harvey may have been confused in attempting to explain the use of the pulmonary circulation by observations in lower animals with common ventricles where it is obvious how blood could get from one side of the circulation to the other.(33) An important observation that materially assisted Harvey in his conclusions concerning the circulation was his knowledge of the existence of valves in veins and his correct interpretation of their function.(18) Marcello Malphigi (1628-1694), professor of medicine at Pisa, made the microscopic observations providing information which permitted further deductions concerning the pulmonary circulation. He concluded that the lung consisted of air sacs at the end of branching of the trachea with no direct connections to pulmonary veins. He observed that closed blood vessels ramified over the surface of the air sacs with no direct connection between air and blood.(32,34)

Plate II—Thomas Willis (1621-1675). One of the Oxford group of scientists active in Oxford and London in the last part of the 17th century, he is remembered for his work in neuroanatomy. His book Cerebri Anatome *remained the authoritative text for many years. He was one of the eyewitnesses to Wren's early experiments on intravenous injection of various substances.*

Chapter III

Evolution of Medicine

Physiology and Chemistry 1600 – 1800

The first anesthetics were administered by inhalation of gases and vapors. Thus, a clear appreciation of the existence of identifiable and variously distinct materials in the gaseous state of matter, as well as a fairly comprehensive knowledge of their characteristics and chemistry, were important prerequisites for the introduction of anesthesia. It was during the course of investigating gases and vapors that the first steps were taken which would ultimately lead to the introduction of anesthesia into clinical practice.

People in ancient times were aware of existence of gases. As mentioned previously, Empedocles in the 5th century B.C. had concluded that "pneuma," or breath, was physical and corporeal because of appearance of bubbles when blowing through a reed submerged in water.

Johannes van Helmont (1579-1644) of Brussels is remembered today as a more recent commentator on matter in the gaseous state. He was responsible for designating aeriform substances liberated from other materials by chemical means as "gas." van Helmont received his M.D. degree in 1599. He was an iconoclast with little regard and considerable disrespect for and skepticism of previous knowlege and discoveries. He felt compelled to do extensive personal research and inquiry. He was on occasion in trouble with the church and was once tried by the Inquisition. His writings were considered heretical because they often followed the "monstrous superstitions" of the school of Paracelsus.

van Helmont's interest in pneumatic chemistry arose from his investigations of smokes from combustion of solids and liquids. He has been called "the father of pneumatic chemistry."(1) He believed that smokes derived from various sources were different. They were unique and specific and represented the essence of the substance from which they originated. They were said to be different from common air and there were as many gases as there were individual objects from which smokes could be derived. These individual specific smokes were designated as "gas." The origin of this term is not clear. Several roots have been suggested: "chaos" from the Greek having the connotation of lack of form and substance; "Geist" from the German meaning spirit; Geest from the Dutch with similar connotation; or perhaps from the German "Gasen" implying fermentation or effervescence. Another term used by van Helmont for this state of matter was "spiritus sylvestris," implying that the substances were wild (Latin "sylvestris" meaning wild or savage); that is, not being confinable or capable of being reduced to a visible body. When an object was converted into gas by chemical manipulation, it had lost its shape but no other essential properties.(2,3) Most commonly all types of matter in the gaseous state were called "airs" until the 19th century.

Use of the term "air" to designate any gas is a legacy from the old Greek concept of the four elements (earth, air, fire, water). Even in our own times some minerals are still called "earths" (e.g. alkaline earth metals such as calcium or rare earth metals) and occasionally liquids are spoken of as "waters," (e.g. aqua regia).

Feelings of modern historians on van Helmont are mixed. He is either praised as a visionary in his own time or condemed as an occultist and alchemist. His medical and scientific views and discoveries are intermingled in his discourses on natural philosophy, religious metaphyscis and cosmology — not easy for modern readers to comprehend. He followed Paracelsus in pursuing the importance of iatrochemistry, that is, the application of chemistry to the formulation of medicinal substances.(1,5) One reason for van Helmont's failure to advance farther in pneumatic research was the primitive nature of the equipment available to him for chemical experimentation with gas. The term "gas" enjoyed little popularity or standing until its use by Lavoisier in his work toward the end of the eighteenth century. In the interim in English language, the term "airs" was almost universally used to designate matter in the gaseous state.(6) The term "gas" was introduced into English chemical terminology by the chemist James Keir in 1777.(7) van Helmont had identified a gas which was the product of fermentation and combustion and recognized that it was distinct from common air.(6) Nevertheless, during the sixteenth and early seventeenth centuries air was considered a physical agent, comparable to light and heat. It was not considered within the domain of chemistry.(8) Air was believed to consist of a simple elastic medium, corpuscular in nature, in which were dispersed effluvia (i.e. invisible emanations) from all bodies. It was these effluvia, essentially contaminants, from which arose the particular chemical properties encountered in air from different sources.

Joseph Priestley, writing in 1775, related that two kinds of air, or at least the effects of them, had been known to all miners for many years.(4) One of these was heavier than common air, lay at the bottom of pits, extinguished candles, and killed animals that breathed it. This was called "choke damp." (The term "damp" signified vapor or exhalations in German and Saxon). The second was lighter than common air and occurred near the roofs of subterranian places. Because it was likely to take fire and explode it was named "fire damp." Air of the former kind had been observed on the surface of fermenting liquors and had been called "gas," which he indicated was the same as "geist" or spirit of van Helmont.(9)

Experimental studies of air from this period explored its physical properties, such as its weight and also its elasticity or "spring," that is, the capability of a gas to undergo compression on application of pressure and to re-expand when the pressure is decreased. Representative studies from this period were those of Evangelista Torricelli (1608-1647) and Blaise Pascal (1623-1662). Torricelli, for a short time assistant to Galileo, was the inventor of the barometer. He observed that, when a long tube sealed at one end and filled with mercury was inverted in a dish of mercury, the height of the mercury column in the tube was about 76 cm. He deduced that the weight of the mercury column was supported by the pressure of the atmosphere acting upon the surface of the mercury in the dish and also that a vacuum existed above the column in the tube. Pascal and his brother-in-law extended the experiment of Torricelli on the mountain "Puy de Dôme" near Clermont-Ferrand in France. They demonstrated that the height of the mercury column in a barometer decreased as one ascended to altitude. Pascal is honored in our own time by having the international unit of pressure named after him (1 pascal = a force of 1 newton per square meter of area).

Several factors influenced the rapid advancement of knowledge concerning physical behavior of gases in the 17th century. Involved scientists became capable of separating the experimental aspects of the problems under investigation from the general questions of the philosophy of nature. They worked in great centers of science (London, Paris, Florence), which offered the opportunity for frequent scientific meetings and extensive critique of work in progress. Concentration of scientific talent in these centers allowed for easier solution of technical problems, more ready access to scientific equipment, and utilization of highly competent assistants.(10)

The Oxford Scientists

Probably the most remarkable group of seventeenth century pneumatic scientists was that composed of individuals who began their professional careers at Oxford in the 1650's. They continued the remarkable advancement of knowledge for which William Harvey had laid the groundwork about two decades earlier. Among these were Robert Boyle (1627-1691), Robert Hooke (1635-1703), Richard Lower (1631-16 91), John Mayow (1641-1679) and others. These men met regulary to confer and debate on scientific matters and made many important and fundamental contributions in pneumatic chemistry, physiology of respiration, clinical medicine and other areas. Their approach to scientific problems was considerably different from that of many of their contemporaries who were quite enslaved by the written word and whose method of procedure consisted more in a perusal of authors than direct investigation and critical analysis of facts obtained by experiment. The activities of these other colleagues, particularly in universities, consisted of "poring continually upon a few paper Idols" and were dominated by textual controversies. The ability of the natural philosopher seemed to depend upon the number of conflicting opinions he could cite and refute. Academic disputation consisted mostly of textbook presentation.(11)

In 1659-1660 the puritan and anti-royalist protectorate weakened and collapsed and the monarchy was restored with Charles II as king. Many in this Oxford group were relieved of their academic appointments which some had secured because of puritan sympathies. The group dispersed but reformed in London. In 1662 the Royal Society was formed with many of the former Oxford Group as members. This most influential organization has since played a pivotal role in the advancement of science in England and the world. In its publications are chronicled some of the grandest achievements of the human mind.

Robert Boyle was one of several scientists of this period born to noble families. Certain of these individuals seem to have preferred to devote their lives to science ignoring the wealth and infuence to which they were entitled by birth.* Robert's father was Richard Boyle, first Earl of Cork and a great Elizabethean adventurer. Robert Boyle was educated at Eton and then by private tutors while spending the years of the English civil war on the continent. He developed an interest in medicine and then in chemistry. Boyle was one of the founders of the Royal Society and was said to be its most notable and influential fellow throughout his life. He was a supporter of atomism and a particulate theory of matter and mechancial explanations of chemical phenomena.

Of particular importance was Boyle's advocacy of the experimental approach to scientific problems.(12) The opposite view to the experimental approach was that the use of logical thought and reasoning was the correct approach to solution of scientific problems. Influential thinkers such as Spinoza embraced the latter concepts. Boyle's reputation as a writer in natural theology, the meeting of science and religion, was in part dependent on his defence of the experimental method. His other interests included heat, light, color and chemical analysis. He continually refused all titles and positions and declined to assume presidency of the Royal Society in 1680 because of his unwillingness to subscribe to the required oaths.(13) In spite of Boyle's strong advocacy of experimental method and the sophistication of some of his observations, it is noteworthy that he still believed in alchemy (transmutation of elements), talismans, amulets, and old wives' remedies.(14)

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* In the 17th century the greatest contributions to chemistry on the continent came from men with pharmaceutical training and who pursued this profession. The major advances in England originated from men who pursued science as an avocation; amateur investigators. They were either independently wealthy or held positions that gave them time for investigation and theorizing. As a result they tended to advance the theoretical science whereas continental pharmacists were discovering new substances and new reactions.(1)

Robert Hooke was the son of a minister and was destined for a career in the church. Delicate health in childhood precluded this course. He exhibited great precocity in mechanics during childhood and from this early age developed an outlook on nature as a great machine. It was said that throughout his career his intuitive insight into scientific matters was always far greater than his ability to analyze and pursue them in great depth. He enrolled in Oxford in 1653 and immediately fell in with the Oxford circle of scientists enumerated previously. Hooke launched his independent career as Boyle's assistant. He became noted for his interest in and contributions to scientific instrumentation. A study of springs, which he used to power clocks which he devised, led to enunciation of the scientific principle describing the relation of stress to strain on elastic bodies which bears his name: Hooke's Law. Shortly after organization of the Royal Society, Hooke was appointed "curator of experiments." It became his responsibility to provide experiments to be performed before the membership of the Society. A relatively unknown side of Hooke's career was as an architect. After the disastrous great London fire of 1666, he was appointed a "surveyor" and had the opportunity to work with Chrstopher Wren (who had also been a member of the Oxford scientific circle) on the rebuilding of London. Among buildings designed by Hooke were the Royal College of Physicians, Bedlam Hospital, and the Monument commemorating the fire. Hooke had wide scientific interests. In 1665 his "Micrographia" was published. This was a description of various microscopic observations that he had made of different objects. Although he was ignorant of the cellular nature of tissues and organs, the first use of the word "cell" can be traced back to Hooke's description of the microscopic appearance of cork. He is also noted for a theory of light and also work in geology and paleontology. A conflicting theory of light proposed by Isaac Newton led to an unfriendly confrontation between Newton and Hooke and the two remained distant throughout their subsequent professional careers. Hooke published papers in which the principles of universal gravitation and laws of motion of bodies were discussed. Newton acknowleged that his own principles of mechanics were inspired in no small way by Hooke's writings.

In 1677 Hooke began a five year tenure of the office of Secretary of the Royal Society; a venture which proved not to be an overwhelming success. His career gradually waned from then on until his death in 1702 in his chambers at Gresham College in London where he had lived for 40 years. His personality has been described as "difficult" and his physical appearance as unappealing. "He was a dedicated hypochondriac who never permitted himself the luxury of feeling well for the length of a full day."(15)

Robert Boyle learned of an air pump developed by von Guericke, a German scientist. This device would permit creation of a vacuum or pressurization of a vessel with air and was used in the memorable "Magdeburg Hemisphere" demonstration. Using the mechanical ingenuity of his assistant, Hooke, an improved air pump was developed at Oxford.(16) Many of the physical characteristics of air, as well as the relationships of air to life (to be discussed later), were then formulated. Boyle confirmed that the result of Torricelli's experiment was due to air, that sound was impossible in a vacuum, that air is permanently elastic, and that an air was given off as a result of fermentation. He demonstrated presence of air dissolved in water. In 1662 Boyle published his work describing the inverse relationship between volume occupied by a sample of gas and the pressure applied to it.(17) Many people contributed to the definition of the pressure-volume relationship of gases, such as Torricelli and Pascal. As mentioned previously, at this time scientific workers tended to become concentrated in centers of excellence and group activity was a tremendous advantage in overcoming technical problems such as construction of air pumps and glass apparatus. Centers were able to receive and disseminate information and knowledge and also highly competent assistants were readily available. The law describing pressure-volume relationships of gases, now known as "Boyle's Law," could have been named after any of these 17th century scientists, singly or in combination. Boyle's work seems to have been published before that of others and none was more influential.(18) Boyle's law is said to be the first numerical law that defined the functional dependence of two variable magnitudes.(10,19)

Boyle and Hooke inferred certain similarities between combustion and respiration. Both the life of an experimental animal and the burning of a candle were extinguished by evacuating the chamber in which they were confined using the air pump.(20) But there is no evidence that the animal and the candle were ever placed in the chamber simultaneously as in the classic "candle-mouse" experiment often attributed to Boyle. The results of such studies done in modern times indicate that the mouse would significanly outlive the candle flame in an enclosed chamber (except under the condition of rapid evacuation of the chamber as in some of Boyle's studies). If Boyle and Hooke had done the study with both animal and candle simultaneously, they may have become confused and concluded that respiration and combustion were basically quite different.(21) They observed that the animal lived longer than expected if the air in the chamber was compressed. Boyle explained the bellows action of the ribs and thorax in moving air into and out of the lungs and extracted air from blood using the vacuum pump. Boyle also observed that combustion of charcoal and sulfur could occur in the absence of air, but in the presence of nitre (Sodium nitrate, saltpeter).(16) In modern terms, the nitre acted as the source of oxygen for the combustion as in the following equation:

$10\ NaNO_3$	$+ 3S + 8C \longrightarrow$	$3Na_2SO_4$ +	$2\ Na2CO_3$ +	$6\ CO_2$ +	$5\ N_2$
Sodium nitrate	Sulfur Carbon	Sodium sulfate	Sodium carbonate	Carbon dioxide	Nitrogen

As mentioned previously, air was thought to be a corpuscular physical medium and any chemical properties exhibited by air were attributed to material dispersed throughout the medium. It is therefore not surprising that nitre suspended in the air was thought to be involved when combustion occurred in air.

Historians have difficulty making sharp distinction between the exact contributions of Boyle, Hooke, and some of their colleagues to various researches as well as the originality of the conclusions. Columbus, Harvey and Malpighi had believed that the essential function of lungs could be attributed to their motion which was neccessary for mixing, stirring and propulsion of blood. Hooke demonstrated experimentally that a dog with a widely opened chest and with pericardium and diaphragm removed would remain alive as long as the lungs were periodically inflated with air using a bellows secured in the trachea. The experiment was described in detail by a contemporary historian of the Royal Society:

> "An Account of a Dog Dissected by Mr. Hook" In the prosecution of some Inquiries into the Nature of Respiration in several animals a Dog was dissected and by means of a pair of bellows, and a certain pipe thrust into the Wind-pipe of the Creature, the heart continued beating for a very long while after all the Thorax and Belly had been open'd, nay after the Diaphragme had been in great part cut away, and the Pericardium remov'd from the heart. And from several trials made, it seem'd very probable that this motion might have been continued, as long almost as there was any blood left within the vessels of the Dog: for the motion of the heart seem's very little chang'd after above an hours time from the first displaying the Thorax; though we found that upon removing the bellows, the Lungs would presently grow flaccid, and the heart began to have some convulsive motions; but on resuming the motion of the bellows the Heart recovered its former motion, and the Convulsions ceased….."(22)

Hooke later went on to prove that it was not the motion of the lungs during respiration that was the essential feature for the preservation of life using the air pump. He widely opened the chest of a living dog and perforated the surface of the lung in many places. He then blew a steady stream of air through the trachea and out the perforations in the lung surface while the lung remained inflated but motionless. The animal remained alive as long as air flowed through the lung. In the publication describing this experiment Hooke stated his conclusion as to the cause of death in respiratory arrest with directness and clarity unusual for early writings:

> "it was not the subsiding and movelessness of the Lung that was the immediate cause of death, or in the stopping the circulation of the Blood through the Lungs, but the want of a sufficient supply of fresh Air."(23)

Hooke stated his intent to carry out further studies to determine the "genuine use of respiration." It should be noted that Vesalius and da Vinci had also previously kept animals alive by artificial ventilation.

Boyle and Hooke suspected that something must be taken from the air during respiration but were unable to confirm this experimentally. One reason for their failure was their unfamiliarity with the knowledge that during respiration, carbon dioxide is added to the atmosphere in a volume almost equal to that of the oxygen consumed.(16)

A colleague of Boyle and Hooke was Richard Lower (1631-1691). He was born in Cornwall to a prominent and old family and received his medical degree from Oxford in 1665. Lower began his career at Oxford as laboratory assistant to Thomas Willis and played an important role in the studies of neuroanatomy described in Willis' book of 1664 "Cerebri Anatome." The philosopher John Locke was closely associated with Lower at Oxford. Although he was a classics don, Locke spent a considerable amount of time working with Lower on his experiments and dissections involving the nervous and circulatory systems.(24) Lower cut the phrenic nerve and demonstrated its signficance and the role of the diaphragm in breathing.(25) He also made many of the pioneering observations relating to uptake of a vital substance in air by blood in the lungs. He showed that blood in the pulmonary artery was venous. Using Hooke's perforated lung preparation he showed that if lungs were deprived of fresh air then arterial blood which was normally bright red became dark. He also showed that if dark blood were forced through aerated lungs of a dead animal, it would undergo the characteristic color change to bright red. He confirmed the hypothesis that color change of blood in passing through the lungs was due to contact with air by observing behavior of shed clotted venous blood in a dish. The surface of the clot turned bright red, but when it was cut the interior of the clot had remained dark. He was another who thought that some "nitrous spirit" was taken up from the air during respiration.(16) Lower was also known for his work on transfusion of blood between dogs.(26)

As a consequence of Harvey's publication on the circulation, there was considerable interest in injecting all sorts of substances into the circulation of animals. Lower undoubtedly got the idea for transfusion from the injection of wine and beer into the venous system by Christopher Wren. It is of interest that the first human blood transfusions (animal blood into man) were done in an attempt to improve the mind of a demented patient and to treat psychosis in another.(27) (Also see section on history of intravenous anesthesia) Lower's scientific work was done in the first part of his career — before about 1678. His major publication, "Tractatus de Corde," appeared in 1669 and was very well received by the scientific communtiy. The book dealt with the structure and function of the heart and the changes in blood as it traversed the pulmonary and systemic circulations.(28) In his later years, he became preoccupied with his medical practice. After Willis's death he became the most prominent physician in London and court physician. He was among those who attended Charles II during his final illness.(29)

Lower was highly regarded as a scientist. He was designated by some as the second greatest physiologist of the 17th century after Harvey and also as Harvey's successor. He provided a foundation for the work of Mayow which followed.(26)

John Mayow (1643-1679), another of the Oxford scientists, came from a well established family of gentlemen. He matriculated at Oxford in 1658 and received a bachelor of Law degree in 1670. He also studied medicine. He was elected to fellowship in the Royal Society on Hooke's recommendation in 1678.(30)

Mayow confirmed a decrease in the volume of air in which either combustion or respiration had occurred. In both processes something was absorbed from air which during those times was often designated as "nitro-aerial spirit." This concept arose from the observation that the salt nitre (now called sodium or potassium nitrate [saltpeter] and which contains available oxygen) was capable of supporting combustion in the absence of air as mentioned above. It was not unreasonble to 17th century thinkers that nitre-like particles were dispersed throughout the atmosphere. During calcination (modern term: oxidation) metals gained weight from combination with nitro-igneous particles from air. Mayow thus concluded that air was of two parts: a large inert portion and a smaller part of nitro-aerial spirit. This nitro-aerial spirit rendered air fit for respiration. It turned blood bright red, was neccessary for support of life, and was the chief agent of combustion.

The origins of the concept of "aerial nitre" can probably be traced to several earlier writers.(31) Mayow understood the bellows action of the thorax and physiology of pneumothorax (free air in the chest cavity but outside of the lung). He extracted "nitro-aerial sprit" from blood. Mayow practiced rational medicine, in contrast to Boyle.(32) Mayow was able to demonstrate loss of part of the air with combustion or respiration because he worked over water. He observed the change in water level under an inverted glass with an animal or burning material inside. (Working over water amplified the reduction in volume associated with the chemical reactions by permitting solution of some of the carbon dioxide generated while oxygen was being consumed. It was also possible to detect small changes in the level of water.) In a closed space, an animal and a flame would expire almost together for want of "nitro-aerial spirit."(16) Mayow was an extremely skilled manipulator of gases. His equipment and methds for transferring gases from one vessel to another were apparently the best to his time.(32) Mayow correctly inferred the function of the lungs, of the gills in fishes, and of the placenta.(33)

Mayow's work was said to represent the high point in understanding respiration in the seventeenth century, from which time knowledge ebbed owing to the phlogiston theory.(25) His writings lapsed into relative obscurity until they were translated and annotated in 1790 by Thomas Beddoes.(34) Commentaries on Mayow's work by subsequent authors exemplified divergence of opinion on the nature, originality, priority and influence of the contributions of all of the workers mentioned above and others writing in the last half of the 17th century. Partington considered Mayow's work in relation to that of his contemporaries, as well as comments and citations of workers in years following Mayow, and concluded that Mayow was "one of the outstanding experimenters and thinkers of his time."(32)

Another of the Oxford group of scientists was Thomas Willis (1621-1675). At one time Robert Hooke was his assistant. His most important work was "Cerebri Anatome" which was published in 1664. Lower, Millington and Wren all assisted with preparation of this classical volume. Wren provided outstanding illustrations. This book remained as the authoritative text on the nervous system for many years. Willis left Oxford in 1667 to set up a large and lucrative practice in London. The "Soul of Brutes" is a further clinical and anatomical study. "Pharmaceutice Rationalis" was his last work in 1674-1675 and was another clinical, anatomical, and physiological book. Willis is best remembered today for his description of the vascular anastomotic channels at the base of the brain which still bear his name, the "Circle of Willis."(35)

Thomas Willis, writing in 1684, summarized the function of the lungs, incorporating the conclusions of his compatriots such as Harvey, Malphigi, and particularly Mayow on nitro-aerial spirit:

> ". . . . air ought only to enter the lungs to that end, that it might pour out to the blood nitrous particles for its flame and vitality or life, and presently return back; and seeing the blood doth pass through the lungs for that cause, that it might meet the air sukt in according to all its parts; therefore it behoves that both these, viz. the air and the blood be divided into small portions, and with these make everywhere distinct and short meetings."(36)

Willis recognized that air can become "depraved" if the quantity of nitrous particles were diminished — e.g. want of nitre in air could occur in confined assembly of men, in the hot sun or on top of high mountains exceeding the top of the atmosphere. Other causes for lowered amount of nitrous spirit were mentioned. There were also situations where not enough air could be drawn in because organs of breathing had their motion hindered or the air passages became obstructed.(37)

Wilson(1960) listed essential advances in respiratory physiology in the 17th century and those primarily responsible for each advance in the following manner:

a. Circulation of the Blood – Harvey

b. Lung composed of membranes surrounding air spaces. Blood circulates through these membranes in capillaries – Malphigi

c. Essential requirement in respiration is a constant supply of fresh air – Hooke.

d. Change in color of blood during its passage through the lungs due to contact with air – Lower.

e. Some portion of the air is removed in respiration. This is the same portion that is consumed during combustion – Mayow.

Certain members of the Oxford group were sometimes called "virtuosi."(38) A "virtuoso" in this context was an accomplished and serious investigator or experimentor. But the term could be used in either a complimentary sense, e.g. signifying a connoissseur, or disparagingly, e.g. to signify a dabbler or one carrying activities to excess. Seventeenth century science attracted a considerable amount of satire and members of the Royal Society and their colleagues were particular targets. An example of this type of literature is a play, "The Virtuoso – a Comedy," by Thomas Shadwell which appeared in 1676.(39) Shadwell, irreverently and with aside comments, described studies designed to elucidate the function of respiration and the experiments of Hooke involving artificial ventilation. He also ridiculed blood transfusion experiments including one allegedly occurring between sheep and man where the recipient began to grow wool.(39) Satire involving physicians and their practices has persisted down the centuries.(40)

18TH CENTURY CHEMISTRY AND PHYSIOLOGY

STEPHEN HALES

Chemistry may be defined as the science that deals with the composition, structure and properties of substances and of the transformations that they undergo. (41) The writings of Stephen Hales (1677-1761) concerning airs are among the first to consider composition and transformation of substances constituting matter in the gaseous state. He can logically be considered as a founder of British pneumatic chemistry and the inspiration for many of the great discoveries of his successors. Hales was an Anglican clergyman and although he had no formal scientific training, during his years at Cambridge he came under the influence of several distinguished men of science including Isaac Newton. He left Cambridge in 1709 to become Vicar of Teddington, a small village outside of London on the Thames near Hampton Court Palace. There he remained for the remainder of his life, ever faithful to his parish duties and pursuing scientific activites to the extent permitted by his ministerial activities.

Hales, while a student at Cambridge about 1706, attended chemical lectures and witnessed demonstrations of the experiments of Torricelli, Pascal, Boyle and Hooke, some of which were described above. He became a fellow of the Royal Society in 1717. Hales initially conducted many experiments on plant physiology and may also be considered founder of this science. His book on "Vegetable Staticks" described these investigations including the measurment of the pressure of sap within plants. Probably his best known researches relate to circulatory physiology. He measured blood pressure in animals by observing the height to which fluid rose in a long tube inserted into the carotid artery. This work was begun at Cambridge and completed a number of years later in Teddington. He also measured cardiac output from estimates of the size of the left ventricular chamber of the heart as assessed from wax casts of the cavity and from the pulse rate. From these measurements he calculated resistance to blood flow imposed by the peripheral blood vessels and also studied other characteristics of the peripheral circulation. These physiological studies of the circulation were published in the book "Haemastaticks."(42)

The great work of Hales was a combination of his studies of plant and animal physiology, published as "Statical Essays" in 1733. This book included a long section on the analysis of air which would have a great effect on subsequent pneumatic chemistry. He related how quantities of air could be liberated from other substances by such means as heating and fermentation. Under different circumstances volumes of air were absorbed, such as in respiration or combustion. Such air that was an integral part of certain substances and could be evolved from them by different techniques was "fixed air." It had been combined, or fixed, in union with other materials and had lost its property peculiar to airs; that is elasticity. It regained its air-like characteristics when liberated. He thought of air as a unifying binding principle "greatly contributing in the fixed state to the union and firm connection of constituent parts of bodies."(43)

Because of his interest in "fixed airs," Hales devised several types of apparatus to assist his studies of matter in the gaseous state. The most important of these was the pneumatic trough. This consisted of a long-necked retort with the end of its tube under water delivering generated airs into a second container which originally could have been filled with water if desired. This apparatus represented a tremendous improvement over existing equipment because the gas generator and gas receiver could be separated, permitting collection of pure gas for study. Quantitative measuremnts of liberated gas volumes could be made and gases could be "washed," i.e. undesired soluble fumes and gaseous impurities could be removed. Previous workers had used a glass cup inverted over water so that both chemical reactants and products were always present and quantitative measurments were uncertain.(44)

Hales was not concerned with the chemical properties of the airs with which he worked and did not recognize their differences. He did suspect that various different types of airs existed. His important contribution to pneumatic chemistry, besides invention of the pneumatic trough, was the establishemnt of the firm conviction that there was such a thing as "fixed air" and that it abounded in all sorts of animal, vegetable, and mineral substances. He clearly demonstrated the absorption of air during combustion. It was his work that transmitted these concepts to his successors, such as Lavoisier, who were to isolate and characterize these airs and discover their roles in chemical reactions.(45,46)

Practically, Hales believed that supplies of elastic air free from noxious fumes were neccessary for respiration. He measured the amount of air absorbed in breathing and defined the site of its absorption as the alveolar-capillary membrane(47) and he recognized other important facts and principles regarding respiration. His contribution to public health was the invention of ventilators to supply fresh air to ships, prisons, hospitals etc.

Another practical application of science which interested Hales was the treatment of urinary tract stones. He tried to dissolve stones, supplied to him by several distinguished physicians, including Sir Hans Sloan, using a number of substances but was unable to find anything that would accomplish this job and was safe to be given to man. Hales invented a surgical instrument to extract bladder stones. He vigorously opposed quacks who tried to promote medicines reputed to be effective in dissolving stones. He was awarded the Copely medal of the Royal Society in 1739. There was no formal mention of the basis for the award at the time, but a contemporary stated that it was for his experiments on stones — his least successful work.(48) These were the remarkable scientific contributions of the Reverend Doctor Stephen Hales, Vicar of the small Parish of St. Mary's-in-the Meadows of Teddington, Middlesex.

HERMANN BOERHAAVE

Hermann Boerhaave (1668-1738) was another important influence on the general development of chemistry, particulary in Britain. He was an important link between the early British pneumatic chemists, such as Boyle and Hooke, and those destined to make the great chemical discoveries in the middle of the eighteenth century. Besides Hales, he was the most advanced pneumatic chemist of the early eighteenth century.(43) Boehaave was a graduate of Leyden University in the Netherlands, obtaining the medical degree in 1693. As a member of the medical faculty at Leyden during the first decade of the eighteenth century he built an enviable reputation as a teacher of chemistry and medicine. During this time his published books established his reputation throughout Europe. He became a botanist of some note and for a time assisted Linnaeus with his system of taxonomy. After 1718 he simultaneously occupied the chairs of Medicine, Chemistry and Botany: three of the five professorships at Leyden. Probably his most important medical influence was as a teacher. During his professional career 1,119 students were enrolled in the medical faculty, of whom 659 were from English speaking countries.

Boerhaave was one of the great eighteenth century medical systematists. He attempted to synthesize the older and newer theories of medicine. He examined and commented upon the old classical and renaissance medical writings. He then attempted to fuse these with modern contemporary medical theory and thought to attain a comprehensive and consistent medical system including all these ideas which he had collected.(49,50) Yet another area of renown for Boerhaave was in chemistry. He introduced quantitative methods such as accurate thermometry and precision weighing on the most advanced analytical balances. He is often regarded as the founder of physical chemistry and he also made contributions to pneumatics and biochemistry. He was aware of the chemical role of air – i.e that air could be incorporated into other compounds where it lost its properties as air. He knew that airs were soluble in water and demonstrated that air which had been extracted from water by application of a vacuum would redissolve if given sufficient time. Boerhaave also distinguished clearly between air that was "fixed" in Hales' sense and that which was merely dissolved. In 1724 his textbook of chemistry "Elementa Chemiae" was published. It appeared in English as "The New Chemistry." This volume went through nearly thirty editions and for decades was the authoritative manual on chemistry. He was elected to fellowship in the Royal Society in 1730 and throughout the remainder of his life was the most famous man of science in Europe.(51)

Samuel Johnson wrote an account of the life of Boerhaave which appeared in "Gentlemen's Magazine" in 1739 as part of a series on lives of eminent people. Johnson's biographer, Boswell, indicated that in writing the Boerhaave biography Johnson discovered "that love of chymestry which never forsook him" and that througout his life, Johnson was fond of performing chemical experiments.(50) In 1708 Boerhaave issued a book of his lectures on medicinal chemistry and the principles of physiology; areas in which he perceived that his students of medicine were deficient. The title of this book was "The Institutes of Medicine." For the next 175 years, chairs of physiology and related basic sciences in Scottish universities and of those elsewhere in the British empire were designated chairs of "Institutes of Medicine."

Albrecht von Haller (1708-1777) also contributed to advancement of knowledge of respiratory physiology. He recieved his M.D. degree in 1727 after studies in Leyden, partly under Boerhaave. He was appointed professor of anatomy, surgery and medicine at the new Universtiy of Göttingen in 1736. He soon left Göttingen and spent the remainder of his professional life at Bern. Haller verified observations on the capillary circulation, thereby confirming the theory put forth by Leeuwenhoek and Malphigi concerning the closed circulatory pathway of the blood. He determined the effect of respiration on filling of veins, reporting that during inhalation the blood was driven into the heart from the large veins and during exhalation blood welled up in the veins of the head, neck, chest and abdomen. He also described the anatomical structure of the human diaphragm and made inferences on the function of the intercostal muscles. He demonstrated experimentally that the pleural cavity contained no air. Haller is regarded as the founder of modern neurophysiology. He is also noted for his emphasis on drawing conclusions from experiments rather than from analogies.(52)

In the early eighteenth century teaching of chemistry was of great importance in Scottish medical schools (Edinburgh, Glasgow, Aberdeen). In these institutions instruction in chemistry was in the tradition of Boerhaave. Obtaining an M.D. degree was apparently the initial step in a career in chemistry.(43) The first chair of chemistry in Scotland was established in Edinburgh in 1713 and it was here some years later that the next important development in pneumatic chemistry was to occur.

JOSEPH BLACK

Joseph Black (1728-1799) was born in Bordeaux where his father had settled to operate a mercantile establishment. His earliest education was obtained at home from his mother. At age 12 young Joseph returned to Belfast to join other members of his family and received further education there. In 1746 he matriculated in university at Glasgow where he remained for four years. One of his teachers at Glasgow was William Cullen (1710-1789), a renowned physician and medical theorist. Cullen became a close friend, confidant and advisor to Black until Cullen's death.(53)

In 1751 Black moved to Edinburgh and began studies which would eventually qualify him for the M.D. degree which was awarded in 1754. Initially he was less than enthusiastic about some aspects of medical study which he found personally repugnant but eventually overcame these aversions and pursued his activities with ease. When Black took his M.D. degree in Edinburgh, he postponed going to London for further education in Edinburgh for some practical instruction in which he felt deficient. It was during this period that he did his studies in pneumatic chemistry, upon which his fame rests. Black returned to Glasgow in 1756 where he had received an appointment as professor of chemistry and anatomy (i.e. Institutes of Medicine) and he remained in Glasgow for ten years. He kept on the firm ground of established principles, declining to travel with the systematists in their attempts to form an all-comprehensive doctrine.(54) He became a friend to 20 year old James Watt, maker of mathematical instruments and a developing scientist. This friendship lasted for over 40 years. Watt had an important role in events influencing introduction of clinical anesthesia which will be examined later. During this period Black worked in his other important area of scientific endeavor: specific heat and latent heat of vaporization. He also engaged in medical practice at this time. Black returned to Edinburgh in 1766 as professor of chemistry. He was an acknowleged master at the teaching of chemistry and had many important and influential students. Among those of particular importance in events described in the present volume were Thomas Beddoes, David MacBride and Samuel L. Mitchill. Black was a supporter of the subsequent researches of Thomas Beddoes on Pneumatic Medicine and was a financial subscriber to support of the Medical Pneumatic Institute at Bristol. He remained at Edinburgh for the remainder of his life.(55)

Black's monumental chemical experiments were done during his first sojourn in Edinburgh 1754-1756. His initial interest was in alkaline substances, specifically compounds of the alkaline earth metals calcium [Ca] and magnesium [Mg]. These particular substances attracted him because of the then current belief that drinking of limewater (a solution of calcium hydroxide [$Ca(OH)_2$]) would be beneficial in dissolving kidney and bladder stones. The interest of the medical community had been directed by Stephen Hales to this application of limestone (calcium carbonate).(56) Two Edinburgh physicians, Robert Whytt and Charles Alston, who were members of the faculty of medicine and professors to Black, did extensive investigations on limewater and its properties but with conflicting results. The work of Alston was said to have been chemically oriented and he came close to some of the discoveries subsequently published by Black who was undoubtedly influenced by his results. Some of the writings of Whytt emphasized the value of naturally occurring alkaline mineral waters for treatment of urinary tract stones.(57) Properties of compounds of alkaline earth metals were selected by Black as the subject for his thesis to be submitted for his M.D. degree. Although medical interest was focused on limewater he chose compounds of magnesium for his initial studies. He believed that the problems associated with limewater would be too difficult to solve. However in addition, as he wrote to his father in a letter, he had no desire to insinuate himself into the controversies betweeen his professors centered about the properties of limewater.(58) But eventually he studied both calcium and magnesium compounds.

Black's thesis was accepted by the faculty in 1754. His work was presented to the Royal Society of Edinburgh in 1755. Most of his chemical work on both calcium and magnesium compounds had been done by this time. His only major publication "Experiments on Magnesia Alba, Quicklime and some other Alcaline Substances," appeared in 1756 and was a major influence in understanding of chemistry.

Some of the important findings which he reported may be summarized as follows: On calcination* both limestone (chalk, calcium carbonate, $CaCO_3$) and magnesia alba** (principally magnesium carbonate, $MgCO_3$) lost part of their weight and became more caustic.*** In modern chemical terms these reactions can be represented as follows: (See also references 59 and 60)

$CaCO_3$	—>	CaO	+	CO_2
limestone	heat	quicklime		carbon
		(caustic)		dioxide

* Calcination – heating of a substance to a high temperature without melting it in order to drive off volatile matter or effect other changes such as oxidation.

** Magnesia alba is actually a complex salt which is a hydrated basic magnesium carbonate of composition $Mg(OH)_2*3MgCO_3*3H_2O$.

*** Caustic – (from Latin causticus: to burn) – capable of destroying or eating away by chemical action. i.e. corrosive.

$MgCO_3$	—>	MgO	+	CO_2
magnesium carbonate (magnesia alba)	heat	magnesium oxide (magnesia usta)		carbon dioxide

The quantity of weight lost during calcination was determined. Black recognized that this loss was due to loss of "air" from the substance being heated. Next he was able to reverse this process by reconverting quicklime to limestone by chemically reacting the quicklime with an alkaline substance. During this reaction the original weight and condition of the limestone was regained; i.e. the lost air had been recovered. In the process, the lime returned to the original mild non-caustic state of chalk while a more caustic alkali free of lime was formed. This reaction was named "caustification." Because it proceeded in the absence of fire, he concluded that loss and gain of air in these reactions was not due to particles added or subtracted by fire.

CaO	+	H_2O	—>	$Ca(OH)_2$	+	Na_2CO_3	—>	$CaCO_3$	+	$NaOH$
quicklime		water		slaked lime* (alkali)		sodium carbonate		limestone (chalk)		sodium hydroxide (strong caustic alkali)

Black also demonstrated that when either magnesia alba or magnesia usta was treated with strong acid, identical salt was formed.

$MgCO_3$	+	HCl	—>	$MgCl_2$	+	H_2O	+	CO_2
magnesia alba		hydrochloric acid		magensium chloride		water		carbon dioxide

MgO	+	HCl	—>	$MgCl_2$	+	H_2O
magnesia usta		hydrochloric acid		magensium chloride		water

For a given quantity of salt formed the amount of acid consumed was approximately the same for both compounds. Visible effervesence and a loss of weight from the reacting ingredients occured with magnesia alba but not with magnesia usta. Comparable reactions between limesone (chalk, $CaCO_3$), quicklime (CaO) and strong acids were demonstrated. Black concluded that the only difference between magnesia alba or limestone on the one hand and magnesia usta or quicklime on the other was the presence of air fixed within magnesia alba and limestone. Magnesia usta and quicklime had already lost their air through heating before treatment with the acid.

Next Black applied the air pump. He demonstrated that when placed in a vacuum generated by the air pump both limewater and plain water yielded

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* Slake – to slake means to make crumbly. Calcium hydroxide [$Ca(OH)_2$] is sometimes called "slaked lime." Quicklime (CaO) when treated with water yields slaked lime which is sparingly soluble in water. A solution of slaked lime is limewater. A heavy suspension of slaked lime is whitewash.

comparable amounts of air and this was ordinary elastic air.* Limewater, but not plain water, effervesced and generated a considerable additional quantity of air when treated with acid. Also, limewater, on exposure to the atmosphere, developed a crust. This phenomenon could be prevented by lightly corking the container.

Thus, the air that quicklime attracted was a different kind of air than that simply dissolved in water. It was one particular species of air which was dispersed throughout the atmosphere in an "elastic" or perhaps in a "particulate" state. This was the air which was liberated from limestone by heating or by acid. This, Black called "fixed air" and it is known today as carbon dioxide (CO_2). He subsequently designated magnesia alba as a "compound of a peculiar earth and fixed air"(61) thus demonstrating an intuitive appreciation of chemical reaction and combination.

Some characteristics of fixed air were described. It was different from common air and comprised only a small part of the atmosphere. It extinguished a flame. Fixed air caused limewater to turn milky and Black suggested the change in appearance of limewater as a test for fixed air. It was absorbed by caustic alkalis. Black used caustic alkali to absorb carbon dioxide from the atmosphere of a crowded church. He recognized fixed air as being produced by respiration, fermentation, burning of charcoal, and action of acids or heat on chalk.

When Black began his observations, air was believed to be an element, a belief going back to Empedocles in ancient Greece. Black was familiar with the earlier work of Hales showing that many substances had air within them that could be liberated but Hales still believed that there was only one type of air. Van Helmont had suspected that more than one type of air existed. Black identified and characterized a particular species of air proving that there was more than one type of aeriform substance.

Black's "Experiments on Magnesia Alba" was recognized as perhaps the first successful model of quantitative chemical investigation and its significance was said to be comparable to works of Newton in physics.(56) Much of Black's success was due to his accuracy in weighing. He has been called the father of quantitative chemistry.(54)

To summarize Black's contribution with the phrase "he discovered carbon dioxide," which is often done, neglects the revolution in chemical thought wrought by the work of Joseph Black.

Black's other great contribution was in the area of the nature of heat. He had been attracted to this area by the observation of Cullen that ether boiled as ambient pressure was decreased. In his investigations Black was assisted by Watt. It was said that Watt applied the results of their joint studies to the invention of the separate condenser for steam engines.(54)

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* Elastic – the property of being compressible and of regaining the original volume when the compressing forces are removed. "Airs" fixed within chemical compounds have lost this property.

John Robinson wrote the introduction to Black's chemical lectures which were published posthumously in 1803. Robinson wrote,

> "He had discovered that a cubic inch of marble consisted of about half its weight of pure lime and as much air as would fill a vessel holding six wine gallons....what could be more singular than to find so subtile a substance as air existing in the form of a hard stone, and its presence accompanied by such a change in the properties of the stone?"(1)

HENRY CAVENDISH AND DANIEL RUTHERFORD

Ten years after publication of Black's work, the second specific species of gas was isolated and identified. Henry Cavendish (1731-1810) described hydrogen in 1766. Cavendish was an aristocrat in contrast to most other scientists of the time. His father was a younger son of the Duke of Devonshire and his mother was a daughter of the Duke of Kent. Henry was born in Nice where his mother had taken up residence because of her poor health. He was educated at Cambridge but left without obtaining a degree. Although he was extremely wealthy, throughout his life he shunned fashionable society and devoted himself almost exclusively to his scientific interests and pursuits. He was encouraged in these directions by his father, also an avid scientist and experimentor, who put his equipment and facilities at Henry's disposal and also introduced the young man to the scientific circle of London and to the Royal Society. Henry Cavendish remained intimately involved in community scientific activities throughout his life. He was elected a Fellow of the Royal Society in 1760. Besides his interests in pneumatic chemistry, Cavendish was involved in pure mathematics, mechanics, optics, electricity and magnetism, thermodynamics, and geology. He wrote no books, published few papers and was not a teacher. He was said to be first after Newton in possessing mathematical and experimental talents comparable to those of Newton and without peer in intellectual stature in eighteenth century British science.(62)

The major contribution of Henry Cavendish to pneumatic chemistry was presented in his 1766 publication, "Three Papers containing Experiments on factitious Air."(63) In these papers he reintroduced the term "factitious air," which was first used by Boyle and which had been appropriated by Black as a generic term for any chemically derived gas.(56) For this publication he was awarded the Copely Medal of the Royal Society.(64) Cavendish's publication began by defining "factitious air" as "in general any kind of air which is contained in other bodies in an unelastic state, and is produced from thence by art." He next defined "fixed air" as "that particular species of factitious air, which is separated from alcaline substances by solution in acids or by calcination; and to which Dr. Black has given that name in his treatise on quicklime." He described and illustrated his apparatus for generation, collection and transfer of gases. He then explained the generation of "inflammable air" (hydrogen).(25) Zinc, iron and tin were treated with either vitriolic acid (sulfuric acid) or spirit of salt (hydrochloric acid (HCl)). The gas generated from the resulting chemical reaction was flammable. The chemical reactions, expressed in modern terms, would have been:

Zn	+	H_2SO_4	—>	$ZnSO_4$	+	H_2
zinc		vitriolic acid		zinc sulfate		inflammable air (hydrogen)
Fe	+	$2HCl$	—>	$FeCl_2$	+	H_2
iron		spirit of salt		iron chloride		inflammable air (hydrogen)

He characterized inflammable air as relatively insoluble and demonstrated that the presence of ordinary air was neccesary for the combustion of inflammable air. He noted that, as increasing amounts of common air were mixed with the inflammable air, the ensuing explosion on ignition became more violent. The density of inflammable air was measured at 1/7 to 1/10 that of common air (but he recognized that his inflammable air may have been contaminated with common air). Next followed experiments on fixed air. He confirmed that fixed air was absorbed by limewater and was also soluble in pure water.

Cavendish quantified the solubility of fixed air in pure water and observed that it could be expelled from the water by boiling or by being permitted to sit in an open vessel. He also determined solubility of fixed air in wine and oil. The weight of fixed air was estimated to be about 1.5 times that of common air and 563 times lighter than water. He verified that fixed air will not support combustion and conducted further experiments on the quantity of fixed air contained in various alkaline substances such as marble (limestone).

The third set of experiments described in his publication examined the airs produced by fermentation. Cavendish observed that air produced by fermentation of sugar or apple juice has a density similar to that obtained by treating marble with acid and will also extinguish a flame. It therefore must have been the same as Black's fixed air. In addition, he obtained a mixture of air from putrefaction of animal material, one species of which was inflammable. This air was considerably heavier than the inflammable air previously obtained from metals and acid. He was not certain to what extent the two types of inflammable airs resembled one another.

In a subsequent publication of 1784 he reported that when inflammable air and common air were exploded together, there was a considerable reduction in volume but no loss of weight of the system, and dew appeared in the container. This he identified as pure water. The explanation offered by Cavendish was complicated and involved phlogiston. When the writings of Lavoisier describing his "new" chemistry appeared, Cavendish remained sceptical of many of the concepts presented.

The apparatus used by Cavendish in his experiments was simple and little different from that of Hales. One improvement made by Cavendish was collection of gases over mercury rather than water to reduce loss of gases by solution.(6) The work of Cavendish marked the beginning of the systematic study of gases. The capability to differentiate gases from one another using physical and chemical characteristics made it possible for Cavendish and his successors to discover and characterize several different gases in the next few years.(58)

Nitrogen was the next gas to be described. Credit for this achievement is given to Daniel Rutherford (1749-1819). He was a son of John Rutherford, a student of Boerhaave, and one of the founders of the medical school at Edinburgh. J. Rutherford became professor of medicine at that institution. Daniel Rutherford studied medicine at Edinburgh and was a student of both Cullen and Joseph Black. He was a practicing physician and also ultimately became professor of botany at the university in Edinburgh. He was an uncle to the novelist Sir Walter Scott.(65) Rutherford described the discovery of nitrogen in his M.D. thesis published in 1772. On assignment of his professor, Joseph Black, Rutherford was investigating some further properties of Black's "fixed air." Initially he discussed air freed from calcareous substances by acid. This he preferred to call "mephitic air."* He then considered the composition of air in which animals had been confined. As the animal breathed, a contraction in volume of the air occurred. Eventually the remaining air was no longer capable of supporting life. He observed that, if the mephitic air (carbon dioxide) was absorbed from this residual air using caustic alkali, it was still incapable of sustaining life and, also, it would not support combustion. However, in contrast to the fixed air of Black, it did not turn limewater milky. Clearly this type of air, which Rutherford called "noxious air," was a different species from the fixed air of Joseph Black.(25) "Noxious air" could also be obtained by treating air remaining after combustion of coal in the same fashion. Although this was the earliest published account of nitrogen and establishes Rutherford's priority of publication, others also knew of its existence earlier. Among these were Priestley, who called the gas "phlogisticated air," and Scheele who called it "vitiated air." French chemists subsequently called this species of air "azote" because it was incapable of supporting life.(65,66,67)

A technological spin-off related to gases near the end of the 18th century was the occasional substitution of light inflammable air (hydrogen) for hot air in aeronautical balloons. The original ballooning experiments of the Montgolfier brothers in France were inspired in part by the publications of Joseph Black. The military value of these devices was recognized quite early. Following publication of Cavendish's work on hydrogen, Joseph Black prepared a small indoor hydrogen-filled balloon using the foetal membranes of a calf. He then suggested use of hydrogen to lift a glazed cloth outdoor balloon.(68,69)

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* Mephitic – resembling a noxious, pestilential or foul exhalation from the earth.

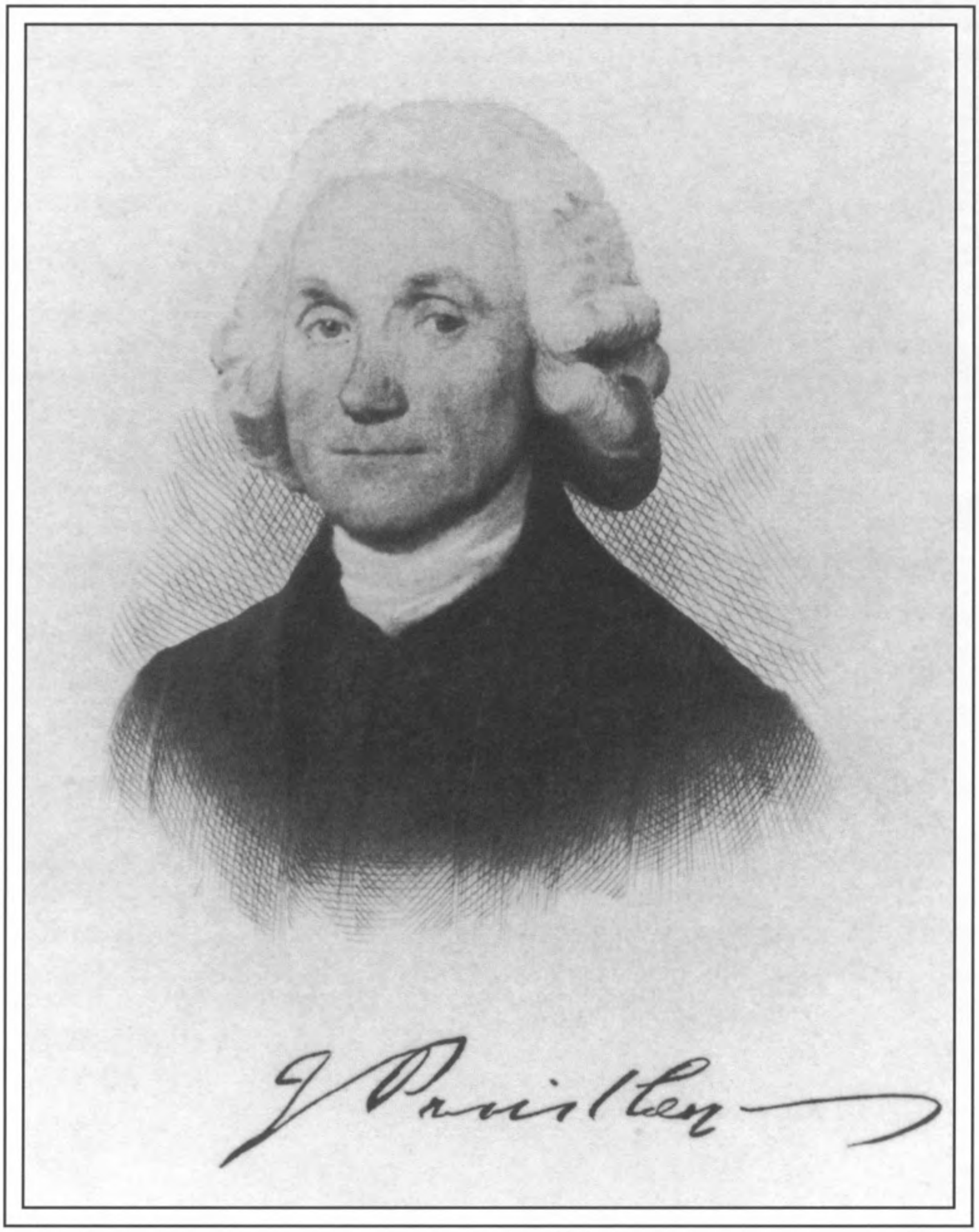

PLATE III—JOSEPH PRIESTLEY (1733-1804). He was the most distinguished pneumatic chemist of his era and discovered several gases. Among these were nitrous oxide and oxygen. He reported the effects of breathing some of the gases on animals and on himself and was an early advocate of pneumatic medicine.

Chapter IV

Joseph Priestley

The life of Joseph Priestley (1733-1804) occupies a pivotal role in the development of anesthesia. He discovered and characterized at least 10 gases, among which were nitrous oxide and oxygen. Knowledge of the properties of these and other gases would become essential in the initial formulation of anesthesia. He was a founder of pneumatic medicine and one of the first to suggest that these newly discovered gases might be applied medically. The roots of modern anesthesia are firmly rooted in pneumatic medicine. He was a member of the Lunar Society of Birmingham. He was best known in his own time as a dissenting religious leader and political philosopher and would pay dearly for his nonconformist views. We will examine first Priestley's life, many details of which are related in his autobiography. Then his scientific achievements will be described.

Priestley was born in Yorkshire. He was separated from his immediate family and raised in the household of an aunt. His early education was obtained in parish schools, by private lessons and by means of intensive self-directed study. At age 19 he gained admission to the dissenting academy at Daventry. The curriculum which he studied was particularly centered on philosophy, but some natural science and mathematics were included. He left Daventry trained as a spiritual leader in 1755.

His initial appointments as a clergyman were not successful, partly because of his heterodox views on some aspects of theology but also because of an inherited speech impediment which he believed interfered with effective delivery of sermons. In 1761 he moved to a new dissenting academy at Warrington as an instructor in literature and languages. Priestley later revealed that he would rather have taught science at the academy than the subjects to which he was assigned.(1) His appointment was based partly on his demonstrated success as a teacher in one of his previous posts. He was ordained while at Warrington.

In the following years numerous writings by Priestley on grammar and language, literary criticism, education, history and government appeared. As mentioned above, he became known as much for his writings and views on politics, theology, philosophy, history, education and language as for his work in science. In

1764 Priestley was awarded the LL.D. degree by Edinburgh University. This honor was based on his work in the field of education. About 1765 he began his scientific work with the book, "History of Electricity." This volume was undertaken with the encouragement of several scientific sponsors or advisers, including Benjamin Franklin whom Priestley had met during a visit to London in that year.(2) The work was published in 1767. "The History of Electricity" as well as the subsequent "History of Optics," were his first scientific books. The use of the word "history" in the titles of these books does not signify history as the word is generally understood today. Rather a general survey of knowledge in these fields was intended.

In 1766 Priestley was nominated and elected to fellowship in the Royal Society. This prestigious recognition was again on the basis of his work and writings in fields other than science. In 1762 he married Mary Wilkinson of the family of famous British ironmasters.

At Warrington, when Priestley began chemical lectures he recruited as a fellow lecturer the surgeon Matthew Turner. Turner was known for his preparation of sulfuric ether on a commercial scale. Because of both doctrinal differences and the meager salary that he received he resigned his teaching post in Warrington in 1767 to become minister of the Presbyterian congregation at Mill Hill chapel in Leeds. It was during his tenure of this post that he began his experiments on gases. Also during this period he embraced Unitarian Doctrine. In 1772 Priestley published his "History of Optics." In 1772 he also published his first paper on pneumatic chemistry. This work was "Directions for Impregnating Water with Fixed Air." (See below.) This work was probably most influential in his receipt of the Royal Society's Copley Medal in 1773.(3) Priestley was both surprised and delighted by an invitation to serve as astronomer on Captain James Cook's second voyage of exploration which was to leave England in 1772. The position offered liberal financial advantages at a time when the Priestley family was growing. However the offer was withdrawn and others were appointed to the post because of strong objections by individuals in influential positions to Priestley's doctrinal and political views.(4) About 1773 William Petty, Earl of Shelburne, persuaded Priestley to enter his service as librarian and advisor to the household tutor. Another function of Priestley in the Shelburne establishment at this time was probably to serve as a liaison between Shelburne and the politically active religious dissenting community.

An insight into Priestley's priorities was provided in an anecdote related by Mary Anne Galton: At the time of Priestley's move from Leeds to Calne (Wiltshire) to become Librarian to Lord Shelburne he was placed in charge of tying and securing certain boxes packed by Mrs. Priestley. When she subsequently opened the boxes she found under the cover of each box specimens of minerals of all sorts and a number of chemical mixtures. The doctor begged her not to distress herself if the clothes were a little injured, for the minerals had come through perfectly well.(5) Yet another anecdote related to an occasion when Priestley travelled away from home and left some gas experiments in progress with the instruction that nothing should be disturbed on his return. The house maid interpreted this to mean that everything should be neat on his return and so she cleaned thoroughly and put everything away. This greatly horrified Mrs. Priestley who had to devise a way to inform the doctor of the fate of his experiment. Upon his arrival she hesitated and beat around the bush at such length that he thought something had happened to one of the children, and was so thankful to find the children alright that he was relatively undisturbed by his ruined experiments.(6)

In 1774 Shelburne and Priestley toured the European continent. This was Priestley's only visit to continental Europe. In Paris, he met many distinguished scientists. Among these was Lavoisier who was already familiar with Priestley's work, particularly his "Impregnation of Water."(7) During the period 1774-1780 Priestley lived both at Calne, the Shelburne estate in Wiltshire and also at Shelburne house in London.

Priestley had intended to produce an encyclopedic scientific work, but gave up the idea in 1774 because of the bleak prospects for making any money from the project. He commented:

> ". . . . I have for the present, suspended my design of writing the history and present state of all the branches of experimental philosophy. This has arisen not from any dislike of the undertaking, but, in truth, because I see no prospect of being reasonably indemnified for so much labor and expense, not withstanding the specimens I have already given of that work (in the history of electricity and of the discoveries relating to vision, light and colours) which have met with a much more favorable reception from the best judges both at home and abroad, than I expected. Immortality, if I should have any view to it, is not the proper price of such works as these."*(8)

In 1780 Priestley left Shelburne's service but retained a lifelong annuity from Shelburne. This arrangement had been a part of the conditions for Priestley's entering Lord Shelburne's employ. During this period of service, Priestley had done most of his scientific work and prepared five of the six major volumes dealing with his experiments on gases. Also, several further important philosophical works were written during this period. In 1780 Priestley, on the advice of his brother-in-law John Wilkinson, settled in Birmingham where he became preacher at the New Meeting House, one of the most liberal congregations in England. This sojourn in Birmingham was regarded by Priestley as the happiest period of his life.

He became a member of the Lunar Society of Birmingham, a remarkable group of individuals from all walks of life who shared an interest in science. However, he had been corresponding with members of the society, for example Small and

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* Academic administrators please take note!

Boulton, as early as 1773. The Lunar Society supported his researches, intellectually and financially, while he consulted on some chemical problems related to the interests and businesses of his colleagues. (Members of the Lunar Society of Birmingham, both individually and collectively, are so important to our story that they deserve and receive a separate chapter in this book.)

During his residence in Birmingham, Priestley was also greatly preoccupied with his non-scientific writings and became the archetypical representative of dissent. He made himself unpopular in certain quarters with his support of both the American and the French Revolutions and boldly expressed these sentiments in writing. He was regarded as a radical, an atheist and a revolutionary. His Aryan religious beliefs (doubt in the validity of the trinity) and his espousal of Unitarianism also contributed to his unpopularity. Priestley has been characterized as a bridge between the 18th century political necessity of natural rights of the individual and the mood of the 19th century characterized by the watchwords "good of the whole." He asserted both a claim for the right of private judgment and principle of toleration and also enunciated the principle of the greatest happiness of the greatest number.(2) The response of the established community to Priestley's advocacy of these unpopular views was the destruction of Priestley's house and church by a frenzied mob as well as threats to his person during the "Church and King" riots of 1791 in Birmingham.

On July 14, 1791, a dinner to celebrate Bastille day was scheduled in a Birmingham hotel. All friends of liberty were invited to attend. Priestley did not go. There were some unpleasant incidents as dinner guests entered the hotel. At about 9:00 P.M. a "riotous mob led by designing men of the baser sort" attacked in succession the hotel and two Unitarian Meeting Houses; by this time, possibly 1,000 strong, they then marched to Priestley's home where they destroyed his library, laboratory and scientific papers. Houses of many other prominent dissenters were also destroyed. William Withering's home was threatened by the mob shouting "No Philosophers!" because , although he was an orthodox member of the Church of England, he was also a Lunar Society Member.* The attack on Withering's house failed. Soldiers arrived on July 17th but by this time the mob had dispersed and returned to work.(10)

There appeared to be three general targets for the wrath of the mob: political reformers, religious dissenters and Lunar Society members. Responsibility for the episode was not clear nor were the exact motives for the disturbance. The government probably did not instigate the rioting, but was apparently not displeased with the results. King George III was gratified that the people saw Priestley and his followers in the "correct" light but deplored the measures taken to demonstrate their feelings. The local magistrates acted shamefully. They

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* It appears that some of the mob weren't really aware of the purpose of their rioting since they carried on shouting "No Popery."(9)

appeared reluctant to stop the rioting. Investigation of the incidents was far from zealous and few of the perpetrators were brought to justice. Priestley wrote a letter to the inhabitants of Birmingham in which he said that the worst effects of riots were in the destruction of his laboratory, equipment and library, but the most important loss was the manuscripts that he was working on which he would never be able to recompose. The Unitarians were temporarily out of public life and Priestley was driven from Birmingham. The 1791 riots probably represented an explosion of latent class hatred and personal lawlessness triggered by the coming together of old religious animosities and new social and political grievances which the attack on those such as Priestley symbolized.(2,9) A few days after the riot Priestley wrote to James Keir. Apparently he was anticipating returning to Birmingham and possibly seeing Keir at the next Lunar Society meeting. However about one week later (29 July 1791) Priestley, in another letter, indicated that his life in Birmingham was finished. He did not know when he would return, if ever, and if he would ever be able to resume experiments. The Derby Philosophical Society sent a letter of sympathy to Priestley after the 1791 riot. At the same time, the membership urged Priestley to abandon his theology and cultivate his philosophy. He thanked them but declined their suggestion. There was considerable internal dissension in the organization over the propriety of this letter and also related to the circumstance that a small minority of members evidently composed the content of the letter.(12) The Manchester Literary and Philosophical Society also considered expressing condolences to Priestley, but in the end did not do so. Appropriateness of this action occasioned bitterness and dissension within the organization and prompted several resignations from membership.(13)

After the riot, Priestley moved to London where he was briefly associated with the dissenting academy at Hackney. His election as a free citizen of France in 1794 reinforced his reputation as a subversive. He was virtually boycotted and found it impossible to preach or carry out his chemical studies. He was harassed and burned in effigy.(2) Continuing and increasing political intolerance prompted his emigration to the United States in 1794. An associate of Priestley had been sentenced to seven years deportation in 1791 for criticism of the government.(14) Perhaps Priestley chose self-imposed exile in a locality of his choice rather than possible forced deportation.

Mrs. Anna Laeticia Barbauld, a popular authoress, regretted that the odium which Priestley had attracted because of his views and writings prevented him from presiding over the Royal Institution which was so popular in the early nineteenth century and to which honor she felt he was entitled.(15) (The appointment went to the much younger and less experienced Humphrey Davy).

In the United States he declined a position as professor of chemistry at the University of Pennsylvania. Instead, he settled in Northumberland, Pennsylvania, near what was intended to be a settlement of English émigrés fleeing political persecution. The settlement never developed. He was eventually befriended by

President Jefferson. William Small (1734-1775), one of the founders and certainly a key member of the Lunar Society of Birmingham in the 1760's, was a link between Priestley and Thomas Jefferson. Small had been professor of natural philosophy at the College of William and Mary in Williamsburg, Virginia. Jefferson and Small became friends, expressed mutual admiration, and remained in communication until Small's death. Priestley had also corresponded with Small about some chemical experiments.

Joseph Priestley died in 1804 at age 71 leaving, two sons in the United States. His daughter, Sally Priestley Finch, had remained in England and had died from pulmonary consumption in 1803. Joseph Priestley is buried in Northumberland, Pennsylvania, and his house remains as a museum.

Priestley's Scientific Work

Joseph Priestley is remembered as one of the world's foremost pneumatic chemists. His discovery of new gases and new processes would make the old chemistry of his day untenable. Yet, he never developed a theoretical basis of chemistry compatible with his discoveries, and refused to accept the new system developed by Lavoisier.

Priestley has been given credit for discovering the following gases:

NO	nitrous air	nitric oxide
N_2O	dephlogisticated nitrous air	nitrous oxide
NO_2	nitrous acid air	nitrogen dioxide
HCl	marine acid air	hydrogen chloride
NH_3	alkaline air	ammonia
SO_2	vitriolic air	sulfur dioxide
O_2	dephlogisticated air	oxygen
H_2S	sulfuretted inflammable air	hydrogen sulfide
$SiFO_4$	fluor-acid air	silicon tetrafluride

Priestley had read Boerhaave's text on chemistry as early as 1755. In 1762 he assisted in the planning and delivery of chemical lectures at the Warrington Academy. He became interested in pneumatics through the writings of Joseph Black. When Priestley began his work in pneumatic chemistry three airs were identifiable as distinct entities: atmospheric air, the "fixed air" of Joseph Black (carbon dioxide) and inflammable air (hydrogen) which had been discovered by Henry Cavendish. Priestley attributed a strong motivation to study pneumatic chemistry to the presence of a brewery close to his residence in Leeds. This establishment provided large quantities of fixed air produced during the fermentation of malt.(16)

About 1766 he began studies of common, mephitic and inflammable airs and in 1770 he began inquiries into Hales' study of airs. Schofield believes that Priestley's pneumatic thinking and explantions of phenomena were based solidly on Hales' chapters on airs in "Vegetable Staticks."(17) Priestley began his studies with the airs generated by Hales and then devised his own methods and experiments to isolate and characterize further airs. Henry Cavendish had utilized a pneumatic trough which was very much like that of Hales. Cavendish recognized the problem of solubility and substituted mercury for water in the trough. It was Priestley, however, who over the years fully exploited the use of mercury to isolate a group of very water-soluble gases.(18) He designed and developed sophisticated chemical apparatus and adapted the pneumatic trough used by earlier workers. In some instances he used common household utensils because the necessary apparatus could not be purchased commercially. A considerable amount of information about Priestley's laboratory and its contents is known.(19) The ceramic components of his apparatus were supplied by Josiah Wedgwood. Glass components were shipped by Parker's, a firm in London.(19) Eventually all Priestley's apparatus was destroyed in the 1791 Birmingham riot. It was said at the time to have been one of the world's greatest collections of pneumatic apparatus.

Priestley used several different tests to characterize the gases with which he worked. He examined their reaction with limewater and determined whether or not they burned or supported combustion. He examined their appearance, odor and taste. He observed how long a mouse could survive in the gas. He employed the technique of eudiometery and observed the characteristics of flames and electrical sparks in the gas.(20) He was also concerned with the role of the blood in respiration.

Some of Priestley's most important work involved the discovery and study of the properties of gaseous oxides of nitrogen. He prepared "nitrous air" (nitric oxide, NO) by treating metals with nitric acid. For example:

$3Cu$	+	$8HNO_3$	—>	$3Cu(NO_3)_2$	+	$4\ H_2O$	+	$2\ NO$
copper		nitric acid		copper nitrate		water		nitric oxide

His experiments proved that nitrous air could be used as a reliable test of the respirability of a gas or mixture of gases. For this purpose nitrous air provided a good substitute for observation of the fate of mice in the atmosphere in question.(20) When nitrous air was introduced into a respirable (oxygen containing) gas mixture, the total volume of the gases would diminish and reddish brown fumes appeared. (The modern description of this reaction is that nitric oxide is oxidized to nitrogen dioxide by the oxygen in the respirable mixture.)

$2\ NO$	+	O_2	—>	$2\ NO_2$
nitric oxide		oxygen		nitrogen dioxide
(colorless)				(reddish brown)

This observation by Priestley became the basis for eudiometry: the quantitative measurement of change in gas volume associated with certain chemical reactions.

At the suggestion of John Hunter, surgeon, Priestley confirmed the poisonous nature of nitrous air on fish.(21) The lethality of the gas was also demonstrated on frogs, snails, mice and insects.(22)

Of greatest importance to the subsequent development of anesthesia was Priestley's preparation of "dephlogisticated nitrous air" (nitrous oxide, N_2O) by exposure of nitrous air to iron. He described its properties of being capable of supporting combustion, but not of supporting life. He wrote:

> "As fixed air united to water dissolves iron, I had the curiosity to try whether fixed air alone could do it; and as nitrous air is of an acid nature, as well as fixed air, at the same, exposed a large surface of iron to both the kinds; first filling two eight ounce phials with nails, and then with quicksilver and after that displacing the quicksilver in one of the phials by fixed air, and in the other by nitrous air; then inverting them, and leaving them with their mouths immersed in basins of quicksilver.
>
> In these circumstances the two phials stood about two months, when no sensible change at all was produced in the fixed air, or in the iron which had been exposed to it. but a most remarkable and most unexpected change was made in the nitrous air; and in pursuing the experiment, it was transformed into a species of air, with properties which, at the time of my first publication on the subject, I should not have hesitated to pronounce impossible, viz. air in which a candle burns quite naturally and freely, and which is yet in the highest degree noxious to animals, insomuch as they die the moment they are put into it; whereas in general animals live with little sensible inconvenience in air in which candles have burned out."(23)

This remarkable gas was nitrous oxide, or as Priestley called it, "dephlogisticated nitrous air."

Priestley's earliest publication in pneumatics had been "Directions for Impregnating Water with Fixed Air etc." in 1772.(24) He believed that water impregnated with fixed air would act as an antiscorbuitc, in accord with the theory of Macbride. The publication was dedicated to John, Earl of Sandwich, First Lord of the Admiralty. Because the Admiralty concurred with Priestely's idea, the Earl believed that these directions ought to be published for guidance of concerned individuals. (The rationale for using fixed air as an antiscorbutic is explained in the discussion of early 18th century pneumatic medicine in this volume.)

The invention of water containing large quantities of carbonic acid gas (soda water) which could be evolved in the stomach is attributed to William Bewley (1726-1783). Bewley, sometimes designated as the "Sage of Massingham," was a surgeon-apothecary and had wide interests in science. He was noted for his reviews and commentaries on scientific works and he wrote appendices to certain of Priestley's works on gases.(25) Priestley's practical instructions directed that fixed air was to be prepared by treating chalk with vitriolic (sulfuric) acid and then led into a second vessel which was inverted over water and agitated. The volume of fixed air taken up was approximately equal to the volume of water used.

Alternatively, one could pour water from one vessel to another while they were held over a brewer's vat in which fermentation was actively occurring. Priestley knew that the gas which escaped from the vat and concentrated in the 9-12 inches above the surface was fixed air (CO_2). The water thus prepared was called "Pyrmont Water" or "Seltzer Water" after prominent spas in continental Europe where such waters occurred naturally.(26) Priestley's apparatus for impregnating water incorporated an animal bladder as a squeezable reservoir. Many (including Brownrigg and Withering) believed that the bladder imparted an objectionable taste to the water. Priestley denied this at first, but when an improved apparatus for impregnating water with fixed air (Nooth's Apparatus) became available he quickly recognized the advantage of the new all glass equipment.(27) Largely on the basis of this communication, Priestley was awarded the Copley Medal of the Royal Society in 1773. On this occasion the oration was delivered by Sir John Pringle, President of the Royal Society.(3) Sir John reviewed the progress of pneumatic chemistry to that time and enumerated many of the important contributors to this area. Priestley's idea for charging water with fixed air (CO_2) was recognized as being based on the prior contributions of Black, Macbride, Cavendish and Brownrigg.(28) Pringle said: "Dr. Priestley, I say, so well instructed, conceived that common water impregnated with this fluid alone might be useful in medicine....."(29) Because of his advocacy of charged water, Joseph Priestley can be regarded as a prominent founder of the soft drink industry about which more will be said later. The Admiralty equipped two warships for impregnation of water with fixed air in the expectation of preventing scurvy.

Another important application in pneumatics attributed to Priestley, which was praised by Pringle on this occasion, was his discovery of nitrous air (NO) produced by the action of nitric acid on metals and its application for testing respirability of gases as described above.(29) Priestley's chemical discoveries up to October, 1772, were summarized in a letter to Thorbern Bergman, professor of chemistry and pharmacy at Uppsala in Sweden and sponsor of Carl Scheele (1742-1786), an independent discoverer of oxygen. Priestley wrote:

> ".....Common air was diminished by one-fifth by means of respiration, putrefaction (which process also poisons the air), calcination of metals, burning of carbon and other similar processes....I impregnate water with fixed air by agitating it as briskly as possible and in this manner imitate the water from the Pyrmont springs. I extract a certain remarkable air from several metals by means of spirit of nitre. Two parts of common air, mixed with one part of this nitrous air, becomes hot, reddish, and undergoes a sudden diminution into a smaller space even than it previously occupied. However, this nitrous air least affects air which, for whatever reason, is unsuitable for breathing. Nitrous air, also, in some miraculous manner, preserves flesh from putrefying and even restores putrefied meat....."(30)

The scientific achievement most commonly associated with Joseph Priestley is the discovery of oxygen. In 1771 he obtained a gas by heating saltpeter:

$2\ KNO_3$	—>	$2KNO_2$	+	O_2
potassium nitrate (saltpeter)		potassium nitrite		oxygen

He remarked on the ease with which a candle burned in this air but did not pursue the matter further at this time.(31) Also in 1771 he demonstrated that air which had been vitiated by animals could be made respirable again by plants growing in the now non-respirable gas mixture, This property of plants was not specific to any group or species, but was a general characteristic of living plants.(32) In August,1774, Priestley obtained a gas liberated when mercuric oxide was heated using a burning lens.(33,34)

$2HgO_2$	—>	$2HgO$	+	O_2
mercuric oxide		mercurous oxide		oxygen

He was perplexed about the nature of this air. It had some important properties of dephlogisticated nitrous air (nitrous oxide) but he knew that no nitrous acid was used in the preparation of mercuric oxide (mercurus calcinatus per se).(35) He listed some of the differences between characteristics of the flames produced by burning embers and candles in the new air and in nitrous oxide. (36). He suspected the purity of the mercuric oxide he had used. Later that year, while visiting Paris, he obtained some mercuric oxide of unquestioned purity. He again liberated the air from this new supply. In addition, he had obtained the identical air from red lead oxide:

$2PbO_2$	—>	$2PbO$	+	O_2
red lead oxide		lead oxide		oxygen

Since both mercuric and lead oxide were prepared by the same calcination process, he suspected that the property of yielding this type of air must originally have come from the atmosphere during calcination.(37) Further tests suggested that this air was not nitrous oxide. In March 1775 he tested this air with nitrous air and found it respirable. (The use of nitrous air as a test for respirability of gases was discussed above). Further tests with the new air in March 1775, using animals, found the air respirable and superior to ordinary air for sustaining life. In that month he read a paper before the Royal Society identifying the air as a new and distinct gas which Priestley called "dephlogisticated air." The spring of 1775 is proposed as the time which can be regarded as marking Priestley's discovery of oxygen.(34) Lavoisier eventually named this new air "oxygene."(38) Priestley and Lavoisier met when Priestley visited Paris in 1774. Lavoisier was already familiar with Priestley's writings.(7) Priestley was unaware that Scheele had described the gas earlier,(13) but Scheele did not publish an account of his work until 1777. However, an account of Scheele's discovery of oxygen was published by a colleague in 1775. The discovery of oxygen is usually regarded as independent and almost simultaneous by Priestley and Scheele.(36)

Karl Wilhelm Scheele (1742-1786) was born in Swedish Pomerania and German was his native language. He moved to Uppsala, Sweden, in 1770 and in 1775 he was elected a member of the Academy of Sciences at Stockholm. That year he opened his own pharmacy at Koping. Scheele worked unceasingly in all fields of chemistry. He investigated composition and properties of air and realized that common air was composed of two parts: fire air (oxygen)(40) and vitiated air. He prepared fire-air in several different ways, including chemical decomposition, and performed many experiments with candles, mice and plants.(41) He analyzed urinary tract stones and attempted to determine their composition.(42) He had wide interests and was regarded as one of the founders of organic chemistry.(43)

The first volume of "Observations On Different Kinds Of Air Etc.," Priestley's major writing on pneumatic chemistry, appeared in 1772. Volume II came out in 1775 and Volume III in 1777. Priestley inhaled oxygen, but with no therapeutic ends in mind. He also proposed some ideas on the role of the blood in respiration. He was an early and enthusiastic proponent of possible medicinal uses of the newly discovered gases. He is another of the founders of pneumatic medicine. Priestley's medical writings will be considered in the section on pneumatic medicine.

False beliefs tenaciously espoused by Priestley throughout his life were serious impediments to his proposing valid explanations for many of the observations and discoveries that he reported. He believed that mechanical operations on gases (e.g. compression, rarefaction, mechanical agitation etc.) could change one gas into another. He used the analogy that milk can be changed into butter by churning.(44). Also, he seldom entertained doubts about the truth of the phlogiston theory. He wondered on occasion whether Cavendish's "inflammable air" (H_2) might be ordinary atmospheric air with an abundance of phlogiston.(45)

Hartog listed obstacles to pneumatic discoveries faced by Priestley. These included the phlogiston theory and uncertainty as to whether both heat and light were corporeal ponderable substances. Although airs had weight and spring, gases and airs were regarded as entirely different in character from solids and liquids though they were thought to be capable of entering into the composition of solids and liquids.(46) Priestley wrote other books which in some editions were combined with his observations on gases and an occasional paper which appeared in "Philosophical Transactions." For over a decade Priestley dominated the scientific scene in Britain and was well known throughout Europe. His preeminence came to an end with the development of the new chemistry of Lavoisier. There were considerable differences between the two in the interpretation of experiments, such as oxidation and the compound nature of water.

A DIGRESSION ON PHLOGISTON

As mentioned, one serious impediment to Priestley's proposing conclusions concerning his chemical experiments, which we in the 20th century would regard as being in accord with our own current beliefs, was his refusal to abandon his lifelong steadfast advocacy of the role of phlogiston in chemical reactions as the science of chemistry advanced. Phlogiston theory arose after 1500 and remained in fashion until it became inadequate and was abandoned about 1800. Included among its adherents were many chemists of the eighteenth century who are still honored as among the founders of the science. Phlogiston was of sufficient importance that Lavoisier devoted considerable attention to it in a publication of 1783. The most prominent exponent of phlogiston theory was Georg Ernst Stahl (1660-1734).(47)

Phlogiston was considered in some respects as involved with some type of elementary "fire substance" contained in combustible matter and liberated when the material burned. It seemed to be involved in a fashion with some primitive concept of energy. Questions of the nature of heat and light were entwined with those involving phlogiston.(48) Ideas concerning this substance were extensively incorporated into thinking and reasoning by scientists working at the dawn of the modern chemical era in the 18th century. In its day, phlogiston theory was an important chemical idea. McKie wrote: "The phlogiston theory was the first general theory of chemistry, uniting a wide variety of observations that were otherwise apparently disconnected. Although the theory was in fact erroneous, it materially contributed to the early progress of chemistry, and its importance is too often underestimated."(47)

Phlogiston theory was eventually displaced by the "new chemistry" of Lavoisier and his contemporaries.

Phlogiston theory was invoked to explain many observed natural phenomena: combustion and calcination of metals (what we now would call oxidation of metals) involved loss of phlogiston to the atmospheric air. Highly combustible materials contained large quantities of phlogiston. A calx of a metal (a metallic oxide) could be changed to the original metal by heating with a substance rich in phlogiston such as charcoal. Air was capable of absorbing phlogiston liberated in combustion or calcination but oxygen (the dephlogisticated air of Priestley) could absorb much more and so combustion proceeded much faster in oxygen. Animals confined in a closed space would survive much longer in oxygen than in air because the oxygen (dephlogisticated air) was capable of absorbing decidedly more phlogiston than atmospheric air. A troublesome point was the gain in weight of substances accompanying combustion or calcination. This led some phlogistonists to attribute to phlogiston a negative weight.

As the true nature of combustion, calcination and respiration was demonstrated, primarily by Lavoisier beginning about 1770, phlogiston theory was continually and ingeniously modified to account for the new observations but then ultimately abandoned to be replaced by the "new chemistry" of Lavoisier. However, as late as 1791 Richard Bewley wrote a long treatise criticizing Lavoisier's chemistry and staunchly defending phlogiston theory.(49) In this work he repeatedly cited and defended the writings of a certain Dr. Harrington who had published earlier on this subject. According to the British library catalog, Harrington was a pen name which Bewley had at one time used. In 1792 George Fordyce wrote that enough chemists still believed in the existence of phlogiston to justify publication of his experiments disproving phlogiston theory by showing that during the calcination of zinc the apparent additional weight could only have come from the chemical reactants and from nowhere else.(50)

Adherence by Priestley and others to the phlogiston theory was quite reasonable for the period in which they worked. It is easy to understand how some simple observations might support the theory. Newton had recently formulated his laws of motion and universal gravitation which taught that all matter should fall to earth because of gravitational attraction. This was an age of potent, invisible forces. An individual watching smoke, flames and other products of combustion rise from a burning fire, and knowing that combustion was associated with a gain in weight, might easily conclude that certain products of combustion had negative weight and that this property caused them to ascend in apparent defiance of the law of gravity. It has been pointed out that Priestley's judgment in accepting phlogiston theory was logical, though erroneous, and had analogies in other areas. For example, advantages of rotating crops on yield of produce were well known. But in this circumstance, and with the limited understanding characteristic of earlier times, was the desired effect due to the addition of some beneficial substance to or the taking away of some harmful material from the soil?(2)

Considerable controversy exists over Priestley's standing and status as a chemist. Sir Oliver Lodge believed that Priestley simply lacked the insight to guess intuitively the correct explanations of his chemical experiments in contrast to many of his contemporaries. This took him out of the first rank of scientists such as Faraday and Newton. Smiles stated that Priestley's joy and forte was observation of facts, while he left explanation of these facts to others.(51) Schofield believed that the principal deficiency of Priestley as a chemist was his failure at any time to grasp the emerging basic chemical concepts of chemical combination, separation and composition of matter as these ideas unfolded during his lifetime. Nevertheless, Priestley remains as a great figure in the history of science and his name is remembered as that of a brilliant chemical philosopher. However his greater claim rests upon his sufferings in the cause of civil, political and religious liberty. "No man not actually engaged in politics was better known to the public of his time by his persistent fearlessness in every kind of thought"(46) He was one of the heroes of his age.

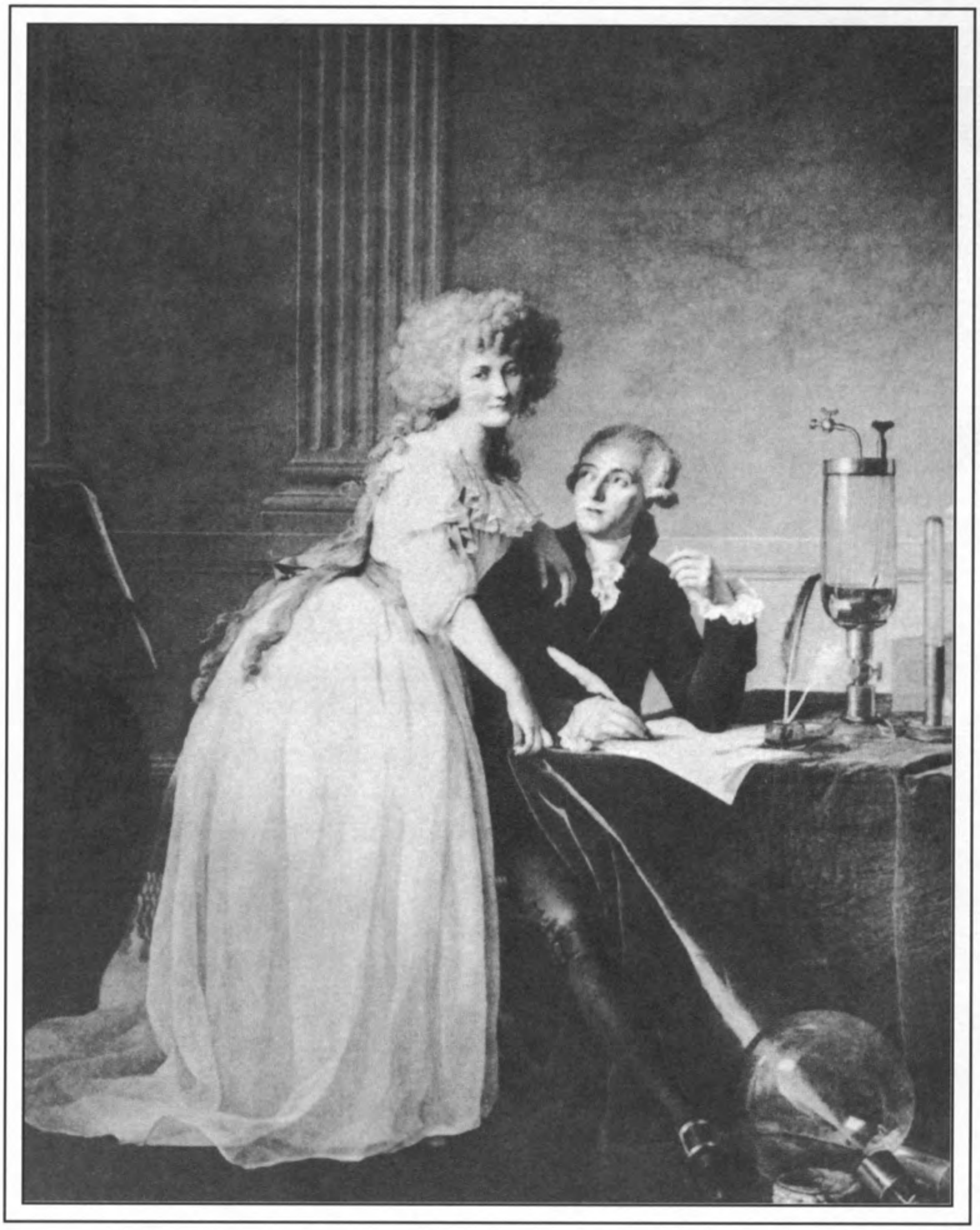

PLATE IV — ANTOINE LAVOISIER (1743-1794), founder of modern chemistry, and Mme. Marie Lavoisier.

CHAPTER V

ANTOINE LAVOISIER

Antoine Laurent Lavoisier was born in Paris in 1743 and remained a Parisian throughout his entire life. His parents were wealthy and provided him with the best scientific education available. He was schooled at the Collège Mazarin where his studies included classics, science, mathematics and literature.(1) From an early age he had the opportunity to associate with the most distinguished members of the French Academy of Sciences.(2) In 1763, in the tradition of his family, he took a law degree but he became increasingly intrigued with science. He became particularly attracted to chemistry via the route of geology and mineralogy. His first paper, read before the Academy in 1765, concerned the composition of gypsum (hydrated calcium sulfate).

During the last part of the 1760's Lavoisier assisted in field work and preparation of a geological atlas of France. The year 1768 was particularly eventful for Lavoisier: he was elected to membership in the French Academy of Sciences. He also bought into the "Ferme Générale." This organization functioned somewhat as a privatized internal revenue service for the monarchy and government of France. It contracted with the government to collect certain taxes, tolls and customs fees. Shareholders in this enterprise were called "Farmers General."(3) Lavoisier soon became a traveling inspector for this body and visited many regions of France on behalf of the organization. Also in this year he wrote a paper on the analysis and composition of various European mineral and spa waters. (The gases and salts in these waters and their possible medicinal applications were important factors in attracting and sustaining interest of continental natural philosophers in chemistry. A considerable body of literature on spa and mineral waters had already accumulated.) Lavoisier's early work in science (1763-1771) was devoted mainly to five topics meteorology, lighting, mineralogy and geology, water supply of Paris and hydrometry, and the apparent weight and density of pure water.(4)

In 1771 Lavoisier married Marie Anne Pierette Paulze, a young woman scarcely fourteen years old and daughter of Farmer-General Jacques Paulze. Marie Anne proved to be a highly capable and talented person in her own right. She acted as observer and recorder for many of her husband's important experiments and did the drawings associated with them. She learned English and it was chiefly through her that Antoine Lavoisier kept up with the writings of Priestley and others. She also collected certain of her husband's works after his death and attempted to prepare them for publication.(4)

Lavoisier was appointed inspector of gunpowder in 1775 and from then on he lived in the Paris Arsenal. His laboratory was located here. He also purchased a country estate. For the next few years his time was divided between his business affairs, his various community service appointments and his scientific activities. Throughout his life he remained a scientific amateur, never occupying a paid position in science. In addition to his activities in the Ferme Générale, the Academy of Sciences and the Gunpowder Commission, Lavoisier held appointments on several important public boards and commissions. His clear thinking and talent for concise writing led to these appointments and also to his being designated to write the reports of these bodies. Lavoisier's researches in respiration formed the basis for his studies of prisons (1780) and hospitals (1786). The report on prisons, which resulted in practical prison reforms, described the shocking conditions which existed and recommended measures based on four principles: cleanliness, an abundant supply of water for washing and drinking, free circulation of air and an appropriate regimen. Lavoisier also served on a commission dealing with the safe and sanitary construction of cesspools and on a hospital commission which found conditions at the Hôtel-Dieu highly unsanitary. Recommendations emphasized fresh water and air, proper sewage disposal, ventilation and cleanliness. The king ordered four new hospitals to be built beginning 1787 but the Revolution stopped this construction.

Another notable commission on which Lavoisier served was that appointed in 1784 to investigate the status and medical applications of Animal Magnetism as advocated by Anton Mesmer. Also on this commission was Benjamin Franklin. After numerous tests and experiments the committee concluded that effects of animal magnetism depended on the imagination and might be harmful in psychologically susceptible individuals.(5) Other public tasks undertaken by Lavoisier as a member of various committees included the investigation of foodstuffs and food sanitation. He was also closely involved in early ascents of hot air and hydrogen balloons and was an important member of the committee to establish the metric system of weights and measures. On Lavoisier's country estate he did considerable agricultural experimentation. He was particularly interested in improvement of livestock.(4,6,7)

When Antoine Lavoisier began his study of science, chemistry was still medieval. Alchemy with transmutation of elements was still a common belief. Chemical nomenclature was old-fashioned. As the eighteenth century progressed, major properties of gases, now known as carbon dioxide, oxygen, hydrogen and nitrogen, had been correctly described. But men responsible for their discoveries, Priestly, Scheele, Cavendish (but not Black), fitted these properties into the phlogiston theory. It remained for Lavoisier to make the next major advances.(8) He was the chief architect of a chemical revolution. He formulated theories and concepts and provided a system of chemical nomenclature. Most of these contributions are applicable in our own times. He was instrumental in laying the old phlogiston theory to rest. He also provided an essentially correct explanation of pulmonary gas exchange during respiration. He appears to have had a remarkable intuition and ability to reach correct conclusions after examining facts and was right much more often than he was wrong. An early chemical contribution (1768-1769) was his disproval of the transmutation of water. Previous workers had often encountered a solid residue in vessels in which water had boiled for a long time. They interpreted this as evidence for transmutation of water into earth. By careful weighing Lavoisier demonstrated that the vessels in which the prolonged boiling had taken place had lost weight and that the residual material came from the glass of the boiling vessels rather than from the water. Lavoisier's new chemistry had no place for the alchemists' transmutation of elements.

Lavoisier was probably set on the path to the correct definition of the role of oxygen in chemical oxidations and in respiration by the reports of Stephen Hales showing that large amounts of air were absorbed during combustion. Lavoisier was very familiar with the work of Stephen Hales and used his pneumatic apparatus. Study of Hales was Lavoisier's first link with British pneumatic chemists. He read little English and was responsible for instigating translations into French of the works of prominent English scientists.(9) It was probably the possible medicinal uses proposed for gases by MacBride and Priestley that was most important in familiarizing French chemists with works of the English chemists.(10) Lavoisier confirmed, about 1772-1774, that metals gained weight on calcination (oxidation) and that large quantities of air were absorbed during burning of sulfur and phosphorus. He could not explain these phenomena until he met Priestley in August, 1775. By this time Lavoisier was already familiar with some of Priestley's work, having cited it in previous publications.(11) At the meeting Lavoisier learned about the remarkable "dephlogisticated air" which the Englishman had liberated in 1774 by heating red mercuric oxide using solar rays focused through a burning lens. Although French chemists knew that an air could be obtained from calxes of mercury and lead by heating they did not know the properties of this gas.(10)

Following studies occupying the next two or three years, Lavoisier was finally ready to present his results. He had concluded that atmospheric air was composed of two different parts. The largest fraction of the atmosphere was incapable of sustaining either life or combustion (identical with the nitrogen discovered by Rutherford). This portion Lavoisier called "azote" or "mofette" (English writers used the term "mephitic" air). These names signify inability to sustain life. The smaller part, which he thought constituted about 28% of the atmosphere, was the portion necessary for combustion and life. He identified this fraction as the "dephlogisticated air of M. Prisley" (sic). This constituent of the atmosphere Lavoisier named "eminently respirable air." Air which had been rendered mephitic by having had combustion occur within it could be purified and reconstituted by removing "chalky acid air" (carbon dioxide) and adding "eminently respirable air" in adequate quantities.

By 1777 he was able to present a theory of respiration. "Eminently respirable air" was the only part of the atmosphere involved in respiration; the remaining portion was inert for respiratory purposes. In the lung, eminently respirable air was either taken into the blood or chemically changed. Simultaneously, "chalky acid air" (fixed air or carbon dioxide) was either produced in the lung or released from blood. Associated with these events was the production of body heat. Lavoisier believed that the pattern of respiration was of some importance. These changes in the nature of air associated with respiration occurred in the interval between inspiration and exhalation and sufficient time must be allowed for their completion.

Many of Lavoisier's ideas concerning pneumatic chemistry and respiration were expressed in a letter which was translated into English by Thomas Beddoes about 1794: "Observations on the Alteration Produced in the Air of Places Where a Great Number of Persons are Assembled." Lavoisier stated that there were a number of gases which were chemically different but physically very much alike. The atmosphere was not simple but was a compound substance "a mixture of all the various substances capable of assuming the state of air at the degree of heat and under the pressure at which we live." He stated that the composition of the atmosphere was 72 parts of azotic air and 28 parts of "oxygene" air. Azotic air contributed nothing to life and could equally be replaced by any other mephitic non-irritating, non-poisonous type of air. Oxygene air was essential. He considered extensively the experiment in which animals were confined under the bell of a container and over mercury. He found that oxygene was depleted and fixed air was added. The oxygene depleted was in excess of the fixed air produced and he calculated that this could be accounted for by combination of the excess oxygen with hydrogene air liberated from the lung to form water. He kept animals confined until they almost died and stated that this would define the limits which animals could tolerate. This proved to be about 10% oxygen and 8 or so percent carbon dioxide. Lavoisier described the deleterious effects of breathing pure oxygene for prolonged periods on animals' lungs. He attributed the finite attention span of audiences to alteration in the respired atmosphere in which they sat. He expressed concern about the miasmata which must derive from the lungs of various individuals breathing in crowded places and recognized the need to keep atmospheres breathed by large numbers of individuals unpolluted. About 1794 Thomas Beddoes noted that " Mr. L. has, I believe, published nothing further on this important subject and his incomparable talents, I fear, are now lost to science and humanity."(12)

The process of respiration was inferred to be in many respects analogous to that of combustion. But Lavoisier and his contemporaries were never certain about the site of the chemical reactions which consumed "eminently respirable air" and produced "chalky acid gas." Did they occur in the lungs, in the blood or in all tissues? And if respiration chemically resembled combustion, why did not the high temperatures at which the latter reaction proceeded harm the body? Lazaro Spallanzani (1729-1799) finally showed that tissues excised from living animals consumed oxygen and gave off carbon dioxide, thus establishing site of metabolism in tissues. However, this work was not published until 1803 and thus the information was not available to Lavoisier.(8,13)

Lavoisier's studies on respiration continued for several more years, into the 1790's. He demonstrated that during respiration consumption of "eminently respirable air" (by now named oxygen) generally slightly exceeded production of "chalky acid gas" and that utilization of oxygen by the body increased during exercise, digestion, and with elevated body temperature. He determined the quantity of heat produced during generation of a measured weight of carbon dioxide from combustion of a measured amount of charcoal and therefore estimated the relation between carbon dioxide production and caloric generation. With some exceptions, Lavoisier's conclusions concerning respiration were essentially in accord with our modern ideas. Among Lavoisier's coworkers at different times during his investigations were Laplace and Seguin.

Another of Lavoisier's interests was in the composition and nature of acids. He had observed that many elements, when burned, ultimately produced acids. (The following chemical reactions are described in modern terms for ease in understanding. There are often other alternative chemical reactions involving different intermediates to provide the same end results. The reactions presented are some of those that Lavoisier could have observed.)

Carbon when burned at high temperature generated chalky acid gas (carbon dioxide) which in turn formed an acid with water:

C	+	O_2	—>	CO_2 ; CO_2	+	H_2O	—>	H_2CO_3
carbon		oxygen		carbon dioxide		water		carbonic acid

Burning of sulfur produced sulfur dioxide, which in turn formed sulfurous acid with water. This in turn could be further oxidized in air to sulfuric (vitriolic) acid:

S	+	O_2	—>	SO_2 ; SO_2	+	H_2O	—>	H_2SO_3
sulfur		oxygen		sulfur dioxide		water		sulfurous acid

$2H_2SO_3$	+	O_2	—>	$2H_2SO_4$
sulfurous acid		oxygen		sulfuric acid

Burning of phosphorus yielded phosphorus pentoxide which in turn formed phosphoric acid with water:

$4P$	+	$5O_2$	—>	$2P_2O_5$; $2P_2O_5$ +	+	$6H_2O$	—>	$4H_3PO_4$
phosphorus		oxygen		phosphorus pentoxide		water		phosphoric acid

Thus, many common acids known to Lavoisier were formed as a result of combustion. He had already established that combustion involved a reaction of the burning substance with the best part of the atmosphere, or "eminently respirable air." He therefore deduced (erroneously) that "eminently respirable air" was perhaps the universal acidifying principle and the crucial ingredient of all acids. He redesignated this gas as "oxygène" or acid former about 1779.

Another interest of Lavoisier was in the nature and composition of water. In 1783 he confirmed that, when inflammable air (hydrogen) was burned, water was formed:

$$\underset{\text{hydrogen}}{2H_2} + \underset{\text{oxygen}}{O_2} \longrightarrow \underset{\text{water}}{2H_2O}$$

As nearly as he could determine, the weight of water produced was equal to the sum of the weights of the hydrogen and oxygen consumed. He concluded that water was therefore not a simple substance, but was a compound of hydrogen and oxygen. He had recognized that "fixed air" or "chalky acid air" (carbon dioxide) was a compound of carbon and eminently respirable air. An important feature of Lavoisier's new chemistry was the classification of materials into substances that could not be decomposed further (elements) and decomposable substances made up of two or more elements (compounds). He also demonstrated how large quantities of hydrogen, which were in demand for aeronautical balloons, could be obtained from decomposition of water.

The roles of heat and light in chemical reactions continually troubled Lavoisier. His theory of heat proposed that gases were held in a state of permanent elasticity by the principle of heat or fire associated with them. Heat and light produced during combustion must come from liberation of this principle contained in the gas.

By 1786 Lavoisier felt confident enough concerning his new facts and scientific deductions to publish his definitive attack on phlogiston. Within a few years most of the members of the scientific community had joined him in rejecting phlogiston theory. In 1787 Lavoisier and associates published descriptions of the method of chemical nomenclature based on the new chemistry. Among the material presented was a list of the elements known at that time. Nomenclature of elements and compounds was almost in accord with those of the 20th century. This system was rapidly accepted. Still listed as elements, however were entities such as fire. Lavoisier's "Elements of Chemistry" appeared in 1789. This book altered chemical thinking forever and was to chemistry as Newton's "Principia Mathematica" was to physics.(14)

Several conceptual and factual errors in the writings of Lavoisier can be identified. He believed that the role of gas in respiration was to hold the lungs in inflation. Fixed air (carbon dioxide) alone could not do this. It would act as an asphyxiant because its very high solubility would permit lung collapse as the gas readily entered solution. In addition, he erroneously regarded the ability to turn various substances red as a general property of oxygen. He recognized that oxygenation of the blood in the lung involved a change in color of the blood to bright red and thought this analogous to the formation of red lead oxide or red mercuric oxide on calcination of the respective metals. But he (as well as many contemporaries and successors) was never sure as to the exact cause of change in coloration of the blood in the lungs. One idea was that carbon in venous blood (which would color it black) combined with oxygen in the lung to form carbon dioxide. This idea apparently originated with Joseph Black about 1760.(15) Lavoisier was uncertain about where in the body and also how the respiratory exchange of oxygen and carbon dioxide occurred. He apparently entertained the idea of fire burning in the lungs with liberation of light and animal heat, neglecting the effect of the temperature required for such combustion on lung tissue. It should be recalled that during Lavoisier's time fire in association with living tissue was regarded as a possibility. The phenomenon of spontaneous human combustion was accepted by many prominent individuals.(16)

Some scholars regard Lavoisier's theory of acids as his greatest mistake. He recognized some of the deficiencies of his theory. He knew that hydrochloric acid, derived from the gas hydrogen chloride (HCl) (discovered by Priestley) contained no oxygen. He was puzzled by his experiment showing that burning of hydrogen and oxygen together produced water and not an acid. He blamed inadequate experimental techniques for these discrepancies and trusted that someday they would be resolved in the laboratory.(4,6)

Lavoisier wrote at considerable length about his studies involving sulfuric ether in about 1783. He examined its properties in both liquid and vapor states and noted its inflammability and explosibility in air and oxygen. He also speculated on some of its possible medicinal applications but does not mention its capability to produce drowsiness and sleep. Authors who reviewed Lavoisier's writings on ether speculated that perhaps because of Lavoisier's interest in both ether and respiration he might have eventually investigated respiratory effects of ether had he lived and thereby might have discovered anesthesia.(17)

Lavoisier was in sympathy with many of the sentiments of the French Revolution and served the new regime in several capacities. Gradually, the organizations and institutions with which he was associated changed. He became increasingly isolated. The Ferme Général was abolished in 1791. With the onset of the Reign of Terror in 1793 Lavoisier's crime of having been a Farmer General was too shockingly flagrant in the eyes of the revolutionary government to be overlooked. He, together with other Farmers General, including his father-in-law Jacques Paulze, were arrested on 24 December, 1793. They were tried on May 8, 1794, found guilty, and executed on the guillotine that same afternoon. Lavoisier had asked the revolutionary tribunal for additional time to complete some unfinished scientific work. The reply of the presiding magistrate was said to have been, "The Republic has no need of scientists." When Lavoisier's colleague and friend Lagrange heard of his death he said, "It took them only an instant to cut off that head, and a hundred years may not produce another like it."

Marie Lavoisier eventually remarried Benjamin Thompson, Lord von Rumford.*(18)

* Benjamin Thompson (1753-1814) was a physicist primarily remembered for his work in the area of heat. He was born in Concord (then Rumford), New Hampshire, North America. He supported the British in the American revolution and eventually settled in England. He spent some time in the Bavarian civil service, was made a Count of the Holy Roman Empire, and also received an English knighthood from King George III. In 1799 Lord Rumford, together with Sir Joseph Banks founded the Royal Institution of Great Britain and chose Humphry Davy as lecturer at that establishment.

Plate V — William Withering (1741-1799). A prominent physician of Birmingham, England and member of the Lunar Society, he is best remembered in our time for his pioneering use and description of foxglove (digitalis) in medicine for treating dropsy. He was also a practitioner of pneumatic medicine. His claims for pneumatic cures were modest and he did not get carried away by enthusiasm as did some others. His pneumatic work was cited several times by Beddoes.

CHAPTER VI

PNEUMATIC MEDICINE

THE FOUNTAINHEAD OF MODERN ANESTHESIA

Therapeutic inhalation of various substances in the gaseous state has been a part of the medical armamentarium for many hundreds of years. In such attempts to define the medicinal uses of gases and vapors, which has been called "pneumatic medicine," lie the origins of inhalation anesthesia.(1)

Breatholding and hyperventilation, as well as inhalation of emanations from the earth were practiced in antiquity and were known to affect the mind.(2) The popularity of inhalation of medicinal substances in the western world has been attributed to Arabic practitioners. The process of distillation originated in the Arabic world. As this procedure became more common, medicinal inhalation of certain fumes arising from stills gained some measure of repute. Also, it had long been supposed that the ambient inhaled atmosphere might exert some measure of influence over health and well being. Tobacco was endowed with medicinal properties in the sixteenth century and its internal use was recommended in a variety of conditions, including asthma.(3)

Paracelsus advocated the inhalation of the fumes of burning sulfur for lung afflictions.(4) Thomas Willis wrote on the influence of the inhaled atmosphere and on therapeutic inhalations of medicinal substances in 1684. He concluded that grosser and also city air was healthy for some consumptives but not for others. He proposed several possible reasons for this. Fires might burn with diminished intensity and with less soot in impure air. Thicker air could contain an abundance of sulfur and nitre, which may have been beneficial in some cases of consumption. Places where turf fires were common may have benefited phthisical patients. He recommended inhalation of certain substances for medicinal purposes:

> "...suffumation of sulfur and arsenic (which is filled with much sulfur) is reputed for the curing of almost incurable ulcers of the lungs, although the last, yet the most efficacious remedy."(5)

Certain techniques of inhalation were advised. Patients were directed to mix together the desired ingredients in water and then to heat the mixture. The resulting steam was to be inhaled through a paper rolled up like a cone or funnel.(5) A fumigation or dry vapor inhalation could be made by taking the dry ingredients and strewing them upon the coals of a fire. Several prescriptions for fumigation were offered. Finally, Willis observed that mountebanks prescribed, sometimes with good success, the "smoak" of arsenic or of cloth impregnated with arsenic to be taken into the lungs using a pipe, like tobacco. When Willis recorded these thoughts there was no knowledge of the existence of different types of gases. The vital principle supplied by the atmosphere for life was believed to be "nitro-aerial" particles, as postulated by John Mayow.

Robert Boyle was interested in natural mineral waters and in the numerous substances in various states below the earth. Mineral waters could be designated as "acidulae" on the basis of taste or as "thermi" on the basis of temperature, and there were numerous chemical and physical tests which could be used to investigate their natures. Mineral waters should be seriously regarded and investigated both in situ and also when withdrawn from their sources. Topics that could be considered included their actions, uses, means of administration, dose etc. Of particular interest were waters found deep in mines.(6) Frederick Hoffman, in 1731, was another of the early authorities to attribute healing and medicinal properties of spa and mineral waters to gas or elastic principles dissolved therein.

Pneumatic medicine was probably greatly popularized by the widely advocated practice of visiting spas and "taking the waters" in the eighteenth and nineteenth centuries. Hoffman wrote:

> ". . . . we think, it plainly appears that the brisk Medicinal Waters contain a certain very subtle active and elastic principle. . . . . and this principle we take for their most curious and effectual Part, or as it were the soul, that gives them their surprising Virtues of curing numerous stubborn and obstinate distempers."(7)

In 1748 an individual identified as "C.L." described an apparatus somewhat like a vented teapot which permitted inhalation of medicated vapor. Applications included use in miners' lung, diseases caused by "animalculae," non-specific cough, etc. It was noted that "A tube for introducing balsam into the lungs was invented and recommended by the great Leeuwenhoek."(8)

Michael Morris, in 1758, described a method for manufacture of sulfuric ether which he perceived to be more reliable and safer than that described by Frobenius. Medicinal applications of ether included local application in headache, toothache, earache and rheumatic pains in the neck and internal administration in whooping cough, hysteria, syncope and lethargy.(9) Matthew Turner, a surgeon of Liverpool, in 1761 again described the preparation and chemical characteristics of sulfuric ether. He discussed the medicinal use of ether in a variety of clinical situations, including nervous disease, digestive disorders, etc. and described tests which could be applied to ether by the public to assure that they were getting the genuine product.(10)

In another publication, Turner described and advocated a different form of pneumatic therapy. He presented a case of intestinal infestation with Ascaris worms. The worms were killed and the patient cured by administration of a tobacco smoke clyster.(11) James Lind (1716-1794) attributed scurvy to the effects of cold climate and moisture in the air at sea.(12) These factors produced their harmful effects by blocking egress of noxious substances from the body via perspiration. Another harmful effect of moisture in the air was thought by Lind to be weakening of spring and elasticity of the air. This made the air less fit to serve its function in respiration and interfered with the ability to change foodstuffs into proper vital juices.

WILLIAM BROWNRIGG AND DAVID MACBRIDE

William Brownrigg (1711-1800) was among the first practitioners to write about the medicinal properties of gases and vapors. Brownrigg received the M.D. degree from Leyden University in 1737. He then settled in Whitehaven and began to investigate the gaseous exhalations from the neighboring coal mines. For these investigations he was elected to fellowship in the Royal Society. Stephen Hales had published his work on fixed airs in the 1730's. As described in a preceding chapter, Hales demonstrated that air was "fixed" in the non-elastic state in many substances and could be liberated by different means from these materials to assume its familiar elastic condition. Brownrigg became interested in some of the properties and medicinal applications of this fixed air. He focused his attention on airs contained in mineral spa waters and performed experiments on them. He observed that these airs could be extracted from the waters by heat or by air pump. They were mephitic and resembled "choke damp" and "fire damp" from mines and the gas produced during fermentation. After the air in the spa water was driven off by heat, materials precipitated from the water and it tasted flat.

Brownrigg's initial communication to the Royal Society on these subjects was in 1741 and his definitive essay, "The Elastic Spirit or Air Contained in Spa Water," appeared in 1765.(13) He concluded that the benefit of these mineral waters lay in the volatile part which could be driven off, and not in the grosser saline earthy particles which were also imbibed by water. This subtle and fugitive ingredient was aerial in nature. These spirits had medicinal properties and strong action on the body.(He pointed out that van Helmont had previously advised more extensive use of fumes and spirits in physick).(13) Water was likely to imbibe any mineral exhalations in the subterranean chambers through which it passed. These elastic fluids were different from atmospheric air and from one another. Such differences might be discovered by analytical techniques. Brownrigg speculated that there may be several different kinds of elastic fluids and that these may have sudden and violent effects on the body, as well as specific virtues.(14) In those mineral waters called "acidulae," Brownrigg believed that the aerial spirit was identical with or was related to "choke damp"(carbon dioxide) found in mines. Many caverns located close to acidulous springs contained choke-damp.(13) In taste this type of air resembled the air generated by beer and other fermenting liquors. This was poisonous when breathed but beneficial when drunk. On ingestion, these spirits were carried to many body locations, producing salubrious effects at several sites.

Brownrigg summarized the beneficial medicinal effects of "acidulae:"

> "(they)....may greatly contribute to strengthen the solids, to accelerate the motion and circulation of the fluids, and to warm and invigorate the whole animal frame. So that these spirits seem in a great measure owing the virtues which the acidulae possess, of attenuating the humors, breaking their unnatural concretions and powerfully opening obstructions; of provoking the appetite, assisting the digestion and concotion of the aliment, and facilitating all the natural secretions and excretions of the body."(15)

Brownrigg had also concluded that elastic spirits:

> "...Being exceedingly subtle, penetrating and active, it seems fitted to pervade the whole body, and to force a passage through the minutest vessels; by its mild and gentle stimulus, to corrugate the fibres, increase their elasticity, and excite them to motion; by its expansive quality, to rarify and as it were to spiritualize the blood and dilate the vessels. By these several ways, therefore, it may greatly contribute to strengthen the solids, to accelerate the motion and circulation of the fluids, and to warm and invigorate the whole animal frame."(14)

Brownrigg was probably the first to be aware of the acid nature of fixed air.(15) In a 1766 publication Brownrigg again extolled the virtues of fixed air writing that the chemical and other investigations that he had conducted to date permitted physicians to:

> ".... form some judgment of the great efficacy of this air, as a de-obstructant and solvent, in many diseases of the human body arising from preternatural concretions and obstructions thence ensuing. If to these we add the great antiseptic powers of this kind of air, which it possesses in common with acids (and which were first detected by Sir John Pringle, and have since been more fully explained by Mr. MacBride and Dr. Priestley); we then, in some measure, may account for those extraordinary effects, which this kind of air is found to produce in the case of many obstinate diseases, with which mankind are afflicted."(16)

The Royal Society recognized Brownrigg's achievements by bestowing upon him the prestigious Copley Medal in 1766. (In that year another Copley medal was awarded to Henry Cavendish, discoverer of hydrogen.)(17)

Another physician who early became interested in the role of various airs in medicine was David MacBride (1726-1778). He was born in the village of Balleymoney, Ireland. He was apprenticed to a local surgeon and subsequently spent a period of time as a naval surgeon during the war of the Austrian succession. Then, after a period of study in England and Scotland, he briefly returned to Balleymoney before settling in Dublin in 1751 where he spent the remainder of his professional life.(18)

MacBride developed a theory concerning the functions and uses of "fixed air" in living beings. Although he was a student of Joseph Black, MacBride still used the term "fixed air" as did Hales; that is to describe any type of air combined in the non-elastic state rather than as applicable to only one specific species of aeriform substance. It would appear that MacBride failed to appreciate the significance of Black's work and regarded Hales as the more authoritative scientist.(19)

Two aspects of the biological importance of fixed air were emphasized by MacBride. One continued the previous ideas of Hales proposing that air was an important constituent of all bodies assigning an important role to the air as a cementing and binding principle in living tissues. In the 18th century there was considerable interest in the means by which matter is held together.(20) Another important use of fixed air was believed to be for the prevention of putrefaction, which was regarded as a dissolution of material associated with the loss of air. (Putrefaction is the decomposition of organic material, usually with the formation of foul smelling products). Airs liberated by any fermenting mixture, whether the ingredients were animal or vegetable, were postulated to be anti-putrefactive. (Fermentation is a chemical breakdown of a substance accompanied by the effervescence of carbon dioxide gas).(21) This conclusion was based on previous observations and thoughts of Sir John Pringle that offensive odors originating from decaying matter seemed to abate when the material was kept bathed in fixed air, while facilitating the escape of fixed air seemed to accelerate putrefaction. Pringle wrote extensively on materials and substances influencing putrefaction.(22)

An immediate consequence of MacBride's theory, published in 1764, was the use of fixed air derived from fermentation of vegetable material to halt and even reverse so-called "putrescent disease."(23) Scurvy at this time, before its true etiology was known, was regarded as the prime example of this class of disease. The specific therapeutic value of fresh vegetable material in scurvy which had been known empirically for centuries was attributed to its fermentive capabilities. A practice suggested by MacBride was the ingestion of vegetable material which need not be fresh but could be stored and reconstituted as required. Such a procedure would be of enormous importance in preventing scurvy on prolonged sea voyages.

For this "wort" was suggested. This was an infusion made from malt which fitted the above criteria of storability and portability and which, after preparation, could be drunk. This vegetable material would then ferment rapidly in the gastrointestinal tract. The fixed air evolved would permeate the body and prevent putrefaction.(23) MacBride believed that he had proved these assertions experimentally. Wort was used by Captain Cook and others on their sea voyages with some perceived success.(24)* MacBride was the first to call attention to the great solubility of fixed air in water. He also reasoned that if fixed air were a cementing substance, removal of some of this "tissue cement" from the body would be a good way to dissolve urinary tract stones.(26) An important non-medical discovery by Macbride was his observation that lime water was superior to plain water for extracting tannin from oak bark.(18) This finding proved to be of importance to the tanning industry.(19)

In 1767 a proposal for the medicinal use of fixed air appeared in a review of Joseph Priestley's "History of Electricity" in "The Monthly Review; or, Literary Journal." The review is unsigned but is attributed to William Bewley (the 'Philosopher of Massingham' previously mentioned in connection with Priestley). He was an editor and is known to have authored the reviews of many scientific articles and books that appeared in the journal. He wrote:

> "The electric fluid, dispensed in that vigorous manner, may in time, we hope, rank as an article in the materia medica, with opium, mercury, and the bark. We shall take this occasion of observing, for the honor of philosophy, that there is reason to hope that the catalogus medicamentorium will ere long be enriched with another promising article, the pure result of philosophical researches: we mean fixed air; a substance successfully investigated by the late excellent Dr. Hales, and which appears in a fair way of being soon happily applied to the relief of putrid disorders, and particularly of the sea-scurvy, in consequence of the ingenious experiments of Dr. MacBride, and his very natural practical deductions from them."(27)

Yet other physicians became attracted to MacBride's theories and performed studies on medicinal uses of fixed air. Most agreed with MacBride's conclusions. Among the best known of these were Thomas Percival and Thomas Henry, both members of the renowned Manchester Literary and Philosophical Society. Both concurred with MacBride's conception that fixed air was anti-putrefactive. However, now these other physicians were employing carbon dioxide gas in their experiments, thus applying the term "fixed air" to designate a specific species of gas, as did Joseph Black. In addition, Percival performed experiments showing that fixed air from decaying plants prevented putrefaction and that a small amount of fixed air in the atmospheres of plants was beneficial. Percival was also concerned

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*Wort could not have been an effective antiscorbutic. It had virtually no ascorbic acid (vitamin C).(25)

with the treatment of stones in the urinary and biliary tracts as will be discussed later.(28)

From these beginnings arose "pneumatic medicine." Advocates of this mode of medical practice proposed the administration of specific gases for treatment of various diseases. William Brownrigg and David MacBride can probably be regarded as the founders of this specialty. They sometimes showed considerable prescience about the involved gases. There were never large numbers of pneumatic physicians, but those that embraced the discipline were vocal and enthusiastic. Popularity of pneumatic medicine peaked in the last decade of the eighteenth century, but interest in the subject persisted well into the 1800's.

JOSEPH PRIESTLEY'S MEDICAL WRITINGS

Joseph Priestley, whose numerous contributions in several fields were discussed in a previous chapter, became an enthusiastic supporter of pneumatic medicine. He freely offered advice even though he was not a medical practitioner. However, certain of his friends and colleagues were among the most prominent physicians in England. Included were Erasmus Darwin and William Withering. Priestley had proposed to the Admiralty that water to be carried aboard ships on long ocean voyages should be impregnated with fixed air. Because the Admiralty acted favorably on his proposal to treat water for marine use, he formulated a set of instructions for so doing which he published in 1772, as mentioned previously.(29) In addition to preserving the potability of water, he believed that water so impregnated would be useful in preventing scurvy, according to the theory of MacBride.(30) Priestley reviewed the sequence of progress and discoveries in pneumatic medicine which formed the basis for his suggestions as follows: Sir John Pringle discovered the inhibition of putrefaction by the process of fermentation. MacBride attributed the antiputrefactive and antiscorbutic effects of fermentation to the fixed air generated by this biological process. Wort, by causing fermentation in the stomach, supplied fixed air. Joseph Black had found that calcareous substances contained fixed air. Brownrigg found that Pyrmont water from Spa in Germany and other mineral waters which have the same acidulous taste, contain considerable fixed air. Upon this their peculiar spirit and virtues depended.

Priestley now reported that one could communicate this property to any fluid and in considerable amounts rendering them antiseptic. The principle proposed was to prepare a large amount of fixed air from chalk and vitriolic acid. The air was introduced into a bottle of water inverted in another vessel and agitated violently.(31) Fixed air could also be collected by pouring water from one vessel to another over vats fermenting in a distillery or brewery. In this instance common air would also be entrained. Extinguishing of a candle would be a good test for assessing the concentration of fixed air above a fermenting mixture.(32)

Possible medicinal uses of fixed air and water impregnated in this manner were suggested by Priestley and his correspondents. One such application was in diseases believed to be of a putrid nature such as sea-scurvy. In some instances better results might be obtained if a few iron filings were placed in the water to render it chalybeate.(33) Another use might be as a clyster for putrefaction in the bowel. Patients with ulcerated lungs might breathe fixed air by putting their heads over vessels in which fermentation was occurring. Concurrently they should drink fluids impregnated with fixed air. Dr. Percival, who had been using fixed air inhalations therapeutically for a considerable time, said that this idea had also occurred to others and had been used with beneficial results.(34) Dr. Percival had good expectation of success with this type of therapy.(35)

Priestley further related that sanies, the thin blood-tinged seropurulent discharge of cancer, was much sweetened by application of fixed air. Cancer pain was mitigated and there was better digestion.(36) External application might be useful in a variety of circumstances. The practice of "following the plow" and also living near lime kilns were old prescriptions for consumption. Now the rationale for these was understood.(37) As mentioned previously, In 1772 the Royal Society awarded the Copley Medal* to Joseph Priestley for his many observations that had been published to that time.(38) (Some of his greatest discoveries, such as oxygen and nitrous oxide, were yet to come). Priestley wrote a letter to Sir John Pringle concerning the noxious quality of the effluvia from putrid marshes. He argued that these emanations could be harmful and might be implicated as causes of disease. Gas evolved from darkened water failed to pass the nitrous air test for respirability of gases and were judged to be noxious in the highest degree. Good air in contact with this type of "spoiled" water became vitiated. But air issuing from soft earth or mud was not always unwholesome.(40)

Priestley's major work, "Experiments and Observations on Different Kinds of Air" was published in 1775. Further thoughts on pneumatic medicine were expressed in these volumes and medicinal applications of recently discovered gases were considered. He expressed a high degree of optimism concerning the benefits to be expected from pneumatic medicine.(41)

> "....I cannot help flattering myself that, in time, very great medicinal use will be made of the application of these different kinds of air to the animal system. Let ingenious physicians attend to this subject, and endeavor to lay hold of a new handle which is now presented them, before it be seized by rash empirics; who by an indiscriminate and

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*The Copley Medal was the most prestigious recognition of scientific achievement awarded by the Royal Society. Sir Godfrey Copley (d. 1709), a parliamentarian, government official and Fellow of the Royal Society, bequeathed a sum to the Society for advancement of knowledge. After 1736 the bequest was used for an annual award of a gold medal by the Society.(39)

> injudicious application, often ruin the credit of things and processes which might otherwise make air a useful addition to the materia and ars medica."

Ongoing medicinal use of fixed air was described. Mr. Hey of Leeds communicated the efficacy of a fixed air clyster in a putrid fever.(42) Dr. Thomas Percival of London used fixed air in various conditions in 1774. He pointed out that the breathing of large amounts of fixed air by bathers at Bath and other spas with impunity was evidence of the relative innocuousness of fixed air. He also recommended fixed air in ulcerous sore throat and aphthous ulcer.(43) He claimed clinical improvement and symptomatic relief in phthisis pulmonalis (pulmonary tuberculosis) with fixed air inhalations but no cures. He believed that Dr. William Withering of Birmingham had cured phthisis with fixed air but Withering later denied this.(43) Percival preferred water impregnated with fixed air to consumption of wort in sea scurvy. He pointed out the value of fixed air in scrofula (tuberculosis of lymph nodes). Priestley again considered the external application of fixed air in cancer and ulcers. He suggested that the whole body could be exposed by suspending the patient above a vat of fermenting material. Priestley considered that nitrous air (nitric oxide) should, like fixed air, be antiseptic and should be a useful adjunct to pneumatic practice. At the suggestion of surgeon John Hunter fish were exposed to water impregnated with nitrous air. They promptly died.(44) He also tried nitrous air as a clyster:

> "I contrived, with the help of Mr. Hey, to convey a quantity of it up the anus of a dog. But he gave manifest signs of uneasiness, as long as he retained it, which was a considerable time, though in a few hours afterwards he was a lively as ever, and seemed to have suffered nothing from the operation..... Perhaps if nitrous air was diluted with common air, or fixed air, the bowels might bear it better and still it might be destructive to worms of all kinds, and be of use to check or correct putrefaction in the intestinal canal, or other parts of the system..."(45)

After Priestley discovered oxygen (vital air, dephlogisticated air), he speculated about its possible medical uses:

> "From the greater strength and vivacity of the flame of a candle in this pure air it may be conjectured that it might be peculiarly salutory to the lungs in certain morbid cases.... But perhaps we may also infer from these experiments that though pure dephlogisticated air might be very useful as a medicine, it might not be so proper for us in the usual healthy state of the body: for as a candle burns out much faster in dephlogisticated than in common air, so we might, as may be said, live out too fast and the animal powers be too soon exhausted in this pure kind of air. A moralist, at least, may say that the air which Nature has

> provided for us is as good as we deserve.....Who can tell but that, in time, this pure air may become a fashionable article in luxury. Hitherto only two mice and myself have had the privilege of breathing it."(46)

When Priestley was awarded the Copley Medal the laudatory address was delivered by Sir John Pringle, President of the Royal Society and a highly accomplished and influential eighteenth century physician and scientist.

Pringle began his medical studies at Leyden under Boerhaave and others. He received the M.D. degree from Leyden in 1730. After further medical training in Paris, he returned to Edinburgh where he began teaching and medical practice. From 1742 until 1748 he was a military surgeon serving on the continent and also at the battle of Culloden in Scotland in 1745. After his military service he settled in London. He gained the attention of the royal family and eventually became surgeon to the King. He became a fellow of the Royal Society and was elected its president in 1772. He had many scientific and literary interests as shown by his numerous appropriate and informed addresses delivered when awarding Copley Medals to individuals of quite varying backgrounds and accomplishments. During his tenure as president of the Royal Society, Sir John delivered six Copley discourses.(39) He counted many prominent scientists of the day as his personal friends.(47) He is regarded as the father of military medicine. His major work was, "Observations on the Diseases of the Army," published in 1752. The concept of the neutrality of military hospitals in time of war was also attributed to him.(48) He was also interested in hospital and jail fever.(49) When studying fevers, Pringle paid special attention to "putrefaction of the air which of all the causes of sickness is perhaps the most fatal and the least understood." He noted several different sources of noxious air: the various miasmas, effluvia, etc., which he perceived as being very common around military camps. He relied mostly on observation and contemporary references and paid little attention to ancient classical writings.(50) Another of Pringle's contributions was the observation, mentioned previously, that fermentation appeared to counteract putrefaction. This conclusion was an important foundation for MacBride's theories.(49)

Sir John Pringle began his address of 1774 honoring Joseph Priestley on his receipt of the Copley medal by reviewing the progress of pneumatics since the days when the sole concern with airs was with their physical properties. This was another excellent review of knowledge of gases to that date and is still well worth reading in modern times. He enumerated contributions of Bacon, Galileo, Toricelli, Pascal, von Guericke, Boyle, Hooke, Newton, Hales and Brownrigg. He also summarized the work of Joseph Black as having chemically characterized fixed air and established that air which combined with alkalis was identical to that mephitic air found in grottos and mines. It was the same air as that emitted by fermenting vegetables and was present in air vitiated by respiration and combustion. Henry Cavendish had continued pneumatic chemistry, determining many quantitative aspects of fixed air such as its solubility and the volume of it liberated under various circumstances. Pringle then listed Priestley's accomplishments. He had availed himself of all this information on preparation, storage and medicinal properties of fixed air and had conceived the idea that water impregnated with fixed air might be useful in medicine. He had discovered nitrous air (nitric oxide) by treating metals with nitric acid. The resulting reddish gas reduced the volume of atmospheric air in proportion to its fitness for respiration and this was a very valuable test for respirability of gas mixtures. (This was before the discovery of oxygen and definition of its importance to life.) Nitrous air was said to be a better antiseptic than fixed air. Pringle also commented on Priestley's discovery of the ability of plants to "repair" air that had been injured by the respiration of animals. Every growing plant was of service to mankind. Pringle then awarded the Copley medal, expressing the hope that Priestley's work would continue.(51)

However, Priestley's enthusiasm for the potential application of gases to medical practice was not shared by all. James Graham, noted 18th century quack, habituee of ether sniffing, and proprietor of the 'celestial bed' severely criticized both Priestley's theology and his medical philosophy. He first took Priestley to task over his Unitarian teachings and his Arian and Socinian beliefs. Graham intended to found a 'new and true' church in which the Trinity would be emphasized! He then denounced Priestley's advocacy of the use of electricity and factitious airs medicinally: "...a certain portion of air, – of our common atmospheric air, inwardly and outwardly, is every moment indispensably necessary for our animal existence; but if we apply even the purest and best air to the inside or to the outside of our body, with a smith's or a great forge bellows, we shall speedily occasion pain, - disease, - death." Graham related the case history of a young girl on whose behalf a large quantity of fixed air was generated to treat a sore throat about 1776. Everyone in attendance found the atmosphere in the room unbearable and was obliged to leave. The patient, who could not leave, was asphyxiated. He also believed that enough dephlogisticated air (oxygen) could not be generated to serve any useful purpose in disease. Good light and air and clean water should be sufficient.(52)

Jan Ingenhousz, in 1780, used the nitrous air (nitric oxide) test proposed by Priestley to assess the fitness of different gas mixtures for respiration to examine the quality of atmospheric air under several circumstances. He concluded that air at sea and close to it was purer and fitter than air tested inland, and the farther from land the purer was the air. The benefits of breathing sea air should be particularly good in consumption and similar disorders. Such beliefs must have influenced physicians to advise certain of their patients to embark on sea voyages or take the air at the seashore. Ingenhousz proposed that air was purer in cold weather while uncommonly warm weather made it impure. Those localities exposed to noxious exhalations were healthier in winter.(53)

A Digression on Scurvy in Bygone Days

Scurvy was a consuming interest of eighteenth century naval surgeons. In maritime nations such as England and Holland the disease was also of consequence for the general medical community. Since various practitioners and enthusiasts of pneumatic medicine became proponents of various etiologies and treatments of scurvy, many of which were related to gases, a brief account of the disease about this time in history is of interest.

Scurvy had been known for centuries and so, on an empirical basis, was its cure. For example, John Woodall (1569-1643),"an old English surgeon whose works seem to be but very little known," wrote that "the juice of lemons is a precious medicine and well tried, being sound and good; let it have the chief place for it will well deserve it. It is to be taken twice a day, a spoonful or two with sugar." Juice of limes, oranges, or citron were also listed as antiscorbutic.(23)

In 1734 a Dutch physician, John Bachstrom, gave a completely correct explanation for scurvy and the treatment he advised was all kinds of green vegetables and fresh fruits. This type of knowledge was not accepted by medical authorities of the 18th century; primarily because it was not in accord with any of the various systems of medicine, such as that of Boerhaave, which were taught at that time.(54) This example of empiricism vs. theory is quite representative of 18th century medical thinking.

John Knyveton, a naval surgeon during the Seven Years War at the mid 18th century, noted in his diary* that the etiology of scurvy was "Acrimounious Salts with which the blood becomes charged when the Body is exposed to the Saltness of the sea." He observed that many treatments had been applied with the idea that the salts must be neutralized with acids. Many acids had been used, but natural acids of fruit, particularly oranges and lemons, were preferred at the suggestion of Dr. James Lind who had cured scurvy with these measures. He further remarked that on one of his voyages several seamen had come down with scurvy and that fresh provisions were the answers to this problem. When fruits were taken on board, Knyveton stated that he hoped this would abate the danger of scurvy.(55) Norah Lofts described scurvy in medieval England:

> "We tend to think of scurvy as a sailor's disease but it was rife among the poor in those faraway winters. The well-to-do suffered less, for their diet was less restricted to food lacking essential vitamins..... Scurvy, beginning with lack of energy and proceeding to loss of sight, spongy gums and underskin haemorehages – the dread "blew spottes" – was not understood, but the cure was known; anything fresh could work a near

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* Knyveton's diary is said to be a semi-fictional work and a composite of several contemporary journals of the period synthesized by E.A. Gray. It is described as such in the catalog of the National Library of Medicine.

> miracle. Spring was the season when fresh stuff began to grow, and a form of grass known as scurvy grass was eagerly sought and devoured. So were the earliest green shoots on the hawthornes. Only fifty years ago country children still pounced on the first hawthorne leaves and ate them, calling them bread and cheese. The poor country man could seek the life-restoring greenstuff at the wood's edge, along the baulks – or banks – which divided one holding from another in the great fields. His fellow in the town had to go further afield and some old maps show, just where the houses end, a lane called Scurvy Lane. The name does not appear on later maps, for being associated with poverty and misery the word became derogatory and has survived in that sense-a scurvy knave; a scurvy trick. "(56)

The tragic consequences of scurvy at sea were exemplified by the expedition of Commodore George Anson. He set sail from England in 1740 in seven ships with over 1000 men.(57) His objective was to capture the Spanish treasure ship which sailed between Acapulco and Manila exchanging new world silver for spices and silks of the orient. He returned to England in 1744 with 145 survivors in one ship. Most of the loss of life was due to scurvy. (It must be observed, however, that this devastated crew still successfully completed the assigned mission.)(58)

A remarkable addition to knowledge concerning scurvy was made by James Lind (1716-1794), a surgeon of the Royal Navy. In what is regarded as the first controlled clinical trial on record, Lind demonstrated the superiority of oranges and lemons in treating established scurvy. Clinical course of sailors consuming these substances was compared with that of others taking remedies such as hard cider, sulfuric acid, vinegar and additional treatments which in those days were considered practical and available for use aboard ship.(59) In 1748 Lind left the navy and quickly qualified for an M.D. degree from Edinburgh University. In 1753 he published his treatise on scurvy(60) with a revision appearing in 1772. In a remarkable portion of this work he cited all the previous writings on scurvy that he could find and critically commented on each. His own theories on the disease were somewhat obscure. They did not fulfill the promise of his earlier work nor did they influence the widespread adoption of the measures which seem so obvious in our own time. He concluded that multiple factors were required to cause scurvy. Of these the most important were moisture, cold air, and damp quarters. Want of fresh vegetables and fruits was a contributing factor as was prolonged and close confinement.(60,61) The principal offending factor was moisture in the air, which blocked elimination of toxic products in perspiration. Oranges and lemons permitted repair of the noxious effects of moisture but by themselves were not believed to prevent scurvy. The prevention of scurvy would therefore involve warmth, dry and fresh air, minimization of confinement in close quarters and consumption of antiscorbutic substances.

Several reasons were proposed to explain why Lind's early clinical trial of lemon juice attracted so little attention from his contemporaries. Lind's treatise was only one among many different writings on scurvy of that day. The multitude of opinions offered and the misinterpretation of data from Captain Cook's voyages must have greatly clouded and confused the scurvy issue. In addition, Lind's position as a Naval Surgeon was quite far down in the medical and scientific hierarchy.(57) James Lind was later designated as "The Father of Nautical Medicine" by one of his junior associates, Thomas Trotter. Another of Lind's junior associates was Gilbert Blane.(60) Both of these men were to play important roles in the conquest of scurvy.

Numerous antiscorbutics were advocated by different individuals for use at sea. Lind advocated a "rob" made by evaporative condensation of orange and lemon juice. MacBride proposed "wort", an infusion of malt. Sourkraut appeared popular. Salop, a starchy thickening agent, was also proposed. Another such substance was "portable soup" prepared from animal products boiled to a gelatinous consistency, which could be reconstituted with green vegetables if available. "Sooins," a type of fermented oatmeal, was another suggestion. All were tried with perceived success by an occasional user, but without universal adoption. Belief in the role of moisture, sea air, and confinement as important etiological factors in scurvy soon lost popularity. One important reason for this was the appearance of reports, primarily from military surgeons, reminding physicians that scurvy could readily occur on land.(61)

The voyages of Captain James Cook (1728-1779) provided an opportunity to test a variety of antiscorbutic measures. His ship was lavishly provisioned with stores for his first voyage of exploration to the South Pacific (1768-1771). Included were the "rob" of oranges and lemons, wort, sauerkraut, portable soup and other proposed antiscorbutics. He also carried water impregnated with fixed air as proposed by Priestley.(62) All of these were used systematically and on this voyage there were no scurvy deaths and nobody was seriously ill from the disease. But this was an exceptional journey and Cook was an exemplary commander. The expedition was never away from land for more than seventeen weeks at a time; apparently unusual for a journey of this magnitude. Also, at each landing Cook compulsively reprovisioned his stores with fresh water and any produce that was available. Writings of some of the other members of the ship's company on this voyage clearly established the superiority of lemon juice in preventing scurvy. In the end, however, MacBride's theory still prevailed and the antiscobutic value of wort was again touted.

Cook's second voyage (1772-1776) was begun in two ships. The ship not carrying Cook became separated from its companion for a time. Since general discipline, restocking, and enforced serving of unfamiliar vegetables were less stringent on this ship scurvy appeared in the crew. There was no manifest scurvy in Cook's crew. On his return Captain Cook reported favorably to the admiralty on antiscorbutic virtues of almost all materials provided. He also emphasized the importance of adequate rest, cleanliness, and ventilation. Apparently Cook was little impressed with the value of Priestley's water impregnated with fixed air and was more favorably inclined towards wort and similar substances. Carpenter suggested that these views were intended partly to please Sir John Pringle, president of the Royal Society, whose theories were supported by these conclusions.(63,64)

One modern assessment of the role of Capt. James Cook in the conquest of scurvy is that he confused the whole issue of scurvy at sea because of the wide range of measures that he employed simultaneously. This probably delayed implementation of effective methods for prevention of the disease.(65) However, the voyages of Cook without scurvy mortality were an impressive accomplishment in his time. For this he was awarded the Copley Medal by the Royal Society in 1776. As usual, the erudite discourse given by the President, Sir John Pringle, provided a capsule history of the field in which the recipient had attained renown and also summarized his contributions.(66) Sir John called attention to his own early observations that meat preserved with salt, as well as dampness, could be contributory factors for scurvy. He emphasized the importance of eating fresh vegetables and fruits and less salt meat. To him, all effective measures against scurvy protected in some way against putrefaction. Therefore Pringle concluded that these useful antiscorbutics act according to the theory of MacBride; that is by providing fixed air by fermentation and this fixed air prevented the putrefaction associated with scurvy. Captain Cook had prudently dispensed these antiscorbutic substances according to current recommendations. He rotated his crew, using three watches rather than two, so the mariners were permitted eight hours of rest between duty watches. He enforced personal cleanliness and that of bedding and clothing. He provided good ventilation and portable fires to promote air circulation and drying of the ship and provided fresh soft water.(64) (Surprise was expressed that icebergs melted into fresh water.) Captain Cook was not present to receive his Copley Medal. He had already departed on his third voyage which was soon to bring him death at the hands of natives on a beach on the island of Hawaii.

In the years following the discovery and chemical characterization of carbonic acid gas, about 1760-1780, concern of pneumatic physicians was almost exclusively with this gas. Oxygen was discovered about 1775. The general biological roles of both oxygen and carbon dioxide as well as physiological events associated with respiration, had been determined by the early 1790's as related previously. Physicians gradually realized that cure of scurvy and other diseases could never be obtained by administration of small quantities of fixed air, a gas naturally produced in large amounts in the body. After about 1780 medicinal use of fixed air (carbon dioxide) declined. Nevertheless, water impregnated with fixed air was still regarded as artificial mineral water and its use in medical practice remained popular as a means of administering an acid solution in palatable form. Attention turned to the possible role of a deficiency of oxygen as a possible cause of scurvy in the early

1790's. Prominent advocates for oxygen deficiency theories of scurvy were Thomas Trotter and Thomas Beddoes. They believed that the dark blotches in the skin of scurvy victims and their dark oral tissues were signs of oxygen lack. (Actually, they were hemorrhages under the skin and mucous membranes.) They also proposed that any acid substance, including inorganic mineral acids, would be a useful antiscorbutic agent. Trotter supported the theory that acids in "recent" vegetable matter could prevent and treat scurvy and that fixed air was of no benefit.(67) (At that time all acids were thought to contain oxygen). The beliefs and writings of Thomas Beddoes on the role of oxygen lack in scurvy and other diseases were particularly important to the development of anesthesia and will be related in considerable detail later.

In 1796 David Paterson, an experienced naval surgeon, proposed that scurvy was caused by excesses of azotic and hydrogene gases, which were said to be of an alkaline nature and sedative. He perceived success in preventing the disease by administering nitrous vinegar. This was prepared by dissolving nitre (potassium nitrate), a rich chemical source of oxygen, in vinegar which, being acid, should also contain oxygen. This mixture would act by restoring gaseous balance in the body. Paterson also advised breathing oxygen and emphasized the importance of fresh air.(68)

In the mid 1790's, thanks in a large measure to Gilbert (later Sir Gilbert) Blane (1749-1834) practical experience and observation replaced theory and speculation. Blane, in contradistinction to Lind and Trotter, was quite class conscious, loved rank and ceremony and enjoyed company and companionship of nobility and high ranking officers. To this, however, is attributed his final success in persuading these extreme conservatives to implement the measures which Lind, Trotter and Blane had suggested as being essential to health of mariners. Lemon juice was supplied to the fleet at public expense beginning in 1795. Consumption of citrus juice effectively eliminated scurvy as a problem among sailors at sea. (Lind had died in 1794, only a year or two before the death of scurvy). Before the conquest of scurvy ships could remain at sea for only about 10 weeks and therefore, for military purposes, an equal number of vessels had to be kept at the ready to exchange with them. One of the important consequences of the conquest of sea-scurvy was doubling the strike capability of the Royal Navy. During the Napoleonic Wars, no English sailor was prevented from doing his duty by scurvy.(69)

CONTINUED PROGRESS OF PNEUMATIC MEDICINE

As the eighteenth century proceeded additional medical practitioners were attracted by the expectations of pneumatic cures of different diseases. Thomas Percival of Manchester advocated water impregnated with fixed air to dissolve urinary tract stones about 1775.

It should be recalled that this clinical problem had initiated Joseph Black's original interest in fixed air almost a quarter of a century earlier. Percival showed experimentally that fixed air in water was a solvent of many urinary tract stones and concurred that this preparation was superior to limewater for the purpose. Part of the rationale for treating stones with fixed air impregnated water was Hales' observation that the effect of liberating fixed air from many firm and hard substances by heating or by treating them with acid was the production of soft, crumbly materials. (Solution of carbon dioxide in water produces carbonic acid, a moderately strong acid).(70) Percival believed that fixed air taken into the body was preferentially distributed to the kidneys since he perceived that water impregnated with fixed air was a diuretic. Since external application of fixed air to ulcers was so beneficial, comparable favorable results were anticipated from internal use. The gas proved ineffective against gallstones. Percival, (in 1775), therefore postulated that improvement in gallstone disease on taking the waters at spas must be due to improvement in liver function. In a subsequent publication, (1788), Percival extended his recommendations for medicinal applications of fixed air. He reiterated his concurrence with Macbride in the opinion that fixed air retarded and corrected putrefaction . He suggested that fixed air might operate by preventing escape from the body of the products of decomposition formed in putrefaction; a type of quenching effect.(71)

Not all physicians shared the enthusiasm for the medicinal use of fixable air. William Falconer concluded that fixable air was very useful in enhancing the power of water as a menstrum or solvent. As such it might have some application in urinary tract stones.(72) But the antiseptic power of water impregnated with fixable air was so small that little stress should be placed on it in putrid disorders. He was unable to prevent spoilage of meat with the gas.(73) In the late 1770's John Mudge advocated inhalation of water vapor for "recent cattarhous cough." He designed an inhaler to this end which was supposed to deliver warm water vapor to patients and remained a popular household item for many years.(74,75) John Melvill was another physician who enthusiastically endorsed pneumatic practice. He published a comprehensive recapitulation of previous work on fixed air and its beneficial effects.(76)

Thomas Henry (1734-1816), a major industrial and manufacturing chemist of Manchester, was an important figure in pneumatics. He began his career as an apothecary and became part of a fruitful collaboration between science and industry in Manchester analogous to that involving members of the Lunar Society in Birmingham. He was well known for making and marketing magnesia and became known as "Magnesia Henry." He was the first to translate Lavoisier's works into English. Some other of his areas of interest were in the chemistry of bleaching, dyeing and other processes related to Manchester's textile industry. Henry was impressed by the benefits attributed by Captain Cook to constant availability of good water at sea. One method used at that time to preserve water on ships was the addition of lime to the water casks. This however, imparted an unpleasant taste to the water and methods to correct this problem were expensive and impractical. Henry suggested precipitating the lime by bubbling chemically generated fixed air through the casks and described an apparatus for doing this. This was proposed as a cheap, acceptable method of preparing large volumes of palatable water which would also have beneficial medicinal properties. He also presented a method, generally using the same technique as for neutralizing lime in water, for impregnating large quantities of water with fixed air. This would have an advantage over Priestley's method, which was primarily suitable for small quantities for use by families. Henry probably developed his technique for neutralizing lime in water and for impregnating water with fixed air at about the same time as and independently of Priestley.(77,78)

Continuing interest in mineral waters was shown in John Elliot's 1781 book on the principal mineral waters of Great Britain and Ireland. Methods of both Priestley and of Nooth for impregnating water with fixed air were considered. Then Elliot classified and reviewed the various types of natural mineral waters and listed the locations at which they could be found, as well as their suggested medicinal application. For example, waters could be chalebeate (containing iron salts held in solution by fixed air), chalebeate purging, sulfurous purging, saline purging, hot, cold, etc. They could be taken internally or externally as baths, vapor baths, mud baths, or by "pumping" (forceful application using high pressure jets) to afflicted parts.(79)

Dr. William Withering of Birmingham incorporated pneumatic techniques into his medical practice. He was particularly concerned with the treatment of phthisis pulmonalis (lung tuberculosis) and indicated that inhalation of fixed air in this disease sometimes caused symptomatic improvement. His patients breathed fixed air directly and he also advised keeping large jars of effervescing materials in patients' rooms. Earlier cures in phthisis which had been attributed to him were denied and explained by supposed uncertainty about the correct diagnosis of the illness in these patients. He had also tried foxglove in phthisis with little benefit. (In the next century foxglove was to become one of the mainstays in the desperate fight against tuberculosis).(80) Withering also published on the analysis and medicinal qualities of water from a mineral spring that he visited in Portugal.(81)

John Harrison commented upon two cases of mortification (gangrene) of the lower extremities. These were treated with fixed air from fermenting poultices, the active ingredient of which was yeast. The results were said to be good, but both patients died.(82) Matthew Dobson was the author of a large medical commentary on fixed air. He reviewed the chemistry and various sources of fixed air and indicated that the value of chemically produced carbonic acid gas was as good as that occurring naturally. He discussed various medicinal uses of fixed air such as in "putrid fevers," scurvy, and urinary stones. He also emphasized mortal dangers of breathing high concentrations of the gas such as may occur near lime kilns.(83)

Thomas Percival, mentioned above in connection with treatment of urinary tract stones, sustained his interest in pneumatics. One of his medical essays was included as an appendix in Priestley's book on airs.(84) He too reported palliation of phthisis with fixed air and reported that other gaseous substances were beneficial in this condition. Numerous other conditions where fixed air might be of benefit were identified. Generally, these were similar to those proposed by his contemporary pneumatic enthusiasts. Percival, in discussing noxious vapors from burning charcoal, provided a clear description of poisoning with carbon monoxide. He wrote that gases from the incomplete combustion of charcoal "...frequently produce their prejudicial and even fatal effects, without being either offensive to the smell or oppressive to the lungs." He admonished, "Never to be confined with burning charcoal in a small room, or where there is not a free draught of air." The treatment for carbon monoxide poisoning was removal of the victim to the outside and stimulation by various means. If the victim was too far gone for these measures then "...let a healthy person breathe into the mouth of the patient; and gently force air into the mouth, throat, and nostrils."(85)

One of the first physicians to apply the ideas on respiration formulated by Lavoisier to medical problems was Edmund Goodwyn. In 1788 he published a monograph on "The connexion of Life with Respiration; or an Experimental Inquiry into the effects of Submersions, Strangulation, and Several Kinds of Noxious Airs on Living Animals: with an Account of the Nature of Disease they Produce; etc." He performed a number of experiments involving submersion of animals and concluded that under these circumstances death was due to exclusion of atmospheric air and not to presence of water in the lungs. Using ingenious techniques he measured resting lung volume (estimated functional residual capacity was 1786 ml) and the volume of air moving with respiration. He clearly recognized phasic changes in volume of blood circulating through the lungs in different parts of the respiratory cycle. He confirmed the change in color of blood on passage through the lungs and attributed this to a reaction between blood and dephlogisticated air (oxygen). He appreciated the mechanism of death with obstruction of the air passages and discussed cardio-pulmonary resuscitation. Goodwyn suggested the term "melanaemia" for all conditions characterized by an abnormally dark color of the blood. When melanaemia was reversible, it could be treated by applying heat to the body and artificial inflation of the lung. For this he recommended large inflation volumes using an air pump of his design. The rationale for this was to wash out dead space and to provide for uniform intrapulmonary distribution of inspired gas.(86)

Christoph Girtanner (1760-1800) was born in Switzerland. He was a friend and fellow student of Thomas Beddoes at Edinburgh. Both generally accepted the teachings of John Brown but with some reservations. Girtanner, like Beddoes, was strongly attracted to chemistry and he wrote a popular textbook on the subject. He studied the chemistry of Lavoisier in detail and came to believe that oxygen was the principle of "irritability" that was so important in Brown's doctrines. His two memoirs on oxygen greatly influenced Beddoes' ideas on pneumatics. They were translated by Beddoes and appear as appendices in his book on "Calculus and Sea Scurvy" in 1793.(87)

Girtanner perceived the various body tissues as irritable structures which would perform their functions in response to various stimuli. As long as the degree of stimulus was appropriate for the required activity and irritability of the tissues a state of balance and health existed. Recognized stimuli included cold, heat, light, nutriements, nervous stimuli, and so forth. On one side of normal health were diseases characterized by a state of accumulation where excessive irritability elicited inordinate response. This state, if not corrected, could deplete irritability and lead to death. The other type of diseases were those of exhaustion. In this state, which could be either temporary or irreparable, irritability was insufficient to permit appropriate response to stimuli. Treatment of disease involved adjusting the level of stimulus and the degree of irritability:

> "There are two methods of preventing the fatal effects of a local stimulus, whose operation on one part of the system is constant. The first consists of preventing the surcharge of oxygen in the blood which is accomplished by diminishing the proportion of oxygen gas in the air breathed by the patient, or by diminishing the quantity of blood by phlebotomy. The second method consists in applying stimuli capable of exhausting the irritability in proportion as it accumulates; such as wine, opium, bark, heat, ..."(88)

The close correspondence between the views of Girtanner and those of his teacher John Brown concerning etiology and treatment of disease is quite evident.

Girtanner described a number of experiments designed to elucidate the role of oxygen on the body. Many of these involved the equilibration and reaction of blood with different gases. Others involved injection of gases into dogs. He demonstrated that the color change of blood upon going from the venous to the arterial state was due to combination with oxygen. At the same time carbonic-hydrogen air was given up. He proved that arterial blood contained oxygen.(89) He appeared to have a fairly good grasp of gaseous exchange associated with respiration. The extent to which these ideas were original is difficult to determine.

One interesting observation was that death following injection of nitrous air (nitric oxide) into the jugular vein of a dog was associated with filling of the air passages with green foam which issued from the mouth in large quantities. This is an early description of what would be recognized today as low pressure lung edema due to injury of the pulmonary membranes.(90)

Oxygen was the principle of irritability. Positive stimuli entering the body deprived it of its irritability and left it in a state of exhaustion. Positive stimuli included alcohol, opium, sulfuric ether and other narcotics (note that Girtanner classified sulfuric ether as a narcotic.)(91) Others were oils and sugar. All of these substances were combustible and all had a greater affinity for oxygen than did tissues. Substances with negative stimuli had less affinity for oxygen and destroyed fibers by surcharging them with irritability. Included in this class were oxides of metals such as mercuric oxide. All periodic phenomena in animals, such as the beating of the heart or menstruation, were regarded as examples of cyclic stimulation followed by exhaustion and then replenishment of irritability of the involved tissues. Girtanner taught that the heart was stimulated by the oxygen brought to it by the blood.

In order to illustrate that oxygen was the principle of irritability, Girtanner used an analogy involving mercury and mercuric oxide. Elemental liquid mercury was practically an inert substance. But the compound of mercury and oxygen was extremely active and its violent stimulating properties caused serious disease if taken into the body. Thus he reasoned that the combination of anything with oxygen greatly enhanced capacity for stimulation of tissues.(92) Poisons acted by depriving the blood of its principle of irritability, i.e. oxygen. Girtanner attributed scurvy in armies on land to excess of oxygen in the atmosphere under certain field conditions.(93) Hunger was satisfied only by substances which could combine with oxygen and decrease irritability. Cooked meats were satisfying and nutritious because all of their oxygen had been driven off in cooking and their oxygen combining capacity was presumed high. Vegetables were a good antidote for metallic oxides because of their abundant oxygen. Vinegar was recommended as a good source for replenishment of oxygen because it was an acid. Vinegar was proposed as an antidote for large doses of opium for the same reason.

Mr. Yonge, medical practitioner of Shifnall and Beddoes' early mentor treated consumption in a young lady named Mary Farmer by having her swallow carbonic acid gas into her stomach.(94)

In 1793 James Wood proposed his ideas on disease. He stated that his theories generally were in accord with those of Cullen and Brown and incorporated the chemistry of Lavoisier. Included in his scheme of disease were states of accumulated and exhausted irritability. As in Girtanner's writings, oxygen was the substance extracted from air which was capable of renewing depleted irritability. The response to various stimuli was determined by the state of irritability of the various body tissues. Wood proposed that there was no such thing as a true sedative in nature. Just as cold was a gradation of lack of heat, the apparent sedative action of some substances represented merely diminution of stimulating properties. It is of interest that Wood characterized both opium and vitriolic ether as substances which rapidly exhaust irritability by their stimulating action. He also stated that oxygen, in addition to restoring irritability, was nature's great antiseptic and antiputrefactive agent. In this role oxygen seems to have supplanted carbonic acid gas in the 1780's and 1790's. Wood applied his theories to typhus. He proposed that in this disease carbon accumulated in the body. He recalled that normally carbon combines with oxygen in the body and is removed as carbonic acid gas and postulated that in typhus there was a deficiency of oxygen for this purpose. The breathlessness of typhus also suggested a shortage of oxygen. Associated with this oxygen deficit were putrefaction and exhausted irritability. The treatment of typhus was primarily oxygen. This was administered by all routes: by inhalation, and by oral ingestion of nitre (potassium nitrate) and all acids presumed to contain available oxygen. Additionally a mild stimulant with nutritive properties, such as beef tea, would help replenish the exhausted irritability.(95)

R. Hamilton had acquired considerable experience in managing victims of drowning by 1794. His principles for care of such individuals were published, with the expectation that medical men would now be capable of saving many of them. The victim was to be taken to the nearest house, undressed, and placed on the right side to facilitate the circulation of blood. The most important resuscitative measure was to expand the lungs with air as soon as possible. Bellows were preferred for this rather than mouth-to-mouth inflation. The environment should be cool, the number of individuals present should be limited and the windows and doors should be opened to permit ingress of oxygen. Common eighteenth century therapeutic measures such as injections, clysters, emetics and bleeding were unnecessary, but application of electricity might be beneficial in experienced hands. These measures were not to be abandoned prematurely. Hamilton advised a four to five hour resuscitative period before giving up the effort. He recognized that there is no water in the lungs of drowning victims and therefore measures such as rolling to remove water were superfluous. He acknowledged the activities of the Humane Society for their work in resuscitation from drowning.(96) Several other individuals wrote on resuscitation of victims of drowning and other forms of suffocation about this time.

Dr. John Ewart of Bath reported successful treatment of advanced ulcerated breast cancer in two women by external application of carbonic acid air. The gas was introduced into bladders or bags fixed over the lesions using pieces of circular leather and adhesive plaster. Relief of pain was prompt and gradual healing of the lesions occurred in about a month. Ewart was not certain whether the carbonic acid air had a specific action or whether it acted by excluding atmospheric air. He regarded the oxygen in air as being excessively stimulating. Perhaps an occlusive dressing or another gas might have been equally effective. Other uses for carbonic acid gas included installation into cavities such as evacuated abscesses to promote healing. He suggested oxygen injection into tissues where it was desired to produce reaction and inflammation, such as in the treatment of hydrocoele.(97)

John Elliot described how water impregnated with fixed air could be sprayed on a putrid sore throat using a syringe and also applied locally to tissues involved in putrid diseases. He advocated supercharging natural mineral waters with more abundant quantities of fixed air using Nooth's apparatus.(98)

In 1793 the first communications from Dr. Thomas Beddoes of Bristol on pneumatic medical subjects appeared. Beddoes took up the cause of pneumatics with conviction and zeal unmatched by any of his medical colleagues. His beliefs, activities and writings are so important to the development of anesthesia that they will be considered separately and in detail later.

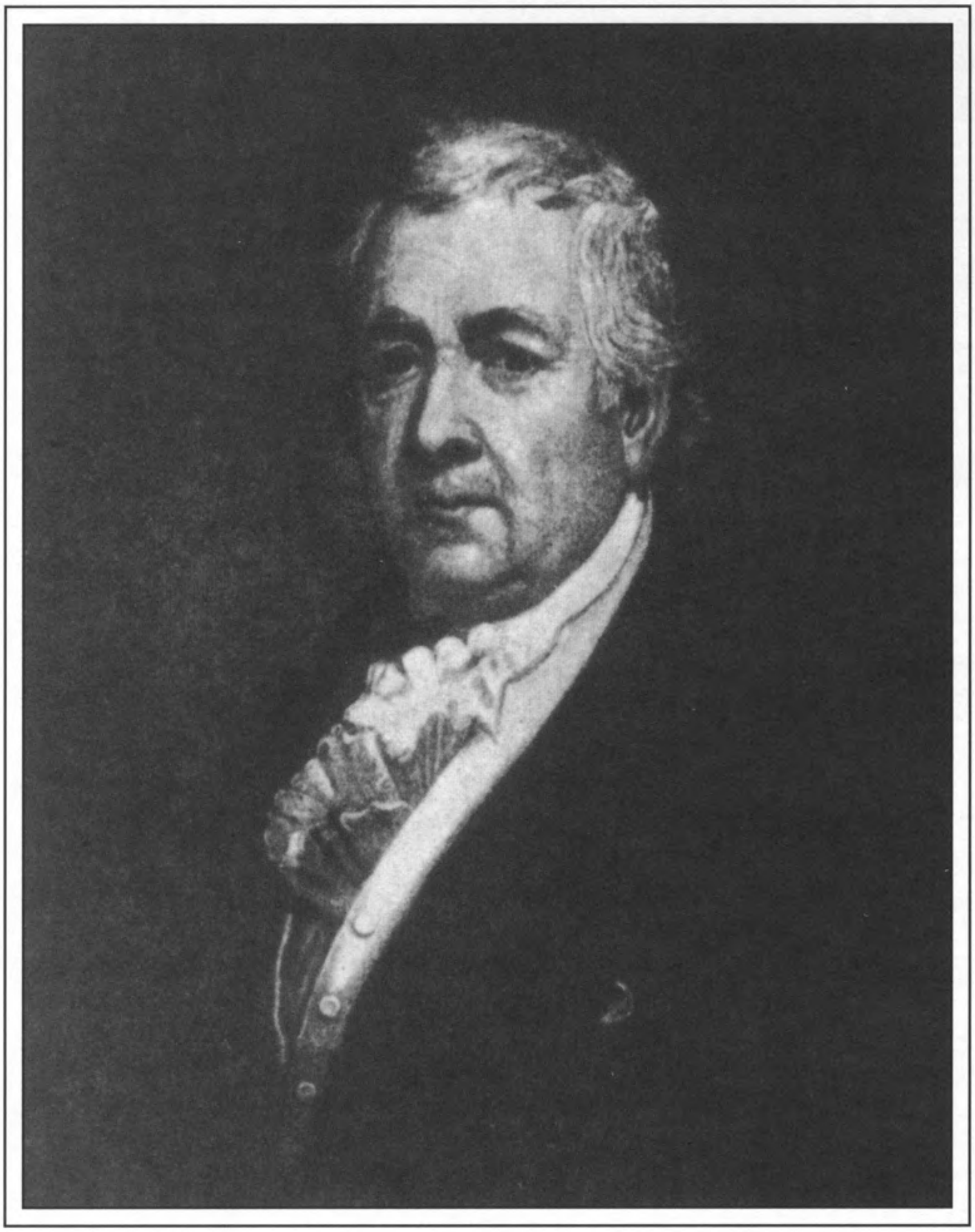

Plate VI — Samuel Latham Mitchill (1764-1831). He was a prominent physician and scientist in New York City during the early years of the republic. His interest in nitrous oxide and his theory that presence of this gas was the cause of pestilential illnesses inspired Humphry Davy to undertake investigation about this substance.

Chapter VII

The Flowering of Pneumatic Medicine

1794 – 1800

Robert Thornton believed that a medical millennium had arrived because of proposals for pneumatic medicine. In 1794 he wrote a letter to Sir Joseph Banks, President of the Royal Society stating that:

> "The late Dr. Hunter ventured to prophesy that if ever the office of the lungs should be discovered, there would arise a great and sudden improvement in the science of medicine."

He further commented that this discovery had now been made, to the honor of the eighteenth century, by a number of philosophers. The learned and ingenious Dr. Beddoes had determined the role of this new knowledge in disease. Although some insinuations against this practice had been made, many prominent physicians had written testimony in favor of the novel means of medical treatment. Now, a new method of practice of "therapeutic and preventive medicine" is developing with Dr. Beddoes as its foremost exponent. Thornton then presented a review of many facets of pneumatic chemistry and related items. This is another excellent exposition of chemical and related medicinal knowledge as it was understood in the 1790's.(1) In 1794 the first appeals for financial contributions toward founding of Beddoes' Medical Pneumatic Institution appeared.(2)

The first American to play a role in the events leading to the availability of clinical anesthesia was Samuel Latham Mitchill (1764-1831) of New York City. He completed his medical education in Edinburgh under such distinguished teachers as Munroe, Hunter and Black. He returned to New York in 1787. Besides becoming one of the foremost physicians of the young Republic of the United States, his diverse interests led him into activities in many areas.(3) He served at various times in the United States Senate, House of Representatives, and in the New York State

Assembly. He also was professor of agriculture, natural philosophy and chemistry in Columbia College and the College of Physicians and Surgeons in New York City. He was concerned with building the Erie Canal, with early steamboat navigation, with studying Indian lore, with ichthyology and in other fields of scientific investigation.(4)

Yellow fever periodically ravaged port cities on the eastern seaboard of the United States. In 1793 and 1794 this affliction was particularly bad and in the summer of 1795 one in twenty New Yorkers died from the contagion and fever. Mitchell, as a student of Joseph Black and with a keen interest in chemistry, could not fail to have been exposed to the developing field of pneumatic medicine during his student days in Edinburgh. He thus developed a theory, based on exposure to nitrous oxide gas (Priestley's dephlogisticated nitrous air), to explain the epidemiology and pathophysiology of the contagion and plague that surrounded him during these years.

He initially became interested in this gas through the writings of Joseph Priestly, as well as those of two earlier Dutch chemists, van Troostwijk and Deiman. Mitchill proposed that plague-like illness was caused by contact with nitrous oxide gas generated under varying circumstances. These might include decay of organic material which accumulated in vast amounts about human habitations or alternatively, during digestion of meats in the stomach. The broad measures advocated by Mitchill and others for prevention of the disease were effective because they improved the general level of sanitation and cleanliness, emphasized importance of proper diet and destroyed potential breeding places for disease-carrying insects. Mitchill's theory of contagion was published virtually simultaneously in 1795 in New York City as a monograph(5) and in England as an appendix to the book on pneumatic medicine, "Considerations on the Medicinal Uses of Factitious Airs etc.," by Thomas Beddoes and James Watt.(6) It was Mitchill's writings on nitrous oxide that aroused the curiosity of Humphry Davy and inspired his extensive researches on this gas a few years later. In addition, Mitchill's monograph contained a vivid description of nitrous oxide narcosis, which appears to be the earliest such description discovered to date.(7,8) Robert Hamilton agreed with Mitchill concerning the pathogenic potential of the gaseous oxide of azote and postulated a role for this substance in the etiology of hydrophobia. Hamilton used the peculiar "septon" nomenclature for gases devised by Mitchill to classify and refer to oxides of nitrogen and related substances.(9) But Dr. H. Clutterbuck objected to some parts of Mitchill's theory. He proposed that buildings and other structures made from calcareous materials, as opposed to siliceous materials, would absorb and neutralize pestilential aeroform substances. Clutterbuck had observed that Lisbon contained many buildings made of calcareous stone and also plenty of noxious effluvia due to profuse refuse, but no particular contagion.(10)

Yet another enthusiastic advocate of pneumatics at this time was Dr. Richard Pearson of Birmingham. His essay was another comprehensive review of pneumatic knowledge which would have served a physician of that era admirably as an introduction to the this mode of practice.(11) He postulated that the 'fineness' and 'subtlety' of medicinal substances govern their operation on living bodies. Therefore, substances administered in the aerial state should be more effective than those administered as liquids and solids. Moreover, noncondensable substances, that is gases, should be more therapeutically advantageous than condensable substances such as water vapor. The former class of substances were more 'subtle'.

Pearson identified six sorts of air available in 1795 for medicinal use. These included two gases of the atmosphere: oxygen and azotic air (nitrogen). He identified three species of inflammable air: one obtained from heated iron and water,another from zinc and water, and yet a third from red-hot charcoal and water. The first two inflammable airs listed by Pearson are identical, both being hydrogen. The third was hydrocarbonate gas (carbon monoxide). The final air was carbonic acid air or fixed air. Yet other gases were available,but had not been tried in a medical setting.

The physiology of respiration, as interpreted by Pearson is briefly discussed. Oxygen for therapeutic use was best obtained by heating manganese dioxide, (MnO_2). Moderate periods of oxygen breathing were stimulatory but, when carried to excess, the stimulation could also be overdone, with inflammatory symptoms appearing. Oxygen air also promoted combustion. Pearson reiterates the conclusion proposed by Lavoisier, based on his analysis that atmospheric air contained 28 parts of oxygen and 72 parts of azotic air. Pearson was not sure whether this stated proportion varied from place to place and with altitude. The existing proportions of each gas in the atmosphere may be best for health.

In various diseases different proportions might be advantageously employed. A greater than normal concentration might be useful to produce increased stimulation. When reduction of stimulation is required a mixture with more azotic air than normal should be useful. For therapeutic inhalation, oxygen should be diluted with eight to ten times its bulk with atmospheric air. These airs could all be obtained by artificial chemical means and so they were called "factitious airs." This type of pneumatic medicine had been tried and found so effective that physicians would now be able to provide both symptomatic treatments and cures of different diseases. He noted that these airs are sometimes called "gases".* Azotic air (nitrogen) differed from other unrespirable airs in being insoluble, in being incapable of precipitating lime water, and in not being inflammable. It could be

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* This appears to be the earliest use of the word "gas" in pneumatic literature. The term "gas" was introduced into English chemical usage by chemist James Keir, a member of the Lunar Society of Birmingham of whom a great deal more will be written later.

made by passing air vitiated by combustion through lime water. If breathed in excessive concentration, azotic air became depressant and then eventually lethal. Inflammable airs had no irritating effects, were unfit for respiration, were insoluble and were the lightest of the known aeriform substances. They were cooling and sedative and were serviceable in some types of consumption and in inflammatory states of the lungs.

The gas from iron and zinc could be administered freely but caution was required with the gas from charcoal and it should be highly diluted. Fixed air or carbonic acid air extinguished flames, was very soluble and precipitated limewater. It was the heaviest of the airs considered. For medicinal use it was best obtained by heating chalk. When inhaled it was sedative, cooling, checked putrefaction, and was particularly useful in ulcerations and abscesses of the lungs. It should also be useful applied externally to allay pain and promote healing.

There were several modes of action postulated for beneficial effects produced by factitious airs administered through the lungs. They could act locally directly on the ulcerated, inflamed parts of the lung or could be absorbed and transported by the blood to act on the humors or on the nerves. Another mode of action might be by exclusion of atmospheric air. Pearson explained how consumption in slaves on West Indian sugar plantations was treated by sending patients to "sugar houses" where the cane was boiled. Here beneficial effects were to be expected by breathing the air which would have a lower than normal oxygen concentration as well as a high concentration of carbonic acid gas from both fermentation and boiling of the sugar. Pearson commented also on the "rude and disgusting" form of pneumatic therapy for consumption which consisted of the patients' breathing the exhalation of cows. This form of therapy seems to have been particularly favored by Thomas Beddoes and Erasmus Darwin who believed that the exhaled gas had specific anti-inflammatory and balsamic effects. Pearson said that if this therapy provided relief, then much more could be expected from the proper and well regulated inhalation of airs. Nevertheless, he prescribed this therapy on at least one occasion reported by Beddoes when he was involved in the care of a certain Swedish lady. She was placed in a large hall upon a stage with her head level with the heads of four cows. After a season under these conditions her physical symptoms, which had been quite far advanced, were completely ameliorated.(6)

Finally, Pearson considered inhalation of the vapor of sulfuric ether in phthisis. He perceived that, unlike inflammable airs, it did not induce languor, nausea or giddiness. "Patients who have inhaled it two or three times find it so grateful to their feelings that they are disposed to have recourse to it too often and cannot readily be prevailed upon to lay it aside when it is no longer necessary." The ether was inhaled from a tea saucer two or three times per day. Ether inhalation was also recommended in spasmodic asthma.(11)

In another publication later that year, Pearson again discussed the value of sulfuric ether in consumption. Sometimes the ether could be impregnated with cicuta which was derived from the wild hemlock for which many medicinal uses were recommended.(12) These preparations were inhaled from a teacup or wineglass. One or two teaspoons were inhaled in this manner three to five times per day for a month or six weeks. Beneficial effects included a feeling of ease and coolness in the chest, abatement of dyspnea and cough and easier expectoration. He observed that when a tincture of cicuta in ether was prepared then inhalation of this ethereal tincture could produce a slight degree of sickness and giddiness which soon passed off. He believed this measure was best in florid consumption when the disease was not too far gone. He advocated adding tincture of cicuta to the ether for improved results. He urged any physician who tried this method to communicate with him at once.(13) Pearson again circularized a virtually identical letter the following year.(14) Beddoes published a letter from Pearson dated 28 January, 1796 again describing use of sulfuric ether inhalations in consumption. However, in this report dizziness and giddiness associated with the ether inhalation was noted.(15) Vitriolic ether could also be inhaled by infants and children from a handkerchief placed over their faces. Pearson recommended this treatment for croup and whooping cough.(16)

Cristoph Girtanner, in 1796, published his experience with the pneumatic treatment of phthisis pulmonalis. Girtanner felt compelled to become involved in this area because of certain perceived deficiencies in Beddoes' methods. These included his random selection of gases, his simultaneous use of multiple gases and failure to document his results carefully. Girtanner chose to use only carbonic acid gas for treatment of phthisis because it was heavier than the atmosphere and would therefore, he reasoned (incorrectly), sink to the bottom of the lungs and would not be immediately exhaled. Observations by previous writers indicated that the gas could diminish pain and promote healing. It was easily prepared and avoided the danger of using inflammable airs near candles. Girtanner presented the case of a student who had moderately advanced tuberculosis. He inhaled a 3:1 or 2:1 mixture of carbonic acid gas in air three times a day and was simultaneously placed on a scorbutogenic diet. These measures produced marked improvement in the patient's condition. Other cases are presented in which there was no effect of the treatment.(17,18) Girtanner was one of the first to suggest that oxygen was absorbed into and transported by blood.(19,20)

Dr. Robert John Thornton advised inhalation of the vapor derived from two teaspoons of ether for catarrh. The liquid ether was to be placed in a teapot. The vessel, with top and spout occluded would then be warmed over a candle until pressure in the teapot could be felt. Then the spout was placed in the mouth and inhalation begun. Thornton was perhaps the first to describe an ether explosion which he caused by placing a match in an ether-oxygen mixture while demonstrating the flare of the match in an oxygen rich environment.(21) Thornton also advised inhalation of vital air (oxygen) in liver disease and reported cures of blindness and fits following some kind of putrid disease as well as improvement of leg ulcers and asthma by oxygen. He mentioned a patient who had secured for himself a barrel of oxygen (24 gallons for one guinea), from which the gas could be "bottled off as easily as wine" into a tin pneumatic apparatus for inhalation.(22)

David Paterson, whose 1796 writings were mentioned previously, was concerned with sea scurvy. Based on his long career as a ship's surgeon he advocated measures to assure a ready supply of oxygen to the body. Oxygen, as present in good atmospheric air or enriched air restored energy to the blood and restored the brain to its original purity. He advised avoidance of noxious atmospheres, breathing of good clean air and taking orally "nitrous vinegar." This was nitre (potassium nitrate – a good chemical source of oxygen) dissolved in vinegar (an acid and therefore presumed to contain available oxygen.) This was written the year after the Royal Navy began distributing citrus juice to all hands on prolonged voyages. Paterson also prepared "nitrous vapor" by treating nitre with sulfuric acid. This gas was effective in fumigation of hospital wards and was also quite beneficial in promoting healing of indolent ulcers exposed to it.(23,24)

Dr. William Withering was only slightly less reserved than many of his colleagues in accepting pneumatic modes of medical therapy. He wrote:

> "With us, pneumatic medicine is advancing; and I think enough has been done to authorize me to say, that a cure of consumption is yet to be sought for. Hydrocarbonate and oxygen are the two airs that have mostly been used and these should be diluted with 18 or 20 times their bulk of atmospheric air. The former weakens the stroke of the pulse, occasions vertigo and sometimes excites nausea. It produces a disposition to sleep, abates the cough, and eases the respiration in some asthmatic affections; but in active hemoptoe* it effects a cure more speedily and more pleasantly than I have seen done by any other means. Oxygen, on the contrary, excites the action of the arterial system, warms the extremities, and seems to invigorate the vital principle without exhausting it. From these last circumstances, you will at once conceive it applicable to a very extensive class of diseases. I have lately used it with advantage in two cases of melancholy and I have seen it remove the paralysis of lead which had been treated to little purpose by the other more usual means."(25)

In another communication to Duncan, the editor of Annals of Medicine, Withering described an apparatus for pneumatic inhalation. Substances which could be administered with the apparatus included vinegar in asthma and camphor in spirit of wine for catarrh's senilis and other diseases. The vapor of ether is particularly mentioned as being employed for inhalation. He appreciated the significance of resistance to breathing in apparatus and stated that sick patients could not tolerate appreciable degrees of such resistance. Sometimes it would be

* Hemoptoe or hemoptysis means expectoration of blood. It is sometimes a prominent sign of active tuberculosis.

advisable to warm vapors being administered. This could be done using chemical means; Withering used the sequential addition of lime to the contents of the inhaler to generate the heat required to warm the materials.(26) He also suggested use of hydrocarbonate gas in treatment, but not cure, of pulmonary consumption.(27)

In 1797 John Rotheram published "The Edinburgh New Dispensatory." He pointed out that, for those accustomed to the old manner of chemical thinking using phlogiston theory, the new chemical doctrine could be inferred merely by inversion of the names of "phlogiston" and "oxygen." For example, loss of phlogiston was equivalent to gain of oxygen and phlogistication was equivalent to loss of oxygen. He had great faith in the new chemistry stating that the distinction between chemical and galenical pharmacy would probably no longer hold up since it would all prove to have a chemical basis. Of particular interest among the recipes in this book is that for preparing vitriolic ether from vitriolic (sulfuric) acid and wine. Rotheram calls the resulting ether "dulcified spirit of vitriol" and claims that it has been widely used as a menstruum and as a medicine. Its medicinal effects include perspiration, promotion of urinary secretion, amelioration of pain, and production of sleep. Use of ether by mouth and externally is described but there is no mention of its inhalation.(28)

Dr. Thomas Garnett pointed out that oxygenated muriate of potash (potassium chlorate; $KClO_3$) was the best method for replenishing stores of oxygen in the body when they were depleted. He reported a case of scurvy in a lady. He had intended to advise her to inhale oxygen gas but could not procure the equipment for this form of therapy. Instead, he prescribed oxygenated muriate of potash and her improvement was remarkable. For maintenance thereafter, the lady took both the salt by mouth and oxygen gas by inhalation.(29) Dr. MacDonald observed that when patients breathed hydrogen air, their breathing became easier but they became florid.(30)

Citizen Alyon was familiar with the work of Lavoisier and also of the French scientist Fourcroy. Because red oxide of mercury contained oxygen and appeared to be of value as an antisyphylitic medicine, he concluded that oxygen would be good for treatment of venereal disease. He prepared oxygenated ointment by adding nitric acid to fresh lard. The citizen speculated that these ointments would readily part with their oxygen and be beneficial in several types of venereal disease. He commented that the ointment had not been universally effective but so far had done no harm. Sometimes he used systematically administered nitric acid with the ointment.(31) Citizen Alyon's countryman, Citizen Fournier, confirmed the therapeutic efficacy of oxygenated ointment in several situations.(32) Mr. Gimbernat, surgeon of Madrid, treated hydrocoele by repeatedly blowing air from his lung into the scrotum to promote inflammation.(33)

Certain pneumaticists believed that hydrogen had the property of producing unconsciousness without profound narcosis. Beddoes had assigned this property to hydrogen and had claimed to have caused a person with consumption to sleep throughout the night without an opiate after inhaling hydrogen mixed with common air. Later, Beddoes employed a mixture of hydrogen and carbonic acid under the title of "hyro-carbonic air" which was believed to have soporific value. Townsend commented on the sedative effects of breathing hydrogen air because, as he reasoned, anyone can observe that if a mouse is confined in hydrogen air he quickly dies.(34) Berzelius also believed that hydrogen possessed sedative properties. In 1824 he wrote:

> "9. When hydrogen gas is substituted for azotic gas in the mixture which constitutes atmospheric air, and this mixture is respired by men or other animals it very soon throws them into a profound sleep, without appearing to have any injurious effect, especially if a little common air is admitted to the mixture...."(35)

In the same article, Berzelius had written:

> "8. When Hydrogen gas,(obtained from iron filings and dilute sulfuric acid,) is passed through pure alcohol, the hydrogen loses much of its odor, and the alcohol, when water is added to it, becomes milky, and in a closed vessel it deposits, in the course of a few hours, an odoriferous volatile oil, which was contained in the gas, and which gave it its well known smell."(35)

Could the "odoriferous volatile oil" mentioned by Berzelius have been diethyl ether formed by the reaction of the sulfuric acid and the alcohol with which it might have come into contact?

Benjamin Silliman, in 1824, also wrote that hydrogen gas was capable of causing a deep sleep in animals and man without any apparent deleterious effects.(36) Benjamin Ward Richardson, with the encouragement of Dr. John Snow, finally confirmed the lack of soporific and anesthetic properties of hydrogen about 1852 in animals and man.(37)

In the journal, "Medical Repository," beginning about 1800, announcements appeared concerning some of the activities and ideas of Drs. Beddoes and Girtanner mentioned above. Also, in this volume Dr. Benjamin DeWitt presented a review on the operation and medicinal uses of oxygen. He concurred with Dr. Beddoes' views on oxygen and also with the opinion of Dr. Mitchill concerning the potential of nitrous oxide to produce disease.(38) In the same issue of this journal Dr. Joseph Johnson wrote on medicinal actions of carbonic acid gas. He proposed that this gas is not depressant but is stimulatory. Techniques to revive animals destroyed by carbonic acid gas included methods to reduce stimulation: bleeding and immersion and bathing in cold water. These measures had proved successful in cats. He provided a list of medicinal uses for the gas.(39) In this issue is yet another letter from Dr. Pearson describing his use of sulfuric ether in varied pulmonary complaints in both adults and children. The diseases treated included consumption, croup, whooping cough and simple catarrh.(40) Dr. Crowther also treated pulmonary consumption with ether inhalations.(41)

CAVALLO AND HAMILTON – TWO NEGLECTED PNEUMATICISTS

Tiberius Cavallo (1749-1809) seems to have been relegated to a position of neglect and obscurity by subsequent medical historians. This is unfortunate because his "An Essay on the Medicinal Properties of Factitious Airs" published in 1798 is (at least in my opinion) the most informative, comprehensive, and objective treatise on late 18th century pneumatic chemistry, physiology and medicine.

Cavallo was born in Naples and was brought to London as a young child. His primary scientific interests were electricity and pneumatic chemistry. In his time he was recognized as an excellent scientist, reserving his opinions until facts were well demonstrated. His electrical measuring instruments were of particularly high quality. He was elected to fellowship in the Royal Society in 1779.(42)

Cavallo's essay on factitious airs was an orderly exposition of the principles of pneumatic chemistry and medicine, as well as of respiratory physiology. He appeared to have had few original thoughts but rather an encyclopedic knowledge of the writings and theories of his predecessors and contemporaries. There were five known gases which he concluded were applicable to the body. These were common air, oxygen, fixed air or carbonic acid gas, inflammable air and azotic air.(43) The purity of common air could be determined by permitting it to react with nitrous air (nitric oxide) in a eudiometer, an instrument for the volumetric measurement and analysis of gases. Reduction in bulk of the air was proportional to its purity. However, he believed that human lungs could be affected by very slight changes in the purity of the respired air. As an example he cited the frequent improvement of the health of some invalids following a carriage ride or some similar outing involving a change of air. Noxious foreign particles not influencing the outcome of the nitrous air test were sometimes mixed with common air. He suggested several different chemical methods for preparing oxygen. Volume of an air sample containing supplemental oxygen was diminished to a greater extent by nitrous air and by other processes known to use oxygen than was common air. Cavallo estimated the consumption of oxygen by the human body at about 5.5 cu.ft./hour (actually about a 6-7 fold overestimate) and correctly deduced the volume of a normal breath as about 30 cu.in. (about 492 ml). He appreciated some of the factors influencing oxygen consumption by the body.

Effects of breathing pure oxygen on the body had been previously demonstrated by Beddoes to be extremely hurtful. The experiments, also cited by Beddoes, showing the deleterious pulmonary effects of oxygen breathing for prolonged periods in small animals were mentioned by Cavallo. In many situations in medical practice, however, breathing of oxygen was beneficial. Cavallo described experiments demonstrating the superiority of oxygen over common air for resuscitation of asphyxiated small animals. Although respiration of pure oxygen was harmful, breathing of common air but slightly improved by addition of a small portion of oxygen, for example 1/15 or 1/20 of its volume, had marked salutary effects. When inhaled for 15-20 minutes a day such inhalation had been known to produce a florid face, to improve sleep and to improve digestion and circulation. Again, supporting evidence was the improvement in health and well being frequently exhibited by invalids upon taking up residence in areas where air was pure, for example in the country or at the seaside.(44)

There appear to have been several types of combustible gases known during Cavallo's time. They were not sharply distinguished but rather lumped under the term "inflammable air." One such air (hydrogen) was prepared from metals and acids or alternatively, by passing steam over red hot iron. This was the lightest of the airs and its bulk was not influenced by nitrous air. It could not sustain life but seemed less noxious for respiration than carbonic acid gas. Good inflammable air, when mixed with oxygen or common air and breathed, caused a feeling of levity in the lungs and a florid appearance of the face. This was perceived as being beneficial in inflammation of the lungs, convulsive cough, or in any other condition of lung irritability.

Hydrocarbonate (principally carbon monoxide) was another type of combustible gas which was prepared by passing steam over red hot charcoal. This gas was pernicious and sometimes two or three breaths was enough to kill an animal. When diluted with 20 or 30 volumes of common air and breathed it caused vertigo, sickness, and malaise. It was recommended for irritability of the lung, but great caution in its use was emphasized. Pure carbonic acid gas was also pernicious. Cavallo noted that animals breathing either hydrocarbonate or carbonic acid gas died more quickly than animals who were simply not breathing at all. He therefore deduced that both of these gases were inherently toxic. They did not kill animals simply by exclusion of vital air. Diluted carbonic acid gas, however, could be breathed for longer periods. Animals in confined areas lived longer if limewater was included in the space (to absorb the generated carbonic acid gas). Carbonic acid gas had considerable antiseptic and antiputrefactive power. It could be applied internally or externally, either combined with water or in the aerial form. Animals asphyxiated in azotic gas (nitrogen) had an excellent chance of recovering if removed in time. He predicted that perhaps stratification of gas in the lung on the basis of differences in density might have some physiological consequences.(45)

Gases could also be absorbed through the skin. When gas was introduced under the skin the duration of swelling varied with the nature of the gas used. Tumefaction was prolonged with common air, azotic gas and hydrogen and considerably less with oxygen and carbonic acid gas. The color of blood exposed to different gases varied according to the nature of the gas employed. This was true even when a thin animal membrane was interposed between gas and blood. When a denuded blister was placed in oxygen, pain was experienced. This pain was relieved on exposure of the raw surface to carbonic acid gas. This was said to demonstrate the stimulatory quality of oxygen.(46)

Cavallo then discussed at length contemporary theories on pneumatic chemistry as related to respiration. An important feature of his discussions was the assertion, (but with considerable reservation), that oxygen gas incorporates both heat (caloric) and light; a common belief of this age. He described the initial step in respiration as a loose combination of blood with oxygen across a thin membrane which separates them in the lung and which Stephen Hales had estimated to be about the thousandth part of an inch thick. The blood turned bright red as a consequence of this oxygenation. Since red oxide of mercury and red oxide of lead were good sources of oxygen, he, like Lavoisier, proposed that redness was a characteristic of oxygenated substances. The combination of oxygen and blood was slight because blood so easily parted with its oxygen. The oxygen was then deposited at the extremities of the arteries where it entered into combination with and gave firmness and solidity to the tissues. Some caloric was also transported to the periphery to provide body heat. Since both oxygen and caloric were transported peripherally, it was presumed that carbonic acid gas and also water vapor were formed here and not in the lung. Presence of bad breath in some individuals who did not have bad teeth confirmed that an other important use of the respiration was to expel putrid effluvia from the body.

Azotic gas was only a diluent and otherwise passive. Yet this was important because it exposed a proper quantity of oxygen air to a great quantity of blood which could not have been the case if the atmospherical fluid had consisted entirely of oxygen. This function was related to the very extensive surface which the lungs presented to the air.(47)

Medicinal use of airs was then considered. In the past, patients had been sent to various localities to take advantage of properties of the air in those places such as sharpness, purity, dampness, etc. The present knowledge explained why those changes in locale were salubrious. Such trips were no longer necessary since it was now possible to alter the atmosphere artificially with factitious airs. The artificial aeriform fluids may be respired, may be taken into the stomach or intestines by means of injections (enemas) or in combinations with fluids, or applied to the external parts of the body. The best apparatus for pneumatic therapy was that of Mr. Watt, Engineer of Birmingham, but other apparatus for respiration was also described. For internal use carbonic acid gas water may be prepared.

Cavallo attempted to assess information on pneumatic therapy in spite of the exaggeration and error which had been associated with the field. Oxygen air was stimulatory and a reduced atmosphere decreased irritability. As mentioned, breathing of pure oxygen was deleterious and its use should be confined to resuscitation and reanimation. In smaller concentrations, adjusted to suit the patient, the stimulatory properties of oxygen were extremely beneficial. It might require one to two weeks of oxygen therapy to produce detectable results.

Reduced atmospheres could be prepared by mixing common air with azotic gas or with one of the species of inflammable gases. In general, the more benign the mixture the less therapeutic value it would have. Hydrocarbonate gas had to be used with great caution. It could be diluted to 1/20 of its bulk with atmospheric air and breathed for five minutes once or twice a day. If dizziness or sickness occurred breathing could be temporarily interrupted until the patient felt better. The therapeutic effects in reducing pain and irritability were most marked. The breathing of the diluted hydrocarbonate was attended with a diminution of sensibility. This was almost always accompanied with vertigo, giddiness, and sometimes with faintness. Hydrocarbonate may be particularly good in hydrophobia.

A reduced atmosphere was capable of diminishing irritation of the lung in inflammations, cough, etc. Some species of asthma had been successfully treated with ether. This could be administered by inhaling it from a vial or through a teapot. Ether when volatalized became an inflammable and explosive aeriform substance similar to inflammable air.

Carbonic acid gas had enjoyed the longest and most extensive use. It was particularly good in putrid fever and in scurvy because of its antiseptic properties. It was also useful in some cases of urinary stone and its external application to sores and ulcers was beneficial. On the basis of this information therefore he believed that pneumatic means had a definite but limited place in medical practice. Certainly, it was over-optimistic to expect cure of consumption in all stages, cure of all sores and ulcers by reduced atmosphere and also cure and improvement in all cases of debility with oxygen.(48) Cavallo then discussed administration of aerial fluids in different disorders. Of particular interest is his prescription for management of "suspended animation." This was one of the indications for pure oxygen administration:

> "...The wooden pipe of a large bladder full of it must be introduced into the mouth of the subject, the lips must be pressed upon the said pipe, and the nostrils must be stopped by the hands of an assistant. Then, by pressing the bladder, the oxygen air must be forced into the lungs as much as possible for about eight or ten seconds, after which the mouth and nostrils being unstopped, without removing the pipe of the bladder the chest about the region of the lungs must be pressed gently....This should be kept for at least a quarter of an hour and bladders of oxygen should be held in reserve."

For asphyxia of the newborn he commented:

> "In cases of children born apparently dead or strangled in laborious parturition, etc. the use of oxygen air cannot be too forcibly recommended. The application is easy and highly promising....a child

> born apparently dead was brought to life merely by forcing oxygen air into his lungs whilst he was held before the fire."(49)

Cavallo enumerated the effects of pneumatic therapy on many diseases, considered in alphabetical order and recommended the appropriate gas to be used in each.(49) He particularly noted that in consumption both positive and negative results had been exaggerated. The dilute hydrocarbonate was the only gas which had produced unequivocal symptomatic relief but its use was attended with diminution of strength. For this reason it was not suitable for advanced cases associated with debility. He reported that in some cases of consumption a reduced atmosphere had provided a perfect cure. But regardless of any success or failure in treating phthisis, lack of any other type of successful treatment provided encouragement to continue to assess this type of therapy. Also, carbonic acid gas was recommended for treatment of putrid fevers but its benefits were not so much as initially thought. In one patient consumption was treated with ether. She claimed to have felt extremely giddy after each inhalation. Some of the hints offered for conduct of gas inhalation resemble instructions for administering anesthetics in more modern times: "When a person is inhaling any species of inflammable gas, or the vapor of ether, the operation should be carried out at a distance from a candle, lest the gas should catch fire, and at least occasion a surprise."(50) The pulse should be monitored at least during the beginning of inhalation of aerial fluids. Finally, Cavallo suggested sources in London where individuals might obtain some of the supplies necessary for gas inhalation.*

Another proponent of pneumatic medicine in the final decade of the eighteenth century was Robert Hamilton. He was primarily concerned with the treatment of hydrophobia (rabies). His two volume work contained, in addition to his thoughts on hydrophobia, much general information on pneumatics. He had considered opium as therapy in hydrophobia but was dissatisfied with it. He then considered the virtues of aeroform substances writing:

> "To pneumatic medicine let us turn our attention. Our experience indeed is but limited in this walk, yet from some trials of aerial fluids in diseases of great nervous irritation and the beneficial consequences resulting from thence, hopes may be entertained that our labor here may not be lost. Among the different species of these fluids the hydro-

* Mr. Watt's apparatus for generating and inhaling factitious airs could be obtained from Chippindall's Birmingham Warehouse in Salisbury Court off Fleet Street. (This short street is more famous as the birthplace of Samuel Pepys and the location of the house where he was cut of the stone.) Artificial airs accurately prepared in any quantity were obtainable from J. Rance, 30 Clipstone Street, Fitzroy Square off Euston Road. Acidulous soda water containing an extraordinary quantity of carbonic acid gas was sold at Schweppe's Artificial Mineral Waters Manufactory, 11 Margaret Street, Cavendish Square. At that time Mr. Schweppe was a recent émigré from Switzerland.

> carbonate is first to be considered, provided we place confidence in some late trials with this gas in the removal of spasms."(51)

Several previous articles from the literature were cited in support of his suggestion for evaluation of pneumatic methods. Beddoes had reported favorably on hydrocarbonate gas as well as a reduced atmosphere for relieving spasms in various spastic states and also in ameliorating irritability of the lungs in consumption. Also, Withering had commented on the beneficial sedative effects of hydrocarbonate. Hamilton described the case of a clergyman, normally a sufferer from chronic insomnia, who secured a welcome and unanticipated night's rest, the best in several years, in a room in which the atmosphere was reduced by presence of many candles burning in celebration of Lord Howe's victory. A servant sharing the room enjoyed a similar night of profound sleep.

Hydrocarbonate gas had been recommended by Cavallo and others as a sedative on the basis of its ability to relieve pain and diminish the irritability of fibers.(53) There were, however, theoretical objections and problems connected with both a lowered atmosphere and use of hydrocarbonate gas in hydrophobia which were reviewed. Hamilton was not certain about the state of body oxygenation in hydrophobia because sufficient observations had not been made. On reasoning from analogy, he speculated that there was probably a deficiency of body oxygen in hydrophobia and that administration of oxygen would be beneficial. Short periods of oxygen breathing should not be harmful, as shown by the writings of Priestley and others.

A novel suggestion was made by Hamilton regarding hydrocarbonate inhalation:

> "As a temporary narcotic I shall not object, if the distressing watchfulness which constantly attends this disorder cannot be removed by the use of oxygen. For the reasons already delivered (the harmful effects of hydrocarbonate enumerated above) its use would appear ill adapted to anything farther than a temporary insensibility. Should it prove in this respect superior to opium, it ought not to be rejected..... I do not see the impropriety of occasionally inhaling it at the same time as oxygen; I mean for the purpose of procuring rest."

This prescient proposal is remarkable on two counts. First, it is another unambiguous suggestion for the inhalation of a gas to procure unconsciousness for a therapeutic objective. Second, the addition of oxygen to the inspired mixture to overcome some of the problems associated with the primary gas is advocated.

Oxygen therapy was next considered. Oxygen was breathed by adding perhaps one or two quarts to eighteen or 20 of common air. Many patients were relieved of convulsions and spasms by oxygen and received needed rest from the inhalations. Hamilton reconciled the capability of both hydrocarbonate, a depressant gas, and oxygen, a stimulatory gas to produce sedation and sleep when they are of opposite natures. He used the logic of the Brunonian system of medicine. Sleeplessness and agitation could be caused by excessive stimulation with excessive excitement, deficient excitability, and indirect debility. In this instance a depressant such as hydrocarbonate was of value. Alternatively, the wakefulness and spasms could be related to deficient stimulation and excitement with excessive excitability and direct debility. Here, a stimulant such as oxygen might correct the problem.(54) (See Brunonian system of medicine.)

Another modality of treatment of hydrophobia recommended by Hamilton was a bath in hydrocarbonate gas to contain the cuticular sensibility so acute in hydrophobia (54). This was believed effective because pain was reported to be relieved in an area of denuded skin exposed to hydrocarbonate. The patient could sit in a cask or other vessel with his head outside in the air and the container sealed with a chamois skin or cloth collar. Precautions to be taken by attendants, particularly when removing the patient from the bath were described. Another situation where aerial baths might be of therapeutic value was in severe burns produced by explosions of gunpowder, or of hydrogen gas in coal pits and other mines and also in scalds from boiling fluids.

Hamilton proposed a possible role for the "gaseous oxide of azote" (nitrous oxide), as postulated by Samuel Latham Mitchill. It will be recalled that Mitchill wrote that this gas, which he believed was produced from putrefying animal material, was the cause of plague and contagion.(55) Hamilton endorsed this opinion and employed the "septon" terminology as did Mitchill.(56) It is worthy of note that Lavoisier had concluded, that during breathing of any respirable air, oxygen in excess of that needed for body metabolism acted as an inert gas. He probably would have raised an eyebrow on hearing these claims for therapeutic efficacy of oxygen.

Another long treatise on respiration and airs was that of Edward Coleman. He considered both natural and suspended respiration, proposing that effects of submersion, strangulation and noxious airs were similar. He discussed the physiology of respiration at length, and emphasized that in treating victims of suspended respiration, one should employ every method of resuscitation and not waste time initially trying to determine whether the victim was still alive. He was acutely aware of the importance of a continuous and uninterrupted supply of fresh air delivered to the lungs.(57)

Artificial Mineral Waters

Drinking of natural mineral waters for therapeutic purposes had been done since the Middle Ages. The taking of these waters at such resorts as Bath and Tunbridge Wells in England, Saratoga Springs in the United States, and many renowned spas on the European continent attained enormous popularity in the late

18th and the 19th centuries and continues into our own times. As described above, an important ingredient in these waters responsible for the beneficial medicinal effect was supposed to be carbonic acid gas, or the fixed air discovered by Joseph Black. In addition, many other components of the various spa waters were identified.

Preparation of water carbonated by artificial means, also presumed to have marked therapeutic efficacy, began in the last half of the 18th century. The first such "soda water" was attributed to William Bewley who instructed that, in order to prepare a "Mephitic Julep," one should "dissolve three drams of fossil alkali (soda) in each quart of water and throw in streams of fixed air."(58) After drinking this preparation, many then swallowed a spoonful of lemon juice with sugar,which was supposed to increase the amount of fixed air liberated in the stomach.(59) Thomas Henry of Manchester was said to be the first to mix alcoholic spirituous beverages with soda water. Consumption of these early highballs on prescription would have been quite in accord with late 18th century medical practice which regarded alcohol as a diffusible stimulus.(60) Also about this time Priestley published his instructions for impregnating water with fixed air (See above). In 1775 Dr. John Mervin Nooth (1737-1828) communicated to the Royal Society the details of his gas-generating apparatus, or "gazogene." He was an Edinburgh graduate and a classmate of William Withering and was highly regarded as a practitioner in his day. This small apparatus was suitable for home use and permitted preparation of small quantities of carbonated water for domestic consumption. Repeated aeration of a sample could produce water highly charged with fixed air.(61) By adding different salts to the impregnated water, Nooth was able to simulate various natural mineral waters. The popularity of this apparatus as a domestic article in affluent homes persisted well on into the 19th century and its use evolved from preparing a medicinal liquid to providing a diluent for alcoholic beverages.(62)*

Nooth's apparatus was adapted by James Robinson to permit administration of the first ether anesthetics in England in 1846 (63) and was also modified by Peter Squire for the same purpose.(64) Thomas Henry of Manchester was the first commercial manufacturer and seller of artificial mineral waters on a large scale about 1781. The consumption of mineral waters peaked in the 18th and early 19th centuries. During this time there was a tendency to change from natural to specifically formulated waters. Sweetened and flavored mineral waters became well established in the United States and in England during the first decades of the 19th century.(66)

Jacob Schweppe (1740-1821), a jeweler, started in the soda water business in Geneva, Switzerland. He was a student of Priestley's writings and is said to have

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*Conan Doyle described a "gazogene" as an important article in the flat of Sherlock Holmes and Dr. Watson at 221B Baker Street. It was one of the very few mechanical devices that Holmes apparently trusted.(65)

become another founder of the soft drink industry when he followed Priestley's suggestion to use a pump to pressurize the carbon dioxide into water. There developed a considerable local demand for the variety of soda and artificial mineral waters and so the Geneva firm of Schweppe, Paul and Gosse was in business from 1790-1793. Schweppe went to England in 1792 to expand the firm's operations. When the partnership was dissolved in 1793, he lost his Geneva interests but retained sole control of the English operations. His products became widely known and sold.(66) Thomas Henry of Manchester was a competitor of Schweppe and also manufactured artificial soda waters and Bewley's Mephitic Julep in large quantities.(62) Several individuals mentioned in this book were known users of Schweppe's products. Matthew Boulton became a regular drinker of Schweppe's soda water and recommended it to Erasmus Darwin. He in turn extolled the medical virtues of the product in "Zoonomia" and in other writings. Darwin recommended "aerated alkaline water," available from Jacob Schweppe, for treatment of urinary tract stones. Tiberius Cavallo, as mentioned above, also recommended Schweppe's soda water, as did other physicians for a variety of complaints.(66) Thomas Mitchell advised medicinal use of artificially carbonated water, which he called "seltzer water," for stomach ailments and also, simply as a good beverage. Soda water could be prepared by adding sodium carbonate to seltzer water. It could also be prepared as a powder which would fizz when dropped into water and was good for the stomach.(67)

By the 1870's carbonated beverages were freely available and included soda and other mineral waters, German Seltzer Water, aerated lemonade, tonic water, dry and sweet ginger ale and others.(66)

Another type of charged water which must have gained some popularity was water impregnated with nitrous oxide. Humphry Davy drank three pints of nitrous oxide water in a day with little effect(68) Jonathan Pereira discussed "Searle's Patent Oxygenous Aerated Water" in his "Materia Medica." This product consisted of nitrous oxide dissolved in water. The manufacturer claimed that the preparation exhilarated, cured torpor, and had other remarkable effects.(69)

Chapter VIII

Pneumatic Medicine of the Nineteenth Century

Several medical historians have written that pneumatic medicine died in the early years of the nineteenth century with the decline of the Bristol Pneumatic Medical Institution and the death of Thomas Beddoes, founder of pneumatic medicine. This is certainly not true. As we have seen above, Beddoes did not originate pneumatic medicine. Also, although pneumatic medicine was never widely practiced, and there were not large numbers of pneumatic practitioners, interest in this mode of therapy was sustained well into the middle of the nineteenth century as the following material will show.(1) Indeed, certain pneumatic means of therapy are used to advantage in modern times.

Joseph Townsend (1739-1816), wrote a book on therapeutics and a guide to health in 1801. One of his motives for doing so was to make the ideas of William Cullen on nosology available in English. Also, the book was intended to be of use to country clergy because they were frequently cast in the role of medical practitioners in time of need. (Recall that John Wesley's book on "Primitive Physick" of 1776 had a similar purpose). Townsend was an ordained Methodist minister and eventually became rector of Pewsey in Wiltshire. His other interests were in geology and in problems related to population. Malthus recognized his contribution in this area.(2) Townsend also considered the properties of stimulants and depressants. Wine was held to be the prototype of such substances:

> "...wine quickens the pulse, raises the spirits, increases vigor and gives more than common animation for the time; but no sooner are the fumes of the intoxicating drink exhausted than the drunkard becomes weak, enervated and depressed in spirits. Here we distinctly see the stimulant and the sedative power of wine; and the same may be observed of opium."(3)

Camphor had some of the same general properties. Then, in a subsequent paragraph he wrote, "What has been said of wine, opium, and camphor applies to its degree to ether. . . ."

Thus Townsend was familiar with a variety of sedative substances and included ether among their number. He dwelt at great length the importance of vital air (oxygen) and other gases to the body economy and in disease states. Vinegar, an acid, contained vital air in abundance and would part with it readily. For fever patients he therefore directed that vinegar be sprinkled liberally on the ceilings of their chambers "like dew" so that its evaporation would revitalize vitiated air. The vital air eased respiration, improved appetite, and aided digestion. Dr. Ingenhousz had reported that the atmosphere in Vienna contained a higher proportion of vital air than that in Holland. This was the reason why individuals in Vienna had such good appetites. Townsend himself observed the relationship between vital air and appetite. He commented on the propensity to eat acid-containing foods presumably rich in vital air during fevers, in warm climates and during the sultry season. In winter there was a strong desire for those foodstuffs which abounded in hydrogen. Heat generated by living bodies appeared to bear some proportion to the quantity of vital air absorbed.(4) He commented on the well-known sedative effects of hydrogen.(5) He advocated inhalation of vinegar fumes to provide oxygen in the treatment of syncope.(6) Townsend, like many of his contemporaries, believed that the oxygen absorbed in the lungs conferred stimulating power to the blood, irritability to solid tissues, and heat (caloric) to both. He commented favorably on the pneumatic treatment of phthisis. One form of therapy which he endorsed was that practiced by the "ingenious and learned Dr. Beddoes" at Bristol Hotwells where patients breathed hydrogen, azotic gas, or sometimes carbonic acid gas.(7)

The description of resuscitation of the newborn in Townsend's writings is quite modern. He prescribed inflation of the lungs with super oxygenated air using either mouth-to-mouth inflation or a bellows while pulling the tongue forward to maintain the airway.

Robert John Thornton

Robert John Thornton's book on the philosophy of medicine, published in 1813, contained a great deal of material on pneumatics. He began his book with a general review of the history and development of chemistry from the time of Galen. It was a good representative summary of chemical knowledge at the time of its writing. He emphasized that it was only natural that the earliest discoveries concerning gases related to their physical properties (such as elasticity and weight) and preceded elucidation of their chemical properties. The former involved corporeal, tactile and visible types of phenomena and responses, whereas the chemical changes had to be inferred from much more subtle types of information. Thornton believed in a relation between oxygen, appetite and digestion. He quoted

Beddoes to the effect that the body might be nourished as much through the lungs as through the stomach. Withering is quoted as writing that certain foods increased the attractive powers of the blood for oxygen. In support of this contention was the statement by Mr. Spalding, who worked with underwater diving bells. This gentleman stated that, after consumption of fermented liquors and animal foods, he used oxygen in the diving bell much faster than after vegetable foods and plain water.(8)

Thornton was a firm believer in the therapeutic value of gases. In his book,"On the Establishment of the Pneumatic Practice of Physick, for the Restoration of Health," he wrote:

> "The introduction of Aerial remedies, for the removal of disease, has produced a new area (sic) in the practice of physick. Whilst Dr. Beddoes went from Oxford to the Hotwells, Bristol, chiefly with a view to remove consumption, by abstracting the oxygen from the air, his friend, Dr. Thornton, on a large scale began to try the effects of the addition of oxygen to common air, and the result of such cases he communicated to Dr. Beddoes, or to the Philosophical Magazine. Other laborers in this new practice, also, have appeared to enrich the harvest of useful discoveries for the benefit of mankind."(9)

Sixty three case reports followed. These were presented in anatomical order, from afflictions of the head downward and included identification of each patient, as well as the source from which information on previously reported cases had been obtained. Most of these cases were treated by inhalation of vital air and were similar to previously reported material. He subsequently discussed death in non-respirable atmospheres, such as chokedamp and firedamp in mines, and carbonic acid gas around lime kilns. Asphyxia by hanging and drowning is discussed and notice is made of the founding of a Humane Society for the revival of persons apparently dead. Thornton also classified ether as sharing some of the same actions as alcohol and opium.(10)

In 1816, Robert John Thornton edited and published "Dr. Cullen's Practice of Physic. . . . . " This volume recapitulated the medical teachings of William Cullen and also presented the ideas and discoveries which had been formulated by various authorities since Cullen's time. Included among these latter were many proposals on the pneumatic cause and treatment of disease. Thornton enthusiastically supported the treatment of a variety of diseases with vital air (oxygen). He strongly advocated the use of vital air in many putrid fevers, including typhus. The rationale for this was orthodoxly Brunonian. These febrile states were stimulants and they exhausted the irritability of the body. The appropriate treatment was to administer the principle of excitability: oxygen.(11) The oxygen could be taken by inhaling about ten quarts of vital air in thirty quarts of common air. Other measures effective in fevers included administration of nitre and exposure to plenty of fresh air. When a body chill occurred, a dram of liquid ether was sometimes effective in stopping it.(12) Another useful means of administering vital air was through the use of oxygenated muriatic acid and its salts (e.g. $KClO_3$) . This was particularly applicable in children who could not be induced to breathe vital air. Other pneumatic treatments included management of hydrophobia with vital air and of croup with azotic gas.(13) On another occasion foxglove and ether were advised for the croup. In pneumonia, fixed air (carbon dioxide) was supplied to the body to exert its anti-putrefactive action. This was accomplished both by oral administration of yeast and by immersion of the extremities in fermenting solutions to permit systemic absorption of the gas.(14)

Thornton published several letters on pneumatic subjects from Edgeworth, Townsend, Beddoes and others. There were several communications advising treatment of consumption with ether. One of these from Dr. Pearson related the experiences of a lady who frequently inhaled ether for the croup and experienced giddiness after each treatment.(15)

Thornton regarded Beddoes as an extremely important influence in the development of therapeutics in spite of the failure of many of Beddoes' hypotheses and described himself as the heir to Beddoes. With Beddoes' death Thornton maintained that he stood alone, but invited other physicians to join him in the practice of pneumatic medicine.

Robert Reid, an Irish physician, reported on the treatment of heart disease with oxygen in 1817. His patient was 66 years old and suffered paroxysms of chest pain, shortness of breath and irregularity of the heart beat. Some of the episodes were prolonged with fluid audible in the air passages and were associated with a blue appearance of the skin and weakness of the pulse. The treatment, consisting of draughts of ether, syrup of squill, serial bleedings, and enemas helped little. When subsequent paroxysms occurred he was given one quart of oxygen to breathe which appeared to improve his condition and, it was believed, to provide a prolonged period of relief. The paroxysms recurred and the patient died from "depressed spirits" in spite of oxygen inhalation. Reid placed little store in the therapeutic value of oxygen in angina pectoris. It was regarded as a substitute for bleeding and only palliative: a measure designed to procure additional time for more effective measures to be instituted.(16)

Thomas D. Mitchell, writing in 1819, was another physician who believed in the curative powers of oxygen. He suggested that pneumatic medicine might have been abandoned prematurely and cited the excellent response of a patient with consumption to oxygen inhalations.(17) He expressed some vague ideas on the relation of oxygenation to health:

> "We know that some of the forms of disease that affect the viscera of the thorax, do depend on an imperfect oxygenation of the blood and it

> is perfectly reasonable to suppose that the administration of this gas in such cases, might be a source of relief and perhaps eventuate in a complete return to health."(18)

Mitchell also advocated administration of carbonic acid gas in various forms for medicinal purposes. This gas had a refreshing and cooling effect on the stomach when given as acidulous waters and was also beneficial in ulcerated lungs and consumption. It was particularly good in typhus fever when administered as yeast. Another substance recommended for volatilization and inhalation was mercury, advocated for stimulation of saliva production and treatment of phthisis pulmonalis. The author, Dr. Little, wondered whether some of the benefit of mercury ointment might be due to volatilization of mercury by body heat. From the case report it is difficult to decide how the author proceeded.(19)

Robert Hare, in 1819, described an apparatus for impregnating water with gases consisting of concentric bowls and bell jars. He considered this device superior to the existing Nooth's and Woulf's apparatus.(20)

W. Wright, Aurist

A most fascinating aspect of pneumatic medicine was the role of aeroform remedies in ear disease. The most prominent proponent of this type of practice was William Wright (1773-1860). He studied for the medical profession under John Cunningham Saunders and also probably for a time at St. Thomas's Hospital, London, but did not take a medical degree, diploma or license. He began his career at Bristol in 1796 and thus would almost certainly have been familiar with the medical pneumatic concepts proposed by Thomas Beddoes. In Bristol, Wright cared for Miss Anna Thatcher and in one year she was transformed from a deaf mute to a speaker. In 1817 she had a long audience with Queen Charlotte, wife of George III. As a result, William Wright was appointed Surgeon-Aurist in ordinary to her Majesty.

Wright moved to London and acquired a large and fashionable otological practice. Among his patients were the Duke of Wellington and many other members of the nobility. He published several works on deafness and ear disease.(21) He suffered a long terminal illness and left his family in a precarious financial position on his death.(22)

Evaluation of Wright in modern times appears to be mixed. One history of otolaryngology discussed him in a section headed, "The Influence of Quackery"; possibly because he lacked a degree or other medical qualification.(23) Another such volume regarded him highly and said that his written works reflected extensive experience and knowledge of the literature.(24) Wright's writings called attention to the exaggerated sense of hearing and the generally heightened awareness and perception of sound often occurring during inhalation of nitrous oxide, which ceased a short time after the inhalation terminated. He attributed this to the participation of the muscles of the hearing apparatus in the general muscular stimulating action of nitrous oxide. Wright related that he had read several encouraging reports of good results using nitrous oxide inhalation in cases of muscular paralysis. He had serious reservations about pneumatic forms of therapy and was reluctant to become involved in this field. Nevertheless he conceded that pneumatic treatment of deafness was worthy of experiment because it stimulated muscular powers so forcibly without leaving any debility. Frequent moderate usage of nitrous oxide inhalation under proper management might permanently increase the tone of the organ of hearing. The type of case in which he believed it might be of greatest benefit was that of the deaf person who heard better in a coach or when a loud noise was present. Wright cited the case of a woman whose husband had to hire a drummer to beat the drum whenever it was necessary to converse with her. Another example was that of a bell ringer who could never understand a conversation except when bells were ringing above his head. Wright concluded that there should be little danger in inhaling gas properly prepared from pure ingredients.(25) His basis for this conclusion was an exhibition of the properties of nitrous oxide gas on the London stage presented during the previous year by a Mr. Henry.(26)

Another pneumatic agent applicable in ear disease was sulfuric ether. It was known that certain individuals with disease, irritation, or inflammation of the external ear canal would develop a sustained episode of coughing when manipulation or instrumentation of the ear canal was attempted.* Wright used inhalation of ether vapor under these circumstances to suppress the cough and permit instrumentation of the ear canal. Details of his technique are related in the section on early anesthetics. Wright concluded that inhalation of ether vapor was also beneficial in suppressing chronic cough.(28) In certain ear diseases he also advocated the blowing of ether vapor into the ear and gave instructions for both inhalation and aural insufflation of the vapor. He recommended further evaluation of the latter procedure.(29) The vapor of sulfuric ether was noted to have sedative properties, which he attributed to the formation of hydrocarbonate gas from ether.(30) He reported the case of a gentleman whose ear affliction had been cured in this manner and who resorted to the same application at the slightest suggestion of a recurrence of his ear problem.(31) Wright also advocated blowing carbonic acid gas into the ear in certain painful conditions. He wrote:

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* This phenomenon is well known in modern practice and has an anatomical basis. A branch of the vagus nerve, which supplies the air passages within the chest and lungs and is involved in the cough reflex, also innervates the external ear canal and may become irritated here by disease.

> "Such has been the quackery relative to the medical administration of aerial fluids, that it has disgusted most of the medical profession, and caused agents that are probably very useful under proper modification to be abandoned. In chronic otits where placing drops in the ear is very painful, carbonic acid gas may be applied to the auditory passage with considerable relief of pain."

He indicated that carbonic acid gas had been recommended in many diseased states because of its antiseptic quality and that soda, seltzer and other similar waters were deemed beneficial.(32)

Late in his career Wright reported on another patient whom he had attended in October, 1847. He was unable to do anything for the patient's deafness but did suggest the use of ether to ameliorate a distressing recurring cough. The patient had a much better than normal winter because of the ether. Wright continued to advocate instillation of vapors and gases into the ear in painful otic conditions until the end of his career.(33)

About 1823 a limited enthusiasm developed for cautious inhalation of dilute mixtures of chlorine gas in consumption. The basis for this was a perceived improvement in phthisical patients working in parts of the cloth industry where there were high concentrations of chlorine in the air.(34) About 1828 Charles Scudamore substituted iodine for chlorine and claimed some success in treating chest complaints.(35,36)

James Murray, in 1829, had became concerned with the effects of heat and the humidity of inhaled gases on pulmonary disease. He had concluded that pulmonary complaints were unlikely to be influenced by oral medications. Rather, the therapeutic agents had to be applied directly to the affected organ. The principal reason that Dr. Beddoes and others had failed with this approach was that they used dry gases. The respiratory system did not work properly in the absence of humidity and some respiratory disease was due to injury of the lung by dry gases. In hospitals the facilities for pneumatic inhalations should be segregated and the temperature and humidity carefully controlled. Iodine had many known beneficial effects. It could be volatilized in a stream of warm moist air and given by inhalation in certain types of pulmonary disease. He also suggested that inhalation of vapors of digitalis, poppy, hyoscyamus, belladonna, etc., be given careful trials.(37) He described a group of experiments which demonstrated (mostly correctly) the fate of substances injected into the lungs.(38) Others had proposed that breathing water vapor was beneficial in various diseases. G.D. Cameron described a simple apparatus for breathing water vapor with little effort. This was useful in throat and chest ailments and medications could be dissolved in the water.(39)

A particular enthusiasm for therapeutic breathing of sea air developed during the first two decades of the 19th century. Laënnec was a strong advocate of this type of therapy for consumption. He advocated hospital rooms festooned with kelp and other seaweed to simulate a marine atmosphere.(40,36) J. Curtis presented two cases of asthma benefited by nitrous oxide inhalation in 1829. Marked improvement was noted in both cases and the endpoint for stopping inhalation was the appearance in the patients of giddiness and a state of languor. On the basis of these two cases he concluded that nitrous oxide was likely to be of benefit in chest complaints where the blood does not undergo its customary change in passing through the lungs.(41)

Interest in the therapeutic value of natural mineral waters continued in the 19th century. John Bell, in 1831, discussed the medicinal uses of various types of baths including cold, warm, hot, sea water, vapor, spout baths etc. He then dealt with mineral waters at length, cataloging the major springs in the United States and Europe. For example, Warm Springs, Virginia was thermal hydrosulfurous; Harrowgate in England was cold hydrosulfurous; Vichi in France was acidulous; Carlsbad in Germany was thermal chalybeate; Bath in England was thermal saline etc. Presumably, a spa with gas and salt content appropriate to the ailment being treated could be selected.(42)

Another major treatise on pneumatic medicine, by T.W. Vincent was published in 1831. The author recognized the increasing application of science in industry, transportation, etc., and decried what he perceived as its minimal utilization in medicine. He traced the development of pneumatic medicine from the early suggestions of Priestley down to his own time. He indicated that generally medical men had tended to ignore or oppose them. Vincent explained how diseases develop as a result of chemical imbalances. Several ideas based on Brunonian concepts such as excitement and irritability are still evident in Vincent's writings. When worn out carbon escaped from the body, the remaining hydrogen could combine with atmospheric nitrogen to form ammonia or with oxygen to form water. The latter reaction was proposed as a cause of dropsy. His ideas on therapeutic applications of gases, including oxygen, carbonic acid gas, hydrogen and others given either by inhalation or by mouth as compounds containing the gases, resembled the concepts of previous writers. He advocated the use of ether, either inhaled or applied directly with a feather, to cool and soothe burned or inflamed surfaces. For disinfecting inert objects he recommended nitric oxide, chlorine gas, or oxygenated muriatic acid gas but cautioned against inhaling these gases. Vincent recognized that one advantage of gaseous forms of therapy was that, once the administration of the gas ceased, its action also stopped. He proposed that gases may be effective when given externally and that some medicines may act by liberating gases which become mixed with the blood.(43)

In 1831 John Elliotson was also advocating pneumatic medicine and believed that doctors were remiss in neglecting this form of therapy.(44,36)

In the early part of the 19th century, during the enthusiasm for medical practice according to the Brunonian system of medicine, treatment of cholera by nitrous oxide inhalation became popular. The appearance of the patient in the final stages of cholera suggested presence of severe "asthenic" disease and called for the administration of stimulants to exhaust excessive accumulation of excitability. What better stimulant was there than diffusable nitrous oxide as advocated by Sir Humphry Davy? In addition, nitrous oxide contained oxygen and was believed to serve as an anti-asphyxiant. A number of authors concurred in the opinion that nitrous oxide should be tried in cholera, but evidently the only complete trial was performed in Orleans, France where some slight benefit was noted in 19 of 34 patients.(45) John Hancock advocated treatment of cholera and other pestilential diseases with nitrous oxide about 1831. He distinguished between contagious disease, contracted by direct contact with animal poisons, and pestilential disease, contracted by breathing bad air and reasoned:

> "poisons acting on or through the organs of respiration, might with most effect, be combated by antidotes applied through the same medium and thus meet the enemy upon his own inroads"

He argued that since nitrous oxide had been advocated for purifying air within a room, it might similarly be useful against pestilential air.*

Other medicinal uses of nitrous oxide included opium or narcotic poisoning and drowning and suffocation.

Pestilential air could be identified by the rapid spoilage of meat and the accelerated souring of milk kept in the suspect atmosphere. Nitrous oxide should be administered on the first exposure to pestilential gas. Butchers were believed to be immune to pestilence, and to have survived the 1665 plague in large numbers, because of the high concentration of nitrous oxide in their shops. Since fear, grief, despondency and similar emotions were an important part of disease, some of the benefit of nitrous oxide was psychological.(46)

Dr. J. Hudson also suggested the use of nitrous oxide as a stimulant in cholera, although he had not personally tried this form of therapy.(47) Robert Strange had observed that in advanced cholera the body was cold, pale and blue. Oxygen was known to produce a flush throughout the body and promote heat. He therefore advocated inhalation of an atmosphere of high oxygen concentration in cholera but emphasized that other means of treatment should be continued concurrently.(48) Back and Morgan reported an attempted cure of hydrophobia with nitrous oxide. The inhalations appeared to intensify the spasms and the patient died.(49)

Pneumatic cures for consumption were discussed by Dr. Francis Ramadge. He attached little importance to materials mechanically received into the lungs in the form of a vapor and specifically mentioned tar, chlorine, iodine, hemlock, and turpentine. But he advised that if pneumatic means were to be applied in

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* Hancock was probably thinking about Paterson's 1798 suggestion, described previously, for the use of 'nitrous vapor' to fumigate a room. However this would likely have been some higher oxide of nitrogen rather than nitrous oxide.

consumptive patients, the inhalers should be designed so that they offered some slight impediment to exhalation. He believed that the slight expiratory effort would tend to bring the walls,of tuberculous cavities in the lung together.(50)

Dr. J.C. Warren Jr. indicated that Dr. John C. Warren Sr. had used sulfuric ether in Boston to relieve the distress attending the last stage of pulmonary consumption.(51) Professor J.A. Albers of Bonn advocated dilute chlorine and muriatic acid gas (hydrogen chloride) in certain forms of lung disease. Patients were kept enclosed in chambers containing the gases for prolonged periods. This therapy did not seem to be useful in consumption. A Professor William Stokes of Dublin seemed to have had a similar idea. These activities of Professor Albers caused a transient rebirth of interest in pneumatic medicine about 1830.(52)

Opinions and ideas of many physicians who had employed pneumatic medicine were collected and discussed by Edward Jenner Coxe in 1841. He explained how some of the beneficial effects of inhalation therapy were mechanical, i.e., related to thoraco-pulmonary exercise. Coxe emphasized the importance of moisture in inhaled air in disease. Some physicians had advocated steam inhalation.(53) Another recommendation was the inhalation of the vapor of boiling tar in consumption.(54) He reported a severe case of "Whooping cough" cured by nitrous oxide inhalation.(55) The previous writings of Beddoes and Pearson were recognized.

A practitioner much admired by Coxe was Dr. F.H. Ramadge of London who, as previously mentioned, had published a volume entitled "Consumption Curable" in 1834. Coxe wrote:

> "The main object of the plan proposed by the Doctor is the producing an artificial enlargement of those portions of the lungs which are pervious to the air, which is effected by causing consumptives to breathe through an inhaler or long tubes. As a necessary consequence, the doctor says, 'of this enlargement of the pervious air vessels, the surfaces of the ulcers, are brought into apposition, and a cure effected......; and in reference to expiration, by allowing this air to escape from the lungs through a very small opening of the lips, as long a time may be occupied in emptying the lungs as by the employment of a mouth piece, however small it may be.'"(56)

Coxe enunciated some pretty modern concepts in respiratory therapy when writing that: "Proper inhalers ought to be arranged, as to offer some slight impediment to free expiration...."(57)

A technique for delivering medications by inhalation in the 1830's was steam diffusion, where the desired medication was placed in the effluent stream of some type of kettle arrangement.(58,36) Stanley related a near fatality with prolonged unconsciousness and recurrent spasms following breathing of impure nitrous oxide. During preparation of the gas the retort probably got too hot and reddish fumes were noted which contaminated the gas. Other explanations for this episode were also possible.(59)

In 1842, Julius Jeffrys became concerned with treating the lungs or the skin with gases of optimum temperature and humidity. He described a humidifier which he believed would deliver properly conditioned gases.(60) Jeffrys' humidifier was the prototype for John Snow's ether inhaler, which appeared about five years later.(61)

Alfred Smee, in 1843, advocated inhalation of ammonia gas in a variety of medical complaints. He attributed the existing knowledge concerning effects of gases on animal economy to Humphry Davy and decried their infrequent use in medical practice. Dilute ammonia gas was useful when inhaled and may have either a local or systemic action, depending on the extent of its application. Ammonia stimulated secretion from all mucous membranes and did not stimulate the epiglottis. It could be inhaled into the lung with good sensations, 3-4 breaths three times a day, and it was a good expectorant. Smee described several types of inhalers of increasing complexity. Specific indications for ammonia inhalation were dry throat, hoarseness, tonsillitis, asthma (particularly cold air asthma) and wherever stimulants were appropriate. It was also advised in poisoning with cyanide or bromine. Individuals working with bromine were urged to keep an open container of ammonia nearby*. The gas was not to be used in infections or fevers.(62)

John Snow (1808-1858), the practitioner who established anesthesiology as a scientific discipline, was an advocate of pneumatic medicine. He explained that there were several reasons why inhalation of medicinal materials might be the preferred route of administration in many circumstances. Larger doses of many substances could be given and more rapid onset of action was anticipated following inhalation as opposed to oral administration. Some drugs smelled better than they tasted and digestion was usually unimpaired following inhalation. Some drugs had local action and this might be of particular importance in the respiratory system. Snow devised an apparatus for administration of medicines by inhalation. Substances could be inhaled either dry or wet. Examples of materials which could be inhaled dry included opium, morphia, extract of strammonium, and gum resins. Substances which were inhaled with the vapor of water included iodine, oil of turpentine, camphor, benzoic acid and creosote. Using a smaller inhaler, some medicines could be inhaled at ordinary temperatures such as hydrocyanic acid(?), conia (hemlock), and ammonia. Snow described inhalation of chlorine and iodine for phthisis pulmonalis.(63)

James Young Simpson reviewed some forms of pneumatic treatment in 1858, eleven years after he introduced chloroform into clinical practice. He advocated application of carbon dioxide gas topically in various conditions and indicated that this mode of therapy had been practiced for a long time. Carbonic acid had been

* Charles T. Jackson, a claimant for the discovery of anesthesia, administered ether vapor to himself before 1846 to treat accidental poisoning with chlorine in the laboratory. This inhalation allegedly revealed the narcotic properties of ether to him.

recommended as a local anesthetic in some forms of uterine disease by Dewees (1835), Mojon (1834) and by Paré and Hippocrates. The gas had been frequently injected into the lower bowel in diarrhea and dysentery by Hey and Percival in 1772 and others. Simpson mentioned Ewart, Beddoes and other pneumaticisits. He speculated that the value of old yeast poultices derived from the carbon dioxide gas liberated. He further suggested that the benefit from effervescing draughts taken internally could have been due to a sedative effect attributed to the local anesthetic properties of carbon dioxide. David McBride had similar thoughts. He continued, discussing a variety of other possible applications of pneumatic medicine. Thus, one of the great pioneers of clinical anesthesia had a genuine interest in the potential of pneumatic remedies in the last half of the 19th century.(64)

Pneumatic medicine is important in our own day. Oxygen, carbon dioxide, nitrous oxide, helium and other gases are part of the modern medical armamentarium. Drugs are inhaled to prevent or abort asthmatic attacks, or taken into the lungs to perform the functions of naturally-occurring materials that are deficient or missing. Like our predecessors, we sometimes enthusiastically adopt procedures which ultimately are shown to be of no value and are abandoned. And modern inhalation anesthesia is actually pneumatic medicine. In subsequent chapters we will see how anesthesia evolved from these attempts to find medical uses for gases.

Plate VII — Fanny Burney (1752-1840), noted diarist and novelist, left a bone-chilling description of her mastectomy performed without anesthesia.

Chapter IX

Medicine In The Eighteenth Century

The Milieu From Which Anesthesia Arose

Most of the knowledge and social attitudes which ultimately produced the possibility and the desire to practice pain relief during surgery matured during the years between about 1675 to 1825. For convenience, this era has been designated as the "long 18th century."(1) It is therefore of interest to examine the status of medicine during this period. There are several good books on this subject (see for example King, L.S., 1958, Porter, R., 1987, and Porter, D. & Porter, R., 1989) and so the present chapter will be a selective survey covering those aspects of the subject deemed particularly relevant to the emergence of anesthesia about the middle of the 19th century. The locality examined will be primarily England and to a lesser extent the English speaking portions of North America because this is where the idea of anesthesia appears to have germinated. Medicine in other parts of the world was considerably different.(2)

18th Century Medical Practitioners

As in our own day, many types of individuals with varying qualifications, philosophical outlooks and modes of medical practice undertook to treat disease in the period under consideration. These rival and frequently antagonistic practitioners of the medical arts may be classified in several different ways. In England the elite of these healers were physicians. They possessed an M.D. degree awarded after a protracted period of university education.

In the reign of Henry VIII (1507-1547) a College of Physicians was chartered whose duties and privileges included examination of all candidates who wished to practice in London, and also to regulate dispensing of drugs. (Outside of London any Oxford or Cambridge graduate could practice without examination.)(3) There were two classes of members in the College of Physicians: fellows who were graduates of Oxford or Cambridge, and licentiates: graduates of all other schools including Scottish and continental. In 1783 there were only 40 fellows and 73 licentiates.(4)

The next rung down on the medical ladder was occupied by apothecaries or surgeon-apothecaries. (see below). The hierarchy of physician over surgeon over apothecary was a feature of the 18th century.(5)

The origin of apothecary practice was the grocery business. Apothecaries were originally members of the grocers' guild selling food and various substances used around the house, including medicinal substances. Their wares eventually became confined to these latter types of products. One component of their business was selling prescriptions written by physicians and brought to them by patients. They were initially discouraged from any attempt at medical diagnosis and therapy and by law apothecaries were prohibited from charging for medical advice. But as time advanced they began to attempt to evaluate the symptoms of patients and to undertake cures on their own. Much of their information was based on their perception of how the physicians with whom they interacted professionally prescribed for the various types of complaints with which they were confronted. Apothecaries practicing in this manner were subject to prosecution on complaint by the College of Physicians, and also to civil liability since an unqualified individual attempting treatment could be indicted in the event of death of the patient. Many times in questionable situations, apothecaries would call a physician in consultation and those physicians who cooperated and handled the situation in a manner compatible with economic and ego-supporting gain for the apothecary were more likely to be called than others.(3) But since the apothecary was not permitted to charge for his advice, he was forced to earn his profit on the medications that he prescribed and dispensed. This arrangement, as might be anticipated, was often abused. The apothecary, as did his physician colleague, often prescribed an excessive number of prescriptions of dazzling complexity, no matter what the nature of the presenting illness. These were then sold at high prices by the apothecary. Quantities of medicines dispensed were enormous. People took large numbers of medicines not only for illness but prophylactically to maintain health in various situations.(6)

The backlash against these prescribing practices was responsible for certain alternative modes of medical practice, such as homeopathy and John Wesley's simple home remedies.(7) Thomas Beddoes was highly critical of "apothecaries and their slops."(8) But on the other hand apothecaries, initially acting outside the letter of the law, provided a valuable community service by delivering medical care to large segments of the population who could not be treated by the physician. Physicians were in limited supply and were frequently unavailable in many geographical localities and to large segments of the population who could not afford their high fees. Irregular practitioners of medicine flourished because the regular practitioners could not satisfy community needs. Contemporary accounts confirm that by the late 18th century, apothecaries were attending most illnesses in the poor and lower middle classes of society.(9) One particularly provocative move on the part of physicians was to establish a dispensary for the poor about 1686 which eventually filled about 20,000 prescriptions per year much to the resentment of the apothecaries. Relations between physicians and apothecaries became particularly strained in 1703-1704 over a case involving an apothecary who was convicted in a lower court for the equivalent of practicing without a license. The judgment was reversed by the House of Lords. This body recognized that there was clearly evil on the part of both physicians and apothecaries and chose what they perceived as the lesser evil in deciding that public policy dictated that, no matter how bad an apothecary's practice might be, on occasion it was preferable to the rigid supercilious monopoly of a few physicians. From this time on relationships between the two groups gradually improved. Apothecaries are sometimes regarded as forerunners of modern General Practitioners.(3) Most provincial apothecaries in 1730 were essentially shopkeepers who at times practiced medicine. By 1800, however, provincial apothecaries had largely abandoned the drug trade and were in full time clinical medical practice. By 1815 (passage of the Apothecaries' Act) merging of scope of practice performed by physician, surgeon and apothecary had proceeded a long way in the provinces, in contradistinction to London, because the logistics of rural practice discouraged division of labor and specialization to the extent attainable in metropolitan surroundings. Most apothecaries also practiced surgery.

From the time of Edward IV (1471-1483) the Guild of Barbers and the Guild of Surgeons were conjoined. This arrangement continued until 1745 when surgeons attained independent status.(3) After the establishment of the College of Surgeons in 1800 many apothecaries also became licentiates of this college and hence really surgeon-apothecaries.(9) After 1730 the words "surgeon" and "apothecary" were used interchangeably in the provinces and the title "surgeon, apothecary and man midwife" was common.(10) There was little connection between the title assumed by a practitioner and whether he practiced as a surgeon, physician, apothecary, surgeon-apothecary, male midwife etc. A medical practitioner was likely to practice in any mode which was economically advantageous. and socially necessary.(6)

An important factor facilitating this transformation of apothecaries from vendors of medicines to medical practitioners was the availability of several types of opportunities for professional education and advancement. These included service as a military surgeon or attendance at one of the proprietary or university medical schools or at a London teaching hospital. Scottish medical schools were relatively inexpensive and usually accessible to people of limited means.(10) Hospital physicians frequently took apprentices. In the mid 1700's many hospitals were being founded outside of London and opportunities for hospital apprenticeship and training increased throughout the land. In the mid 18th century hospital apprenticeship was postgraduate training (the candidate had to have completed the basic apprenticeship with an individual practitioner) and the student still paid tuition for the experience.(11) As apothecaries became less involved in stocking, compounding, and dispensing medicines, druggists or chemists began to appear and assume these functions. There was also considerable dispensing of drugs by physicians, which evoked numerous complaints from the sellers of remedies. Also, in the 18th century, the many available patent medicines were sold by booksellers.(19) There was great animosity and mutual recriminations between chemists who had taken over much of the dispensing, and apothecaries who were increasingly turning their attention to the practice of medicine. Apothecaries and physicians were accused by the druggists of operating in collusion. Apothecaries perceived pressure from both druggists and physicians, while physicians were apprehensive about the expanding role of apothecaries. Each class of medical entrepreneur felt threatened by the others.

Toward the end of the 18th century organized action by educated and/or dissatisfied apothecaries gathered momentum, because of the encroachment by chemists and druggists and the inability to regulate practice and restrain ignorant and unqualified individuals.(9,12) The role of the apothecary in the practice of medicine was finally defined by the Apothecaries' Act passed by Parliament in 1815. Among other provisions, this legislation permitted apothecaries to regulate practice and confirmed their ability to charge professional fees.(9)

At the beginning of the 17th century there were only 20 physicians in London and 114 apothecaries. At the beginning of the eighteenth there were 80 physicians on the roster of the Royal College of Physicians practicing in London and an estimated 1000 apothecaries. A contemporary estimate declared that there were 10 apothecaries for every physician.(4) Eighteenth century practitioners were also sometimes classified or contrasted as either "rationalists" or "empiricists," depending on the basis and the sources of means of diagnosis and therapeutic measures that they employed. Rationalists generally were grounded in the writings and philosophy of recognized medical authorities, including those of antiquity. Their beliefs and mode of medical practice were solidly based on the theories, hypotheses, and concepts of these masters, which in most instances were highly speculative with minimal foundation in observation and experimentation. Physicians and other individuals whose preparation for professional practice had emphasized formal study and attendance at classes in universities could most often be regarded as rationalists. Empiricists, on the other hand, based their medical practice primarily on experience. If measures were perceived to be effective, they were incorporated into the armamentarium of the empiricist, who usually knew little of formal medical theory and beliefs. Individuals who came to medicine chiefly through apprenticeship and other less structured means of medical education tended to practice empirically. Empirics were taken up with the "how" rather than the "why." Rationalists, or physicians, were more concerned with the "why" rather than the "how." In the 18th century the term "empiric" had various connotations. On the one hand it was considered synonymous with "quack" but on the other hand it was opposed to "rationalist," i.e. experience as opposed to reason.

Not surprisingly, rationalists and empiricists frequently held one another in greatest contempt. Joseph Priestley, in suggesting possible medicinal uses for the various gases that he discovered, urged "ingenious physicians" to become involved in this field lest:

> ". . . . it be seized by rash empirics; who by an indiscriminate and injudicious application, often ruin the credit of things and processes which might otherwise might make airs a useful addition to the materia and ars medica."(13)

Thomas Beddoes, although politically radical, was hostile to popular empirical medicine and also violently anti-quack.(8) Robert Southey apparently shared the opinion of his friend, Beddoes, on empirics and classified them with quacks. He wrote:

> "Man is a dupeable animal. Quacks in medicine, quacks in religion, quacks in politics know this, and act upon that knowledge. The credulity of man is unfortunately too strong to resist the impudent assertions of the quack. Credulity has been justly defined as belief without reason. It diffuses itself through the minds of all classes, by which the rank and dignity of science are degraded, and its valuable labors confounded with the vain pretentions of empericism."(14)

John Wesley (1703-1791) may be considered as a typical empiric. He wrote a self-help book on remedies for 275 different complaints. Such books became quite popular in the 18th century and it will be recalled that Thomas Beddoes wrote disparagingly about the extensive practice of self-medication and self-doctoring. These volumes on home diagnosis and remedies were frequently directed toward the religious leader of the community since he might be one of the few literate individuals available for medical advice. Wesley explained how diseases were a consequence of sin and mankind's fall. In more Arcadian days, common people cured themselves and their neighbors using simple remedies discovered by experience. But in more recent times medical practice had escaped from the hands of most people. Physicians had replaced observation and empiricism with abstract reasoning and theory unintelligible to common people and the simple remedies of former times had been replaced by concoctions of enormous complexity.(7)

Wesley's book was designed so that in most cases individuals could prescribe for their families and themselves. All existing books appeared to be too complicated and consisted of extensive lists of ingredients when one component would do. He expressed his opinion on conventional practitioners and their prescribing habits:

> "Experience shows, that one thing will cure most disorders, at least as well as twenty put together, then why do you add the other nineteen? Only to swell the apothecary's bill: nay, possibly on purpose to prolong the distemper that the doctor and he may divide the spoil."(7)

Wesley's book went through at least 32 editions.

In spite of the morals and manners of the times, John Wesley granted to the age a new sensitiveness to human suffering. Wesley and other empirics are sometimes described as being in a sense "anti-intellectual." Medical practice by other laymen was common. The mistress of a manor, or a local "wise woman," might accumulate a large supply of medicines and, sometimes with the aid of one of the numerous self-help manuals, assume responsibility for medical care of many in the locality.(2) Also included in the mixture of 18th century medical practitioners were quacks and mountebanks. These individuals were characterized by having pretenses to medical knowledge which they did not possess. Matthews described several variations of 18th century untutored medical practitioners. The quack (the name was shortened from the term "quacksalver") was one who puffed up his salves or ointments. A mountebank was an itinerant quack who, from an elevated platform, appealed to his audience by means of stories, tricks, juggling and the like, in which he was often assisted by a professional clown or fool. The term "charlatan" was derived from the Italian "ciarlitari," to patter.(15)

The 18th century was a golden age of quackery and many such quacks and mountebanks attained legendary prominence. Among these was James Graham, proprietor of the renowned "Grand Temple of Health."(16) An important feature of this establishment was the breathtakingly flamboyant "Grand Celestial Bed." Couples who desired to conceive a child under optimum conditions were advised to occupy this lavishly elaborate item of furniture in its ornate chamber for a night. Their solution to their fertility problems was guaranteed.(17)

It is noted elsewhere in this volume that James Graham opposed Joseph Priestley's chemistry, as well as his theology, and presented his ideas on the founding of a new church.(18) James Graham was evidently one of the first individuals to develop a habituation to recreational ether sniffing. Robert Southey described his behavior:

> "Graham was half-mad and his madness at last got the better of his knavery. He would madden himself with ether, run out into the streets, and strip himself to clothe the first beggar he met."(19)

Other of the numerous 18th century English quacks included Joshua Ward, well known vendor of drops and pills,(20) and Joanna Stephens whose lixivium for dissolving bladder stones will be described below. Dr. Elisha Perkins, a qualified physician of Connecticut, noticed that some muscles appeared to contract in response to being touched with metallic surgical instruments. He interpreted this as generation of galvanic electricity and concluded that diseases could be "drawn" out of the body by rubbing affected parts with metallic "tractors." Perkins' "tractors," short metallic rods flattened on one side, were patented in 1796 and attained considerable transient popularity both in the U.S. and England.(21) It will be recalled that these tractors were an inspiration for Thomas G. Fessenden's satirical poem of 1803, "Terrible Tractoration," which contained numerous references to Beddoes, Davy, Priestley and nitrous oxide, and which will be discussed and quoted subsequently in the present volume.

Eighteenth century practitioners constituted a whole spectrum, with outright quacks at one end and orthodox medically qualified and graduate physicians at the other. It is frequently difficult to distinguish one from the other.(6) The stigmatization of a particular practitioner as a quack could be quite arbitrary. Some apparently competent and effective 18th and early 19th century medical practitioners appear to have come down to our own times bearing this label. One such example is the otologist William Wright, whose early use of ether inhalation in his otologic practice is noted elsewhere in this volume. In one book on the history of otolaryngology, Wright is designated as a quack, probably on the basis of his lack of formal medical qualification.(22) Also, his stigmatization as a quack could have been due to his specialization. (In the early years of the 19th century specialists or individuals who designated themselves as such, were often regarded as quacks). But in yet another such history of otolaryngology he was described as a competent practitioner whose writings displayed an extensive knowledge of the otologic literature of the day.(23) And yet, many 18th century quacks probably didn't do much worse medically than their contemporaries practicing more conventional forms of medicine. Some of the therapeutic measures prescribed by the best educated physicians, which will be described below, elicit greatest pity and compassion for the poor suffering patients upon whom this enlightened therapy was inflicted. In their professional association, Thomas Beddoes and Humphry Davy appear to have accommodated very well to their markedly different career pathways and their outlook on disease and healing.

Medical Education in the 18th Century

In the early part of the 17th century there was little scientific experimentation in universities. Natural philosophy was taught by examining the works of previous authorities and academic disputation was an important activity. Experimental science originated outside the universities.(24) The elite of the medical profession were trained by the medical faculty of universities. Medical education at the universities in the 18th century was tediously long. Fourteen years of university attendance were required: four for the bachelor degree, three for master, three more for bachelor of medicine and four more for the M.D. degree.

The quality and reputation of the various 18th century medical schools changed as the century progressed. In the early part of the century, Europe's premier medical school became Leyden University in Holland under leadership of the period's most illustrious teacher, medical thinker, and medical scientist, Herman Boerhaave. Boerhaave's influence and career will be noted shortly. Later in the 18th century, the reputation for superiority in European medical education gravitated to the Scottish medical schools. Edinburgh, with its remarkable faculty became the premier institution, while Glasgow, Aberdeen, and St. Andrews also established outstanding reputations. Many of the physicians involved in the evolution of anesthesia in the 18th century were educated here as were many of the most prominent physicians of the American colonies and later, the young republic of the United States. It is curious that the great English universities, Oxford and Cambridge, produced graduates who appear to have been politically important in regulating the practice of medicine but seemed to lack the institutional reputation in medicine possessed by their Scottish counterparts.

Because there was no university in London, in the last decades of the 18th century many private and entrepreneurial arrangements to provide medical lectures had developed in the city.(25) Courses were offered in anatomy, materia medica, surgery, medicine, chemistry and midwifery. The various corporations of physicians, surgeons and apothecaries had little interest in medical education.(26) Individual, authoritative medical practitioners unaffiliated with any group or institution frequently provided lectures and courses independently. Often, staff doctors of hospitals lectured in their hospitals either solo or in conjunction with others of that institution. Eventually, these groups became organized and recognized as the faculty of a school of medicine associated with the parent hospital. Another arrangement was represented by groups of individuals who banded together to provide private extramural medical courses covering one or several of all aspects of medical practice. The best known of these was probably the private medical school founded in 1765 by John Hunter in Great Windmill Street. Here, instruction was provided with attention to detail and emphasis on new material far surpassing that of competing establishments.(27) William Hunter's failure to write and publish very much material was regarded as an entrepreneurial attitude toward safekeeping of the knowledge that he had to dispense. Later, for a brief time in the early 19th century, individuals such as Benjamin Brodie, Peter Mark Roget, and

William Thomas Brande were on the staff here to expand the scope of the institution from anatomy to all core medical subjects except midwifery.(26)*

Thus, between 1780 and 1820 the educational opportunities in London offered what many universities did, without the expense and formality of degree regulations. The 18th century entrepreneurial system of medical education gave the student considerable amounts of flexibility to tailor his course of instruction to suit his own needs.(28) This appealed to students preparing for a variety of careers, including general practice, surgery, military medicine etc. Teaching of surgery and anatomy in 18th century London is also discussed in fairly good detail by Packard.(29) Competent Scottish graduates as well as those of the private medical schools were still barred from membership in the College of Physicians. For this reason many graduates of Scottish medical schools could not obtain desirable posts in London hospitals towards the end of the 18th century.(10)

At this time there appeared rival medical societies and medical journals which were designed to compete with the monopoly of the College of Physicians.(25) As requirements for licensure to practice in London became more liberal, increasing numbers of London practitioners declined affiliation with the Royal College of Physicians. That body prohibited London physicians from practicing surgery and pharmacy and many London practitioners who identified themselves as surgeon-apothecaries wished to retain these aspects of practice.(10)

Founding of the Scottish medical schools permitted upward mobility of many people desiring to practice medicine. Before this avenue became available many students either studied at Oxford or Cambridge or attended one of the foreign universities such as Leyden, Vienna, Padua, etc. During the reigns of the first few monarchs following the glorious revolution of 1688 in England, only those professing orthodox political and religious views could enroll in Oxford or Cambridge and the Universities became very set in their ways and inimical to inquiry and learning.(3)

Scottish medical schools—Edinburgh, Glasgow, Aberdeen, St. Andrews—were excellent. Universities of Aberdeen and St. Andrews often granted degrees without any attendance requirements and many physician-apothecaries obtained degrees on the basis of experience and testimonials from physicians known to the involved faculty. Clergymen often purchased diplomas from these institutions to legitimize their medical practice among their flocks.(10) Degrees from these institutions could

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*Brodie, Roget and Brande are all mentioned elsewhere in this volume as having been closely associated in one way or another with the early preclinical development of anesthesia. Brodie conducted experiments with guinea pigs and ether inhalation, Roget had been an associate of Thomas Beddoes at the Pneumatical Institution in Bristol, and Brande conducted experiments on the inhalation of nitrous oxide and ether vapor. Even though these early inhalation experiments were conducted at different times and in different localities, they illustrate the sphere of interest of the individuals involved. One can speculate that the association of these three men at Great Windmill Street in the early 19th century represented a lost opportunity for discovery of anesthesia years before it actually occurred.

represent either excellent education or, if granted in absentia, good letters of reference and payment of fees.

After about 1750 in many circumstances it became necessary to acquire a university degree by one means or other to gain recognition as a medical practitioner. The titles of "Physician" and "Doctor of Medicine" became synonymous much to the chagrin of Oxford and Cambridge graduates.(10) Many medical men took all different types of training in any order and then obtained their degrees in absentia from Scottish or foreign schools. However, in order to practice in London they were still subject to the jurisdiction of the College of Physicians. Some individuals were granted the status of licentiate in the College and rivalry between licentiates and fellows was active.

In the early 18th century chemistry was of great importance in Scottish medical schools and of minor importance in England. At Scottish schools the teaching of chemistry was in the tradition of Boerhaave and obtaining an MD degree was apparently the first step in a career in chemistry. The first Scottish Chair of Chemistry was established at Edinburgh in 1713 and was subsequently occupied by Joseph Black.(30) The chemical teaching of Black and Cullen influenced many prominent 18th century practitioners. Two disciples of Cullen, George Fordyce and William Saunders, came to London about the middle of the 18th century to teach. They began their instructional careers by providing lectures in chemistry, which proved popular both for medical and nonmedical personnel. Pharmaceutical chemistry attracted considerable interest in the last half of the 18th century because of its relevance in the preparation of tinctures and solutions, and in the search for lixiviums (solutions to dissolve urinary tract stones). Generally, in the last part of the 18th century chemistry was more directly applicable by the druggist or pharmacist than by physician or apothecary. Nevertheless, at this time there was a growing sentiment that medical practitioners should be broadly educated in science and medical students continued to support chemical lectures. John Ayrton Paris, whose biography of Humphry Davy is extensively quoted in this volume, was mentioned as a prominent chemical educator of this era.(31)

The pathway to the practice of medicine as an apothecary in the 18th century was through apprenticeship. The young apprentice was bound for a period of service and training, usually seven years, to a master apothecary. For this a fee was paid to the master and certain obligations were assumed by both master and apprentice. (An example of the formalities and arrangements involved in apprenticeship agreements is presented in detail while describing the contract between Humphry and Grace Davy and Mr. John Bingham Borlase, Apothecary of Penzance. Also, some of the prospects for the newly qualified apothecary after completion of his training are discussed.)

PHILANTHROPY

English secular philanthropy began to assume increasing importance in the Elizabethan era. At this time there developed a general consensus that those unable to take care of themselves should be provided for, that identifiable sources of poverty should be eliminated and that the children of the poor should be educated. Provision for care of indigents, including medical treatment and services of practitioners, was a recognized obligation of the church parish in which the recipient lived. This enlightened view has been attributed to the almost intuitive desire of the Tudor government to maintain proper public civil order. Although the state became the ultimate guarantor of necessary social benefits, most of the charitable activities were performed by private citizens and the government offered various incentives to encourage this type of activity, including the capability to establish charitable trusts.

Motives of private English citizens for undertaking charity at this time included increasing sensitivity to human pain and suffering, which was said to be characteristic of the 16th century in England, and an instinct for "tidying up the kingdom and for polishing off the rough spots in society." Another such motivation lay in Protestantism itself. Calvinism taught that the rich man was a trustee for his wealth which he ought to use responsibly. Jordan stated that "the reformation itself repudiated with great violence one doctrine of works only to raise up another in which social pressures rather than the injunction of the priest determined the good works to be bestowed." Also, some individuals apparently believed that charitable giving would help to counter the argument that the Protestants had wantonly despoiled the monasteries; a previous source of benevolence.(32)

Problems which accentuated the need for philanthropy and charitable activities in the 16th century included land enclosure, which drove many away from their customary rural homes with resulting rapid increase in urbanization. Also, dissolution of the monasteries eliminated an important source of philanthropy.(33)

As the 16th century progressed, the system of voluntary alms evolved into one of compulsory charity where justices were empowered to impose taxes, collect them and punish those who did not comply. Thus, by the end of the reign of Elizabeth I (1603), statutes existed to care for children, to provide work for those unable to find it and to care for the lame, elderly, blind, etc.(33) The considerable progress made in attaining these objectives was abruptly interrupted by the English Civil War in the middle of the 17th century.(32)

About the time of the restoration of the monarchy following the civil war (1660) a new surge of interest in philanthropy occurred. Also, the scope of charitable giving widened. In a pamphlet published in 1715, "An Address to Persons of Quality and Estate, Ways and Methods of Doing Good," Robert Nelson enumerated areas in which charity might be disposed. Among other things he cited hospitals for the incurable, the blind, for stone, gout, rheumatism, consumption, dropsy, palsy, asthma, and for foundlings. As worthy objects of charity he listed other deserving types of individuals, such as fallen women, decayed nobility, converts from Popery, etc.(34)

A prominent feature of late 18th century philanthropy was the development of organized charities and philanthropic associations. Charity became less of a person-to-person affair and more of a collective effort. It is felt that this was partly a growth from experience with joint stock companies of the late 17th century. But also in the last part of the 18th century, some urban centers were growing at astronomical rates, e.g. 50% per decade. Traditional methods of giving, applicable in rural settings, such as direct almsgiving and direct help to the poor, would not work in urban settings. This brought on the changes previously mentioned such as the rise of charitable societies.(35)

Charitable schools were important institutions in the 18th century. Most of the memorable philanthropists of the era were of middle class origin and donors came mostly from trade and commerce, rather than from the great families. Motives for philanthropy included the puritan ethics of doing good with riches, rise of modern humanitarianism, and mercantilist interest. The latter was exemplified by such measures as those designed to safeguard national power, such as the concern about declining population and measures to put the poor to work.(36) The belief that education and medical care preferably ought to be left to private philanthropy (as opposed to becoming a state responsibility) seems to have been a consensus among 18th century community leaders. Certain organizations which undertook charitable work, such as the Society for Promoting Christian Knowledge, had as their primary mission the influencing and elevating of public morals and behavior. In some instances virtue and piety, rather than need, were prerequisites for assistance.(36) Other medical activities dating form the late 1790's were societies for provision of care of patients after discharge from the hospital and suffering from chronic and disabling afflictions. An example of the latter was hernia and organizations such as the National Truss Society, The Rupture Society, and the City of London Truss Society became fashionable and popular charities.

In the last part of the 18th century the state must have had some concern with the needs of the impoverished since "poor rates" (taxes) were mentioned in writings of the period.(37) But as the 18th century progressed, donors became more wary in their philanthropy.(38) New motives and criteria for charitable giving, as well as well-defined attitudes towards charity, became evident. The concept of "the deserving poor" was prominent and more penetrating investigation of the objects of charity was conducted.(39) Malthus theorized that charity should be limited to "unmerited calamities."(40) In addition, there were many reservations regarding the value and societal role of charity at this time.

Many thinkers of the age had concluded that a prodigious outlay for charity had produced only trivial benefits.(41) "Deference owed by the poor to the rich" was an ubiquitous theme. Some believed that welfare of the poor was more adequately promoted by gradations of wealth and rank than by equality of condition. The basis for philanthropic endeavors was regarded by many as "noblesse oblige." Other popular activities of this time, regarded by some as the crowning achievements of what was considered as philanthropy, were the antislavery societies and the foreign missions. Several individuals whom we meet elsewhere in this volume were dedicated antislavery activists. Lunarian Thomas Day's poem, "The Dying Negro," was said to have advanced the antislavery movement considerably. Thomas Beddoes once attended a tea party bearing his own sugar as a protest against slavery in the West Indies where the sugar offered by the host had been produced. Josiah Wedgwood designed a seal portraying a kneeling Negro which as a cameo on snuff boxes and bracelets became something of a rage.(42)

A HISTORY OF HOSPITALS

Institutions devoted to medical care associated with temples in ancient Greece, and also Roman military hospitals for care of sick and wounded soldiers, have been noted previously. In the Middle Ages the connotation of the term "hospital," as well as the mission of these institutions was quite different from what we understand today. One important function of a hospital was to act as a guest house to accommodate pilgrims during their travels to holy shrines. Also, hospitals might serve as almshouses to care for those in the community for whom other arrangements could not be made. They might also serve as institutions for isolation of lepers and as hospices for care of the dying. They sometimes performed certain functions of banks in managing investments, trusts and bequests and in lending money. Some were founded as correctional institutions. They also provided care for the sick and poor, but this was not a high priority. In many medieval hospitals, the church played an important role. In some a significant proportion of the staff were religious brothers and sisters.(43,44) The hospitals of medieval and Renaissance Florence were particularly admired in their day both for their style and their efficient operation. Widows and orphans were particular objects of hospital care in Florence.(45) An example of such an institution which can still be viewed today is Florence's Foundling Hospital, begun in 1419 and designed by Brunelleschi, with decorative artwork by Della Robbia. In some circumstances, beds in hospitals set aside for incurable patients were diverted to accommodation of elderly or disabled retainers of the hospital's principal benefactors. After the 15th century, hospitals gradually became more medically oriented, as manifested by increasing emphasis on care of the sick, increasing numbers of medical personnel in attendance, and more attention devoted to medical teaching.(46) In addition, coinciding with growth of cities, facilities became necessary for treatment of the indigent poor and also to isolate patients with diseases perceived to be contagious, such as syphilis and leprosy.(47)

Although the 17th century was not noted as a period of great interest in care of the sick, three hospitals existed in London at this time: St. Bartholemew's and St. Thomas's for general care of the sick and Bethlehem for lunatics. Support for these hospitals was irregular and came from several sources: municipal taxes, donations collected by various churches, and individual gifts and bequests. The water cures offered at Bath were supported jointly by organized charity, the town governors, and individual alms.

New hospitals began to appear in England around 1725. Gray characterized this period as one of religious languor when charitable giving, rather than other forms of religious activity, was used to attain religious merit by individuals.(33) Founding of hospitals in the 18th century was attributed in no small part to the inspiration which was obtained from the example of continental, particularly French, charities.(48) Hospitals derived from three main sources: each Episcopal see maintained one or more; most trade and professional guilds established houses; and generous patrons founded hospitals of all kinds.(48) A more practical reason for becoming interested in care of the sick was the increasing number of urban poor who were suffering without medical care and were often the victims of unqualified practitioners or of quacks. The existing public hospitals and also the public dispensaries run by the College of Physicians and the Society of Apothecaries were unable to manage the load of sick people who presented themselves for care. This was a strong incentive for the founding of many of the great London teaching hospitals in the 18th century. Among these were the Westminster (about 1719), Guy's (1724), St. George's (1733), London (1740), Middlesex (1744) and others.(33) Also, 16 provincial voluntary hospitals had appeared by 1760 and 38 by 1800, all very similar. All were maintained by various charitable activities in their communities.

Support of an infirmary was an opportunity for non-sectarian charity. Also,serving on the board of governors of the local infirmary tended to smooth relationships between the various classes and factions of society, provide them with opportunities to work together for the common good and to know one another. Some 18th century conflicts in England where this consideration might apply included established church vs. dissenter, Whig vs. Tory, landed aristocracy vs. moneyed wealth and trade and others. The infirmary was a more humane and kinder side of society, as opposed to the poor laws and the workhouses.(49)

Additional pragmatic reasons for founding hospitals existed. John Bellers, a Quaker philanthropist estimated that the death of every industrious laborer capable of having children caused a £200 loss to the kingdom. In his essay he apparently specifically included in the "improvement in physic," hospitals, state support of medicine and endowment of research, which were necessary for the well being of all ranks and classes.(50) Another motive was that hospitals were thought of as demonstration laboratories for medical educators and as incubators of medical progress. At this time medicine was emancipating itself from medieval tradition and many practitioners were men of some scientific training who were eager to experiment and add to the sum of scientific knowledge. Hospitals would supply clinical material both for individual study and for teaching purposes. Physicians were at the forefront in founding hospitals.(51) As hospitals opened and undertook their missions in the 18th century, appointments of physicians to hospital staffs became very important in obtaining a high status and income within the medical profession. Doctors were willing to donate their services gratis in order to reap the benefit of the hospital consultancies. Service on a hospital staff became a good way to be visibly charitable and to build a private practice. For physicians hospital appointments were means to an end and many resigned after a few years. Surgeons took hospital appointments more seriously since these appointments influenced the premium which they could obtain for apprentice training. They tended to retain their appointments for much longer periods.(52)

The movement to found hospitals was one of the outstanding features of 18th century philanthropy. Motives for founding these hospitals were not always purely altruistic but sometimes involved politics and egotistical disputes. Becoming a governor of one of the newly founded hospitals was regarded as a particularly meritorious activity in the community. In such a position, a minimum financial subscription was required and carried the perquisites of voting at meetings of the board. In addition a governor could recommend to the hospital a stated number of patients per year for admission. This gave the patron a feeling of benevolence, but where patients were dependents it might have also resulted in some small saving to him.(53) Besides general subscriptions, measures to raise money for hospitals included theatrical performances, concerts and the annual subscription dinner. At this event, attendees would be provided with a lavish meal and then would be solicited for hospital subscriptions. Also, appeals for infirmaries were made by means of sermons, and at picnics, performances, and by personal appeals. Gifts were common from less affluent individuals.(49,54) As an additional source of revenue, most hospitals were accustomed to collect certain fees from poor patients which proved in many cases to be a severe burden and it was in protest against this that the Royal Free Hospital was founded in 1828. As the century progressed there were increasing numbers of physicians who sought to use their knowledge and skills for the benefit of the masses. These physicians, backed and encouraged by philanthropists, founded numerous dispensaries which appeared to be one of the more productive forms of medical care and achieved overwhelming popularity. Dispensary doctors generally also made house calls on their patients. Dispensaries grew rapidly during the 1770's and 1780's. The dispensaries that originated in the dispute between physicians and apothecaries began operating about 1777-1790 (see above).(33) At the beginning of the 19th century, specialists were often regarded as quacks by the generalists in the profession, but as the century progressed specialization attained a respectable status.(49)

The later 18th century also saw the founding of specialized hospitals, such as lying-in hospitals, a cancer hospital, fever and isolation hospitals, and mental hospitals.(33) Also, there appeared a hospital for treatment for venereal disease and a foundling hospital.(54) This diversification of types of hospitals was in part responsible for a period of severe financial problems for general hospitals in the last part of the 18th century.

Thomas Beddoes' Pneumatical Institution at Bristol would have been such a specialized hospital with its emphasis on treating a variety of diseases using gases, as we have seen elsewhere in this book. It will be recalled that the idea for a hospital dedicated to this purpose was formulated by Beddoes and Georgiana, Duchess of Devonshire, during one of her visits to Bristol in 1793. As related elsewhere, financial backing from the Royal Society and the government for this venture was refused. Therefore Beddoes was forced to resort to multiple appeals for donations, but it was 1798 before he was able to admit patients. This delay must have been one example of the financial hard times experienced by hospitals in general mentioned above. The public would have perceived nothing unusual or unique in Beddoes' solicitations. The wealthy must have been bombarded with such requests. As noted elsewhere, eventually many prominent individuals were donors to the Pneumatic Institution. In comparison with other charitable gifts made in the 18th century, it appears that the £1000 given to Beddoes by Wedgwood (the largest single donation in this campaign) would not be considered a particularly large contribution.(55)

As described above, decisive changes in the nature of hospitals gradually occurred after the 15th century. In medieval times the hospital was a refuge for poor, infirm, homeless, orphaned and often also provided accommodations for pilgrims and other travelers. and the term "hospital" was frequently used to describe this multipurpose facility (e.g. "Hotel Dieu" in Paris). The newly founded 18th century hospitals therefore often chose to use very specific terminology in designating their purpose. This is why many of them were designated as "infirmaries." Examples are "The Infirmary for the Sick and Lame and Poor of Durham, Newcastle-upon-Tyne, and Northumberland," "The Radcliffe Infirmary" at Oxford University, "The Leicester Royal Infirmary," etc. The term "general" in the title of many infirmaries indicated that the institution was not restricted to laborers in the home parish. The ticket of admission to the hospital was a letter from a subscriber authorizing hospitalization for the bearer.(49) For admission to an 18th century hospital or infirmary, there were both personal and medical screening tests. Rules on patient conduct were quite explicit. Patients were to be obedient and docile; they were expected to do their share in domestic running of the hospital and they were to submit to religious involvement. Patients who recovered were expected to make a public show of their gratitude.(49) But even in the 18th century the term "hospital" was occasionally used in the medieval sense to designate a place of shelter and refuge. An example of this archaic use is the designation of the Magdalene Hospital as a place for penitent prostitutes in 1758.(56) In the 18th century the hospitals remained a refuge for the sick poor; one had to be both sick and poor for admission.

Founding of hospitals in America followed the same general pattern as in the United Kingdom, but with considerable lag. The first general hospital, the Pennsylvania Hospital, was opened in Philadelphia in 1751. The second was New York Hospital (1791). Many hospitals were equipped with surgical amphitheaters, such as the facility in which Morton conducted his demonstration of ether anesthesia.(57) The author recalls an occasion, in 1950, when an entire class of junior medical students watched from the tiers of an open and unscreened amphitheater while the professor of gynecology removed an ovarian cyst.

SOME PARTICULARLY IMPORTANT DISEASES, NOTED PATIENTS, AND FAMOUS PHYSICIANS

Every disease is important to the individual afflicted with it, but particular emphasis on certain diseases is justified because attempts to explain and manage them provided important insight into eighteenth century medical thought and practice. Among maladies already discussed are scurvy and tuberculosis. It will be recalled that both of these diseases stimulated intense investigation into the possible medicinal and physiological roles of gaseous substances, with important consequences for anesthesia.

Another disease state worthy of attention is stones in the urinary tract, particularly bladder stones. Bladder stones were quite common in bygone days and were a maddening affliction for significant segments of the population. The pathogenesis of this condition lay, no doubt, in inability to treat urinary tract infection effectively. Many famous people had bladder stones and have left accounts of their disease. Being "cut of the stone" was one of the most common operations of the 18th century and a considerable portion of our knowledge of preanesthetic surgery is derived from patient accounts of this ordeal. Attempts to dissolve urinary tract stones evoked a multitude of imaginative treatments. The remedies prescribed by the most orthodox of physicians were no better than those touted by opportunistic quacks. Joseph Black's experiments on "fixed air," discussed previously, and which became one of the cornerstones of modern chemistry, were inspired by a search for means of managing urinary tract stones.

About the middle of the 18th century strongly alkaline solutions were used as medicines in the treatment of bladder stones. Direct injection of lime water and soap solutions into the bladder was advocated.(58) Other alkaline medicines were prescribed, either suspended in water or mixed with soap and honey as pills. It is hard to believe that these strongly alkaline substances succeeded in their perceived action in dissolving stones, and they probably were too caustic and irritating to tissues, causing additional trauma. Surgical lithotomy was performed, but blunders were frequent and mortality was high.

Joanna Stephens was another quack who gained notoriety in connection with treatment of bladder stones. About 1738 she offered her lithontriptic (medicine to dissolve stones) to the public. It and others were tested thoroughly and in the end parliament awarded her £5000 for the discovery which occasioned considerable debate in that body.(59)

Stephen Hales examined certain preparations alleged to be efficacious in dissolving stones and concluded that limewater was as good as any other lithontriptic. These preparations, though rarely effective, were important because they helped to create an atmosphere that encouraged research concerning chemistry of various calculi and drugs designed to dissolve them and hence applications of chemistry to medicine.(59) One renowned French lithotomist assumed the lifestyle of a monk and went on his rounds dressed in long black robes. He acquired the name "Frère Jacques" and appears to be the inspiration for the children's ditty of the same name.(60)

Because of the lack of effective medical treatment and the frighteningly disappointing results of surgical therapy, the best hope appeared to lie with the animal chemists. In 1776 Scheele identified uric acid and investigated the composition of urinary calculi. T. Bergman, his teacher, commented on his work. About 1786 Fourcroy also investigated the composition of calculi. He and his colleagues analyzed a large number of stones of varying composition from many localities and characterized them. As the 19th century proceeded, many fundamental facts concerning stones were discovered. It will be recalled that Thomas Beddoes was greatly concerned with the treatment of bladder stone and proposed pneumatic means to do this. (See the section on the medical writings of Thomas Beddoes.) His book, "Observations on the Nature and Cure of Calculus, Sea Scurvy, Consumption.... etc." (1793), was dedicated to Benjamin Colborne whom he identified as "discoverer of the virtues of vegetable alkali."(31) Beddoes' writings on bladder stone addressed an important and frustrating medical problem of his time (as did those on consumption). His proposed methods of treatment, though ineffective, must have appeared quite logical to many of his colleagues. They offered a ray of hope in otherwise impossible situations and must have materially helped his campaign for funds to operate his Pneumatical Institution.

TUBERCULOSIS

The importance of tuberculosis to the development of anesthesia will be discussed in relation to Thomas Beddoes and his beliefs and writings. The rise of the towns and the industrial revolution gave tuberculosis mastery over western Europe and North America. The virtually unchallenged reign of tuberculosis lasted from the third quarter of the eighteenth century until the second world war.(61)

The highest death rate from tuberculosis is said to have occurred in London in 1800 and in provincial towns a few years later. Until discovery of the identity of the tubercle bacillus and the advent of fairly modern medicine, treatment of tuberculosis remained essentially dietary and fresh air on an empirical basis.(61)

Famous Medical Men of the 18th Century

Herman Boerhaave (1668-1738) of Leyden, Holland, was one of the most influential physicians of the century, particularly the first half. His contribution was said to be a fusion of the classical medical writings with new medical discoveries which had to be assimilated, such as circulation of the blood, microscopy and newer anatomical knowledge, as well as the rudiments of modern chemistry and the concepts of Newtonian physics. He formulated an elaborate system of medicine which involved such things as excess laxness or stiffness of fibers, failure to alter and assimilate food properly etc. Bloodletting was an important part of this system of medicine and was thought to reduce the force of blood and laxness of fibers. Pathogenesis could be inferred from general principles and treatment could be inferred from pathogenesis. The system was consistent and had the appearance of a logical system, but it did not work. As new ideas and discoveries were uncovered, the system was gradually replaced in the 19th century.(62)

Boerhaave revived bedside teaching of medicine in Leyden and attracted students from all over Europe. By 1718 he occupied simultaneously three of the five chairs at Leyden University: Botany, Medicine, and Chemistry. He was a celebrated teacher. In the years of his tenure, 1,119 students were enrolled under the faculty of medicine. Of these, 659 came from English speaking countries. His influence spread throughout Europe and his texts were published in many countries both during his lifetime and posthumously. The medical faculties at Vienna, Göttingen and Edinburgh were organized or reorganized along the form that he instituted at Leyden and the modern medical curriculum owes much to Boerhaave. His lasting influence on medicine lies not so much on his system of medicine nor in his experiments but in his teaching. In his clinical instruction he indoctrinated his pupils with the old Hippocratic method of bedside observation and taught them to act methodically in the examination of their patients.

It is to Boerhaave that we owe the present basic format of oral and published case presentations: history, physical examination, diagnosis, discussion of the disease, and autopsy findings.(63) He is also remembered for his contributions in chemistry, as described in a previous section.(64) Boerhaave's important work in pneumatic chemistry is regarded as a bridge between the earlier opinions of Boyle, Newton, Mayow and Hales and the later work of Black, Cavendish and Priestley. He summed up for the one and pointed towards the other.(30)

By the early years of the 18th century the English had assumed a position of dominance in surgery previously held by the French and London became the center of surgical teaching and practice. The predominating figure during the first half of the 18th century was William Cheselden (1688-1752). He ultimately became surgeon to St. Thomas's, St. George's, and the Chelsea Hospitals. In addition to his abilities in operative surgery, he became known for his surgical courses and his books on anatomy.(65) Although proficient in a number of surgical procedures, he was probably best known as a lithotomist. He devised a lateral perineal approach to the interior of the bladder and often took less than one minute for the procedure, a blessing in this preanesthetic era. John Hunter was one of his pupils. Many of his American students became influential surgeons in the colonies. He was one of the last wardens of the United Company of Barbers and Surgeons and his influence probably brought about the separation of the company into Surgeons and Barbers in 1745.(65,66)

Another important 18th century British physician was Sir John Pringle (1707-1782). He became an army surgeon and subsequently was greatly honored, becoming physician to the king and also president of the Royal Society. (Sir John, as previously noted, delivered several brilliant orations before the Royal Society on the occasion of awarding Copley medals to individuals closely associated with the early development of anesthesia such as Joseph Priestley). Pringle, in studying fevers, paid special attention to "putrefaction of the air which of all the causes of sickness is perhaps the most fatal and the least understood." He noted several different sources of noxious air: the various miasmata, effluvia etc. which must have been very common around military camps. Sir John Pringle did not believe that living in sea air was a cause of scurvy on long ocean voyages, as did many of his time. He advocated cleanliness, good ventilation and frequent acquisition of fresh provisions. He taught that all effective antiscorbutic measures acted by preventing putrefaction in one way or another.(67) He relied mostly on contemporary references and paid little attention to ancient classical writings. He also gave an excellent description of malignant jail fever, which is today recognizable as typhus.(68)

William Cullen (1710-1790) became the most distinguished English physician of his day as the center of excellence in medical instruction gravitated from Holland to Scotland. He elaborated a system of medicine and was a leader in the nosology movement. Cullen was impressed with the contagious nature of some fevers and became concerned with effluvia; i.e. contagious vapors and emanations from human bodies and also miasmata which were emanations from sources other than human. Although Cullen is said to have been more advanced and open minded than Boerhaave, their two systems of medicine do not seem particularly different today and certainly the methods of therapy suggested by Cullen were minimally different from those of his predecessors.(69)

John Brown (1735-1788), brilliant and vastly influential, allowed his passions to dominate his intellect.(70) He studied medicine at Edinburgh and had been a favorite disciple of William Cullen. He attained international prominence after his system of medicine was first published in 1780. This Brunonian System of Medicine subsequently displaced much of the prevailing theory and practice of medicine in Europe. Several revisions and translations subsequently appeared. John Brown's system burst upon Europe with "the effect of an earthquake" (Virchow) and was particularly influential in Italy and Germany. It became the basis of the popular systems of Rush (1745-1813) and of Broussais (1772-1838).(71)

The fundamental principle in Brown's system was that of excitability; a basic quality inherent in all structures of living beings and characterized by the capacity to perceive outside impressions and by the ability to respond to them. External stimulants continuously act on excitability and are constantly needed to replenish and maintain it in order to avoid disease and death.(72) Health was a momentary equilibrium between an adequate amount of outside stimulation and a normal amount of excitability. Excess or deficiency of excitability led to predisposition to disease or actual disease states. Excessive stimulation, or excitement, exhausted excitability of tissues and led to sthenic predisposition and then sthenic disease with a state of indirect debility. Deficient stimulation, or excitement, led to accumulation of unused excitability, which caused asthenic predisposition and ultimately asthenic disease with a state of direct debility. Brunonianism did not recognize specific diseases so that the patient's history and physical examination were of little significance. Rather, an inventory of the stimulants to which the patient had been exposed and an assessment of the state of his excitability was done.(72) Brown stated:

> "Such is the simplicity to which medicine is now reduced, that when a physician comes to the bed-side of a patient, he has only three things to settle in his mind. First, whether the disease be general or local; secondly, if general, whether it be sthenic or asthenic; thirdly, what is its degree?"(73)

To Brown, any symptom was as likely to be caused by sthenic as by asthenic disease. A detailed survey had to be made of all the stimuli to which the patient was normally subjected. Symptoms only mattered in so far as they helped to differentiate local diseases, and also in that variations in their overall intensity were a guide to progress in general disease.(71) For the excessive stimulation and deficient excitability of sthenic predisposition or disease debilitating measures such as bland or vegetarian diet and watery drinks, gentle cathartics, induction of sweating and vomiting, and occasional prudent bloodletting were prescribed to allow accumulation of excitability. For the deficient stimulation and excessive excitability associated with asthenic predisposition or disease, Brown prescribed stimulating measures such as a hearty diet, rich soups, and drugs which were believed to be stimulants. The weakest degree of diffusible stimuli for use in sthenic disease were white and red wines. Stronger yet were musk, volatile alkali (ammonia) and camphor. Next came ether and strongest of all was opium. These stimulating agents aided in dissipation of undesired quantities of excitability.(73) Many other 18th century physicians, including Beddoes, regarded ether and opium, substances that modern physicians classify as central nervous system depressants, as stimulants.

It is said that Brown's whole theory was based on his observations on the clinical course of his own gout and his perception of events associated with the exacerbations and remissions of this distressing disease.(72) This method of reasoning and clinical practice, improbable as it may sound to the modern reader, dominated medicine for a generation or more. Some of its practitioners modified Brunonianism to incorporate some of the worst therapeutic excesses of the early 19th century. Although some of Brown's contemporaries and disciples might disagree in some respects with his theories on excitement and excitability most agreed with his recommendations for putting them into practice.(74) It will be recalled that Thomas Beddoes rejected some of Brown's ideas but found his total system incontrovertible, as apparently did his disciple, Humphry Davy.

Benjamin Rush (1745-1813), like Brown, was a student of Cullen and shared many of Brown's general views. Following early education in North America, which included a bachelor's degree in 1760 from Princeton, Rush traveled to Edinburgh to continue his medical education. Among his professors was Joseph Black. On return to Philadelphia in 1769 he was appointed professor of chemistry at the College of Philadelphia (today U. of Pennsylvania). Rush gave a number of chemical lectures to varied audiences. His appointment was said to have marked the beginnings of chemistry in America. During the American revolution, he was concerned with manufacture of gunpowder. In 1789 he was appointed professor of the Theory and Practice of medicine.(75)

Rush began his medical practice in 1769 as a disciple of Cullen but eventually developed his own theories of medicine which emphasized the arterial system as the seat of disease and led to his vigorous advocacy of blood letting and other depletive measures. While attempting to treat fever during the great yellow fever outbreak of 1793 in Philadelphia, Rush became an advocate of extreme purging which he exercised much to the horror of many of his contemporaries.(76) He taught about 3,000 students during 44 years and was a pioneer in American psychiatry. Rush was a signer of the Declaration of Independence and fought for a federal constitution. He is remembered today, not so much for medical contributions as for being an "evangelist of science."(75)

The medical activities and ideas of Samuel Latham Mitchill (1764-1831), one of the leading physicians in the young Republic of the United States, will be considered subsequently in the present volume in relation to his theories on the pneumatic origins of epidemics and their influence on Thomas Beddoes and Humphry Davy.(77) King has pointed out that subsequent workers at the end of the eighteenth century paid less and less attention to the past and, although their ideas were wrong, they expressed more thoughts and empiricism that would ultimately lead to explanation of their problems.(78)

Another noteworthy system of medicine was homeopathy. This method of practice was formulated beginning about 1790 by a German physician, Samuel Hahnemann. It was said to incorporate 18th century thinking, employ 18th century logic and rely upon 18th century concepts. Perhaps it arose as a reaction against barbarous 18th century therapy and the absurdly complex prescriptions of the day.(79) Nevertheless, it has carried over into the 20th century and retains popularity in some quarters today. The entire system of homeopathy arose as a consequence of Hahnemann's self administration of "Peruvian Bark." When he took this substance, whose active ingredient was quinine and which was one of the few really useful medicines of the 18th century, he developed what he perceived to be a fever. Since the "Peruvian Bark" was often effective in malarial fevers Hahnemann immediately generalized and concluded that most illnesses could be cured by administration of medications which produced, in healthy individuals, symptoms characteristic of the disease being treated. Moreover, these medicines should be given in infinitesimally small doses since the body in sickness was extraordinarily sensitive to drugs. He reasoned that, if a healthy person set out to make himself sick by overeating, a large quantity of food would be required. But a sick person is sometimes nauseated by the mere smell of food, confirming the extreme sensitivity of the body under this circumstance. Homeopathy emphasized accurate history and treatment of each patient as an individual, practices which were ignored by other systems such as that of John Brown.(79)

Surgeons increasingly gathered respectability as the 18th century proceeded. One of the best known and universally respected surgeons of this era was Percival Pott, who became a staff surgeon at St. Bartholemew's hospital in 1749. In 1756 he was thrown from his horse and sustained a "Pott's fracture" of his ankle, a severe compound fracture. He refused to be moved until an appropriate stretcher was fabricated from poles and a door and then was carried two miles. He was saved from amputation by the timely arrival of his old teacher, Edward Nourse. Pott's surgical interests were extensive. His best known writings concerned his description of curvature of the spine associated with spinal tuberculosis: Pott's disease. This malady had been plaguing mankind since antiquity.(80) He differentiated the condition very decisively from idiopathic scoliosis. In the latter condition palsy rarely occurred. For treatment of spinal tuberculosis he advocated drainage of the associated psoas abscess. He could, of course, not have known about the pathology of the disease. He was the first to describe cancer of the scrotum in chimney sweeps. He was a skilled and meticulous surgeon. Pott was a contemporary and associate of John Hunter. He was elected a Fellow of the Royal Society, an unusual tribute for a surgeon.(81)

Percival Pott was universally liked and noted for his kindness. He frequently had a few impecunious young colleagues living at his house. He served St. Bartholemew's for 50 years and was proud of having been the last of the barber-surgeon apprentices appointed to this hospital. But he was also the first of a new school. As he lay dying in 1788 he said, "My lamp is almost extinguished, I hope it has burned for the benefit of others."(81)

18TH CENTURY MEDICAL AND SURGICAL PRACTICE

Accepted and popular therapeutic techniques of the 16th and 17th centuries included bloodletting, purging, enemas, raising blisters, and other similar types of measures. These violent therapeutic techniques persisted into and beyond the 18th century. The extent to which these forms of treatment were applied is illustrated by the notation that within one year King Louis XIII of France was bled on 47 occasions, purged 215 times, and received 212 clysters.(82)

Bloodletting was one of the oldest and most common means of therapy and its beginnings are lost in antiquity. The origins of this type of therapy are obscure. Withdrawal of blood from a sick person was perceived to produce detectable objective changes and favorable subjective manifestations in most patients, especially those affected by some acute inflammations.(83) Spontaneous hemorrhages, such as nosebleed and menstrual bleeding, were thought to reflect the body's need for a natural outlet; production of excessive secretions during upper respiratory infections and large quantities of phlegm associated with lower respiratory complaints must have accentuated belief in the necessity for the body to rid itself of unneeded materials. The marked local and systemic improvement associated with discharge of blood and pus during spontaneous drainage of an abscess must have supported the rationale of relieving the body of excessive blood in a variety of other circumstances. The practice is extensively described in Hippocratic writings. Creation of leaf-shaped flint knives was a common occurrence in primitive societies and metal lancets have been used in venesection for millennia. Peoples employing this practice in bygone days included Egyptians, Hebrews, Hindus, Greeks, Romans and Arabs. Hindu blood letters were trained on plants and animals before being permitted to practice on humans. Celsus was a strong advocate of bloodletting. A passage quoted from Celsus concerning the technical problems encountered in bloodletting could profitably be studied today by a trainee learning venipuncture.(84) It became a matter of great import to these old time practitioners whether the blood was released from the same side of the body as the lesion being treated (revulsive bleeding) or on the opposite side (derivative bleeding). Galen advocated bloodletting and made specific recommendations on the quantity of blood to be withdrawn. Arab physicians, as devout followers of Galen, were enthusiastic blood- letters. The practice of bleeding continued through the middle ages and became admixed with considerable astrology. In the 15th century large public baths were popular. The bath keeper was often a barber surgeon and the bath became a frequent occasion for bloodletting. Harvey's discoveries had no practical effect on bloodletting.

Bloodletting probably attained its greatest popularity in the 18th century. This century was the Golden Age alike of the successful practitioner and the successful quack. Both found themselves confirmed and fortified in the practice of venesection by the ingenious arguments of the medical theorists, including Boerhaave, van Swieten, Stahl, Brown, Hoffman, Frank, Pott, Pringle, Haller, Cullen, Rush and others.(85) Bloodletting was regarded as a depletive measure designed to counteract excessive excitability associated with asthenic disease in the Brunonian and similar schemes of medical practice. One important problem with bloodletting in the early 19th century was establishing criteria for the procedure in specific diseases, as opposed to the unreserved practice of bleeding in all types of disease.(86) Popularity of venesection continued into the 19th century. It was particularly applicable in the many diseases to which a specific etiology could not be assigned.(71) But a general decline in this activity also occurred and widespread bloodletting became discredited about 1860. The waning of this practice was attributed to the advent of improved methods of evaluating therapy and also availability of more sophisticated means of medical treatment.(81) However, this early 19th century "vampirism" enjoyed a limited return of popularity in the late 19th and early 20th centuries and is still occasionally used in our own day in certain specific situations involving diseases of the circulatory system or blood.(83)

Practice of surgery in the 18th century included operations, reduction of fractures and dislocations, dressing of wounds and ulcers, removal of teeth and opening of abscesses, and all eye and skin diseases. Venereal disease and its complications were also treated. A great deal of time was spent in draining, dressing and otherwise caring for chronic infections of various types. Minor surgery in this era was probably more common than currently believed, although major surgery was still rare and reserved only for life-threatening conditions. It appears that an important 18th century sentiment was that the measures employed by surgeons were generally much more effective than those used by physicians, which rarely worked. Professional fees were standard and were not reduced for poor patients or when paid by overseers of the poor law. These fees represented a considerable amount for people of ordinary means. Medical care was not cheap in the 18th century.(6)

Many 18th century doctors achieved a high degree of visibility and social status.(52) The success of the elite of the medical profession, who often attained high prestige in the community and had incomes rivaling that of wealthy landowners, did not stem from advances in medical science or therapeutic breakthroughs during the 18th century. Rather, they were valued as clinicians. Physicians such as Fothergill, Lettsom, Heberden and Baillie built glowing reputations as expert diagnosticians and sympathetic care providers exhibiting sound judgment of both managing disease and soothing clients.(2)

Appointment to a hospital staff as a means of becoming known in the community and establishing a practice was mentioned above. Alternative routes to success in medicine included service as a military surgeon or patronage of a senior physician, nobleman or royalty.(52)

Workers' health schemes were arranged in the 18th century and such schemes were operative in the businesses of Josiah Wedgwood at Etruria and of Matthew Boulton at Soho, Birmingham.(87)

Before the establishment of medical societies many physicians used the numerous provincial arts and science societies such as the Derby Philosophical Society for scientific communication. Some of these societies were quite large. The Derby Philosophical Society had 56 members in the mid 18th century and that number included 11 surgeons, and 15 physicians and other medical people.(88) These societies, including the ones at Derby and Birmingham will be discussed in detail subsequently in this volume.

The eighteenth century practice of medicine was characterized by strange beliefs and weird practices when judged by modern standards. Nevertheless, some genuine medical advances of greatest importance occurred. These were enumerated by C.C. Booth (1981) and included:

- Introduction of sanitary practices into military activities by Sir John Pringle.
- Introduction of antiscorbutic agents including sweet wort with good effect.
- Foundation of scientific surgery by John Hunter.
- Vaccination against smallpox.
- Introduction of foxglove, initially as a diuretic.
- Recognition and criticism of the wide use of depletives such as bleeding and purging and their eventual replacement by more rational supportive measures.
- Joseph Black and his work on gases.
- Recognition of the properties of nitrous oxide.
- Description of angina pectoris and the eventual recognition of its being due to disease of the heart.

The wide sale and use of opium during this era to control pain represented a real advance in medicine. Patients no longer had to endure severe pain. Opium was a miracle drug of the 18th century and there were a number of indications for its use. Apparently the danger of addiction was minimized.(2) The use of narcotic and sedative drugs in medical practice appeared to have increased markedly during the 18th century. Porter and Porter (1989) wrote: "Of course, the Georgian Age remained the 'Age of Agony' (ref. to Williams, 1984) but relative to earlier times it was an anaesthetized age precisely because of the startling surge in the use of powerful narcotics, particularly alcohol and opium and its derivatives, laudanum and paregoric. It was a habit sanctioned by regular doctors and encouraged amongst the people at large by a free market in the sale of drugs."(2) A concept which began to attain acceptance in the 18th century was the recognition of some specific different kinds of diseases rather than a single disease state.(89)

The 18th century was the age of nosology. This branch of learning, important in its time, sought to classify diseases and to place them in variously defined orders, genera and species according to their observed similarities and differences just as Linnaeus had classified plants and animals. Notable physicians engaged in this activity included Cullen, Brown, and Erasmus Darwin. Darwin's system, like others based on the writers' perceptions of causations of disease states, had little value because of the almost total ignorance in the 18th century of the origins of disease.(90) In the 18th century there was no central authority or statutes, or regulatory codes which could be called ethics.(91)

SURGERY WITHOUT ANESTHESIA

There was little progress in surgery from the dark ages through the middle of the 19th century. Only a part of this stagnation was due to lack of anesthesia. Sigerist attributed much of the delay in introduction of anesthesia as common surgical practice until the middle of the 19th century to changing concepts of the nature of disease.(92) Sigerist proposed that, when disease was explained on a humoral basis and the symptoms of disease were regarded as being due to altered balance in the mode of living, dietetic and pharmacological measures were the therapeutic methods of choice. Then, starting with Vesalius and Harvey, modern anatomy and physiology slowly matured. In 1761 Morgagni performed a large number of autopsies, finding organic lesions which were responsible for certain diseases. When physicians learned that signs and symptoms of many illnesses were characterized by locality of the disease process and the symptoms were the result of anatomical lesions, the objectives of diagnosis and therapy changed. If disease was the result of anatomical changes surgery could correct them directly. Then, lack of a means of pain relief became an important, but not the only, impediment to progress in surgery.(92) But Sigerist's explanation can be only partially correct. It appears that much surgery in the preanesthetic era was done for conditions whose etiology was clear, such as fractures, dislocations and other traumatic incidents, or whose manifestations were quite obvious, such as gangrenous extremities, superficial tumors, or aching teeth. In these situations what had to be done must have been quite obvious. Such indications for surgery required little appreciation of pathology and the frequency of performance of these operations could have provided strong motivation for discovery of anesthesia. Numerous descriptions of operations performed without anesthesia give us some indication of the scope of surgery and the emotions and sensations involved.(93) A most detailed and electrifying account of a mastectomy endured without anesthesia in 1811 was written in a letter to her sister by Fanny Burney (1752-1840).* She described in frightening detail her preoperative dread of the impending procedure, the horrors experienced during the operation itself, and her inability to communicate thoughts on the experience for a long time postoperatively. Surgery was performed by Dr. Dominique Larrey, surgeon to Napoleon's armies, in consultation with several others.(94)

Samuel Pepys (1633-1703), eminent diarist and secretary to the admiralty in the reigns of Charles II and James II, on March 26, 1658, was successfully operated upon for bladder stones. Ever since age 20 he had suffered under a constant succession of attacks of this malady. The winter of 1657-58 was unusually cold and this seemed to bring matters to a head and surgery could no longer be averted. There seemed a high probability of death. The lithotomist was to be Thomas Hollier (or Hollyer), a neighbor of Pepys' father. Since his father's house was too small the location of the operation was to be the home of his cousin, Jane Turner who had inherited her father's house in Salisbury Court. Dr. James Moleyns of St. Bartholemew's hospital was called in consultation. He was Hollier's old master. Moleyns prescribed a draught of licorice, marshmallow, cinnamon milk, rose water and white of egg. The operation was said to be a complete success; a stone about the size of a tennis ball was removed. Hollyer was a master and that year he cut thirty for the stone with no deaths. (But soon after four others that he cut died.) Afterwards the patient received a cooling and demulcent drink of lemon juice and syrup of radishes.(95)

Entries in Pepys' celebrated diary convey his overwhelming gratitude and joy at having survived this perilous procedure with its mortality rate of 50% in some hands.(96) The first entry in the diary, on Jan. 1, 1659, indicated the continuing good general condition of his health: "Blessed be God, at the end of the last year I was in very good health, but without any sense of my old pain, but upon taking of cold." On the second anniversary of his operation, March 26, 1660, he wrote:

> "This day it is two years since it pleased God that I was cut for the stone at Mrs. Turner's in Salisbury Court; and did resolve while I live to keep it a festival as I did the last year at my house, and forever to have Mrs. Turner and her company with me. But now it pleased God that I am prevented to do it openly; only within my soul I can and do rejoice, and bless God, being at this time, blessed be His holy name, in as good health as ever I was in my life."

Further entries in Pepys' diary were as follows:

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*Mrs. Burney was a well known Georgian novelist and diarist. Her novels were said to have had a strong influence on the subsequent writings of Jane Austen.(94)

> March 26, 1661: "This is my great day that three years ago I was cut of the stone and, blessed be God, I do yet find myself very free from pain again. To my father's where Mrs. Turner [and others including Mr. Pierce, Hollier and his wife]...my father and mother and myself and my wife...."
>
> March 26, 1662: "Up early. This being, by God's great blessing, the fourth solemn (sic) day of my cutting for the stone this day four years, and am, by God's mercy, in very good health and like to do well....."

Again he entertained Madam Turner and Co. with a "pretty dinner" and then talking, singing and music all afternoon. From here on the operation is usually remembered but there is no specific mention of a celebration of the event.

> March 26, 1663: "This day is five years since it pleased God to preserve me at my being cut of the stone."
>
> March 26, 1664: ".... This being my solemn feast for my cutting of the stone, it being now, blest be God! this day six year since the time; and I bless God I do in all respects find myself free from that disease or any signs of it......"
>
> March 26, 1665 (Easter Sunday) "... This is the day seven years, which by the blessing of God I have survived of my being cut of the stone....." He is now of good health and has done well all year. "Now I am at a loss to know whether it be my hare's foot which is in my preservation; for I never had a fit of the collique since I wore it or whether it be my taking of a pill of turpentine every morning."
>
> No entry in 1666.
>
> March 26, 1667: "I have cause to be joyful this day for my being cut of the stone this day nine years." Because of family problems with his mother, he will not keep his usual feast.
>
> No entry in 1668.
>
> March 26, 1669: He talks about other things and then says, "... It being also my feast for my being cut of the stone, but how many years I do not remember, but I think it to be about ten or eleven."

The diary ends May 31, 1669. Because of the references to his usual feast in the 1667 and 1668 entries it seems likely that Pepys continued to enjoy an anniversary banquet on the customary date but no longer recorded the events in his diary.(97) One can still visit Salisbury Court, Fleet Street, London. Here, a blue plaque on one of the buildings explains that on that site, in the 17th century, dwelt Mrs. Turner and her troop of actors. It will be recalled that Josiah Wedgwood had his leg amputated (See section on Wedgewood in chapter on the "Lunar Society of Birmingham") and intended to observe the anniversary of this ordeal annually calling it "St. Amputation's Day."

Even children could not be spared the ordeal of surgery without anesthesia. They were subjected to procedures such as amputation(98) and extraction of congenital cataracts.(99) Admiral Viscount Nelson faced the amputation of his right arm with fortitude. Nevertheless, when going into battle at the Nile, he insisted that warm water be available so that the surgeon's instruments would be warm in case he should need surgery again.(100) Pain relief during surgery in the 18th century may not have been regarded as being within the concern of the surgeon or of any other physician attending a surgical patient. In the diary of John Knyveton,* supposedly an 18th century London and military surgeon, statements are recorded which leave the impression that management of surgical pain was the responsibility of the patient and his friends. Remarking on an amputation following a compound fracture the author wrote:

> "The patient being a poor man had few friends able to make him drunk and so he being a well developed specimen many ropes were necessary to control his struggles."(101)

Description of an operation for removal of bladder stones included the comment that the patient was: ".... brought into the theater tolerably fuddled with drink brought him by sundry friends;... "(102)

J.Y. Simpson collected mortality statistics for operative obstetrics before and after the introduction of ether. In 1846, before ether, operative mortality was about 38% (107/284). After advent of ether mortality was 25% (37/145). (Simpson first used ether on 19 January, 1847 in delivery for turning and extracting a large child from a mother with a severely contracted pelvis).(103)

The preceding material describes certain of the institutions, social attitudes and aspects of medical practice which influenced the manner in which the 18th and early 19th century people who have been discussed approached illness and medicine. They were gradually discerning the foundations of knowledge that were necessary for introduction of clinical anesthesia but the actual implementation of relief of pain during surgery still eluded almost all practitioners.

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*Knyveton's diary is identified in the card catalog of the National Library of Medicine, Bethesda, Maryland, USA, as a semifictional account of the education and career of an 18th century surgeon. Material in this book should be interpreted accordingly.

PLATE VIII — THOMAS BEDDOES (1760-1808). He was foremost among practitioners of pneumatic medicine, founder of the Pneumatic Institution at Bristol and author of several books advocating medicinal application of various gases. He recruited Humphry Davy to his staff and probably guided many of his early experiments on gases.

Chapter X

Thomas Beddoes

His Early Life and Career

Thomas Beddoes must surely stand in the first rank of those individuals who set the stage for the introduction of clinical anesthesia. His interest and widely circulated writings in pneumatic medicine and particularly his engagement of Humphrey Davy to work with him in Bristol are certainly among the most important factors initiating and influencing the trials of nitrous oxide and ether for anesthesia which occurred about half a century after Beddoes' pneumatic career. He deserves the detailed attention which we will now accord to him in this volume.

It appears that in the eighteenth and early nineteenth centuries the widows of prominent men who merited a biography often selected the biographer. To memorialize Thomas Beddoes, Anna Maria Edgeworth Beddoes chose Dr. John Edmonds Stock who had succeeded Beddoes as Director of the medical facility in Bristol. She selected Stock probably believing that he would be most likely to edit the life and writings of Beddoes to his advantage while suppressing material that might show Beddoes in an unfavorable light.(1) Some of Beddoes' literary colleagues regarded this as a disastrous choice. Upon hearing of the proposed arrangement, Robert Southey wrote to John King, Esq.:

> Keswick, Feb. 6, 1810
>
> "My Dear King, I expected to hear that Mrs. Edgeworth [Most likely Maria Edgeworth, novelist and sister-in-law of Thomas Beddoes] was to be the biographer of Beddoes and that if she declined the task you would undertake it. Davy would have done himself more honour by volunteering upon this service than by waiving it; for not to show respect in this instance is to manifest a want of it. Peace to the memory of the dead, if — is to write his history! It will be without feeling and without philosophy! and the properest frontispiece would be a portrait of the historian, putting an extinguisher upon a sepulcher, which else might burn forever"(2)

Southey said that he could not write a memorial epitaph but suggests that Coleridge might. He continued:

> "If Coleridge will do anything he will do this, for he had the most thorough esteem for Beddoes, and has been very greatly affected by his death, even to a superstitious depression of spirits. I expect to see him in a day or two...... From Beddoes I hoped for more good to the human race than any other individual; and if you have not received his mantle he has taken it with him. This, too, increases my regret that you are not to be his biographer; for no man living is so competent as yourself to explain his views, and so to develop his principles that they shall be understood and fairly appreciated, and thus continue in some degree their action. ___'s book will answer his purpose very well — that of advertising himself as the successor — but it will not answer any other."(2)

On 30 Jan., 1810 Coleridge wrote to Humphrey Davy. He expressed regrets at not having received the assignment of writing Beddoes' biography. The commission for this work was declined first by Davy, then by Davies Giddy, possibly because of his position as executor of the Beddoes estate and guardian of the Beddoes children.(1) The task finally devolved on Dr. Stock. Coleridge, too, had been extremely disappointed in this designation and wrote:

> " I could not help assenting to Southey's remark that the proper vignette for the work would be a funeral lamp beside an urn and Dr. Stock in the act of placing an extinguisher on it."(3)

However it was said that the Coleridge of this period was undependable and Beddoes' friends, knowing this, probably thought that an "uncritical and pompous life" by Stock would be better than no biography at all by Coleridge. No great public objection was made and Stock completed the biography. The work appeared in the year following Beddoes' death (1810) and is an important source for many of the details of Beddoes' life.

Beddoes' Early Life

Thomas Beddoes was born in the village of Shifnall in Shropshire on April 13, 1760. His family was of Welsh descent and was successful in business. Thomas' grandfather early recognized the apparently extraordinary intelligence and native abilities of the boy, and secured for him the best and broadest fundamental education to be had in the neighborhood. Fortunately there were excellent schools with concerned and caring masters available.

Beddoes attributed his resolve to pursue a medical career to events associated with the death of his grandfather following a riding accident about 1769. During the old gentleman's brief terminal illness young Thomas was constantly present in the sickroom and most favorably attracted the notice of the attending surgeon, Mr. Yonge (or Young). After this, Beddoes was a frequent visitor to Yonge's dispensary and surgery and assisted with routine medical tasks. At this time he appeared determined to become a physician and acquired the sobriquet of "The Little Doctor." His classical education continued. A schoolmaster from this period testified to Thomas' unswerving attention to his studies, his sobriety, his reserve and his equanimity. These were characteristics of his personality for the remainder of his life. He enrolled in Pembroke College at Oxford University in 1776. There, in addition to establishing an enviable academic record, he taught himself French, German and Italian. Inspired by the examples of Joseph Black and Joseph Priestley, Beddoes studied and demonstrated competence in pneumatic chemistry. Other fields of interest for him were botany and mineralogy.

By the time he took his bachelor's degree, Beddoes had acquired a considerable manipulative skill in pneumatic chemistry.(4) and attained a prodigious proficiency in this subject before his 20th year.(5) His interests at this time were not confined to academic matters. He was said to have been one of the best card players in England. He would play for many hours on end and after a hand of whist he was said to have been able to recall the order of play of all the cards and who played them. Following receipt of the Bachelor of Arts degree, Beddoes temporarily located in London. There, he studied anatomy with Sheldon and attended other lectures offered in the metropolis. He took the degree Master of Arts in 1783. He soon began to attract notice as a translator, editor and annotator of important foreign scientific texts not theretofore available in English language editions. These included works of Spallanzini in 1784, of Bergman in 1785 and of Scheele in 1786. In 1784 Beddoes had removed to Edinburgh to undertake the formal study of medicine. He quickly distinguished himself by being elected chairman of two medical student scientific organizations simultaneously as well as successfully representing the students in a dispute with the managers of the Edinburgh Royal Infirmary. He returned to Oxford for a short period and was awarded the Doctor of Medicine degree from Oxford in December, 1786.

During the autumn of 1787 Beddoes visited France. The high point of this trip was the opportunity to spend several weeks in Paris with Antoine and Marie Lavoisier. Upon his return to England he assumed the position of lecturer in Chemistry at Oxford.(6) In this post he has been referred to as lecturer, reader or professor. In truth, archives of Oxford show nothing of Beddoes so that his position must have been completely unofficial and his precise title is immaterial. Laboratory notes (not his own) suggest that he was doing chemical experimentation at Oxford in the spring of 1787. He therefore probably settled at Oxford before his continental excursion.(7) He must have been a popular instructor since, in a subsequent letter to Joseph Black, Beddoes wrote that the audiences at his chemical lectures were the largest at Oxford in the memory of man.(8) Other correspondence related that the crowds at the lectures were the largest since the 13th century.(9)

In a letter of 1787, Beddoes wrote to Erasmus Darwin saying: "I am going through a course of lectures with, I believe, the largest class that ever was assembled in Oxford, at least since the discovery of Justinian's code drew together thirty thousand students."(10) Beddoes was an enthusiastic teacher and researcher. A pupil and friend observed that "science at Oxford was pursued with a degree of enthusiasm and competence in Beddoes' time which had not been attained previously or since."(11) He taught every day except Saturday and Monday when he worked in the library. Matthew Boulton, manufacturer and Lunarian, was anxious for his son to acquire chemical knowledge and sought admission for the young man to Beddoes' chemical lectures.(12)

The dissenting academy, the philosophical society (see the chapter on the "Lunar Society of Birmingham"), and the scientific library were three connected and reinforcing impulses in scientific education during the latter half of the eighteenth century. The individuals noted in science at this time tended to work within all three institutions. Their sphere of influence was outside the main and old English Universities. Thus, presence of Beddoes, a recognized, authoritative and competent chemist, at Oxford was an important influence promoting science at that institution in the years 1789-1792. His subsequent resignation arrested a movement for reform in scientific teaching. Beddoes was a fellow of Pembroke College but many of his close friends were at Christ Church.(13)

This period in Beddoes' life also marks the beginnings of certain important and lasting friendships. One was with Mr. William Reynolds, a kindred spirit from Shropshire, with whom he spent a great deal of time when his duties permitted. Another was with Erasmus Darwin with whom he kept up a lively correspondence.(10) They appeared to hold one another in highest regard. Beddoes, via the mail, read and commented candidly upon the proofsheets of Darwin's "Zoonomia." His third friend from this period was Davies Giddy.(14) This future President of the Royal Society was born Davies Giddy but died Davies Gilbert because on the death of his wife's bachelor uncle in 1817 he took the name "Gilbert." His wife's uncle's will specified a generous inheritance if the family name of Gilbert were to be perpetuated. Davies took the new name but seemed to retain a fondness for the name "Giddy." Davies Giddy (also Gilbert) was born in St. Erth, Cornwall 6 Mar., 1767 son of Edward, a Church of England curate, and Katherine, daughter of a minor peer . He was educated at public school in Penzance and at home by his father and then entered Oxford. At that time Thomas Beddoes was lecturing in chemistry at Oxford. Gilbert attended Beddoes's lectures in 1786 and in 1789 and found in him a man, like Black and Lavoisier, unafraid to experiment.

A very deep friendship extending far beyond the limits of medicine and chemistry developed between Beddoes and the younger Gilbert. Ultimately Gilbert often played a moderating and restraining role to Beddoes' enthusiasms in all areas including politics and science. Gilbert developed many areas of interest and expertise. He was an accomplished mathematician and became noted for his calculations relating to improvements in steam engines and also to the length of chain which would be required to span the Menai straits. He served as High Sheriff of Cornwall 1792-1793 and was a Member of Parliament 1804-1832. He was also a chemist, classical scholar, geologist, mechanical engineer, farmer, and landowner. He became treasurer of the Royal Society when Humphrey Davy was elected president in 1820. When Davy was forced to resign because of ill health in 1827 Gilbert was elected president and served in this capacity until 1830. He died in 1839.(15,16)

In 1790 Beddoes published an analytical account of the writings of John Mayow. These had evidently fallen into relative obscurity. In this work Beddoes predicted future triumphs to be realized by the combination of medicine with chemical science; particularly pneumatic chemistry.(17) In 1793 he became familiar with galvanism and conducted experiments in this field. He predicted additional important advances and applications following a merger of medicine with galvanism. He published papers on geology and mineralogy in the Philosophical Transactions of the Royal Society of 1791-1792. He abandoned the phlogiston theory and became a convert to the "new chemistry" of Lavoisier.(4)

At this time (1792) his epic poem "Alexander's Expedition to the Indian Ocean" appeared. This was his first published literary work. It was perceived by most readers as a parody of Erasmus Darwin's "Botanical Garden"(18) but in reality was said to be a political tract in opposition to British domination in India. He dealt with several aspects of the Indian natives and their civilization in associated explanatory material. Also, he again described his theories on the relation of skin color to oxygen and light as well as some experiments designed to bleach the skins of black people.(19,20,21)

Beddoes did not hesitate to attempt to set right perceived deficiencies and wrongful situations at Oxford. In 1789 when he found that fees paid to him by students, his only source of income from the teaching of chemistry, were insufficient for his needs he attempted to procure a salary from the university for the Lecturer in Chemistry. In 1792 he was urged to petition the Secretary of State for financial support. Stansfield inferred that, since this was done at the suggestion of university officials, Beddoes must have been held in high regard by most members of the Oxford community at this time.(22) However, he was unsuccessful and a salaried post in chemistry was not created until a number of years after Beddoes had relinquished this position.(23)

Beddoes also sought to improve the scientific collection at the library. In May 1787, Beddoes sent " A Memorial concerning the State of the Bodleian Library, and the Conduct of the Principal Librarian, addressed to the Curators of that Library by the Chemical Reader."(24) He accused the librarian (Rev. John Price) of neglecting his duties; particularly failing to buy appropriate scientific books. Many scientific journals were not purchased and certain important ones, such as "Philosophical Transactions," arrived months late. Beddoes, who had just returned from his continental trip, thought that the Bodleian was one of the worst maintained public libraries in Europe. It was not up to standards of even small subscription libraries which were springing up in the provinces such as that of the Derby Philosophical Society. Beddoes complained that although the librarian was in full charge of purchasing, he was not up on scientific developments. In fact, a bookseller supplied the University with what he thought fit. The library bought translations of French books while lacking the books in the original language. Relevant German books were not in the library at all. Beddoes' agitation was an important service to the University and promoted valuable discussion. The curators wanted to set things right but were foiled by the heads of houses who seemed to be more concerned with secure appointments for the library staff. In the end, it is said, that nothing important was achieved until Price died.(13,25)

Thomas Beddoes enjoyed associations with several members of the illustrious Lunar Society of Birmingham. The relationship with Erasmus Darwin, conducted principally by correspondence, has been mentioned above. In a letter dated Nov. 21, 1791, Beddoes, writing to Giddy, indicated that during his return from Shifnall to Oxford he had stopped briefly in Birmingham. There he spent the day with fellow chemist James Keir.(26) The day was most interesting because the opinions of Keir and Beddoes differed considerably on many points of chemistry. Keir invited Beddoes to contribute articles to a new chemical dictionary. Beddoes declined because, as a believer in the "new chemistry" of Lavoisier, the orientation of the his material would likely conflict with those of the phlogistonist Keir.(27) Beddoes expressed great admiration for Thomas Day, whom he never met, and of his widow with whom he had a slight acquaintance.(28) Josiah Wedgwood supplied Beddoes with ceramic chemical apparatus.(8) Other Lunarians with whom Beddoes was associated at one time or another included Richard Lovell Edgeworth, James Watt, and William Withering. (The Lunar Society of Birmingham is of sufficient importance in the preclinical development of anesthesia that it will be discussed separately.)

In 1792, academic duties at Oxford occupied Beddoes' attention and were said to provide great personal gratification and honors for him. His most important book written in this year was "Observations on the Nature and Cure of Calculus etc."(29) This was his first purely medical work and is of sufficient importance to merit close examination at another point in this narrative. It was written at Oxford, but was not published until after he had left. It appears to have been well accepted and the edition quickly sold out.(30) Another volume written in 1792 was "...Letter on Early Instruction, Particularly that of the Poor." In this communication he discussed topics such as the best methods to teach reading and the materials for this, the necessity for humanizing the minds of the poorer class of citizens, and the cautions respecting religious instruction. He was particularly concerned with the excessive danger of strongly attaching to the dogmas of any sect, the minds of those who cannot examine the grounds on which they rest.(31) Another of Beddoes' publications at this time involved the manufacture of cast iron and was a straightforward chemical technological work. The communication was written at Shifnall in February, 1792 and was read before the Royal Society in May. A series of experiments was presented and conclusions were drawn.(32) This paper showed that Beddoes did and could perform experimental work, some involving gases, and that Sir Joseph Banks, President of the Royal Society to whom the communication was directed, should have become familiar with Beddoes' capabilities. Beddoes published three additional papers dealing with geology and metallurgy in "Philosophical Transactions" about this time.(33)

In the early parts of his career, Beddoes' chemical instruments and equipment were made by James Sadler, a master instrument maker. Sadler was the first Englishman to make a balloon ascent and was therefore sometimes called an "aeronaut."(34) At that time ballooning and chemistry were closely allied fields.(35,36)

The early phases of the French Revolution were a turning point in Beddoes' life.(37) He embraced the egalitarian and republican ideals of the Revolution with a degree of enthusiasm and vigor which many of his more conservative colleagues found alarming and offensive. Initially his views and ideas were confined to his conversation, but beginning in 1792 these sentiments, distasteful to some, began to appear in his published writings and to influence his behavior. At a certain tea party he brought his own East India sugar, refusing to use the usual Jamaican sugar prepared by slaves.(38)

The hostility which his attitudes elicited forced his resignation from Oxford that winter.(39) However by this time Beddoes may have already made up his mind to leave the University to test some of his theories on pneumatic medicine.(40) Circumstances of Beddoes' departure from Oxford were also related a number of years later by Peter Mark Roget, who had briefly been one of his colleagues at the Bristol Pneumatic Institution:

> "His opinions, which it was no part of his character ever to conceal within his own breast, were, on the occasion expressed with his usual freedom, and were of a nature to give offense to many of his former admirers; and the circulation of a political article which he inserted in a Shropshire paper, in reply to some misrepresentations which had previously been made, in an advertisement soliciting relief for the French emigrant clergy, excited a clamor against him, which accelerated his adoption of the step he had previously determined upon, that of resigning his Lectureship and quitting Oxford." (Roget, P.M., 1824.)

When he abandoned Oxford he had no specific plans or locality choice for the future. As the French revolution turned ugly and the terror began, Beddoes quickly lost much of his enthusiasm for support of the French and their new state but the damage to his reputation had already been done. In 1792 the name of Thomas

Beddoes (together with that of Joseph Priestley) appeared on a Home Office list of "disaffected and seditious persons." With very little more provocation, Beddoes could have been arrested and have suffered the penalties prescribed by law for sedition, including transportation to Australia.(8,41) It is noted that when he left Oxford he had a good and solid scientific reputation.(42) From Oxford he returned to Shifnall for a brief visit and then stayed for several weeks with his friend Reynolds at Ketley in Shropshire.

EARLY SCIENTIFIC AND LITERARY ACTIVITIES

Beddoes first developed and applied many of the ideas, such as those enunciated in "Calculus and Sea Scurvy," relating to the medicinal use of gases in the treatment of disease during this visit with William Reynolds at Ketley early in 1793.(43) At this time Beddoes performed some trials of gas inhalation in patients. The equipment for generating, storing, and administering the gas was crude and imperfect, but the results were perceived to be sufficiently promising to suggest to Beddoes the need for more extensive trials under better conditions. This was an ambitious goal for an unemployed physician-chemist. Most welcome, therefore, were offers of assistance from William Reynolds, his brother Joseph, and Mr. Yonge, surgeon-apothecary of Shifnall, Beddoes' old mentor. Each agreed to provide £200 toward the expenses of a Pneumatic Establishment. Beddoes was to contribute a like amount, select the staff, and superintend activities at the facility.

Beddoes, accompanied by Messrs. Yonge and Sadler, set out for London in March, 1793 to locate accommodations to house the Pneumatic Establishment. During the protracted search, Beddoes became convinced that the Bristol Hotwells might be a more favorable location for a medical facility of this nature. At this spa, there would likely be a large number of individuals afflicted with the diseases of which Beddoes was anxious to attempt pneumatic cures, particularly consumption.(44)

By the end of the 18th century Bristol had become the second city of England and was the intellectual capital of the West Country. The Hotwells at Clifton in Bristol became a spa rivaling Bath and was a center of medicine with many kinds of practitioners active in the area.(45) Beddoes informed Reynolds of his decision to relocate in Bristol by mail and abandoned London. The Bristol Hotwells were described by the Rev. John Evans writing in 1814:

> "The Hotwells discharge about 60 gal/min. The salubrious effects are described by William of Worcester. Its medicinal qualities became famous. The sedative effects of the waters were first noted by Dr. Winter in 1725. Waters issue at a temperature of 72-76 F and contain an 'uncommon quantity' of carbonic acid gas or fixed air and a certain quantity of magnesia, soda and lime in combination with muriatic, vitriolic and carbonic acids. It is beneficial in a wide variety of

> complaints. The water is clear, bubbling and odorless with a mild taste. Dr. Keir thinks the water is safe and effective. One should start gradually and work up to a pint several times a day. This is combined with gentle exercise and the good local air."(46)

In Bristol, Beddoes' reputation and intent to begin a medical institution had preceded him. His renown was in part based on the brisk sales of his recently published book on calculus, sea scurvy, consumption etc.(47) But the prospect of a neighborhood medical facility caused some initial opposition from residents around Hope Square, where a house had been rented for this purpose. One of the objections of the local public was that noxious gases might be released into the atmosphere.(4) The apprehensions of the landlord and neighbors were allayed with the aid of Richard Lovell Edgeworth and the scientific activities could proceed.(48)

> "...with his aid the difficulty in procuring a suitable house was surmounted; for the rumor had got abroad that the gases to be employed were dangerously explosive, and that the house in use as a hospital would be a focus of contagious disease..."(49)

Edgeworth, another member of the Lunar Society of Birmingham, was temporarily residing in Bristol. He had previously been acquainted with Beddoes.(48) Both men shared a profound interest in education of children. They had been introduced by James Keir, who had written a biography of Thomas Day after the latter's death.(50) When Keir learned of the great admiration of Beddoes for Day, a letter of introduction was provided for Beddoes to Day's best friend, Richard Lovell Edgeworth.(40) Maria Edgeworth wrote, concerning Beddoes: "My father admired his abilities, was eager to cultivate his society; and this intimacy continuing some months, he had opportunities of assisting in establishing the doctor in Clifton."(3)

Beddoes became a frequent visitor to the Edgeworth household and participated in many of their family activities. During these visits, he developed a deep affection for Anna Maria Edgeworth, second daughter of the family.(51) Expression of these sentiments in letters to some of his friends was no doubt occasioned by the impending departure of the Edgeworth family for their vast estates in Ireland.

Medical activities at the Pneumatic Institution proceeded slowly. By the end of May, 1793, some of the required apparatus was ready, some gases had been prepared and a few limited experiments had been made.(52) As time progressed, additional pneumatic experiments were made including some on animals, some self-experimentation on effects of breathing oxygen, and some clinical trials in disease. Important published works from this period include "A Letter to Dr. Darwin on a New Method of Treating Pulmonary Consumption"(53) and "Letters from Dr. Withering, Doctor Ewart, Doctor Thornton etc."(54)(55) The latter work included communications from other physicians who were trying pneumatic means of therapy.

Beddoes also wrote and published "The History of Isaac Jenkins and His Wife and their Three Children" in 1793.(56) This short volume was a work of "moral fiction" and gave an account of "the reformation of a drunken laborer, and his return to habits of sobriety and industry." It was a parable and a sermon designed to inculcate the lower social classes with the virtues of temperance and hard work. In the story, Sarah, wife of Isaac, procured some ale and wine for her sick children on the prescription of Mr. Langford, Surgeon. This was done with great personal humiliation, since the proprietress of the inn at which the purchase was made, "Big Martha" Pritchard, berated Sarah at length because Isaac owed her considerable money and was at that very moment drunk in the pub. When all recovered Mr. Langford established that the dire plight of the Jenkins family was due to Isaac's character: an "unfeeling and sottish" drunk. With a series of lectures, meekly accepted by Isaac, Langford made Jenkins see the error of his ways. Isaac Jenkins reformed, Big Martha was paid and the family fortunes markedly improved. Appended to this moralistic tale was another similar work: "A Friendly Gift for Servants and Apprentices."(57) In this essay Beddoes advised servants on topics such as choice of a position, behavior towards masters and mistresses, behavior towards fellow servants, dress, company, amusements, religious duties, etc. For the type of preaching in "Isaac Jenkins" and "Friendly Gift" Beddoes would probably be labeled, at the very least, as an elitist, a snob and a busybody in our modern times. However in the eighteenth century the book was enthusiastically received by the public. It went through many editions and is said to have been the most widely circulated English language book of its day. More than 40,000 copies were disposed of before the end of 1796 and the publishers indicated that no tract not sponsored by an official sect had ever enjoyed such good circulation as this.(3,58)

In December, 1793 Georgiana, Duchess of Devonshire, was staying in the Bristol area. This remarkable woman had an unusually broad and thorough education. Her maiden name was Spencer and she was an ancestor of Winston Churchill. Her brother-in-law was Henry Cavendish, discoverer of hydrogen. She was an intimate companion of both the Prince of Wales (the future George IV) and of Charles James Fox, the Whig politician. Although she appears to have practiced all of the vices of eighteenth century nobility with enthusiasm, she still found time to pursue interests in science and politics; unusual activities for ladies of her class and station.(59) The Duchess visited Beddoes in Hope Square and inspected the facility and the pneumatic apparatus. Her seriousness and her insight into chemistry deeply impressed Beddoes. She was so fascinated by what she had seen that she returned for another visit, which lasted three hours.(60) It was during this second visit of the Duchess that the idea of replacing the existing outpatient facility with a hospital — a Pneumatic Institution — was first enunciated. How much more effective it would be to demonstrate the beneficial effects of medicinal airs on hospitalized, resident patients, who might have their expenses subsidized, than to depend on casual and unpredictable private patients.

The Duchess was enthusiastic about the idea and urged Beddoes to keep her informed of progress by post. Then on Nov. 26, 1794 Georgiana, Duchess of Devonshire, wrote to Sir Joseph Banks, President of the Royal Society, soliciting his support and that of the Royal Society for Dr. Beddoes in the medicinal application of gases. Sir Joseph had already made some medical observations in his own right when he had been naturalist with Capt. Cook's first expedition, 1768-1771. During this voyage he had recorded in his notebook that early symptoms of scurvy which he developed were promptly cured by drinking lemon juice.(61)

Sir Joseph did not respond favorably to the Duchess' request. He replied that he found it impossible to give his support to a man "who has openly avowed opinions utterly inimicable to the present arrangement of the order of society in this country." At this time there was a marked antirevolutionary sentiment in the Royal Society.(62) He continued, writing that normally, recommendation of Beddoes by the Duchess would have been sufficient to overcome the political criticisms, but in addition he objected on scientific grounds. He indicated that he could not "give encouragement, either public or private, to an undertaking more likely to be attended with mischievous than beneficial consequences." On December 1st Georgiana again appealed to Sir Joseph on Beddoes' behalf. She indicated that she was much impressed by Beddoes' work to date and that his ideas should be given a fair and open trial. She understood that the doctor had modified his revolutionary views, and restated the importance of Sir Joseph's support in this matter. He again demurred, writing that because of his lack of connection to medicine, he could not believe that his support would be of any use to Beddoes. Surely, support of a fashionable physician would be more valuable! There was no further correspondence between Sir Joseph and Georgiana.(63,64)

On December 7, 1794 James Watt, engineer and Lunarian also wrote to Sir Joseph soliciting support for Beddoes and a pneumatic institution. Sir Joseph again replied negatively and with considerably less deference to his correspondent giving the same reasons which were set out in the his last letter to Georgiana. He further wished that he should be pestered no further by friends of Thomas Beddoes. His wish was evidently granted. (64,59,65) Sir Joseph Banks, in addition to being politically conservative, appears to have been quite selective in choosing scientific projects to endorse. On another occasion when King George III became interested in aeronautical balloons, particularly their military application, Sir Joseph discouraged expenditure of funds in this area.(36)

Gregory Watt wrote that all the great scientists of the day supported Beddoes' ideas with the exception of Henry Cavendish.(65) Meanwhile Beddoes had published "A Guide for Self Preservation and Parental Affection" (1794).(66) In this work, written for laymen, Beddoes presented some guidelines for raising children and for preserving health. Individual parental instinct was not to be trusted to do this. In the event of illness, self-medication and self-physic were to be avoided. Beddoes abhorred these common 18th century practices.(67) The preventive measures which he advocated were provision of good food, proper clothing, and fresh air. Overeating, sudden chilling, abrupt changes in environmental temperature, and excessive warmth for sick children should be avoided. He emphasized that compliance with these directives would require sobriety on the part of the breadwinner (he cited his tale of Isaac Jenkins) and planning and management skills on the part of the homemaker.(68) Beddoes was most gratified with the volume of sales of this work. He attributed its popularity to either its plain and clear style or to the fame of his previously published moral essay "Isaac Jenkins."

Despite the success of his prose, Beddoes' poetry was not greatly admired by his literary friends in Bristol. Southey later wrote to Davy in 1799: ". . . . at Bristol you have a good society but not a man who knows anything of poetry. Dr. Beddoes's taste is very pessimism. Cottle only likes what his friends and himself write."(3) Though Southey didn't think much of Beddoes as a poet he regarded him very highly as a physician. Several of the Bristol literary circle placed themselves under Beddoes' medical care.(3)

In March 1794 Beddoes travelled to the Edgeworth family estates at Edgeworthtown, County Longford, Ireland, where he married Anna Maria Edgeworth.(69) Upon the return of the young couple to Bristol, Beddoes continued his writing and editing activities. He agreed to edit the medical works of John Brown. The Brunonian method of medicine had become one of the most influential systems of medical practice in Europe. The profits from this new work were to be used for the benefit of Brown's widow and children who had come upon hard financial times. The book, published in 1795, had required considerable rewriting and editing because Beddoes found Brown's writing in a number of places "uncouth and obscure." Nevertheless Beddoes generally concurred with Brown's principles and vindicated his system of medicine with certain exceptions.(70)

Also during this period Beddoes remained occupied with his medical practice and with publicizing his plans to establish a Pneumatical Institution. He did this by means of letters to professional and scientific colleagues as well as by publication of a pamphlet "Proposal for the Improvement of Medicine."(71) A solicitation for funds in the guise of a report of progress of the Medical Pneumatic Institution appeared in the journal "Medical Commentaries" in 1794. It was probably written by the editor, Dr. Alexander Duncan:

> "Dr. Thomas Beddoes, formerly lecturer on chemistry at Oxford now at Clifton, in the neighborhood of Bristol, who is already well known to the philosophical world by his several ingenious publications, has circulated a proposal for the establishment of an institution for ascertaining the effects of those powerful agents, elastic fluids, in various diseases, and for discovering the best method of procuring and applying them.

> That elastic fluids of different kinds, acting on the animal system by means of respiration have very great influence, no one will deny; and from some late observations by Dr. Beddoes it is abundantly proved that the application of elastic fluids to cure diseases is both practical and promising. The ascertaining, therefore, with precision how far they may be successfully employed in the alleviation of human misery, is a subject which claims the attention, not merely of the practical physician but of every philanthropist. We would therefore fain hope, that this laudable investigation will meet with support and success which it deserves."(72)

There followed a list of the London bankers who agreed to manage the funds and expend them in a way approved by the contributors. It was hoped that various country bankers would transmit the money received for this venture to the designated individuals in London.(72) The individuals contacted by post appeared to offer aid and support but the published prospectus attracted considerable opposition to the idea of treatment of disease by pneumatic means despite a moderate statement of Beddoes' views and lack of extravagant claims. There were many subscribers in Edinburgh and the Midlands but very few from London. The presence of so many known radicals around Beddoes insured hostile publicity for the Institution. There was a critical and unfavorable article about the Pneumatic Institution in "The Anti-Jacobin Review and Magazine."(65)

A most important event in the development of pneumatic medicine was the association of Dr. Beddoes and Mr. James Watt. Watt was a giant in the fields of engineering and technology and also made contributions to pure science. In June 1794, he had lost his daughter, Jessie, to tuberculosis and in his grief associated with her terminal illness and death had vowed to do something against this disease. Watt described his daughter's death and Beddoes attempts at pneumatic treatment during the terminal phase of her illness.(73)

Beddoes was concerned lest Watt interpret these pneumatic measures as pure and unjustified experimentation.(40) Watt wrote to Darwin on June 30, 1794:

> "....I have long found that when an evil is irreperable, the best consolation is to turn the mind to any other subject that can occupy it for the moment. This is not always possible, but we must make the best of our imperfect nature, and do what lies in our power. I told you that I had turned my contemplations to the subject of medicinal airs; not from any idea that I understood the subject, but because nobody else does, and therefore that my hints might by chance be as good as another man's. Where the regular physician expresses his ignorance, the quack may safely be called in, and Dame Fortune suffered to throw the dice. I have made an apparatus for extracting, washing, and collecting of poisonous and medicinal airs....I have written a short list of my hints for Dr. Beddoes, and am sending him an apparatus, a description of which he means to insert in his next publication."(74)

As he noted in his letter, Watt designed and built the pneumatic apparatus used by Beddoes and later by Davy for experimentation, and himself became somewhat of an authority on medicinal uses of airs. In a subsequent letter to Davy, Watt expressed further thoughts on pneumatic equipment and also his recommendations for medicinal inhalation of certain gases.(75)

1794 marked the appearance of the first two parts of "On the Medicinal Uses of Factitious Airs, etc.," by Beddoes and Watt. Beddoes was receiving so many communications from physicians in various parts of Britain claiming cures and good results with pneumatic therapy that the third part of "Factitious Airs" was published in 1795. Again, this elicited what Beddoes and his circle considered excessive opposition to pneumatic means of therapy. It should be noted that the extravagant cures and successes reported in this publication were not those of Beddoes. He merely assembled them and provided a few comments. By 1795 £800-900 had been pledged for a Pneumatic Institute. Among the subscribers listed at this time were several members of the Lunar Society of Birmingham: Boulton, Darwin, Edgeworth, Keir, Watt and several Wedgwoods. Also listed were J.Constable, Mrs. Congreve, Alexander Monroe, J. Reynolds, the Sneyds, and the Royal Society of Medicine. Altogether about 200 subscribers were listed at this time.(76)

1795-1797 was a period during which Beddoes enthusiastically re-entered the political arena.(77) He wrote and published several political tracts which, in this time of national apprehension and unease, could not have been well received by the establishment. In one of these he appealed for an early peace with France. He enumerated some of the perceived governmental abuses and discussed the futility of pursuing the war further.(78) His "Essay on the Public Merits of Mr. Pitt" (1796) did nothing to endear him to supporters of government policy.(79) The reign of terror had tempered his enthusiastic support for France and all things French, but he maintained a fervent lifelong support for the institutions and beliefs of equality and justice on which the French Revolution was founded. He was an outspoken advocate for abolition of slavery.(80)

A general crop failure in 1796 stimulated him to propose, in another of his political tracts, several ways in which food supply for the populace could be made more plentiful in future times of trouble.(81) He was critical of the government for having taken no measures at the start of the war to assure continued domestic food production. One measure that he recommended to secure more food was that farm animals, as far as practicable, should be fed on types of food which would be readily convertible to human use if the necessity arose. He observed that "an ounce of beef may contain the quintessence of tons of grass, hay and other vegetables." There was no known way to directly adapt this fodder for human use. But if animals were fed on potatoes, turnips, carrots and similar vegetables, which would presumably be grown by farmers instead of hay and grass, there would always be a large store of these available which could be converted to human use if required. He recommended evaluation of various vegetables and fruits not then considered palatable by man as well as conservation of barley by limitation of its use in brewing beer during periods of shortage. He considered possible condiments to make food more appetizing. He deprecated the steady use of opium by the poorer classes which was apparently becoming increasingly prevalent, but acknowledged that this drug might be useful for counteracting hunger for short periods.(82) These not unreasonable suggestions were to return to taunt Beddoes before long. But the increasing cultivation of root crops for animal fodder did in fact occur.(83) An important indication of his genuine concern for the welfare of the poor was his deliberate suppression of advertisements soliciting financial support for the Pneumatic Institution in 1795. He did not wish to divert money away from providing food for the poor.(84) In 1796 Parts IV and V of Beddoes' and Watt's "Factious Airs" were published. He also continued to solicit financial support for his projected Pneumatic Institution.(85) By 1796 he had secured enough pledges to begin something concrete with his plans for pneumatic medicine. He published "Suggestions towards setting on foot the projected establishment for ascertaining the powers of factitious airs in medicine." Also, about this time he published a pamphlet supporting the benefits of nitrous acid in the treatment of syphilis(86) and became involved in lectures in anatomy and chemistry aimed at the general public.(87,88)

Other interests of Beddoes included the design and manufacture of rational toys which could be disassembled to provide children with mechanical insight and instruction as to how common devices operated. He was also concerned with methods of education of young children; an interest which he shared with his father-in-law, Richard Lovell Edgeworth.(35)

About 1796 he assumed responsibility for the education of two of the sons of a deceased friend, Mr. Lambton.(89) This gentleman had consumption and had given Beddoes £1500 for support of the pneumatic institution.(90) Presence of these young children in his household gave Beddoes an opportunity to implement some of his theories on education. In 1797 Beddoes was visited by Mrs. Anna Laeticia Barbauld (1743-1825) who is remembered as a poet, a popular author of childrens' books and an advocate of progressive education for children. She and Beddoes concurred on many of their ideas on education and politics.(91) She may have inhaled nitrous oxide and experienced the characteristic effects while visiting the Pneumatic Institution.(30) She also knew Joseph Priestley and wrote poems to and about him.(92) Her father had been a teacher at the Warrington Academy while Priestley was there and Mrs. Barbauld's husband was a dissenting minister. Mrs. Barbauld commented on a spectacular pneumatic therapeutic measure. This was Beddoes' treatment of consumption in cow houses. (The rationale for this will become apparent later.)(93) In a letter to a friend dated August, 1797 she wrote:

> "I have seen Dr. Beddoes, who is a very pleasant man; his favorite prescription at present to ladies is, the inhaling the breath of cows; and

> as he does not like the German doctors, send the ladies to the cow house, the cows are to be brought into the ladies chamber, where they are to stand all night with their heads within the curtains. Mrs. ___, who has a good deal of humour, says the benefit can not be mutual; and who is afraid, if the fashion takes, we shall eat diseased beef. It is a fact, however, that a family have been turned out of their lodgings, because the people of the house would not admit the cows; they said they had not built and furnished their rooms for the hoofs of cattle."(94)

In Bristol the Barbaulds also met the Edgeworths and a long term friendship developed between Mrs. Barbauld and Maria Edgeworth, the novelist sister-in-law of Thomas Beddoes.(95)

Chapter XI

The Pneumatic Institution

In 1798 the Pneumatic Institution opened.(1) The marginal financial basis of this facility at its beginning was stabilized by a gift of £1000 from the Wedgwood family who had always been enthusiastic supporters of Dr. Beddoes' endeavors. The donation was one of the last acts of the old Lunarian Josiah and was made by him one month before his death. It fell to his son Thomas to assure delivery of the money. Apparently some time later, when the interest in pneumatic therapy at the Institution had begun to decline, Thomas Wedgwood contributed an additional £1000. He thought that it might be worthwhile to expend the sum, even at that late date, "in order to assure us that elastic fluids would not be serviceable as medicines."(2) The Institution was located in the buildings at numbers 6 and 7 Dowry Square in Bristol Hotwells. Uncertainty expressed by some previous authors regarding the location of the Pneumatic Institution must relate to the quarters occupied before the move since there can be little question as to the validity of the above-stated address in Dowry Square. The site was identified as the house forming the northeast corner of the square (#6 and #6A) by Joseph Cottle, Bristol publisher and close friend of Beddoes. Dr. George Parker, in the 1920's, was shown the property deed to these houses by the owners. These papers confirmed that these buildings had at one time been a single unit and that they had been owned by Dr. Thomas Beddoes. The garden mentioned by Humphry Davy was still present.(3) In our time the house is identified by a bronze plaque which indicates that at this location was the Pneumatic Institution founded by Thomas Beddoes, M.D. at which Humphrey Davy did his experiments which led to the use of nitrous oxide for pain relief in surgery.

According to modern street maps of Bristol, Rodney Place, where Beddoes lived, is about 1/4 mile north and slightly west of Dowry Square. It is downhill going from Rodney Place to the Pneumatic Institution in Dowry Square but uphill with quite a steep gradient returning. Considering Beddoes' complaint of breathlessness and his body habitus, he would have faced a difficult climb home. Dowry Square is off Hotwells Road just as it turns south to lead to the Avon Bridge. Rodney Place is on top of the "palisades" and loops off Clifton Down Road.

Announcement of the opening of the Pneumatic Institution appeared in the "Bristol Gazette and Public Advertiser" for Thursday, Mar 21, 1799:(4)

> **New Medical Institution**
>
> This Institution is fixed at the upper end of Dowry Square, Hotwells, corner house. It is intended among other purposes for treating diseases, hitherto found incurable, upon a new plan. Among the subscribers are almost all the Medical Professors at Edinburgh and a large portion of the physicians in England, who have done anything to improve the practice of their art. At present it is nearly ready for out-patients, and the attendance of persons in Consumption, Asthma, Palsy, Dropsy, obstinate Venereal Complaints, Scrofula or King's Evil, and other Diseases, which ordinary means have failed to remove, is desired.
>
> Patients will be treated gratis. The application of persons in confirmed Consumption is principally wished at present; and though the disease has heretofore been deemed hopeless, it is confidently expected that a considerable portion of such cases will be permanently cured.
>
> It has been perfectly ascertained by experience, that none of the methods to be pursued are hazardous or painful. Attendance will be given from Eleven till One o'clock by Thomas Beddoes or Humphrey Davy.
>
> Subscriptions for the support of this Institution received by John Savery, Esq; Narrow Wine Street, Bristol.

It can be presumed that this must have been a paid advertisement since it appeared in a column with other advertisements for a theatre performance, firearms for sale, houses to let, etc.

Of parallel interest is the Sea-Bathing Institute that opened at West Brook in 1796. The staff of this facility claimed many fantastic cures with sea bathing and sea water. This type of activity confirms that the Pneumatic Institution was not unique at the end of the 18th century as a medical institution offering therapy using a particularly recommended method.(5)

Members of the Lunar Society of Birmingham had important roles in launching the Pneumatic Institution. Included were Darwin and Edgeworth's giving of advice and Watt's extensive participation in designing and manufacturing apparatus, as well as selective solicitation of subscriptions. The younger James Watt secured support of Withering, Boulton, Watt and Galton and probably Keir. Eventually he enlisted all of the Birmingham physicians. James Watt Jr, in his correspondence, notes that all great scientists save Cavendish supported Beddoes. No reason for Cavendish's stand is given.(6)

Davies Giddy was unsuccessful in raising money for support of the Pneumatic Institution among his fellow Cornishmen. Apparently the idea of giving money for scientific research rather than to "visible objects of distress" was too novel.(7) Joseph Cottle indicated that Dr. Beddoes was well regarded in Bristol at the time of the opening of the institution and it was generally believed that the goals that he set could be accomplished.(8) The brothers Josiah Wedgwood Jr. and Thomas Wedgwood moved to Bristol about this time "in their anxiety to be near Dr. Beddoes." Thomas Wedgwood was said to be the earliest discoverer of photography. He was a chronic invalid and apparently wished to place himself under Beddoes' care.(9) Maria Edgeworth, a novelist and Beddoes sister-in-law described her life at Bristol when she visited in 1793 and again in 1799.(9)

Alexander Tilloch in his Philosophical Magazine in 1799 reported that the Pneumatic Institute was now well founded and that Dr. Beddoes was the "learned, ingenious and meritoriously persevering founder of it."(10) Beddoes' library must have grown in size to enviable proportions. On the visit made by Professor Joseph Frank of Vienna to Bristol in 1803, Beddoes was able to locate immediately in his library several books written by authors named "Frank."(11) Beddoes had reviewed 136 items for the Monthly Review in the period 1795-1800 and presumably these would also have been in his library. Gregory Watt wrote to Davy at Bristol commenting on Davy's access to foreign journals as timely as his own, confirming the comprehensiveness of the library at the Pneumatic Institution. Coleridge read many books and articles borrowed from Beddoes' library (and also the Bristol library).(12) Another activity of Beddoes was the planning and delivery of various series of public lectures designed to educate the populace on matters concerning health and medicine. However these were given sporadically and Beddoes acquired a reputation for undependability and unpunctuality as a public lecturer.(13)

A most fortunate and important circumstance associated with the opening of the Pneumatic Institution was the recruitment of Humphry Davy as its "Medical Superintendent." Davy, at nineteen years of age, had been educated in one of the remotest parts of Cornwall with "little access to philosophical books, and none at all to philosophical men." At this time his aim was to become a medical practitioner. He had formulated some theories involving heat and light. His scientific ability and a reputation for superior talent attracted the attention of Davies Giddy, also a Cornishman. While Beddoes was occupied in Clifton, Giddy had been engaged in activities in West Cornwall associated with new developments in engineering. He was working with Jonathan Hornblower and Richard Trevithick. One of their ideas was to break the monopoly of Boulton and Watt over the steam engine.(7) Giddy met Davy and wrote to Beddoes concerning the extraordinary abilities of his young new friend. At Giddy's instigation, Davy also wrote to Beddoes in April, 1798 offering to send him details of his experiments on heat and light. When Beddoes subsequently received this material, he was greatly impressed and was eager to include them in a volume of collected works from the west of England that he was editing. He quickly wrote to Giddy to determine if it might be possible to secure Davy's services at the Pneumatic Institution. This was arranged. Giddy took part in the negotiations to release Humphry Davy from his indenture as an apprentice to John Bingham Borlase, surgeon-apothecary of Penzance. With the blessings of his friends and family (except his patron and benefactor Mr. John Tonkin), Humphry Davy set out for Bristol in September, 1798. An unsuccessful contender for the post of Medical Superintendent was Thomas Thomson who later became Regius Professor of Chemistry at Glasgow University.(14) About this time the first patients were being received at the Institution.

The facility was initially planned to accommodate ten hospitalized patients and with facilities for care of 80 outpatients.(15) Rules and regulations of the Pneumatic Institution were published for guidance of patients. These pertained to regular attendance, details of diet and penalties assessed for infraction of the rules.(16) Common remedies were most frequently employed while gases initially were used relatively infrequently and most usually in patients receiving no benefit from more conventional types of therapy. This was a stated policy at the beginning designed to avoid unwarranted objections by those strongly opposed to pneumatic medicine.(17,18)

The apparatus used for storing and administering gases was designed by James Watt. The gases used in Beddoes' practice were oxygen prepared by heating powdered pyrolucite (manganese dioxide, MnO_2) or treating pyrolucite with concentrated vitriol (sulfuric acid), hydrogen from water dropped on red-hot iron, fixed air from chalk, and hydrocarbonate or water gas by dropping water on red-hot charcoal.(19)

As a scientist, Davies Giddy was able to appreciate Beddoes' ideas and aims and sometimes contributed suggestions. He wrote to Beddoes concerning "heavy inflammable air" (active ingredient; carbon monoxide):

> "The power of heavy inflammable air, as I take it, to diminish the secretions of excitability in the brain may possibly be applied to many useful purposes. May it not be used before painful operations?"(20)

This suggestion by Gilbert has apparently been overlooked or forgotten. As a proposal for use of inhalation of a gas for anesthesia it antedates Davy's analogous statement on nitrous oxide by five years.(7) It also was undoubtedly the source of a similar suggestion made by Beddoes to Dr. Frank of Vienna several years later (vide infra). Activities associated with the Pneumatic Institute sometimes took unexpected turns. On one occasion Beddoes had depleted the local waters around Bristol of frogs which he caught for his experiments. He requested a shipment of frogs from a friend in his native Shropshire. These were duly collected, placed in a barrel, and shipped down the Severn River. On Bristol quay the barrel was dropped. It burst and hundreds of frogs leapt in all directions to the dismay of bystanders who thought they must be meant for food for French revolutionaries concealed within the city.(21,22)

In 1799 the volume of miscellaneous papers entitled "Contributions to Medical and Physical Knowledge from the West of England" appeared. In this work were Davy's papers on heat and light. Davy subsequently wished that these had never been published and Beddoes was later criticized for encouraging his young protégé in groundless speculation by allowing these youthful, fanciful conjectures to appear in print. Also in this volume was Beddoes' denunciation of the conduct of certain individuals who unceasingly criticized his work. He characterized them as "certain British literary ruffians, who engage by the day, or the week, or the month, to assassinate literary reputations on account of delinquencies not literary."(23) These comments were no doubt directed to those critics of Beddoes who persisted in taunting and satirizing him and his works on the basis of previous political and exuberantly fanciful scientific writings. Richard Lovell Edgeworth, Beddoes' father-in law wrote that Beddoes would have avoided most of this criticism and ridicule and would have been successful if he could only have stayed out of politics.(6) Stock had previously commented how an earlier publication, "Proposal for the Improvement of Medicine" in 1794 had elicited intense opposition in spite of a moderate statement of views and lack of extravagant claims. This publication was eventually affixed as a preface to "Factitious Airs, Parts I & II."(24) Satire may be written to either urge improvement in the condition being satirized or to punish the alleged offender.(25) Most of the indignities suffered by Beddoes at the hands of his "British Literary Ruffians" were clearly of the latter type. They aimed directly at the jugular vein and were designed to destroy Beddoes' reputation and credibility. But Beddoes in turn was often not kind to certain colleagues in his own writings. His hostility was sometimes directed at conservative doctors, but most frequently at "apothecaries and their slops." He was politically radical, yet hostile to popular empirical medicine and violently anti-quack, and well-nigh authoritarian.(26) In "Contributions from the West of England" also appeared accounts of attempts to use gases therapeutically from the European continent.

One particularly vicious attack on Beddoes by an anonymous "British literary ruffian" was "The Golden Age" published in 1794. This communication was in the form of a poem and was labeled as "A Political Epistle from Erasmus D________N, M.D. to Thomas Beddoes, M.D ." The poetry parodied the literary style of both of these doctors and mercilessly raked Beddoes over the coals for a variety of his more outlandish opinions and predictions expressed in previous publications. As examples:

> "No more immers'd in many a foreign dye.
> Shall British wool be taught to blush and lie;
> But all our pastures glow with purple Rams,
> With scarlet Lamkins and their yellow Dams!"

These lines chide Beddoes for his suggestion that the color of animals might be altered by raising them in atmospheres of varying gaseous composition. He had reached this conclusion based on the observations that breathing an atmosphere deficient in oxygen caused bluish coloration of the skin and mucous membranes while breathing an oxygen enriched atmosphere was perceived to cause ruddiness. The parodist continued:

> "No more the lazy Ox shall gormandize,
> And swell with fattened grass his monstrous size;
> No more trot round and round the groaning field,
> But tons of Beef our loaded Thickets yield!"

These lines were written in response to the suggestion of Beddoes, made in the years of famine in the early 1790s, that farmers should not dedicate their land and efforts toward raising hay to fatten cattle. Rather they should raise vegetables such as turnips or carrots as animal fodder so that in case of famine the crops could be diverted to human consumption. The parodist continued:

> "The patient Dairy-Maid no more shall learn,
> With tedious toil to whirl the frothy Churn;
> But from the Hedges shall her Dairy fill,
> As pounds of Butter in big drops distill!"

This verse resulted from Beddoes' beliefs in the etiology of obesity. He believed that oxygen deficiency in the body predisposed to formation of fatty tissues (see section on "Medical Writings of Beddoes" which follows). He had suggested that perhaps plants, if raised in an atmosphere of low oxygen concentration, could be taught to provide butter and tallow! In this poem Beddoes was also thoroughly taken to task for his support for the French Revolution and its ideals, his anti-Christian and atheistic views, his opposition to class systems, his endowing of plants with animal characteristics, his suggestions on scurvy and consumption, his suggestions for prolonging life and vigor by pneumatic means and other perceived unpopular and outlandish views.(27) It is apparent that Beddoes invited much of this type of criticism by the enthusiastic and uncritical presentation of his frequently eccentric opinions.

Another example of Beddoes as a victim of ridicule by a "literary ruffian," though this time an American, was in the poem "Terrible Tractoration," by Thomas Fessenden of New Hampshire, first published in London in 1803.(28) The title of this poem was derived from certain medical devices called "Metallic Tractors," invented by Elisha Perkins of Connecticut, and intended to be applied to the body to draw off "excess electrical fluid" which was perceived to be involved in many disease processes. Fessenden claimed that he believed in the power of the tractors. In the poem, he did not confine himself to comments on the tractors, but considered a wide variety of contemporary individuals and topics. His self-stated objective was to give them "...notoriety, or honorable mention in a humorous way..." The reader was to "laugh with rather than laugh at" the inventors and the purpose was "rather to advertise than to stigmatize" their inventions. Nevertheless the poem still gives the impression of derision and ridicule of its subjects, who were unlikely to have been amused by the verses.

The protagonist of the poem is Dr. Christopher Caustic, a physician of great accomplishments and many inventions who has fallen from his high place and is now petitioning for financial assistance. However he is unable to formulate the verse in which to do this. Some extraordinary stimulus or aid is required to provide the necessary poetical eloquence. This arrives in the form of nitrous oxide. Caustic (Fessenden) wrote:

Beddoes (bless the good doctor) has
Sent me a bag full of his gas,
Which snuffed the nose up, makes wit brighter,
And eke a dunce an airy writer.
With this a brother bard, inflated,
Was so stupendously elated,
He tower'd like Garnerin's balloon,
Nor stopp'd, like halfwits, at the moon:
But scarce had breath'd three times before he
Was hous'd in heavens's high upper story,
Where mortals none but poets enter,
Above where Mah'met's ass dar'd venture.

The 'brother bard' mentioned was Robert Southey and the verses allude to his statement that "the atmosphere of the highest of all possible heavens was composed of this gas" (referring to nitrous oxide). In a subsequent verse, Dr. Caustic finally inhaled nitrous oxide but resisted excessive inhalation. He described the sensations experienced and some of his hallucinations:

And now, to set my verses going,
Like "Joan of Arc," sublimely flowing,
I'll follow Southey's bold example,
And snuff a sconce full, for a sample.
Good Sir, enough! enough already!
No more, for Heaven's sake! -steady! -steady!
Confound your stuff! - why how you sweat me!
I'd rather swallow all Mount Etna!
How swiftly turns this giddy world round,
Like tortur'd top by truant twirl'd round;
While Nature's capers wild amaze me,
The bedlam's cracked or Caustic crazy!

I'm larger grown from head to tail
Than mammoth, elephant or whale!—
Now feel a "tangible extension"
Of semi-infinite dimension!—
Inflated with supreme intensity,
I fill three quarters of immensity!
Should Phoebus come this way, no doubt,
But I could blow his candle out!

Then after expressing a few delusions of grandeur experienced under influence of the gas in the next few verses, the effect wanes.

But now, alas! a wicked wag
Has pulled away the gaseous bag:
From heaven, where thron'd, like Jove I sat,
I'm fall'n! fall'n! fall'n! down, flat! flat! flat!

Dr Caustic considered the fate of those who inhaled to excess and directed a few sarcastic comments to Beddoes questioning his involvement with these practices.

How these confounded gases serve us!
But Beddoes says that I am nervous,
And that this oxyd gas of nitre
Is bad for such a nervous writer!
Indeed, Sir, Doctor, very odd it is
That you should deal in such commodities,
Which drive a man beside his wits,
And women to hysteric fits!

Later in the Poem Priestley and Davy became the subjects of Dr. Caustic's remarks.(28)

Yet another British literary ruffian assaulted Beddoes in the press in the "Anti-Jacobin Review and Magazine" in 1800 in a review of Beddoes "Notice of Some Observations made at the Medical Pneumatic Institution." The critic wrote:

> "Most of our readers know the zeal with which Dr. Beddoes has investigated the medicinal effects of the gases; the numerous theories and new medicines with which he has successfully treated the public and the many disappointments to which the failure of these theories and new medicines has subjected him: still he continues to prosecute new plans and to invent new theories with as much ardor as ever; disappointments seem rather to have increased than diminished his confidence of ultimate success. He has lately established under the name of the Medical

> Pneumatic Institution, a kind of hospital at Bristol, for the express purpose of trying the effects of new and especially of pneumatic medicines....."

The publication being reviewed, i.e. "Some Observations at the Pneumatic Institution" gave an account of these proceedings. The "ruffian" continued:

> ......"A new medicine, he tells us, has actually been found, which professes very wonderful effects, This new medicine is the dephlogisticated nitrous gas of Priestley and the Dutch Chemists, to which Dr. Beddoes and his associate Mr. Davy have given the name of...."

Nomenclature and method of preparation of nitrous oxide were described. Also related were circumstances of Davy's first breathing of the gas, Beddoes' and Davy's descriptions of its effects, and some of its medicinal applications.

> "....Such is the substance of Dr. B's publication. We sincerely wish his Institution all the success he deserves. If it be the means of discovering a cure for palsy, the author of it will be entitled to the eternal gratitude of the human race. At the same time our author who knows how to make "allowance for prejudice" and to treat "vulgar, plodding, doubting minds" with proper contempt will forgive us if we are not quite so sanguine as he is in our expectation of the wonderful effects which this new remedy is to produce. The phenomena of life are not so easily reduced to subjection as the heated brains of modern theorists lead them to suppose."

The reviewer opines that the phenomena of life have escaped from description and control of chemists and mathematicians. They have far outstripped explanation and action by ideas of stimuli and excitability; they defy control by electricity and galvanism: ..."nor have the assaults of the modern chemists been hitherto more successful, armed as they are from head to foot, with their oxygens, their carbons, their sulphurets, their hydrocarbonates, their oxyds, and their gases." ...The reviewer is skeptical and will require much more proof that cures are at hand. He employed many quotes from Beddoes own writings and turned upon him with his own expressions such as "reptiles that plant themselves in the high road to improvement" etc. Beddoes' plan to prepare a series of gas mixtures with varying degrees of stimulating or depressing powers was particularly viciously ridiculed:

> ...."We shall be made immortal in the twinkling of an eye, or rather we shall be made over again; for we are to receive new bodies and new minds too: frogs are to be converted into oxen; and oxen, no doubt, into men."..."Nothing would be necessary but to convert the whole

> atmosphere into a gaseous oxyd of azote. This would make us all angels in a trice; not to mention the inexpressible pleasure of being drunk all our lives long."

The reviewer believed that modern science surpassed that of the ancients because real contributors, such as Harvey and Newton trod the plodding path of investigation established by their predecessors rather than venture far out in speculation such as "men of genius" as understood by Beddoes. Beddoes should have heeded the admonition to "keep the beaten track and extend it."(29)

Another of Beddoes' critics was John Ayrton Paris, a biographer of Humphry Davy. Writing in 1831 Paris related the following anecdote to illustrate what he perceived as Beddoes' wildly exuberant approach to medical practice:

> "Caught by the loosest analogies he would arrive at a conclusion without examining all the conditions of his problem. In the exercise of his profession, therefore, he was frequently led to prescribe plans which he felt it necessary to retract the next hour. His friend Mr. T_ had occasion to consult him upon the case of his wife: the doctor prescribed a new remedy; but in the course of the day he returned in haste, and begged that, before Mrs T_ took the medicine, its effect might be tried on a dog!"

Another story designed to show Beddoes' unhesitating acceptance of facts which agreed with his preconceived notions was also told by Paris:

> "The following anecdote which was lately communicated to me by Mr. Coleridge will not only illustrate a trait of character, but furnish a salutary lesson to the credulous patron of empirics. As soon as the powers of nitrous oxide were discovered, Dr. Beddoes at once concluded that it must necessarily be specific for paralysis. A patient was selected for the trial, and the management of it was entrusted to Davy. Previous to the administration of the gas, he inserted a small pocket thermometer under the tongue of the patient, as he was accustomed to do upon such occasions to ascertain the degree of animal temperature with a view to future comparisons. The paralytic man, wholly ignorant of the nature of the process to which he was to submit, but deeply impressed, from the representations of Dr. Beddoes, with the certainty of the success, no sooner felt the thermometer between his teeth that he concluded that the "talisman" was in full operation, and in a burst of enthusiasm declared that he already experienced the effects of its benign influence throughout his whole body: – the opportunity was too tempting to be lost – Davy cast an intelligent glance at Mr. Coleridge, and desired the patient to renew his visit on the following day, when the same ceremony was again performed, and repeated every succeeding day for a fortnight;

> the patient gradually improved during that period, when he was dismissed as cured, no other application having been used than that of the thermometer. Dr. Beddoes, from whom the circumstances of the case had been intentionally concealed, saw in the restoration of the patient the confirmation of his opinion, and the fulfillment of his most ardent hope – nitrous oxide was a specific remedy for paralysis! It were criminal to retard the general promulgation of so important a discovery; it were cruel to delay the communication of the fact until the publication of another volume of his "Contributions"; the periodical magazines were too slow in their rate of travelling – a flying pamphlet would be more expeditious; paragraphs in the newspapers; circulars to the hospitals: such were the reflections and plans which successively agitated the physician's mind, when his eyes were opened to the unwelcome truth by Davy's confessing the delusion which had been practiced."(30)

These anecdotes, although generally in accord with what others wrote about Beddoes, were probably greatly exaggerated and embellished as were many of the statements in Paris' biography of Davy. Coleridge also related the story of the cure of palsy with the thermometer. He told it as a simple clinical occurrence and observation by Davy and did not mention any inane response by Beddoes. In a letter dated January, 1799 Davy stated to his friend in Penzance, Mr Penick, that he considered Beddoes to be the most liberal, candid and philosophic physician of the age since he readily abandoned theories which proved to be untenable.(14) While he was working at the Pneumatic Institution, Davy characterized Beddoes as a "celebrated medical philosopher and being the only one who has used chemistry to assist in the cure of diseases."(31) Beddoes characterized Davy as "the most extraordinary person that I have seen, for compass, originality and quickness of thought."(32) Others of Beddoes' contemporaries praised his scientific and clinical abilities. Dr. L. Maclean wrote:

> "Dr. Beddoes' name is familiar wherever the sciences are cultivated, his capacious mind having embraced every branch of them; and his zeal in making his labours and discoveries more especially subservient to the health and comfort of his fellow-creatures, is highly meritorious, and lays the public under weighty obligations to him.(33) Dr. George Mossman observed that: "....surely the ingenious Dr. Beddoes is entitled to much applause, for the industry, which he has exhibited, in his attempts to obviate the fatality of phthisis."(34)

Davy wrote a sketch in the last year of his life and delivered his final assessment of Beddoes:

> "He was admirably fitted to promote inquiry better than to conduct it. Beddoes was reserved in manner and almost dry; but his countenance

> was very agreeable. He was cold in conversation and apparently much occupied with his own peculiar views and theories. Nothing could be a stronger contrast to his apparent coldness in discussion, than this wild and active imagination, which was as poetical as Darwin's. He was little enlightened by experiment, and, I may say, little attentive to it. He had great talents, and much reading, but had lived too little amongst superior men. On his deathbed he wrote a most affecting letter, regretting his scientific aberrations. I remember one expression: `Like one who has scattered abroad the avena fatua of knowledge, from which neither branch, nor blossom, nor fruit has resulted, I require the consolations of a friend.' Beddoes had talents which would have exalted him to the pinnacle of philosophical eminence if they had been applied with discretion."(35)

Robert Southey had selected Beddoes as his personal physician and remained under his care for complaints originating in what Beddoes diagnosed as a nervous condition due to a sedentary mode of life. Southey communicated his opinion of Beddoes in a letter to a Mr. May:

> "Of Beddoes you seem to entertain an erroneous opinion. Beddoes is an experimentlist in cases where the ordinary remedies are notoriously and fatally inefficacious: If you will read his late book on consumption you will see his opinion upon this subject; and the book is calculated to interest unscientific readers, and to be of use to them. The faculty dislike Beddoes because he is more able, and more successful, and celebrated, than themselves, and because he labours to reconcile the art of healing with common sense, instead of all the parade of mystery with which it is usually enveloped. Beddoes is a candid man, trusting more to facts than to reasonings: I understand him when he talks to me, and, in case of illness, should rather trust myself to his experiments than to be killed off *secundem artem*, and in the ordinary course of practice....."(36)

In 1799 there also appeared Beddoes' "Essay on the Causes, Early Signs, and Prevention of Pulmonary Consumption for the Use of Families."(37) This pamphlet quickly sold out and a second edition was required. He extensively reviewed the influence of class, occupation, climate, diet, exercise, temperature and temperature variations on the incidence of consumption. He described the physical signs and clinical course of the disease. The most effective treatment of consumption was said to be foxglove. There is an obscure reference to the possible utility of the newly evaluated nitrous oxide, but beyond this, application of pneumatic treatments in phthisis are scarcely mentioned. Beddoes ideas on consumption as set forth in this pamphlet, especially his enthusiastic advocacy of the then popular foxglove, again attracted considerable criticism and ridicule.

Meanwhile, the activities for which the Pneumatic Institution is principally remembered today were well under way.

When Davy initially arrived in Bristol, his first laboratory was at Beddoes' residence at No. 3 Rodney Place in Clifton. When the house at 6-7 Dowry Square was acquired the laboratory was moved there.(38) Davy turned to his detailed examination of the chemical and physiological effects of nitrous oxide gas. This gas had been discovered by Priestley and named "dephlogisticated nitrous air." French chemists knew the gas and named it "gaseous oxyd of azote." Davy had proved the respirability of this gas and had noted the surprisingly pleasurable sensations and peculiar activity of the mind whilst breathing this gas. The first communication of these observations was by Davy and appeared in Nicholson's Journal.

In 1799 the effects of breathing nitrous oxide were also described and commented upon by Beddoes in a pamphlet titled "Notice of some observations made at the Pneumatic Institution." In this publication Beddoes assured his readers that he would not be turned aside from his stated intentions by what he perceived as premature criticism. Beddoes described his administration of nitrous oxide in some cases of palsy and was highly gratified with the results. Nitrous oxide had been administered hundreds of times to paralytic patients. Caution was necessary in administering the gas to patients predisposed to hysteria. They might develop recurring hysterical fits. Beddoes had personally inhaled nitrous oxide and was able to describe its effects. He said that although he felt alert and refreshed after the inhalation he appeared to an expert onlooker to be intoxicated. Nitrous oxide inhalations had apparently cured him of headache under some circumstances. Potential users of the gas were admonished concerning the dangers of improperly prepared gas. Joseph Cottle, in his memoirs, also described experiments performed by Dr. Beddoes involving nitrous oxide.(39)

Beddoes came to regard nitrous oxide as a more perfect form of oxygen so that by using both gases, a wider range of medicinal powers might be expected. Many of the expectations that he had previously expressed regarding oxygen he now settled on nitrous oxide and even to a greater extent. These included enhancing of bodily and mental powers, renewing excitability and converting a torpid to a vivacious personality. On the basis of some observations on nitrous oxide, he reiterated questions that he stated previously in opposition to some aspects of the Brunonian system of medicine.(40) He proposed that the gas could be used to rule over the cause of pleasure and pain. Not unexpectedly, these expectations and observations by the Doctor attracted disbelief and ridicule. In addition to pneumatic activities, Beddoes continued to advocate the use of nitrous acid in venereal disease and encountered considerable opposition in this area. Also, in this communication Beddoes announced that he had abandoned his original hypothesis on the nature and cure of consumption. However, he still held out promise for certain gases in consumption when used in conjunction with foxglove. The observations included a fervent plea for further financial support to permit the

Pneumatic Institution to continue its work. One point emphasized was that it availed parents little to accumulate wealth for their children if the children succumbed early to some dread disease for which effective therapy might have been discovered by suitably endowed investigation.(41)

About 1799 or 1800 Beddoes was consulted by Josiah Wedgwood Jr. concerning a developing spinal curvature in his daughter, Sarah Elizabeth. There are several reasons why Wedgwood might have selected Beddoes in this circumstance. First, Beddoes and the younger Wedgwood had been friends for a number of years. In addition, Wedgwood may have thought that the condition was caused by tuberculosis of the spine. Beddoes was one of the few physicians who held out any hope for a cure of tuberculosis. Finally, Wedgwood may have needed the reassurance of Beddoes' universal optimism which caused him to promise a good result in every patient. In one of the early letters from Beddoes to Wedgwood (April 1799) Beddoes gave an enthusiastic report on the progress at the Pneumatic Institute. He was having impressive results with foxglove in consumption and the preliminary results with nitrous oxide were extremely promising. He described the gas as:

> "A species of air of which a small quantity has repeatedly exhilarated different persons in the most remarkable manner and a larger quantity produces perfect intoxication without subsequent debility."(42)

The measures prescribed by Beddoes for Sarah's spinal curvature, including rest, cautious exercises, medications and hanging by the hands were of no avail. Sarah Elizabeth Wedgwood retained her scoliosis throughout her long life of 87 years. She never married because of her deformity. She became known as a kind and gentle philanthropist because of her good works among the poor.

Another type of "mechanical medicine" involved an apparatus contrived to shake patients.(43) The object of this type of "swinging therapy" was to induce motion sickness to help promote absorption of material from ulcers. Beddoes and Erasmus Darwin both applied swinging as a less drastic method of inducing nausea than emetics.(44) It should be recalled that in the Brunonian system of medicine nausea and vomiting were debilitating measures and medically useful in decreasing excitement and permitting accumulation of excitability in sthenic disease.(45)

In 1800 Mr. King was engaged as another medical superintendent to take charge of physiological investigations outside of the pneumatic area.(46) King was a surgeon recommended to Beddoes by Dr. John Abernethy of St. Bartholomew's Hospital, London. He was born in Switzerland and originally had the name Nicholas Johann Koening. He came to London to study anatomy and physiology. Following his move to Bristol he married one of the Edgeworth sisters, Emmaline, thereby becoming Beddoes' brother-in-law. After Beddoes' retirement in 1807 the institute, as a conventional medical institution, passed into the hands of Drs. King and John Edmunds Stock.(14) Stock indicated that Dr. Beddoes suggested experiments to King which he then cleverly executed. Robert Southey had a high opinion of King. In 1827 he wrote to Mr. May, who had evidently just moved to Bristol:

> "I would have you know King, the surgeon, also, with whom I lived with great intimacy and for whom I have great and sincere regard. His wife is sister to Miss Edgeworth. A more remarkable man is rarely to be found and his professional skill is very great..."(47)

Another physician who for a time was associated with the Pneumatic Institution was Peter Mark Roget (1779-1869) Some of the common friends of Roget and Beddoes included Erasmus Darwin, James Kier, Lovell Edgeworth and probably Davies Gilbert. In 1798 Roget wrote a letter to Beddoes on the non-prevalence of consumption among butchers, fishermen, etc. In 1799 he sent a communication to Davy on the effects of breathing nitrous oxide. He subsequently held an amazing number of responsible positions both in Manchester and in London. He was among the founders of Manchester University Medical School and also London University. He had very wide interest in fields other than medicine and was elected FRS primarily because of a logarithmic slide rule that he invented. He was secretary of the Royal Society and edited the "Proceedings" for many years. Roget's famous "Thesaurus" was compiled after retirement in 1840. Roget remained in Bristol with Beddoes only a short time and left at the end of summer of 1799. In 1816, considerably later in his career, Roget worked for a period with professor J.A. Albers of Bonn Germany and was co-author with Albers of a paper on skin coloration in argyria. Professor Albers was probably among the last of the pneumatic physicians. His work on the inhalation of chlorine in tuberculosis spurred a brief revival of pneumatics about 1829-1833.(48,49)

In contemporary directories, the staff and the official title of the Pneumatic Institute over the years were listed as follows:

> 1799 and 1800 – Hotwells Medical Pneumatic Institute. Physicians: Thomas Beddoes, M.D.; R. Kinglake M.D.; P. Roget, M.D.; Medical Superintendent, H. Davy.
>
> 1801 – Hotwells Medical Pneumatic Institute. Physician T. Beddoes; Surgeon, J. King; Medical Superintendent, H. Davy.
>
> 1803 – Hotwells Medical Pneumatic Institute. Physician: T. Beddoes; M.D.; Surgeon, J. King.
>
> 1805 – Medical Institution, Broad Quay and Hotwells. Physicians, T. Beddoes, J.E. Stock; Surgeon, J. King.(3)

In 1800 Davy published his "Researches, Chemicals and Philosophical Chiefly Concerning Nitrous Oxide." Surprisingly little is said of this event in Stock's biography of Beddoes. The point specifically mentioned is that Beddoes had come to believe that excitability and excitement could increase and more often decrease together.

Late in 1800 a typhus epidemic ravaged Bristol. The facilities and staff of the Pneumatic Institute were fully occupied with victims of this disaster. Beddoes wrote simple instructions for avoiding and treating the typhus. These were circulated in the form of a handbill, particularly among the poor of the city. Preoccupation of Institute personnel in coping with the epidemic, along with the departure of Humphry Davy to take up his new post at the Royal Institution in London effectively marked the end of pneumatic activities in Dowry Square.(50,51,52)

In 1801 Beddoes published "On the medical and domestic management of the consumptive, on the powers of digitalis, and on the cure of scrofula." This work began by stressing the therapeutic importance of attaining optimum ambient temperatures in various disease states. Consumption, in contrast to other diseases, was best managed by elevation of temperature. It had been observed that the consumptive improved in the summer and that removal to a warm climate often had a salubrious effect in consumption. One particular method proposed to maintain a warm and steady temperature was to lodge the patient in a confined chamber with cows as mentioned previously. The body heat and exhalations of the animals, together with occasional use of a stove could sustain a healthy temperature. One patient who was treated in this manner was Sally Priestley Finch, daughter of Joseph Priestley. Long standing bothersome symptoms of consumption in Mrs. Finch were relieved on her second night in the cow house. Beneficial effects of this type of therapy were attributed both to the warm temperatures and to a specific effect of the exhalations of the cows. These were believed to be alkaline in nature and to favorably influence the course of consumption in the same manner as other previously advocated gaseous remedies. Beddoes then discussed his views on the pharmacology of digitalis and the use of this drug in the treatment of consumption.

In a letter to Davy, Gregory Watt commented on the perceived success in treating Mrs. Finch and on the benefits of cowhouses or warm environments in general:

> "The reputation of the cowhouses I should think must be nearly established by the very successful case of Mrs Finch. At present I hear you have few patients in them and that the advantages derived from rooms of a heated temperature appear equal if not greater than those derived from residence in a cowhouse. Certainly, if equally efficacious, the hot room must be a much more agreeable medicine and perhaps more generally acceptable than the cowhouse."(53)

An example of Beddoes' kindness was found in the situation of a hysterical lady who reacted poorly to nitrous oxide and who was set forth as an example of a type of individual who should not receive nitrous oxide, as recorded in Davy's "Researches." She was taken into Beddoes' house after her attempt to breathe nitrous oxide.(54) She became a great friend of both Dr. and Mrs. Beddoes. She was involved in some type of domestic trouble. Stock published a considerable correspondence between her and the doctor subsequently.

During these busy years at Bristol Beddoes' domestic life was sufficiently tranquil to permit his continuing work without major distraction. However, his marriage was not without difficulties and he surmounted several personal problems. Anna Maria Edgeworth was 20 when she and Dr. Beddoes were married. Davies Giddy had spent some time in Bristol in 1800 believing he was consumptive. When he left, Anna Maria sent him what he considered quite inappropriate, intimate and suggestive letters. In these she admitted an affair with a married man and related that when she confessed this affair to Dr. Beddoes he regarded it as quite absurd and laughed it off. Anna Beddoes appeared eager to become Giddy's mistress and rather shamelessly pursued him in the latter years of the first decade of the 1800's. Giddy appears to have behaved consistently ethically and on numerous occasions rejected her advances. One opinion stated that Anna Beddoes was bored and resentful of the neglect of her husband and was looking for adventures and companionship from other sources.(7) She appears also to have resented living in such an intensely intellectual atmosphere without the education to participate in it fully. In spite of all this, it is likely that she had become resolved to make her marriage a success. In a letter written to Giddy in July, 1801 she related that Dr. Beddoes had contemplated suicide as the only escape from the chronic shortness of breath from which he always suffered. He begged Anna Maria "in the most serious manner to let him put himself out of pain, this he repeated two or three times saying he could bear it no longer." The birth of her first child, Anna, in Dec 1801, seemed to inject new interest and vitality into her life. She took new interest in the doctor's work. Then during a visit to Cornwall in 1803 she became more attracted to Giddy and he expended considerable effort in rejecting her attentions. This pursuit of Giddy by Anna Maria increased in intensity.

A profound emotional shock to Giddy was the marriage of his sister in 1804. Apparently one solution to the Anna Maria problem entertained by Giddy was a platonic type of brother-sister relationship with Mrs. Beddoes. Finally the problem was solved when Giddy married Mary Ann Gilbert in 1808. It has been suggested that a part of the motivation for this marriage was to escape the situation with Anna Beddoes.(7) All through his marriage, Beddoes seemed to have been preoccupied with larger matters while Anna Maria believed, with remorse, that she did not serve him well. Perhaps she was not physically strong, although her health was generally good. It was said that she was more comfortable in the presence of poets than of scientists and saw something of herself in her son Thomas Lovell Beddoes.(55)

In 1803 Dr. Joseph Frank of Vienna visited Dr. Beddoes at Clifton. Dr. Joseph Frank (1771-1842) and his father, Dr. Johan Frank (1745-1821) were enthusiastic supporters of Brunonian practice and were very much instrumental in establishing it on the European continent as a viable method besides humoral based therapies.(56) Dr. Frank had taken advantage of an interval of peace on the continent to visit European charitable medical facilities and had included the Pneumatic Institute in his travels. He remarked that the pneumatic modes of therapy which had been tested at the Institute had proved disappointing. The facility at the time of his visit was functioning chiefly as a dispensary but occasional experiments with gases were still being performed under the zealous direction of the celebrated Dr. Beddoes. Frank wrote that he was "anxious to become personally aquainted with a physician of whom such various opinions are entertained, both abroad and at home." Armed with letters of introduction from Richard Lovell Edgeworth (Beddoes' father-in-law) and Madame Lavoisier, Frank appeared at the doctor's house in Clifton. Details of the visit were recorded minutely by Frank:

> "On entering his house, I gave the servant my introductory letters, that his master might be somewhat prepared, and not taken by surprise. After waiting about half a quarter of an hour, Doctor Beddoes appeared with several books under his arm. The first words that he addressed to me were, "Which Doctor Frank are you? for there are a great many of you." Before I could answer him, he laid before me, in a row, several books, all written by Franks, constantly asking as he turned them over, "Is that you? Is that you?" The first that met my eye, was a Materia Medica, by Solomon Frank. I protested against this being mine. Then followed some of the works which I had written in elucidation of the Brunonian system. Having now recognized me, Brown became the first topic of our conversation. We were soon agreed upon what was worthy of praise and what of censure in that system............. Doctor Beddoes, in his conversation, which grew every moment more interesting, showed the same fire and animation that are observable in his writings. On this occasion, as well as at subsequent interviews, he constantly insisted upon what he had insisted in his works, with regard to the utility of various gases and the digitalis purpurea, in phthisis. He proposes to add to his former publications upon this subject. - The inspiration of the Nitrous Oxyd of Ammonia, he says, has been beneficial in cases of paralysis. He suggested the idea of employing Hydro-carbonate in strangulated Hernia, with a view to throw the patient into syncope; and of attempting the reduction of the intestine, while he remained in that state. The Muriate of Lime is, in his opinion, superior to all other remedies in scrophulous diseases.... (Other medical opinions of Dr. Beddoes)..... These are the brief minutes that I have preserved of Doctor Beddoes's conversation. I now proceed to some observations on the spring called the Hotwell"(57)

Of particular interest is the description of Beddoes' explanation for the mode of action of oxygen in dropsy. He wrote (and also quoted Beddoes' "Factitious Airs") on the relief obtained by breathing of oxygen in dropsy and explained the relief thus:

> "that by presenting a more highly oxygenated medium to those air-cells which were not obstructed, the systems of such persons received nearly an equal supply of this essential principle, with those of persons in ordinary health; who though they inhaled it in a form so much less concentrated, imbibed it by a more extended surface."(58)

(This must be a very early description, perhaps the first, of ventilation-perfusion relationships or of diffusion abnormalities in the lung). Also of great interest is the above related concept that Beddoes expressed to Dr. Frank:

> "He suggested the idea of employing Hydro-carbonate in strangulated Hernia, with a view to throw the patient into syncope; and of attempting the reduction of the intestine, while he remained in that state."

This is clearly an unambiguous enunciation of the concept of inhalation anesthesia and will be further discussed later. (See Early Suggestions for the Use of Anesthesia.)

The fraction of patients who were treated with pneumatic means diminished continuously during the life of the Pneumatic Institute. This was in part due to the large numbers of applicants for medical care that were attracted to the facility.(59) After the departure of Davy, Mr. Sadler, son of Beddoes' associate at Oxford, was engaged to conduct limited chemical experiments in one room. Eventually, both name and purpose of the Institute changed.(60)

Stock provided an extensive summary of the views on pneumatic therapy as discussed in "Factitious Airs." It was emphasized that most of these case reports were transmitted to Dr. Beddoes and were not his own cases.(61) Generally, therapeutic trials of gases at the Pneumatic Institution had produced results quite similar to those described in the 1794-1795 book by Beddoes and Watt on the medicinal uses of factitious airs.(62) The additional results obtained with nitrous oxide were striking and dramatic. Of particular interest were the results with this gas in palsy. Nitrous oxide was identified as a diffusible stimulus, that is one being capable of being absorbed systematically and then of diffusing throughout the body to act at many sites. But within the context of the Brunonian system of medicine it was a unique stimulus by virtue of its ability to elicit excitement while simultaneously permitting accumulation of excitability. (Beddoes was disposed, partly on the effects of nitrous oxide, to dispute some particulars of Brown's doctrine of excitability).(63) The importance of this property was emphasized by Stock as he wrote, "In cases of extreme debility, every medical practitioner knows the difficulty in applying stimuli in such due proportion, that the excitement produced may not be succeeded by a fatal degree of exhaustion." In 1801 Beddoes reported a case involving an individual who had allegedly inhaled nitrous oxide at the Royal Institution in London without experiencing any subjective effects from the gas. On subsequent inhalation of genuine nitrous oxide at the Bristol Pneumatic Institution the same person experienced all of the expected physical and mental changes. Beddoes postulated that he must have been breathing air at the initial inhalation since nitrous oxide will produce the expected results about 95% of the time.(64)

Therapeutic nitrous oxide inhalation at the Pneumatic Institution persisted for some time after the use of other gases had been supplanted by other forms of therapy. Even nitrous oxide was rarely used in the last years of the Doctor's life and interest in pneumatic medicine seemed to have declined in other quarters to the extent that it was rarely mentioned. What little pneumatic work that was done was supported by Dr. Beddoes private funds.(65) John Ayrton Paris, biographer of Humphry Davy, wrote in 1831, "The gases are now never employed in the treatment of disease except by a few crafty or ignorant empirics...." Joseph Cottle, a Bristol publisher and a member of the circle about Beddoes believed that when Davy left the Institute Beddoes appeared to lose interest.(66) Cottle wrote:

> "This Pneumatic Institution, though long in a declining state, protracted its existence for more than two years, till the departure from Bristol, of Mr. D. and then, by its failure, it established the useful negative fact, (however mortifying) that medical science was not to be improved through the medium of factitious airs."(67)

Robert Southey also commented upon the declining pneumatic activity at the institution in the early years of the 19th century. In a letter of June, 1802 to Mr. Rickman he wrote:

> "...The Pneumatic Institute continues. The name should be changed, as they do little with gases, on account chiefly, of the expense of experiments. Beddoes now chiefly supports it. Davy's successor, King, a Swiss, is a very able man with a hand of dexterity almost as convertible as yours. Their patients are very numerous. They sometimes succeed in curing early consumption by the caustic; and their treatment of syphilis rarely or never fails. I forget whether you saw Beddoes. The old medical language fits his character admirably; he is of nature cold and dry. It is to be lamented that they have not pursued pneumatic experiments steadily; the gases act so immediately and powerfully that they should appear to be great agents in medicine....."(68)

When pneumatic cures failed to materialize Beddoes was forced to pay certain patients to attend the Pneumatic Institute. To assure the supply of patients Beddoes paid 16d per day at a time when the parish charitable allowance was 3d per day. Many patients believed and resented the fact that they were being experimented upon.(69) Stock indicated that Beddoes never abandoned his interest and trust in gaseous remedies. He further wrote, regarding pneumatic medicine, that "it appeared to have expired with its founder." But this statement was not warranted since Beddoes did not found pneumatic medicine. In addition, there were several enthusiastic articles on the subject published in the nineteenth century. (See chapter on pneumatic medicine.)

Beddoes' original plans had incorporated provisions for construction of air-tight apartments so that patients could be exposed to modified atmospheres for prolonged periods. It would be possible to make up in duration what one might lose in intensity of action. In addition absorption of gas through the skin was perceived as a possibility. There were some who believed that air-tight apartments were such a good idea that their lack had severely compromised therapeutic evaluation of gases. Stock wondered whether pneumatic medicine had fallen into a "premature and unmerited oblivion." Others believed that the popularity of pneumatic medicine might some day be revived. Townsend, commenting on phthisis in 1801, wrote that some people still believed in Beddoes' theory even though Beddoes himself may have questioned or even abandoned his pneumatic proposals.(70) The Pneumatic Institution changed both its orientation and its name. After 1803 it became a "Preventive Institution." The objective was to prevent diseases or to treat them early before they could take their toll. Still of particular interest were consumption and scrofula. To insure regular attendance and compliance with instructions each patient or family enrolled was required to deposit half a crown. This would be refunded upon proper completion of attendance requirements. Proper diet was emphasized and was made the responsibility of the patients and parents in cooperation with the physician.(16) The physicians of the Pneumatic Institution were apparently not welcomed with enthusiasm into the general medical community. A letter that appeared in a Bristol newspaper on 6 September, 1805, written by an unidentified correspondent who signed the letter "Old Subscriber," urged that Institute physicians be excluded from operations at the Bristol Infirmary to prevent them from:

> ".....rushing a muddy torrent into your hospital and converting your operating rooms into a theatre of endless disputation and dangerous contention. What security have you in such a case, that your wards should not be turned into cowhouses, and your apothecaries' shop into a manufactory of gases?"(71,72)

John Edmunds Stock came to the Institute in 1804. Dr. Beddoes practiced actively until 1807 and then gave up direction of the Institute to Drs. King and Stock. By that time over 10,000 patients had been treated. A letter written by

Robert Southey in January, 1807 to an ailing friend (Mr. Grosvener Bedford) attests to his perception of Beddoes professional competence and reputation:

> "Judging of your complaint by your medicine I suppose your liver is affected. Now, though calomel is usually the best medicine in such cases, it is not always so; and I know one instance, that of Mrs. Clarkson, wherein by immediately proscribing it and prescribing something else, Beddoes checked the disease and saved the patient. For God's sake, Grosvener, if you do not certainly feel yourself recovering by this ordinary mode of practice, state your case to Beddoes, a man who never tries experiments, except when ordinary methods would fail; and who in liver cases, is eminently successful. This is not said from any personal liking to the man, – I do not like him, – but I have the highest respect for his professional talents, and would, in any case of illness, resign myself into his hand, with the most perfect confidence that he would do for me whatever could be done by medical skill..."(68)

At the end of his professional career, Dr. Beddoes had become extremely dissatisfied and perturbed over many of his contemporaries who though practicing medicine were, in his opinion, grossly inadequately educated. In 1808 he wrote one last letter of protestation. This was addressed to Sir Joseph Banks decrying the "destruction and disgrace from unauthorized intruders into medical practice." His complaints were directed at physicians without degrees, surgeons and apothecaries without sufficient education, and sweepers of shops who put themselves on a level with the most instructed. The profession was degraded in all its branches and greatly injured by the granting of diplomas to the illiterate. Practitioners were too numerous and emoluments of practitioners were reduced. Dangerous impostors received a large share of medical practice. Pernicious empirical medicines injured the public's health and chemists (druggists) took it upon themselves to prescribe.(73)

Beddoes' accusations and his proposed solutions to the problems would almost certainly have led to vocal denunciation and further ridicule in the press by an appreciable part of the medical profession had he lived. Beddoes' last letter to James Watt was written in November, 1811. The doctor's concern for the health of common people is evident in his appeal for someone to invent a washing machine for the poor. The necessity to do frequent and voluminous laundry excessively undermined their health.(74) In 1808 Beddoes had decided to move to London, but a bout of illness prevented him from doing so. In December of 1808 he visited some patients during cold weather, took a chill, and after a short illness died on December 24, 1808.

EVALUATION OF BEDDOES BY HIS CONTEMPORARIES AFTER HIS DEATH

Beddoes' Death was noted quite simply in the next issue of a Bristol newspaper:

> "On Friday, the 23rd inst. Died at his house in Rodney-place, Clifton, of a dropsy in his chest, Dr. Thomas Beddoes, an eminent physician, whose learning and ingenuity have been displayed in numerous publications and whose ardent zeal in the cause of science will occasion his death to be long and deeply regretted."(75)

In the February, 1809 issue of the "Gentlemen's Magazine" there appeared a brief article signed by an individual calling himself "Amicus." The communication was dated at Bath, Jan. 18:

> "I much doubt whether the sorrow expressed for his [Dr. Beddoes'] loss be universally sincere; and, either affected or otherwise, I am sure it is unmerited. I do not mean, on any account, to call the ingenuity of Beddoes in question. I allow that he was a man of very lively parts, of highly respectable talents; but he was of that school the doctrine of which have operated, with poisonous influence, on the great mass of society. He is said to have avowed his contempt for Christianity. He was a disciple of Darwin and thus, glaringly Atheistical. Of his political opinions, his publications speak with `sufficient energy' – I shall say, impudence..... In regard to medicine, he was such a theorist that it is a question at this moment with some of his admirers, whether on the whole he has done more than harm as a physician? – In my mind there is no room for hesitation on the subject. After many around him had, probably, suffered, he at length fell himself a victim to experiments. Here, however, no moral censure can attach to Dr. Beddoes. We impeach his judgment only – which had no time for cool deliberation – which was enfeebled and lost its power of action admidst the continual fervors of fanciful discovery. There seems something like what the common people call a judgment, in the dissolution of this great Empiric of Bristol. He died of experiments tried upon himself, to tell the world with an awful voice of admonition that they who thus overstep the bounds of medical practice ought to be regarded with distrust. And may we not add, Mr. Urban, that having seen the fallacy and the folly of his medical notions in himself and others so indisputably proved, even Candour herself would trace up his other hypotheses, especially his atheistical system, to the same source of error, an imagination guided only by vanity?" (Signed 'Amicus')(76)

Even in death there was no respite for Dr. Beddoes from his "British literary ruffians" critics. In the same issue of Gentlemen's Magazine is a memorial verse on the "Decease of Dr. Beddoes" by Dr. Crane. This is a highly complimentary elegiac piece of doggerel praising Beddoes true genius, etc.: Beddoes in chemistry — praised for being a great teacher who demonstrated with experiment; Beddoes in physic — praised as a controversial writer who took his ideas from the writings of the controversial Brown. Beddoes' mind was ever "Athenian-like" in search of some new thing. He had a good heart. He lived to virtue and died an honest man. The verse is quite complimentary in distinction to that of "Amicus" in the same issue.(77)

One evaluation of Beddoes is worthy of particular note. It appeared as an entry on Thomas Beddoes in the supplement to the 4th, 5th, and 6th editions of the "Encyclopaedia Britannica" about 1824 and was written by Dr. Peter Mark Roget. Beddoes was described as "a physician of great eminence for his talents and philanthropy." The public was thankful for the "choice of that profession in which he was destined to run so brilliant a career." An anecdote was related about how a friend verified that Beddoes had actually learned fluent French in two months. Readers were reminded that his chemical lectures at Oxford attracted full and generally overflowing audiences. Roget then confirmed the wide influence of Beddoes' medical writing upon contemporary medical practice: "The new views of pathology which these speculations [i.e. on calculus, sea scurvy, consumption etc. to be discussed below] presented, and the hopes of valuable practical results which they raised, excited great attention in the medical world, and contributed much to increase the reputation of their author." Beddoes' morality book, "Isaac Jenkins," was praised profusely and it was related that over 40,000 copies had been printed. Then Roget discussed some materials presented in Davy's "Researches Concerning Nitrous Oxide" of 1800:

> "....it raised the most sanguine anticipations in the mind of Dr. Beddoes, and called forth all his eloquence in the description of what it already had and might be expected to accomplish. These, like the other splendid visions, in which his ardent imagination was but too prone to indulge, have never been realized; and have even created, by their signal failure, an unfortunate prejudice against future attempts to improve the art of medicine by novel methods of treatment founded on chemical or philosophical principles."

Roget then continued with his assessment of Beddoes' professional career:

> "Dr. Beddoes has been very justly characterized as a pioneer in the road to discovery. He was full of ardor and enterprise in the pursuit of knowledge, and was easily captivated by every new project that seemed to lead towards any practical improvement. He was more active, however, in exciting the labours of others, than of labouring himself in the field of experiment. He had the imagination of a poet, and could paint in the most vivid colours the sufferings entailed by the disease, and

> enforce with the most powerful eloquence whatever he wished to impress on the minds of his readers. He has been accused of versatility of opinions; but if he was perhaps hasty in publishing the first conceptions which he formed, he has atoned for the fault by the remarkable candour with which he retracted them the moment his confidence in them was shaken."(78)

These comments by a close professional associate of Thomas Beddoes minimized those traits which attracted the harshest criticism from others and emphasized Beddoes' positive contributions to medical knowledge. Robert John Thornton was highly enthusiastic and positive in his praise of Beddoes' ideas and contributions to medicine. Writing in 1816, he affirmed his continuing enthusiasm for pneumatic medicine and identified himself, as well as Dr. Beddoes, as founders of this mode of therapy.(79)

Thus the written elegies and opinions on Beddoes' death were divided. Some could not forget his political and religious transgressions and disapproved of his fanciful approach to medical practice. Others praised him as a distinguished physician and chemist. His literary companions were particularly affected by his death. Initially, Beddoes had made a strong impression on Coleridge because of his integrity, political realism, and because he realized the importance of the mind in treatment of the body. The friendship between them was maintained until Beddoes' death.(80) By 1801 Coleridge had become somewhat disillusioned with Beddoes. He wrote in his notebook, "Beddoes hunting a Pig with a buttered tail — His whole Life an outcry of "Eurekas" and all eurekas Lies."(81) Nevertheless, on hearing of Beddoes' death Coleridge is said to have remarked, "more has been taken out of my life by this than any other event."(82)

Beddoes' Estate and Family Upon Beddoes' death

Davies Gilbert was named guardian of the Beddoes children and executor of his estate. He had a difficult time comforting and managing Anna since she believed that she had missed having Gilbert as a husband by only a few months. In Feb. 1809, Gilbert's first child was born with a congenital malformation of the nervous system which left her in a vegetative state for seventeen years until she died. As Beddoes executor Gilbert did very well in managing the Beddoes assets and providing a stable income for Anna and almost enough for her children's school fees. From time to time he had to supply some of this money from his own pocket.

The elder son of Thomas and Anna Beddoes was Thomas Lovell Beddoes (1803-1849), a notable romantic poet and master of dramatic blank verse. He was educated at Charterhouse School and at Pembroke College, Oxford. He continued to produce poetry all through his life at school e.g. "The Bride's Tragedy" (1822). He then studied medicine at Götingen from about 1825-1829 or 30. He subsequently led a turbulent life and became involved in politics and revolutionary activities on the continent and committed suicide in 1849. Lytton Strachey evaluated the abilities and character of the younger Beddoes. He wrote:

> "Thomas Lovell Beddoes inherited his father's talents and his father's inability to make the best use of them. He possessed in no less remarkable degree his father's independence of mind. In both cases this quality was coupled with a corresponding eccentricity of conduct which occasionally, to puzzled onlookers, wore the appearance of something very near insanity."(83)

Gilbert regarded Beddoes' sons as his own. His own son died in childhood. He took great pleasure in sponsoring Thomas Lovell Beddoes's education since he did quite well in school. The second Beddoes son, Charles, was destined for the navy. On many occasions Gilbert had to loan Thomas Lovell Beddoes money while he was at Oxford. Anna Beddoes died in Florence while Thomas L. was at Oxford in 1824. Forever after Thomas was grateful to Gilbert for aid he had given. In Anna's last letter to Gilbert, which was extremely cordial, she thanked him deeply for what he had done for her and her family and confirmed that his was the proper course of action relative to their one-sided romantic involvement.(84)

MORE RECENT EVALUATIONS OF BEDDOES

Although Thomas Beddoes was famous in his own day, he left little to familiarize his name to people of our time. Nevertheless writers in the 20th century rate the contributions of Beddoes much more highly than did most of his contemporaries. Jones is quite positive that the direct contribution of Beddoes to the investigative work on nitrous oxide at the Pneumatic Institution was greater than usually supposed. He has been given little credit and according to Davy is said to have acted primarily in an administrative capacity. However, based on Beddoes' and Davy's writing from this period Jones concluded:

> "It must appear that more is due to Beddoes than has been rendered him. The raw Cornish lad of nineteen could not have gained in the short space of eighteen months the familiarity with chemical literature and method that is so evident in Davy's writings, and also at the same time carry out the mass of experimental work he did, had not Beddoes not only aided, but planned and in part executed the work."(19)

There is a section in Davy's "Researches" titled "Observations on the effects of Nitrous Oxide, by Dr. Beddoes."(85) This material confirms that Beddoes' participation in research was more than simply as an administrator. Stansfield, too, commented on why "Researches" was published without reference to the

Pneumatic Institute and with little reference to Beddoes. She explained these observations on the basis of avoidance of ridicule and of desire to avoid political prejudice. She quoted Davy as stating that the "Researches" was "written throughout on a strictly inductive plan with a total rejection of abstract speculation or hasty generalization."(86) The life and career of Beddoes had been closely intertwined with those of three different Presidents of the Royal Society: Sir Humphry Davy, Sir Davies Gilbert (formerly Giddy), and Sir Joseph Banks. The association with Banks was indirect and conducted by means of correspondence and mediation of others. But Beddoes profoundly influenced the scientific development of both Davy and Gilbert. For this, he must be reckoned as an important contributor to eighteenth century science.(87)

Jacques Barzun rated Beddoes' achievements much higher than most other assessors. Among statements that he wrote were: "He was a rising figure in a world seething with new ideas." Also: "His life work was to combine scientific theory and experimentation with social preoccupations and their embodiment in medical practice and propaganda. His lifelong relationship with the poor and concern about society led to a few political acts, but enough to tarnish his reputation with the establishment." Barzun listed Beddoes endeavors in three categories: the campaign for public health and preventive medicine, the intellectual passion for experimental science pursued both for knowledge and as an aid to medicine, and finally, the faith that applying the mind to society is bound to relieve misery, poverty and injustice. "Dr Beddoes, in short, was a great observer and synthesizer at a time when close attention and numerical results were only beginning to be reported. He had the intuition of all that a science-based medicine should be....... "(50)

Another modern observer rated the quality of Beddoes' career much more positively than did many of his contemporaries. Gottlieb characterized it as imposing and creditable. Beddoes was an accomplished scholar of science and the arts, physician, writer, and the founder of inhalation therapy and the developer of the genius of Humphry Davy.(52)

Stanley Hutton, a historian of Bristol, was another who believed that the contribution of Beddoes to acquisition and dissemination of knowledge concerning nitrous oxide was greatly underrated. He wrote:

> "In regard to the application of nitrous oxide gas, the world has unfairly given all the credit to Davy; but in justice to Dr. Beddoes it must be stated that years before Davy joined him he had been experimenting with the pneumatic treatment and it was solely at his insistence that it was used. Truly has it been said that "fortunate in having voiced the views of Beddoes and his fellow workers on the anaesthetic properties of nitrous oxide, Davy has received today the credit of having discovered them, and to the general public the name of Thomas Beddoes, the real discoverer, is practically unknown." It is indeed to the latter that the world owes the birth of modern anaesthetics. What, however, is to the

> credit of Davy is the daring way with which he experimented at this period."(88)

Cartwright commented upon Beddoes' enthusiastic lack of discrimination in reporting cures wrought by pneumatic means. However Cartwright emphasized that Beddoes' wilder claims were not based upon personal experience but rather upon reports from his correspondents:

> "Beddoes was no charlatan; in all his work there is complete honesty and even an underlying note of caution. The claims that he, himself made for his methods are by no means reckless, but he was far too sanguine, too credulous, and he did not possess a critical mind. It was not Beddoes but his correspondents who brought pneumatic medicine and so Beddoes own reputation into disrepute."(89)

Abbott summarized Beddoes contribution to medicine and science:

> "Although one of the first to suspect that the recent discoveries in chemistry might be applied to medicine, Beddoes failed to add any outstanding discovery because his talents were not applied with discretion. He was not of sufficient calibre to follow the lead of Lavoisier nor Davy. He had all Priestley's "butterfly curiosity" without his genius."(71)

OBSERVATIONS

ON THE

NATURE AND CURE OF

CALCULUS, SEA SCURVY, CONSUMPTION, CATARRH, AND FEVER:

TOGETHER WITH

CONJECTURES UPON SEVERAL OTHER SUBJECTS OF

PHYSIOLOGY AND PATHOLOGY.

BY THOMAS BEDDOES, M.D.

LONDON:

PRINTED FOR J. MURRAY, Nº 32, FLEET STREET.

M.DCC.XCIII.

PLATE IX — THE TITLE PAGE of Beddoes' 1793 pamphlet which presented many of his original ideas on the relationship of gas imbalances in the body to the diseases mentioned and their pneumatic treatment.

Chapter XII

The Medical Writings of Thomas Beddoes

Stock presented a list of books and pamphlets written by Thomas Beddoes. 45 such documents were enumerated.(1) In addition to these, Beddoes wrote numerous brief articles which appeared in various journals and periodicals. His literary output spanned twenty four years (1784-1808) and included materials of medical, chemical, political, sociological and moralistic orientations. In this chapter attention will be limited to the scientific and medical opinions and writings of Dr. Beddoes.

Beddoes' earliest works (1784-1792) were translations of the writings of prominent continental scientists: Spallanzani, Thorbren Bergman, and his pupil Scheele. Another notable accomplishment from this period (1790) was an analytical account of the writings of John Mayow, a member of the illustrious Oxford group of philosophers who had been active over a century earlier and who had been involved in the early years of the Royal Society. Beddoes' book rescued Mayow from the obscurity into which he had fallen and re-established him as a pioneer in respiratory physiology and pneumatic chemistry. It was in his comments on this book by Mayow that Beddoes first postulated that great benefit might accrue from the merger of pneumatic chemistry and medicine. He speculated on some of the ways in which gases could be used to treat disease.(2) Beddoes published four articles in "Philosophical Transactions." All appeared before 1793 and none dealt with airs or pneumatics.(3)

Beddoes' first major treatises on pneumatic medicine were "Observations on the Nature and Cure of Calculus, Sea Scurvy, Consumption, Catarrh, and Fever" and "A Letter to Doctor Darwin, on a new method of treating Pulmonary Consumption."(4) These appeared in 1792 and 1793 respectively. They were written while he was Reader in chemistry at Oxford.* The latter communication consisted chiefly of the response, in the form of an open letter, to a communication from Erasmus Darwin in January, 1793. Darwin's letter had expressed enthusiastic support and encouragement for Beddoes' work and offered a few additional observations.(5)

Beddoes forecast a new era in the practice of medicine with addition of pneumatic measures to the armamentarium of the physician. Capability to alter the state of oxygenation was to be of particular importance; especially in treatment of consumption, typhus and scarlet fever. Beddoes had also proposed that perhaps the new science of galvanism might be the basis for another new system of medicine.(7)

Brunonian beliefs of Beddoes were apparent in his statement that patients with any of a variety of diseases, including the aforementioned fevers, may be excessively or inadequately stimulated. The system of medicine formulated by John Brown, Beddoes' professor at Edinburgh, had taught that all disease originated from inappropriate degrees of stimulation with abnormal levels of excitability of tissues.(8) In this circumstance the primary goal of therapy was to adjust body stimulation to appropriate levels and to restore the principle of excitability. Christoph Girtanner (1760-1800), a fellow student and colleague of Beddoes at Edinburgh University, had carefully studied the works of Lavoisier. He concluded that oxygen was the principle of irritability and that irritability and excitability of tissues could be altered by inhalation of oxygen in proportions other than that in the atmosphere. He communicated his ideas in two memoirs which were translated by Beddoes and which appeared as appendices in Beddoes' "Observations on the Nature of Calculus, Sea Scurvy etc." (1793). Their content was considered in the discussion of early pneumatic medicine presented above. The Brunonian orientation of Girtanner's thinking was apparent and his writings undoubtedly influenced many of Beddoes concepts about gaseous imbalance in the body related to the onset and course of diseases and their treatment by pneumatic means.

Beddoes readily concurred with his friend that oxygen imbalance, by altering excitability, could cause disease. Also, he agreed that treatment of disease might be accomplished by inhalation of atmospheres modified by addition of specified gases or "airs" which had recently been identified. He conveyed the concepts which had persuaded him of the potential usefulness of pneumatic therapy:

> "Several years ago a firm persuasion settled upon my mind that the system might be as powerfully and as variously affected by means of the lungs as of the stomach"(9), and also:

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*In 1778 Benjamin Colborne applied soda and potash waters to calculous disorders. His preparation "aqua mephitica alcalina" became very popular. Colborne is apparently the individual praised so highly by Beddoes and to whom he dedicated these "Observations on the Nature and Cure of Calculus etc." Colborne was the discoverer of the virtues of "vegetable alkali etc." mentioned by Beddoes.(6)

> "By the lungs we can also introduce effectual alternatives of the blood, and by consequence of all the parts nourished by the blood."(10)

Gases that might be of therapeutic use included fixed air (carbon dioxide), azotic air (nitrogen), oxygen air and others. If this proved possible then extraordinary stimulants or anodynes might not be necessary. He continued:

> "the more you reflect the more you will be convinced that nothing would so much contribute to rescue the art of medicine from its present helpless condition as the discovery of the means of regulating the constitution of the atmosphere. It would be no less desirable to have a method of reducing the oxygen to 18 or 20 in a hundred than of increasing it in any proportion"

(On the basis of Lavoisier's analysis, many believed that the atmosphere contained 28% oxygen).

Beddoes recognized that many of the remedies of the day that he sought to replace with pneumatic measures were useless. He provided an explanation for their retention in the medical armamentarium:

> "The physician stalks about with an air of greater dignity when he feels a full quiver at his shoulders, however blunt may be the arrows that it contains..."(11)

He questioned whether different gases, such as inflammable air (hydrogen) or azotic air (nitrogen), which could be used as diluents to lower the standard (i.e. decrease oxygen concentration) of inhaled atmospheres, might have varying physiological effects.(12) Such "unrespirable airs" differed in their power to induce insensibility and cause death. Hydrogen and azote were least deleterious. Nitrous air (nitric oxide) was very bad — it combined over the whole surface of the lung to produce nitrous acid, a markedly corrosive substance. Perhaps carbonic acid gas acted in the same way. A particularly poisonous gas was hydrocarbonate. This gas was prepared by strongly heating the charcoal of some soft, non-resinous wood (e.g. willow) in a tubular retort or crucible and then allowing water to drop sparingly on to it. Such a process would produce what is today called water gas, a mixture of hydrogen, some carbon dioxide and carbon monoxide. The proportion of the latter was higher the higher the temperature of the crucible.(13) Thus, physiological effects of the known irrespirable airs were different. Most did not act by mere exclusion of atmospheric oxygen.

Beddoes was well equipped to conduct studies in pneumatic medicine according to the standards of his day. He was completely conversant with the work of Black, Priestley, Lavoisier, Scheele, Cavendish, Mayow, and others. He had comprehensive knowledge of the properties of the gases which they had identified and was familiar with the composition of the atmosphere and with the chemistry of combustion. He had a good knowledge of physiology of respiration as it was understood in the final decade of the eighteenth century. He was aware of many general principles of pulmonary function such as the site, purpose and magnitude of oxygen uptake and carbon dioxide production, and that oxygen but not other gases would turn dark blood bright red. He knew about congenital heart disease with intracardiac shunts and also about gas stores in the lungs. He appreciated the dependence of the different functions of the body such as cerebral activity, muscular contraction and glandular secretion on a continuous supply of oxygen.

There were some areas in which Beddoes harbored concepts that have subsequently been shown to be erroneous. He believed, in common with other chemists of his time, such as Lavoisier, that oxygen was a constituent of all acids. He therefore believed that ingestion or external application of acids could supply oxygen to the body. He failed to differentiate the various causes of hyperpigmentation and darkness of the skin and mucous membranes. He attributed all such dark discoloration to oxygen lack and, conversely, skin ruddiness to oxygen excess. The dark skin of African natives was attributed to many generations of living in a hypoxic environment.(14) The attempted experimental verification of this supposition was described by Beddoes:

> "At Oxford in 1790, I had proposed to a distressed Negro to try to whiten part of his skin with oxygenated marine acid air (modern terminology; hydrochloric acid)...his arm was introduced into a large jar full of this air and the back of his fingers lay in some water impregnated with it at the bottom of the vessel. It was perceived that he had ulcerations from the itch between his fingers and this made me very cautious about the experiments. In twelve minutes he complained about severe pain from the ulcers and the arm was withdrawn. The back of his fingers had acquired an appearance as if white lead paint had been laid upon them, but this was not permanent. A lock of his hair was whitened by this acid. Next day the ulcers became extremely painful and the hand swelled from the inflammation."(15)

A similar experiment was attempted at the Pneumatic Institute several years later.(16) This subject subsequently stationed himself outside the door of the Institute and begged for money from pedestrians on the grounds that he had been experimented upon within.

The fanciful experiment of attempting to change the color of a black man's skin was also reported in the popular press:

> "Dr. Beddoes astonished all the green and philosophical amateurs, with his account of his having turned a black man white! with oxygenated muriatic acid; but the philosophical bubble burst in less than a month! –

> the epidermis had been slightly affected, without injuring the rete mucosum. – The whole affair ended by all the town considering the chemist, not as a philosopher, but a conjurer."(17)

Beddoes shared Lavoisier's uncertainty about whether the actual chemical reactions involving oxygen that were analogous to combustion occurred in the lungs or in body tissues. He could thus postulate that oxygen excess might cause pulmonary injury by excessive production of heat in the lungs. He also believed that when fish were taken out of water they died from hyperoxia since the blood in their gills turned redder in air.(18) He did not appreciate the relatively small total store of oxygen in the human body and that brief oxygen inhalation would at best cause only a transient increase in quantity of body oxygen. Also, Beddoes (and others of his day) believed that in a mixture of gases, the heavier gases would layer out at the bottom while lighter gases would float to the top. He inferred that oxygen and nitrogen must have some kind of mutual attraction; otherwise they would separate. Oxygen, being heavier, would concentrate at the surface of the earth and "occasion violent diseases." Animals trapped in the lighter nitrogen at higher elevations would asphyxiate. Yet there must also have been special circumstances to keep these two gases from uniting. Otherwise they should combine to form poisonous nitrous air (nitric oxide) and the world would become uninhabitable.(19) He also believed that as one ascended to very high altitudes the air became not only more rarefied but also contained a smaller fraction of oxygen.(20)

For a number of years Beddoes had been trying to determine the role of oxygen in the animal economy.(21) Based on his ideas he had identified excesses and deficiencies of oxygen in the body as a cause of certain diseases. Among these were scurvy, obesity and consumption (tuberculosis). He presented his ideas in some of his previously mentioned books and monographs published between 1793 and 1799 . In these he discussed how the gaseous imbalances might contribute to the pathophysiology of the various diseases and proposed methods of therapy based on his pneumatic concepts. He wrote:

> "supposing the proportion of ingredients in the atmosphere to be that best adapted to the average state of health, is it not likely that there may be certain deviations from this state, where that fluid body contains too little vital air, and other deviations, where it contains too much?"(22)

SEA SCURVY

The first of the oxygen-related morbid conditions that Beddoes discussed was sea scurvy. The general history of the conquest of scurvy was related in the discussion of pneumatic medicine. There, several different theories on scurvy were expounded. Prominent among these were ideas based on pneumatics. As enthusiasm for a deficiency of fixed air (carbon dioxide) as an etiologic consideration in scurvy declined in the early 1790's, attention was directed to a possible role for oxygen. Thomas Trotter in 1792 had proposed that scurvy was due to a deficiency of oxygen. His reasoning leading to this conclusion was very much like that of Beddoes which follows below, and Beddoes acknowledged the importance of Trotter's earlier concepts.(23). Fruits and berries with reputation as antiscorbutic were acid substances and as such contained oxygen which they could supply to the body. [(Paterson, in 1796, advocated ingestion of "nitrous vinegar" (nitre [potassium nitrate] dissolved in vinegar) as an excellent supplemental source of oxygen in scurvy.(24)]

Beddoes, writing in 1793, claimed to have independently concluded that scurvy was due to a deficiency of oxygen in the body. He supposed that the cause of this illness was the gradual abstraction of oxygen from the system just as death by drowning was caused by the abrupt withdrawal of oxygen. Proofs of systemic oxygen lack included his perception of dark color of the blood, the large livid spots over the body, and the purplish hue of the gums and mucous membranes. All of these dusky changes in the various body tissues were attributed to oxygen lack in accord with Beddoes' current beliefs. As mentioned, Beddoes interpreted all dark colorations everywhere in the body as indicating oxygen lack whether actually due to cyanosis* or to abnormal pigmentation, hemorrhages under the skin and mucous membranes (as is the case in scurvy), or racial characteristics.

Further confirmatory signs of an important role for oxygen lack in scurvy was the prompt recovery of scurvy victims on eating acid-containing foods and vegetables. These were believed at that time to represent a rich source of readily available oxygen.

There were some additional points relating scurvy and oxygen lack. Besides the deficiency of oxygen in blood, skin, and mucous membranes previously noted, he concluded that oxygen deprivation must also exist in muscles. Scurvy at sea frequently appeared after severe storms. The muscular exertion required in dealing with storms at sea was believed to deplete body oxygen stores rapidly. He stated without supporting evidence that sailors breathe an air with an oxygen concentration lower than normal. He suggested that scurvy at sea could be prevented by assuring an adequate supply of oxygen, citing Captain Cook's reputed success in preventing scurvy on his ocean voyages by keeping ships well ventilated.(25) Beddoes gave a vivid description of conditions aboard slave ships. He believed that, on these vessels, the foul air breathed and not the diet was the cause of scurvy. The crews were relatively free from scurvy because they could obtain vegetables and fresh meat, acid foods containing oxygen, from individuals

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*cyanosis: bluish discoloration of the skin and mucous membranes due to inadequate oxygenation of the blood.

along the coast by barter.(26) He speculated that perhaps too much emphasis was placed by others on lack of vegetables as an essential factor in etiology of scurvy. To support this argument he cited the existence of people who subsisted almost entirely on meat and fish (for example Laplanders) yet never exhibited scurvy.(27) He suggested that perhaps a better means of preserving meats at sea was needed. The necessity to keep ships well supplied with fresh air was obvious. Beddoes urged that victims of scurvy should be given high standard (oxygen enriched) air to breathe. Success with this therapeutic measure would substantiate his theory. Also more extensive use of acids should be made. The native acids of vegetables should suffice. A full trial of mineral acids was also suggested. These included vitriolic elixir (sulfuric acid), nitric acid, and oxygenated marine acid (chlorine gas), all diluted in water. Nitre (potassium nitrate) should be of value, as should sweet wort (an infusion prepared from malt) and "sauerkraut." Salted meat might produce scurvy by destroying oxygen in loose combination in tissues. Scurvy in besieged garrisons and in prisoners of war (land scurvy) was also explained on the above principles. In patients dying from scurvy, enlargement of chambers of the heart with "corrupted blood" was taken to indicate lack of stimulating power of the blood with resulting failure of irritability of the heart. The necessity of oxygen for muscle contraction and to confer stimulating properties on blood was illustrated by case presentations including one of congenital heart disease and a death at high altitude. He compared death at altitude to death of an animal in an evacuated chamber and mentioned an expedition which was attacked by scorbutic symptoms while on the summit of a mountain.(28) In 1795 the superior antiscorbutic value of lemons was finally acknowledged and Royal Navy ships were accordingly provisioned with sufficient quantities of citrus. This was accomplished largely through the efforts of Sir Gilbert Blane and others, as previously described. There was little further interest in a pneumatic basis for scurvy.

OBESITY

Yet another morbid condition considered by Beddoes as related to oxygen deficiency was obesity.(29) This condition had attracted comments and interest since ancient times. Obese individuals were encountered infrequently during the Paleolithic age. In this era food was scarce and much energy was expended in gathering and hunting it. In Neolithic times agriculture developed and food became more plentiful. Life became more sedentary for some and the proportion of obese individuals in society increased.(30) The ancient Greeks, with their orientation towards moderation in all things, also emphasized temperance in eating. However, the age of Pericles was more tolerant of variations in body size and shape than is our own time. A woman with the measurements of Venus de Milo would be on a weight reducing diet today.(31) The relationship between overeating and obesity has been recognized since antiquity. In ancient Rome, obesity was so frequent that certain laws were in effect from time to time limiting expenditure on food.(31) In medieval times obesity occurred among those who could afford food and does not appear to have attracted much comment. However the sin of gluttony was regarded with disfavor. Conversely, fasting and abstinence from specified foods were (and still are) regarded as signs of devotion in certain cultures. In Renaissance times, attitudes about obesity were depicted by writers and artists. The danger of overeating was expressed by Shakespeare: ". . . . they are as sick that surfeit with too much as they that starve with nothing."(32) Nevertheless, large, buxom women were in vogue. An example was Bathsheba as painted by Rembrandt. Rubens' subjects generally appear to exceed 200 pounds.(31) In the eighteenth century many influential individuals were weighing themselves in shops with large hanging scales. When disturbed about the result they sometimes dieted and followed their progress by weighing themselves at intervals.(33)

Beddoes' unique theory concerning obesity added new consideration. He believed that fat differed from the part of animals called flesh in containing a smaller proportion of oxygen and also that conversion of tissues between muscle, cellular substance and fat could occur. If the blood contained a small amount of oxygen then the substance containing the lowest amount of this gas should be formed. There was thus a tendency to form fat whenever a deficiency of oxygen existed. An additional piece of evidence on the relation of oxygen to obesity was the abundance of oil in the liver of the skate.(34)

There was a relationship between corpulence and scurvy. Obesity predisposed to scurvy and was sometimes the harbinger of onset of the disease. Scurvy rarely caused emaciation. Beddoes believed that emaciation was caused by acids taken in excess. As supporting evidence he submitted the observation that, in cider country, people tended to be thinner than in beer country because the cider was more acid. "Unwieldy corpulence" could be treated in a manner similar to scurvy, by a strict vegetable diet. Fat people were observed to be dyspneic frequently and Beddoes regarded the dyspnea as a contributing cause rather than as a result of the obesity. The livid and suffused appearance of the obese was contrasted to the red noses and cheeks, attributed to inflamed lymphatics, of individuals harmed by excess of strong drink. Exercise, by introducing more oxygen into the body, inhibited formation of fat, which was associated with low oxygen intake. Conversely persons who slept too much developed obesity. During sleep respiratory rate was slow and a smaller quantity of oxygen was taken up by the body. There were two periods in life during which fat was likely to accumulate. The first of these was during infancy when oxygenation was said to be impaired because of incompletely expanded lungs and the presence of the foramen ovale and ductus arteriosus. The second was at about age forty, associated with the onset of an "indolent disposition" as well as a diminished irritability of various body fibres. One wonders how Beddoes applied these precepts on obesity to his own person. He was described by Humphry Davy as being "...uncommonly short and fat." Also Stock noted his peculiar body habitus.(35) He was known to be particularly subject to breathlessness on exertion. There appear to be no indications in his writings that he personally systematically tried the measures which he advocated for treatment of obesity such as a vegetable diet or oxygen inhalations.

Beddoes extended his views on oxygen and fat production to the plant kingdom. He believed that elaboration of vegetable oils was possibly related to chemical reactions in plants involving an excess of azotic air and a deficiency of oxygen. He wondered whether it might be possible to modify the functioning of plants by pneumatic means and thus to "teach our woods and hedges to supply us with butter and tallow. "This capability would be extremely advantageous in feeding a large increase in population. It would be much better to feed on the immediate produce of the soil rather than use tons of vegetables condensed into every fat ox."(36) These bizarre suggestions were later to be the basis for some of the intense ridicule which plagued Beddoes throughout most of his professional life.(37)

Excessive consumption of alcoholic beverages was believed to create a state of oxygen deprivation in the body. Beddoes claimed to have seen a drunk reduced to insensibility just by breathing a slightly hypoxic gas mixture but of a standard which was higher than that breathed comfortably by normal individuals. He also claimed to have seen drunks brought to the verge of asphyxia by breathing mixtures of low standard.(38) Beddoes invoked the apocryphal phenomena of "spontaneous human combustion" and "preternatural human combustibility" as further evidence that alterations in body oxygen stores predisposed to serious systemic abnormalities.(39) He cited the remarkable case of the "Inflammable Woman of Coventry," a notorious victim of spontaneous human combustion. He concluded that this lady had induced a state of marked oxygen deprivation in her tissues by intemperate use of strong drink. She had thus developed such a forceful avidity for oxygen that one day she spontaneously burst into flame, leaving only a few charred remains and some ashes. Beddoes suggested that perhaps some of the symptoms of mercury poisoning such as bleeding are caused by the presence of oxygen in some salts of mercury. The harmful effects on the body might be produced by this oxygen rather than by the mercury. He also indicated that divers should be able to continue much longer under watér if before immersion they were to breathe air of a high standard or pure oxygen. The most important area of Beddoes' theories regarding oxygen was probably his concepts on the etiology and cure of tuberculosis.

TUBERCULOSIS BEFORE AND DURING BEDDOES' CAREER

Tuberculosis was known in the ancient world. Figurines from Egypt as early as 3700 BC appear to demonstrate kyphosis (angulation of the spine) characteristic of tuberculosis of the spine. Tuberculous spondylitis and a psoas abcess (further manifestations of tuberculosis of the spine) have been found in a mummy from 1000 BC.(40) Hippocrates. named the disease "phthisis." This word is said to originate in the Greek "phthiein" meaning to decay or waste away.(41) Alternatively, it has been suggested that the derivation of the term is from the Greek meaning "to spit."(42) Hippocrates recognized phthisis as a grave disease and difficult to cure. An aphorism of Hippocrates was, "From spitting of blood spitting of pus, and from this phthisis and death."(43) The disease was probably common in the Roman World. In the Dark Ages incidence of the disease probably declined because the population tended to be dispersed in isolated, self-contained units. Thereafter, incidence probably increased throughout the Middle Ages.(44) Galen, Avicenna and Rhazes all believed that tuberculosis was incurable(42) and the prognosis did not change over subsequent centuries. Thomas Young, writing in 1815, observed that not one in a thousand with phthisis could recover without medical aid, and even with the best possible help perhaps one in one hundred might be saved.(45)

The infectious nature of tuberculosis had been recognized by a few individuals over the years.(46) For a time during the seventeenth and eighteenth centuries there were laws in existence in southern Europe regarding the isolation and disinfection of tuberculous individuals and their possessions.(45) However the predominant opinion until fairly modern times was that the disease was hereditary.(41) A milestone contribution was the "Phthisiologia" of Richard Morton (1637-1698). This volume dealt with the course, signs, symptoms and treatment of the disease. Other Medical writers commenting and prescribing included Willis, Sydenham, Morgagni, Boerhaave, and van Swieten. William Cullen, in 1777, wrote that pregnancy "retards the symptoms, but these generally recur and become fatal soon after childbirth."(42) This precept was to be of great importance in Beddoes' reasoning. The presumed hereditary nature of tuberculosis tended to place a stigma on the families of tuberculous patients in the eighteenth and early nineteenth centuries, and to restrict prospects of siblings and parents for advantageous marriages, business opportunities, social connections etc. To evade this there appeared to be a great deal of falsification of cause of death by attending physicians.(47)

For explaining the etiology of tuberculosis, humoral pathology retained its ruling position into the 18th and early 19th centuries. One concept used by proponents of humoral pathology was suppression of the natural flow of humors and their discharge through unnatural outlets. An example of this might be suppressed menstruation and displacement of blood from uterus to lung with beneficial hemoptysis (blood spitting). (Nosebleed might be another manifestation of this phenomenon). Some authorities attributed tuberculosis to the coughing up of blood.(43) Leopold Auenbrugger, in 1761, developed the diagnostic technique of percussion of the chest permitting demonstration of certain chest abnormalities in living subjects.(48) In 1865 Jean Antoine Villemin proved the infectious and specific nature of tuberculosis by injecting tuberculous material into rabbits, and in 1882 Robert Koch identified the tubercle bacillus. These discoveries clarified the true cause of phthisis and permitted rational treatment to develop. But Beddoes' founding of the Pneumatic Institute and the activities of the staff there represented the first organized effort to study and attack tuberculosis.(45) Mortality from tuberculosis was appalling in the eighteenth and early nineteenth centuries. Parish records suggested that this disease caused one death in four in 1741.(41) Mortality continued to increase and reached a peak somewhere about 1780. Mortality from tuberculosis about this time in England was said to be 1121 per100,000 population.(44) In 1801 30% of deaths in England were tuberculous.(45)

The periodic rise and fall of the disease in ancient and medieval times corresponded with changes in population density. There was a rise in the incidence in all countries with industrial revolutions, followed by a steady drop in all countries where sanitary reforms were introduced.(49,44) Decline in mortality from tuberculosis as the 19th century progressed was attributed to gradual improvement in the monstrously squalid living conditions of the early industrial revolution.(45)

Numerous modes of therapy for tuberculosis had been used over the centuries. In ancient Greece mystical cures in temples were advocated. Other measures suggested included fresh air, exercise, appropriate diet, and bathing. Roman physicians advised sea voyages, good nutrition, and hydrotherapy. Pliny suggested inhalation of the effluvia of burning resinous woods. Christopher Bennett (1617-1655) prescribed "balsamic fumigations." Hindu physicians recommended residence in goat stables.(47) Therapy in the eighteenth century had scarcely changed from that of antiquity. Some measures advocated in Georgian England included residence in cow sheds, ass's milk, mother's milk and innumerable changes of climates and diets.(41,45) Thomas Percival advised use of cod liver oil and inhalations of fixed air (carbon dioxide).(42)

Particularly noteworthy was the treatment of scrofula (tuberculosis of lymph nodes) in England by the "King's touch."(46, 50,51) A multitude of patients afflicted with scrofula would pass before the sovereign, who would touch each in turn and recite a brief prayer for their recovery. The practice was said to have originated with Edward the Confessor in the eleventh century. Charles II (r. 1660-1685) was probably the most enthusiastic practitioner of this form of therapy. The ritual continued through the reign of Queen Anne (r. 1702-1714).(42) Not all monarchs had faith in their own healing powers. William III (r. 1689-1702) said to each recipient of the royal touch, "May God cure you and give you more sense!"

Before the last quarter of the 18th century the combination of gibbus with psoas abscess and paralysis of the lower extremities and incontinence (deformities and dysfunctions which were consequences of tuberculosis of the spine) was well known in western Europe. The relation with tuberculosis was suspected. The treatment that Percival Pott (1714-1788) recommended in 1779 was drainage of the abcess and keeping the cavity open to drain. This was quite a novel mode of therapy at the time in England.(52) Pott was elected a Fellow of the Royal Society, an accomplishment for a surgeon at that time.(53)

BEDDOES' THEORIES AND PRACTICE CONCERNING TUBERCULOSIS

Before he developed a special interest in the disease, Beddoes might have shared the opinions of his contemporaries concerning tuberculosis. He would have believed that tuberculosis was communicable or hereditary. He would have known about tubercles and ulcers in the lungs of afflicted individuals. He might have believed that certain body characteristics predisposed to phthisis and that a certain constitution was necessary for contraction of tuberculosis. However in the early 1790's he formulated his own unique theory of tuberculosis. He concluded that the disease was caused by a high level of stimulation due to excessive amounts of oxygen in the body. He stated, without further explanation, that to him the only possible means of attacking tuberculosis was to use the observation that the occurrence of pregnancy sometimes slowed the progress of the disease and improved the clinical status of the patient.

> ". . . . the only circumstance in phthisis in our present state of ignorance we can hope to reason to any purpose has always appeared to me to be the occasional effect at least of pregnancy in suspending the progress of phthisis; for if we could once discover how pregnancy produces the singular effect we might be led to discover also a method of superinducing and prolonging the same change in the system at pleasure."(54)

This opinion was in accord with the observations and conclusion of Cullen, stated above. These ideas are now known to be incorrect. A more modern view expressed in a book published in 1951, when modern antibiotic and chemotherapy were in their infancy, stated:

> "Preponderence of opinion currently is that childbearing is hazardous for the tuberculous woman. During pregnancy and the puerperium arrested lesions tend to become dangerously reanimated and progressive disease tends to advance with greater rapidity. . . . . . "(55)

Beddoes presumed that the essential feature responsible for the improvement in tuberculosis during pregnancy was relative oxygen lack brought on by the physiological changes associated with this condition. He reasoned that the fetus received its oxygenation through the mother via the placenta; yet during pregnancy there seemed to be no provision for the reception of an unusual quantity of oxygen in the mother. On the contrary, in consequence of the impeded action of the diaphragm less and less should continually be taken in by the lungs. He then asked:

> "May not the somewhat diminished proportion of oxygen as an effect of pregnancy be the way in which it arrests the progress of phthisis? If

> so, is there not an excess of oxygen in the system of consumptive persons and may we not by pursuing this idea discover a cure for this fatal disorder?"

Beddoes again showed his acceptance of all kinds of skin discolorations as being related to changes in oxygenation by identifying the so-called stigmata of pregnancy as further confirmation of a hypoxic state. These physical signs included purplish striae (stretch marks) on the thighs and abdomen, the "mask of pregnancy" (pigmentation of the face) and various other regional changes in skin pigmentation normally associated with pregnancy. He also compared his notion of the natural cravings in appetite of gravid women to those of scorbutic patients which were characterized by the desire for foods of vegetable and not of animal origin. He then asked whether the consumptive patient might exhibit any signs of oxygen excess in the same way that he perceived the pregnant woman to show such striking evidence of oxygen deficiency. He answered affirmatively indicating that the

> ".....clear, bright, and florid hue of the flushed hectic countenance so diametrically opposite to that of the scorbutic complexion affords some presumption about the state of the underlying blood, equally receding, but in an opposite direction from the standard of health."(56)

The skin of the consumptive was warm in contrast to that of the scorbutic patient which was cool, clammy, and blue. The bright florid condition of the skin in consumption reflected the color of the blood underneath just as in asthma and congenital heart disease where a lack of oxygen colored the blood dark. This was reflected in the appearance of the skin of these patients. The breathlessness of asthma was associated with dark coloration of the skin. The breathless consumptive patient exhibited a bright red skin color despite his respiratory difficulty. Even in conditions of breathlessness hyperoxygenation was evident in phthisis! Beddoes was uncertain about the color of the blood actually taken from individuals with various diseases and targeted this problem for future investigation. He believed that a phthisical patient would take a longer time than an unaffected person to drown or to suffocate in most of those airs unfit for respiration. Phthisical patients are in effect already preoxygenated.(57) A case history supporting this contention was related. Inhalation of oxygen was deleterious for consumptives. Although they may have an initial transient improvement, within three weeks their appearance became more flushed and their symptoms of cough, blood spitting, fever and chest pain became worse.*

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*In 1816 Dr. Robert John Thornton recounted an early trial of oxygen in 20 consumptive patients at the Hôtel Dieu in Paris. The perception was that the gas gave these individuals increased strength and a feeling of well being but the eventual "fatal catastrophe" was accelerated. The oxygen "spread flowers on the borders of the tomb."(58)

The death rate among sailors from consumption was believed to be smaller than expected even though a large proportion of them were in the proper age group for consumptive mortality and were exposed to cold and wet, presumed inciting features of consumption. They were believed to breathe a low oxygen atmosphere aboard ship. Beddoes also concluded that scorbutic patients rarely contracted consumption and that consumptive patients rarely became scorbutic.(59) He was uncertain whether the primary change in consumption was inflammation in the lungs permitting them to transmit a greater than usual amount of oxygen to the blood or rather in the blood or other tissues causing them to attract more oxygen thereby harming the lungs.(60) However the hyperoxygenated state of the system preceded those symptoms which characterized phthisis. In phthisis the chemical combinations which occurred in the lungs were carried on to too great an extent and then the lungs, being the principal focus of animal heat, might be injured being constantly exposed to too high a temperature and by having too much oxygen offered to the attractive power of their own substance.(61) He cited certain experiments done by Priestley and Lavoisier in which animals were confined in oxygen. They lived longer than if they had been placed in ordinary air but showed inflammation of the lungs after several hours of breathing oxygen.

The general incidence of tuberculosis in France was less than in England. The difference was attributed to the French mode of cookery which tended to divest foods of oxygen or to combine the oxygen more tightly than with English cooking. Also, the French let bread rise longer and cooked food longer.(57) A tendency of French chefs to use oils and sauces was noted. French writers maintained that the incidence of consumption was less common in the southern than in the northern districts of France. This was attributed to differences in climatic heat between northern and southern France. Beddoes emphasized that not only in France but also in any hot country the incidence of consumption is lower than in England and this seemed to be associated with less oxygen in the body in conditions of heat. The decrease in solubility of gases in liquids as temperature increased was known.(62) Beddoes stated unequivocally that the incidence of consumption was much more frequent in the England of his day than in previous times. This was not due to any constitutional differences between people in different ages. His contemporaries were believed, without exception, to breathe a freer and purer air than their ancestors. He wrote:

> "...you see then that subjects of our Edwards, and our Henrys, and good Queen Bess may have found, in being more free from so formidable a disease than their delicate and airy posterity, some compensation for the confined air and filth in which they passed their existence."

He described his personal response to inhalation of oxygen. He reported loss of weight, change of skin color, increased production of heat and insensitivity to cold, and increased tendency to bleed an increased quantity of more florid blood.(63)

Beddoes outlined his proposed treatment for tuberculosis.(64) First, the patient with early tuberculosis should be placed on that kind of diet which is known to promote scurvy: one free from vegetables and stimulants and providing ample quantities of salty meats and oily foods. A second important therapeutic measure was to supply the lungs with an air of lower than normal oxygen concentration. Such air could be prepared by mixing ordinary atmospheric air with a quantity of either azotic air (nitrogen) or of hydrogen air. The mixtures could be breathed for a few moments several times a day. The patient should be removed from airy spacious apartments and should sleep in confined rooms where a cool temperature was maintained. Beddoes cited experiences of other investigators who tried therapeutic gas inhalation in consumption. including Priestley, who caused consumptives to breathe mixtures of common air and fixed air with considerable benefit but no cure. Priestley in turn mentioned three patients treated by Withering with fixed air who appeared improved by the treatment.

Beddoes observed that it was common in France and in Ireland to lodge phthisical patients in cow houses because the sweet breath of the cow was thought to be healing and balsamic. But Beddoes questioned whether the beneficial effects were not much more probably owing to the subtraction of oxygen by the respiration of the animals than to specific properties of their exhalations.(65) Erasmus Darwin expressed support for Beddoes' concepts in a letter written in January, 1793. Darwin admired Beddoes' work and declared that hyperoxygenation was the cause of this fatal disease. Further characteristics of consumption were believed by Darwin to be its hereditary and infectious nature. Darwin stated that one reason for failure of tuberculous ulcers in the lung to heal was their exposure to air in the lungs, since then current theory indicated that exclusion of air from wounds was important to healing. He hoped that Beddoes would determine which fraction of air was the culprit in this situation.(66) Beddoes considered the situation where, as the disease progressed, the quantity of lung tissue decreased and perhaps, because of the resulting oxygen lack, the disease should have been self-limiting. He believed that such instances had occurred. He cited the case history of an individual who had collapse of the ribs during the course of phthisis and as a consequence of this the progress of the disease slowed markedly, but death eventually ensued.*

Beddoes believed that catarrh was caused by excessive stimulation of the body, and particularly the air passages, brought about by abrupt change from cold to warm external temperature. The prevention of cattarhal sydromes (such as colds, bronchial affliction, and rheumatism) involved minimizing transitions of temperature, the use of proper dress and undergarments and the maintenance of

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*Inducing collapse of a tuberculous lung by various means was an important mode of therapy of tuberculosis in the pre-antibiotic era. The diseased lung was allowed to rest and heal.

proper indoor temperatures.(68) He recommended use of oxygen as a cosmetic to redden the cheeks and also in asthma. He had hoped that an oxygen generator would be a common piece of furniture in every household and that this gas would be useful in fortifying one against the cold.

About 1794 Beddoes also published letters which he had received from M. Lavoisier summarizing his conclusions on gas exchange and respiration and from Drs. Withering, Thornton, Ewart and Biggs on their favorable experience with pneumatic means of therapy. Withering responded to many of the topics discussed by Beddoes in "Observations on Calculus etc." He indicated that there were causes for cattarh other than going suddenly from a warm to a cool environment. He stated that a method sometimes used on an empirical basis to treat consumption was based on the observation that workmen employed about lime kilns never become consumptive. The practice was for consumptive patients to breath vapor from lime kilns which Withering believed was deprived of part of its oxygen. Also, he concurred that butchers and catgut makers were exempt from consumption. He agreed that pregnancy arrested the progress of consumption and congratulated Beddoes on being the one to use this observation to advantage. Withering then reasoned that application of an abdominal binder would have the same effect on consumptives as pregnancy. However he pointed out that insanity also stops consumption and presented cases supporting this contention. Withering could not confirm the effect of scorbutogenic diet on consumption but confirmed that administration of acids exacerbated symptoms. Carbonic acid air was valuable in a case of consumption. Withering wished Beddoes success in his endeavors with pneumatic medicine.(69)

In the summer of 1794 Erasmus Darwin wrote to Beddoes indicating that he had read the pamphlet "A Guide for Self-Preservation and Parental Affection." Darwin believed that Beddoes deserved a "civic crown" for saving the lives of fellow citizens.(70) Another activity of Beddoes in the early 1790's was reviewing material for a journal called "Monthly Review." It is possible that he received S.L. Mitchill's writings on the poisonous nature of nitrous oxide, which he included as an appendix in "Factitious Airs" (1795), from the editor of this periodical. Beddoes reviewed several articles dealing with the scourge of yellow fever in the port cities of the United States.(71) However, in the journal "Medical Repository" there is a letter from Samuel Latham Mitchill to Beddoes dated September 15, 1797. This letter confirms that Mitchill and Beddoes were in correspondence and Beddoes could have received Mitchill's work directly from the author rather than as a reviewer for the "Monthly Review."

"FACTITIOUS AIRS"

Beddoes, together with co-author James Watt, published the major work in pneumatic medicine in 1795-1796. This was "Considerations on the Medicinal Use of Factitious Airs and on the Manner of Obtaining Them in Large Quantities." 500-600 copies of the first edition were printed and quickly sold, followed by several more editions in the following years. In the introductory portion of the text, Beddoes began by emphasizing the purely experimental purpose of his investigations of pneumatic medicine — there was no guarantee of success. He promised to abandon his views if they were not proved experimentally. He strongly urged support for his planned Pneumatic Institution, using the argument that more could be done in two years in an institution than in 20 years of individual practice. He stated the objectives (physiological and practical) that might be attained by operation of such an institution. He predicted that in two to three years the Institute could be phased out and that pneumatic medicine would be practiced by all physicians. Patients for the Institution would be selected on the basis of medical interest; the rich would not be given preferential treatment.(72) The mood of optimism and enthusiasm regarding the future of pneumatic medicine expressed by Beddoes in his "Observations on Calculus Scurvy etc." (1793) and his "Open Letter to Erasmus Darwin (1793) was reiterated and extended in "Factitious Airs." He hoped that tuberculosis and other diseases which were then incurable might effectively be treated by pneumatic means. Other suggested applications for pneumatic medicine included typhus, diabetes, hysteria, anasarca and hydrothorax, liver disease, ulcers, particularly on the legs, palsy, and hydrophobia. Different airs might relieve or exacerbate pain of skin lesions. Ingenhousz maintained that a blister on the finger would hurt in air, more in oxygen, and not at all in azotic air.

Beddoes recounted his personal experience with a self-inflicted blister which generally confirmed this theory. He proposed that the topical use (application to body surfaces) of different gases might be of use in certain situations. Beddoes also discussed the possible value of application of herbal substances containing oxygen in the form of oxalic acid to various skin lesions. This treatment might be particularly useful in scrofula (tuberculosis of lymph nodes).(72) He speculated that there might be a particular gas mixture more favorable to intellectual faculties than atmospheric air and "hence chemistry be enabled to exalt the powers of future poets and philosophers." His Brunonian training again became evident when he wrote that "diseases of excitement on the one hand and debility on the other might be cured almost solely by a proper air."

Beddoes provided recipes for preparations of airs — the chemicals to be used and the advantages and disadvantages of each ingredient, for example comparing oxygenated marine (hydrochloric) and vitriolic (sulfuric) acids.(72) Several experiments which he had performed were described. He demonstrated that a preliminary period of breathing high oxygen mixtures markedly prolonged survival in dogs and cats subjected to asphyxia. He also showed that duration of survival in animals breathing a hypoxic gas mixture was shorter if violent struggles occurred than if a tranquil state was maintained. He studied air embolism and recognized that the undesirable effects associated with this phenomenon didn't occur until air reached the heart. Beddoes eloquently defended the ethical basis for his experiments which caused suffering in animals. All these experimental studies would seem to refute the claim of Davy (and others) that Beddoes "was little enlightened by experiment, and, ... little attentive to it."(73) Beddoes ended part I of "Factitious Airs" by commenting on the necessity and problems of modifying language to describe the new sciences of pneumatics and pneumatic medicine. It is of interest that half a century later John Snow started his book "On the Inhalation of Ether" by noting his difficulties in adapting language to describe and discuss the new phenomenon of anesthesia.(74) (See Gravenstein, 1984 for some considerations concerning the language of anesthesia and of science in general.)

Part II of "Factitious Airs was written by James Watt and dealt with the equipment for generating, storing and inhaling the various gases used for pneumatic therapy. In August, 1794, Erasmus Darwin had recently received some pneumatic apparatus from Watt. He wrote to Watt suggesting that comments and instructions related to manufacture of various gases might be useful. This correspondence was apparently one of the factors motivating Watt to write part II of "Factitious Airs."(75)

Apparatus for inhalation of factitious airs was to be made as cheaply as possible by the firm of Boulton and Watt, Birmingham. It consisted of a pot in a furnace, a refrigeratory (condenser, scrubber) and hydraulic bellows (very much like a modern water spirometer). Airs were then placed in oiled silk bags fitted with a spigot to provide for retention of air. For inhalation of the airs, a bonnet shaped like a beehive was placed over the patient's head. The spigot was introduced under the cap and the bag was then squeezed to introduce the air. An alternative method of inhalation was directly from the bellows through a flexible tube and mouthpiece. The tube could be made from caoutchouc (rubber) or treated leather sewed together over a spiral of brass wire. To store and transport gases Watt invented a gas cylinder. It was filled and emptied by water displacement. The original gas cylinder was 12 inches in diameter and 16 inches high. Its capacity would have been about 1 cubic foot or about 30 liters.(76)

Watt presented some hints on generating the various types of airs for therapeutic use and suggested that some attention be paid to their purity, using standards suggested by Dr. Priestley. He described how he inhaled hydrogen air and then exhaled against a match – "it took fire." He admonished against preparing inflammable airs by candlelight. Watt, although lacking in medical training or qualification, also offered several suggestions for the medicinal use of factitious airs.(76)

In part III of "Factitious Airs" Beddoes described his clinical experience as well as that of others in treating a variety of complaints and diseases with pneumatic means. He presented in tabular form lists of diseases treated, number of patients seen, and the type of gas used in each. Stock commented upon the great amount of opposition to gaseous therapy which was encountered about the time of publication of part III.

In part IV of "Factitious Airs" enumeration of different kinds of medical conditions treated using pneumatic measures continued. Most of the patients presented and discussed in "Factitious Airs" were not Beddoes' own cases. Many accounts of pneumatic successes were sent to him by his numerous correspondents in all parts of Britain. A 1796 book review of "Factitious Airs" expressed an optimistic view of pneumatic practice and discussed the many case reports in parts III and IV of the book.(78) Part V of "Factitious Airs" is primarily a catalog of respiratory equipment. The simplified apparatus and portable apparatus are described. The price list of the equipment as manufactured by Boulton and Watt of Birmingham was: Large Simplified Apparatus £6/16/6; auxiliary articles (airholders, spare fire tube, cast iron pot, oiled silk bag & bellows) £3/6/0. Second size simplified apparatus £4/15/9; auxiliary articles £2/15/0. Portable apparatus £2/12/6; auxiliaries £1/2/6.

Watt stated that articles called "auxiliaries" were necessary, and that greater numbers of air holders and silk bags than specified were useful. They could be purchased at any time from Boulton and Watt.

As the eighteenth century drew to a close, Beddoes gradually realized that many of his hypotheses regarding the pneumatic basis of various diseases were untenable. In a 1797 publication he recognized that aboard ships scurvy is prevented by fresh and particularly acid vegetables, and he no longer emphasized a pneumatic factor in scurvy.(79) By 1796 Beddoes had observed that both oxygen and hydrocarbonate (containing carbon monoxide) could turn the blood a bright red color. Since causes other than hyperoxygenation could produce the bright red color of the tissues he realized that this appearance was not as characteristic of phthisis as he had originally thought. Nevertheless he still believed that hyperoxygenation could be the basis for the disease.(80) But by 1799, Beddoes had abandoned the oxygen related hypotheses of 1792 upon which his early notions concerning consumption and sea scurvy had been based. He wrote:

> "It becomes me to acknowledge that the very imperfect trials hitherto made of gases and vapours are far from having established anything like a successful mode of treating consumption."(81)

This popular essay on consumption published in 1799 (Essay on the Causes, Early Signs and Prevention of Pulmonary Consumption etc.) sold out unexpectedly rapidly so that a second edition was required almost immediately. The enthusiastic response to the pamphlet confirms the widespread interest in consumption among the populace of the day.(82) Beddoes retained a favorable opinion on the value of other gases and vapours in consumption, particularly when combined with foxglove (83) and other remedies.(84) Beneficial actions of foxglove in consumption might include diminution of secretions, perhaps facilitating absorption of secreted materials.(85) and "powerfully retarding the circulation."(86) He persisted in extolling the value of the atmosphere of cowhouses in treatment of consumption:

> "It is indeed certain that the exhalations of cowhouses (for I cannot impute anything to the breath of the animal) have produced effects so strikingly beneficial as to render the expedient highly worthy of more complete trial......"

In 1799 Beddoes also reported further cures of consumption which had been reported to him. These involved inhalation of ether vapor, administration of foxglove, and residence in cowhouses.(87) Work in progress at the Pneumatic Institution was reported in "Notice of some Observations made at the Medical Pneumatic Institution" published in 1799. Beddoes identified pneumatic medicine as the first application of experimental science to medicine. In this publication the consuming interest in nitrous oxide at the Institution became evident. Beddoes described effects of nitrous oxide inhalation in volunteers. Marked stimulating properties of nitrous oxide were suggested to Beddoes by the striking appearance of those who inhaled it. It was obvious that they experienced great pleasure from the inhalation. This pleasurable state was accompanied by many motor activities which were not associated later with fatigue or sadness.(88) Both Beddoes and Watt also personally inhaled nitrous oxide and experienced pleasurable sensations.(89) Beddoes was initially reluctant to inhale nitrous oxide because of his "apoplectic make." He finally became convinced of the safety of the gas and took it daily for some time. His experiences were pleasant. He described how once when he had eaten intemperately the gas inhalation relieved the feeling of distention. Nitrous oxide was particularly favored for palsy.(90) This gas was regarded as a more powerful kind of oxygen. Between the two gases there should be an infinite gradation of powers to furnish any desired degree of pneumatic stimulation.(91) Possible therapeutic applications of mixtures of oxygen and nitrous oxide were considered. Some were so wild and far-fetched that they would almost certainly invite criticism and ridicule.(92) Style, context, and stated facts of "Observations" perhaps might suggest that Davy and Beddoes must have done a considerable amount of work together and that Davy concurred with many of Beddoes's conclusions, including the favorable effects of nitrous oxide in palsy.(93)

"Notice of Observations" concluded with an emphatic solicitation for continuing financial support. The appeal emphasized that it availed parents little to accumulate wealth for their children if the children were not going to be able to collect it because of premature death. Also, Beddoes observed that even a high degree of affluence would not buy exemption from dread and debilitating disease.(94) Beddoes also emphasized at this time that it was quite possible to advance the cause of mankind without producing tangible results – an early statement of the value of basic (as opposed to applied) research. He identified the pneumatic work as the first instance of experimental science applied to medicine. Editorial notice of the developments reported in Beddoes' 1799 "Observations" was provided by William Nicholson in his "Journal of Natural Philosophy, Chemistry and the Arts."(95)

Activities at the Pneumatic Institution were also favorably reported in the American medical press. The editor of the journal "Medical Repository" noted that Beddoes and Watt had completed their volumes on "Factitous Airs." He was extremely optimistic about the results to be anticipated from use of factitious airs and believed that Beddoes and the Pneumatic Institute would determine with certainty the peculiar situations in which each species of air was applicable.(96) But by 1801 pneumatic therapy had fallen into disuse at the Pneumatic Institute although Stock indicated that Beddoes retained a lifelong faith in pneumatic remedies. The "Medical Pneumatic Institute" had become a "Preventive Medical Institute."

Beddoes' "Essay for Parents and Preceptors" which had been published in 1799 was written as a guide for laymen to assist in the prevention and early recognition of consumption.(97) Another such publication was the 1801 pamphlet on "Medical and Domestic Management of the Consumptive."(98) In this publication Beddoes emphasized the importance of adjusting the patient's ambient temperature and gaseous environment in the treatment of disease. Apothecaries were advised to rid themselves of some of their more exotic remedies and to construct ice houses for the treatment of some diseases. In consumption, breathing warm moist air was an important therapeutic measure. This was the cause of improvement in patients residing in cow houses and "cow apartments." He presented in detail the case report of a lady cured of consumption by a several month residence in a cow house drinking nothing but ass's milk. He also related that Sally Priestley Finch had been greatly relieved of consumptive symptoms by residence in a cow house. She remained in the cow house for six months and was very happy with the results. Beddoes did not believe that presence of cows was essential but rather that the heat and moisture arising from presence of the cows and their effluvia was beneficial. "Temperated apartments" which were artificially heated to maintain room temperature above 65° were also useful. There is no more mention of alteration of composition of the inhaled atmosphere.

Beddoes also expressed some ideas on digitalis. He thought that the beneficial effects of digitalis in consumption might reside in stimulating properties which would eventually exhaust excitability in nerves and irritated tissues.(99)

Beddoes' later writings on tuberculosis emphasized the value of proper diet, body warmth, exercise, maintenance of proper environmental temperature, and the early diagnosis of the condition. He considered the relationship of clothing and of heating of dwellings to the high incidence of consumption in England. He concluded that the disease was somehow related to chilling of the body and attributed this to inadequate domestic heating and the wearing of clothing made of thin English cloth rather than of traditional Scottish woolen material.(100) Appearance of early signs of tuberculosis should intensify pursuit of the recommended anti-tuberculous regimen. These signs included a general indisposition, great liability to increase quickness of the circulation from very slight causes, and habitual quickness of respirations. Beddoes, as did others, noted certain occupational exemptions and predispositions to consumption.(101) Butchers, fishwives, and those in other select occupations appeared to enjoy a high degree of immunity from tuberculosis. Among those who seemed to be particularly susceptible to the disease were stone cutters, players on wind musical instruments, miners, and individuals who inhale various types of particulate foreign material. Also those with sedentary occupations in confined quarters were more susceptible.(102) When Coleridge believed that he had consumption, Beddoes advised him to find a residence over a butcher shop.(103) Beddoes' later teachings have been regarded as notable contributions to phthisiology.

Beddoes' thoughts on treatment were generally ignored, most probably because of his inclusion of pneumatic means and foxglove. But his preventive measures and education of the laity in early recognition of the disease should secure him an important place in medical history.(104) However, his early writings on the role of oxygen excess in the etiology of consumption and alteration of this state by pneumatic means as a possible treatment had important results. These theories were published at about the time when mortality from tuberculosis had attained a dismaying maximum. Probably every family in the social circle in which Beddoes moved had one or more members afflicted with the disease. There was no cure. Beddoes offered a theory of consumption adapted from much of the knowledge of that time. The hope offered for the relief from the scourge of tuberculosis by the proposed treatment, formulated by an admittedly controversial but nevertheless authoritative and recognized member of the scientific community, must have attracted intense attention from wealthy members of industrial, literary and scientific circles. They were able to provide support for further trials and evaluation of Beddoes' ideas. This support enabled opening of the Medical Pneumatic Institute whose lasting achievement was dissemination of knowledge concerning nitrous oxide, leading directly to the introduction of clinical anesthesia about fifty years later.

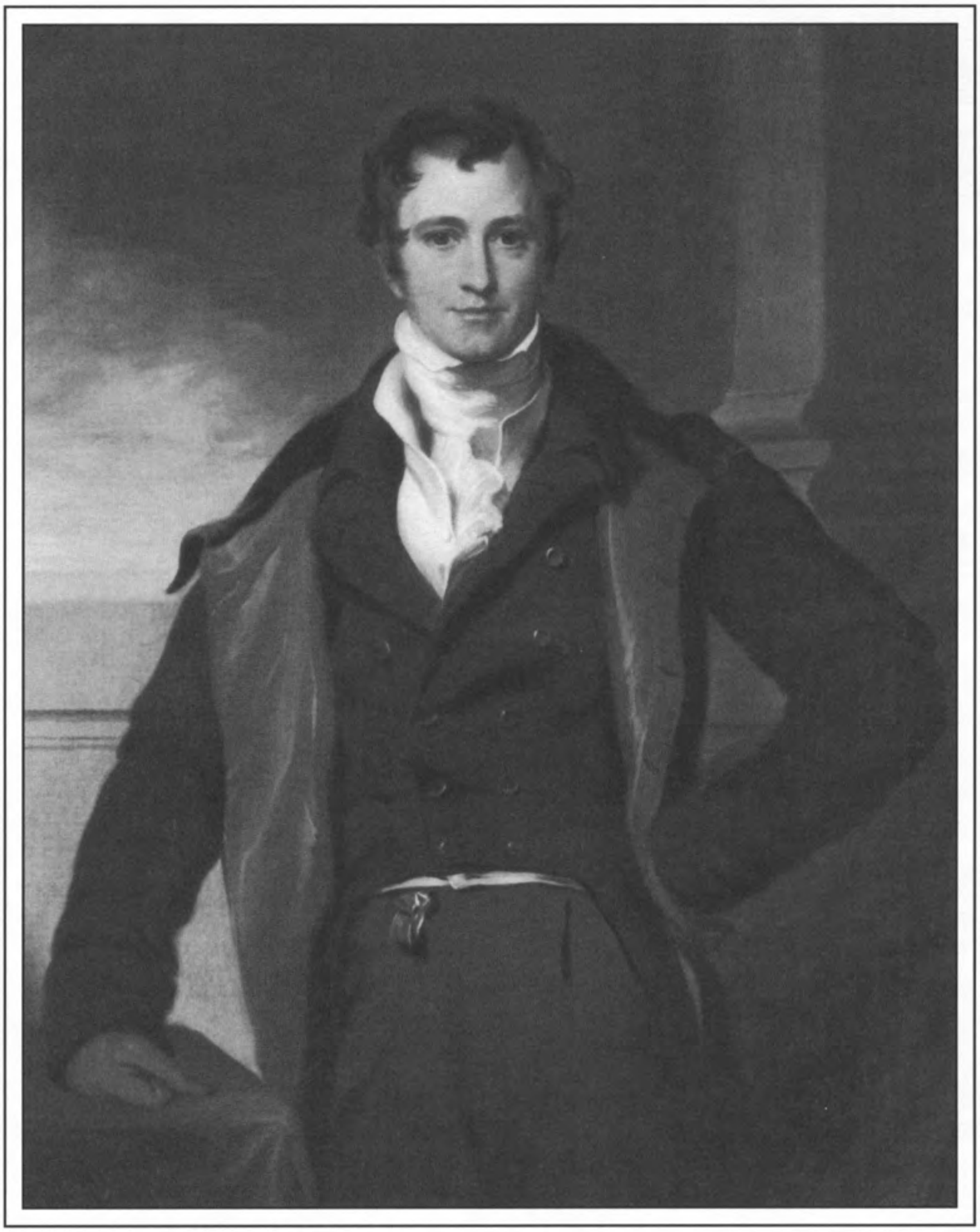

Plate X — Humphry Davy (1778-1829). As a young man he was "Medical Superintendent" at Beddoes' Pneumatic Institution where he performed his chemical, physiological and medical experiments with nitrous oxide. His promotion of nitrous oxide inhalation led to its subsequent widespread recreational use. In later life, Davy became a renowned chemist and President of the Royal Society.

Chapter XIII

Humphry Davy

His Life and Career

As with Thomas Beddoes, the selection of an official biographer for Humphry Davy by his widow was regarded, in some quarters, as unfortunate. Lady Jane Aprese Davy selected John Ayrton Paris, a physician and scientist, to write the biography which appeared in 1831. The selection was made on the basis of an earlier sketch of Davy which had been written by Paris. Sir Humphry's younger brother, John Davy, later chided Paris for writing material of which "much was objectionable" about Humphry Davy and which tended to "deliver his name to posterity with a sullied reputation." In 1836 John Davy also published a biography of Sir Humphry, partly in rebuttal to Paris' book. The five year gap between the books was due to John's service as an army medical officer on Malta. John Davy spent much of his life as a military physician. During his career he did considerable work involving animal physiology. He applied the thermometer extensively and is regarded as the father of clinical thermometry.(1)

In more modern times J.Z. Fulmer was highly critical of Paris as a biographer accusing him of doctoring material and misrepresenting facts but alledged that John Davy did the same. He wrote that, "Generations of unwary readers have been trapped between them."(2)

Humphry Davy was born at Penzance in Cornwall on 17 December, 1778. His father was a skilled woodcarver who was described as an ingenious but shiftless man. He appeared to be somewhat financially independent and pursued this career almost as a sideline. When he died he left his family in a state which was not really definable as poverty (income at least 150 pounds/yr). But there was not enough money to permit Humphry to attend university.(3) Humphry was said to be a precocious child, but his early schooling was indifferent. He attended an infant school and then a grammar school in Truro. His schoolmaster was a Mr. Cardew who recalled the lad as a "clever boy" but no signs of genius were evident at the time.(4) Davy was described as a dreamy lad who learned by observation and attempted to make up his lack of formal education by self-study.(3) Paris provided several examples showing the liveliness of Humphry's mind and the variety of his activities as a child. He had an early fondness for fiction and frequently harangued his friends into participating in dramatizations which he had adapted. He frequently wrote ballads and verses, made fireworks, and went fishing and shooting to obtain specimens. His formal education ceased in December, 1793. Humphry Davy then lived for a year (December, 1793-February, 1795) in Penzance pursuing independent study in various fields. He resided at the home of Mr. John Tonkin, a family friend. Following the death of Humphry's father in December, 1795, Mr. Tonkin became his unofficial patron. This arrangement may have been a death bed wish of Humphry's father.(5)

On February 10, 1795 Humphry was apprenticed to Mr. John Bingham Borlase,* surgeon-apothecary of Penzance. This apprenticeship was undertaken with the advice and encouragement of Tonkin. At that time, the apprentice surgeon was considerably better off in terms of treatment and working conditions than apprentices in other trades or professions. Also, the professional and social lot of the surgeon-apothecary was improving considerably so that this career must have appeared attractive to the prospective apprentice. The parents of the apprentice generally paid a premium to the master for various aspects of the training. Term of service was most frequently seven years and the period of apprenticeship began at about age 14 following preliminary classical education.(6)

Davy's certificate of indenture is preserved at the Royal Institution in London and is representative of similar documents of that era. It was made between Grace Davy of the parish of Penzance in the County of Cornwall and Humphry Davy of the same locality and John Bingham Borlase of Penzance. This indenture was for a period of five years. The duties and obligations of Humphry Davy were outlined. He promised to serve his master and look out for his interests and goods and not to frequent taverns and involve himself in any illegal games etc. Mrs. Davy promised to provide for said Humphry Davy during this period sufficient meat, drink, washing and lodging and apparel appropriate for these activities. John Bingham Borlase for the above consideration and also for the sum of sixty pounds paid by Grace Davy agreed to teach and instruct Humphry in the art, skill, profession and practice of Surgeon and Apothecary. No hard or laborious work or other non-relevant employment were to be exacted. If Borlase were to die during this interval, terms of repayment were specified.

Davy was not a particularly conscientious apprentice. He had wide-ranging interests in philosophy, languages, mathematics, poetry and religion. The organization and extent of his notebooks from this period suggest that he probably paid more attention to his independent study program in these areas than to physic. Some of his early poems from this period included "Sons of Genius," "Song of

*Borlase later earned an M.D. degree and became a physician. Borlase was the first director of the Penzance Infirmary founded in the 1790's. He was succeeded in this post by Dr. John Ayrton Paris, Davy's biographer.

Pleasure," "Ode to St. Michael's Mount in Cornwall," and others. The geography and economy of Cornwall were believed to have a great influence on Davy's preoccupation with history and philosophy.(7)

There are records of his medical activities at this time which indicate that he did perform and assist in surgical tasks. He was characterized by Mr. Borlase, his sister and others as a skillful, compassionate and beloved practitioner of medicine, particularly to the poor.(8)

According to Paris, Humphry Davy had an objectionable quality to his voice and was tone-deaf. It was alleged that he had an unhandsome face, round shoulders and an insignificant manner.(9)

He was said to be inordinately clumsy and very inept at learning military drill when he joined the local volunteers. Such allegations were denied by his brother John.

A most curious story relates how Humphry Davy was once bitten by a dog which he believed to be rabid. On the spot, he took out his knife and excised the affected area. He then returned to the surgery to cauterize the bed of the wound. The truth of this incident was later verified by Davy's sister. In connection with the pain associated with this procedure upon himself, Paris quoted Davy as declaring his disbelief in the existence of pain whenever the energies of the mind were directed to counteract it.(10) But he also quoted Tonkin as saying that on another occasion when Davy was bitten by a conger eel he "roared out most lustily." John Davy also related the story of the dog bite with a slightly different time frame. He interpreted his brother's response to the wound excision, which was said to have occurred about six months after the dog bite, not to denial of the existence of pain but to the control of the mind over the body:

> "This is a striking instance of that mental intrepidity which he possessed and on many occasions exerted through life arising not from the boldness of nerve or animal courage simply, but from the control of mind over body. That he believed, at this early period, in the possibility of such a controlling power being exercised, I do not doubt and who can? but this is very different from a sentiment attributed to him by the same author [Paris] on hearsay – his disbelief in the existence of pain whenever the energies of the mind are directed to counteract it'; a proposition which I have no hesitation in rejecting as his, both because it is illogical, and because it is associated with a ludicrous incident in its enunciation."(11)

Although Paris indicated that Humphry began studying chemistry at the beginning of his apprenticeship in 1795, John Davy dated his interest in this subject from 1797. His texts were Lavoisier's "Elements of Chemistry" and "Nicholson's Dictionary"; a book of questionable value.(3) His earliest experiments were related to the composition of gas in bladders of seaweed. At this time he also began preparing gases. These experiments were conducted in Humphrey's bedroom and in the kitchen of Tonkin's house. Paris wrote:

"His instruments , however, were of the rudest description, manufactured by himself out of the motley materials which chance threw in his way; the pots and pans of the kitchen, and even the more sacred vessels and professional instruments of the surgery, were without the least hesitation or remorse put in requisition."(12)

Davy was thrilled to receive the gift of a set of instruments from a French surgeon who had been shipwrecked in Cornwall. The old clyster apparatus of this set was put to use as an air pump in some subsequent experiments. The availability of minerals from Cornish mines, a variety of rocks and the seashore all furnished material for speculation and experimentation. Paris continued:

> "Had he, at the commencement of his career been furnished with all those appliances which he enjoyed at a later period, it is more than probable that he might never have acquired that wonderful tact of manipulation, that ability of suggesting expedients, and of contriving apparatus. . . . "

John Davy concurred that the chemicals used by his brother were substances in common use, such as acids, alkalis and medicines from the dispensary, and that his equipment was rudimentary. One of the reasons given by John for the number of chemical discoveries made by his brother was that the extent of scientific knowledge was sufficiently primitive that new information was quite easily obtained. He wrote,

> "The known boundaries of science were of small extent, the knowledge of it easily acquired and in every direction unexplored regions tempted enterprise and ambition."

John Davy believed that Paris' telling of this early phase of Humphry's professional life contained many errors of fact. Among these were details of Humphry's introduction to and association with two individuals who were to be of great importance in the subsequent advancement of his career.

One such person was Davies Giddy. At this time Giddy was engaged in activities in West Cornwall associated with new developments in engineering. He was working with Johnathan Hornblower and Richard Trevithick. One of the objectives of his efforts was to break the monopoly of Boulton and Watt for the steam engine. One of Giddy's frequent visitors was the studious Thomasin Dennis whom he was tutoring. She was the daughter of a Penzance miller. Giddy first met Davy through Thomasin's cousin, John Dennis. In a letter to Miss Dennis he commented on Davy stating how surprised he was to find an individual so disadvantageously situated performing experiments worthy of Dr. Priestley.(13)

Yet other accounts of the meeting between Davy and Giddy are given in the biographies of Paris and John Davy. They differ markedly. The former wrote that the first meeting occurred while Humphry was swinging on the half-gate of Mr. Borlase's house making humorous contortions of his face.(14) On this occasion a companion walking with Giddy identified the youth as Davy, fond of making chemical experiments. Paris wrote that there followed several meetings between Davy and Giddy during which Davy's genius and the depth of his knowledge became apparent. Giddy offered any type of assistance which Davy might require. According to John Davy, his brother and Giddy were first introduced by a certain Mr. John because of their mutual interest in chemistry.(15) This sounds more plausible than Paris' apocryphal tale. During one of the meetings between Davy and Giddy, they were said to have visited a chemist, Dr. Edwards, who had an elaborate laboratory. Davy was entranced and thrilled to see the apparatus which had been previously familiar to him only through illustrations in books. He was particularly attracted by an air pump and worked this repeatedly.

In any case, Giddy gave Davy a copy of Beddoes' and Watt's "Factitious Airs" and drew his attention to the appendix by Samuel Latham Mitchill on the "gaseous oxide of azote." This essay on the alleged catastrophic effects of breathing nitrous oxide was Davy's inspiration to investigate this gas further and to prove its respirability.* On the advice of Dr. Beddoes, Josiah Wedgwood Jr. had gone to Penzance to spend the winter of 1797-8. As a tutor for Wedgewood's daughters Giddy recommended Thomasin Dennis.(13) Another of Davy's friendships from this period was that with Gregory Watt, son of James Watt, Lunarian, engineer and collaborator with Thomas Beddoes.

In the autumn of 1797 Gregory Watt had become seriously ill and was sent to Cornwall to recuperate.(16) Watt had early consumption and had been advised to take the air in Cornwall by his physicians. There he resided in the household of Davy's mother.(17) Perhaps Giddy had arranged to have Gregory Watt board with Mrs. Grace Davy during his sojourn in Cornwall so that both Gregory Watt and Humphry Davy could mutually enjoy the benefits of this association.(13) Paris claimed that the relationship between Humphry Davy and Gregory Watt was initially cool and distant because of Watt's aristocratic manner. John Davy denied this contention. Nevertheless, the common ground of chemistry soon formed a warm bond between the two young men. Also about this time Thomas and Josiah Wedgewood Jr. were resident in Cornwall. The friendship of all these individuals was undoubtedly beneficial to Davy's career.

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* Davy and Beddoes appear to have used the designation "respirable" as applied to gases in different senses. To Beddoes, respirable gases were capable of supporting life. Examples were air or oxygen. Hydrogen and nitrogen were regarded as unrespirable. To Davy, only gases that were too irritating to breathe were non-respirable. An example was nitric oxide which he was unable to breath and gave him burns of the mouth. He regarded gases such as nitrous oxide and hydrocarbonate (partly carbon monoxide) as respirable.

Davy's first formal scientific papers concerned his theory of heat and light. In April, 1798, Gregory Watt arranged for Davy to send these manuscripts to Thomas Beddoes in Bristol. Beddoes was greatly impressed by the work of this young chemist and apprentice apothecary-surgeon. He wished to include this work in a publication that he was preparing on contributions to medicine and science from the west of England. These youthful works were indeed rapidly published in Beddoes' book to the subsequent everlasting regret of Davy.

At this time Beddoes was also involved in opening his Pneumatic Institution and was seeking a "Medical Superintendent" to take charge of the studies on gases and their possible therapeutic effects. Davies Giddy recommended Humphry Davy for the post. In a letter dated 4 July, 1798 Beddoes asked Giddy to begin discussions with Davy on the possibility of Davy's assuming the superintendancy and on specific details of the position.(18) He mentioned some possible advantages to Davy in accepting. In a second letter dated 18 July, 1798 Beddoes wrote to Giddy that Davy's response was generally favorable, but that he would require a "genteel maintenance." Beddoes indicated that he would be unable to offer much of a salary but that the position would be advantageous for Davy and might establish his reputation. He asked Giddy to conduct further negotiations, writing:

> "Certainly nothing on my part shall be wanting to secure him the credit he may deserve. He does not undertake to discover cures for this or that disease; he may acquire just applause by bringing out clear, though negative results."

Giddy strongly urged Davy to go to Clifton to work with Beddoes. He recognized this as a situation in which the full genius of Davy could begin to germinate. But in addition, Giddy thought that the presence of Davy at Clifton might accelerate the cure for consumption. The condition of a certain Miss Lydia Bains, a victim of early consumption, was of particular concern to Giddy. The young lady had sought relief at Clifton but eventually died.(13)

Davy, his mother, his friends, and Mr. Borlase all concurred that the post in Bristol seemed too good an opportunity to pass up. In releasing Davy from his indenture Mr. Borlase wrote:

> "Because being a youth of great promise, I would not obstruct his present pursuits which are likely to promote his fortune and his fame."(19)

The lone dissenter in this opinion was Davy's benefactor Mr. John Tonkin whose unshakable desire was to have Davy complete his apprenticeship and remain as a surgeon-apothecary in Penzance. Mr. Borlase released Humphry Davy from his term of indenture on October 1, 1798 and on the following day Davy left Penzance for Bristol. Mr. Tonkin altered his will, revoking certain legacies to Davy.

(At a later date he, too, became convinced of the desirability of the move and readjusted his will accordingly). John Davy inferred that his brother's progress in medical studies must have been considerable to be able to occupy the position at Bristol during his fourth year of studies.(20)

Davy must have been greatly pleased by his appointment at the Pneumatic Institute and looked with anticipation on what he might accomplish. He had written before his appointment and departure for Bristol:

> "...chemistry had as yet afforded but little assistance in the cure of diseases or in the explanation of organic functions except for theories of a celebrated medical philosopher, Dr. Beddoes."(21)

HUMPHRY DAVY AT THE BRISTOL PNEUMATIC INSTITUTION

Davy's initial impressions of Bristol were conveyed to his mother in his first letter home on Oct 11, 1798. (This was about ten days after his departure from Penzance).(23)

He described briefly the scenery and physical setting of the country and the house at Clifton. He stated that he had a large laboratory available for his work. He continued:

> ".... Dr. Beddoes, who, between you and me, is one of the most original men I ever saw – uncommonly short and fat, with little elegance of manners, and nothing characteristic externally of genius or science; extremely silent, and, in a few words, a very bad companion."(24)

On another occasion Davy again commented on Beddoes' disinclination to engage in conversation: "Nothing could be a stronger contrast to his apparent coldness in discussion than his wild and active imagination which was as poetical as Darwin's."(25) Beddoes' behavior to Davy was described as "handsome" and the entire management of the Pneumatic Institute had been given up to Davy. Mrs. Beddoes was the reverse of Dr. Beddoes. She and Davy became the best of friends and: "she has taken me to see all the fine scenery about Clifton; for the Doctor, from his occupations and bulk is unable to walk much."

Also mentioned is the presence of the three children of Mr. Lambton who were being raised in the Beddoes household. It will be recalled that Mr. Lambton had donated £1500 towards the founding of the Pneumatic Institution before his death from consumption.(26) Davy then related some of his future plans to his mother.

In a later letter to his mother he communicated some other facts about the Beddoes family and his position in their household:

> "You have been told he (Dr. Beddoes) is fond of money; I assure you it is quite the contrary, he is good, great, and generous; and Mrs. Beddoes is the best and most amiable woman in the world. I am quite naturalized into the family and I love them the more the more I know them."

Davy must have initially regarded the position at the Pneumatic Institute as a temporary one. Some letters around this time stated his objectives: to remain active in medical practice and to ultimately graduate from Edinburgh University and become a physician. But he was soon immersed in the investigative activities at the Institute and slowly abandoned thoughts of a medical career. The environment and facilities at the Pneumatic Institute were ideal to permit him to pursue his interests. In his chemical experiments, as he wrote in other letters, he was greatly aided by the conversation and advice of Dr. Beddoes. He was also occasionally assisted by Mr. William Clayfield, a person greatly interested in chemistry and known for other accomplishments in science. Also mentioned as advantageous to Davy's development were the acquaintance of James Tobin, a dramatist, and the large number of other people visiting Beddoes in Clifton, including Lunar Society Members.(27) The circle meeting at Beddoes' house was more literary than scientific and included Coleridge, Southey, and Tobin. Coleridge and Southey were said to be on "terms of close friendship" with Dr. Beddoes.(28) An additional lifelong friend made at this time was a Mr. Poole, a gentleman from Somerset characterized by Coleridge as being at home with all classes of society and types of individuals, and of superior and "racy" intellect.(29) Davy found adequate time to mix with this circle.(30) Of particular influence on Davy's thought at this time was Richard Lovell Edgeworth, Thomas Beddoes' father-in-law. In later years, Maria Edgeworth wrote that: "Her father possessed much influence over Davy's mind. When he was a very young man at Clifton, unknown to fame, Mr. Edgeworth early distinguished and warmly admired his talents, and gave him much council which sunk deep into his mind."(27)

Davy's "Essays on Heat and Light etc.," his first publications, appeared in Beddoes' "Contributions to Physical and Medical Knowledge etc., from the West of England." This volume was published in May, 1799.(31) These theories were formulated because of some perceived deficiencies in current chemical thought; primarily failure to account satisfactorily for heat and light during combustion. They incorporated certain hypothetical complex forms of oxygen which he invented and termed phos-oxygen and illuminated phos-oxygen. John Davy discussed these essays in his biography of his brother. He concluded that they were an early product of a very imaginative mind which at that point had an extremely limited chemical education. John Davy said that this was the only time that Humphry Davy ever speculated hastily in this manner. Later in life Humphry expressed the wish that he could have withdrawn these early essays. This was an exciting time in politics and in science and it was believed that Humphrey Davy was carried away by the excitement. Nevertheless, his brother John believed that the essays were an important milestone regardless of their error because they give a clue to Humphry Davy's mind when he was a young philosopher.(32) Priestley, in the Appendix of his last chemical work on the doctrine of phlogiston wrote that these ideas of Davy were very striking and of great consequence.

The first of these two early essays was "An Essay on the Generation of Phos-oxygen or Oxygen Gas; and on the Causes of the Colours of Organic Beings." An interesting speculation in this essay dealt with the origins of differences in skin coloration among the various races. These depended on varying quantities of carbon and oxygen in the blood of cutaneous vessels. Color in turn depended on the reaction of these substances with different amounts of light:

> "Light, acting on the rete mucosum of the African, is continually abstracting oxygen, the principle to which its whiteness is owing. When the oxygen is subtracted the carbon becomes the predominant principle, and hence, that blackness peculiar to the Negroes and the inhabitants of the torrid zone.....Americans, the inhabitants of Asia, and the southern Europeans, ...are less exposed to light than the Negroes, consequently their skin contains a larger proportion of oxygen....A subtraction of oxygen from the rete mucosum by any means, uniformly blackens it....By combining with oxygen the rete mucosum is uniformly whitened. Dr. Beddoes whitened the fingers of a Negro by muriatic phos-acid, which appears capable of giving out a small portion of oxygen...."(33)

Why then did not the European who was resident in the tropics or the African who removed to a temperate climate exhibit a change of skin color? Davy continued:

> "When certain colors are considered as beautiful, degenerating imagination makes them hereditary and the chemical changes from the influence of light are more slowly produced. Thus Europeans, though exposed to light in the African countries, do not become black but in a great length of time and Negroes, though deprived of light their accustomed oxygen attractor, are not blanched for many generations."

The second of the early essays was the "Essay on Heat, Light and the Combinations of Light with a new Theory of Respiration." In this paper he modified then current theories of respiration enunciated by others so that they better correspond to his perceived ideas in this area.(34) Paris stated that in later life Davy thoroughly regretted his theories involving phos-oxygen and illuminated phos-oxygen and any reference to the subject became a source of painful irritation. Paris severely criticized Beddoes for not restraining Davy on publication of these theories: "much as Davy needed the bridle, Beddoes required it still more: for, notwithstanding his talents, he was as ill-fitted for a Mentor as a weathercock for a compass;....."

At the beginning of 1799 Davy began his pneumatic experiments. In a letter to Giddy on Feb 22, 1799, Davy gave his old friend an account of some chemical experiments that he was doing. He stated that the laboratory in the Pneumatic Institute was nearly finished and they expected to begin investigations in about a fortnight. He related that about five weeks previously, he had spent nine or ten days in Birmingham, chiefly with Keir and Watt. He characterized Keir as "an able chemist and a great man."(35) In January, 1799 Davy wrote to his friend, Penneck, in Penzance stating that he considered Beddoes to be the most liberal, candid and philosophic physician of the age since he readily abandoned theories which proved untenable. By this time Beddoes had developed great reservations concerning Brown's method of medicine. It was indicated, however, that Beddoes retained considerable portions of Brown's method in his clinical practice while condemning it in theory.(36)

As previously noted, Davy first became interested in nitrous oxide when he read the theory regarding the contagion caused by this gas proposed by Dr. Samuel Latham Mitchill of New York City.* Davy subsequently disproved Mitchill's theory.(37) [This reference to Dr. Mitchill's theory and his disapproval of it is emphasized at least three times in his various journals]. Davy must have suspected that this gas should have some special medicinal properties. Part of Davy's duties at the Pneumatic Institute was to investigate the physiological effects of such aeroform fluids which held out any promise of use. By the spring of 1799, Davy and Beddoes had experimented with nitrous oxide prepared by interaction of nitric acid (HNO_3) and zinc. The products of this mode of preparation would be heavily contaminated with higher oxides of nitrogen. By April, at the suggestion of Beddoes, this method of preparation had been replaced by another suggested by Bertholet in 1785: The gentle heating of ammonium nitrate.(3)

It is also possible that James Watt called Davy's attention to Bertholet's method of preparing nitrous oxide(38) During his attempts to purify nitrous oxide Davy had the opportunity to give a complete account of combinations of nitrogen and oxygen or hydrogen, i.e. the chemistry of gaseous oxides of nitrogen, nitric acid and ammonia.(39) Davy's progress with nitrous oxide was conveyed to Giddy in a letter written on April 10, 1799:

> "I made a discovery yesterday which proves how necessary it is to repeat experiments. The gaseous oxide of Azote is perfectly respirable when pure. It is never deleterious but when it contains nitrous gas [nitric oxide]. I have found a mode of obtaining it pure and I breathed, today,

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*In Thomas Beddoes "Contributions to Physical and Medical Knowledge. Principally from the West of England" (1799) Davy had expressed the belief that ignorance of the composition of organic matter and of the changes effected in the blood caused by oxygen gas was a considerable source of the imperfection of medicine. One wonders why he did not select the vitally important gas oxygen for extensive investigation rather than nitrous oxide, one of little physiological importance.

> in the presence of Dr. Beddoes and some others, sixteen quarts of it for near seven minutes. It appears to support life longer than even oxygen gas and absolutely intoxicated me. Pure oxygen gas produced no alteration in my pulse nor any other material effect; whereas this gas raised my pulse upwards of twenty strokes, made me dance about the laboratory as a madman, and has kept my spirits in a glow ever since. Is not this a proof of the truth of my theory of respiration? For this gas contains more light in proportion to its oxygen than any other, and I hope will prove a most valuable medicine. We have upwards of eighty-eight out-patients in the Pneumatic Institute and are going on wonderfully well....."

In further experiments done on April 16, he breathed three quarts of nitrous oxide in and out of a silk bag for more than half a minute and felt giddiness, fullness of the head, loss of voluntary power but unattended by pleasurable sensation. He could not determine whether the gas was stimulant or depressant. On April 17, he inhaled having first exhausted his lungs and occluded his nose and experienced great exhilaration and a pleasurable sensation. These experiments continued and he demonstrated impending loss of consciousness and almost involuntary motor activities to express his pleasure with the gas.

Davy also reported that nitrous oxide inhalation relieved the headache associated with a severe hangover from alcohol. Davy had earlier concluded that nitrous oxide was a stimulant drug and he had wished to determine whether it would act synergistically with alcohol, another substance perceived as stimulant. He therefore drank a whole bottle of wine quickly and "passed out." He awoke with a severe headache and promptly called for his "green bag" of nitrous oxide. Upon breathing the gas his headache was temporarily relieved and he felt better. He thus reported the analgesic properties of nitrous oxide and concluded that debility of intoxication was not increased by excitement from this gas.(40) Maria Edgeworth wrote following a visit to Bristol in 1799:

> "A young man, a Mr. Humphry Davy, at Dr. Beddoes, who has applied himself much to chemistry, has made some discoveries of importance, and enthusiastically expects wonders will be performed by the use of certain gases, which inebriate in the most delightful manner, having the obvious effects of Lethe, and at the same time giving the rapturous sensations of the nectar of the gods!"(41) She continued: "Pleasure even to madness is the consequence of this draught. But faith, great faith, is, I believe, necessary to produce any effect upon the drinkers, and I have seen some of the adventurous philosophers who sought in vain for satisfaction in the bag of "Gaseous Oxyd" and found nothing but a sick stomach and a giddy head."(42)

The first public announcement of inhalation of nitrous oxide was a letter dated Clifton, April 17, 1799. It was published in Nicholson's Journal of Natural Philosophy, Chemistry and the Arts. In this, and in several subsequent announcements, Davy used his designation of oxygen as "phosoxygen" to insure that the gas would conform to his theory of heat and light. He wrote:

> "I have this day made a discovery, which, if you please, you may announce in your Physical Journal, namely, that the nitrous phosoxyd, gaseous oxyd of azote, is respirable when perfectly freed from nitric phosoxyd (nitrous gas). It appears to support life longer than common air, and produces effects which I have no time to detail at present. Dr. Mitchill's theory of contagion is of course completely overturned; the mistakes of Priestley and the Dutch Chemists probably arose from their never having obtained it pure."*

Davy expressed the hope that no injudicious self-experiments by others would be made on the basis of this preliminary report. He perceived that additional safety recommendations on the gas were necessary. He was anxious that this notice be published because:

> "some of the most remarkable phenomena witnessed by diverse persons, in the Pneumatic Institute, and leading to useful practices, have been a good deal talked of at Bristol, and as erroneous anticipation may get into print, before the true account can be prepared."(43)

A further public notice of Davy's researches with nitrous oxide was another letter. This was dated Clifton, April 21, 1799 and also published in Nicholson's Journal. He announced that experiments had been done using nitrous phosoxyd, or the gaseous oxyd of azote, the principle of contagion of Dr. Samuel Latham Mitchill. The gas was given to animals mixed with 1/3 its volume of phosoxygen (oxygen gas) and no ill effects were observed.(44)

Davy related that he himself had breathed nitrous oxide both pure and mingled with oxygen gas** and experienced some strange effects. During some of these experiments Davy must have been enclosed in an airtight box; the "breathing chamber.... like a sedan chair" devised by Watt in which the occupant was provided with a large feather which he waved to assist in gas mixing.(45,46) Davy speculated that the gas might be useful as a medicine. He also discussed some chemical

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*The Dutch chemists were Adrian Paets van Troostwijk and Rudolph Dieman who did some very early work on nitrous oxide and who were cited by Samuel Latham Mitchill in his discussion of his theory of contagion.

**Origin of the technique of administering nitrous oxide with oxygen for clinical use is generally attributed to Dr. Edmund Andrews of Chicago, U.S.A. about 1868. However Davy appears to have used this method in some of the earliest administrations of the gas.

theories involving heat and light which would justify his "phos" nomenclature and would account for the generation of light in certain chemical reactions. Finally, he reported that the Pneumatic Institute was doing well. Over 50 patients were being treated.(44)

A subsequent communication in Nicholson's Journal explained that accounts of the nitrous oxide studies had been printed in Dr. Beddoes' "Notice of some Observations from the West of England" in order to prevent "dangerous and inconclusive" experiments. This article appears to be the first in which Davy called the gas "nitrous oxide." He described the chemical preparation of his nitrous oxide by the heating of ammonium nitrate. He emphasized the importance of regulating the temperature of the chemical reaction carefully lest unwanted and toxic gases be produced, and recommended washing of the gas before use to remove impurities. Several individuals had inhaled the gas with generally pleasurable results. It had been used to date only in palsy, but he hoped it would prove serviceable in other debilitating diseases. He again stated his theories of light and heat.(47) William Nicholson, editor of the influential "Journal of Natural Philosophy, Chemistry and the Arts," commented editorially on the inhalation of nitrous oxide and its applications in medicine.(48)

Davy's final contribution to Nicholson's Journal on nitrous oxide in 1801 was an overview of his book "Researches" and outlined his chemical and physiological observations made on the gas at the Pneumatic Institute.(49)

Davy undertook some extremely dangerous experiments which had the potential to end in disaster! He attempted to breathe nitrous gas (nitric oxide [NO]), despite warnings by Mitchill and Priestley, with resulting chemical burns of his mouth and tongue and damage to his teeth.(50) Joseph Cottle indicated that on this occasion Davy attempted to rid his lung of as much oxygen as possible in the belief that a low oxygen environment would minimize the formation of acid from the nitrous gas. He also breathed carburetted hydrogen gas.(50,51) The gas was too irritating to permit a large inspiration into the lungs. On another occasion he breathed hydrocarbonate in the conviction that this gas, the major ingredient of which was carbon monoxide (CO), was a completely depressant gas whereas nitrous oxide was stimulating. Davy is quoted as believing this experiment showed that hydrocarbonate was a pure sedative. He began to lose consciousness during the inhalation and one or two more breaths would have destroyed his life. He suffered several hours of giddiness, nausea and headache from this exposure.(52) Paris believed that society was indebted to Davy for this daring experiment. First it demonstrated the danger of inhaling hydrocarbonate (water gas), widely used as illuminating gas by Paris' time, and the importance of assuring complete combustion of this gas when used for illumination. This was not always possible and therefore Davy's experiments explained the headache, nausea, and languor experienced by individuals in gas lighted rooms. Paris also stated that another important finding of Davy's experiment was that in cases of asphyxia there exists a period of danger after respiration has been restored and circulation reestablished during which unanticipated death might still occur. Davy next attempted to breath fixed air (carbon dioxide [CO2]) but was unable to breath the gas undiluted because of laryngospasm. He was able to breath about 25-30% of the gas and experienced a sedative effect. On another occasion he reported that he lost consciousness rapidly after breathing, in succession, hydrogen and then nitrous oxide.(53)

Paris expressed admiration for the "ardor for investigation which the most imminent personal danger could not repress." He presented these experiments as exemplifying the "zeal" and "intrepidity" with which Davy pursued his experiments. Davy probably could not have known of the extreme danger posed by inhalation of these lethal gases. Probably "foolhardiness" and "recklessness" would be more appropriate descriptors of his self-experimentation. Because of fatigue and ill health, possibly caused by the persistent self-experimentation, Davy was forced to take a months vacation (Oct-Nov, 1799) at home in Cornwall. John Davy related that Humphry regretted having attempted one or two of his experiments almost as soon as they were made because they were instituted in the face of manifest danger and without any reasonable prospect of a beneficial or even innocuous result. He seems to have published them, chiefly as a warning to others. Later in life he opposed self-experimentation and advised others to avoid it.

During his stay at the Pneumatic Institute Davy also began studies on voltaic electricity which were related to some of his most important subsequent studies.(54) In another letter to his mother on Sept. 1, 1799, Davy defended his somewhat infrequent correspondence home. He then wrote, "We are going on gloriously. Our palsied patients are getting better; and, to be a little conceited, I am making discoveries every day." (This letter also includes considerable advice on the education of Davy's younger brothers and sisters.)(55)

Davy received a letter from James Watt in Birmingham in November, 1799. This communication included ideas on many aspects of the chemicals and equipment proposed for use in Davy's experiments. Included were details of the sedan-chair-like chamber in which an individual could be confined while breathing altered gaseous atmospheres. Watt also suggested use of various gases in different situations and proposed a new method of making nitrate (presumably for manufacture of nitrous oxide). In December, 1799, Davy spent two weeks in London. During his stay in London his hosts included Coleridge, Southey, Gregory Watt, Underwood, James and John Tobin, Thompson, and Clayfield.

In a letter written on Jan 12, 1801 from Dowry Square, Clifton to John Tonkin, his Penzance benefactor and friend, Davy wrote:

> ...."My discoveries relating to the nitrous oxide, the pleasure-producing air, are beginning to make some noise: the experiments have been repeated with the greatest success, by the professors of the University of Edinburgh, who have taken up the subject with great ardor; and I have

received letters of thanks and praises for my labours from some of the most respectable of the English philosophers. I am sorry to be so much of an egotist; yet I cannot speak of the Pneumatic Institute and its success without speaking of myself. Our patients are becoming daily more numerous and our institution, in spite of the political odium attached to its founder, is respected, even in the trading city of Bristol. I shall soon send you an account of the success we have had in curing some of the most obstinate diseases by new remedies. The nitrous oxide we have found very beneficial in many cases of palsy. . . . ."(56)

This letter attests to the increasing attention paid to Davy's work and writings by individuals in influential positions who could assist with advancement of his career. The letter also clearly demonstrates Davy's belief in the validity of Pneumatic Medicine at the time that he left the Pneumatic Institute, which extended into the time after publication of "Researches." Entries in Davy's laboratory notebooks confirm that while he was at the Pneumatic Institute he believed firmly in the benefits of pneumatic forms of therapy. His thinking was typically Brunonian and in accord with the published writings of Thomas Beddoes. He believed that an important determinant of intensity of action of an inhaled gas in the body was its temperature on inhalation. An objective in treating pulmonary consumption was to promote pulmonary absorption and pulmonary lymphatic absorption and the stimulus for this must be applied directly to the lung. Therefore the treatment must be gaseous.(57) Davy wrote:

"The motives that induced Dr. Beddoes to propose an institution for investigating the process of aeriform remedies have been already laid before the public. This institution is now established. Pneumatic medicine is founded on the theory of respiration and the known change effected in the living functions by the inspiration of different gases. A specific gaseous stimulus for the pulmonary lymphatic and venous absorbents is one of the greatest desiderata. From the discovery of this we might hope for the cure of several diseases almost universally fatal: pulmonary consumption, hydrops pectoris etc."(58)

One of Davy's closest friends and most ardent supporters in Bristol was the poet Robert Southey. Southey was a zealous inhaler and advocate of nitrous oxide. His enthusiastic acceptance of nitrous oxide was described in a letter to his brother Tom dated Friday, July 12, 1799:

"Oh Tom! such a gas has Davy discovered, the gaseous oxyde! Oh, Tom! I have had some; it made me laugh and tingle in every toe and fingertip. Davy has actually invented a new pleasure for which language has no name. Oh,Tom! I am going for more this evening; it makes one strong and so happy! so gloriously happy! And without any after-debility, but, instead of it, increased strength of mind and body. Oh, excellent air-bag! Tom, I am sure the air in heaven must be this wonder-working gas of delight. Yours, Robert Southey."(59)

Mr. C.W. William Wynn, one of Southey's friends from Exeter must have expressed doubts about the propriety or the effects of nitrous oxide inhalation. Southey replied and also commented upon certain medical activities at the Pneumatic Institute, including the tale of the cure of palsy with a thermometer by Davy and the trials of foxglove in consumption by Beddoes. The letter is dated Sept. 24, 1799:

> ".....You are mistaken in supposing I play pranks with myself; the gaseous oxyd had been repeatedly tried before I took it, and I took it from curiosity first, afterwards as a luxury, not medicinally. The foxglove you may be assured is a powerful and valuable medicine. You astonish me about the tractors.* Did I tell you that trials had been made at Bristol with pieces of wood, which had actually cured paralytic cases? The inference is that faith works the cure. There is always a difficulty in distinguishing between the effect of a medicine and of credulity. Davy put a thermometer into the mouth of a patient to ascertain his animal heat. A few days afterwards the man came to him: "Do ye, Sir, put that thing in my mouth again; nothing ever did me so much good. I felt myself better directly."(60,61)

In letters from Bristol in February, 1800 Southey further explained his use of nitrous oxide gas. In addition, he mentioned the use of cows' breath in treating consumption and alluded to his own illness. Southey wrote to Mr. John Rickman:

> ".....This is a place of experiments. We have consumptive patients, in cow houses some and some in a uniform high temperature and the only result seems to be that a cure may sometimes be effected but very rarely. I have taken the nitrous oxyd the wonder-working gas – I think with benefit. At first I was apprehensive that it might injure me and refrained from it with continence that would not have disgraced a hermit, but on trying its effects, they appear beneficial and certainly have not been injurious. Davy is making important experiments upon the respiration of the different airs which will probably occasion an alteration in the nomenclature. I saw a mouse die for want of azote...."(62)

In a letter to John May, Southey wrote:

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*Tractors were devices, usually metallic, advocated by Perkins, which, when applied to the body, were alleged to extract diseases and restore health. They were the inspiration for Thomas Fessenden's poem "Terrible Tractoration" in which Beddoes and others were mercilessly satirized. See section on Beddoes.

> "...The state of my health is in some respects amended, in others stationary......the starting and miserable feelings.. at night still continued and were only lessened by aether not removed. About a fortnight ago I breathed the oxyd of azote, the air whose strange effects you must have seen some account of in the Reviews. I had been fearful of it since my return to Bristol, but on making the experiment was surprised by its beneficial influence. I slept without the disease, which, for months before, had invariably preceded sleep. After several nights, it recurred again: I repeated the dose and have taken it about once in three days since and the complaint has been till now removed. To say the gas has been the cause would be hasty, but I cannot help thinking so....."(63)

Southey, as well as his medical friends believed that there was probably no organic basis for his disease.

There are a considerable number of letters from Southey to Davy, but none from Davy to Southey have been found. They grew somewhat distant in later years of their lives, but this was attributed to deteriorating health of the poet. Robert Southey's physician was Thomas Beddoes. He diagnosed Southey as suffering from a nervous condition brought on by his sedentary manner of life and prescribed exercise. (Southey had thought that he was suffering from consumption.) For this, the poet took a walking tour. Southey published an issue of a literary magazine in 1798 or 1799 to which Davy was a contributor. When Southey left Bristol shortly thereafter, Davy was nominated as one of the editors but another issue never appeared.(64) Joseph Cottle attested to Davy's qualifications for this position: "....if he had not shone as a philosopher, he would have become conspicuous as a poet."(65)

In later life Southey reminisced about these halcyon days in Bristol when Davy was at the Pneumatic Institute:

> "This....was one of the happiest portions of my life. I was then also in habits of the most frequent and familiar intercourse with Davy, then in the flower and freshness of his youth. We were within an easy walk of each other, over some of the most beautiful ground in that part of England. When I went to the Pneumatic Institute he had to tell me of some new experiment of discovery, and of the views which it opened for him; and when he came to Westbury there was a fresh portion of `Madoc' for his hearing. Davy encouraged me with his hearty approbation during its progress and the bag of nitrous oxide with which he generally regaled me upon my visit to him, was not required for raising my spirits to the degree of settled fair, and keeping them at that elevation."(66)

John Davy wrote that Southey maintained his affection and respect for Davy throughout his life.(67) In 1805 Davy visited Southey at Keswick Hall; primarily for some fishing. Davy was an ardent angler throughout his life.(64) In his letters of this period Southey almost never fails to make some reference to nitrous oxide. May 4, 1799 "At Lymouth I saw Tobin's friend, Williams, who opened upon me with an account of the gaseous oxide. I had the advantage of him, having felt what he, it seems, had only seen." Aug. 3, 1799. "I have seen nothing of Dr. Roget and can hear nothing of him: you still, I suppose, go on working with your gaseous oxide, which, according to my notions of celestial enjoyment, must certainly constitute the atmosphere of the highest of all possible heavens. I wish I was at the Pneumatic Institute, something to gratify my appetite for that delectable air, and something for the sake of seeing you." Oct. 18, 1799. "Massena, Buonaparte, Switzerland, Italy, Holland, Egypt, all at once, the very spring-tide of fortune, it was a dose of gaseous oxide to me, whose powerful delight still endures. I was about writing to you when your letter reached me. Your researches into the science of nature and of man I shall look for with periodical eagerness, fully estimating the importance of researches which unfortunately, I shall only be able imperfectly to understand. Science I have none, except in anatomy, knowing little but terms. (Apparently the geographical references relate to travel books which he had collected for his winter reading as a basis for use in his poem "Thalaba").(60,62)

Another prominent poet of the Bristol circle who became a close friend of Davy was Samuel Taylor Coleridge. In 1795 Coleridge came to Bristol having abandoned careers as a Cambridge undergraduate and as a soldier. The attraction of Bristol was its lively political environment and also the presence of his friend Southey. He met Beddoes, presumably at a political meeting. Beddoes became Coleridge's latest hero and made a strong impression on him because of his integrity, political realism, and because he realized the importance of the mind in treatment of the body; one of Coleridge's current interests.(68)

Coleridge's interest in science is said to date from 1795 and probably originated with the expectation that the type of thinking and reasoning involved in science should be applicable in all areas of human inquiry.(69) Coleridge became interested in the relationship between mind and body and what we could now call psychosomatic aspects of disease. He used observations from the fields of anthropology, phrenology, and mesmerism as 'scientific' approaches to the workings of man. One reason that Coleridge became so interested in Davy's work was that effects of nitrous oxide resembled some of the psychosomatic phenomena in which he was interested.(70) He worked toward a coordination of all scientific and philosophical and other types of knowledge with one another. Apparently Coleridge believed that poet, philosopher and scientist were one in this enterprise. Humphry Davy's chemistry was poetry realized in nature.(71) Beddoes was an enthusiastic subscriber to Coleridge's magazine "The Watchman." Coleridge was initially a great admirer of Darwin and was influenced by the ideas in his scientific poems. He regarded Darwin as an individual possessing an enormous fund of knowledge in all areas.(69) Coleridge suffered from frequent episodes of illness which began during his childhood and persisted throughout his life. During his residence in Bristol, he began taking opium and remained addicted for the remainder of his life.(68) Coleridge dealt with pain and suffering in several of his poems.

Coleridge and his versifying colleagues were an important element in the eventual introduction of clinical anesthesia. Papper has concluded that attention to individuality and individual experience by romantic poets, such as Coleridge, and also by romantic essayists and philosophers, led to a change in orientation of clinical medicine so that attention to pain and suffering, particularly the prevention of pain, was emphasized. This in turn, together with the pragmatism born in the industrial revolution, made anesthesia desirable, acceptable, and inevitable.(72,73)

The Davy-Coleridge friendship began in 1799 when Coleridge returned to Bristol from Germany where he had been studying in several different areas.(74) This was made possible by a stipend granted by the Wedgwoods. Coleridge and Davy had complementary interests and extravagant ambitions. They impressed one another from the start and applauded, cheered, cajoled and inspired one another. For a while Coleridge regarded Davy as the greatest man of the age after Wordsworth. Coleridge believed that since Davy didn't engage in much philosophizing, that the poetry was implicit in his chemistry.(70) Davy was searching in science for the same things that Coleridge sought in poetry. The friendship between Davy and Coleridge lasted on into middle age.(75)

Perhaps the avidity with which the poets of the Bristol circle sought nitrous oxide and the unrestrained praise which they lavished upon its mental effects was related to their perception and definition of the nature of poetry. Wordsworth defined poetry as "....a selection of the real language of men in a state of vivid sensation...". He also wrote, "...Poems to which any value can be attached were never produced on any variety of subjects but by a man who, being possessed of more than organic sensibilities had also thought long and deeply..."(76)

Some of the poets probably recognized that the nitrous oxide gas would help them transcend mere organic sensibilities and attain the necessary state of vivid sensation. Nevertheless, Wordsworth appears to have declined all offers to breathe nitrous oxide and never participated in the inhalations.(77) Coleridge's description of his experiences with nitrous oxide was in simple unembellished narrative prose.(78) His disinclination to wax poetical over the pleasurable sensations brought on by the gas was attributed to his increasing concern and possibly shame associated with his opium addiction which began about this time.(77)

Humphry Davy is said to have composed poetry while wandering across the hills inhaling nitrous oxide from a bag.(79) The following verse by Davy expresses his emotions while partaking of the gas:

On Breathing Nitrous Oxide:
Not in the ideal dreams of wild desire
Have I beheld a rapture wakening form
My bosom burns with no unhallowed fire
Yet is my cheek with rosy blushes warm.
Yet are my eyes with sparkling lustre filled
Yet is my mouth impolite (?) with murmuring ??orem
Yet are my limbs with inward transports thrilled
And clad with new born mightiness around.(80)

(? signifies uncertainty regarding or illegibility of Davy's handwriting)

According to John Davy, Humphry Davy had nine publications while at Clifton in slightly more than two years: Essays on heat and light (appearing in Beddoes' Contributions to Knowledge from the West); Experiments and Observations on the Silex etc. (Nicholson's Journal); On the nitrous oxide or Gaseous Oxide of Azote etc. (Nicholson's Journal Vol. 3, Feb, 1800; the major work on "Researches" 1800, and five more articles on galvanism appearing in Nicholson's Journal. John Davy appears to have overlooked some of the correspondence concerning nitrous oxide in Nicholson's Journal noted above.(81) Davy's notebooks from his period at Clifton are full of poetry, metaphysical thoughts, plans for literary works and a wide variety of different types of writing. John Davy evaluated the total contribution of his brother to the Pneumatic Institute:

> "If the Medical Pneumatic Institute had any reputation it was because of Humphry Davy's exertions in its cause. If it was any service to medicine or science it was chiefly through Humphry Davy's instrumentality. However useful Dr. Beddoes was to Humphry Davy, he was of more use to Dr. Beddoes."(82)

Davy's work from his period at the Bristol Pneumatic Institute for which he is best remembered in modern times was his book "Researches, Chemical and Philosophical, Chiefly Concerning Nitrous Oxide," published in 1800. This volume detailed his chemical, physiological and medical experiments involving nitrous oxide. It will be discussed in detail below.

DAVY AND THE ROYAL INSTITUTION

Before the vivid impression produced by publication in 1800 of the "Researches" could fade, Davy attracted the attention of Count Rumford, an important member of the British scientific establishment. At that time the Count was looking for a rising philosopher who might contribute to the chemical fame of the recently established "Institution of Great Britain."

The Royal Institution was seeking an individual to become public lecturer in chemistry. The position was offered to Davy. Davy's friends, Mr. Underwood and Mr. James Thompson, carried on preliminary discussions with Count Rumford and then Thompson wrote to Davy urging him to accept the proffered appointment. In a letter to Gilbert dated Hotwells, March 8, 1801, Davy says that he visited London in the middle of February and was invited by the managers of the Royal Institution (which also included, besides Count Rumford, Sir Joseph Banks and Henry Cavendish) to become director of their laboratory and assistant professor of chemistry with promise of promotion to Professor. The salary was good. He announced that Beddoes has absolved him from his obligations at the Pneumatic Institute. Later in the letter he said:

> "Here at the Pneumatic Institute, the nitrous oxide has evidently been in use. Dr. Beddoes is proceeding in the execution of his great popular physiological work, which, if it equals the plan he holds out, ought to supersede every work of the kind."

In a letter to his mother on 31 Jan, 1801, Davy again announced his intention to leave the Pneumatic Medical Institute for the Royal Philosophical Institution pending reaching of satisfactory specific terms of engagement though he indicated that in some respects he was quite reluctant to make the change. In March, 1801, he left the Pneumatic Institute to take up residence in London. By doing this, Davy was rescued from a rapidly declining medical world at Clifton.(83) Nevertheless when Davy departed the Pneumatic Institute he believed that the medicinal use of gases was still worthy of attention and further investigation. He had written:

> "Pneumatic chemistry in its application to medicine is an art in infancy, weak, almost useless, but apparently possessed of capabilities of improvement. To be rendered strong and mature she must be nourished by facts, strengthened by exercise, and cautiously directed in the application of her powers by rational skepticism."(84)

John Davy, in contradistinction to Paris, indicated that Humphry received the appointment on his own merits and on the merits of his published work rather than because of the intercession of any outside parties.

Davy received a touching letter from Dr. Joseph Priestley written from Northumberland, (Pennsylvania), U.S.A. on Oct 31, 1801. Priestley remarked that it gave him great satisfaction that he was leaving such a capable philosopher to carry on the work in his native land. He commented that he was forty before he undertook any experiments on air and emphasized the primitive conditions under which he had to work. He stated that his unexpected success induced his scientific friends to assist him subsequently. (He was undoubtedly referring in part to the Lunar Society.) He expressed admiration that Davy had been able to accomplish so much at a relatively early age. He asked to be kept informed as to progress in science but could offer nothing in return since in his present situation he was isolated and out of communication with coworkers on both sides of the Atlantic. He indicated that he had done some studies which had puzzling results and requested that perhaps Davy could pay attention to some of these. He thanked Davy for the favorable mention which had been accorded to him in some of Davy's publications.(85)

Davy's last publication on pneumatics, in Nicholson's Journal, presented work done at the Bristol Pneumatic Institute and appeared in 1801. In this article, he was identified as "Director of the Chemical Laboratory of the Royal Institution." The history and chemistry of nitrous oxide were discussed. Some of the experiments and conclusions from his "Researches" were also included.(86)

A conspicuous activity of Davy at the Royal Institution was the delivery of public chemical lectures. Davy's lecture notes written verbatim in his own hand are preserved at the Royal Institution. They demonstrate his extraordinarily capable manner of organizing material and certainly illustrate why his lectures delivered at the Royal Institution attained such popularity.(87)

Coleridge attended an entire series of Davy's lectures at the Royal Institution in 1802 to gain chemical knowledge and also to enrich his stock of metaphors.(75) Davy and Coleridge continued on quite a friendly basis in London and saw one another frequently. Coleridge subsequently lost some of his enthusiasm for Davy and his work. Perhaps this was related to Davy's marriage and to his enthusiastic joining of the establishment.(88) A contemporary cartoon by Gilray(89) showed a number of dignitaries gathered to witness experiments conducted by Davy at the Royal Institution. Some are depicted in an irreverent and uncomplimentary manner. The cartoon was said to be an attempt to castigate Lord Rumford politically. Many of the individuals portrayed can be identified.(90) It was noted in a contemporary magazine that after a lecture on respiration on 20 June, 1801, and again on 23, June Davy offered the opportunity for any who desired to inhale nitrous oxide. On some of the worthies the effects were described as "truly wonderful." "The irresistible tendency to muscular action produced by this gas was such as cannot be described; it must be witnessed to be conceived."(91) Another account confirmed that nitrous oxide inhalation continued at the Royal Institution. Isaac Disraeli wrote that a number of distinguished individuals got quite drunk on nitrous oxide at the Institution and called the gas "Philosophical Brandy." He stated that "Professor D—Y" acted quite silly and that Count Rumford, in keeping with his sanguine personality, fell asleep.(92)

Paris related an anecdote concerning the popularity of the practice of inhaling nitrous oxide. A certain French gentleman, a M.M.T. Fievée

> ". . . . appears to have considered the practice as a national vice, and whimsically introduces it amongst the catalog of follies to which he considers the English nation to be addicted."

Paris contrasted the elegant way in which Davy conducted his public experiments in the amphitheater at the Royal Institution with the apparently careless, slovenly, and yet methodical style of his manipulations in the laboratory. He said:

> "It was his habit in the laboratory, to carry on several unconnected experiments at the same time and he would pass from one to the other without any obvious design or order: upon these occasions he was perfectly reckless of his apparatus; breaking and destroying a part, in order to meet some want of the moment. So rapid were all his movements, that, while a spectator imagined he was merely making preparations for an experiment, he was actually obtaining the results, which were just as accurate as if a much longer time had been expended. With Davy, rapidity was power."(93)

(Perhaps this type of behavior explains how he managed to complete his "researches" in less than two years).

There is little doubt that Davy recognized his own abilities and potential. His career proceeded along lines designed to ever enhance these abilities and realize this potential. He is said to have described himself as poet, philosopher, sage, benefactor of mankind, and genius.(94)

In 1804 Davy enrolled in Jesus College, Cambridge, to undertake studies leading to a medical degree. It is probable that his motivation for this was the opportunity for economic self-improvement in medicine. The possibility of a career in medicine remained in his mind until 1807. This period of ambivalence towards chemistry and consideration of returning to medicine coincided with a time of trouble and uncertainty at the Royal Institution.(95)

While under the influence of the poets Southey, Coleridge, and Wordsworth at Bristol, Davy's outlook has been described as "poetical romanticism." He believed that science was poetry in nature.(96) Davy wrote a considerable amount of poetry throughout his life. Subjects of Davy's poetry were virtues of hospitality, praise of individuals. but chiefly nature. Around 1806 Davy wrote poems concerning Beddoes' infant daughter with complimentary references to both parents and also another poem dedicated to and about Anna Beddoes and his high regard for her.(97)

At the Royal Institution, under new influences and in a different social sphere Davy's views changed to those encompassing pragmatism and empiricism. Scientific discovery was grand and the achievements of scientific thought became for Davy higher than those of poetical imagination. The double function of conferring material benefits on mankind while offering light and enrichment to the intellect marked the superiority of science to poetry. The achievements of scientific imagination bore fruit while those of poetical imagination were brilliant but materially barren. Coleridge was said to be appalled by this apostasy of his friend.(98) Nevertheless Coleridge, in 1817, wrote:

> "Davy would have established himself in the first rank of England's living poets, if the genius of our country had not decreed that he should rather be the first in the first rank of its philosophers and scientific benefactors."(99)

Some details of Davy's later life were narrated by his great-nephew speaking at a ceremony on 8 June, 1929 marking the centenary of Sir Humphry's death. The great-nephew had never seen Sir Humphry but was well acquainted with his brother John Davy who survived until 1868 and who was the orator's grandfather. Sir Humphry's many contributions to medicine and chemistry were noted. Davy's grave illness of 1807 was described. On this occasion he had contracted a fever, probably typhus, on a visit to Newgate prison where he had gone to improve the ventilatory and sanitary state of the facility. This illness debilitated him for several months and permitted rival scientists to get ahead of him in some discoveries. In 1812 He was elevated to knighthood shortly before he married Mrs. Jane Aprece. They were separated in 1815. In 1807 Davy was elected secretary of the Royal Society and in 1820 its president.(97)

Sir Humphry was a founder or trustee of many scientific and cultural organizations. He and Lady Davy were socially prominent in both London and Edinburgh.(99) He was believed by some writers to be a social climber and snob. Others deny this allegation. Southey and others complained that Davy had become too grand to know his old friends.(64) Perhaps some have misinterpreted his efforts to associate with the intellectually elite as social climbing.(100) Davy was lionized and attracted intense interest of the populace. His works were of extensive interest throughout Europe and were widely printed and discussed. Napoleon awarded him a prize in 1806 for his electrochemical studies despite existence of a state of war between England and France. Nevertheless Davy never lacked for detractors and virtually every one of his achievements was criticized in one way or another; for example his knighthood, his marriage, his election as President of the Royal Society, his discoveries and inventions etc.(101) In our own time, Davy is remembered primarily for the abilities that he displayed while at the Royal Institution and for his discoveries made at this establishment. He received the adulation and thanks of the whole country for his invention of the miners' safety lamp. This portable device permitted illumination of mine tunnels and shafts with the open flames used at that time but without the associated danger of ignition and explosion of dreaded "fire damp" (usually mostly methane); a gas sometimes present in mines. He was also the founder of modern electrochemistry and the discoverer of sodium, potassium, calcium, barium, magnesium, strontium and chlorine. He also introduced Michael Faraday to chemistry and guided his early scientific career.(102)

Davy traveled widely in his later years and became somewhat of a wanderer.(97) He died in Geneva on May 29, 1829. John Davy stated that he would have had an autopsy done on Sir Humphry:

> "But this was contrary to his desire and to a promise which I had made to him at Rome. He had a dread of a post- mortem examination founded on an idea which occurred to his active mind, that it was possible for sensation to remain in the animal fibre after the loss of irritability and the power of giving proof to others...." "....he had also a horror of being buried alive, before animation was completely extinct, and he desired that the interment should not be performed till after 10 days."(103)

In Geneva where he died, however, this was against the law and after three days the need for burial became obvious.(83)

On November 30, 1829, Davies Gilbert delivered the annual address marking the anniversary of the Royal Society. He sadly noted the death of some distinguished members including W.H. Wollaston, Thomas Young and Sir Humphry Davy. Gilbert related that he knew Davy, his family and his career since Davy's childhood. Gilbert claimed the good fortune of having been able to fix and smooth the course of Davy's early career. The first experiment that Gilbert observed Davy perform was designed to investigate the materiality of caloric (heat), and Gilbert was greatly impressed:

> "...few young men remote from the society of persons conversant with science, will I believe any where present themselves, who are capable of devising anything so ingenious."

Gilbert continued, speaking of nitrous oxide: "The ingenuity of the chemist who investigated Gaseous Oxide remains upon record, but the panacea has long since vanished into empty space."

He then commented upon some of Davy's more recent discoveries:

> "The discoveries that will enroll his name among those few destined to go down to the latest posterity were made in London and at the Royal Institution..."

Some of these great discoveries were the metallizing of alkali's and earth's, electrolysis of solutions, discovery of chlorine, the miners' safety lamp, and the utility of copper sheathing on ocean-going vessels. Gilbert stated that Davy was much taken with romantic tales as a child and later graduated to poetry. He had considerable abilities as a painter. Some of his contemporaries maintained that he was attracted to chemistry by a desire to prepare colors and pigments.(104)

RESEARCHES,

CHEMICAL AND PHILOSOPHICAL;

CHIEFLY CONCERNING

NITROUS OXIDE,

OR

DEPHLOGISTICATED NITROUS AIR,

AND ITS

RESPIRATION.

By HUMPHRY DAVY,

SUPERINTENDENT OF THE MEDICAL PNEUMATIC INSTITUTION.

LONDON:

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1800.

PLATE XI — THE TITLE PAGE of Humphry Davy's monumental book presenting all of his work on nitrous oxide done when he was at the Pneumatic Institute.

Chapter XIV

Humphry Davy's Researches

His Contribution to Anesthesia

Davy's book "Researches, Chemical and Philosophical; chiefly concerning Nitrous Oxide" was published in the middle of the summer of 1800. Coleridge, in January of 1800, had negotiated with Longman for the publication of the volume.(1) Davy emphasized the short time span involved in accomplishing the studies on nitrous oxide and then of writing the book. A rough draft of a preface said:

> "These experiments have been made since April, 1799, the period when I first breathed nitrous oxide. Ten months of incessant labor were employed in making them, three months in detailing them."

In addition he did experiments in other areas concurrently.(2) He also performed many experiments involving voltaic electricity. John Davy regarded "Researches" as a monumental work that would have immortalized Humphry even if he had done nothing else. Only one edition of "Researches" was required. The book, however, was reissued in 1839 as a part of Davy's collected works as gathered by his brother John Davy.(3) In the introduction to "Researches" Davy wrote:

> "In the arrangement of facts, I have been guided as much as possible by obvious and simple analogies only. Hence I have seldom entered into theoretical discussions, particularly concerning light, heat, and other agents, which are known only by isolated effects. Early experience has taught me the folly of hasty generalization......."(4)

But the explanations proposed by Davy for the mode of action of nitrous oxide, factors influencing its operation in the body and some possible therapeutic applications of nitrous oxide inhalation demonstrate that Davy was just as capable of formulating theories and speculation as any other 18th century systematist.(5) These theories and speculations do not support the statement made that the "Researches" were written on the strictly inductive plan with no abstract speculation or hasty generalization. Davy related how he became interested in nitrous oxide several times in his writings. In "Researches" he again wrote:

> "A short time after I began the study of chemistry, in March, 1798, my attention was directed to the dephlogisticated nitrous gas of Priestley, by Dr. Mitchill's theory of contagion."(6)

These events occurred before he came to the Pneumatic Institution. Davy composed one dedication of "Researches" in 1799 or early 1800 which is preserved in one of his laboratory notebooks. He expressed almost unlimited gratitude to and admiration for Thomas Beddoes:

> "DEDICATION TO THOMAS BEDDOES, M.D.
>
> I know of no one to whom I can with so much propriety dedicate this work as to you. There are few persons to whom I have greater obligations. The hopes awakened in my mind by your observations on Chemical Physiology were among the motives that induced me thirty months ago to begin the study of Pneumatic Chemistry. Without you the Researches detailed in this volume would probably never have been made. Receive them as pledges of more important labors in that infant Science which your benevolent and philosophical exertions have so much contributed to enlarge..... and believe me be with respect and affection.
>
> Your friend,
> Humphry Davy"(7)

However when the book was published a much curtailed and less dramatic acknowledgment of Beddoes' help was included:

> "In the conception of many of the following experiments, I have been aided by his conversation and advice. They were executed in an Institution which owes its existence to his benevolent and philosophic exertions."(8)

What happened during the course of a year or less to cool Davy's apparent uninhibited admiration of and reverence for Beddoes? This marked change in attitude by Davy and Beddoes quite limited participation in the preparation of the "Researches" will be considered later when their relative contributions to the development of anesthesia are discussed.

DAVY'S ANIMAL AND CHEMICAL EXPERIMENTS

Davy did considerable chemical and animal experimentation in the laboratory. Davy defined a respirable gas as one that could be taken into the lungs by voluntary action. Atmospheric air was the only gas capable of supporting life. Some airs killed by asphyxia while others by producing a specific toxic action. Davy believed that nitrous oxide supported life for a longer period than other mephitic gases and therefore concluded that this substance had some action other than simply excluding atmospheric air.(9) Perhaps animals actually did survive longer in nitrous oxide than in other mephitic gases because the sedative properties of nitrous oxide minimized struggling and violent activity and thus decreased oxygen consumption.(10) Another observation by Davy was that animals placed in mixtures of nitrous oxide and oxygen could survive in the unconscious state for prolonged periods and would revive when removed from that atmosphere. A small guinea pig was well anesthetized by a mixture of three parts of nitrous oxide and one part of oxygen. It lived quietly for nearly 14 minutes in this atmosphere and survived and recovered after removal from this mixture. Similarly, a mouse survived for 10 minutes. A goldfinch lived in 50% nitrous in oxygen without difficulty.(11) These observations are important because they suggest that Davy or a contemporary could have administered nitrous oxide as an anesthetic safely for a period long enough to complete surgical operations if the idea had occurred to them. Effects of nitrous oxide on various types of animals, including fish, were investigated. Beddoes believed that fish removed from water died because of hyperoxia-another deleterious effect of breathing what was for them too much oxygen in the atmosphere.(12) (It should be recalled that Beddoes wrote that some diseases, such as consumption, were caused by a relative excess of oxygen in the atmosphere). Davy concluded that "nitrous oxide destroys warm blooded animals by increasing the living action of their organs to such an extent, as finally to exhaust their irritability and sensibility."(13)

Davy's physiological observations on gases continued with some measurements on the absorption of nitrous oxide by the body. He concluded that the uptake of the gas must be quite rapid and the estimates that he made of the rate of its absorption are in reasonably good agreement with modern determinations.(14) He concluded that hydrogen, when breathed, appeared not to be absorbed by the body; therefore the quantity of the gas in the lung was not diminished. Thus the gas could be used to measure the volume of the lung.(15) Using this principle, he determined his own lung volume and its subdivisions.(16) with the following results as expressed in modern terminology:

Lung Volume	Measured Volume (cubic inches)	Measured Volume (milliliters)
Vital Capacity	190	3000
Total Lung Capacity	254	4200
Functional Residual Capacity	118	1950
Residual Volume	41	650

These values were entirely appropriate for an individual of Davy's apparent body habitus. He recognized considerable variability in these values among individuals and further noted that Mr. Goodwyn had measured functional residual capacity in an experimental subject as 109 cubic inches or about 1800 ml.(17) Edmund Goodwyn had written a comprehensive treatise in 1788 describing his studies and conclusions on respiratory physiology which were strikingly accurate when evaluated by modern standards.(18) In Davy's studies volume of carbon dioxide present in a mixture of gases was measured by absorption in strong alkali (potash [potassium hydroxide]). Volumes of oxygen were determined by absorption with nitrous air (nitric oxide) and the remaining excess of the latter gas was absorbed with iron chloride. Hydrogen was removed by inflammation. He concluded that during nitrous oxide breathing the nitrogen, carbon dioxide and water vapor appearing in exhaled gas were not derived from chemical reactions in the lungs but were liberated from the venous blood and/or were released from the moist lining of the lung.(19)) He did not rule out the possibility that in certain circumstances some of the carbon dioxide produced was generated by a combination of oxygen with charcoal in the red particles of the blood.

Humans appeared capable of breathing nitrous oxide for a much longer time than would cause death in small quadrupeds. This observation was related to such variables as rapidity and vigor of respiration and circulation and other factors influencing rate of nitrous oxide absorption.(20) During March and April, 1799, Davy's initial inhalations of nitrous oxide and the notations of the sensations and objective effects produced by the gas occurred.(21) During May to July he breathed the gas frequently; sometimes several times a day. Then after July he decreased the frequency of his self experimentation.(22) An important effect of nitrous oxide noted by Davy was its ability to relieve pain in several situations:

> "In one instance when I had a headache from indigestion it was immediately removed by effects of a large dose of gas; though it afterwards returned, but with much less violence. In a second instance a slighter degree of headache was wholly removed by two doses of gas."(23)

Nitrous oxide also had the capability to relieve physical pain in certain other illnesses. He described the severity of his symptoms relating to eruption of a wisdom tooth. Nitrous oxide diminished the pain after 4-5 inspirations and uneasiness was swallowed up in pleasure. However after termination of the inhalation the pain returned and he thought it might have been more severe than before.(24) Davy summarized the effect of nitrous oxide breathed while he was suffering the effects of a hangover due to the rapid consumption of a full bottle of wine. He concluded that debility from intoxication was not increased by excitement from nitrous oxide. The headache and depression were probably helped by nitrous oxide and there was slight nausea again after inhalation of the gas.(25)

Davy's writings on effects of nitrous oxide inhalation in humans contain clues to the chronology of Davy's work. These suggest that his laboratory chemical experiments, his physiological work on animals, and his observations on effects of nitrous oxide inhalations in man were done simultaneously, not sequentially.

INHALING NITROUS OXIDE FOR PLEASURE

Davy described the sensations elicited by nitrous oxide in the numerous individuals who inhaled this gas at the Pneumatic Institution. Most people evaluated the feelings as pleasurable and some compared them to those experienced in other emotionally provocative situations such as climbing mountains or hearing impressive music. Others declined to characterize the inhalations as pleasurable and yet others had dysphoria with various unpleasant feelings.(26) Among those reporting highly pleasurable sensations from nitrous oxide inhalations were Mr. Thomas Pople who inhaled nitrous oxide on two occasions. He compared the experience to climbing a high mountain.(27) Mr. Henry Wansey wrote, that the inhalation of the gas provided,

> "....sensations so delightful, that I can compare them to no others, except those which I felt (being a lover of music) about five years since in Westminster Abbey, in some of the grand choruses in the Messiah, from the united powers of 700 instruments of music."(28)

Davy believed that the subjective response to nitrous oxide inhalation in any individual depended on the state of pre-existing nervous "sensibility." Individuals with least sensibility enjoyed the least effects; those with more sensibility have sublime effects while nervous action in those who have exquisite sensibility will have disagreeable effects. Nitrous oxide could be mingled with oxygen or common air to permit those of greatest sensibility to enjoy it.(29) Anna Beddoes also inhaled nitrous oxide and her impressions were reported: "Mrs. Beddoes – pretty uniform pleasurable sensations — propensity to muscular exertion, could walk much better up Clifton Hill — has frequently seemed to be ascending like a balloon, a feeling which Mr. Burnet strongly expressed."(30) Thomas Beddoes, based on his own response to nitrous oxide inhalation, warned of its possible undesirable effects:

> "A deleterious, instead of a salutary fluid, as the author can attest from his own painful experience, may easily be obtained. Probably neither Dr. Priestley nor the Dutch chemists ever procured that which can be respired with safety."(30)

Davy was an enthusiastic inhaler of nitrous oxide. There were several entries in his laboratory notebooks describing his sensations on breathing the gas. One such entry was dated Sept. 17:*

> "At ten took a dose of the air with the finest possible effects. The sensations were most delightful. I danced about the room most furiously. Was sleepy and splenetic before I took it but afterwards became vigorous and active. Now take up the pen to write: took it yesterday with usual effects – twice."(31)

Several letters from Davy's friends confirm that they were quite preoccupied with the pleasurable effects of nitrous oxide inhalation. On one occasion Gregory Watt indicated that he was having difficulty in making nitrous oxide that would provide the desired mental effect and solicited Davy's advice on how to generate the "ladder by which we may ascend to the heaven of heavens."(32) In another letter dated Oct. 11, 1800, Gregory Watt indicated that he was on his way to Clifton. He requested of Davy to "Get an airholder of gas prepared for I am determined the heavens. NB As far as a couple of bottles of port wine will convey me, I am there already, but this, alas! is only one stage."(33)

On Nov. 12, 1799, Robert Southey requested of Davy that:

> "...if a Mr. Elliott visits you at the Pneumatic Institution, you will have the goodness (unless from his state of health you should deem it hurtful) to beatify him with a dose of the gaseous oxyd. I do not myself know Mr. Elliott, but write at the desire of my particular friend here, Rickman.(33)

MEDICINAL USE OF NITROUS OXIDE

Davy formulated certain medicinal applications of nitrous oxide inhalation based on the perceived unique stimulating properties of the gas. He discussed the relationship and apparent similarity between nitrous oxide and other diffusable stimuli. These were generally related to their action on irritable and excitable tissues.(34) He believed that oxygen and nitrous oxide mixtures could be applied to resuscitation after suffocation or drowning or hanging because of their stimulatory properties.(35) Davy wrote:

*This would have been in 1799. Davy's laboratory notebooks have mostly incomplete or absent dates for the entries.

> "As nitrous oxide in its extensive operation appears capable of destroying physical pain, it may probably be used with advantage during surgical operations in which no great effusion of blood takes place."(36)

This famous statement is often interpreted as a suggestion by Davy for use of anesthesia during surgery with the same rationale that it is applied in modern times. The significance of this sentence will be considered shortly.

Dr. Robert Kinglake, another physician on the staff of the Pneumatic Institution summarized the properties of nitrous oxide thus:

> "Among the circumstances most worthy of regard in considering the properties and administration of this powerful aerial agent, may be ranked, the fact of its being (contrary to the prevailing opinion*) both highly respirable, and salutary, that it impresses the brain and system at large with a more or less strong and durable degree of pleasurable sensation, that unlike the effect of other violently exciting agents, no sensible exhaustion or diminution of vital power accrues from the exertions of its stimulant property, that its most excessive operation even, is neither permanently or transiently debilitating; and finally, that it fairly promises under judicious application to prove an extremely efficient remedy, as well in the vast tribe of diseases originating from deficient irritability and sensibility, as in those proceeding from morbid associations, and modifications, of those vital principles."(37)

The asterisk in the above quotation directed attention to a footnote explaining the erroneous opinions of Dr. Samuel L. Mitchill on the violently poisonous nature of nitrous oxide.

Davy reminded readers of the sedative action of hydrocarbonate and believed that with nitrous oxide and hydrocarbonate there would be a series of exciting and depressing powers applicable to every deviation of the constitution from health: Typical Brunonian thinking. These two gases could be mixed in any predetermined proportions to provide any desired degree of stimulation or depression as indicated by the clinical evaluation of the patient. But he recognized that the theory of excitability may be founded on false generalization. He ends the conclusions by indicating that pneumatic medicine still requires gathering of an enormous amount of additional information.(38) Earlier in the book he had written:

> "And thus, if the hopes which the experiments at the end of those researches induce us to indulge, do not prove fallacious, a substance which has been heretofore almost exclusively appropriated to the destruction of mankind, may become, in the hands of philosophy, a means of producing health and pleasurable sensation."(39)

There is a section of "Researches" describing observations made by Dr. Beddoes beginning on page 533. This material would certainly be evidence against the accusations and insinuations that Beddoes was never involved in experiments.

Humphry Davy has sometimes been identified as the discoverer of anesthesia (40) and it is therefore of interest to examine the contribution of Humphry Davy to the introduction of anesthesia into clinical practice. One of the effects of nitrous oxide noted by Davy was its ability to ameliorate pain. He specifically described relief of discomfort from an erupting tooth and of a bothersome headache as noted above. The section of the book in which Davy described his conclusions contains the following sentence which was noted above and is restated: "As nitrous oxide in its extensive operation appears capable of destroying physical pain, it may probably be used with advantage during surgical operations in which no great effusion of blood takes place."(41) On the basis of this sentence Sir Humphry Davy has been given varying degrees of recognition by several historians of medicine for the discovery of anesthesia. F.F. Cartwright stated unequivocally that "Humphry Davy discovered anaesthesia"!(40)

To the modern reader, the above-quoted statement of Davy certainly suggests that he was recommending the use of nitrous oxide as an anesthetic in the modern sense of the word. It would seem that Davy proposed to render surgery comfortable and bearable by altering consciousness and by ameliorating the unimaginable pain usually associated with this ordeal in his time. However consideration of the publications of Davy and those professionally associated with him, as well as certain events in his life, demonstrates that the thought of patient comfort during surgical operation probably never crossed his mind at any stage of his life. Careful reading of Davy 's writings within the context of their presentation and with attention to details of the Brunonian system of medicine (See Brunonian System in section on Medical World of the 18th century), which he and many other late 18th century medical practitioners embraced, reveals the probable reason why he recommended the use of nitrous oxide during surgery. Such consideration also could explain the curious restriction by Davy of nitrous oxide to "operations in which no great effusion of blood takes place."(42)

Davy proposed two general objectives for inhalation of nitrous oxide gas by humans. The first was to provide pleasurable sensations which had been described by many who had inhaled the gas at the Pneumatic Institution. The second objective was the therapeutic use of the gas in various clinical situations as a "diffusible stimulus." Most individuals who inhaled nitrous oxide at the Pneumatic Institution described pleasurable physical and mental sensations. Davy described his reactions to the gas at length.(43) Probably the most enthusiastic inhaler was the poet Robert Southey, Davy's close friend during his Bristol period. Southey's impressions of nitrous oxide were expressed in a previously quoted letter to his brother dated July 12, 1799:

> "Oh Tom! such a gas has Davy discovered, the gaseous oxyde! Oh, Tom! I have had some; it made me laugh and tingle in every toe and fingertip. Davy has actually invented a new pleasure for which language has no name. Oh, Tom! I am going for more this evening; it makes one strong and so happy! so gloriously happy! And without any after-debility, but, instead of it, increased strength of mind and body. Oh, excellent air-bag! Tom, I am sure the air in heaven must be this wonder-working gas of delight. Yours, Robert Southey."(44)

Another example of the pleasures of nitrous oxide inhalation was provided by Mr. Henry Wansey who, as noted above, compared the sensations on breathing nitrous oxide to being immersed in a massed collection of musical instruments.(45) Mr. Thomas Pople described vivid and pleasurable sensations similar to those experienced on ascending a high mountain.(47) Davy enthusiastically proposed to share the pleasurable and intoxicating experience of nitrous oxide inhalation with mankind. In addition, he emphasized that the pastime could be made quite inexpensive. He wrote:

> "Thus, if the pleasurable effects, or medical properties of the nitrous oxide, should ever make it an article of general request, it may be procured with much less time, labor, and expense,* than most of the luxuries, or even necessaries of life."

The asterisk in the above quotation directed the reader to a footnote in which Davy analyzed the expense of nitrous oxide and calculated that a medicinal dose of nitrous oxide should cost about 2d. He concluded, "What fluid stimulus can be procured at so cheap a rate?"(47)

Great hopes were entertained for medicinal uses of nitrous oxide. Within the framework of the Brunonian system of medicine, the immediate effects of nitrous oxide on the living body were analogous to other diffusible stimuli. All increased force of circulation produced pleasurable feeling, altered condition of the organs of sensation, and, in great quantities, ultimately destroyed life.

John Brown listed diffusible stimuli known to him according to their strength. Those of the weakest degree were white and red wines. The strength of stimulus depended on whether they were dilute, full strength, or distilled to provide a higher alcohol content. In the next order of magnitude on the scale were musk, volatile alkali and camphor and they have been incompletely tried. Next came aether and last of all, opium. (This was not the only place in Brown's writings where aether and opium were identified as having similar actions).(48) But considerable differences existed between operation of most diffusible stimuli and nitrous oxide. The former acted directly on nerve and muscle while latter operated by producing peculiar changes in the composition of the blood. Conventional diffusible stimuli acted on the site of application and affected other parts only to the extent that their functions were related to the site of application.(49) Moreover, with inhalation of nitrous oxide, excitement and excitability increased together. (It should be recalled that with administration of most stimulants, excitement was believed to increase while excitability diminished). As one item of evidence confirming this singular property of nitrous oxide Davy pointed out that after excessive use of alcohol, regarded as a stimulant by Brunonian physicians, the ensuing disagreeable physical effects, or the "hangover," was a state of residual debility caused by depleted excitability. In contrast, taking of nitrous oxide to the point of intoxication left no such residual symptoms. This feature made nitrous oxide a unique stimulant with several potential valuable medicinal applications.

The concluding section of Davy's "Researches" deals almost entirely with nitrous oxide as a diffusible stimulus and the action of stimulants within the framework of the Brunonian system of medicine. The suggestion for the use of nitrous oxide during surgical operations appeared in this section. The idea of pain relief during surgery occurs nowhere else in Davy's writings. It is thus reasonable to propose that Davy's recommendation for nitrous oxide during surgery was designed to fulfill some perceived action based on Brunonian theory rather than as a compassionate measure for patient comfort. The location and context of Davy's proposal for use of nitrous oxide during surgery in the concluding section of his "Researches," as well as his known adherence to Brunonian principles,* suggests that his reasoning might have been somewhat as follows: Pain of surgery was an extraordinary stimulus which was expected to produce inordinate degrees of excitement. This in turn would markedly diminish excitability and could lead to a state of sthenic disease. These events could perhaps be prevented by inhalation of nitrous oxide. Its action as a unique diffusible stimulus, causing level of excitement and excitability to increase or decrease simultaneously, might prevent the excessive decrease in excitability and its capability to diminish pain would also achieve the same effect. Hemorrhage was a debilitating event which would diminish excitement but also augment excitability. Perhaps use of nitrous oxide during hemorrhage might be expected to act synergistically with blood loss to increase excitability excessively and produce a state of asthenic disease. Over-treatment with undesired alteration in the nature of patients' disease was an important concern in Brunonian medicine. Stock wrote:

> "In cases of extreme debility, every medical practitioner knows the difficulty in applying stimuli in such due proportion, that the excitement produced may not be succeeded by a fatal degree of exhaustion."(52)

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*Both Davy and Beddoes appear to have agreed in general with Brown's principles of medicine but believed that in some places it was obscure and they had some reservations about the system.(50) Beddoes was disposed, partly on the effects of nitrous oxide, to dispute some particulars of Brown's doctrine of excitability.(51)

Of course it will never be possible to state unequivocally that the above train of reasoning was that followed by Davy in advocating use of nitrous oxide during surgery except where blood loss was anticipated. Nevertheless, the ideas proposed appear to be in accord with Davy's stated views and with Brunonian principles.

Others have speculated on Davy's enigmatic restriction of nitrous oxide to "operations where no great effusion of blood takes place." Duncum proposed that Davy might have believed that the vigorous circulatory stimulation attributable to the stimulating properties of nitrous oxide might exaggerate surgical hemorrhage.(53) Raper thought that Davy might have been concerned that the patient was unlikely to survive both hemorrhage and nitrous oxide administration.(54) Cartwright suggested a concern that the nitrous oxide administered to the patient might be lost in the shed blood so that the patient would awaken prematurely.(55) Luckhardt speculated that perhaps Davy's restriction related to the venous congestion which might be produced by nitrous oxide administered without oxygen which would result in great bloodshed.(56) It will be recalled that Davy began his professional career as an apprentice to the surgeon-apothecary, Mr. John Bingham Borlase of Penzance. As such, he would certainly have been familiar with the painful ordeal of surgery. Certain events in his life suggest that he was no more concerned with pain relief during surgery than was any other man of his generation. Among these was Davy's management of his own dog bite by personally excising the wound and cauterizing the site with a hot iron while evidencing little apparent response to the pain involved, as previously related. Whatever the explanation for this apparent indifference to suffering, an individual with such disregard for distress can hardly be expected to be greatly concerned with pain relief during surgery. Davy had determined that animals inhaling mixtures of nitrous oxide and oxygen survived much longer than those breathing only nitrous oxide. Knowledge and technology for administering surgical anesthetics which would have been successful, or partially so in many circumstances, were thus available in 1800 if this idea had really occurred to Davy.

Another series of events suggests that the concept of pain relief during surgery for patient comfort remained completely foreign to Davy. Dr. Henry Hill Hickman, physician of Shifnall (the Shropshire village which was Thomas Beddoes' birthplace) conceived of amelioration of operative pain by "suspended animation" during surgery in 1824. This state would be induced by controlled carbon dioxide excess with or without associated oxygen lack. He performed animal experiments which demonstrated that painless surgery was indeed possible during such a state and indicated that he, himself, would gladly be a candidate for suspended animation if he were ever to require surgery.(57) He communicated his ideas and the supporting data to Mr. T.A. Knight Esq. of Downtown Castle, Herefordshire. with the expectation that they would be transmitted to the Royal Society of London. Knight met with the President of the Royal Society, Sir Humphry Davy. It has been suggested that they dined together and discussed Hickman's recommendations.

Initially, Davy appeared enthusiastic but he rapidly lost interest in Hickman and his ideas. There was no presentation to the Royal Society and Hickman was forced to seek support elsewhere. Reasons suggested for the rapid waning of Davy's interest in suspended animation include objectionable associations of asphyxia with hanging and other violent forms of death as well as the inherent danger of the procedure.(58) If Davy had really envisioned pain-free surgery one quarter century earlier using an effective agent free from the objections of Hickman's "suspended animation," it seems inconceivable that he would not have commented upon his earlier proposal to Knight or Hickman. There is no indication that he did so, possibly because there was nothing familiar to him in Hickman's suggestion.

Davy's invention of the miners' safety lamp resulted in a great saving of life among miners. For this invention Davy received enthusiastic tributes and testimonies from many sectors of society acknowledging him a major benefactor of mankind. It seems unlikely that Davy, having enjoyed this degree of public adulation, would have passed up the opportunity to be again a public benefactor when his attention was directed to pain relief during surgery, if he really appreciated the concept.

Humphry Davy made several contributions to the collective accumulated body of knowledge and experience which opened the way to the introduction of clinical anesthesia. He proved the respirability of nitrous oxide. He discovered numerous important facts concerning the chemistry of nitrous oxide and other gases and reported many physiological effects of their inhalation in both animals and man. He first noted the ability of nitrous oxide to abolish physical pain. He popularized inhalation of nitrous oxide for pleasurable and intoxicating purposes. Key individuals associated with the actual introduction of clinical anesthesia in 1846, such as G.Q. Colton and C.T. Jackson, were familiar with Davy's work. But the nomination of Davy as a discoverer of anesthesia probably credits him with possessing concepts and attitudes which he never had. Like almost all others of his generation, the possibility of pain-free surgery or of patient comfort during surgery, appears not to have occurred to him.(59) Davy's greatest contributions to the introduction of anesthesia into medical practice were his chemical and physiological investigations of nitrous oxide. Other than this, he should be recognized for the popularization of recreational nitrous oxide inhalation, but not the enunciation of the concept of surgical anesthesia.

G.M. Smith emphasized the preoccupation of Davy and his contemporaries with nitrous oxide intoxication to the exclusion of its capacity to ameliorate pain. He wrote:

> "Maria Edgeworth speaks of 'certain gases which inebriate in the most delightful manner, having the obvious effects of Lethe etc.; but unfortunately the hallucinations, excitement, etc., were thought more of than the dulling of sensation, and it so happened that this, the most perfect anaesthetic for short operations, was not actually introduced into surgical operations until 1868."(60)

Plate XII — Erasmus Darwin (1731-1802). Another member of the Lunar Society, he was one of the foremost physicians in England in the late 18th century. He encourged Beddoes to pursue his experiments and pneumatic medical practice.

CHAPTER XV

THE LUNAR SOCIETY OF BIRMINGHAM

ITS INFLUENCE ON THE SUBSEQUENT DEVELOPMENT OF ANESTHESIA

The Lunar Society of Birmingham might appear to some to occupy a somewhat peripheral and tenuous position in relation to introduction of anesthesia. While it is true that several members of this group were loosely associated with individuals, events and ideas generally acknowledged to be in the main stream of anesthesia history, these efforts represented only a very small fraction of their total activities. However one chooses to judge the contribution of the Lunar Society to modern anesthesia, its members deserve our attention. They were representative of those individuals and forces which altered society towards the end of the 18th century. They were among the prime movers of the industrial revolution. The widespread areas with which they concerned themselves have been summarized as chemistry, botany, geology, engineering, medicine, instrument making, exact measurement, pottery making, chemical manufacturing, assaying, color, electricity, canals, roads, aeronautical balloons, education, history and other interests.(1) These men helped to change England from a primarily rural society of isolated communities to an urban civilization whose population centers were connected by adequate means of transport necessary for the movement of raw materials, finished goods, men and ideas. This type of society, on both sides of the Atlantic, became ready to accept the concept of pain-free surgery when it was finally offered.

ORIGINS AND OBJECTIVES OF THE LUNAR SOCIETY

In England in the last half of the 18th century groups of prominent citizens formed organizations whose objectives were mutual education as well as support and advancement of arts and science. These enclaves arose in several important provincial population centers. The Lunar Society of Birmingham was probably the most prominent and distinguished of all such provincial arts and science leagues. This informal organization was founded in 1766 and more formally constituted about 1775. It was composed of a group of friends tied by mutual interests in science and technology. All had demonstrated success in some endeavor useful to or of interest to others. All were prepared to experiment and try ideas of the others. The first formal meeting was apparently on Sunday, 31 December, 1775. Because of the press of individual business, scheduling of and attendance at meetings was irregular. But meetings constituted only a small part of the society's activities. Many notable accomplishments occurred by a voluminous correspondence or in small subgroups.

The membership, about eight to ten individuals at any one time, met monthly for a two p.m. dinner at one-another's houses on the Monday nearest the full moon - hence the name "Lunar Society." Each member was permitted to bring a guest. At meetings members presented both their own thoughts and those communicated by outsiders for presentation. Monday, rather than Sunday, became the meeting day because of Sabbath commitments of Joseph Priestley to his Unitarian congregation. The members frequently referred to themselves as "Lunarians," or perhaps as "Birmingham Philosophers," but it was inevitable that occasionally, in a tongue-in-cheek manner, they should be called "Lunatics." Meetings lasted until about eight o'clock when members returned home by the light of the full moon.(2) Science of the Lunar Society was never aimless but always practical! The type of problems most commonly considered demonstrated the industrial orientation of the scientific interest and the Lunar Society could, in some respects, be regarded as an informal technological research organization. They were all involved in an attempt to turn knowledge to practical advantage.(3) The Manchester Literary and Philosophical Society was another such organization. It was founded in 1781. Important members were Thomas Percival, John Dalton and J.P. Joule.(4) Similar groups arose in Newcastle, Leeds, Liverpool, Derby, and in other locations . Some of these organizations had rosters of over fifty members.(5) These "Provincial Societies" were usually centres of the best and most intelligent members of the community society of their neighborhoods and were for the most part distinguished by an active and liberal spirit of enquiry.(5a)

There were several reasons why these provincial arts and science fellowships emerged in the last half of the 18th century. At this time, London was losing some of its claim as the intellectual capital of Britain as enclaves of scholarly excellence arose in other centers throughout the land. Travel was extremely arduous. The trip by stage from Birmingham to London took two bone-jarring days on frightful roads. Individuals began to look to their own communities for intellectual stimulation and gratification. In late eighteenth century England and Scotland, the Royal Society and also the Society of Arts, (later Royal Society of Arts, an organization of manufacturers), were in a slump and membership in these organizations was only a matter of prestige with little practical advantage to scientists.(3) Nevertheless, the Society for Encouragement of Arts, Manufactures, and Commerce promoted solutions to practical problems in contradistinction to the Royal Society and the Universities. Many individuals distinguished in areas of technology became members of the Society of Arts early in their careers while election as Fellow of the Royal Society (FRS) was a later honor. Many of the provincial societies, including the Lunar Society, took the Society of Arts as a model. Nine of the fourteen Lunarians appeared to have connections with the Society of Arts.(6)

There were also important social and political reasons which partially explain the emergence of the provincial arts and science societies. Great liberalization of educational procedures and practices had occurred during the English Civil War (1642-1651), and the subsequent commonwealth and protectorate of Oliver Cromwell. With the restoration of the monarchy in 1660 these educational opportunities were abruptly curtailed for many people by the Clarendon Code. This conformist legislation, among which were the Test Acts, dated from 1662 and demanded strict orthodox views concerning the Book of Prayer and the 39 articles of faith of the Church of England for all who held public office or taught in universities.(7) Religious non-conformists or dissenters were discrimanatorily excluded from many aspects of public life. They could not attend the great English universities (Oxford and Cambridge) and they could not join many socially and professionally advantageous organizations such as the Royal College of Physicians of London. Religious dissenters therefore founded and operated their own academies of learning. The curriculum at these institutions was frequently considerably more comprehensive than that of the universities. The dissenting academies often taught mathematics, science, modern languages and other practical subjects. (It will be recalled that Joseph Priestley, a Unitarian minister, spent a significant proportion of his career teaching at dissenting academies, e.g. at Warrington). The English universities at this time were not strong in these areas(8) and continued to emphasize classical studies. Perhaps this stress on subjects with minimal practical applicability represented some perceived need for their privileged students to practice conspicuous consumption by shunning useful knowledge.(9)

A general idea of the nature of science instruction provided in the seventeenth century can be obtained by examining some of the textbooks known to have been used. These had often emphasized authority and opinions of previous writers rather than empiricism and experience and this attitude apparently persisted into the next century.(10) By the eighteenth century, emphasis was on scientific knowledge acquired by observation and experimentation. The provincial arts and science societies generally did not exclude potential members on religious or political grounds. They offered an avenue for the many talented religious nonconformists to participate in the intellectual life of the community.(7) Concerning the Lunar Society Priestley observed:

> "The members have nothing to do with the religious or political principles of each other; we were united by a common love of science, which we thought sufficient to bring together persons of all distinctions – Christians, Jews, Mahometans, and heathens, monarchists and republicans."(2,3)

Birmingham was particularly favorably situated for possessing such an illustrious society, in part, because it was disadvantageously located for conduct of heavy industry. The town was situated at a considerable distance from the coal fields and no abundant alternative source of power was at hand. Importation of bulk quantities of raw materials and shipping of large amounts of finished goods via the poor transport system existing around 1750 would have imposed major problems. Light industry developed instead. The town, whose population was about 30,000 in 1760, became a haven for ingenious entrepreneurs among whom were a variety of dissenters and freethinkers. Many of these people adapted their commercial and intellectual activities to the particular situation of Birmingham with phenomenal success.(11) During the period that the Lunar Society was most active (1760-1790) the population of Birmingham doubled from 30,000 to 60,000.

Members of the Lunar Society

Different sources and authorities vary in their listings of members of the Lunar Society. Robert Schofield, whose definitive study of this organization provided much of the following material, lists 14 Lunarians.(12) Not all were members at the same time. Their names and dates of birth and death are:

Matthew Boulton	1728-1809
Erasmus Darwin	1731-1802
Thomas Day	1748-1789
Richard Lovell Edgeworth	1744-1817
Samuel Galton Jr.	1753-1832
Robert Augustus Johnson	1745-1799
James Keir	1735-1820
Joseph Priestley	1733-1804
William Small	1734-1775
Johnathan Stokes	1755-1831
James Watt	1736-1819
Josiah Wedgwood	1730-1795
John Whitehurst	1713-1788
William Withering	1741-1799

An important source of information concerning the personalities and later activities of Lunar Society members is the writings of Mary Anne Galton Schimmelpennink (1778-1856). This lady was the daughter of Lunarian Samuel Galton Jr., a Quaker gun maker. She married into the family of Dutch tobacco merchants related to the Statholder of Holland. She read widely and was zealous and opinionated in the practice of religion. Barr Hall, the family home in the vicinity of Birmingham, became a frequent meeting place for the Lunar Society. She produced some of the few first hand accounts of Lunar Society meetings. She was an eye-witness to the meetings and a personal acquaintance of the members from age 8 to age 25. Some of her early playmates included Jessie and Gregory Watt and William Priestley.(13) She was said to posses a tenacious memory and delicate power of discrimination; her mother was an intimate friend of Mrs. Priestley.(2) Unfortunately her memoirs, published at age 75, have been evaluated as inaccurate and highly prejudicial and her motives in writing them were said to be "not disinterested." Her outlook was colored by extraordinary religious experiences and views acquired in early life.(11)

Before about 1775 the early Lunarians were loosely associated through individual friendships. At this time they could probably be designated as a "Lunar Circle" rather than as a society. The three oldest acquaintances might be called the founding fathers of the Lunar Circle: Erasmus Darwin, Matthew Boulton and John Whitehurst. From the beginnings of these associations about 1760 until the mid 1780's others were added from time to time while old members were lost because of relocation or death.

ERASMUS DARWIN

About 1760 Erasmus Darwin was becoming one of England's most distinguished physicians. He had studied medicine in Edinburgh and had come in 1756 to establish a medical practice at Litchfield, a town close to Birmingham. He was the physician to the family into which Matthew Boulton married. Darwin was elected to Fellowship in the Royal Society in 1761; the first of the Lunar Society to be so honored. He was described by Richard Lovell Edgeworth as being large and rather clumsy. He had an intelligent and benevolent countenance and an impediment of speech but his words were worth waiting for.(14) Anna Seward also described Darwin as a large man who stammered excessively. He did not tolerate egotism or vanity and could be extremely sarcastic. He was apparently quite suspicious of human nature. Seward suspected that this suspicion contributed to his abilities as a physician. He was always diligent and generous in providing medical care for the poor.(15)

The year after his marriage in 1757, Darwin purchased an old half-timbered house in the Litchfield Cathedral vicarage. He added a handsome new front, restored much of its old beauty and did extensive remodeling to the grounds and house. To this house a knot of his philosophic friends frequently came. These included Mr. Keir, Mr. Boulton, Mr. Watt, Dr. Small, Mr. Edgeworth and Mr. Day.(15) James Watt came to visit Darwin in 1767. He had invented the separate condenser for steam engines and was impelled to consult Darwin because of his interest in steam carriages.(16) About 1763 Darwin tried to talk Boulton into making a steam carriage but Boulton was not too keen on the idea.(16,17) Because of the press of his medical practice, Darwin's attendance at Lunar Society meetings was somewhat irregular.

On 5 April 1778 Darwin wrote one of several letters to Matthew Boulton apologizing and expressing regret for missing a meeting of the Lunar Society:

> "Dear Boulton, I am sorry the infernal Divinities, who visit mankind with diseases, and are therefore at perpetual war with Doctors, should have prevented my seeing all you great men at Soho today – Lord! what inventions, what wit, what rhetoric, metaphysical, mechanical and pyrotecnical (sic) will be on the wing bandy'd like a shuttlecock from one to another of your troop of philosophers! While poor I, I by myself I, imprizon'd in a post chaise, am joggled, and jostled and bump'd and bruised along the King's high road to make war upon a pox or a fever!"(17)

(This is another of the few eyewitness descriptions of the Lunar society in session.) Another similar letter of regret was sent to James Watt in January, 1781:

> "Dear Mr. Watt, "You know there is a perpetual war carried on between the Devil and all holy men. Sometimes one prevails in an odd skirmish or so and sometimes the other. Now you must know this said Devil has play'd me a slippery trick and I fear prevented me from coming to join the holy men at your house by sending the measles with peripneumony amongst nine beautiful children of Lord Paget's. For I must suppose it is the work of the Devil?"(17)

In 1781, upon his remarriage, Darwin left Litchfield (near Birmingham) and moved to Derby. His new wife had objected to Litchfield and particularly to the presence of Anna Seward in the city. This young lady acquired many gentleman admirers and had the sobriquet "The Swan of Litchfield." The relationship between Darwin and Anna Seward was probably quite innocent and included antics such as exchanging flirtatious letters using the names and personalities of their cats.(16) The increased distance from Derby to Birmingham made Darwin's subsequent direct contacts with the Lunar Society still less frequent but he maintained active participation in the affairs of the group using alternate means. After Darwin moved he expressed clearly how much he missed personal participation in activities of the Lunar Society. On Dec. 26, 1782 Darwin wrote to Boulton, "I am here cut of [sic] from the milk of science which flows in such redundant streams from your learned lunations." Darwin therefore founded a philosophical society in Derby.

The Derby Philosophical Society was probably founded early in 1783. The inaugural address of Dr. Darwin is recorded. He suggested, as appropriate activities, performance of experiments, correspondence with other societies, and collection of a scientific library. Eventually the society met on the first Saturday night of each month at the King's Head in Derby at six p.m. The society collected a fairly comprehensive and large library and continued to sponsor scientific lectures until 1857.(18) An unnamed contemporary writer characterized Darwin's propensity to practice personal vices thus:

> "...He was fond of sacrificing to both Bacchus and Venus; he soon discovered that he could not continue his devotions to both these deities... he therefore resolved to relinquish Bacchus but his devotion to Venus was retained to the last period of his life."(19)

Erasmus Darwin had five children by his first wife, Mary Howard, and nine children with his second, Mrs. Eliza Pole. In addition he had two other daughters by a lady whose name may have been Mrs. Parker but who has been somewhat difficult to identify. These two children, known locally as Susannah and Mary Parker, were raised on equal terms and in the same household as the legitimate Darwin-Pole children and were educated to be teachers. They were provided with a house, opened a school, and subsequently attracted pupils including the daughters of Mrs. Pole and many of the female offspring of Lunar Society members. Eventually Susannah became the well respected wife of Derby's foremost surgeon.(20) It was about this time that Darwin's remarkable poem, "Botanic Garden," enjoyed its transient success. Lester King described Darwin as a contender for the title of "Worst Poet in the English Language." Nevertheless Coleridge, Wordsworth and Shelley greatly admired him.(20) King further opined that Darwin had a powerful mind, a vigorous imagination, strong scientific leanings and occasional flashes of insight. He was also a man of prejudice and passion who lacked balance and intellectual discipline. Dr. Samuel Johnson, a literary giant of the age and Dr. Darwin could not abide one-another and Darwin was generally ignored on Johnson's visits to Litchfield.(15,21)

In 1785 Erasmus Darwin published "An account of the successful Use of Foxglove, in some Dropsies, and in the Pulmonary Consumption."(22) His earlier publication on foxglove in 1780 was the origin of the dispute between him and Withering. (See below in material on Withering) He now presented additional cases involving use of foxglove and attempted to define the types of dropsy in which the drug might be useful. He also described successful use of foxglove in a patient with pulmonary consumption. A suggested rationale for using the drug in this situation was that lung ulcers would never heal while they were secreting fluid and the foxglove must help by promoting absorption of fluid from them.

There are several letters in the correspondence of Erasmus Darwin indicating that he enthusiastically incorporated pneumatic methods in his practice about 1794-1795. In a letter to Thomas Beddoes written in July, 1784 Darwin indicated that

Watt had sent him an air apparatus which he had not yet unpacked. He was waiting for a further book from Beddoes instructing him on the best way of making and using airs.(17) In "Zoonomia" Darwin advised the use of "alcaline aerated water" for treating bladder stones. This medicine could be procured from the firm of Jacob Schweppe at No. 8 King Street, Holborn. It was sold under the name of "factitious seltzer water."(17)

Darwin advised Watt concerning the treatment of his daughter Janet (usually called Jessie) for her consumption. In January, 1794 Darwin proposed use of foxglove, emetics, and particularly swinging circularly to the point of developing nausea. Also, common air mixed with fixed air were recommended. Jessie Watt died in June, 1794. Darwin wrote to James and Ann Watt expressing his deepest condolences on the loss of their daughter (undoubtedly with the realization of how ineffective his recommended treatment had been). It was in the reply to this letter that Watt indicated his intention of becoming involved in the effort against consumption.(17)

Zoonomia, Erasmus Darwin's great essay on medicine and physiology in poetic form first appeared in 1794. In the first portion of the work animal economy and physiology were discussed. Part two dealt mainly with nosology. This was a catalogue of diseases distributed into natural classes, according to their proximate causes with their subsequent orders, genera and species together with their methods of cure.(23) Such attempts to classify various natural phenomena employing systems resembling those used by Carolus Linnaeus to classify animals and plants were popular and common in the 18th century.(24)

Darwin declined the opportunity to become personal physician to King George III.(16) He had a great admiration for Thomas Beddoes and his medical opinions. Robert Southey noted in a letter to Charles Wynne:

> "The late [?] Erasmus Darwin of Shrewsbury [?], whose kindness to me as a schoolboy is pleasant to remember, had a very high opinion of Beddoes. Following in his steps, he sent all consumptive children, with their nurses into cow houses, and made them walk up and down the butcher's row whilst the meat was fresh."(25)

Mary Anne Galton intensely disliked Erasmus Darwin, who was her mother's doctor and whose methods of medical practice were said some times to shock his contemporaries. On one occasion she wrote that a new and hurtful influence — Dr. Darwin — appeared at Barr Hall. He arrived in a carriage which was strangely outfitted to permit him to eat and write as he traveled. His figure was vast and massive and he stammered but his eyes were sagacious and inspired confidence in his patients. His conversation was entertaining and full of amusing anecdotes, some about his patients. Mary Anne related how once when Dr. Darwin was summoned to treat her mother his demeanor was not appropriate to the occasion. She accused

Darwin of considering his own comfort above the needs of his patients and of sometimes bending the truth to suit his own needs.(26) Mrs. Galton was frequently ill, and Darwin enjoyed being called to see her because he was so well entertained by the Galtons. He could obtain the late Lunar news from Galton, and since they were rich Darwin felt no qualms at charging them high fees for the long journey from Derby.(17) Miss Galton was sometimes thoroughly shocked at Darwin' s conversation and the atheistic and materialistic views which he apparently espoused. About that time the "Botanic Garden" was published and was read and thoroughly enjoyed by the Galton circle. Nevertheless popularity of the poem declined with time. Mary Anne believed that this was due to total concern with matters earthy and not spiritual.(27) On one occasion when Dr. Darwin was consulted about the health of one of Mary Anne's zealously religious cousins, he advised that her cure should be having something to laugh at and suggested burning all of her religious books.(13) But others had contrasting opinions about the character of Erasmus Darwin. James Keir wrote:

> "I think all those who knew him will allow that sympathy and benevolence were the most striking features. He felt very sensibly for others, and, from his knowledge of human nature, he entered into their feelings and sufferings....." (James Keir, letter to Robert Darwin [nephew of Erasmus] May 12, 1802)(28)

In 1778 Darwin's eldest son, Charles, died at age 19 from, it is said, putrid fever contracted during his dissections.(16) Some consequences of this tragic event will be considered later. Then in 1799 Erasmus Darwin Jr. committed suicide by drowning himself. The cause of this was the size and burden of his financial obligations. It is said that after this Erasmus Darwin never recovered his joy of living.(17) Erasmus Darwin's son, Robert Darwin, married Susannah Wedgwood. Erasmus's grandson by this marriage, Charles Darwin, the naturalist and best known Darwin, was born on Feb. 12, 1809, the same day as Abraham Lincoln.(2) Erasmus Darwin's last letter was to Richard Lovell Edgeworth dated 17 April,1802. It remained unfinished since Darwin died the day after he began this letter. It was appropriate that Darwin's last letter should have been to Edgeworth. They had enjoyed 35 years of unclouded friendship.(17)

MATTHEW BOULTON

Matthew Boulton had inherited a manufactory from his father which made small metal objects such as shoe buckles and buttons. He improved the machinery for manufacturing coins and medallions and also became well known for his high quality thermometers. In 1758, the year in which he probably met Darwin, Boulton was building a new factory at Soho, just outside of Birmingham. Also during this year Benjamin Franklin visited Birmingham and performed experiments with Boulton. He visited again in 1760. Eventually Franklin had met and knew half of the Lunarians. In the 1760's Boulton was already thinking about steam engines for his plant and had done some preliminary planning. He was described by Josiah Wedgwood in 1765 as "the first and most compleat manufacturer in England in metal. Ingenious, philosophical and agreeable."

Mary Anne Galton was greatly impressed with Boulton's appearance and bearing. She wrote that he was: "...tall, and of a noble appearance; his temperament was sanguine with that slight mixture of phlegmatic which gives calmness and dignity; his manners were eminently open and cordial; he took the lead in conversations and with a social heart had a grandiose manner like that arising from position, wealth, and habitual command. He went among his people like a monarch bestowing largesse. His forehead was magnificent; the organs of comparison, constructiveness, and individuality were immense."*(13,29)

At Boulton's urging, the Birmingham assay office was opened in 1773. This permitted him to get his silver products hallmarked without having to ship them to an existing office. This type of semi-political activity was typical of those undertaken by prominent business leaders at this time for furthering civic improvement. For a time Boulton engaged in a limited manufacture of pottery and there existed a friendly rivalry but also cooperation between him and Wedgwood.

When James Watt moved to Birmingham in 1774 he went into partnership with Boulton. Their concern was steam engines and they became so preoccupied with this aspect of the business that for a period James Keir, another Lunarian, was given responsibility for management of Boulton's company. Apparently the firm of Boulton and Watt was always in financial difficulty and, discouragingly, always verging on bankruptcy.(30) The firm of Boulton and Watt marked the border between older and modern methods of manufacture. They made all the modern machine tools that they needed. The Soho works employed nearly 1000 men in various operations, a number far greater than had ever been engaged together in manufacture before. The organization of the Soho works was quite modern with managers and foremen. This systematic organization of workmen was one of Boulton's great contributions. The Encyclopaedia Brittanica, in its article on 'metalwork' summarized the contribution of Matthew Boulton:

> "Boulton transformed craft into an industry establishing standards of design, factory management and welfare rivaling that of the 20th century."

Workers' health plans came into existence in the 18th century. Such schemes were arranged by Josiah Wedgwood at Etruria and by Matthew Boulton at Soho,

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* At the time of this writing Mary Anne was fascinated with phrenology.

Birmingham.(31) Many famous engineers and technologists got their start working for Boulton and Watt and probably for other Lunarians as well. However the distinction between employer and employee was scrupulously maintained. These talented and productive individuals were always regarded as merely workers and Lunar Society membership was not open to them (although on occasion they have been listed as Lunar Society members by some authorities). One example was William Murdock (1754-1839) superintendent of the Boulton and Watt works. He was an engineer and inventor of, among other things, gas lighting. However, Murdock was an employee and thus a social inferior. During the period of maximum activity of the Lunar Society he resided in Cornwall as representative and agent of Boulton and Watt and did not return to the Birmingham area until 1798. During this time his correspondence with his employees was solely concerned with business matters. It is very unlikely that he was a Society member. Another Birmingham man occasionally listed as a Lunarian was John Baskerville (1706-1775), an inventor and publisher.(2) However he belonged to the previous generation and was a friend of Matthew Boulton's father.(12)

Matthew Boulton was one of the more conservative members of the Lunar Society. In the American Revolution he supported England against the colonies. Part of the reason for this was undoubtedly to restrain the trade of his colonial competitors.

The partnership between Matthew Boulton and James Watt ended in 1800. Upon their retirement the business was carried on by James Watt Jr. and Matthew Robinson Boulton.

JOHN WHITEHURST

John Whitehurst was a watch and instrument maker of considerable abilities and was also a geologist. He and Wedgwood made geological and paleontological observations during the excavations for buildings and canals. In 1775 Whitehurst accepted the post of "Stamper of Money Weights" in London but remained in close correspondence with Lunar members. He continued to subcontract for the firm of Boulton and Watt. He was elected to membership in the Royal Society in 1777 and brought many Lunar Society members to meetings as his guest. Whitehurst published an important book on geology about 1777 which had practical application in mining.

WILLIAM SMALL

Small arrived in Birmingham in 1765 to set up a medical practice carrying a letter of introduction from Benjamin Franklin. Franklin and Small had probably met in Williamsburg in 1763. One of his earliest patients was Matthew Boulton. Small had been a Professor of Natural Philosophy at the College of William and

Mary in Williamsburg, Virginia from 1758-1764. Thomas Jefferson was a particular friend of Small who had bestowed special attention on the future president when he was a student. Small acquired many other friends in Virginia, but he also apparently made some enemies; particularly among the Board of Visitors. During a trip to England to buy scientific instruments in 1764 he was notified that his services would no longer be required at William and Mary and so decided not to return to North America. In pursuit of an alternative career, he undertook the study of medicine and qualified at Aberdeen.(33)

Small is said to have had a passion for anonymity,(11) having no publications and belonging to no scientific organizations. But he did not lack scientific ideas. In 1773 he conceived a plan to blow up the polar ice cap and float its fragments to tropical countries to make them temperate. He appeared to be perpetually unwell.

The loose, informal association which we have designated as the "Lunar Circle" continued until 1775. In that year William Small died. In a letter of Feb., 1775 to William Withering, Erasmus Darwin eulogized the recently deceased Dr. Small. Darwin wrote that Small had no equal in strength of reasoning, quickness of invention, learning in the discoveries of other men, and integrity of heart.(17) The death of Small seems to have affected his colleagues more strongly than any other event in the history of their association. Small appeared to have been the cement that tied them together in their early days. Perhaps in compensation for the loss of this key individual, the fellowship became much stronger and more formal. The true Lunar Society of Birmingham began in 1775.

Josiah Wedgwood

Josiah Wedgwood, manufacturer of pottery, became well known to Erasmus Darwin in 1765 because of their mutual interest in the Trent-Mersey canal for which planning, financing, and enabling legislation were proceeding. The canal was of particular importance to Wedgwood because it offered ease of transportation for raw materials and finished pottery. Wedgwood was born into a family of pottery makers. He had little formal education. However he educated himself extensively. A particularly good opportunity for self-education occurred during his convalescence from smallpox. This disease had been complicated by an infection in a knee joint. The knee continued to plague him into later life. Wedgwood had bought property at "Etruria," a few miles north of Birmingham, which adjoined the land through which the Trent and Mersey Canal was to be dug. Some of the pottery which Wedgwood manufactured was modelled after pottery discovered in Italy and falsely believed to be of Etruscan origin. Hence the copies were called "Etruscan ware" and their site of manufacture was named "Etruria." Other ceramic products of the Wedgwood factory were "black basalt" pottery, "Queen's ware" and "Jasper ware." Production of these various types of pottery were good examples of Lunar cooperation. The chemical advice of Keir and Priestley was invaluable in solving the numerous chemical problems which arose. Among these were glass making and the glazing of pottery. Priestley had first begun to communicate with Circle members in 1773.

Certain aspects of Wedgwood's commercial operations illustrate the kind of business ethics sometimes practiced in his time (and also, it would appear, in our own). He obtained the property at Etruria on the basis of confidential knowledge, which he acquired as an officer of the canal company, concerning the route which would be chosen for the Trent and Mersey canal. Also, there seemed to have been some cases of lead poisoning originating from improper formulation of the glazing on some of Wedgwood's Queen's ware pottery. Persuasion in proper places was successfully applied to minimize effects of this occurrence.(34)

In 1775 Darwin became Wedgwood's physician and the two families became very close. Wedgwood began a school for the children of both families in Etruria. He believed that existing education was for "gentlemen" and unsuitable for people destined to enter a trade or profession. Josiah Wedgwood was a religious non-conformist, a Whig, and a supporter of the cause of the American colonies during the revolution.

About 1780, Wedgwood began to manufacture earthenware drains and pipes and subsequently various types of chemical apparatus such as tubes, dishes, mortars, and crucibles. He supplied other Lunarians with chemical apparatus. Thomas Beddoes also purchased many items of chemical equipment from Wedgwood.

Josiah Wedgwood's encounter with smallpox when he was a child was severe. It left him markedly weak and debilitated and with great pain and stiffness in the knee. He had extreme difficulty in using his leg as a consequence of this.(35) During his apprenticeship he had to abandon the thrower's bench, where pottery was made, because of inability to sit before the bench. He bore this affliction for a good number of years (although he had made up his mind to have his leg amputated). Years later (1768) he had an exacerbation of his knee problem. The pain in his knee was intense and when it got better he developed severe constitutional symptoms. Then when these abated the pain in his knee recurred. A surgeon, probably together with Dr. Darwin, were called in consultation and an amputation was decided upon. He knew that he could not carry on in his existing state. The surgery was performed on May 28,1768. Wedgwood's conduct during the amputation was described: "He would not be assisted or have the operation hidden from his view; but seated in his chair bore the unavoidable pain without a shrink or a groan."(35) He made a remarkably uneventful recovery and a great concern was shown for his welfare by many people. In a subsequent letter he referred to this date as "Saint Amputation's" Day as if he were going to celebrate it annually.*

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* The anniversary of an operation for bladder stone had been celebrated annually with a banquet for several years by Samuel Pepyps in the preceding century.

Richard Lovell Edgeworth

In 1766 Richard Lovell Edgeworth joined the Circle. His autobiography provides the only coherent account of the early days of the Lunar Circle. He was independently wealthy and owned considerable property around Edgeworthtown, County Longford, Ireland. Edgeworth's early life was typically that which might be expected for a youth from a wealthy land-owning family of the mid 18th century. Like many other Anglo-Irish landlords, he spent extended periods living in England. According to Bishop Cahal Daly of the diocese of Ardagh and Clonmacnois in County Longford, speaking in 1969, the Edgeworths deserve a place in recognition and affection of the Irish which is understandably refused to most 18th and 19th century landlords in Ireland. Three members of the family were nominated by Bishop Daly for special attention:

Richard Lovell Edgeworth (1744-1817), the Lunarian, was an inventor with a wide variety of interests such as carts and carriages with springs, railroad tracks, architecture, heating systems, road building, and bog drainage. Another area of interest of Edgeworth was education. He proposed ideas highly advanced for his time. He received several medals and awards for his inventions from the Society of Arts.(36) He believed that an educated man was one who could generalize his thoughts rather than one possessing large amounts of memorized facts. He advocated equal education for Catholics and founded a school based on these beliefs near his Irish estates. He was extremely liberal as a landlord and the British loyalists regarded him as a renegade.(37)

Maria Edgeworth (1767-1849), ever dedicated to her father's projects and interests, shared his tolerance and liberalism. She turned out to be better known than he. Her place in English letters is that of a gifted minor writer.(37)

The Abbé Edgeworth (1745-1807), first cousin of Richard Lovell Edgeworth, was the son of Robert Edgeworth, a Protestant clergyman who converted to Catholicism and was forced to flee to France. The Abbé had the name Henri Essex de Firmont. He became associated with the French Royal family and was with Louis XVI when he was beheaded. He died in Poland while attending soldiers of Napoleon's army who had caught the fever.(37) Richard Lovell Edgeworth eloped with Miss Anna Maria Elers and their first child, Richard, was born before Richard Lovell was twenty. These developments put an end to Edgeworth's education at Oxford. Other children of this marriage were Maria, the novelist, Emaline, who married Dr. John King of the staff of the Bristol Pneumatic Institution, and Anna Maria who married Dr. Thomas Beddoes.(38)

Richard Lovell Edgeworth was introduced to the Lunar Circle about 1766 through a mutual interest with Erasmus Darwin in carriages and they jointly submitted a design for a new carriage to the Society of Arts.

Edgeworth became a frequent visitor to Litchfield and Birmingham. Though at this time he was 22 he appeared much younger. He was very well educated in mathematical science, classical learning and modern languages and had exceptional mechanical ingenuity. His address, manners and appearance were eloquent and he danced, fenced and had other graces yet he did not let these lighter endowments abate his ardor in the pursuit of knowledge.(15) Because of their interest in education of children Darwin and Edgeworth shared an admiration for Rousseau who was living in the vicinity of Birmingham at that time.(16) Edgeworth raised his son according to the principles proposed by Rousseau.

In the late 1760's the deep and lasting friendship between Edgeworth and Thomas Day began. Day and Edgeworth had been in the same college at Oxford and had shared the same tutor. Day visited Edgeworth's Irish estates. He was generally disliked by the senior Edgeworth and was rejected as a suitor by Richard Lovell's sister. In 1770 Richard Edgeworth Sr. died and Richard Lovell succeeded to the estate in Edgeworthtown. This death relieved Richard Lovell of the necessity for further preparation for study of the law as his father had wished.(38)

In addition to the Lunar Society, Edgeworth became an associate, through introduction by James Keir, of an Arts and Science society in London. This circle met first at Jack's and then Young Slaughter's Coffee House for many years. The organization had no formal name. Members included John Hunter (Chairman), Sir Joseph Banks, Capt. James Cook, James Smeaton and others.(41)

In 1770 Edgeworth again visited Litchfield accompanied by Thomas Day. There, in the house of Mr. Seward, a Canon of Litchfield, resided his daughter Miss Anna Seward, minor poetess. Her presence, it will be recalled, was an important reason for the wife of Erasmus Darwin to insist on the doctor's removal to Derby. Also living there was Miss Hornora Sneyd. Edgeworth became a member of the circle centered about the Seward home and was immediately struck with the qualities of Miss Sneyd which were exaggerated because of the unhappiness of his own marriage. Honora Sneyd was overshadowed by the graces of Anna Seward and therefore apparently appreciative of Edgeworth's attention. Another suitor of Honora Sneyd was Mr. and later Major John André who would subsequently gain notoriety as the British accomplice of Benedict Arnold in the abortive attempt to betray West Point during the American Revolution.(42) Edgeworth accompanied his friend Thomas Day on his venture on the European Continent so that Day could acquire certain social graces and polish (see below). Edgeworth's motivation for this trip was to escape the currently impossible relationship with Honora Sneyd.(43) On his return from this trip he learned that his wife had died in childbirth. In July,1773, Edgeworth married Honora Sneyd and returned to Ireland where he remained from 1773 to 1776. Children of this marriage were Honora and Lovell. Upon his return to England he carried on his work on carriages and transportation. The happy marriage was ended when Honora died from consumption in 1780. Edgeworth and Elizabeth Sneyd, sister of the late Honora, were married on Christmas 1780. At that time marriage with a deceased spouse's sister was considered scandalous because of certain religious teachings. However societal disapproval was soon forgotten. In 1781 Edgeworth became a fellow of the Royal Society on the basis of his knowledge in mathematics (with apparently only one contribution to the literature). In 1782 he returned to Edgeworthtown.

In 1791 the Edgeworth family returned to England and settled in Bristol. It was about this time that Richard Lovell Edgeworth assisted in establishing Thomas Beddoes in the Bristol medical community and that Beddoes met and courted Anna Maria Edgeworth. The Edgeworths returned to their estate in Ireland in 1793. Beddoes soon followed and he and Anna Maria Edgeworth were married at the family estate as noted previously. In 1797 Elizabeth, like her sister Honora, succumbed to consumption. Richard Lovell Edgeworth was now past 50 and a third time a widower with numerous children by different wives. His fourth wife was Frances Beaufort. All together he had 18 children by 4 wives. Edgeworth played an active role in the rebellion of 1798 and the abortive French invasion which occurred at that time.(38)

THOMAS DAY

Also brought into the Circle in 1766 was Thomas Day, a neighbor of Edgeworth in Berkshire. Of all the Lunarians, Day probably had least to do with the origins of anesthesia as related in the current volume, but his idiosyncratic behavior and his weird exploits qualify him as one of the more interesting members of this group. Day was an independently wealthy eccentric who had little concern with science but strong interests in humanistic areas such as metaphysics, philanthropy, education and political theory. An important attraction of the Birmingham-Litchfield area for Day was Darwin's reputation in education. Day required advice concerning the education of his wards, Sabrina Sydney and her companion, Lucretia. His appearance was described as "unkempt" and his manner "boorish."(11) He can probably be best described as a "moralist."

Anna Seward described Day, who was 24 at the time, as being tall and of acceptable appearance. He wore neither fine clothes nor hair powder. Although less socially graceful than Edgeworth, he was more highly imaginative and a deeper reasoner. He was said to be a "rigid moralist who proudly imposed on himself cold abstinence, even from the most innocent pleasures; nor would he allow an action to be virtuous, which was performed upon any hope of reward, here, or hereafter." He had very definite ideas on female education. Ever despicable, in Day's estimation, were the distinctions of birth and the advantages of wealth, and the allurements of the graces. He formulated requirements of a wife which obviously could not be found ready-made.(15) Day had little in common with the interests of other members of the Lunar Circle but a high regard for their activities. Members of the Circle probably regarded Day highly because he had the eloquence to present the beliefs of the society and the means and courage to espouse unpopular opinions. It appears to be this mutual respect that brought and kept Day in the Lunar Circle. Keir wrote that Day had a sterling character which he used for the benefit of mankind. His father was a collector of customs. He was educated at Charterhouse School and Corpus Christi College, Oxford. He was distinguished by a consistency of principle with conduct. Keir wrote, "Virtue was the true interest of man and he therefore determined to pursue it as his most substantial good." Some of his character attributes included "sympathy" and "fortitude." Keir believed that it was easy to trace relation between Day's character and his conduct for his entire life.(44) He frequently agitated and wrote in favor of government reform in taxation and other areas.

Day was apparently ready on more than one occasion to duel to defend his ideas. He lived below the standard which his fortune would allow. He gave frequently to charity and must have been often victimized in his charity work. His one expenditure was good books. He was tall and strong and erect; of a manly disposition and deportment and was unaffected in manner and conversation. He and his motives were frequently misunderstood because he was so different.

About 1768 Day began his most remarkable and bizarre experiment in female education involving two girls which he, Edgeworth, and his friend Bicknell selected from a foundling home. Keir described the experiment:

> "...an experiment in female education, in which he proposed to unite the purity of female virtue with the fortitude and hardiness of constitution of a Spartan virgin, and with the simplicity of taste that should despise the frivolous vanities, the effeminate manners, and the dissipated pleasures...characteristic of the present age."

In order to accomplish this with minimal distraction, the girls were taken to France and placed in the care of non-English speaking individuals. Some specific measures employed included unannounced firing of pistols next to the girls' ears, infliction of mild pain, endurance of physical discomfort, and forced renunciation of fine clothes, jewelry, etc. as well as more conventional types of intensive instruction. In this fashion it was intended that the girls would develop into rational, serene, philosophical adults who were not deluded by the vanities and fashions of the world. Perhaps one of Day's motives was training of a wife suitable for his temperament although Keir believed that this was a minor consideration in this program.(44)

A certain Miss deLuc, during a visit to the Galton family, related episodes describing the education of Sabrina Sidney, one of Day's wards. Mary Anne Galton wrote:

> "We were much interested in anecdotes she told us of Sabrina Sydney, the élève of Mr. Day who was boarding at the same house with her. We heard how she stood unmoved when, every morning, he fired a pistol close to her ear and how she bore melted sealing wax dropped on her

> arms and back; and we were told of her throwing a box of finery into the fire at his request."(45)

In later years, Sabrina developed into a very excellent young lady and frequently visited in Litchfield where Darwin was often her host. At age 26 she married Mr. Bicknell, a barrister, who was the very individual with whom Day went to the foundling hospital to find Lucretia and Sabrina 14 years previously. On the death of Mr. Bicknell about 5-6 years later, Day allowed Sabrina 30 pounds per year to help maintain her and her two young boys. She lived many years thereafter.(15,46) The meeting of Day and Edgeworth with the Sneyd sisters was related above in the narrative on Edgeworth. Day's ultimate proposal of marriage to Honora Sneyd was rejected. After a tumultuous period Day was more smitten by Honora's sister, Elizabeth Sneyd. She insisted that Day acquire some refinement so he, Richard Lovell Edgeworth, and young Richard Edgeworth set off for France where Day attempted to acquire the necessary social arts and improvement in appearance to permit him to be eccentric with confidence.

In 1773 Day returned to England. but the relationship between Elizabeth and Day came to naught.(38) The effects of the "social graces" which were acquired by Day during his continental sojourn were described by Anna Seward thus:

> "The endeavor, made at intervals, by the visible effort, was more really ungraceful than the natural stoop and unfashionable air. The studied bow on entrance, the suddenly recollected assumption of attitude prompted the risible instead of the admiring sensation; neither was the showy dress in which he came back to his fair one, a jot more becoming."(15)

Day left the Birmingham area for London in 1775 and was called to the bar. Dr. Small then introduced Day to Miss Esther Milnes, a wealthy heiress whose philosophical views proved to be in accord with Day's own ideas. It was said that his courtship took the form of a final examination. They were married in 1778 and settled in isolation progressively becoming more distant from their friends. The Days bought an estate in Surrey where he applied some of his bizarre theories to agriculture. He built a remarkably strange house on his estate. At one time, the craftsmen working on the house repeatedly asked him for instructions but he appeared too preoccupied to make many decisions. Accordingly, a room was completed without any windows and it was left in this state.

Day was best known in his own time for his writings. His moralistic tale "The History of Sanford and Merton," first published in 1783 was a story for children extolling the virtues of honesty and hard work. It was said to have been seen by more readers than any other book of the period and for a while rivaled Daniel Defoe's "Robinson Crusoe" as an 18th century best seller.(47) The book related how Merton, the spoiled son of a rich squire, acquired an appreciation for hard work and consideration for others under the tutelage of Sanford, a supernaturally virtuous farmer's son. The book related their adventures and employed many stories within stories.(48) Day's violent opposition to American slavery and the slave trade was expressed in his poem, "The Dying Negro," which appeared in 1773. The scenario of the poem was taken from a true story: A slave who had escaped and had agreed to marry a white fellow servant was recaptured on his way to be baptized. He was confined on a ship and was about to be returned to his master. He wrote a letter to his intended and then stabbed himself. The poem was dedicated to Rousseau. Day wrote that America had no legal or historical basis to hold slaves and looked to Britain to remedy the situation. In the poem the slave decried his fate, questioned reason, related how he was captured, reflected on his future life and what might have been, called for revenge and prepared to die.(49) Then followed "A fragment of a letter on the slavery of the Negroes," by Thomas Day. It was an essay directed to an American gentleman who thought he ought to free his slaves if Day could justify it — he did. Day appeared to have considerable anti-American sentiment due to slavery. The poem was important to the abolitionist movement. Nevertheless he supported the Americans in the revolution because he believed that this was the side supporting human rights. Day gradually withdrew from the company of his friends and progressively became more isolated until his death in 1789. Erasmus Darwin wrote to his son, Robert, following Day's death:

> "I much lament the death of Mr Day. The loss of one's friends is one great evil of growing old. He was dear to me by many names..., as friend, philosopher, scholar, and honest man."(50)

JAMES WATT

In 1767 James Watt joined the Circle. He had been an instrument maker and surveyor in Glasgow. He had also been associated with Joseph Black in a business which manufactured alkali.

Watt's father was a shipwright and maker and supplier of nautical instruments. Young James had a sporadic formal education in school but a great deal of training and experience in such arts as woodworking, metalworking, smithing, instrument making and model making in his father's works. At 18 he determined to follow the career of scientific instrument maker and obtained further training in London.(54) The principal association of James Watt is with the steam engine. The capability of steam to power engines had been known since ancient times. Thomas Newcomen (1663-1729), a Devonshire blacksmith, invented the first real pumping engine. Watt initially became interested in the steam engine because he was given a model of one (probably Newcomen's) to repair but could not make it work. He sought the advice of Joseph Black on the properties of steam. Black became one of his financial backers.(51)

During operation of a Newcomen engine the cylinder chamber was filled with steam and then sealed by closing a valve. Cold water was then sprayed into the chamber and a vacuum was generated by the condensing steam. Atmospheric pressure would then cause the piston to descend within the cylinder. A counterweight would then restore the piston to its original position while steam was again admitted to the chamber through another valve and the cycle would repeat. The extravagant inefficiency and waste of energy due to the wide swings in cylinder temperature with each cycle are readily apparent. The rate at which the machine could cycle was also limited. Watt's crucial contribution to steam engine technology was the separate condenser which he patented in 1769. This was an arrangement of components which permitted condensation of the steam to take place outside of the cylinder chamber. Since the cylinder did not have to be cooled with each cycle, efficiency improved strikingly. Over the years he continued to invent additional improvements.(52) By 1765 he had a design for a practical engine but it would be 10 more years before an effective engine was built and a further five years before any financial return appeared. One problem was that current machining techniques were inadequate for the precision required. Watt became acquainted with Small and Darwin on a trip through Birmingham on an occasion when he was returning to Scotland from London. They agreed to attempt to influence Boulton to assist Watt financially with his steam engine project. Over the next few years experiments to refine Watt's concepts were undertaken simultaneously by Small and Boulton in Birmingham and by Watt in Glasgow.

There were several encumbrances on the patents related to Watt's ideas, but when he finally moved to Birmingham in 1774 he had acquired exclusive rights to his improvements on the steam engine. He became a partner in the firm of Boulton and Watt. They franchised the steam engines that powered the industrial revolution. The first commercial B&W steam engine was set in operation in May, 1776. The first engine outside of their own works was built for the ironmaster Wilkinson and subsequently several engines were erected around London. By 1778 and after great difficulty the engine was becoming a commercial success. The Chasewater (deepest mine in Cornwall, 66 fathoms down) was being pumped by a steam engine and this installation attracted wide attention.

Boulton and Watt did not sell their steam engines outright. They supplied certain parts and revealed to clients the sources of others. Then when the necessary components had been assembled, a representative of the company would travel to the site of installation and oversee the assembly and early operation. It was in a search of a basis for charging the user's fee for steam engines that Watt became interested in physical work and power. He determined the quantity of work which could be accomplished by a horse and how rapidly this work could be done and thus first defined a unit of power; the "horsepower." Watt calculated the number of horses that would be required to accomplish the various tasks, e.g. pumping water and turning machinery, in which steam engines were initially applied. The charge to the client was then assessed on the basis of the cost of feeding, maintaining, and otherwise caring for an equivalent number of horses. A considerable fraction of the firm's effort was expended in litigating matters of patent infringement and also in the detection of cheating when reporting steam engine use.(53) Watt's association with Thomas Beddoes and his role in pneumatic medicine are considered elsewhere in this volume.

Watt was apparently the first to conclude that water is not an element. (Lavoisier was first to state its correct composition.) Watt's career was characterized as exhibiting "modest achievements as a scientist and extraordinary originality and inventiveness as an engineer."(54) However the debt of science to Watt's inventions is great. Many theoretical studies in heat and thermodynamics were inspired by Watt's steam revolution. Mary Anne Galton contrasted Watt's appearance and behavior with that of Matthew Boulton:

> "The characteristics of his [Boulton's] partner, Mr. Watt, were altogether different. Mr. Boulton was a man to rule society with dignity; Mr. Watt to lead a contemplative life of a deeply introverted and patiently observant philosopher. He was one of the most complete specimens of the melancholic temperament. His head was generally bent forward or leaning on his hand in meditation, his shoulders stooping and his chest falling in; his limbs lank and unmuscular and his complexion sallow."
>
> "His intellectual development was magnificent and he was constructive and concentrative and cautious. While Boulton's eye and face were radiant, Watt's were calm and contemplative. He was slow and unimpassioned in speech with deep low voice and a broad Scottish accent. He sometimes became lost in his own thoughts and became unsociable. He often became the center of attraction in a gathering for all and his advice on many matters was sought."

She related how on one occasion, when he was touring the Tuileries Palace, he instructed a French maid in how to clean the grate of a new English stove.(13,55) Watt was anti-American in his views on the American Revolution. He was offered a baronetcy but declined the honor.

JAMES KEIR

James Keir was of an ancient Scottish family and was born, youngest of eighteen children, in Edinburgh on 29 September, 1735. He was educated in Edinburgh and began his career as a medical student but abandoned these studies to become an army officer. He served in the Seven Years War. In 1767 he left the army when he became convinced that his fellow officers did not fancy intellectual pursuits, but continued to be called Captain Keir. He settled near Birmingham.

James Keir's proficiency was in chemistry. In 1769, while a guest of Edgeworth, Keir translated and annotated Macquer's dictionary of chemistry, an authoritative and highly regarded work of its day. This translation and annotation was acknowledged as an important contribution to contemporary chemistry. As a consequence of the favorable notice received by his work, Keir became a member of the Lunar Circle. James Watt characterized Keir as "a mighty chemist and a very agreeable man."(56) In 1777 Keir published his "Treatise on the Different Kinds of Elastic Fluids or Gases." This work was highly regarded and a second edition was required in 1779. He also became a partner and manager in a neighboring glass works. Keir gave up glass in 1778 to become associated with the firm of Boulton and Watt. He declined full partnership when the precarious financial state of the firm became obvious to him.(57) On the basis of his observations on crystallization of glass he became the first individual to postulate that certain rocks and basalt structures originated from the crystallization of lava. Keir was evidently the first person to introduce the word "gas" into English chemical usage as a generic term to describe aeroform substances. He held on to the phlogiston theory for a long time but eventually abandoned it by 1801 after he appreciated many of its deficiencies, which were becoming increasingly apparent.(58) The capability to manufacture alkali by a process devised by Keir was regarded as a most important contribution to British industry.(6)

Keir was a Whig and supported the French revolution. He was also an English patriot, stating that the government in England was too good to risk. He was chairman and organizer of the Bastille Day celebration in Birmingham on July 14, 1791 which was used by others as the pretext for the infamous "Church and King" riots in which Priestley's home, laboratory and church were destroyed. Later, he was repelled by the excesses of the Terror in France and wrote enthusiastically endorsing measures to defend against Bonaparte. In contrast to most other Lunarians, Keir was orthodox in his religious views. Humphrey Davy visited Birmingham in January, 1799 and was entertained by James Watt, Matthew Boulton, and James Keir. In a letter to his mother he singled out James Keir as a great man.(61)

Except for Samuel Galton Jr. (d. 1832) Keir was the last surviving member of the Lunar Society. He died in 1820 at the age of 85. During his lifetime it was his unhappy lot to write eulogies for both Thomas Day in 1789 and Matthew Boulton in 1820. Keir's daughter Amelia (1780-1857) married John Louis Moilliet in 1801 and their son James married Lucy Galton, granddaughter of both Samuel Galton and Erasmus Darwin. Thus the Moilliets eventually became a triple Lunar family.(17)

William Withering

William Withering was born in Wellington, Shropshire in 1741. His father was a prosperous apothecary-physician. The younger Withering had his early education from a neighboring clergyman who prepared him for University at Edinburgh. Edinburgh, during the second half of the 18th century, was not saddled with consequences of the test acts and was therefore the strongest university center in all Britain. Earlier in the century the best medical education had been obtained by travelling to Holland, particularly Leyden. But a chair in medicine was established in 1726 in Edinburgh and soon the distinguished medical faculty there was attracting students from many countries. Among outstanding faculty figures were Alexander Munro primus, Joseph Black, Robert Whytt, and William Cullen. After completion of his studies in Edinburgh, Withering went to London to attend medical lectures and received his degree as "Doctor of Physick" in 1766. After graduation, he began his career in Stafford. Here he did not find his duties particularly time consuming and had time for his other interests such as botany and geology.(62) In 1775 William Withering was alerted by Erasmus Darwin concerning the existence of the vacant medical practice of the late Dr. William Small and he moved to Birmingham.(63) In several letters Darwin had urged him to make this move and suggested that Withering contact Boulton about the details. The practice seemed to provide £500-600 per year with the advantage of being an urban practice not requiring a great deal of travel to attend patients.(17)

Withering described how he continued certain medical activities begun by Small and thereby obtained adequate clinical material for his evaluation of foxglove:

> "My worthy predecessor in this place, the very humane and ingenious Dr. Small, had made it a practice to give his advice to the poor during one hour in a day. This practice, which I continued until we had an hospital opened for the reception of the sick poor, gave me an opportunity of putting my ideas into execution in a variety of cases; for a number of poor who thus applied for advice, amounted to between two and three thousand annually..."(64)

Withering proved to be extremely successful both professionally and socially.(66) He had previously published works on chemistry as related to agriculture and on botany. Eventually he authored the two-volume treatise on the plants of Britain which became a classic. These writings, together with his acquaintance with other Lunar members secured him membership in the society.(62) Helena Cook had been one of Withering's early patients. She was interested in flower painting. During her convalescence from an illness, he applied his expertise in botany to gather many flowers for her to paint. She subsequently became Mrs. Withering. Withering's activities were many and he was extraordinarily versatile and quite gregarious. In addition to botany he was involved in geology, antiques collection, amateur dramatics, music (flute and bagpipe) and poetry.(63) He enjoyed considerable status as a mineralogist and a certain form of barium carbonate ($BaCO_3$) still bears his name: witherite. Darwin related that Withering's house was the first in Birmingham to have a flush water closet. Withering lacked strong political views and tended to support the government and the established church. The Galton children would sometimes scour the woods at Barr for fungi for Withering to identify. He was described by Mary Anne Galton as kind and cautious. He was very often puzzled by some of the specimens, which was not surprising, since the children would sometimes paint them different colors in order to widen the variety offered.(13,65)

Withering was interested in medicinal chemistry and in the analysis of spa waters, a subject which was to help direct attention to pneumatic medicine, and he had developed an intense personal interest in pneumatic medicine. He was also interested in meteorology and was especially concerned with effects of different climates on consumption. He always remained primarily a practicing physician. Withering's two significant medical treatises were "Account of the scarlet fever and sore throat" (1778) and "Account of the foxglove, and some of its medicinal uses" (1785). He is best remembered today for this association with digitalis, or foxglove. He was apparently not the first to write on the medicinal use of foxglove. He had proposed its use in all kinds of accumulations of fluid in the body and not specifically for the swelling of tissues associated with heart failure as it is used today. He regarded digitalis as a diuretic. This remedy was initially investigated because an old Shropshire woman had therapeutic success in cases of dropsy using a mixture of ingredients where regular physicians may have failed. He identified the active herb as foxglove and had the opportunity to evaluate it on the large population of clinic patients at his Birmingham clinic (largely charity patients). Before 1775, he had worked out the method for standardizing the dose of the leaf and noted a profound diuresis, slowing of the heart with strengthening of its beat and striking improvement in the sense of general well-being. From 1775-1779 it was the practice to push the drug to the point of toxicity and then stop. From 1779-1785 he used a smaller dose with excellent results.(66) Despite Withering's modest but definite claims for the efficacy of foxglove, use of digitalis was extended by the medical community from the treatment of dropsy to the treatment of consumption to therapy of almost all diseases; most of which it could not hope to cure. Digitalis became a true panacea and retained that status into the 1890's.*

Use of digitalis in consumption attained a considerable popularity in the early years of the nineteenth century. Among the many physicians who advocated

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* To explain the panacea phenomenon one authority invoked the medical aphorism: "New Drugs Always Work." Other drugs which attained a panacea status about this time included quinine and iodine.) (67)

employment of digitalis in consumption was Thomas Beddoes.(68) Also, in 1799 John Ferriar wrote on his experience in using digitalis, or foxglove, for consumption following the suggestions of Drs. Darwin and Withering and Sir George Baker. In early consumption the drug diminished the pulse rate and lessened the cause of irritation. The diuretic properties of digitalis would also be helpful.(69) Combinations of opium and foxglove were often useful therapeutic measures. The "sedative power" of digitalis often was perceived to suppress cough and mucous secretion. These results were most often temporary and the full clinical picture of consumption returned eventually. Occasionally, however, a cure of consumption might be obtained by digitalis.(70) An appended letter indicated that Thomas Percival, another pioneer of pneumatic medicine, also used digitalis in consumption. Dr. L Maclean stated that he had used digitalis in over 20 cases of consumption with variable but generally good results. He indicated that earlier writers thought that beneficial results of digitalis in consumption were due to diminished secretion, facilitated absorption of secretions, and a "quieter" circulation.(71) Others who wrote on digitalis in consumption included Dr. George Mossman(72) and Robert Kinglake.(73) The latter physician, a member of the staff at Beddoes' Pneumatic Institution in 1799-1800, attributed the salubrious effects of digitalis in consumption to improved lymphatic flow.

Withering had been induced to try the foxglove in phthisis pulmonalis because he was told that common people in the West country did this. However, in that disease it had done but little service and he expressed the need for further and more extensive therapeutic trials.(74) As noted elsewhere, Withering also used pneumatic therapy for phthisis and his clinical reports were cited by several authors. He never believed that this form of treatment was a cure for the disease, but thought that certain pneumatic measures could provide symptomatic relief under some circumstances.(75)

Publication on foxglove was the basis for one of the most serious disagreements in Lunar Society history. In 1780 Erasmus Darwin edited and published a posthumous work of his son, Charles Darwin.(76) This highly promising young man had died unexpectedly and prematurely in 1778. He had been a medical student and the cause of his death was said to have been an infection contracted in the dissecting room. Darwin's book began with an essay on methods for distinguishing mucus from pus which had won a medal for the young author from the Aesculapian Society of Edinburgh in 1778. Then, in an appendix to this work, was reported the first ever case history involving cardiac edema (swelling of tissues due to water accumulation associated with heart failure) treated with foxglove. This most important patient was a Mrs. Frances Houlston who developed some type of febrile abdominal complaint. William Withering and Charles Darwin were both called in consultation. Both started and stopped medications and therapeutic measures at will without consulting with one another. A proper diagnosis was never made. Both Darwin and Withering used inappropriately high doses of foxglove and neither could have come close to the real rationale and indications for use of the drug. The patient eventually recovered and lived another forty years in spite of the treatments prescribed by both consultants. The case was said to be one of the most extensively documented and discussed of the eighteenth century.(77) In the Darwin publication there was no reference to William Withering even though foxglove had been Withering's discovery and he and Charles Darwin had jointly consulted on the case. (Withering didn't publish on foxglove until 1785.) So Darwin enjoyed priority of publication, but it was Withering who inaugurated systematic use of the drug complete with documentation and detailed publication. Erasmus Darwin's publication of his son's posthumous work omitting credit to Withering considerably cooled the friendship between Erasmus Darwin and William Withering but they remained civil to one another throughout the remainder of their association in the Lunar Society.(78)

In 1795 William Withering, in a letter to his son who was attending medical school in Scotland, cautioned the young man against infecting himself through even a small scratch when involved with any putrid substance. This admonition was almost certainly inspired by the earlier death of young Charles Darwin.(79)

Mary Anne Galton commented on William Withering:

> "He was the personification of that which belongs to a physician and a naturalist...His features were sharpened by minute and sagacious observation. He was kind but his great accuracy and caution rendered his manner less open and it had neither the wide popularity of Mr. Boulton's nor the attraction of Mr. Watt's true modesty."(80)

In 1783 pulmonary tuberculosis first struck Withering at the age of 43 and he went to the country estate of Matthew Boulton for recuperation. Years later, in 1799, Withering moved to an estate outside of Birmingham on the site of Priestley's house which had been destroyed in the riots of 1791 and immediately became ill. He was visited by a colleague who remarked, "The flower of English physicians is indeed withering."(81) He died 6 Oct., 1799; eight days after moving into his new house.

JOSEPH PRIESTLEY

The life and career of this "father of pneumatic chemistry" are detailed elsewhere in this volume. Priestley had been a friend of Wedgewood and Franklin since 1765 and was communicating with Small and Boulton in 1773-1774 concerning certain chemical experiments. He had also been associated with Darwin and Boulton in experiments involving electricity, one of his greatest interests. When Priestley left the employ of Lord Shelburne in 1780 he moved to Birmingham and became a member of the Lunar Society. He had married into the Wilkinson family whose name in our time is still associated with cutlery of all types. The move to Birmingham was at the suggestion of his brother-in-law. In the 18th century Wilkinson made, among other things, most of the parts for Boulton and Watt steam engines. Commerce and industry were therefore familiar pursuits to Priestley. Several other Lunarians subsidized Priestley and he, in turn, served as a paid consultant to them on various projects involving chemistry.(82) Lunar Society membership gave Priestley shelter which in more liberal times he would have found in a university.(83) The years 1781-1791 that Joseph Priestley spent with the Lunar Society were the happiest and most peaceful of his life. He wrote:

> "I consider my settlement at Birmingham as the happiest event in my life, being highly favorable to every object I had in view, philosophical or theological. In the former respect I had the convenience of good workmen of every kind and of the society of persons eminent for their knowledge of chemistry, particularly Mr. Watt, Mr. Keir, and Mr. Withering. These, with Mr. Boulton, Dr. Darwin, who soon left us by removing from Litchfield to Derby, Mr. Galton, and afterwards Mr. Johnson from Kenilworth and myself, dined together every month calling ourselves the Lunar Society, because the time of our meeting was near the full moon."(84)

He became minister to the dissenting congregation which gathered at the New Meeting House in Birmingham and remained extremely busy with his pastoral obligations, such as Sunday school. He also produced voluminous religious and philosophical writings at this time, persisted with his Arian and Socinian* religious beliefs, and continued to be regarded as atheistic, radical, revolutionary etc. by many. These were actually years of scientific decline for Priestley. He had already made his greatest discoveries, for example the identification of oxygen, and was fighting a losing war defending the phlogiston theory against the new "French" chemistry of Lavoisier and his colleagues.

As described elsewhere, Priestley's happy life in Birmingham was abruptly terminated in 1791 by the "King and Country" or "Church and Country" riots. In four days, July 14-17, 1791, over £100,000 of damage was done. Violence was directed against religious dissenters and those with liberal political views. Members of the Lunar Society were a particular target. The mob attacked Withering's house but little damage was done because of the timely arrival of troops. Boulton and Watt's employees were armed and deployed to protect the firm's commercial buildings but didn't have to fight. Priestley lost everything, and worst of all, his manuscripts covering 20 years of scientific work. He subsequently attempted to pick up the pieces of his life in the London area and then in the United States.(2) Priestley's friendship with Boulton, Watt, and others kept up even after 1800 by

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* Arian and Socinian – religious doctrines related to the existence and nature of the Trinity.

correspondence. Boulton and Watt sent scientific apparatus to Priestley in Pennsylvania.

Mary Anne Galton disliked Priestley's Unitarianism but had great admiration for the man. She described him as a person of admirable simplicity, gentleness and kindness of heart united with great acuteness of intellect. Priestley spent a great deal of time in meditation and prayer.

Samuel Galton Jr

Galton was born into a Quaker family and eventually directed a portion of the family business. He was self educated in science and published 3 minor works during his career. He joined the Lunar Society in 1781. There were eventually several marriages between the Darwins, Wedgwoods and Galtons.(16) Samuel Tertius Galton married Violetta Darwin. This Lunar Society marriage produced a distinguished line of thinkers and scientists which has continued into the 20th century. Samuel Galton Jr.'s most notable contribution to the Lunar Society was the presence of his daughter, Mary Anne Galton, at group meetings as noted previously. Throughout her life Mary Anne seemed to be somewhat preoccupied with religion and morality. Among the books which she remembered as exerting a particular influence during her childhood were Anna Laeticia Barbauld's "Little Charles" and also her "Prose Hymns for Children." (In 1798 she passed a month visiting Mrs. Barbauld in Hampstead.) Of particular importance to her was Thomas Day's "Sanford and Merton."(85) She noted that her father was often deeply occupied in experiments on optics, colors, electricity and chemistry. He was a Fellow of the Royal Society of Arts and an early member of the Linnaen and Lunar Societies.(86)

Mary Anne listed the distinguished visitors to Barr hall, her family residence, on those occasions when the Lunar Society met there. She also provided a brief comment on each. There were Mr. Boulton, Father of Birmingham, institutor of the mint there, Mr. Watt whose immense general knowledge was the delight of those who knew him and whose discovery in the application of steam had revolutionized the process of manufacture and of land and ocean travelling through the whole civilized world. Captain Keir was the wit, the man of the world, the finished gentleman who gave life and animation to the party. He often brought with him his intimate friends Mr. Edgeworth and Mr. Day. To this society also belonged the celebrated Dr. Withering, distinguished alike in botany and medicine. Then came Dr. Stokes, profoundly scientific and eminently absent. Dr. Priestly, the father of discoveries on air was a man of admirable simplicity, gentleness, and kindness of heart united with great acuteness of intellect and a serene expression. She recalled that in the assembly of these men Mr. Boulton stood out by virtue of his princely munificence and by his noble manners and fine countenance which she thought resembled that of Louis XIV. When Dr. Priestley entered after him "the glory of one was terrestrial and of the other celestial" (even though she was far removed from Priestley's theological creed). She wished "that those who were in possession of far more complete views of Christian truth than Dr. Priestley, had held them half as vitally!" She wondered why or how Priestley could meditate for one hour daily since his Unitarianism would prevent him from meditating on proper subjects.(87)

Jonathan Stokes

Stokes was a protégé of Withering. An early presentation to the Medical Society of Edinburgh of the result of Witherings's experience with foxglove was made in February, 1779 jointly by Withering and Stokes.(88) Stokes was trained as a physician having studied in Edinburgh and with John Hunter in London. He had interests in botany, pneumatic chemistry, zoology and geology. Another of his interests was in the classification of just about everything. He knew Carl Linnaeus, the Swedish father of taxonomy. He joined the Lunar Society about 1783, but soon dropped out of the organization after a disagreement with Withering and a move from Birmingham. Stokes was in correspondence with the Society of Arts concerning agricultural developments and ideas.(6) Mary Anne Galton related that once, on the way to a Lunar Society meeting at Barr Hall in winter, Stokes found a snake in the frozen state and had put it in his pocket. The creature revived and emerged during dinner. It was captured and given to Mary Anne who later set it free.(13,89)

Robert Augustus Johnson

This last member joined the society in the mid 1780's. Little is known of him or his qualifications for being asked to join. The citation on the occasion of his election to the Royal Society in 1788 indicated that he was well versed in chemistry and other branches of experimental philosophy.

Further Observations

Some interactions of Lunar society members and associates were summarized by Clow and Clow:

> "Phlogistons and anti-phlogistons dined at the same table: Watt and Priestley vied with Cavendish and Lavoisier over the discovery of the composition of water: Keir achieved the manufacture of alkali where Watt, Black and Roebuck had failed: Murdock's light illuminated the mills powered by Boulton and Watt's engines: Wedgwood supplied chemical utensils for Priestley's experiments: Priestley in turn analyzed

> minerals of possible utility in pottery: a leaven of wit and philosophy was added by Darwin and Edgeworth."(90)

It is interesting that Watt, Withering, and Boulton were elected fellows of the Royal Society (FRS) on 24 Nov. 1785. Galton and Keir received similar honors on 8 Dec. 1785. One wonders whether anything special happened to cause election of almost half the membership of the Lunar Society to this fellowship in such a short period.(91)

Lunar Society members were among the important patrons of the arts in late 18th century England. Matthew Boulton became associated with many famous painters, engravers and sculptors; a patronage which was closely connected with his business life. He was primarily interested in the arts because he saw that elegance was good business and his trade was related to plates, buttons, buckles, coins, medals etc. He therefore commissioned and bought many engravings and prints. He took industrial designs from these. He also caused many young apprentices to be trained in drawing and developed a type of "School of Industrial Design" at Soho. He became well acquainted with painters, architects, engravers and sculptors throughout England. Other Lunar Society members were similarly patrons of the arts. Erasmus Darwin patronized Joseph Wright of Derby and he also employed other artists to illustrate his "Botanical Garden." Wedgwood likewise patronized Joseph Wright and also hired additional artists to work for him. Boulton's attention to quality and design applicable to development of mass production techniques is said to have helped ameliorate the changes that occurred in British standards and taste of this age. He said, "Nor would anything induce me to make a shabby appearance."(92)

The Lunar Society and the Discovery of Anesthesia

Many members of the Lunar Society of Birmingham contributed both directly and indirectly to the introduction of anesthesia. Their roles were often related to their associations with Thomas Beddoes and his Pneumatic Institution. Activities mentioned in the following summary are also described and documented elsewhere in the text.

Joseph Priestley, pneumatic chemist of the first order and a founder of pneumatic medicine, was the discoverer of nitrous oxide and oxygen. His discoveries and observations started a train of events which led directly to the introduction of anesthesia about 72 years after his identification of nitrous oxide. He made several suggestions for medicinal applications of the various airs that he and others had discovered, which were important influences on the pneumatic medicine activities of Beddoes and his contemporaries. Priestley's daughter, Sally Priestley Finch, suffered from consumption and was under Beddoes' care until her death from the disease in 1803. James Watt and his family also played direct roles.

His son, Gregory, was consumptive and on the advice of his physician, Thomas Beddoes, he had been sent to Cornwall to recuperate. He boarded at the home of Grace Davy, Humphrey Davy's mother in the neighborhood of Penzance. Humphrey Davy and Gregory Watt became good friends. At this time Thomas and Josiah Wedgwood Jr. were also living in Cornwall on the advice of their physician, Thomas Beddoes.(93)

James Watt's daughter, Jessie, died from tuberculosis in 1794. Her final illness and death motivated Watt to attempt to attack this dread disease actively. He affiliated with Thomas Beddoes and became a co-author of "On The Medicinal Uses of Factitious Airs" published from 1792 to 1796. In his portions of the book he described the apparatus which he had devised for generation, collection, storage and administration of gases. It would have been Watt's apparatus that Davy used in his studies of nitrous oxide. He also conducted studies involving inhalation of gases and discoursed at length on the possible uses of certain gases in medicine in spite of his lack of medical qualifications.(94) Watt, his wife, and James Jr. contributed financially to the founding of the Pneumatic Institute.

The firm of Boulton and Watt tried unsuccessfully to get Parliamentary support for founding of the Pneumatic Institute. This company also manufactured and sold apparatus for generating, storing and inhaling nitrous oxide. It is probable that many individuals involved in the subsequent recreational and exhibitionistic use of the gas used equipment obtained from Boulton and Watt. Gregory Watt died in 1804 from tuberculosis following a long illness. James Watt's only surviving child was James Jr. who carried on the business in partnership with Matthew Robinson Boulton.

Thomas Beddoes greatly admired Erasmus Darwin and was inspired in his pneumatic medical work by some of Darwin's ideas. Beddoes published a poem "Alexander's Expedition" (1792) which was imitative and highly evocative of Darwin's unusual poetic work in "Botanical Garden" and "Zoonomia." Darwin had sent Beddoes portions of the manuscript of "Zoonomia" for his review and comments before its publication. Beddoes announced several of his theories on the origins of many diseases arising from gaseous imbalances within the body and their treatment by therapeutic gas inhalations in "An Open Letter to Erasmus Darwin" of 1793. The reply from Darwin to Beddoes' open letter was also published in that document. Darwin agreed with Beddoes' reasoning and encouraged him to continue his pursuit of pneumatics. He stated his view that consumption was infectious and that ulcers in the lung were partly the result of exposure to air. He believed that open wounds didn't heal well when exposed to air. These ideas supported Beddoes' contention that breathing air with a subnormal oxygen concentration would be beneficial in tuberculosis.

Erasmus Darwin and sons Robert Waring and Erasmus Jr. contributed to the founding of the Pneumatic Institute. Beddoes arrived in Bristol in 1793 to begin his practice and commence his inquiries into pneumatic medicine with letters of introduction from Erasmus Darwin. Beddoes' initial attempts to begin a medical institution in Bristol Hotwells encountered considerable opposition from neighbors and other influential individuals of the city. They were naturally concerned about the impact of this type of activity on their neighborhood. The rumor was circulated that the gases to be employed were dangerously explosive, and that the house in use as a hospital would be a focus of contagious disease."(95) These objections were overcome chiefly by persuasive arguments put forth by Richard Lovell Edgeworth who at that time was residing with his family in Bristol.(96) Edgeworth was favorably impressed by his previous knowledge of Beddoes and by the letters from Erasmus Darwin. When Beddoes became established in Bristol he divided his time between a busy medical practice, his laboratory, and a circle of intellectuals surrounding Edgeworth. It is said that this circle was frequently visited by remaining members of the Lunar Society on their way west.

In the spring of 1794 Beddoes accompanied the Edgeworth family to Edgeworthtown, Ireland and on April 17,1794 he married Anna Maria Edgeworth. Thus Richard Lovell Edgeworth became Thomas Beddoes' father-in-law. Dr. John King, who was subsequently appointed as surgeon assistant to Beddoes at the Medical Pneumatic Institute married Emmaline Edgeworth in 1802. Richard Lovell Edgeworth and Lovell Edgeworth contributed financially to the founding of the Pneumatic Institute. Matthew Boulton became aware of Beddoes' reputation as a teacher of chemistry in 1791 while Beddoes was reader in chemistry at Oxford. It will be recalled that Beddoes' chemical lectures had become extremely popular and were said to have attracted the largest audiences at Oxford since the Middle Ages.(83) Boulton was eager to have his son, who was destined to take over the family business, enrolled in this series of lectures. Matthew Boulton and his son and daughter contributed financially to the founding of the Pneumatic Institution. Boulton and Watt tried unsuccessfully to get Parliamentary support for founding of the Pneumatic Institute.(66)

William Small, at the request of Mr. Young, surgeon of Shifnall in Shropshire, did some studies to determine whether there was an "elastic vapor" of some kind in blood in vessels about 1772. Mr. Young (or Yonge) was the surgeon who cared for Thomas Beddoes' grandfather during his final illness. The very young Beddoes took a great liking to Young and spent a considerable amount of time in his surgery. This association was probably Beddoes' motivation to study medicine.

Beddoes ordered chemical apparatus (similar to Priestley's) from Josiah Wedgwood in 1789. Wedgwood, one month before his death in 1795, gave £1000 toward founding of Pneumatic Institute. His sons, Josiah Jr. and Thomas, supported Beddoes' activities. Thomas Wedgwood was ill for a long period (1792-1805), probably with consumption. His physician was Thomas Beddoes. While Beddoes was reader in chemistry (1791) he visited James Keir. During this visit they had extensive conversations on chemical matters. James Keir and his partner Alexander Blair contributed financially to the founding of the Pneumatic Institute.

William Withering, in the last 15 years of his life, suffered from a chest complaint — (probably tuberculosis) which caused his death at age 58 in 1799. Withering was an early practitioner of pneumatic medicine. On the basis of his observations he did not share Beddoes' enthusiasm for a pneumatic cure for consumption, but he believed that perhaps other diseases might be amenable for cure by inhalation of gases. Withering was quoted several times in Beddoes' writings. Beddoes greatly admired the principles and writings of Thomas Day and the character of Mrs. Day.(99) Robert Augustus Johnson contributed financially to the Pneumatic Institute.

The following members of Lunarian families had or died of consumption: William Withering, Honora Edgeworth (d. 1779), her daughter Honora (d. 1790), Elizabeth Sneyd Edgeworth (d. 1797), Watt's daughter Jessie (d.1794), Watt's son Gregory (d. 1804), Sally Priestley Finch (d. 1803), and Tom Wedgwood (ill 1792-1805, most likely with consumption) and probably others. This disease was a scourge on Georgian and Victorian society. Mortality rates from tuberculosis were appalling and peaked about the turn of the century.(100) It is not hard to see why Beddoes had little difficulty in obtaining the financial backing and other types of support from influential people for his Pneumatic Institution despite some of his unpopular political and scientific views. The expectation of a cure by pneumatic means was offered by Beddoes, a well known and respected physician and scientist, in his "Open Letter to Erasmus Darwin," "On the Medicinal Uses of Factitious Airs," and other writings must have appeared as the only glimmer of hope in an otherwise dismal situation beyond remedy.

The most important contribution of Beddoes' Pneumatic Institute to the introduction of anesthesia was undoubtedly the popularization by Humphrey Davy of the practice of inhaling nitrous oxide for its pleasurable and intoxicating effects. Among those whose interest was excited by this gas and who inhaled it, as listed by Davy, were James Watt Jr. and Gregory Watt, Matthew Robinson Boulton, Joseph Priestly Jr. (back from the US for a visit), Thomas Wedgwood, Josiah Wedgwood Jr., and Lovell Edgeworth.(101) The names identifying Lunar families in the foregoing list should now be familiar to the reader. But these were not the old Lunarians. These were the next generation — their sons. They were all successful men of high reputation but most lacked the spark of genius and greatness which had characterized the Lunarians. They did not inherit the animated drive and compulsion of their fathers.(102) In discussing members of the Lunar Society, their curiosity and ingenuity were emphasized. Also their wide-ranging interests and their willingness to entertain new ideas were stressed. Another of their characteristics was their pragmatic emphasis on knowledge which was immediately applicable to some desirable end.

One could speculate that if nitrous oxide, which had been discovered in 1774, were available for human inhalation in the late 1770's so that the original Lunarians could have tried it, the practical application of the sensations evoked might have occurred to one of these inspired individuals. Perhaps one of these Lunarians, always on the cutting edge of science and technology, might have associated the alteration in consciousness and analgesic state of nitrous oxide with practical pain relief during surgery because they were used to thinking in this manner. Perhaps the connection would have been made by Josiah Wedgwood who knew the pain of surgery first hand. Thomas Wedgwood, son of Josiah, was an ingenious scientist who is given credit for many early developments in optics and photography. He died at an early age. In discussing his life, Meteyard, writing in 1871, also speculated that the idea of anesthesia might have occurred to a trained mind whose attention had been directed towards pneumatics. She wrote: "It would necessarily occur to a philosophic mind like his, that the various gases engendered by heat, if not remedial agents, might contain latent principles of equal value in scientific medicine – an opinion of account, as time has proved for in this experimental quackery of the early part of the present century lay the germs of the great modern discovery of anaesthetics and their application."(102)

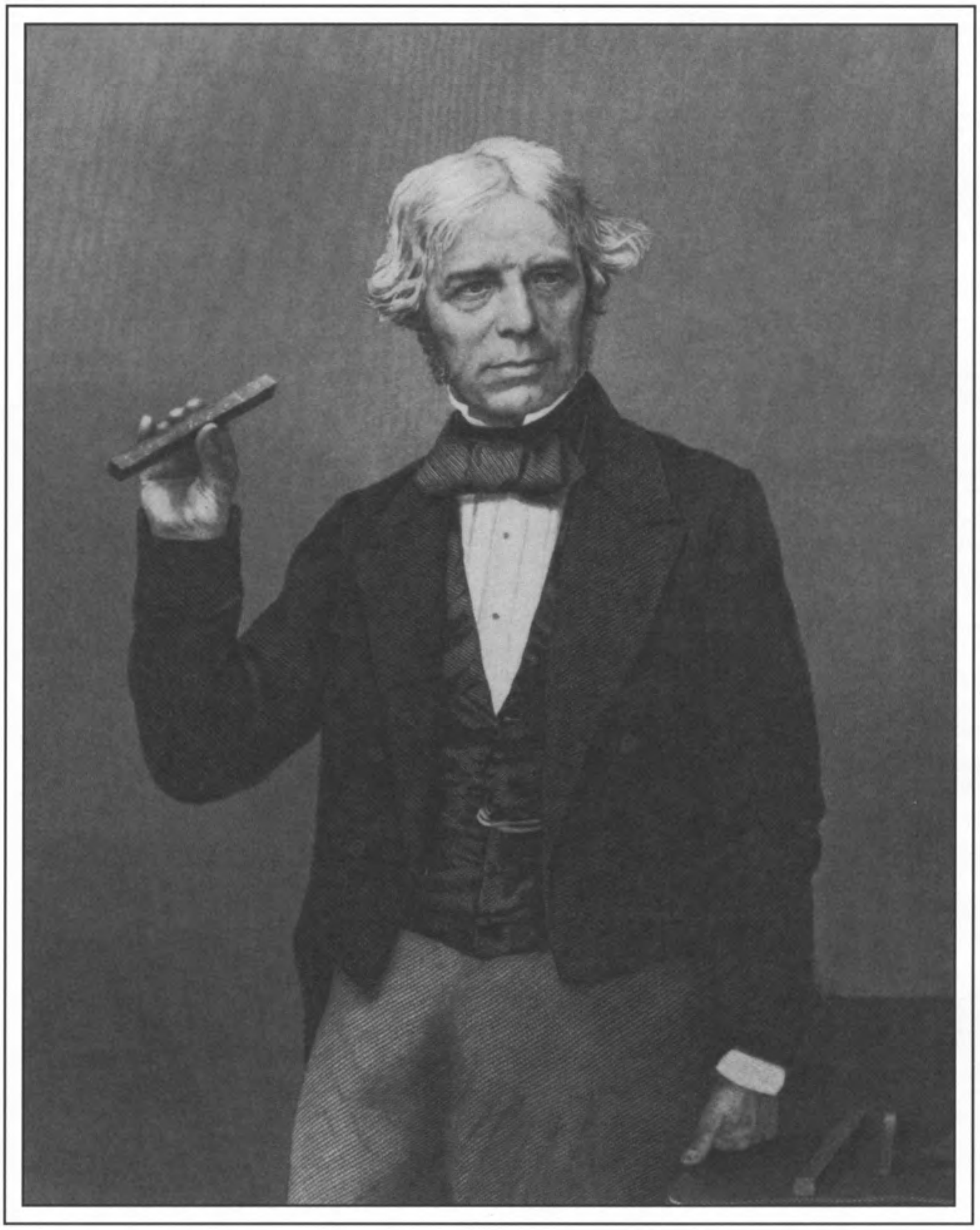

Plate XIII — Michael Faraday (1791-1867). A protege of Humphry Davy, he became one of the most talented experimental scientists of all times. He is probably best remembered for his discoveries related to electromagnetic induction. Faraday pointed out that inhalation of the vapor of sulfuric (diethyl) ether produced the same effects on consciousness and behavior as did breathing of nitrous oxide.

Chapter XVI

Diethyl Ether and Nitrous Oxide

Early Uses, Medicinal and Otherwise

The vapor initially used to introduce the world to practical clinical anesthesia was that of ether. The reports regarding ether in general medical practice, as described above during the discussion of pneumatic medicine, confirm that it was one of the best known and widely used drugs in general medical practice years before its application as an anesthetic agent. As mentioned previously, sulfuric ether (perhaps more properly called diethyl ether) was first described by Ramon Lull in the thirteenth century. One of the earliest writers on ether was Valerius Cordus (1515-1544). An uncle of Cordus was an apothecary and probably introduced Valerius to sulfuric ether. A publication in which Cordus described his work involving ether was "De Artificiosis Extractionibus" which appeared in 1561 and 1571. In this work he first gave instructions for preparing sulfuric acid (sour vitriol) and described some therapeutic applications of this substance. "Sweet oil of vitriol" (sulfuric or diethyl ether) was prepared from sour oil of vitriol (sulfuric acid) and "strong very biting thrice purified wine." He explained how to separate the sweet oil of vitriol. The yield of ether from this reaction was small and the substance tended to evaporate easily. Cordus was not the first to synthesize ether but he was the first to record the method. He also described some of the physiological responses to ether such as mucus production. He proposed some therapeutic uses for ether which included all situations in which sulfur was applied. Additional uses included all body putrefactions including plague, extraction of pus and mucus from the lung in pleurisy, and other applications. Ether could be taken internally: 2-3 drops in wine.(1)

Paracelsus (ca 1493-1541) knew of the narcotic and sedative properties of ether-like preparations that he obtained either from the interaction of alcohol and sulfur, or alternatively, from Valerius Cordus during a visit to Nuremberg or

Leipzig.(2) Paracelsus clearly described ether and considered several general medicinal uses for the substance. He identified ether as anodyne and stupefacient. He administered ether to chickens and caused a temporary state of stupefaction in them. He probably selected these animals to study because of the well-known narcotic effect of hyoscyamus (henbane) upon them (an effect also called "mort aux poules").(4) He appeared to be familiar with administration of substances by inhalation but gave the ethereal substance to the chickens orally. There is some question as to the nature of the substance given to the chickens since a modern investigator established experimentally that fasting chickens would not eat feed to which ether had been added but would eat when it contained something like Hoffman's Anodyne.* Nevertheless Paracelcus is generally credited with being the first to describe the soporific properties of sulfuric ether.(5) "Aether" was named in 1730 by Frobenius and some of its properties were described. He indicated that Sir Isaac Newton had been interested in this fluid.(6) By the eighteenth century ether was extensively prescribed by a number of practitioners as discussed in the section of this volume on pneumatic medicine. Michael Morris, in 1758, described a method for manufacture of sulfuric ether which he perceived to be more reliable and safer than that described by Frobenius and proposed several medicinal applications of ether including local application in headache, toothache, earache and rheumatic pains in the neck and internal administration in whooping cough, hysteria, syncope and lethargy.(7)

In 1761 Matthew Turner, a surgeon of Liverpool published "An Account of the Extraordinary Medicinal Fluid Called Aether."(8) He indicated that he had used this substance for a considerable period in his practice. He intended to inform the public about the details of its preparation and use and to give the criteria by which genuine aether could be distinguished from a spurious product. Previous writers on aether familiar to Turner had included Robert Boyle, Isaac Newton and Frobenius. The substance was prepared by the action of vitriolic acid (sulfuric acid, H_2SO_4) on vinous spirits (primarily alcohol). It was extremely inflammable, being capable of igniting at the approach of a candle or of an electrified body.(9) It was light and very volatile; a powerful solvent and extremely cold when dropped on the hand. Clinical applications recommended by Turner were many. Aether was most useful in fits of all forms and in other nervous diseases. It was also recommended in a wide variety of arthritic, rheumatic, digestive and other types of disease.(10) For any of these complaints one teaspoon of ether could be taken internally once or twice daily. It could also be applied to the affected part or placed on a rag and inserted into the nostrils for inhalation. For deafness, aether could be instilled into the ear. As promised, directions for detecting "good" aether in terms of color,

* Many extraneous products can be obtained during preparation of ether.(3) One such mixture is Hoffman's anodyne which has rectified spirits (e.g. alcohol or brandy of some type), ethereal oil (ethyl hydrogen sulfate?) and ether.

volatility and miscibility with water were presented.(11) Turner indicated that previously the price of aether had been kept artificially high because of refusal of earlier chemists to reveal details of its preparation. He was willing to sell aether for two shillings the ounce. It is of interest that dizziness or giddiness associated with aether inhalation is never mentioned by Turner.

Many other pneumatic physicians who employed inhalations of aether did describe these sensations.

William Lewis in 1761 mentioned "dulcified spirit of vitriolic acid" (ether) in his "Materia Medica." It was made from rectified spirit of wine and vitriolic acid. He wrote that it was a curiosity and that not too much was known about its medicinal properties. Among the several therapeutic indications suggested for the substance were as a tonic, a cordial, and an anodyne. In addition, it could be rubbed on the temples to relieve headache. The dose for internal use was 3-12 drops in water.(12) John Rotheram, writing in 1797, provided directions for making sulfuric ether which he called "dulcified spirit of vitriol." Suggested medicinal uses were as a solvent and also to promote perspiration and urinary secretion, ease pain and produce sleep. Its action resembled that of Hoffman's anodyne and the dose was 80-90 drops in any convenient fluid.(13) William Withering also advocated ether inhalation in various types of pulmonary disease(14) as did Tiberius Cavallo.(15) Also, Antoine Lavoisier undertook researches on ether and proposed several medicinal uses for it.(16)

A physician who is known to have prescribed ether early in the 19th century was Dr. Woolcombe of Plymouth. His experiences with ether were chronicled by Sir Thomas Watson writing in 1871 who wondered why it had taken so long to introduce anesthesia into clinical use. Watson wrote:

> "Here, as in many other instances it is curious, how close a great discovery may be approached, and yet missed. Long before its power was used to prevent the inflicted pain of surgical operations, the vapor of aether had been successfully employed to suppress the inbred sufferings of natural disease. A former patient of mine told me this story of herself – She had been sorely tried, in her earlier years, with paroxysms of urgent dyspnoea, frequently recurring and her life was thought to be in danger. After fruitless trials of various other remedies, the following method was adopted with the happiest result (under the advice of a physician of high promise, who died young, the late Dr. Woolcombe, of Plymouth): About two teaspoonfuls of sulfuric aether were poured into a saucer, which was placed on her lap, and over which she breathed, as she sat gasping in bed, with a shawl thrown over her head to prevent the escape of the vapor. Very soon a delightful sensation of tranquillity ensued; 'she felt' (I quote her own words) 'as if going to heaven in the heavenly way' and presently she sank back unconscious. As soon as this happened, her husband the late distinguished Admiral of the Fleet, Sir

> T. Byum Martin by whom the process was managed withdrew the shawl and in a short time Lady Martin recovered breathing calmly. This mode of quieting attacks of asthma was begun in 1806.....Lady Martin survived the prediction of her early death for forty four years."(17,18)

After presenting the case history of Lady Martin, Watson remarked in a footnote, "Is there anything whereof it may be said, See, this is new?"

Ether was commonly prescribed as a "diffusible stimulus" within the context of the system of medicine of John Brown; that remarkable method of medical practice so popular among 18th and early 19th century physicians. Brown considered `diffusible stimuli' for use in 'asthenic diseases.'(19) The weakest degree of diffusible stimuli were white and red wines. The potency of these stimuli depended on whether they were dilute, full strength, or distilled to provide a higher alcohol content. Of the next order of magnitude on the stimulus scale was musk, volatile alkali and camphor which had been incompletely tried. Next came aether and strongest of all was opium. Other authors also believed that ether and opium had similar types of actions.(20)

Dr. Robert John Thornton described Dr. Townsend's method for inhaling the vapor of sulfuric ether in certain respiratory diseases:

> "The manner of inhalation is very simple. Two teaspoonfuls of aether are put into a teapot. This is held near a candle and thumb is put over the spout. When the vapor begins to press on the thumb it is transferred to the mouth, and the air is drawn into the lungs. This is to be repeated until the whole be consumed, or ease acquired."(21)

Thornton demonstrated the inflammability and explosiveness of ether when 1 drop of ether was placed in one ounce of vital air (oxygen) in a vial and ignited with a glowing match. A violent explosion occurred.(21) He also indicated that Dr. Richard Pearson was treating a chest complaint with sulfuric ether inhalations. The patient reported a sensation of giddiness after each inhalation.(22) Use of ether by Richard Pearson in his pneumatic practice of medicine was mentioned during the discussion of pneumatic medicine. He directed patients with phthisis pulmonalis to pour one or two teaspoons of pure or vitriolic aether (or vitriolic aether impregnated with cicuta) into a tea cup or wine glass and afterwards hold the same up to the mouth and draw in the vapor that arose from it until all aether is evaporated 3, 4, or 5 times a day for a month or six weeks. Alternatively, the teacup containing the ether could be placed in a small basin and in winter the cup could be placed in warm water. Then a funnel was inverted over the cup or both cup and basin and the ether was breathed with greater economy, through the stem of the funnel.

Children, and even infants, could be made to inhale the vapor by wetting a handkerchief with aether, and holding it near the nose and mouth. He described a side effect of inhalation of the aetherial tincture of cicuta* as a slight degree of sickness and giddiness, which however soon passed. Pearson was probably the first individual to describe the 'open drop' technique of administering ether which retained its popularity, at least in the United States, as long as ether anesthesia lasted.(24)

In the late 1820s William Wright, aurist (ear specialist) to Queen Charlotte wrote at length on ether and nitrous oxide in the treatment of deafness and diseases of the ear. He commented on sedative properties of the vapor of sulfuric ether. He used inhalation of ether vapor successfully to suppress a troublesome cough elicited by manipulations within an inflamed external ear canal and thus established a good claim as a discoverer of anesthesia! The work and ideas of W. Wright are extensively considered in the sections on late pneumatic medicine and early anesthetics.

The narcotic properties of ether and the reversibility of this action were clearly demonstrated during a lecture presented by Benjamin Collins Brodie (1783-1862) on Feb 5, 1821 at the Royal College of Surgeons of England. He placed a guinea pig under a bell jar into which he introduced ether vapor. After about twelve minutes the guinea pig appeared motionless and dead. The animal was revived by removing it from the vapor and by application of artificial respiration. Brodie attributed these effects to specific actions of ether — not to suffocation. He commented that he had made no experiments on nitrous oxide but that this gas also produced intoxication. He believed that there must be other gases which acted similarly. These experiments were subsequently published in his book "Physiological Researches" in 1851. At that time he wrote: "......I am however induced to record the following experiment as it derives a peculiar interest from the circumstance of the use of ether and other anesthetic agents having been lately introduced into the practice of surgery."(25)

Brodie designated ether as a narcotic poison. Perhaps this classification of ether vapor and the performance of the above described experiment in connection with a discussion of poisonous gases inhibited any consideration of practical applications of the results at that time.**(26,27)

Thomas Mitchell described the method of preparation of ether from sulfuric acid and alcohol in an 1832 publication. He noted that ether vapor was violently explosive. Sulfuric ether was used to produce cold when applied externally. He did

* Cicuta is identified as the "water hemlock." This was also an ingredient of the soporific sponge of Theodericus.(23)

** Later in his career, Sir Benjamin Brodie became interested in the role of artificial ventilation in sustaining body functions under a variety of circumstances. He suggested that an isolated but in situ heart could be kept beating indefinitely if artificial ventilation to the host were supplied. Examples were given where various poisons caused respiratory arrest but life was maintained by application of artificial ventilation. Of particular interest are many experiments with "woorara" (curare).

not believe that internal use of ether was of particular value. It was not as good a solvent as alcohol.(28)

Sir Robert Christison, a respected and authoritative forensic pathologist of his day, considered the consequences of inhaling sulfuric ether in 1836. The symptoms described for ether poisoning were virtually identical to those portrayed, presumably by Faraday, eighteen years previously. Christison described the case history of an asthmatic individual who took large quantities of ether for many years without ill effect. He also related the misadventure of a young man who was found in a chemist's establishment completely insensible from breathing air loaded with sulfuric ether and who remained "apoplectic" for some hours. He would undoubtedly have perished had he not been discovered and removed in time.(29) Some properties of sulfuric ether were considered in material on poisons in other works on medical jurisprudence. Beck and Beck, in 1835, discussed ether as a "narcotico-acrid" poison. They noted that in animals, gastric administration of ether caused vertigo, weakness and death. They then presented a quotation from page 172 of Dr. T.D. Mitchell's book on chemistry:

> "Some years ago a practice obtained among the lads of Philadelphia of inhaling the vapor of sulfuric ether by way of sport. A small quantity placed in a bladder, was almost instantly converted into vapor, by the application of hot water. By means of a tube and stop cock, the gas could be easily inhaled. In some instances, the experiment excited more playfulness and sprightly movement, but in several cases delirium, and even phrenitis was induced, which ended fatally."(30) Beck and Beck also reported an observation by Dr. Godman: "Dr. Godman has announced a curious result from the inspiration of the vapor of sulfuric ether. It produces all the effects of nitrous oxide. Its exhilarating effects were striking, but in one individual, a female, predisposed to consumption, the muscular action induced left a cough, derangement of mind, and pain. She had several attacks of violent syncope, and remained ill for some time."*

William Brande, one of Faraday's associates at the Royal Institution characterized sulfuric ether as a powerful and diffusible but transient stimulus acting upon the brain like alcohol and therefore narcotic. It was also antispasmodic. Its medical applications included intermittent fever, hysterical fits, epilepsy, cramps, and spasmodic asthma. It was of pleasant smell, pungent taste, and was highly exhilarating, producing a degree of intoxication when its vapor was inhaled by the nostrils.(32) He noted that inhalation of the vapor had been recommended, but the practice was not always safe.(33). Nitrous oxide gas had similar properties and

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*Godman's Western Reporter. vol 2, p 111: Sulfuric ether was included in the U.S. Dispensatory before 1840.

dangers. Its singular effects resembling intoxication when respired were first ascertained by Davy and should be avoided by those liable to a determination of blood to the head.(34)

The properties of ether were well known in New England in the first half of the nineteenth century. Eli Ives (1779-1861), professor of materia medica at Yale University, lectured on some general medicinal properties of ether before 1846. Ives characterized ether as the most diffusible stimulus known and stated that its use was not followed by indirect debility. The cooling action of ether when applied to the skin was noted. It was useful when poured on the scrotum for strangulated hernia and on the head for head pain. Inhalation of ether vapor was also valuable in the last stages of consumption. Ives appeared to have no idea about the central nervous system effects of ether.(35)

> "Ether is a powerful diffusible stimulant, though transient in its operation. It is also an esteemed antispasmodic and narcotic. Its vapor when breathed from a bladder in which a few teaspoonfuls have been put, produces a transient intoxication, resembling that caused by respiring nitrous oxide, but very dangerous if carried too far......In catarrhal dyspnoea, and spasmodic asthma, it may be inhaled with advantage by holding in the mouth a piece of sugar, to which a few drops of ether have been previously added...."(31)

Thus, inhalation of ether for relief of asthma preceded inhalation of ether for anesthesia.

Dr. John Collins Warren Jr. indicated that Dr. J. C. Warren Sr., one of the physicians involved in William T.G. Morton's ether demonstration in 1846, had previously used ether in Boston to relieve the distress attending the last stage of pulmonary consumption. He mentioned a letter indicating that it had been so used and that its effect in producing unconsciousness had been noted at the Massachusetts General Hospital in 1836. In this connection, Warren also referred to material on ether in the textbook on materia medica of Jonathan Pereira in common use about this time.(36) Descriptions of the soporific properties of ether were included in the extensive discussions of this drug presented in several textbooks in the early nineteenth century. One such book was the "Elements of Therapeutics" by Townsend (1801). Also, in the 'Materia Medica' published in the 1830s and 1840s, Jonathan Pereira described the effects of ether taken orally: excitement followed by depression occurred. In somewhat larger doses it produces intoxication like that caused by alcohol. In excessive doses it occasions nausea, a copious flow of saliva, giddiness and stupefaction. He then quoted, verbatim, Faraday's description of the effects of ether inhalation.(37) Chapman, in 1827, praised ether as a stimulant and an antispasmodic. He recommended it in typhus, as an enema in tetanus and applied externally.(38) Wood, in 1844, classified ether as a cerebral stimulant and discussed its effects on the brain. He described its external use and also the circumstances under which it could be inhaled.(39)

James Y. Simpson presented a historical review of early writings about anesthesia and anesthetic drugs in 1847 in connection with his introduction of chloroform into clinical practice. Among those identified by Simpson as having been involved in the early history of sulfuric ether were Lully (Lull), Hollander and Frobenius who named it in 1730. Among previous practitioners who advocated its inhalation for medicinal purposes were Cordus, Hoffman, Cullen, Alston, Lewis and Monroe. Other individuals were said to have advocated or described inhalation of ether vapor in various circumstances. Included were Pearson, Duncan, Murray, Brande, Christison, Thomson, Nysten, Barbier, Wendt, Vogt, Sundelin and others. Writers working before Simpson who emphasized the intoxicating properties of sulfuric ether were Samuel Jackson (1833), Wood and Bache (1834), and Miller (1846).(40)

Thus ether must have been very familiar to medical practitioners in the late 18th and 19th centuries. It appears that it was frequently prescribed both orally and by inhalation for a wide variety of complaints. An important step towards the introduction of clinical anesthesia was dissemination of the information that inhalation of the vapor of ether produced the same effects on consciousness, mentation and subjective sensation as the breathing of nitrous oxide gas. This announcement is generally attributed to Michael Faraday.

Michael Faraday and His Contribution

As a youth, Faraday was apprenticed to a stationer and bookbinder. This occupation gave him access to many books and he was an avid reader. He also attended scientific lectures whenever possible and performed simple scientific experiments. Despite his advantageous position he strongly wished to leave commercial trade which he regarded as "selfish and vicious." He attended several of Humphry Davy's chemical lectures at the Royal Institution and took detailed notes at these presentations. He then carefully transcribed these notes and bound them in a volume which he sent to Davy together with a request for employment in science. As a consequence of these efforts Faraday was engaged as Davy's assistant at the Royal Institution in 1812. In this capacity he assisted Davy in his laboratory experiments and at his lectures and eventually began lecturing on his own.(41)*

Faraday accompanied Davy and his wife on a European tour in 1813. Part of his duties on this trip was to serve as Davy's valet (and also as his gunbearer and

*John Tyndall, author of this article cited on the biographical details of Faraday's life was a also a well known scientist and a personal friend, and professional colleague of Michael Faraday. The "Tyndall Effect" explains the reason that the sky appears blue.

loader on hunting expeditions). Davy treated Faraday with every consideration but Mrs. Davy insisted that Faraday maintain his subordinate status and would not permit him to dine with the Davys and their company. But this trip provided Faraday with the opportunity to vastly improve his knowledge of science through frequent tutorial sessions with Davy and also, with the opportunity to meet many prominent continental scientists. He was re-engaged at the Royal Institution in 1815. On his return he became associated with William Thomas Brande, who was Davy's successor as Professor of Chemistry. This association included assisting Brande with chemical lectures delivered in the theater of the Royal Institution and also in editing the "Quarterly Journal of Science and the Arts" which began publication in 1816.(42) Faraday was a member of the Sandemanian Church and retained deep religious convictions throughout his life. In 1821 he entered a happy but childless marriage with Sarah Barnard.

Faraday soon began to publish some of his own works. Many of these from this period in his life appeared as brief anonymous communications in the "Quarterly Journal of Science and the Arts." By 1825 he was Director of the Laboratory at the Royal Institution and towards the end of 1831 he began the studies on electromagnetic induction and electrochemistry for which he is primarily remembered today.(43)

Chemical and Physical Discoveries

Faraday has been characterized as "arguably the greatest experimental scientist ever."(43) Initially, he worked with Humphry Davy on invention of the miners' safety lamp and on a method for retarding corrosion of ships. His subsequent chemical contributions included advances in metallurgy, identification of clathrates and liquefaction of several gases with enunciation of the concepts of critical temperature and critical pressure. He also studied and characterized several aromatic organic compounds. In addition, he elucidated the laws of electrolysis, the basis of electrochemistry, and conducted investigations in many other areas of chemistry. Perhaps Faraday's most striking discovery was electromagnetic induction: the phenomenon wherein changing magnetic or electromagnetic lines of force oriented about a coil of wire induce an electric current in the coil. Faraday's work in electricity and electrochemistry lay the foundation for much of the subsequent work of others in theoretical chemistry and physics, as well as the operation of many electrical and electromechanical devices, such as dynamos and electric motors, which have become indispensable in our own time.(43)

Faraday's Later Life

Faraday was a superb lecturer and certain of his public scientific lectures delivered at the Royal Institution, some of which were designed for young audiences, are still read and admired today. In 1841 he suffered an episode of physical and mental exhaustion from which he recuperated for a period in Switzerland but soon returned to London for many more years of scientific productivity. In recognition of his contributions he received a generous pension from the government and a "grace and favour"* house at Hampton Court where he died peacefully on 25 August, 1867. Michael and Sarah Faraday are buried at Highgate cemetery in London.(43)

Michael Faraday's small but important contribution to the development of anesthesia is detailed in a brief and unsigned communication published in a "miscellania" section of the "Quarterly Journal of Science and the Arts" in 1818:

> "v. Effects of Inhaling the Vapour of Sulfuric Ether. When the vapor of ether mixed with common air is inhaled, it produces effects very similar to those occasioned by nitrous oxide. A convenient mode of ascertaining the effect is obtained by introducing a tube into the upper part of a bottle containing ether and breathing through it; a stimulating effect is at first perceived at the epiglottis, but soon becomes very much diminished, a sensation of fullness is then generally felt in the head, and a succession of effects similar to those produced by nitrous oxide. By lowering the tube into the bottle, more of the ether is inhaled at each inspiration, the effect takes place more rapidly, and the sensations are more perfect in their resemblance to those of the gas. In trying the effects of the ethereal on persons who are particularly affected by nitrous oxide, the similarity of sensation produced was very unexpectedly found to have taken place. One person who always feels a depression of spirits on inhaling the gas, has a sensation of a similar kind produced by inhaling the vapor. It is necessary to use caution in making experiments of this kind. By the imprudent inspiration of ether, a gentleman was thrown into a very lethargic state, which continued with occasional periods of intermission for more than 30 hours, and a great depression of spirits; for many days the pulse was so much lowered that considerable fears were entertained for his life"(44)

No associate of Humphry Davy could have failed to become well versed in the effects of nitrous oxide inhalation. It will be recalled that, during 1799-1800 at Thomas Beddoes' Pneumatic Institution in Bristol Davy breathed nitrous oxide with enthusiasm, and sometimes to excess, and administered the gas to many others. He described its effects in great detail.(45,46) Administration and inhalation of nitrous oxide by Davy continued after his appointment to the Royal Institution in 1800. The famous 1802 cartoon by Gilray depicted his impression of a wild inhalation session at the Royal Institution, presided over by Davy, and witnessed

*Government owned living accommodations granted at the discretion of the Sovereign to worthy subjects.

by a large audience of contemporary dignitaries.(47,48) An 1806 account related that a group of distinguished men got quite drunk on the "gaseous oxyd of azote" and called it "Philosophical Brandy." It was noted that on this occasion, "Professor D—Y" acted quite silly while Count Rumford fell asleep in accord with his phlegmatic personality.(49) These activities were no doubt continued into the time of Faraday's early career at the Royal Institution and it would be no mystery how Michael Faraday learned about the effects of nitrous oxide inhalation. The means by which Farady became familiar with the properties of sulfuric ether that he described are not known. But, as discussed above, ether was a common, readily available and widely used medicinal substance in Faraday's time. Others had commented on the peculiar cerebral effects of ether which they had encountered during its medicinal use.(50)

Nitrous oxide inhalation was expensive, well beyond the means of most people. Davy had calculated that, if sufficient demand for nitrous oxide for medicinal use developed, the cost of the gas could eventually be lowered to about two pence per dose.(51) Thus, though the gas was cheap, the apparatus required to generate, store and administer nitrous oxide was very expensive. This equipment was available from the firm of Boulton and Watt of Birmingham and would have cost anywhere from about £10 for a large apparatus to £3.15 for the small portable apparatus including the necessary accessories.(52) This was at a time when a working man's family could subsist on £30-40 per year.(53) Also, considerable skill in chemical manipulation was required in preparation of nitrous oxide for inhalation in order to obtain gas of high quality free from toxic higher oxides of nitrogen.

It is not possible to say with certainty that Faraday's publication was directly responsible for the increased frivolous use of ether and the displacement of nitrous oxide by ether for this purpose which seemed to take place after about 1825. Nevertheless, the important influence of the above quoted suggestion of Michael Faraday on the eventual introduction of anesthesia was probably to make the inhalation of intoxicating vapors safer and widely available to anyone who wished to try it. Rather than invest a large sum in equipment and chemicals to embark on a hazardous experiment with nitrous oxide one merely had to purchase the desired quantity of ether from the chemist's shop. Recreational inhalation of ether became a popular pastime. The earliest administrations of ether for pain relief during surgery by Crawford Long(54) and William Clarke(55) were inspired by student "ether frolics."

ETHER: ITS RECREATIONAL USE AND ITS ABUSE

The recreational inhalation of ether and the popularity of "ether frolics" were described by several individuals. Thomas D. Mitchell wrote in 1832:

> "Some years ago, a practice obtained among the lads of Philadelphia, of inhaling the vapor of sulfuric ether, by way of sport. A small quantity, placed in a bladder, was almost instantly converted into vapor, by the application of hot water. By means of a tube and stopcock, the gas could be easily inhaled. In some instances, the experiment excited mere playfulness and sprightly movements; but in several cases delirium and even phrenitis was induced which terminated fatally."(56)

Dr. John Collins Warren Sr. is quoted as having commented on the soporific properties of ether in 1848:

> "its general properties have been known for more than a century, and the effects of its inhalation in producing exhilaration and insensibility has been understood for many years, not only by the scientific but by the young in colleges and schools, and in the shop of the apothecary who has frequently employed it for these purposes."(57)

Ether was manufactured by Soubeirain's process which was a continuous process.(58) Other instances of ether abuse were also noted. James Graham, an infamous 18th century English quack was habituated to ether inhalation. Southey is quoted as having written:

> "Graham was half-mad and his madness at last got the better of his knavery. He would madden himself with ether, run out into the streets, and strip himself to clothe the first begger he met."(59)

The activities of Dr. James Graham involving ether were confirmed by another witness, Dr. Thomas Lee, who told how he had observed Dr. James Graham sniffing ether in a Bristol drug store sometime in 1802-1803. The druggist told him that Graham would do this three times a day or so while in town and how he enjoyed the practice greatly.(60) Perhaps Graham's experiences with sulfuric ether inspired his advocacy of his quack panaceas such as "Electrical Aether" and "Nervous Aetherial Balsam" concerning which he wrote so enthusiastically.(61)

Ether (and other drugs destined to be used as anesthetics) when used as intoxicants by inhalation or drinking, have replaced or rivaled alcoholic beverages at certain times in various cultures.(62)* The practice of drinking ether to experience a brief period of intoxication arose about the time that ether anesthesia was introduced into medical practice; about 1846. Localities where this appeared to be a common occurrence included Russia, France, Norway and Britain. Ether

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* Newer anesthetic agents have had their devotees as intoxicants. Some users have even contended that these drugs had possibilities for psychic exploration similar to those now alleged for hallucinogens. Recently, addiction to anesthetics has been fairly well confined to those with access to the drugs.(62)

was readily available and was cheaper than legal alcohol. In Ireland, ether drinking was confined to counties Tyrone and Londonderry and was said to be a major problem. The practice was popular for several decades and then gradually died out owing to pressures by governments and the church as well as a general improvement in the standard of living.(63)

Nitrous Oxide

Joseph Priestley first encountered nitrous oxide in 1774 and published several chemical observations concerning this "gaseous oxyd of azote." Samuel Latham Mitchell attributed pestilential disease to presence of the gas in the atmosphere originating from decaying organic material about 1793. Humphry Davy was first attracted to a study of the properties of nitrous oxide by Mitchell's theory of contagion. Easily disproving this theory, Davy went on to perform his monumental researches, chemical and "philosophical" chiefly concerning nitrous oxide detailed elsewhere in this publication.(64) An important component of Davy's investigation included administration of the gas to himself and others. This practice quickly evolved into recreational use of nitrous oxide. Davy continued this type of activity well into his tenure at the Royal Institution. Probably most of the subsequent frivolous use of nitrous oxide was inspired by the writings and conduct of Davy. Also, nitrous oxide enjoyed a certain popularity and use in medical practice, but apparently not as extensive as that of ether.

William Allen (1770-1843), later a professor at Guy's Hospital in London, and a group of his friends experimented with nitrous oxide inhalation in 1800. Historians of Guy's Hospital subsequently described that episode:

> "It was at this time that Davy and others had made experiments with nitrous oxide gas and the effects struck them as so remarkable when it was inhaled that they called it 'laughing gas'. At the present time, when the gas is so universally administered and the effects are so well known, surprise is felt at the name then given to it but fortunately Allen has described with some detail the results on himself from which it is evident that the gas has no more title to the appellation than it has at the present time." In his diary, March 1800, Allen says,

> "Present Astely Cooper, Bradley Fox and others. We all breathed the gaseous oxide of azote. It took the surprising effect upon me abolishing completely at first all sensation; then I had the idea of being carried violently upward in a dark cavern with only a few glimmering lights. The company said that my eyes were fixed, face purple, veins in the head very large, apoplectic stertor. They were all much alarmed, but I suffered no pain and in a short time came to myself."(65)

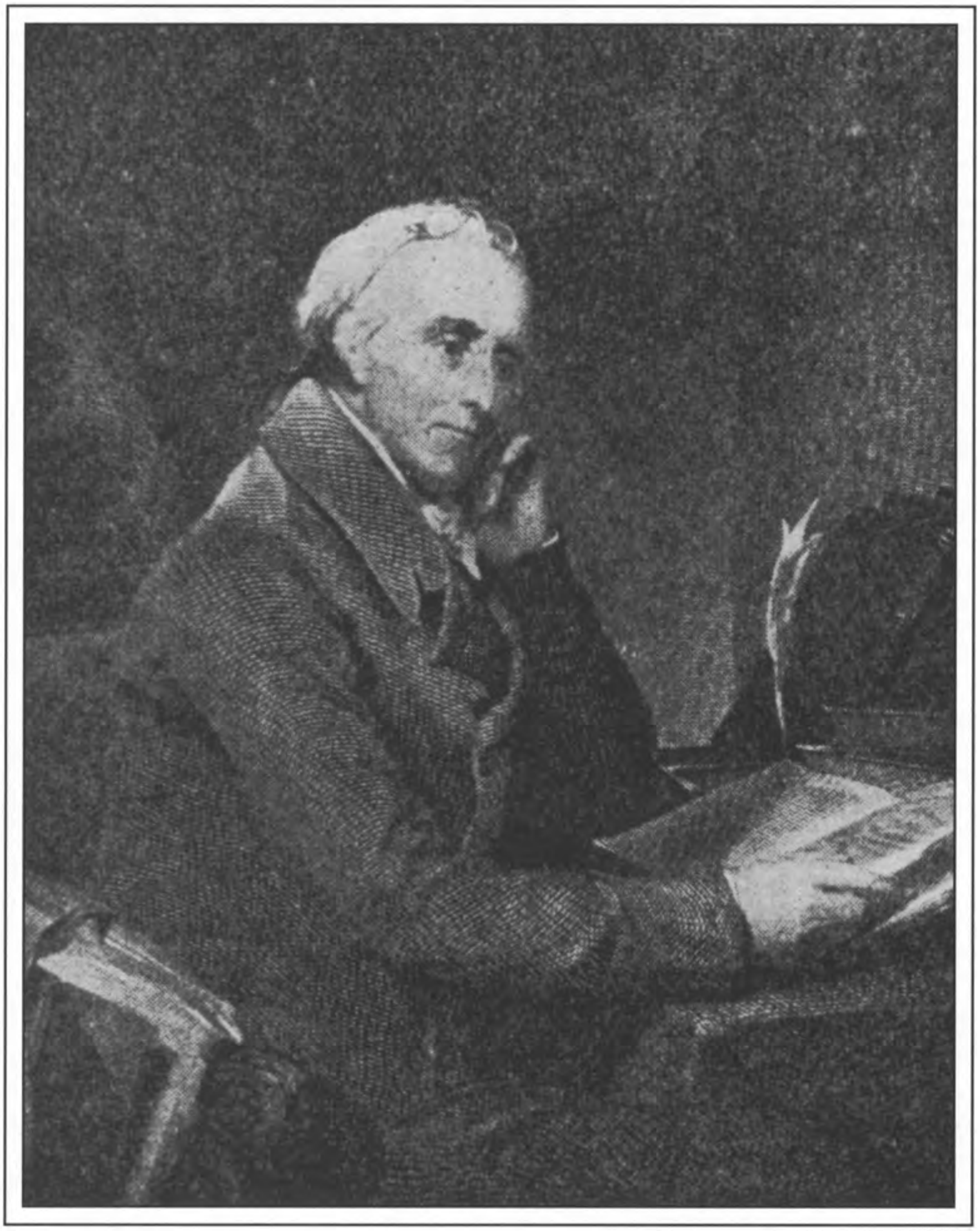

PLATE XIV — BENJAMIN RUSH (1746-1813). This signer of the Declaration of Independence was a celebrated physician in North America during both colonial times and in the early days of the new republic. He was an enthusiastic advocate of drastic bloodletting in many clinical situations. On occasion, he did painless surgery and obstetrical procedures by preliminarily bleeding patients until they fainted.

Benjamin Rush was familiar with ether, oxygen and nitrous oxide in 1801 and these gases were used as pneumatic remedies.(66) James Stodart breathed nitrous oxide on several occasions with pleasurable results about 1802. On two occasions he believed that the gas was related to improvement in the facial pain from which he suffered and speculated: "A better acquaintance with this most extraordinary agent would probably lead to important and useful discoveries."(67) When Priestley declined the chemical chair at the Medical School at the University of Pennsylvania it was awarded to James Woodhouse. Woodhouse edited a chemical textbook in 1807 in which he gave instructions for preparation of ammonium nitrate and then for evolution of nitrous oxide from this salt by gentle heating. He, in contrast to his New York City colleague Samuel Latham Mitchell, emphasized that nitrous oxide never occurred naturally but was always an artificially produced substance. By observing some of his students during their breathing of nitrous oxide, he was able to confirm Davy's results and quoted extensively from Davy's writings. He noted that nitrous oxide was capable of causing a trance.

Woodhouse entertained transient doubts about the reality of the mental changes produced by nitrous oxide. On one occasion in 1802 he generated a bad batch of gas as a result of excessive temperatures used in heating of his ammonium nitrate. Not wishing to disappoint a group who was expected at the laboratory to inhale nitrous oxide, Woodhouse substituted atmospheric air and permitted them to breathe this. The breathers of the air experienced many of the symptoms which had previously been attributed to nitrous oxide. Woodhouse, now convinced that Davy's results were due to imagination, sent an account of these happenings to Samuel Latham Mitchill, who published the material.

In this publication, Mitchill stated his revised belief, now concluding that nitrous oxide gas was entirely an "artificial thing." Nitrous oxide was made by adding nitrous (nitric) acid to volatile alkali and then gently distilling the resulting salt, nitrate of ammoniac:

HNO_3	+	NH_3	—>	NH_4NO_3	—>	N_2O	+	$2H_20$
Nitric acid		Ammonia		Ammonium nitrate		Nitrous oxide		Water

Therefore nitrous oxide was entirely synthetic and was rarely if ever found in nature. He now maintained that it was not the same as his "septic acid gas" which he had previously proposed as the cause of plague and pestilence. Mitchill wrote: "There has been a degree of credulity exercised in relating the effects wrought by 'nitrous oxyd' which is really laughable, and makes the whole subject ridiculous. . . . . "

After relating Woodhouses experiences in administering atmospheric air Mitchill continued: "But we believe these deceptions imposed upon the world about `nitrous oxyd' are now pretty well understood."(68) It appears that perhaps Mitchill harbored a degree of resentment against Davy and others who toppled his theory of contagion so easily. But in 1806 Woodhouse's belief in the validity of Davy's reports was reconfirmed following administration of pure nitrous oxide to some of his students. It was reported that Mr. Maclean fainted after three minutes of nitrous oxide breathing, Mr. Allison fainted twice, while Mr. Priloleau delivered a brief oration and then fainted. Several others simply fainted peacefully. Other partakers of the gas postured and stamped their feet. Mr. Barton (the same gentleman whose writings on nitrous oxide will be described shortly) ran about, bellowed, and assaulted the audience and would not give up the mouthpiece of the gas bag. (The same results were observed in Mr. Barton one week later). Others became belligerent and aggressive while yet others experienced no effect from nitrous oxide.(69)

Woodhouse received a letter from Benjamin Silliman (founder of Yale University Medical School) indicating that he too had investigated nitrous oxide. He had taken the gas himself, given public demonstrations of the effects of the gas, and had confirmed Davy's findings.(69,70) When Woodhouse died in 1809, work on nitrous oxide was continued by his former students mentioned above, Benjamin Silliman and William P.C. Barton. Barton (1786-1856) was a member of a prominent Philadelphia family. He is best remembered for his career as a naval surgeon and he became the first chief of the Bureau of Medicine and Surgery of the United States Navy where he advocated several reforms relating to the health of seamen and published several works on naval medicine.(71) William Barton's M.D. thesis was titled "A Dissertation on the Chymical Properties and Exhilarating Effects of Nitrous Oxide Gas; and its Application to Pneumatic Medicine," and was published in 1808. He reviewed the history of nitrous oxide, its means of preparation, its chemical properties, and some of the experiments of Silliman and Woodhouse that he had probably witnessed as a student as well as other trials of nitrous oxide which had been reported in the literature. Barton was optimistic about the possibilities for use of nitrous oxide in medical practice and concurred with Davy's conclusion that nitrous oxide was stimulant and not narcotic.(72)

Barton and his associates must have engaged in frequent nitrous oxide inhalation. He described feelings experienced by his companions during taking of the gas: 'Mr. Bryce: "these feelings produced in him by viewing the cataracts of the Nile;" Mr. Brydone: "upon surveying the burning of mount Aetna;" Abbe Spallanzini: "body sensations and state of mind upon summit of mount Aetna." Barton compared effects of nitrous oxide to those due to wine or opium. In a quotation attributed to Benjamin Rush, Barton summarized the experiences of his generation with nitrous oxide: "It would require a pen, made of a quill, plucked from an Angel's wing to describe half the pleasure arising from this source."(73) Barton described his personal perceptions during nitrous oxide breathing.(74) The physical effects were similar to those reported by Davy. He had several suggestions for the use of nitrous oxide gas in general medical practice. Conditions where it might be of service included paralysis and hemiplegia and also as a stimulant for resuscitation in states of "suspended animation" (e.g. submersion, strangulation) where it was expected to be superior to atmospheric air. It was also indicated in tetanus, typhus, and mania.(75,76,77)

Benjamin Silliman (1779-1864) founder of Yale Medical School, was another who did considerable early experimentation with nitrous oxide. He wrote in 1808:

> "Since my return from Europe, I have given the nitrous oxide a full and fair trial, and the result has been such, as to confirm in the most satisfactory manner, Mr. Davy's account of the effects of this wonderful agent. In my own case, after only two inspirations, I felt a momentary loss of distinct thought; then sensations of pure and vehement delight, tingling through every fiber of my frame, to the extremities of my toes and fingers, then, after failing in an attempt to express to my friends by articulate words, the pleasure I felt, I demonstrated it by leaping up and down, stamping on the floor, and loud convulsive laughter. One of our gravest citizens, a man of thirty eight or forty years of age, was made to caper about like a monkey, with all the extravagant gestures of a tragedian, and the grimaces of a harlequin. Some effect was produced on all who breathed the gas, and the full effect was manifested in six instances out of eight. One of these took place before many spectators, and was so marked as to banish any doubt. The reason that these experiments have not generally succeeded is, that the gas has not been employed in sufficient quantities. Six or eight quarts breathed into and out of a silk bag, will always produce the effect."(78)

Silliman subsequently explained that at Yale University, the medical class and the two senior academic classes had been in the habit of preparing nitrous oxide in conjunction with their studies of chemistry and of administering the gas to themselves. During the most recent of such experiments responses of two individuals were deemed to be worthy of publication. One individual had alternating paroxysms of mania and depression lasting for a few hours, with residual effects persisting for several days. This case history was to be a warning to those with sanguine temperaments. The second case history involved a habitually gloomy older individual in delicate health. On breathing nitrous oxide he was greatly invigorated for over a week and his personality changed to cheerful. His sense of taste was so altered that he preferred only sweet foods and for a week ate only cake and began pouring sugar and molasses on everything he ate, including meat and potatoes. This state had persisted.(79)

M. M.P. Dispan of Toulouse, in 1808, communicated the manner in which he and his scientific amateur friends of this French city generated and then inhaled nitrous oxide. They generally observed the same phenomena as others. Their difficulties in obtaining satisfactory nitrous oxide illustrated the problems which would be encountered by scientific amateurs attempting to prepare pure nitrous oxide for inhalation.(80)

William Nicholson, editor of the journal in which many of the early findings of Beddoes and Davy were published, commented on some medicinal uses of nitrous oxide gas in his chemical dictionary which appeared in 1808:

> "In the debility arising from residence in a hot climate and intense application to business, this gas has provided a complete remedy. It has given voluntary power over palsied parts while inhaled and the subsequent application of other remedies has effected a cure. Dr. Pfaff has suggested its use in melancholia but in some cases of this disease it has done no good, and in one harm."(81)

Individuals associated with the events in Boston in 1846 which resulted in the acceptance of anesthesia into clinical practice were familiar with the earlier writings on nitrous oxide. Gardner Quincy Colton appears, in his advertisements of his medicine show, to have used the words of Southey regarding "the atmosphere of the highest of all heavens etc." and it is inferred that Colton must have been familiar with previous works on nitrous oxide since the quotation occurs both in Beddoes' "Notice of Some Observations" and the review of that pamphlet in Nicholson's Journal, both of 1799. Charles Jackson had also read Davy's researches although he attempted to prove that nitrous oxide lacked effective analgesic action.(82)

In a medical dictionary that he edited and which was published in 1817, Robert Hooper wrote an entry on nitrous oxide. The entry appeared under the heading, "Nitrogen, Gazeous Oxyd of," and this material was later used to advertise the nitrous oxide performance of G.Q. Colton at which Horace Wells conceived the idea of inhalation of gas for painless dental extraction.. It was identified as a gas discovered by Priestley and investigated by a society of Dutch chemists (though not very accurately). Most of the facts used in the entry were taken from Davy's "Researches." Hooper wrote:

> "Animals, when wholly confined in gazeous oxyd of nitrogen, give no sign of uneasiness for some moments, but they soon become restless and then die. When gazeous oxyd of nitrogen is mingled with atmospheric air, and then received into the lungs it generates highly pleasurable sensations; the effects it produces on the animal system are eminently distinguished from every other chemical agent. It excites every fibre to action and rouses the faculties of the mind, inducing a state of great exhilaration, and irresistible propensity to laughter, a rapid flow of vivid ideas and unusual vigor and fitness for muscular exertions, in some respects resembling those attendant on the pleasantest period of intoxication without any subsequent languor, depression of the nervous

> energy, or disagreeable feelings; but more generally followed by vigor, and a pleasurable disposition to exertion which gradually subsides."

Hooper described some of the erroneous conclusions concerning this gas stated by certain previous writers, as well as techniques for its preparation. There was no reason to believe that this gas was formed in nature.(83)

In his chemical dictionary of 1821 Andrew Ure, in his entry on nitrogen or azote, extensively quoted Humphry Davy's writings on effects of nitrous oxide. Ure indicated that he had often verified these results upon himself and his pupils. He also commented on the immediate death of mice confined in nitrous oxide but not in certain other gases. It is interesting that there is a lengthy entry in this same 1821 chemical dictionary on sulfuric ether, but no mention of the effects of inhaling ether vapor. Little apparent advance in these areas occurred in the next few years since the entries concerning these items in the 1835 edition of Ure's dictionary are identical with those of 1821.(84)

On 9 Oct. 1888, at a meeting of the New York State Medical Association, Dr. Oliver P. Hubbard presented an episode involving accidental production of profound unconsciousness with nitrous oxide in 1821 in Rome, NY. (17) He mentioned several episodes and individuals relating to the history of anesthetics and commented upon the long interval which existed between the observation of the effects of anesthetic drugs and their applications. Hubbard then related how a German druggist from Utica came to Rome, N.Y to demonstrate nitrous oxide gas in 1821. After the exhibition closed, the druggist returned to his dressing room and found a young man lying on the floor by the gasometer, entirely senseless:

> "He had gone in stealthily, turned the stopcock, and taken his fill, and here was the legitimate result – a case of complete anesthesia, probably the first by this means ever authenticated. The alarm was great. Death seemed imminent, if not present. He was lifted with difficulty by two persons, one under each arm, and brought into the large ball room; and after long and anxious suspense, he came to his natural state unharmed. How long he had been under the influence of the gas could not be known...."(85)

Hubbard's brother, who had taken the gas that evening, as well as others present confirmed occurrence of these events.

Lectures on nitrous oxide were given at the Royal Institution by Professor William Thomas Brande in 1827. He described discovery of the gas by Priestley, its preparation in pure form by Davy, and also gave an account of the chemistry of the gas. He then considered nitrous oxide inhalation:

> "It is a very curious fact, in regard to this gas, that it may be breathed for some time and that it produces effects very analogous to intoxication,

> making persons incoherent in their talk, rambling in their walk, and so on, in the same way as if they had drunk spirituous liquors, and it has been supposed, that persons may inhale it without inconvenience; but I have seen ill effects from having inhaled it, such as pain in the head, giddiness, and so on, so that I should advise you never to do it; and I speak this, because in some of the schools of chemistry, I know that it is customary to allow the pupils to breathe it, but it is a foolish experiment, and you may be content with the statement of the facts. . . . . "(86)

William Brande (1788-1866), a noted chemist, was an acquaintance of Humphry Davy and attended his lectures. His first chemical publication was in 1805. In 1808 he was lecturing at the new Medico-Chemical School in Great Windmill Street, London, and also gave a course in materia medica. He was elected a fellow of the Royal Society in 1809 and was awarded the Copely Medal in 1812. In 1813 he succeeded Davy as professor of chemistry at the Royal Institution where he devoted himself to chemical investigations and lectures. His assistant and later associate was Michael Faraday. Together they worked in the laboratory, delivered chemical lectures and edited the "Quarterly Journal of Science and Art," the journal in which Faraday's notice on ether was published.(87)

Michael Faraday provided some technical information on the manufacture of nitrous oxide in 1819. He related that in many instances the injuries and alarming effects sometimes produced by nitrous oxide inhalation were often due to impurities in the gas. Undesirable substances included chlorine, chlorides of nitrogen and nitrogen itself. These impurities were caused by contamination of the commercial ammonium nitrate, from which nitrous oxide was generated, by ammonium chloride. This situation could be corrected by removing undesired gas from the nitrous oxide and by rejecting the first portion of the gas coming over in the distillation. Contaminated gas had an odor, and odorless gas could be breathed with safety "except by the few who experience effects apparently anomalous to those which belong to this gas."(88)

During the years 1812-1814 the faculty of the proprietary medical school in Great Windmill Street, London, included William Brande, Benjamin Brodie, and Peter Mark Roget.(89) Brande's interest and experience with nitrous oxide, as well as that of Brodie with ether have been described above. Roget, a former professional associate of Thomas Beddoes, must certainly have had considerable familiarity with therapeutic inhalation of gases. Although Brande and Brodie did not publish on nitrous oxide and ether until several years after their association at Great Windmill Street, it is not unreasonable to speculate that they, as well as Roget, may have had some early interest in inhalation of various gases. One may further speculate that, if this trio of fertile minds had jointly pursued or discussed studies in gas inhalation at this time (1812-1814), the idea of surgical anesthesia might have occurred to one of them. John Davy, brother and biographer of Sir

Humphry, succeeded W.T. Brande as a lecturer in chemistry at the Medical School in Great Windmill Street.(90)

Ryan discussed asphyxia by various gases. He wrote:

> "The cause of death is irritation of the mucous membrane of the bronchi. The nitrous oxide, or laughing gas, protoxide of azote, destroys life in this manner."

Fear of misinterpreted complications of the gas, as expressed by Ryan, might partially explain reluctance to attempt wider therapeutic applications of nitrous oxide in medicine.(91)

In an 1836 discussion of the properties of the "protoxide of nitrogen," or nitrous oxide, Robert Hare noted that the gas didn't exist in nature and that it could be liquefied. He described its preparation and furnished a diagram of the an apparatus to do this. Concerning its effects in man he wrote:

> ". . . . When respired it stimulates and then destroys life. Its effects on the human system, when breathed, are analogous to a transient, peculiar, various, and generally very vivacious ebriety. . . . "(92,93)

Robert Christison, a noted forensic pathologist, classified nitrous oxide as one of the narcotic gases and a poison in his 1836 treatise on poisons. Its pharmacological activity was described: "Frequent observation, however, has shown that it is by no means so inert when breathed by man." Christison wrote that in Davy's experience the ultimate effects were stimulatory but in many other situations depression occurred. Insensibility in certain individuals had been noted. It was believed remarkable that, unlike other stimulants, nitrous oxide did not lose its virtues under the influence of habit nor did the habitual use of it lead to any ill consequence.(94) But about this same time Beck and Beck, in their book on Medical Jurisprudence concluded:

> "Occasionally this gas [nitrous oxide] has proved injurious to persons breathing it, and there is every probability of its being harmful to such as have weak lungs. Chemists are hence unwilling to make it the subject of exhibition at the present day."(95)

Bodily harm associated with inhalation of nitrous oxide could have been due to frequent contamination of clumsily made nitrous oxide with toxic higher oxides of nitrogen.

The tradition of public chemical lectures begun by Thomas Beddoes in Bristol in the late 18th century continued in that city. William Herapath (1796-1868), a well-known chemist of Bristol gave a series of lectures on chemistry for the general public in 1836 which seemed to emphasize the domestic applications of chemistry.

As part of these lectures he gave several presentations and demonstrations involving nitrous oxide gas, which would have resembled those given by Colton in America. The audiences were greatly interested and amused. Each lecture was a sellout and had to be repeated. Ten years later Herapath was invited to the Bristol General Hospital to administer the first ether anesthetic given in Bristol. Evidently he used the same type of apparatus involving a bag and mouthpiece to administer the ether as he used ten years previously to give nitrous oxide at his lectures.(96) Johnathan Pereira administered nitrous oxide and observed the usual effects including stupefaction.(97) He also discussed "Searle's Patent Oxygenous Aerated Water." This nostrum consisted of nitrous oxide dissolved in water. Davy had drunk three pints of nitrous oxide water in a day with little effect.(98) However, the manufacturer of Searle's Water claimed that the preparation exhilierated, cured torpor etc.(99) W.D.A. Smith described several other instances of nitrous oxide inhalation in the 1820s and 1830s.(100) Thus, inhalation of both ether and nitrous oxide before 1846 was not an unusual practice. The effects of these inhalations on the body should have been familiar to a number of different individuals in many localities

Intravenous Anesthesia

Intravenous administration of various drugs to induce or maintain anesthesia has become an important technique in modern anesthesia. The injection of various substances directly into veins was apparently first recorded at Oxford University about 1656. The monumental writings of William Harvey on circulation of the blood(101) initially sparked the interest in this area and the first injection experiments were undertaken to determine the role of the circulation in the transport of substances throughout the body. The type of problem investigated related to whether substances unmodified by gastrointestinal digestion could be carried around in the body and exert their characteristic effects. Another question of interest was whether circulatory transport was responsible for rapid collapse sometimes following poisoning or bites from venomous serpents.(102)

The depressants opium and alcohol were among the first substances injected into the veins of dogs. Christopher Wren was the first to undertake such experiments with the aid of certain of his Oxford colleagues and the procedures were witnessed by others. Wren described these activities to a former associate, William Petty, in a letter probably written in 1656 but which remained unpublished until 1973:

> "....But the most considerable [experiment] I have made of late is this. I have Injected Wine and Ale into a living (sic) Dog into the Mass of Blood by a Veine, in good Quantities, till I have made him extremely drunk, but soon after he Pisseth it out: with 2 ounces of Infusion of

> Crocus Metall*: thus injected, the Dog immediately fell a Vomiting & so vomited till he died. It will be too long to tell you the Effects of Opium, Scammony** and other things that I have tried in this way: I am now in further pursuit of the Experiment, which I take to be of great concernment, and what will give great light both to the Theory and Practice of Physic."(103)

Yet other eyewitness accounts of Wren's injection experiments were provided by Robert Boyle(103,104) and Thomas Willis (See this volume; "Anesthetics of the Ancients")(105) Both were known to have been at Oxford at the time during which Wren was conducting these studies and Willis was a particularly close associate of Wren(106) Wren provided many of the illustrations for Willis' book on anatomy of the nervous system. An additional experiment was the injection of a small quantity of Crocus Metallorum into a convicted human malefactor. The above described injections would have been accomplished by surgically inserting a hollow goose quill onto which an animal bladder containing the material to be administered had been tied into a large vein, often the jugular, and then squeezing the bladder. Another use for intraveonous injection proposed was the administration of materials postmortem to emphasize blood vessels for anatomical study. It is said that Wren's injections provided the impetus for some of the early attempts at blood transfusion by Lower and others,(107) but other historians claim that transfusions were tried before Wren's studies(108) and that the first transfusions were from man to man.(109) (History of blood transfusion is beyond the scope of the present volume). Robert Boyle kept one of the early dogs that survived injection experiments as a pet and subsequently complained that someone had stolen the animal. Another investigator working with intravenous injection about this time was Daniel Major of Keil, Germany who published details of his work about 1664. Major injected opium into the veins of a dog and subsequently was able to place needles in the animal's tongue without reaction. This experiment appears to be the first demonstration of intravenous anesthesia. He also tried various other substances given intravenously.(108)

Another investigator writing about intravenous injection around the mid 17th century was J. Sigismund Elsholtz, physician to the Elector of Brandenburg. His book, "Clysmatica Nova," or the new clysmatics was in large part inspired by the previous work of Harvey. This volume, which appeared in 1665, summarized Elsholtz's observations on the circulation and the effects of injections directly into the bloodstream. He regarded these procedures as closely related to enemas or clysters; hence the designation of intravenous injection as clysmatics. He related how, in a cadaver, he had opened the axillary artery and injected water. The veins

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* Crocus metallorum - Impure anitmony sulfoxide used as an emetic in the 17th century.

** Scammony - Material of vegetable origin used as a purgative in the 17th century.

of the arm subsequentially distended and water flowed out of an opening in the median vein. He recognized that he had confirmed the circular nature of blood flow and also the presence of valves in veins and concluded that substances injected into veins would eventually reach the heart. He tested the safety of the method by injecting water and then wine into the femoral vein of a dog. Intravenous injection of opium in a dog caused a moderately profound stupor of about one and a half days duration, during which the animal had a noticeably diminished response to pinprick. Other common materials were also given to dogs.

Next came human trials on volunteer soldiers into whom substances such as Galenical balsamic substances or antifebrile preparations were given by vein. Elsholtz concluded that this mode of therapy was potentially valuable and much more easily accomplished in man than in dogs. He believed that this technique for medicating sick patients in certain circumstances was worthy of further investigation and he presented a list of complaints for which intravenous therapy might be particularly suitable. The method would be in accord with one of the teachings of Hippocrates that the most direct passage to the seat of illness was the most appropriate.(110,111)

Further descriptions of Wren's injection experiments of 1656 appeared in "Physiological Transactions" in 1665-1666 and in 1668. These followed publication of the work of Major and Elsholtz and were possibly intended to remind readers of English priority for intravenous infusion. The first of these articles appeared anonymously, but is attributed to Henry Oldenburg (1618-1677). He was one of the secretaries of the Royal Society and an editor of "Philosophical Transactions." Although Oldenburg was not formally trained in science, he became well informed and competent through lifelong association with the foremost men of science of his time. He is remembered today chiefly for his correspondence, writing, and organizational activities(112) Oldenburg wrote:

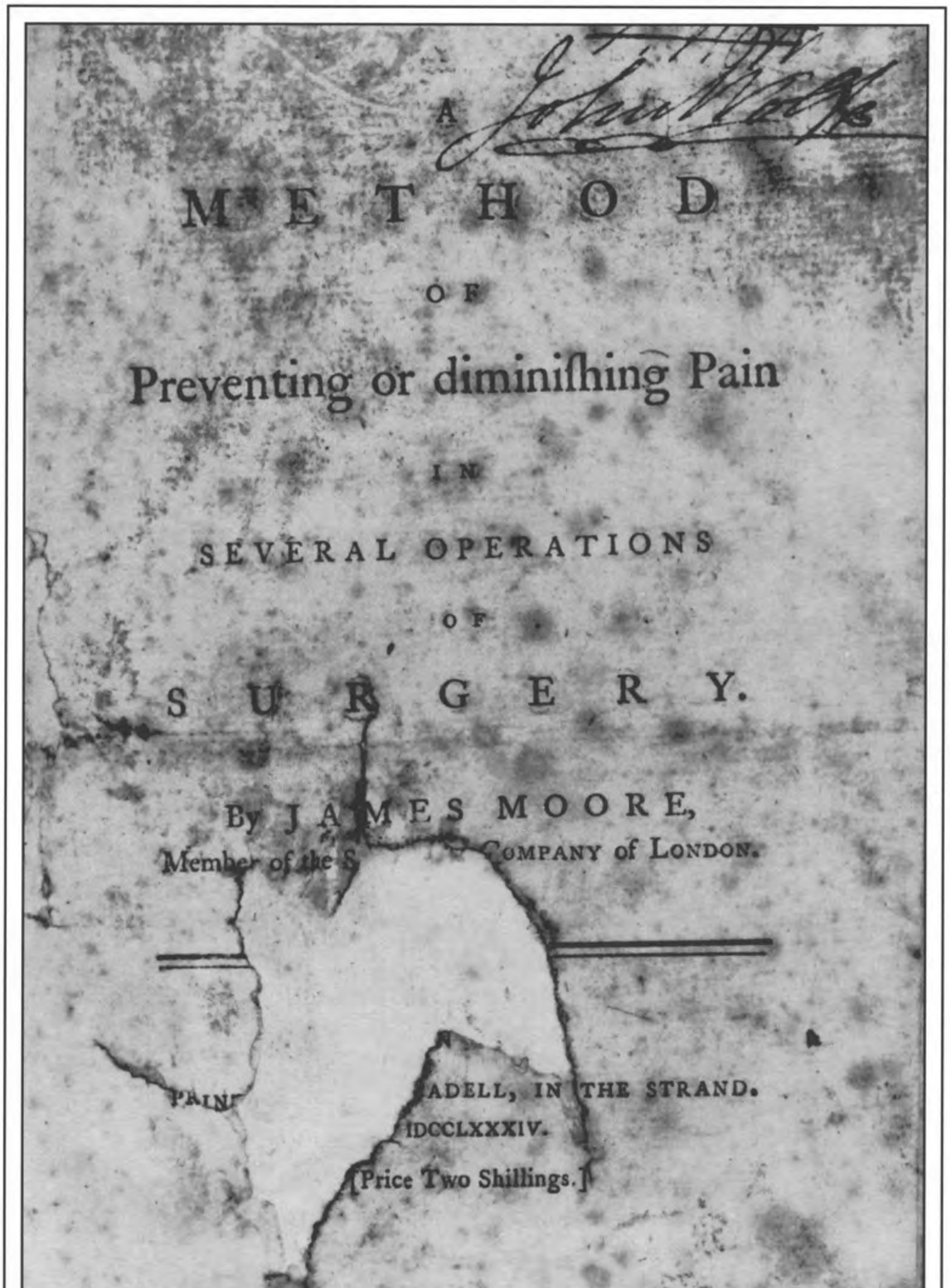
> ".....he thought, he could easily contrive a way to convey any liquid thing immediately to the mass of blood; videl: by making ligatures on the veins and then opening them on the side of the ligature towards the heart, and by putting into them slender syringes of quills, fastened to bladders (in the manner of clyster-pipes) containing the matter to be injected; performing that operation on pretty big and lean dogges, that the vessels might be large enough and easily accessible."(113)

In 1668 Dr. Timothy Clark, a scientist who performed a number of injection experiments of his own confirmed that Christopher Wren first infused a variety of liquors into the mass of the blood of living animals.(114) Samuel Pepys witnessed an injection of opium by Clarke into a dog which killed the animal. Following these initial observations on intravenous injection and the brief flurry of interest in this area about the middle of the 17th century the topic attracted little attention, except for sporadic and isolated attempts to treat disease with medicated injections, until several 19th century workers wrote on the subject.(114a)

In 1831 M. Dupuy of Alfort, France, director of the Veterinary Medicine School at Toulouse, injected various substances into the jugular veins of horses. He described the effect of alcohol injection:

> "A deciliter of alcohol was injected into the jugular vein of another horse and produced the following effects: – The animal tottered, his head quickly fell, and he presented all the appearances of intoxication, which continued about an hour. During this time, the circulation and respiration were very frequent; the expired air smelt strongly of alcohol; the conjunctiva and mucous membrane of the nose and mouth were injected and of a red color; the skin was very hot, and the several secretions increased. All the muscular movements were feeble and uncertain, the limbs bent beneath the weight of the body, and the animal seemed entirely devoid of strength."(115,116)

Injection of ammonium carbonate intravenously in another horse promptly reversed the state of inebriation in the animal. Other substances were also injected. Clinical intravenous anesthesia was introduced by Pierre-Cyprien Oré in 1875 using injections of chloral hydrate.(117)



A

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OF

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IN

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OF

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Plate XV — The Title Page from James Moore's 1784 book. This volume appears to be the first book dealing exclusively with anesthesia.

Chapter XVII

Anesthetic Techniques

Before 1846

The characterization of the era before 1846 as an absolute "age of agony" where the surgical patient had no choice but to submit and bear the suffering is not completely accurate. A few surgical procedures are known to have been done painlessly in the era before the introduction of modern anesthetic agents. Many methods then used for anesthesia would be unfamiliar to a modern practitioner. Most techniques employed to produce insensibility during surgery in those bygone days were cumbersome or had a significant potential to cause serious damage to the body and thus would be inapplicable in modern anesthetic practice. Nevertheless, it is difficult to conceive of a patient's declining the offered primitive anesthesia on those rare occasions when it was proposed if the alternative is considered. The subjective feelings of the patient were not the only reason to think about diminishing pain during surgery or labor and delivery. Some physicians believed that pain itself could be a cause of death if severe and protracted. Gamble presented several case histories, such as that of prolonged labor in the presence of a large uterine tumor or of a perforated ulcer, where he perceived that nothing more than pain caused the patient's demise. He speculated on possible mechanisms involved and observed that death from pain could occur in prolonged operations.(1) Simpson also discussed the contribution of pain to morbidity and mortality in surgical practice.(2)

Some of the individuals involved in these early anesthetics and the methods that they used will now be considered. In the light of modern clinical knowledge and experience these methods, in contradistinction to the soporofic sponges and similar concoctions of yet earlier days, are likely to have been partially or completely effective in abolishing operative pain.

Anesthesia by Nerve Compression

James Moore (1763-1834), a surgeon of London, had a concern for relieving operative pain and an intuitive insight into the need and potential for applying anesthesia to surgery far beyond any other man of his age. His book, "A Method of Preventing or Diminishing Pain in Several Operations of Surgery" (1784), appears to be the first published volume dealing exclusively with anesthesia. He was of a distinguished family and his brother was Lt. General Sir John Moore, a noted military commander. For a time, James Moore served as a military surgeon. He was a friend of Edward Jenner and also worked in the area of vaccination against smallpox. He had wide interests in medicine and chemistry and wrote many general medical works.(3) Moore complained that physicians had been accused of lacking feeling for patients who were suffering and that surgeons had been blamed for being cruel. He discussed these accusations and concluded that these alleged attitudes were in reality states of mind or appearance assumed by the practitioners which had to be adopted in order to permit individuals to pursue their professions successfully.

He continued, and proposed that the advantage of the art of medicine was that it was less painful but that surgery was more certain. He wrote:

> "Cruelty cannot with justice be imputed to an art which preserves the lives of many; and, by transient and temporary pains saves many more from years of torture."

Surgeons will avoid inflicting unnecessary pain both at operation and at subsequent dressings. Moore continued:

> "...humanity of disposition when joined to knowledge and steadiness tend to render a surgeon not only more agreeable but more successful in his practice."(4)

Moore then traced developments in surgery that contributed to patient comfort over the ages. The first discovery in surgery probably was that it was proper to keep a wounded limb quiet without motion. Another early observation was probably that cold aggravated pain of various conditions. Therefore wounds would frequently be covered with leaves and these leaves acquired a reputation as healing agents when in reality they had nothing to do with healing of lesions. This sequence of events might explain the evolution of salves and other materials applied to wounds. According to Moore, the next advance was probably related to invention of cutting instruments. It was observed how enlarging a wound to facilitate the removal of arrows or other missiles facilitated healing and this principle was carried over to other types of lesions such as sinuses where no foreign object was present. Excessively painful devices such as actual cautery and scissors were abandoned.

Nevertheless, after every improvement of the instruments and of the manner of operating an inordinate degree of pain still remained in surgical operations. Moore continued:

> "An obvious means of dulling and diminishing this was early tried by giving anodynes internally, some time before he [the patient] underwent an operation. Opium is the most powerful of this class of drugs, and a moderate dose is highly expedient to abate the smarting of the wound after the operation is over, and to induce sleep; but the strongest dose we dare venture to give has little or no effect in mitigating the suffering of the patient during the operation." .... "...what can diminish acuteness of the pain without increasing the danger is also an improvement very much wished."(5)

He pointed out that those who said: "what is a few minutes of pain?" are not usually those who are about to undergo surgical operations.

Moore identified sensation with nerves. He discussed and rejected the possibility of preliminary severance of nerves at surgery and suggested that perhaps compression of nerves might be useful. Then he related the succession of experiments which he had done leading to the conclusion that if, by means of separate compression pads, he applied pressure to sciatic, obturator and crural nerves he could produce numbness of the entire leg. The apprehension about stopping the circulation for long periods led to the fabrication of a type of C-clamp device for compressing the nerves. Instruction for locating the nerves was provided. The sciatic nerve was located by means of a line drawn between the ischial tuberosity and the greater trochanter while the crural (femoral) nerve was located with reference to the crural artery. The plexus in the axilla was located with reference to pulsation of the humeral artery. (These methods for locating nerves to the lower and upper extremities are similar to those which are used by modern anesthesiologists performing nerve blocks with local anesthetic drugs). Marked collateral circulation in the leg is present and requires use of a tourniquet in addition to a compressor. With the compressor some sensation was retained above the knee.(6) Moore then described how this nerve compression technique was used successfully in a patient having a below-knee amputation at St. George's Hospital, London. The surgeon on this occasion was John Hunter.(7) Moore wrote:

> "The trial had all the success I expected; there was evidently a most remarkable diminution of pain particularly during the first incisions through the skin and muscles, which are generally by far the most severe parts of the operation. And I am convinced that what pain the patient felt, was chiefly owing to some small branches of the lumbar nerves which extend below the knee, and were not compressed."(8)

A few technical details for using the compressors were provided. In patients having above-knee amputations, Moore advised early application of the tourniquet to compress whatever nerves might have escaped the compression provided by the pads on his device. Benefits of this compression method at surgery included not only pain relief but also capability to use better, technically improved, and more extensive operations and also to conduct examinations and search for foreign bodies at surgery. Moore submitted this monograph to the public after only experiments on himself and trial on just one patient so that it could be used and tested more widely. Leake believed that John Hunter demonstrated that the plan was impractical.(9) Keys stated that John Hunter tried the method with partial success.(10) Agnew also stated that Hunter employed Moore's technique and that, "The limb was amputated while thus constricted and, it is said, with only a trifling degree of suffering."(11) Thus, it is not possible to be certain how well the method of nerve compression would have worked in practice, and it appears that the technique was subsequently ignored, but the ideas and concepts expressed by Moore leave little doubt that he truly appreciated the concept of anesthesia and tried to do something about the problem of operative pain. Sykes confirmed Moore's clinical trial and wondered why the method was not evaluated further.(12,13)

There were other primitive attempts to practice anesthesia by nerve compression. John Snow related how Dr. Liégard of Caen described the practice of peasants in tying bands tightly around extremities before operation to diminish subsequent pain.(14)

The capability of a constriction applied in this manner to diminish or abolish sensation in a limb must have been fairly common knowledge. Edmund Scot, writing about 1602, attributed the ability of a certain individual to withstand torture, such as avulsion of the fingernails without reacting to the pain, to the circumstance that "his hands and legs had been nummed by tying."(15)

ANESTHESIA BY DEADLY INTOXICATION

Offering a patient a few swallows of rum or whiskey before a surgical operation in bygone days was indeed a feeble measure to render pain more bearable. Contemporary testimony confirms that means such as this were quite ineffective. Any state approaching real anesthesia produced with alcohol was likely, in many cases, to be accompanied by potentially lethal depression of body functions far beyond the capability of old time practitioners to manage. Death associated with rapid consumption of a large quantity of alcohol is all too well known in modern medical practice. An exceptionally strong constitution would be required to survive such an attempt. Nevertheless, some surgical procedures were accomplished during deadly intoxication with alcohol. One such anesthetic, administered in 1818, was conducted with prodigious quantities of alcohol in a patient with a dislocated shoulder. The attending physician, Dr. Simeon A. Dudley of Winchester, Kentucky, described the necessity for producing profound relaxation for reduction of dislocations. The author of the following case report suggested that a number of measures including a blow to the stomach, ingestion of certain vegetable poisons etc. could be applied by the "intrepid and judicious practitioner" for practical use, but in this case alcohol was selected. On Oct 1, 1818 a laborer about 30 years of age and of intemperate habits experienced a luxation downwards of the humerus. Immediate attempts at reduction were unsuccessful. About 8 weeks later the standard remedies of the day such as long continued nausea, blood letting, warm baths etc. were applied without success. It was resolved to try "deadly intoxication":

> "A copious potation of rum, brandy, whiskey and gin was given and by 10 o'clock three pints had failed to produce the desired effect or even any approach toward intoxication."

Another half-pint of a mixture of equal parts rum and whiskey was administered. A few minutes later:

> "the patient's whole energy suddenly deserted him and he fell as if pierced by a bullet or stricken by a flash of lightening. His stupor and insensibility were deep and alarming, far beyond what the spectators had ever witnessed as the effect of liquor."

Then the strength of six men succeeded in effecting reduction of the dislocation. However the patient appeared to be in extremis with unconsciousness, respiratory depression, impalpable pulses and clammy and cadaverous skin. Swallowing was now impractical and injections seemed inadvisable. External applications were alone employed. These included boiling water applied to the feet and ankles without effect. After 10 hours, however, he began to revive and in 20 hours he was able to ride the ten miles home on horseback and in 3 weeks he had returned to work. It is recorded that the patient was ever after cured of his intemperate alcoholic intake and developed a dislike for strong drink.(16,17)

Dorsey recommended intoxication as an alternative in reduction of dislocations when exsanguination for production of unconsciousness (see below) was not applicable.(18) He described the case history of a young lady with a dislocated jaw which had defied all previous attempts at reduction:

> "...her molar teeth being almost carious prevented any violent efforts upon them with a wooden lever. Her extreme debility and dropsical habit precluded bloodletting and I suggested to Dr. Physick the propriety of trying the nauseating effects of tobacco. She refused this, however, and the Dr. next proposed to give her as much ardent spirit, as should occasion intoxication. She consented and became perfectly

> inebriated, during which time the measures which had been before unavailing, very promptly succeeded in effecting the reduction."(19)

ANESTHESIA BY EXSANGUINATION

The circulatory response to withdrawal of a large quantity of the patient's blood includes a marked reduction in the volume of circulation to the brain. Following a copious hemorrhage, fainting ensues as a consequence of the cerebral bloodlessness. This period of unconsciousness induced by removal of a considerable fraction of the patient's blood volume was used to perform surgical procedures in past eras. (Bloodletting in general medical practice was considered in the discussion of medicine of the 18th century). Physicians in earlier times were familiar with the consequences of blood loss and were quite accustomed to withdrawing blood from the body; sometimes in alarming quantities.

Wardrop, writing in 1819, suggested some means by which surgery could sometimes be accomplished in patients with "irritable minds." Many such subjects totally disrupted operative procedures by wresting themselves away from surgeons and attendants. In this circumstance, children could be managed by "enclosing all the body, excepting the part to be operated on, either in a bag or wooden box." Adults could be bound hand and foot and restrained, but this was frequently unbearably distressing. The case history of a robust young woman with a tumor about the eye was presented. Several attempts at surgery were made but each time she managed to free herself from the restraints. On a subsequent occasion, she was seated in a warm room and 50 ounces of blood were taken from an open vein. The subsequent syncope lasted long enough to permit removal of the tumor. She awakened without having experienced any discomfort. She remained pale and feeble for a few days but soon recovered better than most patients. The author suggested that the more blood lost during surgery, the better is the recovery and that in urgent circumstances this method may be ventured upon fearlessly!(20)

Wardrop again proposed bloodletting as a method of pain relief during surgery in 1833. He substantiated the testimony of his contemporaries that large doses of opium (i.e. laudanum) in quantities greater than 40-50 drops frequently given in an attempt to mitigate operative pain was often quite ineffective. He proposed that since many patients suffer syncope as a result of the operation, might it not be advantageous to induce this state initially to minimize the pain? He further rationalized exsanguination for anesthesia by reiterating his previously stated observation that the more blood lost during surgery the more benign the recovery. Was this not a good reason for inducing syncope? Wardrop wrote:

> "In the reduction of dislocations and of herniae, it is a common rule of surgery to produce syncope before an attempt is made at reduction,

> either of the misplaced bone or of the prolapsed intestine; and why should not the same practice be adopted in order to save the pain of operation?"(21)

Apparently then, at least in some surgical situations, attempts to render patients unconscious before proceeding with operations may have been routine in the early 19th century but the motive for this was not always simply mitigation of operative pain. Exsanguination was perceived as an effective, safe method of producing syncope. An ingenious method of inducing syncope was said to have been suggested by Dr. James Arnott in his *Elements of Physics*:

> "...inclose one or both limbs in a bag or box, from which the air is to be exhausted by an air pump, and thus, the pressure of the atmosphere being removed from the vessels of the limb so inclosed, such an increased flow of blood would take place into the limb as would produce a state of fainting, by occasioning a corresponding diminution in the quantity of blood in the brain."(21)

Additional advantages of inducing syncope before surgery would include a bloodless operating field.(21)

John Syng Dorsey discussed methods to overcome the muscle contraction which opposed attempts to reduce dislocated shoulders. When simple measures such as distracting the patient's attention or inducing fatigue in the opposing muscles failed more drastic alternate methods were suggested. Dorsey wrote:

> "Dr Physick many years ago employed copious blood letting with this view. He bled the patient till fainting was produced, and during his continuance in a state of syncope all muscular action being suspended the reduction was readily accomplished. In a great number of instances which have since occurred, the practice has been found completely successful. There are several writers who recommend bleeding to diminish the action of the muscles in obstinate luxations, but none (so far as I know) who propose bleeding ad deliquium animi, except Dr. A. Monro Sen, who suggested in his lectures on surgery copious bloodletting from one or both arms in an erect posture as a probable means of facilitating the reduction of dislocations; but Dr. Physick I believe was the first who had the boldness to carry the practice to the extent necessary for complete success."

That technique had been found successful since and several other writers had recommended it. The first case in which this technique succeeded was said to be a luxated humerus which had resisted every other attempt and a great degree of force. But during the faintness stage produced by exsanguination, "the hands of the operator were the only means employed and in a single moment without the slightest difficulty he replaced the head of the bone in its socket."(22,18) The effects of blood-letting "ad deliquium animi" (to failure of life) in facilitating the reduction of dislocated bones had been very strikingly exemplified in several chronic luxations. A case history involving a 35 year old seaman was presented. He had dislocated his shoulder and it had resisted attempts at reduction for between five and six months. He was bled of nearly five pounds of blood before fainting could be produced. Once this occurred, however, the shoulder was reduced with comparative ease. The erect posture for bleeding of the patient was preferred as being most favorable to the production of syncope.(23)

The redoubtable Phillip Syng Physick of Philadelphia, who was graduated M.D. from Edinburgh in 1792, was John Syng Dorsey's uncle. As noted above, it was Physick's custom to bleed a patient with a chronic joint dislocation from the veins of both forearms in the erect posture until he collapsed on the floor. At this point the patient was insensitive to pain and completely relaxed. The dislocation could then be reduced.(24) Thus Dorsey, as an enthusiastic advocate of exsangunation, was merely following in the family tradition. Alternate means of relaxing muscles when bloodletting was inapplicable were suggested. These included nauseating doses of emetics or a tobacco clyster.(18) Copious bleeding, long known to reduce muscle tonus, was proposed by Monro II of Edinburgh as a means to facilitate reduction of luxations. In his lectures as early as 1774 Monro II had advised blood letting "in a large stream, the patient standing.... to bring on langour and faintness, when the surgeon [would] begin to attempt ye reduction."(24)

Astley Cooper (1822) endorsed phlebotomy as the "most powerful" remedy for reducing dislocations.(24) Cooper recognized that it was the power of the muscles that resisted attempts at reduction of dislocations and had to be overcome by one means or another. He wrote:

> "The constitutional means to be employed for the purpose of reduction, are those which produce a tendency to syncope, and this necessary state may be best induced by one or other of the following means, viz: by bleeding, warm bath and nausea. Of these remedies I consider bleeding the most powerful; and that the effect may be produced as quickly as possible, the blood should be drawn from a large orifice, and the patient kept in the erect posture, for by this method of depletion, syncope is produced before so large a quantity of blood as might injure the patient is lost; however, the activity of this practice must be regulated by the constitution of the person, for as the accident happens to all the varieties of constitution, it must not be laid down as a general rule; but when a patient is young, athletic, and muscular the quantity removed should be considerable, and the method of taking it away, that which I have described."(25)

A warm bath of 100° or 110° could be employed either alone or after bleeding to aid in producing syncope. Antimony tartrate could be administered orally to cause nausea with or without vomiting. This would sustain the syncopal state produced by the bleeding and the warm bath and thus assist in overcoming tone of muscles. Perhaps large doses of opiates might be of value. In other patients, mental distraction and direction of the patient's attention to other muscle groups might be of value during reduction of dislocations. The patient could be requested to perform other motor tasks, such as raising an arm or a leg, while reduction was being attempted.(26)

Several case histories were presented. A 22 year old patient underwent successful reduction of the hip after a warm bath, a phlebotomy of 24 ounces of blood, opium and antimony tartrate. A healthy 33 year old had a phlebotomy of 60 ounces (without production of syncope) for reduction of a hip. In a 50 year old with a dislocated hip a 34 ounce phlebotomy, a warm bath and antimony tartrate produced syncope and the hip was easily reduced.(27)

Judging from the number of surgical textbooks or manuals which recommended bloodletting as a method for causing unconsciousness and providing muscle relaxation for reducing dislocations, it must be inferred that knowledge of this technique was widespread and frequently used. Samuel Cooper wrote: "The practice of copious bleeding in cases of obstinate luxations was first employed in this city by Dr. Physick with the happiest effect. It has since been adopted by many practitioners and has proved a valuable remedy. Dr. Monro recommended it, in his lectures many years ago."(28)

Another advocate of bloodletting in reduction of dislocations was William Gibson. He wrote in 1825:

> "Constitutional as well as local means are generally necessary in the reduction of dislocated bones. The former indeed, often exert greater influence over the action of muscles, the chief impediment to reduction, than any mechanical force, however powerful, that can be employed. The most efficient remedies of this description are blood-letting ad deliquium animi, the warm bath, nauseating emetics, intoxication & c. Of these blood letting is decidedly the most powerful. The practice is said to have been first suggested by Monro, but was never until the time of Dr. Physick carried to an extent necessary for complete success...."(29)

The several case histories and quotations presented above demonstrate that the concept of the anesthetic state, though in these instances produced quite crudely, was not completely foreign to medical practitioners before the 1840's. Some years later, well after the introduction of chemical anesthesia, Agnew remarked on the precariousness of copious bleeding to provide anesthesia:

> "But the adoption of such a degree of depletion for the object contemplated is too hazardous to be entertained for a moment by any sensible person."(30)

EXSANGUINATION FOR OBSTETRICAL ANESTHESIA

Another indication for the induction of syncope by exsanguination was as an analgesic technique during complicated labor and delivery. The patient was often bled to the point of fainting and then the painful labor could be continued or obstetric maneuvers such as version and extraction could be accomplished during the ensuing unconsciousness. Bloodletting in obstetrics became popular once the physician began replacing the midwife in many situations.(31) It will become apparent that the arguments and rationale for the propriety of providing pain relief during childbirth did not begin with the introduction of inhalation anesthesia into obstetrics in the 1840's.

A zealous advocate of exsanguination in obstetrics was Benjamin Rush, a true enthusiast of bloodletting. His biography was briefly narrated in the section on famous 18th century physicians. Rush did not consider that pain in childbirth was inevitable. He cited the manner in which women in many other civilizations gave birth with minimal discomfort and disruption of their daily routine. He had concluded that the biblical curse condemning womankind to suffer during labor could operate selectively, and also that the other part of the sentence was not universally applied since many men did not live by the sweat of their brows.(32) Rush stated several assumptions upon which he based his obstetrical practice. The female system at term was believed to be plethoric . He regarded pregnancy as a disease in which nature exhibited certain perceived excesses or deficiencies and required help to bring delivery to a successful termination. Labor, then, should be treated like any other convulsive or spasmodic disease.(32) Rush initially got the idea of using bleeding in labor while watching Dr. Physick reduce a dislocation in 1791, and he noted that others practiced this technique during labor also. About 1795 he had concluded that since bloodletting was so relieving in spasmodic and painful diseases, it should also be of value in parturition. This was not a new or exclusive idea and had been practiced by Dr. Dewees who advocated withdrawing 20-80 ounces of blood until fainting occurred in difficult labor. But this practice was not universally applicable and certain restrictions were noted.(33) Bleeding was regarded as a depletive measure expected to convert a morbid reaction into a natural one.

Rush observed that labors in women with chronic diseases tended to be short and easy. He advised use of opium in some circumstances. He reported the case history of a lady painlessly delivered during an epileptic seizure.(32) Other material dated from about 1806 also advocated the extreme blood letting, as proposed by

Benjamin Rush, to produce syncope for surgical interventions.(34) But Dr. Rush expressed higher expectations for the future of obstetrical anesthesia. He wrote:

> "I have expressed a hope in another place (Medical Repository, volume 6) that a medicine would be discovered that should suspend sensibility altogether, and leave irritability, or the powers of motion, unimpaired, and thereby destroy labor pains altogether. I was encouraged to cherish this hope, by having known delivery to take place, in one instance, during a paroxysm of epilepsy, and having heard of another, during a fit of drunkenness, in a woman attended by Dr. Church, in both of which there was neither consciousness, nor recollection of pain."(35)

Another early 19th century advocate of bloodletting during labor was Peter Miller (1773-1848). He too concluded that pain in labor was not inevitable since many women in certain other cultures deliver relatively painlessly. In many cases, failure of relaxation of the soft parts of the birth canal was an impediment to delivery. The use of opium to assist in relaxation might be associated with dangerous overdose and warm baths were probably of limited value. Miller listed the complications of waiting for nature to take its course in labor as ruptured uterus, vesico-vaginal fistula, cervical laceration, etc. As a consequence of suboptimal life styles, a "plethoric disposition" develops in pregnant women and this is the basis for the above named obstetrical complications. Means to manage this problem included proper diet, adequate exercise, laxatives and other medicines. At term, bloodletting and nauseating doses of emetics could be used. Miller advocated bloodletting for relief of pain in labor. This technique first proposed by Rush in 1803, as described above, was a valuable measure. A relatively large volume of blood could be withdrawn, but it was not necessary to bleed to the point of fainting. Soft parts of the birth canal would relax adequately even if syncope did not occur. A bleed of more than 20 ounces was generally indicated but sometimes up to 40 ounces of blood had to be withdrawn. This measure could be used at any stage of labor and would minimize obstetrical complications.(36)

Dr. William Dewees commented on opinions advanced by a certain Dr. Osburn who believed that pain in labor was inevitable because of presence of extraordinarily developed supporting structures and peculiarities of pelvic structure that nature had provided to human females as opposed to quadrupeds. This configuration of the pelvis was required because of human erect posture and permitted them to retain the fetus until term. In addition, Osburn believed in the divine curse relating to the pain of childbirth. But Dr. Dewees argued that the relevant pelvic anatomical structure of "brutes" was not that much different from that of humans. In addition he maintained that the scriptural quotation "In sorrow shalt thou bring forth children" (Genesis 3.15) referred to the state of the mother's mind regarding maternal and child outcome of labor and early life in those uncertain times. The pain was not a punishment but rather the result of civilization and refinement. "Savage" women delivered easily. Dewees believed that pain was the result of an artificial and in part remediable life style and habits related to refinement and civilization. Pain in labor did not necessarily depend of rigidity and failure to relax. It was the consequence of a systemic disease and the "inflammatory action" of the uterus could be helped by bloodletting.(37)

Dewees's measures for pain relief in labor were based solidly on his perception of the physiology of uterine contraction. He, too, noted that opium never relaxed the uterus and may stop labor. Warm baths were of no value. Bloodletting, on the other hand, diminished pain, disposed the os uteri to dilate, the external parts to unfold and cicatrices to yield. He first got the idea of bloodletting in delivery while attending a lady who had been placed in a state of debility following a massive hemoptysis. Dewees presented a number of illustrative case histories featuring bloodletting dating from the 1790's. Bleeding was useful to quiet "premature commotion" of the uterus. In desperate situations bleeding "ad deliquium animi" could be used. His regular practice was to remove 30-40 ounces (900-1200 ml) of blood from an arm vein with the parturient standing erect to the point where she fainted. After being returned to bed the patient was often unaware that the child had been born. Bleeding in the erect position was preferred because withdrawal of a smaller volume of blood was required to produce the desired state of syncope than with the patient supine.(38,31) In a subsequent 1824 textbook by Dewees he casually mentioned bloodletting during labor but little else concerning this subject is touched upon.(39) There were other indications for bloodletting in obstetrical practice including obstetrical hemorrhage.(31)

ANESTHESIA BY PHYSICAL METHODS

James Simpson, writing in 1847, stated that the idea for painless operations was actually quite old. He illustrated his point by citing application of pressure on peripheral nerves to deaden sensation as advocated by Moore almost 65 years previously. He further noted the practice of compression of vessels in the neck to produce unconsciousness was alleged to have been practiced in the ancient world and advocated in more recent times by Valverdi, Hoffman and Morgagni.(40) More recent application of this technique in the Far East was described by Dr. Steiner of Surabaya. He related how certain individuals in Java were treated for a variety of complaints by being rendered unconscious by pressure on the neck. Steiner personally performed this maneuver on 30 healthy Javanese. In no patients were changes in pulse rate or pupillary size associated with the loss of consciousness.* On one such occasion, a suppurating inguinal lymph node was painlessly excised.

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* This observation suggests that loss of consciousness was due to simple physical interruption of blood supply to the brain rather than to a reflex initiated by massage of the carotid sinus in the neck.

It was further noted that:

> "...Dr. Steiner suggested that this method, which, as is shown by the extensive experience of the Javanese, is free, if properly applied, from danger, may claim further investigation with a view to its application for purposes of anaesthesia in surgical operations."(41)

It can probably be presumed that use of this technique extended back to times before availability of modern anesthetic methods. Another physician, commenting on Steiner's communication and the arteries to the brain noted that according to the "Institutes of Medicine" by Boerhaave:

> "Their name (carotids) is generally supposed to be derived from KAROS (Somnus) because Galen deduces that denomination of them from the experiment of Erasistratus, namely that upon placing a ligature on them the animal falls into a carus or drowsiness."(42)

Anesthesia by Refrigeration

The first practical anesthetic was said to be of Anglo-Saxon origin about 1000 A.D. and appeared in a medical book of that time: "Again, for eruptive rash. Let him sit in cold water until it be deadened; then draw him up. Then cut four scarifications around the pocks and let drip as long as he will."(43) Refrigeration anesthesia was rediscovered periodically over the ages. One famous surgeon often identified as a writer on cold as an anesthetic was Dominique Jean Larrey (1766-1842). He was apprenticed to his uncle and then for a while was a ship's surgeon. In 1789 he helped care for a number of casualties during the street fighting associated with the Revolution in Paris. He became a military surgeon and originated the "flying ambulance" concept. He became a fast friend of Napoleon and served in every one of his campaigns in France, Germany, Spain, Italy, Egypt and Russia, and was thrice wounded in the 60 or so battles and more than 400 engagements in which he participated. He had excellent results and was said to be an extremely rapid surgeon. It was in association with the battle of Eylau that Larrey was said to have commented upon the anesthetic effect of extreme cold.(44) But careful search of the writings of Baron Larrey has failed to identify advocacy of such a form of surgical anesthesia.(45)

James Arnott (1791-1883), writing in 1848, noted that eight months previously he had proposed cold for local benumbing of tissue. He related that James Y. Simpson had proposed some local measures during the previous year (see above) which were unlikely to be effective.(40) Arnott noted that refrigeration anesthesia was likely to be particularly useful in operations primarily on the skin. He recommended that pounded ice and salt be placed in a pig's bladder and then put in contact with the skin to be operated upon. It would take about 15-20 minutes to be effective.(46) Throughout the remainder of his long life he continued to advocate local anesthesia as being superior and safer to inhalation anesthesia. Surface application of refrigerant solution was eventually replaced by ether and then by ethyl chloride spray to the proposed operative site.(47)

Inhalation Anesthesia with Ether in 1820

Inhalation of ether was used successfully by William Wright, aurist, to suppress a troublesome cough caused by working within the external ear canal in the early years of the 19th century. It was known that certain individuals with disease, irritation, or inflammation of the external ear canal would develop a sustained and protracted episode of coughing if manipulation or instrumentation of the ear canal were attempted.* This behavior would obviously render examination and treatment of the ear most trying under some circumstances. Wright had observed that the inhalation of the vapor of sulfuric ether would inhibit the troublesome cough and permit instrumentation of the ear. He related that in 1820 he attended an 83 year old ex-admiral who was stout, with a short neck, and had a severe cough. On the first visit he was unable to work in the ear because of the violence of the cough. On the next visit he administered ether by placing a dessert spoon of ether in a saucer which was placed in a basin of 110 degree water and this was breathed. Wright stated:

> "When the aether had all vaporized, the irritation of the trachea was so subdued that I could perform any little necessary manipulation on the ear without the least difficulty."(48)

The patient got such good relief of cough from this treatment that he continued to employ ether until his death at age 90. Wright therefore concluded that inhalation of ether vapor was also beneficial in suppressing chronic cough.(49) This was a bona fide administration of an inhalation anesthetic. Wright used an agent of known effectiveness to suppress a bothersome reflex which then permitted accomplishment of a previously impossible operative manipulation. Should not William Wright therefore be accorded some measure of recognition as a "discoverer" of anesthesia?(50)

Smith has concluded that nitrous oxide might have been in use to relieve post-operative pain associated with dental extractions as early as the 1820's.(51) In a poem of rather questionable authorship which appeared in 1820, "Doctor Syntax in Paris," is a description of how a dental practitioner, a certain 'Le Charlatan',

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* This phenomenon is well known in modern practice and has an anatomical basis. A branch of the vagus nerve, which supplies the air passages within the chest and the lung and is involved in the cough reflex also innervates the external ear canal and may become irritated here by disease.

invited Mrs. Syntax to partake of nitrous oxide for relief of her post-extraction pain immediately after removal of two teeth. The effects of inhalation of the gas that could be anticipated were described at length. Why the gas had not been recommended for relief of operative pain remains a mystery.(52)

ANESTHESIA BY HYPNOSIS

The hypnotic state and some of its medical applications were known in the ancient world.(53) In more recent times, hypnosis has been associated with the name of Anton Mesmer (1734-1815) and his curious ideas about "animal magnetism" which evolved in the 1770's. Magnetism had been previously invoked to explain certain medical phenomena and Paracelsus is said to have prescribed magnetic iron as a medicine. Mesmer postulated that a universal magnetic fluid flowed freely in the body during health but not in disease and that flow of this fluid could be influenced by magnetism. For Mesmer, there existed only one disease – disturbance of the flow of magnetic fluid. For a cure to be effected an initial rapid abrupt worsening of the disease had to occur followed by a crisis. Then calm and cure could be expected.

Mesmer began his career in Vienna but was eased out of that city and went to Paris in 1778 and achieved wide popularity. Many of the nobility became his ardent supporters. Initially he wrought his cures by applying magnets to patients' bodies. But as his treatments became increasingly popular, he began to "magnetize" larger and larger objects such as trees and gardens so that medical cures could be procured merely by contact with these objects. Eventually he decided that the magnetic force originated within himself and could be transmitted to patients by rubbing them and gesticulating at them.(54) For various reasons and partly at the insistence of Mesmer, King Louis XVI asked the French Academy of Sciences to appoint a commission to investigate animal magnetism in 1784. Chairman of this commission was Benjamin Franklin and other distinguished members included Antoine Lavoisier and Dr. Joseph Guillotin. After extensive study they concluded that, although there may have been some positive features of animal magnetism, the commission could neither recognize the validity of nor otherwise approve the concept. A discredited and disheartened Mesmer soon left France and returned to Austria where he isolated himself and died a few years later. Mesmer had been criticized as much for his threat to dominance of the 18th century medical establishment as for his beliefs which were, after all, no less fantastic than those of many of his detractors. To a large degree the academies had replaced the papacy in condemning scientific heresy.(55)

It had been observed that hypnotic trances, or states of somnambulism, could be induced under several conditions by types of gestures and patter originally employed by Mesmer. The forces involved in hypnotism were initially believed to be related to Mesmer's mysterious fluid and the process of hypnotism thus became known as "mesmerism."(54) The first use of a mesmeric hypnotic trance to perform pain free surgery occurred in Paris in 1821 by Dupotet and Récamier and sporadic reports of similar activities from France appeared over subsequent years.(56) An example was the amputation of a breast during a mesmeric trance by Jules Cloquet in 1829.(57)

Probably the most enthusiastic and vocal supporter of mesmerism used for anesthesia was John Elliotson (1791-1868). This distinguished Edinburgh graduate was appointed the first Professor of Practice of Medicine at the University of London and was associated with University College Hospital. He was considered among the most capable and distinguished of London's physicians. He began his inquiries into animal magnetism in 1837 and became a staunch supporter of this practice in spite of increasing opposition from the medical community and from the University authorities. Rather than relinquish his mesmeric activities at the insistence of his critics, Elliotson resigned his University post in 1838. Elliotson continued his enthusiastic promotion of mesmerism. He and some colleagues published a journal, the "Zooist," which was primarily devoted to mesmerism and which appeared from 1843 to 1855. His 1843 book, "Numerous Cases of Surgical Operation Without Pain in the Mesmeric State," included a case report of a painless above-knee leg amputation. Then came his ironic exposition of the "Determination of the Royal Medical and Chiurgical Society of London that this fact was not a fact" and his reporting of the "Resolution of the Royal Medical and Chiurgical Society not to leave a trace in their records that this fact had been presented to them."(58) In 1845 and 1846 he published many further reports of surgical procedures accomplished without pain using mesmerism. These included venesection, many tooth extractions, excision of tumors, amputations, and labour and delivery. In the articles he castigated surgeons and teachers in the London metropolitan hospitals, the College of Surgeons, Sir Benjamin Brodie and others for not employing mesmerism in surgery. He also described and commented upon the large series of pain-free operations accomplished by Dr. James Esdaile, Civil Assistant Surgeon in Hooghly, India.(59,60)

James Esdaile (1808-1858) acquired an impressive amount of clinical experience in surgery performed during mesmeric trances. He was a medical graduate of Edinburgh University (1830) and following graduation he obtained an appointment with the British East India Company in 1831.(61) By 1845 he was surgeon to a hospital for paupers and criminals in Hooghly near Calcutta. Here he was inducing trances and performing, with considerable success, many major operations with minimal or no pain and discomfort. A commission investigated his activities in 1846 and submitted a noncommittal report, but praised Esdaile's efforts.(62) James Braid summarized the findings of the commission which evaluated the observation of a small group of patients during surgery with mesmeric trance. Of these three could not be mesmerized. In an additional three patients there was no evidence that any pain at all was experienced. In another three manifestations of pain were observed, but patients subsequently denied that any pain was experienced.(63) Braid attributed the rapid pulse rate of those patients not responding to painful stimuli as due to "rigid catalepsy" with stiffness of muscles. He commented that Esdaile was still a "mesmerist" since he believed that induction of a trance involved transferring some type of force from operator to patient.(62) The commission commented upon the great amount of time required to induce a trance and its uncertainty once established. Esdaile continued to work at Hooghly and performed about 300 major operations during hypnotic trances.(57) When the United States Congress offered a monetary reward of $100,000 (which was never bestowed) to the true discoverer of the anesthetic properties of ether in 1853, Esdaile wrote to congress reminding them that mesmerism preceded the use of ether during surgery.(61)

James Braid (1795-1860), surgeon of Manchester, was partly responsible for separating the clinical phenomenon of hypnosis from the encumbering mantle of "animal magnetism." In contrast to Esdaile, Braid did not believe that induction of a hypnotic trance involved the transference of some mysterious power from operative to subject. He described the appearance of patients in various depths of hypnotic trance and some of the associated physiological changes.(64) In 1843, he noted that hypnosis could abolish or greatly modify pain of surgery and described several pain-free dental extractions conducted during hypnosis. He warned that patients being hypnotized for eventual surgery should be unaware of the time or instance when surgery would occur lest they be distracted and impossible to hypnotize.(65) In a subsequent publication, Braid remarked upon the initial opposition and disbelief in mesmeric surgery pointing out that following the introduction of etherization, the same individuals who were most adamant in rejecting mesmerism enthusiastically accepted etherization using the same evidence on which they discarded mesmerism; i.e. the state of the patients and the evidence of their condition during inhalation. He had seen all degrees of depression from both methods from deep sleep to conscious analgesia. With hypnotism, induction took a long time and preliminarily had to be done repeatedly while keeping the timing of the surgery a secret from the patient. Some patients who could be hypnotized couldn't be put into a trance deep enough for sleep. Advantages of ether included its rapidity and its almost universal applicability. Advantages of hypnosis were said to be less postoperative problems and less physiological disturbance.(63)

There were several reports on mesmerism from America where there was generally less opposition to the practice than in England. Crawford Long subsequently stated that his wish to assure himself that etherization was different from the mesmeric state was a reason that he delayed publication of his work with ether anesthesia.(66) But with the popularization of swift dependable chemical anesthesia after 1846 time consuming and not always successful mesmeric techniques fell into disuse. A brief resurgence of interest in hypnosis in anesthesiology occurred in the 1950's (67) and many modern practitioners will attest that hypnosis is indeed an effective anesthetic technique under some circumstances.

EARLY SUGGESTIONS FOR ANESTHESIA

The concept of anesthesia as we understand it in modern times appears not to have occurred to many individuals before the 1840's. Many historians of anesthesia relate how in this decade the idea for pain relief during surgery burst on the medical scene as a result of almost divine inspiration in a few unlikely individuals. But well before the 1840's a few thoughtful practitioners had offered unambiguous and prescient suggestions for use of certain measures for anesthesia though most did not follow up their proposals with implementation. Certain criteria may be suggested which, when applied to these early proposals for provision of pain free surgery, will assure the modern reader that he can be reasonably certain that these writers from former ages were really talking about anesthesia as the term is understood in our times. One such criterion is that the agent or means proposed for the anesthetic should be recognized and acknowledged as being capable of producing unconsciousness and/or insensibility by anyone experienced in administering modern anesthetics. Another criterion might be that the circumstances suggested for the use of anesthetics should be appropriate for solving a surgical or medical problem recognizable to modern practitioners. These criteria eliminate such proposals for alleged anesthesia as the sedation before mystic rites, as described previously as practiced by followers of the Cult of Aesculapius in ancient Greece. Also ruled out are the consumption of mandrake (belladonna alkaloids alone seem very unlikely to work as anesthetics) or attainment of complete surgical anesthesia with opium derivatives* (in the absence of means for provision of artificial ventilation for the inevitable respiratory arrest that would occur with these drugs before surgical anesthesia was attained).

Before considering some early proposals for anesthesia, Davy's famous suggestion should be recalled:

> "As nitrous oxide in its extensive operation appears capable of destroying physical pain, it may probably be used with advantage during surgical operations in which no great effusion of blood takes place."(68)

This passage has traditionally been regarded as a reference to providing patient comfort during surgery and, indeed, F.F. Cartwright believed that it represented

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* In modern practice it is possible to conduct an anesthetic using very large intravenous doses of opium derivatives, their synthetic analogs, and related drugs; so called "total intravenous anesthesia." Physiological consequences of these techniques include cessation of breathing and some degree of circulatory depression which are easily managed by provision of artificial ventilation and expansion of intravascular fluid volume. Such clinical problems and their management, however, would have been beyond the understanding and capabilities of medical practitioners in bygone days.

the discovery of anesthesia.(69) But for reasons described above in the chapter on Humphry Davy his rationale for using nitrous oxide during surgery was far more likely to have been some perceived medicinal use of the gas as a "diffusible stimulus" than to provide pain relief for its own sake.(70)

One bona fide early suggestion for anesthesia was offered by Thomas Beddoes. The occasion during which this proposal was made was a visit by Dr. Joseph Frank of Vienna to Beddoes in Bristol. The incident was related by Dr. Frank and was recounted in Stock's biography of Beddoes:

> "He [Beddoes] suggested the idea of employing Hydro-carbonate in strangulated Hernia, with a view to throw the patient into syncope ; and of attempting the reduction of the intestine, while he remained in that state."(71)

This is an unambiguous enunciation of the concept of inhalation anesthesia: rendering a patient unconscious and relaxed using an agent known to be capable of producing the desired state during performance of a difficult and painful surgical maneuver.

Beddoes appreciated the idea of surgical anesthesia! He was familiar with the ability of hydrocarbonate to produce unconsciousness because of previous trials of the gas for pneumatic cures of disease. Hydrocarbonate, apparently identical with 'water gas,' was prepared by dropping water on red hot charcoal and is a mixture of gases with the principal ingredient being carbon monoxide. Beddoes presented a case history of human hydrocarbonate inhalation performed therapeutically for treatment of consumption. The patient became very faint, lost consciousness and was not well for a considerable period.(72) Another pneumatic practitioner who used hydrocarbonate gas was William Withering. He suggested that hydrocarbonate and oxygen should be diluted with 18-20 times their bulk in atmospheric air and described a weak pulse, vertigo, nausea and a "disposition to sleep" as a consequence of inhaling this mixture.(73) It may also be recalled that Humphry Davy did some very foolish self-experimentation with carbon monoxide which almost took his life.(74) Thus, the depressant effects of hydrocarbonate and the capability of this gas to produce unconsciousness was known before 1800.

But apparently the idea of inhaling hydrocarbonate gas to provide surgical anesthesia did not originate with Thomas Beddoes. Davies Giddy, in a letter to Beddoes in 1795, suggested the inhalation of "heavy inflammable air" (i.e. hydrocarbonate as opposed to light inflammable air or hydrogen) before painful surgical operations. He wrote:

> "The power of heavy inflammable air, as I take it, to diminish the secretions of excitability in the brain may possibly be applied to many useful purposes. May it not be used before painful operations?"(75)

This suggestion by Giddy has apparently been overlooked or forgotten. As a proposal for use of inhalation of a gas for anesthesia it antedates Davy's analogous statement on nitrous oxide by five years and perhaps was the origin of Davy's famous proposal. It also was undoubtedly the source of the similar suggestion made by Beddoes to Dr. Frank of Vienna several years later as related above. Perhaps Beddoes and Giddy are worthy of some of the recognition for conceiving the idea of inhalation anesthesia that has until now been accorded to Davy.

There is no evidence that carbon monoxide was ever tried as a clinical anesthetic. This is probably just as well since it would appear to have a very narrow margin of safety. Robert Hamilton suggested inhalation of hydrocarbonate and oxygen in hydrophobia to provide sedation against the extreme "watchfulness," or heightened nervous excitability, characterizing this condition. He wrote:

> "...As a temporary narcotic I shall not object, if the distressing watchfulness which constantly attends this disorder cannot be removed by the use of oxygen. For the reasons already delivered (the harmful effects of hydrocarbonate enumerated above) its use would appear ill adapted to anything farther than a temporary insensibility. Should it prove in this respect superior to opium, it ought not to be rejected.....I do not see the impropriety of occasionally inhaling it at the same time as oxygen; I mean for the purpose of procuring rest."(76)

This suggestion was based on the experience and writings of Beddoes and Tiberius Cavallo who had noted the ability of hydrocarbonate to relieve pain, diminish sensibility and cause faintness.(77,78)

It is thus apparent that there were several early suggestions for the use of carbon monoxide to provide sedation and pain-free surgery years before nitrous oxide was used for anesthesia. One could speculate that the road to clinical anesthesia could have involved attempted administrations of carbon monoixde just as well as the nitrous oxide or ether that was ultimately used. The eventual application was undoubtedly greatly influenced by the public familiarity with nitrous oxide and ether associated with their frivolous recreational use. A much less practical proposal was Sir Benjamin Brodie's 1821 suggestion for use of hydrocyanic acid as an alternative to ether for obtaining unconsciousness.(79) In the winter of 1815-16 Benjamin Rush, in a lecture delivered in Philadelphia, is quoted as having said:

> "Might we not induce coma to a low degree of apoplexy in order to bear long operations and parturition well?"(80)

However the specific means under consideration for producing the coma are unclear.

Dr. Parsons Shaw discussed a popular poem published in 1820 describing the adventures of a certain Dr. Syntax in Paris. Mrs. Syntax had undergone dental extraction and was offered some nitrous oxide to breath afterwards to provide some measure of postoperative pain relief.(81) Shaw wondered why if someone had associated nitrous oxide, with its pain relieving properties, and tooth pulling as early as 1820, why nobody had thought of giving the gas before extraction?(82)

HENRY HILL HICKMAN

Of the several early proposals for methods to perform painless surgery, one that hit very close to the mark was that of Henry Hill Hickman (1800-1830). He was seventh of thirteen children of a tenant farmer and studied medicine at Edinburgh during 1819-1820. It was possible that while he was a student the first seeds of his idea for painless surgery were planted in his mind.(83) He was shortly thereafter admitted as a Member of The Royal College of Surgeons on 5 May, 1820 (though he was underage for admission to that body). Few details of his life are known.(84) In 1824, while he was practicing surgery in the village of Shifnall,* Hickman penned his letter proposing "suspended animation" to provide surgical anesthesia. He wrote:

> "there is not an individual, I believe, who does not shudder at the idea of an operation, however skillful the surgeon, or urgent the case, knowing the great pain that must necessarily be endured; and it is frequently lamented by the operator himself, that something has not been done to tranquilize fear, and diminish the agony of the patient."

He submitted this letter to Mr. T.A. Knight of Downton Castle Herefordshire, in the expectation that the material would be submitted to the Royal Society. Knight was a Fellow of the Royal Society and a friend of Humphry Davy.(85) Hickman continued:

> "Sir, the facility of suspending animation, by carbonic acid gas, and other means, without permanent injury to the subject, having been long known, it appears to me rather singular that no experiments have hitherto been made with the object of ascertaining whether operations could be successfully performed upon animals whilst in a torpid state....."

He also suspected that wounds inflicted while in such a state would heal more readily (Perhaps due to the reputed antiseptic action of carbonic acid gas?). The

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* It will be recalled that Shifnall was the birthplace of Thomas Beddoes. Was Hickman's interest in suspended animation by means of gas inhalation inspired by some factor influenced by the legacy of Thomas Beddoes or was the connection coincidental?

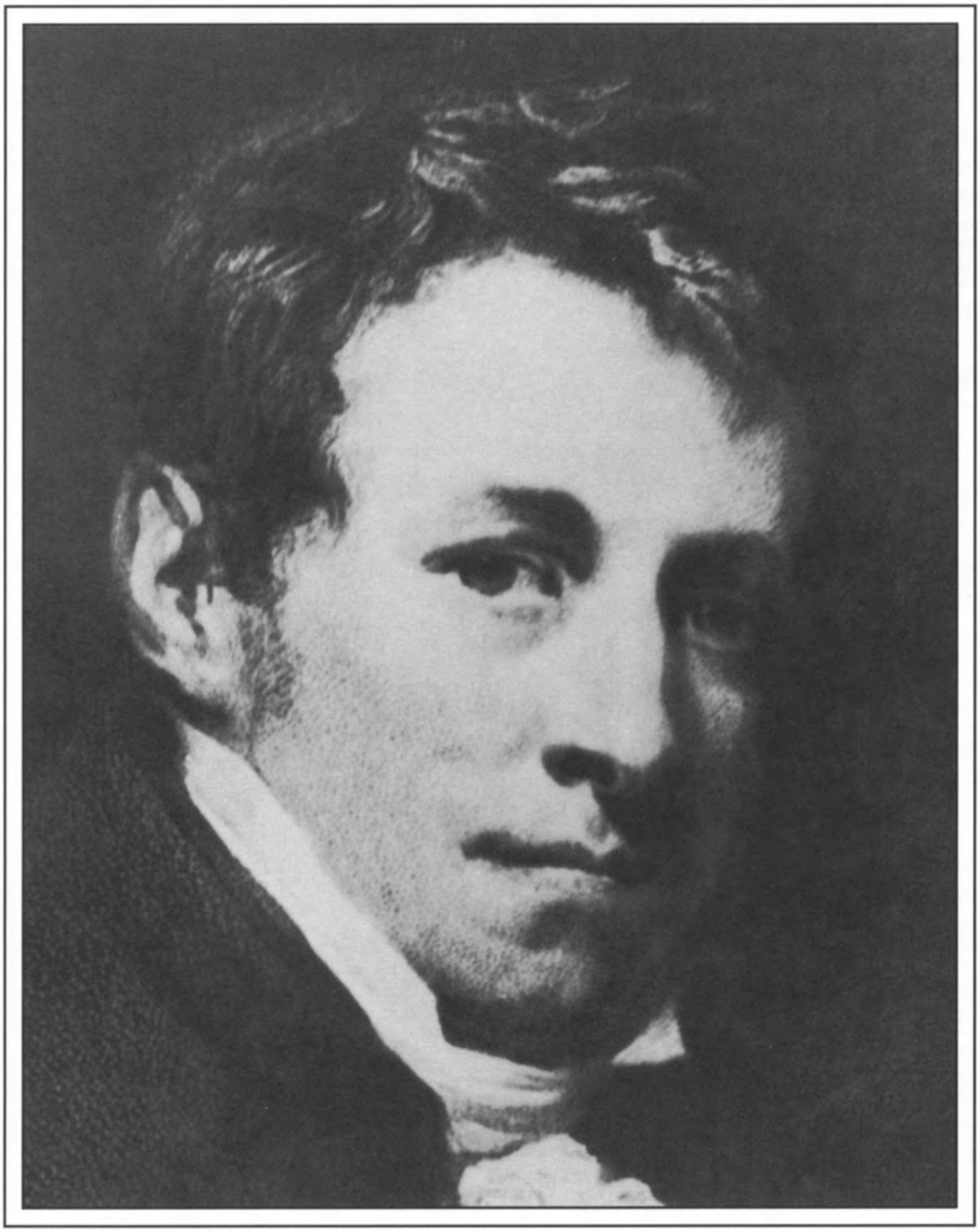

Plate XVI — Henry Hill Hickman (1800-1830) unequivocally formulated the principle of general surgical anesthesia by the inhalation of a gas.

animals selected for his experiments on suspended animation had already been condemned to death and Hickman believed that, since their suffering was so minimal, they received overall benefit rather than harm. More experiments were done than were presented in this letter, primarily on puppies, but the results were so uniform that only selected experiments are presented here.

The experiments were as follows: Experiment 1. Animation was suspended by confining puppies in a chamber under water. When respiration had ceased they were taken out and a small portion of one ear was removed with no hemorrhage and good wound healing. When the operation was done subsequently on these animals in the conscious state, there was a good deal of blood flow, some degree of inflammation and slower wound healing. When suspension of animation in puppies occurred by means of administration of carbonic acid gas produced from sulfuric acid and carbonate of lime results were not so satisfactory: some blood escaped, there was slight inflammation, and wound healing was somewhat slow. The fourth experiment used mice confined in a glass tube into which carbonic acid gas was introduced in small quantities. One foot from each was taken off with no hemorrhage and with rapid, good wound healing. In the fifth experiment insensibility was induced by means similar to those used in experiment 4 in an adult dog. Muscles and blood vessels of one of its legs were divided. In this experiment animation was suspended during seventeen minutes allowing inspiration to occur by means of inflating instruments. In the sixth experiment related, another dog was operated upon without feeling pain by being placed in a closed chamber until sensibility was lost.(86)

On the basis of these experiments Hickman concluded that operations could be performed perfectly well in the insensible state and that the insensible state could be maintained for as long as necessary "for performance of the most tedious operation." He mentioned the psychological and physiological advantages to the patient. Surgeons could operate more skillfully when not inflicting pain.

Hickman also believed that bleeding during the operation would be less if done in the state of suspended animation. He tested the effects of serial episodes of suspended animation in one animal and believed that repeated anesthetics would be safe. He could think of no possible complications of this in humans, particularly if insensibility were induced simply by respiring confined air. He was not prepared to comment on the possible role of inflating instruments (i.e. to produce artificial ventilation) since he only used them once. He also suggested stimulation by "galvanic fluid" (electricity). He concluded:

> "....I feel so confident that animation in the human subject could be safely suspended by proper means, carefully employed, that, (although I could not conscientiously recommend a patient do this to his life with the experiment I certainly should not hesitate for a moment to become the subject of it, if I were under the necessity of suffering any long or severe operation."

The letter was dated and signed at Shifnall, August 14, 1824.(87)

It is probably unfortunate that Hickman chose to label the state which he proposed to produce to provide painless surgery as "suspended animation." Most of Hickman's contemporaries would not have been enthusiastic about the idea of suspending animation since in the context of early 19th century thinking, this state was usually associated with hanging, drowning, suffocation and a high probability of death.(88) Various forms of suspended animation had been known since ancient times. It is difficult to determine the exact meaning that Hickman imparted to the term. Was it simply asphyxia or did it have wider meaning? There were a number of conditions and states which could qualify to be called "suspended animation." Among these were accounts of long and profound death-like sleep from literature (e.g. Shakespeare's Juliet) or the trances in which eastern mystics could exist. Certain hysterical and cataleptic states could be included. Particularly distasteful to people of Hickman's time and to Victorians was the "suspended animation" associated with premature burial following apparent death. In various European countries mortuaries were founded to receive recently deceased bodies for a period of observation where some doubt existed about the actuality of death. Feelings and apprehensions concerning these situations were so acute that, in the middle of the 19th century, various types of alarm systems were devised to permit the apparently deceased to signal.

There were numerous tales relating to people who revived after apparent death but before burial.(88) Edmund Goodwyn, in his book on the connection between life and respiration, was concerned with asphyxial states and how they could be distinguished from death in his studies on life and respiration.(89) Phillipe Aries identified the nineteenth century as an age in which death became more distant, dramatic and full of tension than it had been previously.

> "At this time death appeared omnipresent: funeral processions, mourning clothes, the spread of cemeteries and of their surface area, visits and pilgrimages to tombs, the cult of memory."

There seemed to be a preoccupation with everything surrounding death and any state resembling death would be regarded with great repugnance.(90) The Rev. Walter Whiter regarded death as a disorder or disease which might be the final crisis in other illness. If treated, a patient dying with a particular disease might be revived in a cured state. He suggested that if death occurred during the course of an operation, this state be used as an anesthetic and the surgeon should take the opportunity to finish his operation. (Whiter's book appeared in 1819).

Also, as mentioned, the state of 'suspended animation' was associated with hanging, drowning and other violent forms of death.(88) Thus, for many, suspended animation meant and included all the forms mentioned above and the term was not necessarily confined to asphyxia. It is little wonder that Hickman's contemporaries were reluctant to become involved with his ideas.

When anesthesia was finally successfully introduced it was regarded by many as merely another way to produce suspended animation. The unfavorable associations mentioned above undoubtedly contributed to the reluctance to employ anesthesia routinely in many operations in its early years. Hickman probably had little or no experience reversing suspended animation in man. Today we know that carbon dioxide, alone and combined with oxygen lack, can indeed produce anesthesia, but only with considerable risk. Chauncey Leake and Ralph Waters acknowledged the work of Hickman in their own investigations of the anesthetic properties of carbon dioxide.(91) Mr. T.A. Knight, to whom Hickman's letter was addressed, was not a president of the Royal Society as erroneously set forth in the letter's salutation. At that time, however, Sir Humphry Davy was. Davy was accustomed to visit Downton Castle to engage in his favorite avocation: fishing.(92) W.D.A. Smith suggested that Knight and Davy dined together in March, 1824 and discussed Hickman's ideas. Initially, both apparently seemed to be enthusiastic and it was possibly intended that Davy should communicate Hickman's letter at a meeting of the Royal Society. However Davy's interest in anesthesia by suspended animation rapidly waned and the material was never presented. Possible reasons might include Davy's reluctance to become involved with the potentially dangerous practice advocated by Hickman. In addition, apparently at this time there was a strong anti-vivsection lobby in the Royal Society (evidenced by some correspondence between Knight and Sir Joseph Banks). Perhaps comments by Hickman in his letter emphasizing minimal cruelty to animals was inserted at the suggestion of Knight. Perhaps Hickman's letter may have been drafted after Knight had dined at the Royal Society Club as Davy's guest.(83,84) The intriguing problem of why Davy failed to suggest that Hickman try nitrous oxide at this time is considered in the discussion of Humphry Davy's contribution to anesthesia elsewhere in this volume.

Even though Hickman's pamphlet was not presented to the Royal Society, it did attract attention. It was published and reviewed and it generated correspondence. A review in "Lancet" by an anonymous author who signed himself as "Antiquack" was a merciless, scathing and malicious attack on both Hickman and his ideas. Antiquack compared Hickman's idea to suggesting that, before a dental extraction, a patient should be drowned, hanged, or smothered for a few minutes. He hoped that the letter was a joke since no reputable Doctor of Physic would disgrace himself and the profession in such a manner by proposing such outrageous practices!(93)

Hickman's letter was also reviewed in "Gentleman's Magazine." The objectives, procedures, and supporting experiments for "suspended animation" were described in a simple and direct fashion. Hickman's willingness to employ these techniques on himself, if necessary, was noted. In the reviewer's opinion:

> " – notwithstanding Dr. H.'s confidence, it may be doubted whether the pain of his operation, and especially in the recovery, would not equal or perhaps surpass, that experienced in the usual mode of operation."(94)

A subsequent appeal for support by Hickman to King Charles X of France who referred the matter to his Royal Academy of Medicine was also almost completely ignored. M. Gérardin reported on this matter to the Royal Academy of Medicine at its Autumn, 1828, meeting. The general nature of Hickman's idea was presented and a committee was appointed to look into Hickman's ideas. Apparently the announcement was received with extreme skepticism and derision by the academy. The only defender appears to have been Baron Larrey, formerly Surgeon General to Napoleon, who offered himself for experiment. In spite of appointment of the committee the matter was allowed to drop.(86,95)

Few biographical details of Hickman's life are known. He died at an early age, within a year of his return from France, and undoubtedly died greatly disappointed at his failure to interest influential individuals in his idea.

In February, 1847, shortly after the introduction of ether anesthesia into England, Dr. Thomas Dudley of Kingswinford, a former friend of Hickman, wrote to Lancet announcing that Hickman had discovered ether in 1824.(96) Following receipt of a copy of Hickman's pamphlet, which he had previously requested from Mrs. Hickman in January, Dudley again wrote to Lancet in March, 1847 amending and revising his views. He related how Hickman's pamphlet of 1824 described the techniques for producing insensibility by various means viz, by exclusion of atmospheric air, and by the exhibition of carbonic acid gas made from sulfuric acid and carbonated lime (but not with ether). It was obvious to him that Hickman was the originator of the idea of producing insensibility to surgical operation. He stated that the introduction of ether was at best an improvement on that idea. He speculated that perhaps there were subsequent publications by Hickman with better ideas and that some of the claimants for priority in discovery of anesthesia of 1847 may have borrowed ideas from this work.(97) On March 11 Dudley wrote to Mrs. Hickman indicating that he had received the copy of the pamphlet and that he believed that Hickman was clearly entitled to the claim for originating anaesthesia. He again wrote to Mrs. Hickman several more times and continued to be an advocate for Hickman's claim. Had it not been for Dudley's efforts on Hickman's behalf, Hickman's writings on anesthesia might have been completely forgotten.(84) Meanwhile the French Academy of Sciences met on July 20, 1847. They noted that etherization had spread around the world and that there was almost unanimous approval of its utility in selected cases. It was worthwhile to endeavor to ascertain to whom credit for the discovery was actually due. The claims of Morton, Wells and Jackson were considered. The academy then announced, "We think, however, we can set these various claims at rest by the following extract from the printed reports of the Academy of Medicine of Paris;"

They then reprinted the notice from the meeting of Sept 23, 1828 where Hickman requested cooperation of this body in applying the results that he obtained in animals to man. They believed that the wording of the passage was sufficiently explicit so that no doubt could be entertained that the principle was discovered by Hickman. (It is in principle that invention resides, they said). They believed that Hickman took the safest and best measures for carrying out his invention — that they failed (or more properly were ignored) was not his fault. Moreover, a scientific body was put in possession of the facts, the communication was made generously and freely, no patent was taken out nor was there any attempt to garner profits. The discovery of the method of performing operations by inhalation of medicated vapors was his [Hickman's] property.(98)

Dr. Thomas Dudley wrote to the "Medical Times" in response to their publication of the proceedings of the French Academy of Medicine in July, 1847. He indicated that his previous letters to "Lancet" had not accomplished much to substantiate Hickman's claims. He pointed out that Mrs. Hickman still lived and was anxious for her husband's claim to be established. Dudley wished the editors of the "Medical Times" to continue efforts on Hickman's behalf so that the widow could get any benefit which would accrue from this discovery.(99)

In the concluding section of this volume which follows, the introduction and acceptance of anesthesia into clinical practice in the 1840's will be related. This part of the anesthesia story is probably already familiar to many readers and so the material presented here will not be an analysis of the topic in depth. But by now it should be apparent that the events to be narrated do not constitute the discovery of anesthesia. The anesthetic state had already been speculated upon, produced, observed and utilized well before 1846. The concept of surgical anesthesia had already been enunciated by many individuals. All that was needed was a fortunate combination of time, place, and participants necessary to raise consciousness about anesthesia and launch it on its world wide journey of acceptance.

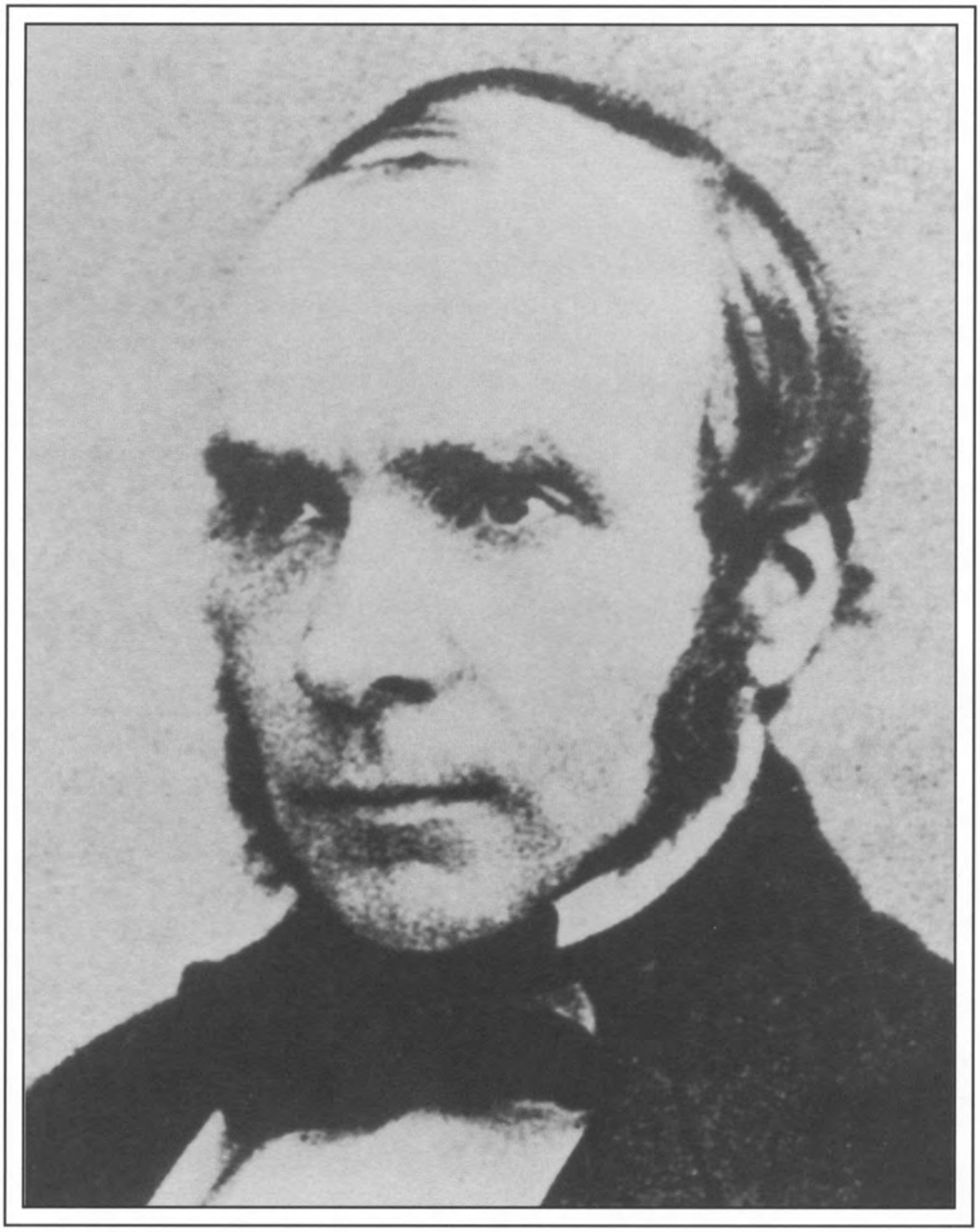

PLATE XVII — JOHN SNOW (1813 – 1858). The founder of modern scientific anesthesia.

EPILOGUE

INTRODUCTION OF ANESTHESIA INTO CLINICAL PRACTICE

It is easy to get the impression that mankind had been eagerly awaiting the possibility of undergoing surgery without pain since the dawn of time. Such does not appear to have been the case. As has been related in previous chapters, there are many references to surgery from preanesthetic days and many descriptions of imaginative anesthetic techniques, some of which must have been successful or partially so. But there appears to have been little if any hope for routine implementation of useful anesthesia as we would understand the term nowadays. Some believed that painless surgery was not attainable. Velpeau, a leading French surgeon, wrote in 1839:

> "To escape pain in surgical operations is a chimera which we are not permitted to look for in our day. A cutting instrument and pain in operative medicine are two words which never present themselves one without the other in the minds of the patients, and it is necessary for us surgeons to admit their association."(1)

Two of the persons who did administer successful ether anesthetics and could have introduced anesthesia into general use some years before 1846, Crawford Long and William Clarke, were actively discouraged from further experiments with ether by professors and associates. And when anesthesia finally became a recognized part of clinical practice there were a surprising number of objections to its regular use and it was initially employed quite selectively.(2,3) In 1862 Valentine Mott, a surgeon of New York City, felt compelled to write an essay on "Pain and Anaesthetics" in order to encourage the wider use of ether during operations performed by army surgeons.(4)

By the middle of the 19th century, knowledge, experience, and social attitudes had finally evolved to the point that several daring pioneers administered inhalation anesthetic agents that eventually became part of the medical armamentarium. This was done by persons forearmed with information concerning an action of ether and nitrous oxide upon consciousness and mentation, and with the deliberate intention of producing insensibility to pain during surgical procedures. These purposive administrations of anesthetic vapors and gases in the 1840's represent the introduction of anesthesia into medical practice. At this time four perceptive individuals discerned a relationship between stupefaction produced by inhaling sulphuric ether or nitrous oxide under various circumstances and potential provision of pain free surgery. Between them, they changed a recreational pastime into an indispensable medical practice.

In January 1842, Willam Clarke, a student of chemistry accustomed to inhaling ether vapor for amusement in the company of companions, administered ether from a towel to a young woman named Hobbie, and one of her teeth was then extracted without pain by a dentist named Elijah Pope at Rochester, New Yotk.(5,6,7,7a)

In March 1842, Crawford W. Long, a physician of Jefferson, Georgia, administered ether to James Venable, and while the patient was under the influence of the vapor Long painlessly excised a small tumor from his neck. Long had had frequent opportunity to observe the effects of ether inhalation during the many "ether frolics" commonly conducted in the rural south in his time, and had noticed that injuries sustained while breathing the vapor were not accompanied by external manifestations characteristic of pain.(8-15)

In December 1844, Horace Wells, a dentist of Hartford, Conn. deduced the capability of nitrous oxide to provide an analgesic state while witnessing a public demonstration of effects of inhaling this gas. He subsequently performed painless dental and surgical procedures in Hartford using nitrous oxide inhalation but an attempted demonstration of nitrous oxide anesthesia for tooth extraction before a medical class at Boston, Mass. was unconvincing and only partially successful.(16-24)

Finally, on October 16, 1846, William T. G. Morton, a dentist of Boston, Mass., administered ether to Gilbert Abbott for painless excision of a tumor of the jaw. Morton found out about the remarkable properties of ether vapor by reading descriptions of "ether frolics," and from accounts of its effects on consciousness provided by his young apprentice who had inhaled it as a schoolboy, or from his mentor in chemistry, Charles T. Jackson.(25-45)

Charles T. Jackson subsequently claimed to have demonstrated several important points about ether which collectively constituted the discovery of anesthesia.(46-49)

Thorough accounts of these pioneers of anesthesia have been given by others and will not be repeated here.

As anesthesia was applied clinically bitter controversy erupted over who should be designated as THE discoverer and who should receive financial benefit from the discovery. The disagreement continued for years after the public had appeared to lose interest in the issue. The persistent quarreling between the supporters of

Morton, Wells, Jackson and Long could not have presented a very flattering or reassuring impression of the healing professions. In our own time vestiges of this unresolved and often chauvinistic argument surface, sometimes with additional nominees such as Hickman or Davy.

WHO DISCOVERED ANESTHESIA?

If a single discoverer of anesthesia is to be designated, what should be the qualifications for selection? What should have been the nominee's accomplishment? What should he have contributed towards demonstrating the feasibility of pain free surgery? At least three different ways of answering these questions have been proposed by different individuals or agencies.

One set of criteria for acknowledging an individual as the discoverer of anesthesia was proposed by Sir William Osler during remarks made on presenting Morton's original papers to the Royal Society of Medicine in 1918. Sir William would have insisted that such a person should have forced a method for providing pain relief during surgery into general acceptance or have influenced surgical practice in some way. He wrote:

> "In science, the credit goes to the man who convinces the world, not to the man to whom the idea first occurs."(50)

But a completely opposing view had been expressed by the Academy of Medicine of Paris in 1847. At that time they noted that etherization had spread around the world and an inquiry seemed worthwhile to ascertain to whom credit for the discovery was actually due. The Academy considered the claims of Morton, Wells and Jackson but then returned to the record of their meeting of September 23, 1828 where Henry Hill Hickman requested cooperation of that body in applying the results that he obtained in animals to man. They believed that the wording of Hickman's writings on painless surgery as recorded in their proceedings was sufficiently explicit so that no doubt could be entertained that the principle was discovered by Hickman. They emphasized that, in their opinion, *it is in principle (and not necessarily in application) that invention resides* and for this reason the discovery of the method of performing operations during inhalation of medicated vapors was his [Hickman's] property.(51)

Later, in an 1869 address, a municipal official of Edinburgh designated Dr. J.Y. Simpson as the discoverer of anesthesia because of his application of chloroform to medical anesthetic practice. Chloroform was regarded as a greater discovery than ether because the former was perceived at that time as being more readily applicable in most clinical situations. Simpson did not deny this conclusion in his lengthy response to the oration. Dr. Henry Jacob Bigelow of Boston read the account of these proceedings. He subsequently stated in the press, thus initiating an acrimonious public correspondence, that Simpson had failed to render due credit to Boston for discovery of anesthesia.(52) But, from a 20th century point of view, the wider clinical applicability of an agent or technique advocated by an individal does not justify nominating that person as discoverer of anesthesia. An updated designation would have to be made each time a newly introduced anesthetic agent caught the popular fancy. Also, many problems associated with administration of chloroform came to light and its use was eventually far eclipsed by that of ether until both were overshadowed by more modern anesthetic agents. It was erroneous to generalize that chloroform was a greater discovery than ether even though that might have been the Scottish perception at the time.

So, should unambiguous annunciation of the concept and principle of pain relief or other desirable modification of patient response during surgery be sufficient to establish a claim for discovery of anesthesia, or should some effort at dissemination or implementation also be expected? Is it necessary that the individual who discovered anesthesia and the individual who was responsible for the introduction of anesthesia into practice be the same person? Should public acceptance of these ideas or practices be a consideration in nominating a discoverer? Should ready applicability of the discovery be a consideration?

Osler backed Morton as discoverer because, "Morton convinced the world; the credit is his."(50) Osler must therefore have believed that Morton persuaded the world as to the value of etherization during surgery, thereby forcing adoption of anesthesia and noticeably influencing the practice of surgery. But Morton did not convince the world; it was the surgeons with whom Morton originally worked who were primarily responsible for the rapid dissemination of the technique for pain-free surgery involving ether. The first announcement of successful ether anesthesia published in a recognized medical journal was that of Dr. Henry Jacob Bigelow. It appeared in the Boston Medical and Surgical Journal for November 19, 1846.(39) This material had been previously presented by Bigelow at meetings of Boston medical societies on November 3 and 9.(53) Transmission of the information to England which led to the first British use of ether in London on December 19, 1846 by James Robinson was via personal letter from Dr. Jacob Bigelow to Dr. Francis Boot.(54,55) Subsequent worldwide adoption of anesthesia then ensued with unprecedented speed as a result of newspaper articles, professional publications and personal communications. Most European countries had the news within four months and other parts of the world within nine months. The use of ether seems not to have spread faster in the United States than in Europe.(56) Probably no medical discovery, before or since, was more rapidly adapted to clinical practice than anesthesia.

But this was not due to the efforts of Morton; his publications were a few among many and his early writings reflected his preoccupation with his patent on ether. Thanks to his professional associates, Morton's etherization simply attracted better media coverage than did Wells or Long before him, so that the introduction of anesthesia quickly became self propelled. Was the practice of surgery modified as a result of the activities of any of the claimants for priority in the discovery of anesthesia? Without minimizing the obvious impact of the ability to provide painless surgery on patients and surgeons alike, the progress of surgery did not appear to be influenced in a qualitative manner as much as might be expected by the introduction of anesthesia. Almost a half-century elapsed before surgery advanced significantly beyond the stage it was at before the introduction of anesthesia in 1846.(57) Although surgical operations appeared to increase in frequency after the introduction of anesthesia in 1846, they were the same types of procedures as performed in preanesthetic days. And this was not an unmixed blessing. One writer believed that the greater number of procedures performed was associated with a higher incidence of wound infection, related to factors such as sequential operations in a single operating theatre and ward crowding. But this problem may have set the stage for hurdling the next important obstacle to safe surgery: the control of surgical infections.(58)

Thus it would appear that the claim for Morton as the discoverer of anesthesia advanced so passionately by Sir William Osler does not stand when evaluated by Osler's own criteria.

According to the French Academy of Sciences, priority for discovery of anesthesia should have gone to the individual who first unambiguously stated the concept that it was possible to render a patient insensitive to painful surgical stimulation. But a constraint should probably be placed on this criterion: the proposed method should be known to have the potential of being successful according to modern knowledge. This restriction would eliminate suggestions for methods and agents later known to be ineffective, such as those of Ugone da Lucca, Dioscorides and others among worthy predecessors from ages long past. (See anesthetics of the ancients in this volume). It would also enhance the likelihood that had the innovator been motivated to action, he might have enjoyed some success with his method.

What was the earliest proposal for anesthesia? Certainly not that of Morton (1846), nor those of Jackson (1846), Wells (1844), Long (1842), or Clarke (1842). The ideas of Hickman (1829) were clearly formulated and backed by experiment. The French Academy, re-evaluating his proposals in 1847, emphasized that he tried to publicize his theories by presenting them to a recognized scientific body without any attempt at personal financial advantage. That he was ignored was not his fault. Hickman stands as a likely candidate for priority. Yet several suggestions for anesthesia did antedate his.

William Wright, aurist, described his use of inhalation of ether vapor to suppress paroxysms of coughing associated with surgical instrumentation in an inflamed ear canal, as was noted above in the discussion of succesful anesthetics before 1846. This use of ether about 1820 to suppress a troublesome reflex and provide optimum operating conditions must be regarded as a *bona fide* anesthetic administration in a specific clinical situation, employing an agent whose efficacy was subsequently proved. Although Wright probably never attained the state of true surgical anesthesia in his patients, the concept of anesthesia is clearly recognizable in his ideas and performance. Wright described this use of ether in his books and applied this knowledge in his clinical practice, but made no further attempt to either publicize the practice or make any claim concerning discovery of anesthesia, even though he lived well into the anesthetic era.(59) William Wright would be worthy of consideration as discoverer of anesthesia.

Successful anesthetics administered before 1846, using techniques largely inapplicable in modern practice for one reason or another, such as exsanguination "*ad deliquium animi*" and "deadly intoxication,"were described earlier in this volume. The frequent references to these occasionally-applied methods of anesthesia confirm that the concept of inducing an anesthetic state prior to surgical intervention was widely appreciated years before etherization for anesthesia was introduced.

Opinions expressed by James Moore in his 1784 book on preventing or diminishing pain during operation by nerve compression have been discussed previously in this volume. There is no doubt that he fully appreciated the concept of surgical anesthesia. The method of accomplishing pain-free surgery which he developed at that time was tried on only one patient, but was likely to have been at least partially effective.(60) A strong case could be made for designating James Moore as the discoverer of anesthesia.(61) It was not for lack of trying that his pleas fell upon deaf ears.

Humphry Davy has been a popular nominee for the originator of anesthesia, on the basis of his statement published in 1800: "As nitrous oxide in its extensive operation appears capable of destroying physical pain, it may probably be used with advantage during surgical operations in which no great effusion of blood takes place."(62) Cartwright enthusiastically exclaimed: "Humphry Davy discovered anesthesia!"(63) Without minimizing Davy's other essential contributions to anesthesia, it appears logical to conclude that Davy did not fully appreciate the concept of surgical anesthesia and that his proposal could very well have been for a purpose quite different from patient ease and mitigation of pain during operation, as argued in the discussion of Humphry Davy elsewhere in this volume.(64)

But Davy was not alone in suggesting inhalation of a gas before surgical manipulation to facilitate accomplishment of the task at hand. It will be recalled how during a visit by Dr. Joseph Frank of Vienna to Thomas Beddoes in 1803, Beddoes expressed the idea of employing inhalation of hydro-carbonate gas (primarily carbon monoxide) in strangulated hernia, with a view to throwing the patient into syncope; and then of attempting the reduction of the intestine, while he remained in that state.(65) The suggestion was not purely theoretical. Beddoes had used hydrocarbonate gas in his pneumatic medical practice and was familiar with its effects, including its ability to produce syncope. Furthermore, Robert

Hamilton, also, suggested the inhalation of hydro-carbonate gas to temporarily assist patients to overcome the "distressing watchfulness" of hydrophobia and procure a little rest.(66) If one is willing to accept the dangers and probable high morbidity of carbon monoxide inhalation (which were known to Beddoes and Hamilton), then these represent real suggestions for inhalation of gases to produce anesthesia or sedation.

Moreover, Beddoes' idea for an anesthetic technique in managing strangulated hernia was probably not original with him. In 1795 Davies Giddy had written in a personal letter to Beddoes:

> "The power of heavy inflammable air,* as I take it, to diminish the secretions of excitability in the brain may possibly be applied to many useful purposes. May it not be used before painful operations?"(67)

Giddy thus envisaged the possibility of diminishing the response of the brain to surgery by prior inhalation of a depressant gas. This appears to be the first clear enunciation of the principle of surgical inhalation anesthesia in modern times. Should Davies Giddy then be selected as the discoverer of anesthesia?

The futility of attempting to designate a single individual as the discoverer of anesthesia should be apparent. This volume has recounted how the evolution of anesthesia proceeded over the centuries. Each new accomplishment brought effective anesthesia closer to reality and was based on the efforts of those who had gone before.

Virtually all valid discoveries have been due to more than one worker. Nobody started from scratch and nobody got very far ahead of the rest.(68) "In science," said Albert Einstein, "the work of the individual is so bound up with that of his scientific contemporaries that it appears almost as an impersonal product of his generation."

And why was the introduction of anesthesia into clinical practice delayed for nearly half a century after virtually all the physiological and chemical knowledge for its implementation had become available to physicians? There appears to be little reason why an anesthetic could not have been administered in 1800 or in 1820. Probably, the idea simply never occurred to anyone in a position to act who found the prospect of pain free surgery of sufficient interest — not until almost mid-century, when a small group of perceptive Americans began to pursue the problem.

Then there could be gentle, merciful sleep.

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*heavy inflammable air," or hydrocarbonate, was carbon monoxide gas, as opposed to "light inflammable air" which was hydrogen.

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