THE PRINCIPLES AND PRACTICE OF GASEOUS ANÆSTHETIC APPARATUS

A. CHARLES KING

SECOND EDITION

BAILLIÈRE, TINDALL & COX

To Dr. William B. Neff

with Compliments

A Charles King

May 1947.

THE PRINCIPLES OF GASEOUS ANÆSTHETIC APPARATUS

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BY

A. CHARLES KING

(OF A. CHARLES KING, LTD., 27, DEVONSHIRE STREET, LONDON, W.1
A SUBSIDIARY OF THE BRITISH OXYGEN CO., LTD.)

With a
Foreword by

I. W. MAGILL, C.V.O., D.Sc., M.B., D.A.

SENIOR ANÆSTHETIST WESTMINSTER AND BROMPTON CHEST HOSPITALS

SECOND EDITION

PUBLISHED FOR THE AUTHOR BY
BAILLIÈRE, TINDALL AND COX
LONDON: 7 & 8, HENRIETTA STREET, W.C.2
1946

First Edition	.	*October*, 1941
Reprinted	.	*April*, 1945
Second Edition	.	*April*, 1946

PRINTED IN GREAT BRITAIN

FOREWORD TO SECOND EDITION

I AM happy again to subscribe a brief foreword to Mr. King's book. Nothing changes very much in fundamental principles, and from my personal experience this second edition will be as welcome to-morrow as it was yesterday to all concerned and interested in the working and upkeep of anæsthetic apparatus.

I. W. MAGILL.

March, 1946.

FOREWORD TO FIRST EDITION

MR. A. CHARLES KING needs no introduction to those who are interested in Anæsthesia. In the minds of many his name is happily associated with a praiseworthy effort to concentrate under one roof all the armamentarium required by an anæsthetist.

The effort which Mr. King makes in this brochure to explain, in a simple manner, the working principles of anæsthetic apparatus will be welcomed, not only by the profession, but by orderlies and nurses who are concerned in the maintenance of apparatus and who may not have access to other sources of information.

The notes on " The Care of the Unconscious Patient " might well be read with advantage by nursing, ambulance and rescue workers who may be called to the assistance of a patient unconscious from causes other than Anæsthesia.

LONDON,
August, 1941.

I. W. MAGILL.

PREFACE TO SECOND EDITION

This handbook is intended to give to all members and associates of the Medical Profession who are interested in Anæsthesia a general idea of the functioning of apparatus and control of gases, both of which are necessary for the administration of a good anæsthetic.

In order that the handbook may be more lucid and of service to laymen, the history and theory of Anæsthesia is very briefly sketched.

Techniques are not included as they are outside the province of such a handbook. Proficiency in the administration of anæsthetics can be acquired only in the anæsthetic room and operating theatre and the less experienced anæsthetist may avail himself of every opportunity to practise (under supervision) the important technique of nitrous oxide and oxygen anæsthesia with or without supplementary ether, and to obtain such up-to-date text-books as :

"The Theory and Practice of Anæsthesia." M. D. Nosworthy, M.A., M.D., B.Ch.

"Handbook of Anæsthetics." R. J. Minnitt. M.D., D.A., and John Gillies, M.C., M.B., Ch.B. (Edinburgh), D.A.

"Essentials of General Anæsthesia." R. R. Macintosh, M.A., M.D. Oxon, F.R.C.S. Ed., D.A., and Freda B. Bannister, M.D., D.A.

"Recent Advances in Anæsthesia and Analgesia," C. Langton Hewer, M.B., B.S., D.A.

"Aids to Anæsthesia." Victor Goldman, M.R.C.S., L.R.C.P., D.A.

"Inhalation Anæsthesia." Arthur E. Guedel, M.D.

"Precautions against Anæsthetic Explosions in Operating Theatres." A Ministry of Health pamphlet published by H.M. Stationery Office, 1936.

A. C. K.

LONDON,

March, 1946.

CONTENTS

PRINCIPLES OF GASEOUS ANÆSTHETIC APPARATUS

THE history of attempts to produce unconsciousness as an aid to surgery dates back many hundreds of years. The Book of Genesis reads that " the Lord God caused a deep sleep to fall upon Adam, and he slept, and He took one of his ribs and closed up the flesh thereof." In the third century the Chinese performed operations, employing inhaled fumes of Indian hemp to produce insensibility.

To Joseph Priestley is credited the discovery of nitrous oxide in 1772 and oxygen in 1774, or at least, Priestley was the first man to separate oxygen from the red oxide of mercury.

There is a gap between the discovery of nitrous oxide and its application to the relief of pain. The *Boston Medical Journal* records that " Laughing Gas " was used in 1844 by Horace Wells in the extraction of teeth, the term " Laughing Gas " having been given to nitrous oxide by Humphry Davy in 1800. Although Hickman had experimented with animals in 1824 in Ludlow, Shropshire, it was not, however, until 1868 that the first major operation was performed under this agent.

In 1864, a Dental Association was founded in New York by Gardner Quincy Colton, for the painless extraction of teeth under nitrous oxide.

The use of the word "Anæsthesia" was suggested by Oliver Wendell Holmes in 1846 when he was Professor of Physiology and Anatomy at Harvard University and a friend of Morton, who was responsible for the first public operation conducted under ether anæsthesia. It is only within the last twenty years, however, that the art of keeping a patient suspended between life and death has become recognised as a speciality, calling for the use of accurately made apparatus of advanced technical design.

The modern theory holds that anæsthesia is a depression of the function of nerve cells, caused by a curtailment of their oxygen intake. Nitrous oxide, when inhaled, diffuses into the blood stream, and is distributed to the various parts of the body. It should be remembered that the cells of the brain metabolise more rapidly than all the other cells of the body, the brain centre, therefore, being the first to be affected.

Arthur E. Guedel, M.D., in his book "Inhalation Anæsthesia" shows how inhalation anæsthesia is divided into four stages, the first being the stage of analgesia, which is the period from the beginning of induction to the loss of consciousness.

The term " analgesia " implies the loss of the sense of pain without loss of consciousness or sense of touch ; mental control is present throughout this stage but becomes depressed until consciousness is lost. The second stage is one of delirium, or dreams. The third, or surgical stage is divided into four planes, the second and third being those in which the majority of operations take place. The fourth stage represents the period beginning with central respiratory paralysis and ending with cardiac failure and death. From this, it is possible to see that the secret of successful gaseous anæsthesia lies primarily in the immediate and accurate control and measurement of our agents, gas and oxygen.

Stage	Consciousness	
1	Analgesia	
2	Unconscious Excitement	
3	Plane 1	Light Anæsthesia
	2	Surgical Anæsthesia
	3	Deep Anæsthesia
	4	Profound Anæsthesia
4	Respiratory Paralysis	

MANUFACTURE OF NITROUS OXIDE AND OXYGEN

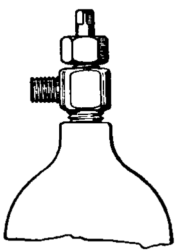
The process of manufacturing nitrous oxide is as follows: Ammonium nitrate is heated in a metal retort; the issuing gases, consisting of steam and nitrous oxide, together with various impurities, are passed through scrubbing towers where most of the impurities are removed, then to a gas-holder, and after final purification and drying compressed into cylinders, these also having been thoroughly dried. Extreme dryness is essential to ensure a regular flow of gas from a cylinder. The average purity of the gas is over 99·9 per cent., the small impurity being nitrogen.

Oxygen is extracted from the air by a process of liquefaction at low temperatures and rectification of the liquid so produced. The low temperature necessitated is reached by compressing and expanding air, either in an engine or merely through a throttling valve. As a consequence of rectification a liquid is procured which is almost pure oxygen at a temperature of -183° C. This liquid is evaporated, and the gas thus formed is brought to atmospheric temperature by passage through a heat interchanger. The gaseous oxygen is then compressed into steel cylinders.

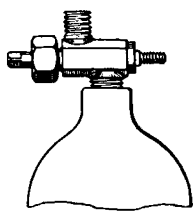
The pressures at which various gases are compressed into cylinders is as follows :

Oxygen	120 ats.	at approx.	15°C.
Helium	132	,,	,,
Nitrous Oxide	45	,,	,,
Carbon Dioxide	50	,,	,,
Ethylene	70	,,	,,
Cyclopropane	4.2	,,	,,

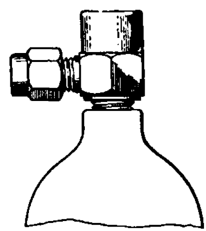
Cylinders are made in varying sizes and there are three types of valve, i.e. straight, angled and bull-nosed.



STRAIGHT
TYPE 7.
FIG. 1.



ANGLED
TYPE 8.
FIG. 2.



BULL-NOSED
FIG. 3.

The two former are always found on nitrous oxide cylinders, and on 15-, 30- and 60-gallon oxygen cylinders, and the latter on oxygen cylinders of 20-, 40-, 100- and 150-cubic feet capacity.

CYLINDER DATA

Nitrous Oxide

Type	Average Weight of Cylinders	Weight of Gas	Contents (galls.)	Contents (litres), approx.	Contents (cu. ft.), approx.
25 gallon	2 lb. 12 oz.	0 lb. $7\frac{1}{2}$ oz.	25	114	4
50 ,,	4 ,, 4 ,,	0 ,, 15 ,,	50	227	8
100 ,,	9 ,, 8 ,,	1 ,, 14 ,,	100	455	16
200 ,,	15 ,, 12 ,,	3 ,, 12 ,,	200	909	32
800 ,,	41 ,, 4 ,,	15 ,, 0 ,,	800	3,636	128

CYLINDER DATA—*continued*

OXYGEN

Type	Average Weight of Cylinders	Weight of Gas	Contents (galls.)	Contents (litres), approx.	Contents (cu. ft.), approx.
15 gallon	4 lb. 4 oz.	0·21 lb.	15	68	2
30 ,,	9 ,, 8 ,,	0·42 ,,	30	136	5
60 ,,	15 ,, 12 ,,	0·84 ,,	60	273	10
20 cu. ft.	25 ,, 4 ,,	1·68 ,,	125	567	20
40 ,,	41 ,, 4 ,,	3·36 ,,	250	1,134	40
100 ,,	99 ,, 12 ,,	8·4 ,,	625	2,835	100
150 ,,	146 ,, 12 ,,	12·6 ,,	937	4,252	150

It is always advisable to blow out any particles of dust which may have accumulated in the cavities of the cylinder valves by momentarily opening the cylinder before attaching a reducing or fine-adjustment valve.

The contents of all oxygen cylinders should be checked with a pressure gauge. A full cylinder will register 120 atmospheres (1,800 lb. per sq. in.). Nitrous oxide, carbon dioxide and cyclopropane cylinders have to be checked by weight, the reason being that these gases are compressed into their respective cylinders to pressures at which they assume the liquid condition at atmospheric temperature. The full and empty weights are clearly stamped on the necks of the cylinders and a suitable balance should be at hand for checking the contents.

All medical gas cylinders have either the name or the chemical symbol of the gas contained stencilled on their shoulders and standard colour markings to distinguish their contents, as follows:

Oxygen . . .	Black—white neck.
Oxygen with carbon dioxide mixture.	Black—green band below white neck.
Nitrous oxide . .	Black.
Carbon dioxide (inhalation).	Green—black base.

Carbon dioxide (snow making).	Green.
Helium	Medium brown.
Ethylene	Mauve—red neck.
Air	Light grey.
Cyclopropane . . .	Aluminium—red neck.

Gas is released from cylinders by three methods :

(1) Direct from the cylinder, the gas being turned on or off by means of a foot key (Fig. 4),

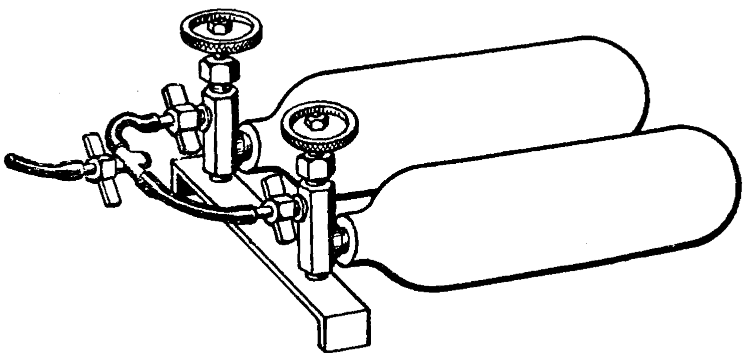


FIG. 4.

and led to a gas bag from which the patient inhales. This method is in common use to-day in many dental hospitals where nitrous oxide only is employed. There has been very little, if any, change here in the past forty to fifty years.

(2) Through the medium of a fine-adjustment valve (Fig. 5), that is, a valve provided with a

screw spindle so that the movement of the valve off its seating is slow, relative to the number of turns of the hand-wheel. Such an arrangement is—for many purposes—reasonably satisfactory. It has, however, one great disadvantage: if the apparatus is itself provided with control valves and these are turned off whilst gas is still flowing, pressure will build up in the connecting tubing which ultimately will be blown off its mount. When using a fine-adjustment valve make sure that it is the only master control.

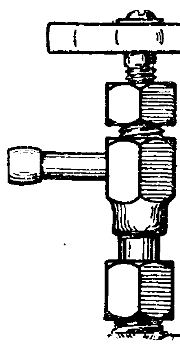
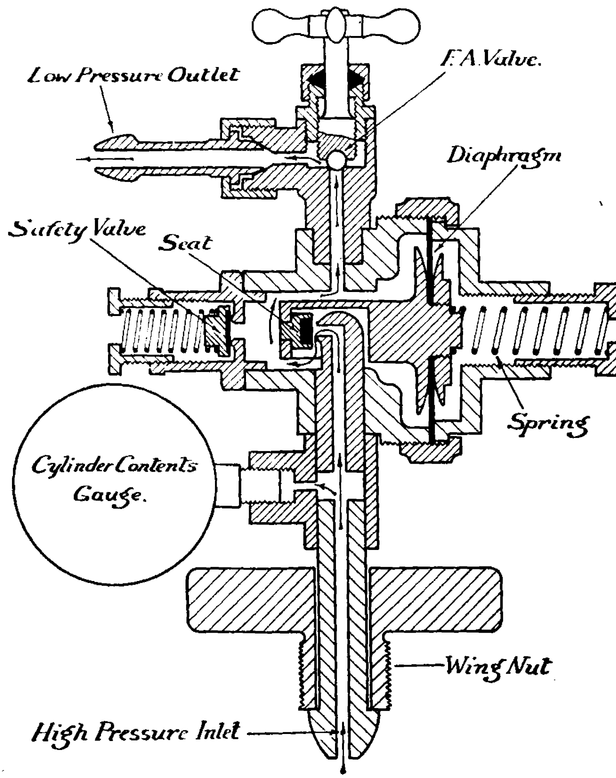


FIG. 5.

(3) Through the medium of a reduced-pressure valve (Fig. 6), this being the most satisfactory method of controlling the gas supply. This valve embodies an automatic pressure shut-off. Most, if not all, regulators incorporate a diaphragm of reinforced rubber or flexible metal which is connected to the valve. The working principle of this type of regulator with the valve coupled directly to the diaphragm may be followed in the cross-section drawing. It will be appreciated that with this arrangement (assuming the valve to be just clear of its seat and the gas outlet shut) low pressure would build up inside the valve

body, causing the diaphragm to pull the valve on to its seat, thus shutting off the gas supply and preventing any further rise in pressure. This may also be tested by pinching the end of a piece

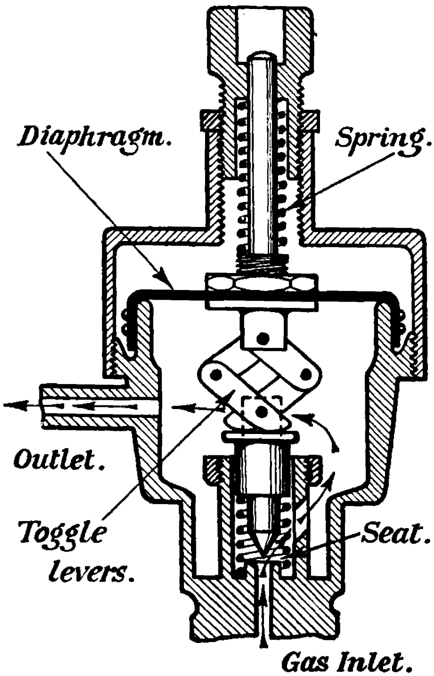


WORKING PRINCIPLE OF THE BRITISH OXYGEN COMPANY'S ENDURANCE REGULATOR

FIG. 6.

of rubber tubing attached to the regulator outlet ; the flow of gas may easily be stopped.

This is the most simple form of automatic



WORKING PRINCIPLE OF ADAM'S VALVE

Fig. 7.

shut-off valve ; in practice it is usual to add a spring behind the diaphragm to enable the pressure at which the diaphragm shuts off the valve to be increased. A screw is also employed to exert pressure on the spring. When the control valve or tap is opened, the effect of the spring is to force the valve off its seat, thus ensuring a clear passage for the gas. When the outlet is closed the pressure rises and loads the diaphragm until the spring is compressed and the valve shuts. The more the spring is compressed by the screw, the higher the shut-off pressure. In some types of regulators a scale is engraved on the shaft of the adjusting screw correlating spring tension and shut-off pressure.

Another type of regulator, the Adams' reducing valve (Fig. 7), which is to be found on the well-known Walton and Walton-Minnitt apparatus, embodies a more elastic diaphragm, the valve seating being closed by means of the lower arms on toggle levers. With this valve there is no pressure adjustment, as it is constructed to deliver and maintain a pressure of approximately 4 lb. per sq. in.

MEASUREMENT OF GASES

There are several methods, the earliest and most simple being the gauging of gas flow by observation of the number of bubbles emerging from a tube immersed in water—thus termed " Water-Sight-Feed " (Fig. 8). First mention of this type

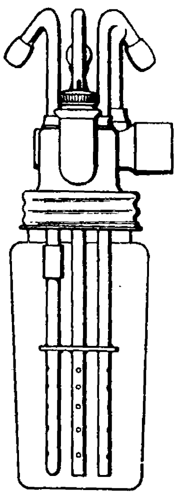


FIG. 8.

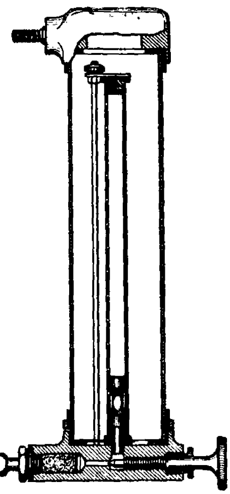


FIG. 9.

was made by Drs. Boothby and Cotton in America when describing Dr. Gwathmey's apparatus in *The Journal of Surgery, Gynæcology and Obstetrics* in October 1912.

Dry flowmeters have, in recent years, been very much to the fore. The Coxeter pattern (Fig. 9) consists of a vertical cylindrical glass tube, with perforations throughout its entire length, and a bobbin or float within, which rises in proportion to the gas flow, the gas escaping through those holes situated below the bobbin.

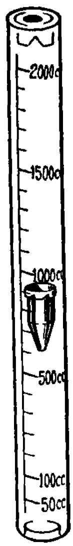


FIG. 10.

The Siebe Gorman and Rotameter type (Fig. 10) of flowmeters consist of vertical glass tubes with the bores tapering towards the lower ends. Within a tube of this description, a bobbin or float is held in suspension by the upward flow of gas, the gas being led away from the top of the tube. The height of these bobbins or floats indicates the actual rate of flow on a scale engraved on the glass tubes.

Both Heidbrink and Connell flowmeters are based on this principle, the former having an elongated float, and the latter two steel balls, the flowmeter tube being inclined approximately 10° to the horizontal.

Two other methods of measurement are termed "Water Depression" (orifice type) (Fig. 11) and "Flowmeter Gauge" (Fig. 12). The principle governing these is the measurement of a built-up pressure of gas behind a fixed orifice.

With the former method (which is employed by very few in this country) the built-up pressure is measured by depressing a column of water in a glass tube enclosed in a glass jar. The depth of depression is a measure of the driving force, and

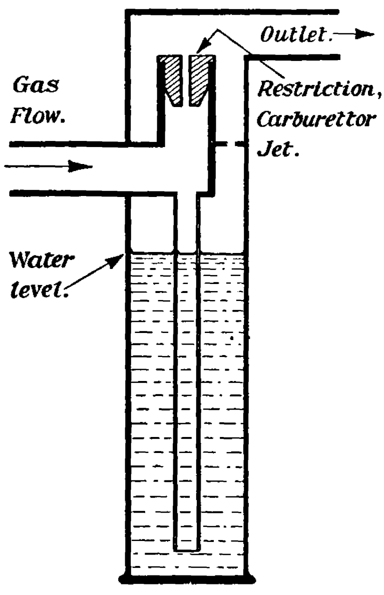


FIG. 11.

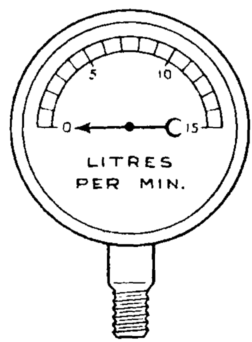


FIG. 12.

for a given orifice a fixed depression will give a constant flow. As the pressure is increased so will the flow according to the square law (flow^2 being proportional to the depression of water).

With the "Flowrate Gauge" the built-up

pressure behind the orifice is measured on a bourdon or similar type of gauge. The orifice is usually smaller and the pressure correspondingly higher.

FLOWRATE CONVERSION TABLE

Litres per Minute	Gallons per Hour	Cu. Ft. per Hour
0·25	3·3	0·528
0·5	6·6	1·056
0·75	9·9	1·584
1·0	13·2	2·112
2·0	26·4	4·224
3·0	39·6	6·336
4·0	52·8	8·448
5·0	66·0	10·560
6·0	79·2	12·672
7·0	92·4	14·784
8·0	105·6	16·896
9·0	118·8	19·008
10·0	132·0	21·12

100 GALLONS NITROUS OXIDE—455 LITRES

At:

1 litre	per minute	will last	7·5	hours.
2 litres	,,	,,	3·75	,,
3 ,,	,,	,,	2·5	,,
4 ,,	,,	,,	1·875	,,
5 ,,	,,	,,	1·5	,,
6 ,,	,,	,,	1·25	,,
7 ,,	,,	,,	1·0714	,,
8 ,,	,,	,,	0·937	,,

---

30 GALLONS OXYGEN—136 LITRES

At:

200 c.c.	per min.	will last	11·333	hours.
400 ,,	,,	,,	5·666	,,
600 ,,	,,	,,	3·777	,,
800 ,,	,,	,,	2·833	,,
1 litre	,,	,,	2·266	,,
2 litres	,,	,,	1·133	,,
3 ,,	,,	,,	0·755	,,
4 ,,	,,	,,	0·566	,,

---

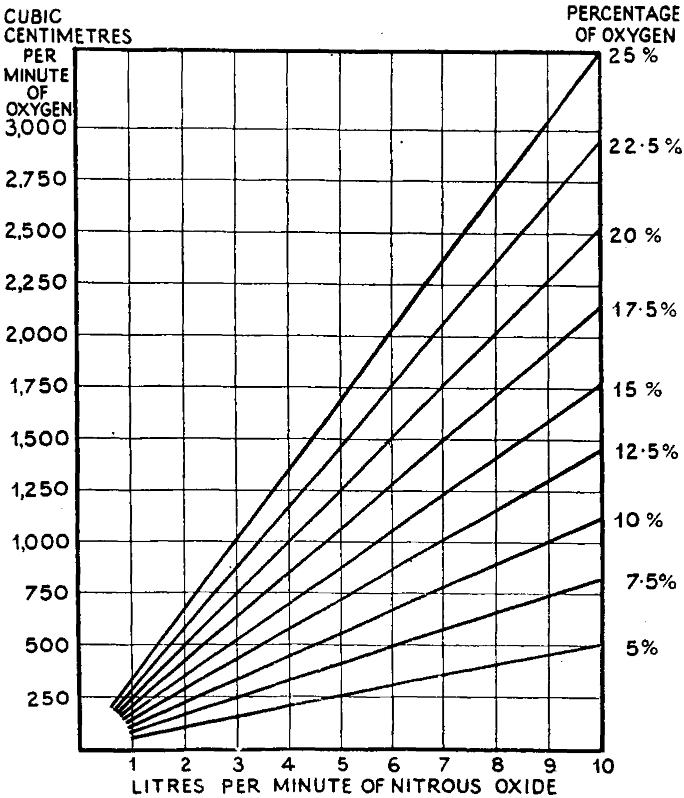
100 CU. FT. OXYGEN—2,835 LITRES

At :

2.0 litres per min. will last 23·5 hours.

2·5	„	„	„	19·0	„
3·0	„	„	„	16·0	„
3·5	„	„	„	13·5	„
4·0	„	„	„	11·75	„
4·5	„	„	„	10·5	„
5·0	„	„	„	9·5	„
5·5	„	„	„	8·5	„
6·0	„	„	„	8·0	„
6·5	„	„	„	7·25	„
7·0	„	„	„	6·75	„
7·5	„	„	„	6·25	„
8·0	„	„	„	6·0	„

PERCENTAGE CHART



ANÆSTHETIC MIXTURES

Gas and oxygen are frequently administered to-day with ether and chloroform, the most common method being to bubble the gases through the anæsthetic liquid, the amount of turbulence accounting for the strength of vaporisation of the anæsthetic. In order to fill the need for more flexibility in control, the bubble system has in recent years been elaborated in the Boyle apparatus by a piston device (Fig. 13).

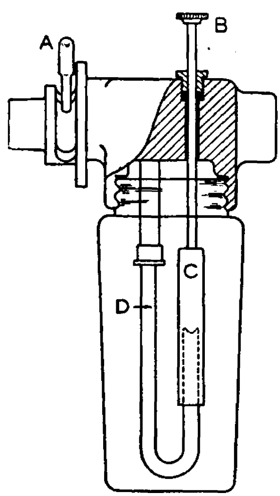


FIG. 13.

Instead of an inlet tube extending almost to the bottom of the anæsthetic bottle as in the water-sight-feed, the tube is " U "-shaped, D, with its outlet well above the surface of the liquid ; over this outlet an inverted cowl, C, is actuated by a plunger rod, B, protruding through a gland at the top of the bottle.

Gases are directed into, or by-passed, the anæsthetic bottle by means of control lever, A.

It will be seen from the illustration that when the plunger rod is down, the open end of the cowl is below the surface of the liquid and the gases will bubble through when maximum concentration of vapour is obtained. If the cowl is raised so that its open end is just above the liquid, gases will impinge on the surface and collect a medium concentration of vapour. The cowl may be raised still further when the gases will emerge above the surface, collecting the minimum of vapour.

In passing it may be mentioned that the inlet tube with cowl is not chrome plated but left polished, the reason being that as copper is a most powerful anti-catalyst ether coming into contact with it will not decompose so rapidly.

A water jacket is usually placed around an ether bottle to delay the cooling of the ether, as with a rapid flow of gas the ether becomes too cold to give off sufficient vapour. Hot water is undesirable.

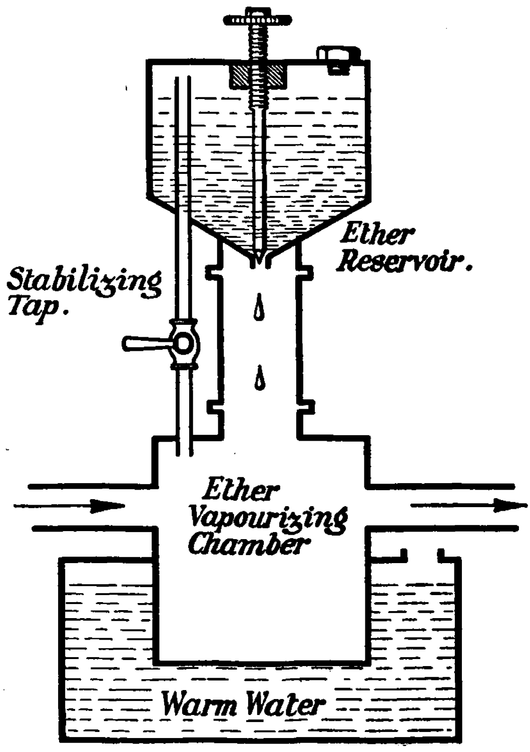


FIG. 14.

Another system employed in vaporising ether is by means of a drip feed attachment (Fig. 14). This consists of an ether reservoir and vaporising chamber, which can be surrounded, or partially so, by hot water contained either in a tank attached to the vaporiser, or in a removable bath. This type of apparatus is favoured by those who prefer the dosimetric method where they can count the actual number of drops of ether passed into the circuit.

REBREATHING

A corrugated breathing tube is now universally employed for delivery of the gaseous mixtures to the patient ; and to this tube is attached the face-piece at one end and the rebreathing bag at the other. The rebreathing bag serves as a reservoir for both the patient's exhalations and the incoming gases. Rebreathing is not only economical but physiologically sound in that it prevents the patient suffering from carbon dioxide deficiency. The amount of rebreathing is determined by (*a*) volume of gases flowing, and (*b*) by adjustment of the expiratory valve, the latter preferably being placed at the face-piece end.

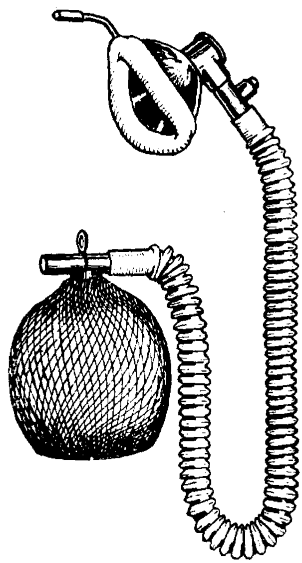


FIG. 15.

Complete rebreathing would not only deprive the patient of oxygen but would build up the percentage of his exhaled carbon dioxide and in time cause asphyxia.

CARBON DIOXIDE ABSORPTION

The complete rebreathing of anæsthetic mixtures with absorption of carbon dioxide is an example of an improvement in the administration of inhalation anæsthesia that was not widely popular for more than two decades after its original description. Introduced in the laboratory by Jackson in 1915 and applied clinically by Waters in 1923, the carbon dioxide absorption technique in now being universally accepted. Its acceptance was accelerated by the introduction of cyclopropane in 1933, although Dr. C. Langton Hewer had for some time previously been conducting researches into closed circuit anæsthetics with ethylene, and in 1925 published observations of 120 administrations.

Carbon dioxide absorption has many advantages : it conserves the patient's moisture and heat ; there is no cooling of the patient's respiratory tract by cold ether vapour ; shock and respiratory effort are very much reduced and the resulting anæsthesia being a much closer approximation to normal sleep.

Waters experimented for many years to perfect the technique of absorption of carbon dioxide from anæsthetic mixtures, and evolved a soda lime canister, the dimensions of which conform to physiological requirements. This canister is interposed between the face-piece and rebreathing bag and is commonly known as the " to-and-fro "

of the exhaled breath is as follows :

from patient to :—

A. Uni-directional valve.
B. Soda lime canister.
C. Rebreathing bag.
D. Ether vaporiser.

E. Uni-directional valve.

Back to patient, anæsthetic gases returning to the patient with the addition of the basal oxygen flow and any new gas required to maintain or deepen anæsthesia.

FIG. 17.

Carbon dioxide absorption with nitrous oxide and oxygen calls for a very high degree of skill on the part of the anæsthetist. Nevertheless, it is possible, by this method, to economise considerably in gas consumption. With this principle as already shown, the measurement of oxygen is of immense importance, no two people needing the same amount to maintain life. The requirements of each patient must be carefully watched, the average being in the neighbourhood of 250 c.c. per minute. If too much oxygen is given the anæsthetic gas will be diluted, with the consequent lightening of anæsthesia. If, however, too little oxygen is administered the patient will suffer from " oxygen want " and approach the danger area.

The carbon dioxide absorption method is, incidentally, the only one whereby cyclopropane may be economically administered, since cyclopropane costs twenty-five times as much per gallon as nitrous oxide.

INTERMITTENT FLOW MACHINES

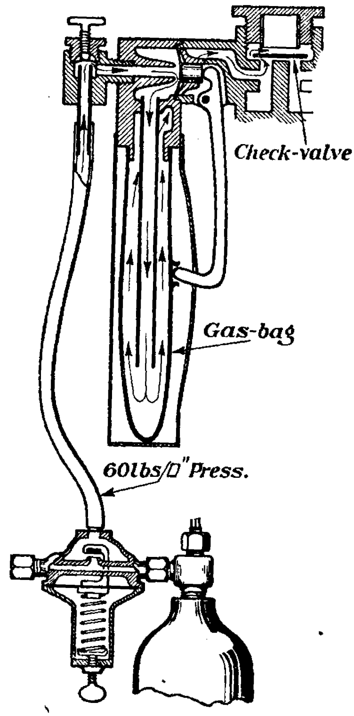
Previous chapters have dealt with principles governing what is termed " Continuous Flow " apparatus and cover every form of apparatus other than " Intermittent."

The difference between these two classes can be summarised thus : Continuous—where the gas flows continuously from the cylinder at a rate controlled by the anæsthetist ; and Intermittent —where the gas flow is controlled by the patient's respirations.

The essential requirements of an intermittent flow machine are firstly that it shall be capable of delivering the gases with the minimum inspiratory effort on the part of the patient and at a rate high enough to supply the maximum tidal flow called for by the most robust patient. Secondly that the pressure at which the machine delivers the gas shall be easily varied from a slight negative or suction pressure to a positive pressure of about 15 in. water gauge. Thirdly the percentage shall be reasonably constant at all flows and pressures.

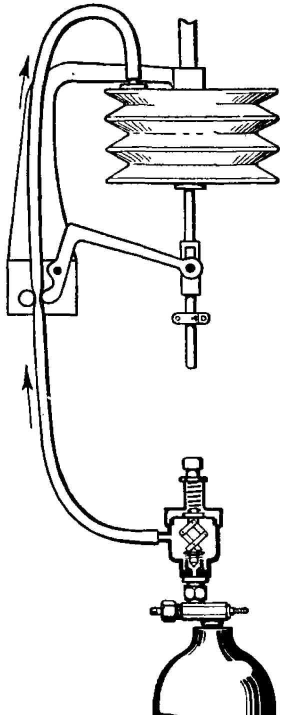
Two machines which fill these conditions to a high degree are the Walton machine made in England, and the McKesson made in America.

While the underlying principle in the two



McKESSON PRINCIPLE

Fig. 18.



WALTON PRINCIPLE

FIG. 19.

machines is similar there are interesting differences in mechanical detail.

The McKesson machine first reduces the high and variable pressure in the cylinder to 60 lb. per sq. in. by means of an automatic reducing valve. This pressure (now approximately constant at all cylinder pressures) is still further reduced by means of a gas bag which, expanding on filling, cuts off further supply of gas by means of a lever closing down a rubber diaphragm on to a valve seat. The action of this stage will be seen from the diagram (Fig. 18).

When the machine is set to low pressure the pressure in the gas bag is about 1–2-in. water gauge. There are two of these two-stage pressure-reduction units, one for nitrous oxide and one for oxygen. The outlet of the nitrous oxide gas bag passes to one side and the outlet of the oxygen gas bag to the other side of the mixing chamber. By means of rotating a ported drum in the mixing chamber the relative areas of the oxygen and nitrous oxide ports can be varied and this causes an alteration to the percentage of nitrous oxide in the mixture. Both gases are prevented from leaving the machine set at low pressure by a check valve, the weight of which is sufficient to hold back the gases at this pressure. On applying suction, however, the valve lifts and the gas flows from the machine at the rate demanded by the patient. Pressure in the gas bags is increased by two automatic levers being directed inwards towards the bags by means of a central spring control.

The Walton machine first reduces the cylinder pressure to 5 lb. per sq. in. by means of a low pressure automatic reducing valve. Rubber tube passes gas at this pressure through a pinch cock to a bellows type gas bag, the top plate of which is fixed and the bottom free. The bottom plate is connected to the pinch cock by means of levers and the weight of the plate and its levers is sufficient to keep the pinch cock closed.

Two of these units, one for nitrous oxide and one for oxygen are coupled to a mixing chamber similar in operation to the McKesson except that no check valve on the mixer outlet is necessary. When the patient inspires the bottom plate is raised by suction and gas is allowed to flow into the bag. As the area of the bottom plate is large a very slight suction spread over this area will open the pinch cock so that the machine is "light to breathe from." Pressure increase is effected by means of a foot control operating a cam which makes it necessary for the bottom plate to drop further against a spring before the pinch cock is closed.

Connected to the oxygen unit is a by-pass valve, which will allow, by pushing a press button, pure oxygen under pressure to be delivered direct through the corrugated tube to the face-piece.

In order that there will be always an uninterrupted supply of gas the machine is fitted with two 60-gallon oxygen and two 200-gallon nitrous oxide cylinders. A high-pressure gauge shows the contents of oxygen cylinder in use. On the nitrous oxide side an indicator is provided which shows whether nitrous oxide is being supplied by the machine or whether it is cut off, either due to the cylinders not being turned on or to their being exhausted.

There is also an automatic change-over system which operates as follows: A regulator is connected to each of the two nitrous oxide cylinder outlets, that is one to the " Running " and one to the " Reserve " cylinder. The regulator on the " Running " cylinder is set at 6 lb. per sq. in. delivery pressure and the " Reserve " to 4 lb. per sq. in. While there is any gas in the " Running " cylinder the " Reserve " regulator is held closed because its outlet pressure is kept above 4 lb. per sq. in. by the " Running " regulator set to the higher pressure of 6 lb. per sq. in. When the " Running " cylinder becomes empty the regulator pressure drops until it reaches 4 lb. per sq. in., at which pressure the " Reserve " regulator cuts in and commences to deliver gas.

The Portanaest Machine is similar in principle to the Walton Machine but is much smaller for portability. After gas pressure has been reduced from cylinder pressure to 5 lb. per sq. inch by

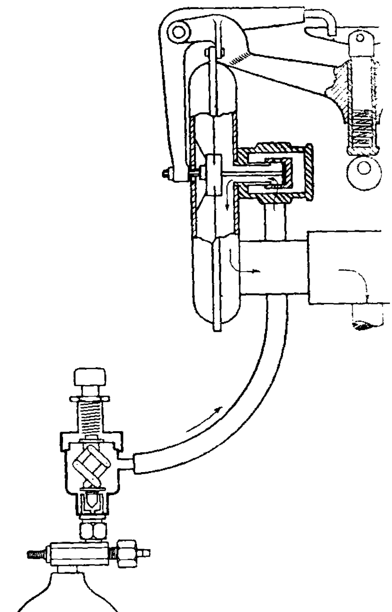


FIG. 20.

means of low-pressure automatic-reducing valves it passes to a lung-operated control valve. This lung-operated control valve inhibits the flow of gas until the patient inspires.

As the patient inspires the diaphragm-operated control valve is drawn inwards. This movement lifts the valve and allows the gas to flow. The diaphragm is large and the valve seating and gas pressure small and therefore very little inspiratory effort is necessary.

There are two of these units, one for nitrous oxide and one for oxygen, the outlets of which are connected to a mixing chamber similar to the one used on the Walton. The mixing chamber can be set at any desired percentage of oxygen and nitrous oxide so that as the patient inspires the desired proportions will be delivered.

The machine can be set to deliver a continuous flow of gas at any predetermined pressure. This is done by rotating a cam which, through a spring, causes the lung control valves to be lifted and, by a series of levers, balances out the pressures on the two diaphragms.

THE INJECTOR VALVE

The principle of the Bunsen Burner has been applied in devising apparatus for mixing gases accurately where one of the constituents is available under pressure. The diagram will serve to illustrate the principle.

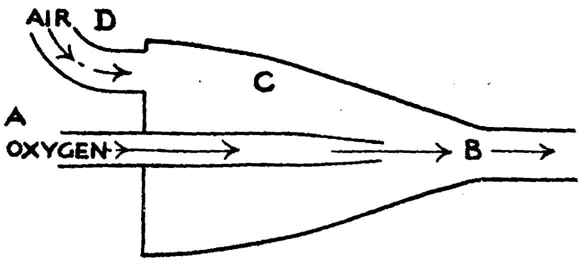


FIG. 21.

The compressed gas supplied from a cylinder and regulated by means of a pressure reducing valve is injected from a nozzle, A, at high velocity into a venturi-shaped diffuser, B, where it expands and creates a partial vacuum in a mixing chamber, C. Air is thus drawn in through an aperture, D, and mixes with the injected oxygen. The percentage of air entrained varies with the size of the aperture but is constant in relation to the flowrate of injected gas.

Such apparatus may be employed in mixing any desired gases provided that one is compressed and the other at atmospheric pressure.

EXPLOSION RISKS

Accidents due to anæsthetic explosions are fortunately rare in England but precautions should be taken to ensure against such possibilities.

Accidents come under two categories :

Explosions.
Fires.

Explosions can occur either by static conditions or from electrical apparatus (diathermy, illuminating) or through faulty electrical connections in the theatre. Extreme care should be taken, therefore, when mixtures of oxygen and ether or cyclopropane are used.

Explosions occur usually with reducing valves igniting through friction set up by dust and grit. To guard against these, cylinder valve cavities should be blown out before attaching reducing valves and all reducing valves should be returned to the makers at least every two years.

A Ministry of Health pamplet $\frac{\text{Memo. 191}}{\text{MED.}}$ on " Precautions against Anæsthetic Explosions in Operating Theatres " was published by H.M. Stationery Office, 1936.

THE CARE OF THE UNCONSCIOUS PATIENT

During induction and maintenance of anæsthesia the care of the patient is naturally in the hands of the anæsthetist. During transit to bed, however, through corridors and by elevators, many an untoward incident might be prevented by prompt action on the part of an intelligent nurse or orderly. Thus, whilst the maintenance of a free airway is recognised as of paramount importance in the operating theatre, it is none the less imperative at all times to prevent obstruction of the breathing until the patient has recovered sufficiently to do so himself.

Here it should be pointed out that the observation of respiratory movement alone is not sufficient. It is necessary to be sure that air is freely entering the patient's lungs ; this can be proved by listening carefully whilst respiratory movements are taking place. If no sounds are audible some obstruction may be present and in such a case medical help would naturally be summoned, but, meanwhile, it is a simple matter to support the jaw and turn the patient's head to one side to ensure easy expulsion of vomitus. Even when a pharyngeal airway is in position this simple manœuvre may be necessary to remedy obstructions.

In order to avoid circulatory collapse, which may suddenly occur during recovery from anæsthesia, the patient's head should be kept low until consciousness has fully returned.

CYCLOPROPANE

The anæsthetic proporties of cyclopropane were first demonstrated by Lucas and Henderson at Toronto ; its use was developed by anæsthetists in America.

Cyclopropane is a colourless gas, heavier than air, with a not unpleasant naphtha-like odour, having a specific gravity of 1·46. Its formula is C_3H_6, and it is supplied as a liquid compressed in cylinders at a pressure of approximately 85 lb. per square inch at 70° F., 3½ gallons weighing approximately 1 ounce.

It is flammable, but no more so than ether, and is explosive in mixtures with oxygen or air. Precautions must be taken, therefore, as with other inflammable anæsthetics, to eliminate sources of ignition and its use with the cautery or diathermy is definitely contra-indicated.

Usually cyclopropane-oxygen is administered in a proportion of approximately 15 per cent. cyclopropane to 85 per cent. oxygen or oxygen-air.

CHEMICAL FORMULÆ AND SPECIFIC GRAVITY (AIR = 1)

Chloroform, $CHCl_3$	4·12
Ether, $(C_2H_5)_2O$	2·6
Ethylene, C_2H_4	0·97
Cyclopropane, C_3H_6	1·46
Helium, He	0·138
Nitrogen, N_2	0·967
Carbon dioxide, CO_2	1·5
Nitrous oxide, N_2O	1·53
Vinyl ether, $(C_2H_3)_2O$	2·2

AIR BY VOLUME (DRY)

O_2	20·93	per cent.
N_2	78·10	,,
CO_2	0·03	,,
Rare gases	0·94	,,

Inspired Air-O_2 158 mm. H.g.
Expired Air-O_2 116 mm. H.g.
Area of Alveolo 100 sq. metres.

AIRWAY (MALE)

Distance from lips to larynx . .	12–13 cms.
Length of larynx	4–5 ,,
Larynx to carina	12–14 ,,
Diameter of trachea . . .	2·5 ,,

Resting minute volume exchange : 8–10 litres per minute.

Tidal air : 500 c.c. equals volume of an ordinary inspiration or expiration.

Capacity of both lungs : 4 to 5 litres.

Dead space : air in trachea and pharynx, 150 c.c.

Vital capacity : from the end of the maximum inspiration to the end of the maximum expiration, 3·500 c.c.

Reserve air : from the end of the ordinary expiration to the end of the maximum expiration, 1·500 c.c.

Residual air : part left after maximum expiration, 1·500 c.c.

GLOSSARY

Absolute zero .	-273° C.
Acapnia .	Diminished CO_2 in blood.
Flash point	Lowest temperature at which vapour ignites.
Anoxæmia	Oxygen want.
Anoxia .	Oxygen want in tissue.
Apnœa .	Respiratory cessation.
Amnesia .	Loss of memory.
Arhythmia	Irregularity of breathing or heart.
Bradycardia	Slow pulse rate.
Dyspnœa	Shortness of breath.
Hyperpnœa	Exaggerated respiratory movements.

Printed in Great Britain by William Clowes and Sons, Limited,
Beccles, for Baillière, Tindall and Cox.