7
Clinical use of anaesthetic equipment[1]

This chapter deals with the safe *clinical* use of the sort of anaesthetic equipment best suited for and most likely to be found in a district hospital. It should be read in association with Chapter 15 which deals with the technical aspects of equipment maintenance and gas supplies. All equipment will rapidly deteriorate and become dangerous unless it is regularly inspected, maintained, and repaired, so the anaesthetist working alone in a small hospital must take responsibility both for care of patients and the upkeep of apparatus.

Draw-over apparatus

Two fundamental pieces of equipment are needed for draw-over inhalational anaesthesia: a vaporizing device for the anaesthetic and an SIB to ventilate the patient's lungs. These must be linked together and to the patient by a breathing system containing one or more one-way valves (to prevent the patient from breathing out through the vaporizer). The breathing system must connect to the patient's airway at its outlet via a breathing valve and face mask or tracheal tube, and the inlet to the system must be open to the atmosphere to allow air to be drawn in, either by the patient's inspiratory effort or by the recoil of the SIB. Various types of apparatus are commercially available for draw-over use; some examples are shown in Fig. 7.1.

Vaporizers

For effective and safe use in a draw-over system, a vaporizer must have a low resistance to gas flow (since air must be drawn through it by the patient's inspiration), and it must be capable of accurately delivering the required concentration of vapour despite the wide fluctuations in flow that occur during the inspiratory period. The range of vaporizers currently in use includes the EMO (Epstein, Macintosh, Oxford), OMV (Oxford Miniature Vaporizer), and PAC series (Fig. 7.2 & 7.3). The OMV and EMO have a wide application, as they can also be used with continuous-flow anaesthetic systems. Vaporizers with a high internal resistance (for example the "Tec" series, Boyle's bottle, and Dräger Vapor) are completely unsuitable for draw-over use and must never be used for draw-over anaesthesia, as the patient cannot breathe through them.

When a volatile anaesthetic liquid is vaporized, heat is lost as latent heat of vaporization. If this heat loss is not compensated for, the vaporizer and contents will

[1] In some cases, the breathing valves, ventilating apparatus and vaporizers described in this chapter (and elsewhere in the book) have been identified by the manufacturer's name or trademark. However, this does not imply that such products are endorsed or recommended by WHO or the author in preference to others of a similar nature that are not mentioned. Rather, the specific products mentioned represent those that are known to the author to be in common use in district hospitals with limited resources. In the event that there are others in common use, WHO would be pleased to be so informed for the purpose of including a description of their use in future editions of this book.

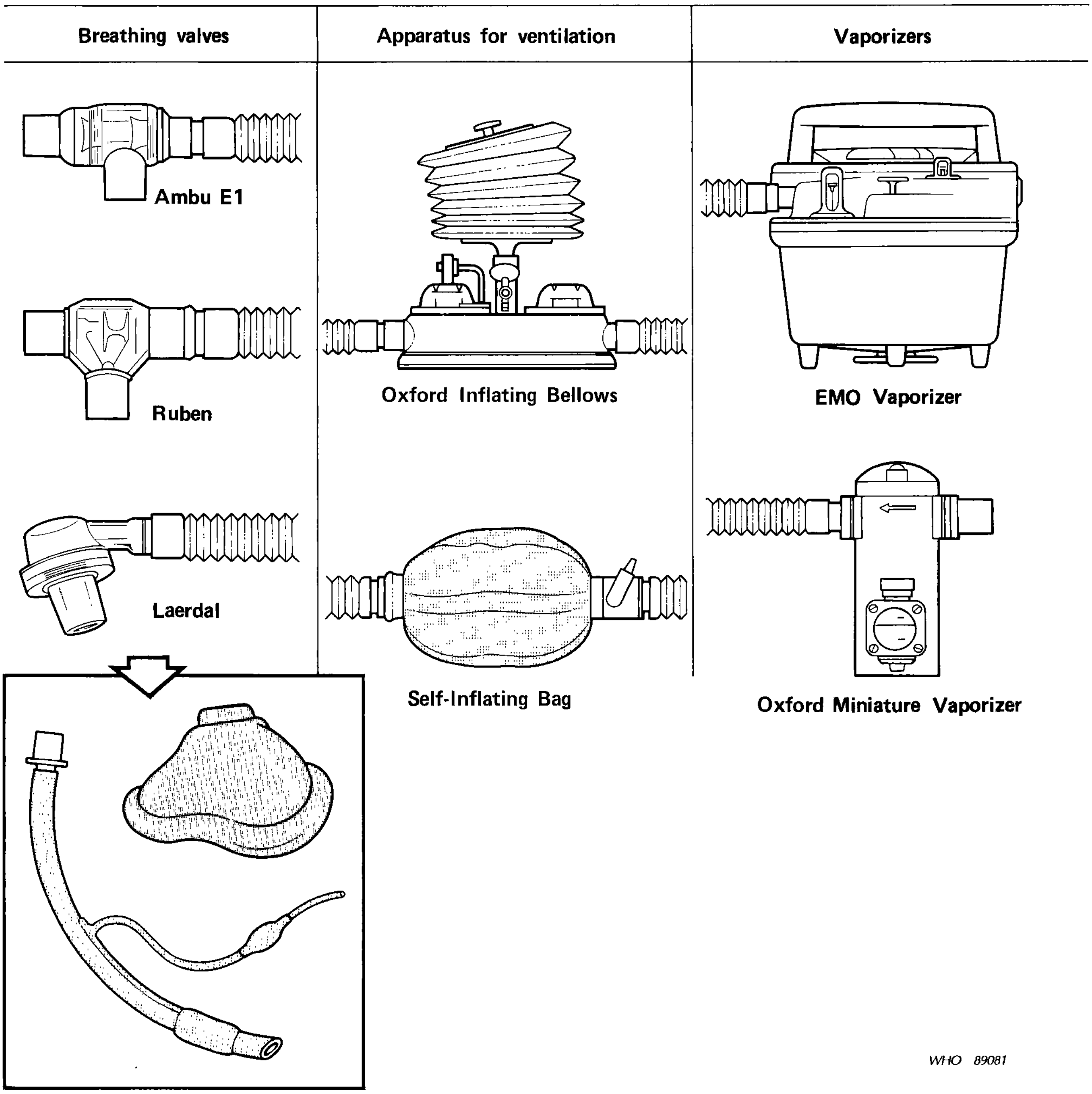
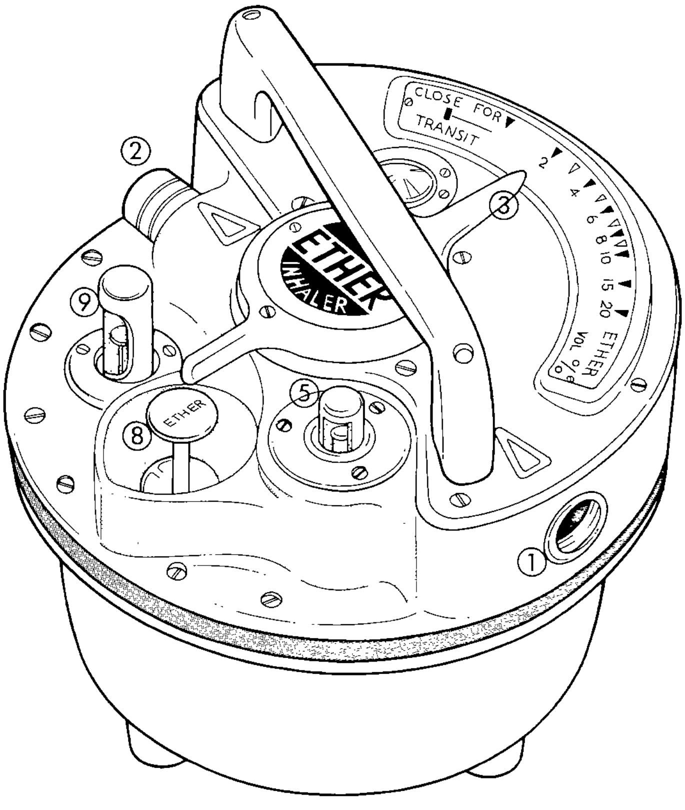
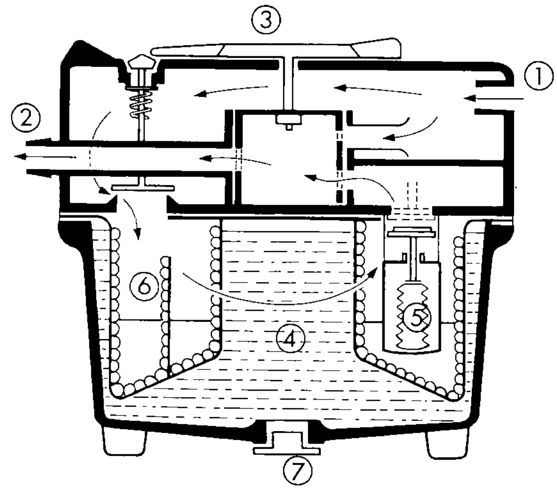


Fig. 7.1. Draw-over anaesthesia systems.

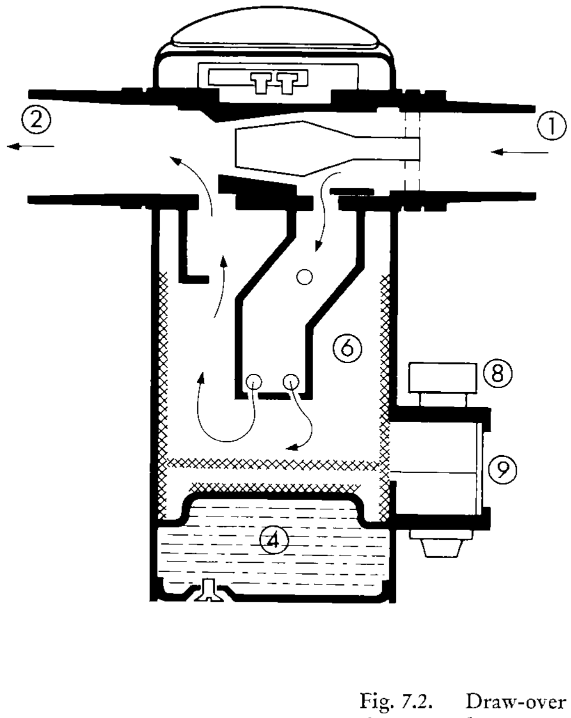
cool. This will result in a rapid fall-off of the concentration of vapour delivered, since the vapour pressure of the anaesthetic falls with temperature. To prevent this from occurring or to minimize its effects, most draw-over vaporizers have a thermal compensation or buffering system or both. Thermal buffering is the provision in the vaporizer of a mass of substance of high specific heat capacity (usually copper or water) that resists sudden changes in temperature. Thermo-compensation is achieved by building into the design of the vaporizer a thermostatically operated valve to control the amount of air entering the vaporizing chamber and keep constant the concentration of vapour delivered. The EMO ether vaporizer (Fig. 7.2) uses both thermocompensation and thermal buffering, with water as the heat reservoir. (New vaporizers are sent from the factory with the water chamber empty, and the first user must fill the water chamber in accordance with the manufacturer's instructions.) The thermocompensation valve of the EMO is automatic and can be seen through a small window on top of the vaporizer, which also indicates whether the vaporizer is within its thermal

EMO VAPORIZER





OXFORD MINIATURE VAPORIZER



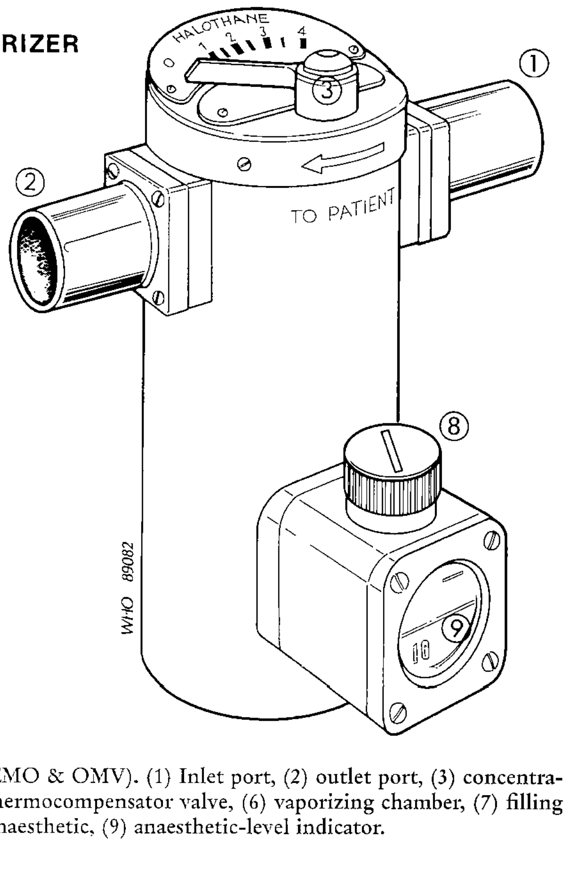


Fig. 7.2. Draw-over vaporizers (EMO & OMV). (1) Inlet port, (2) outlet port, (3) concentration control, (4) water jacket, (5) thermocompensator valve, (6) vaporizing chamber, (7) filling port for water, (8) filling port for anaesthetic, (9) anaesthetic-level indicator.

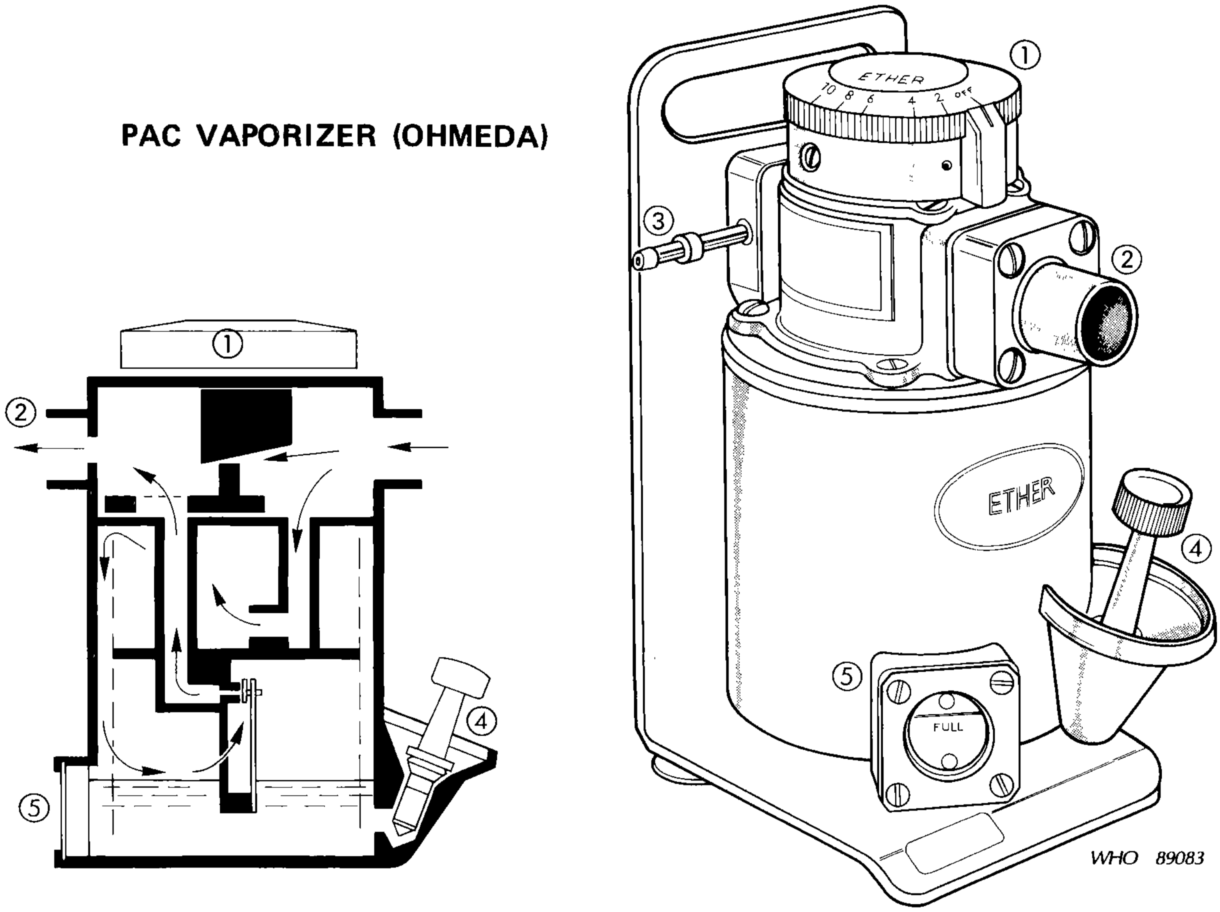


Fig. 7.3. PAC draw-over vaporizer. (1) Concentration control, (2) outlet connector and one-way valve (inlet opposite), (3) port for oxygen enrichment, (4) filling port, (5) filling gauge.

working range of 10–30 °C (Fig. 7.4). In normal use a black ring should show at the window. If the vaporizer overheats, for example by being left in direct sun on a hot day, a red ring also appears, and the vaporizer must be cooled before use. If the vaporizer becomes too cold, for example by being left in an aircraft luggage bay, the black ring disappears, and only an aluminium disc is visible; the vaporizer must then be allowed to warm up before use. If the black ring is not showing and the vaporizer does not appear cold, the thermocompensation valve (TC valve) may have fractured and need replacement (normal valve life is about 10 years). Replacement is relatively simple and does not require return of the vaporizer to the manufacturer.

The PAC series vaporizers use automatic thermocompensation and, if their accuracy is to be ensured, should be serviced only by a manufacturer's agent. The OMV does not have full thermocompensation, but changes in temperature are minimized by thermal buffering with a mixture of water and antifreeze, which is put into the core of the vaporizer during manufacture and needs no further attention from the user. The output concentrations of the vaporizer are controlled with a pointer that moves over a graduated scale.

It is possible to connect two vaporizers in series, but *never* connect any vaporizer containing halothane to the *inlet* port of the EMO, since if halothane enters the EMO it rapidly causes severe corrosion. It is perfectly safe to connect a halothane vaporizer such as an OMV to the outlet port of the EMO (Fig. 7.5). In fact, the OMV was designed to be used in this position.

During anaesthesia, it may become necessary to refill the vaporizer with anaesthetic liquid. You must first turn the concentration control to the zero position

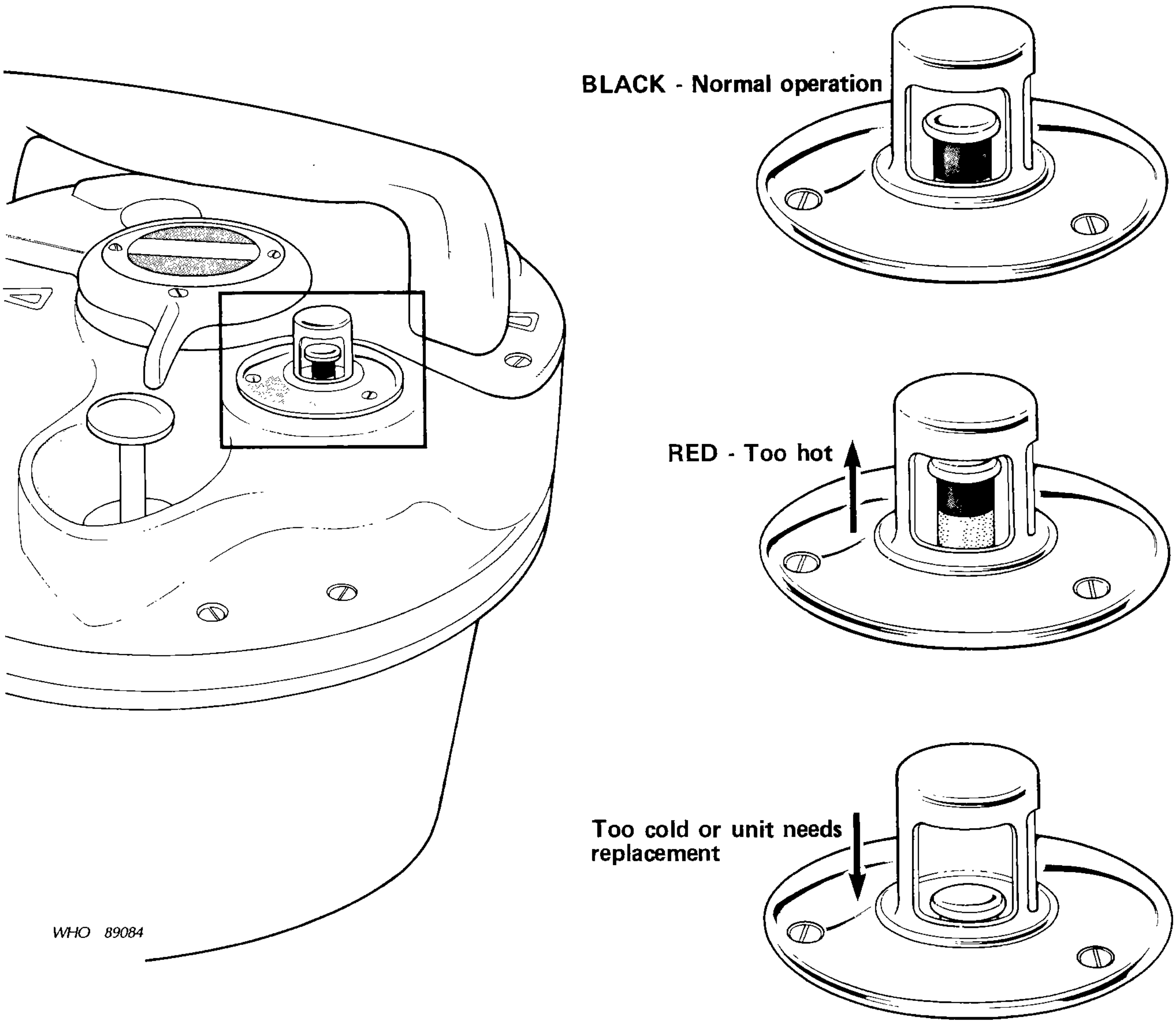


Fig. 7.4. Thermocompensation valve and temperature indicator on the EMO vaporizer.

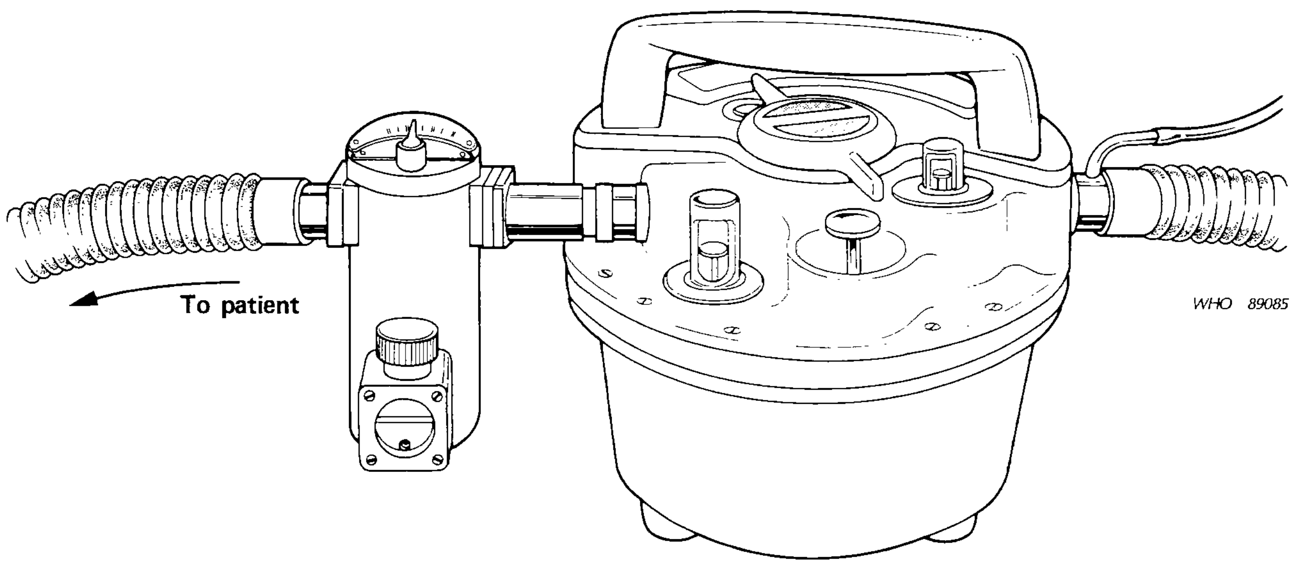


Fig. 7.5. The OMV connected to the outlet port of the EMO.

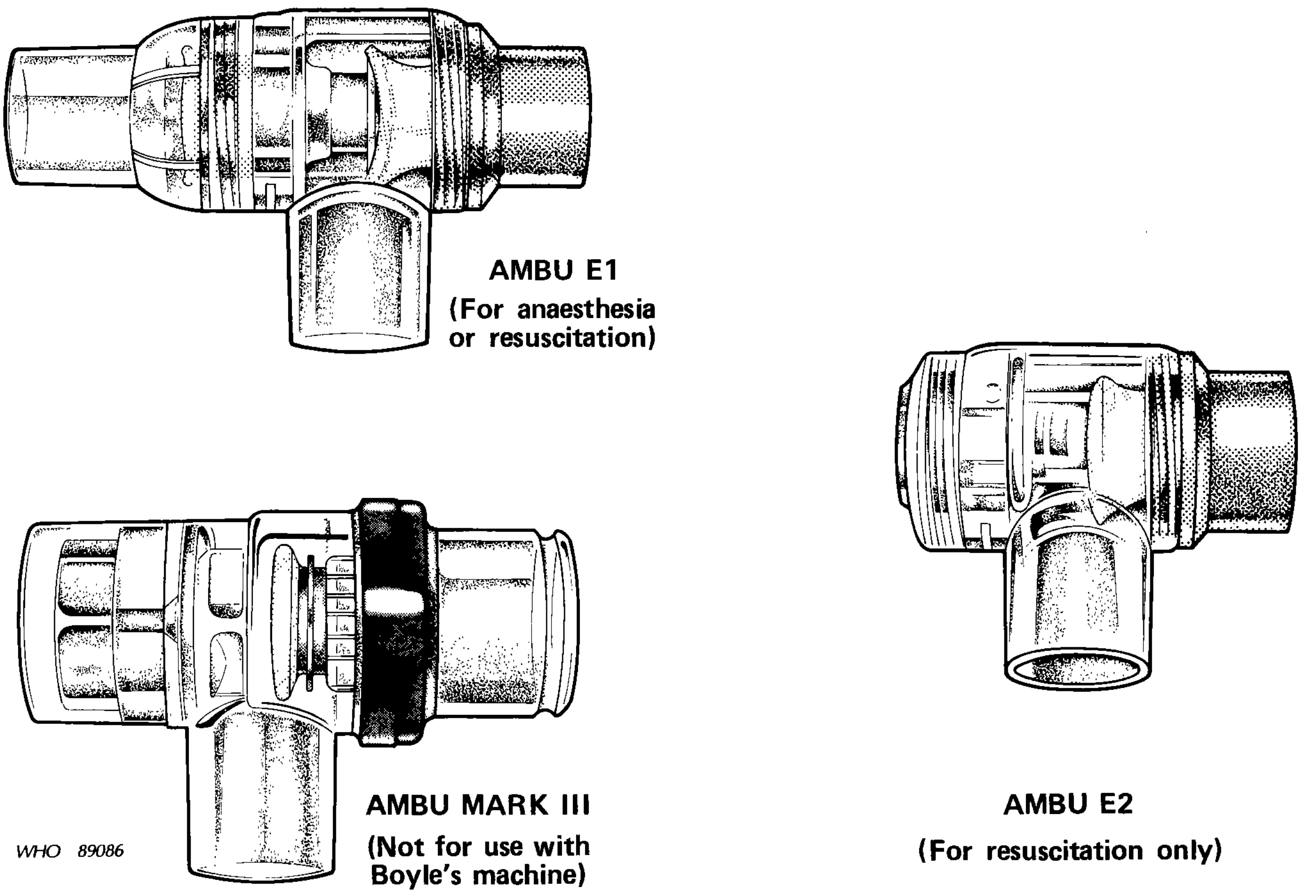


Fig. 7.6. Types of Ambu valve.

before opening the filling port. If you fail to do so, air will be drawn into the vaporizing chamber and a dangerously high concentration of anaesthetic will be delivered to the patient. For the same reason, you must never use a vaporizer that has no filling plug or that has any route through which air can enter accidentally, for example a broken glass window on the filling gauge.

Breathing systems and an important note about valves

The purpose of the breathing system (formerly called the breathing circuit) is to deliver anaesthetic vapour from the vaporizer to the patient, to pass the patient's expired gas into the atmosphere, and to provide a method of giving controlled ventilation (IPPV) when muscle relaxants are in use or for resuscitation. The breathing system contains several valves: one valve connects the patient's airway to the system; another one or two are built into the SIB; and certain vaporizers, for example the PAC system, have their own one-way valves.

In principle, at least two valves are needed in a breathing system to make gas flow in the correct direction. A universal breathing valve (see Fig. 2.10, p. 18) at the patient's end of the system ensures that, during spontaneous or controlled ventilation, gas always reaches the patient from the vaporizer and passes out into the atmosphere (preferably through an antipollution system). You are strongly recommended to use a universal breathing valve for all patients. [Beware of confusing the Ambu E1 (anaesthesia) valve with the E2 (resuscitation only) valve (Fig. 7.6). The E2 valve is of no use for anaesthesia, as it allows the patient to breathe in atmospheric air from downstream. The anaesthetic valve has two sets of yellow valves inside, the resuscitation valve only one.]

A second one-way valve is needed to prevent gas from flowing into the vaporizer, rather than into the patient, during IPPV. In the PAC system, this

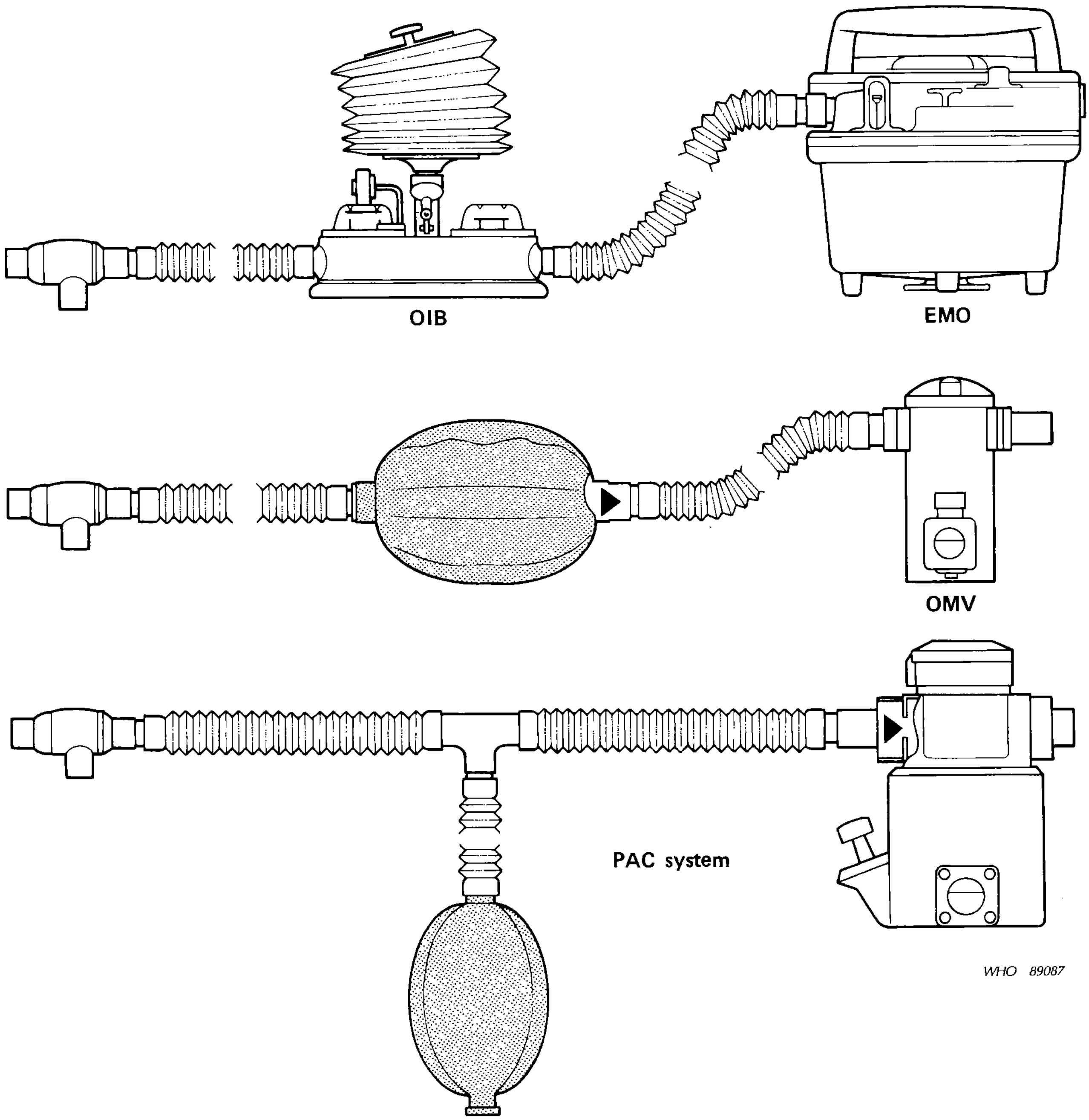


Fig. 7.7. Breathing systems (OIB, Oxford inflating bellows).

second valve is built into the vaporizer itself (see (2) in Fig. 7.3, p. 60) and the SIB can be mounted on a T-piece. The EMO does not have a built-in one-way valve and must therefore be connected in series with the SIB, which does have its own valve to prevent gas flowing backwards to the vaporizer (Fig. 7.7).

The breathing tubes that form the system are connected to the vaporizers and SIB by conically tapered metal or plastic connectors (ISO 22-mm diameter, 1-degree taper). Connections should be made firmly without excessive force. Study the diagrams of breathing systems in Fig. 7.7. It will help you understand the function of the breathing valve if you draw your own diagram of it from the manufacturer's instructions. If you are unsure about the assembly of the system, try breathing through it yourself (with the vaporizers turned off!).

Self-inflating bags or bellows

Several of the different types of SIB available are shown in Fig. 2.9 on p. 16. All SIBs have a one-way valve upstream of the bag or bellows; gases can enter the SIB through this valve, but must leave through the other end of the SIB in the direction of the patient. The Oxford inflating bellows also has a one-way valve located downstream from the bellows.

The Oxford inflating bellows should be placed in the breathing system between the vaporizer and the breathing valve. During storage, the bellows is held down by a light internal clip, which is released by pulling upwards on the knob on top of the bellows. An internal spring will then tend to keep the bellows at about a third of its maximum capacity. The patient is free to inspire through the bellows.

Because the system has a low resistance to flow, only a small movement of the bellows will be noticed, since air enters the bellows almost as fast as it leaves when the patient breathes in. Fig. 7.7 shows some possible arrangements of vaporizers and breathing systems.

During controlled ventilation, lift the bellows slightly from the "rest" position and press down to inflate the patient's lungs. Inspiration should be started sharply to ensure that the breathing valve snaps smartly into the inspiratory position. Do not press down too hard at the end of inspiration, or the clip will engage and lock the bellows down. It is not necessary to lift the bellows to its maximum capacity, as this would produce a tidal volume of 2 litres, far in excess of the patient's need. At the base of some bellows is a small tap or nipple labelled "oxygen inlet", which was originally intended to allow the addition of oxygen during resuscitation. It is not compatible with modern universal breathing valves and should not be used (for the recommended technique of adding oxygen with an SIB, see Fig. 2.11, p. 19). For paediatric use, a small-volume bellows is available that can be exchanged for the adult one on the same base and valves and used with an Ambu "Paedi-valve".

To allow a universal breathing valve to work properly with the Oxford inflating bellows, you must disable the one-way valve located downstream from the bellows, i.e. at the end of the bellows nearest the patient, by clipping the magnet supplied over the valve, thus lifting the valve disc to the top of the chamber. As a permanent alternative, the valve disc could be removed altogether. If you do not disable this valve, the breathing valve may stick and the patient will be harmed.

In some hospitals you may find that there are no universal breathing valves and that only a Heidbrink valve (also called an expiratory or pop-off valve) is available. This valve has no mechanism for preventing the patient's expired gas from flowing backwards to the SIB. It is not recommended for IPPV, but it can be used for spontaneous breathing with an Oxford inflating bellows (but not with any other SIB). In these circumstances, both the valves on the Oxford inflating bellows are needed, so remove the magnet from above the downstream valve and place it in the holder at the side. The valve is then free to move and will prevent the patient's expired gas from passing back into the bellows (Fig. 7.8).

Ambu, Cardiff, Laerdal, and similar bags can be used in a similar way to the Oxford inflating bellows. The bag is fitted with an inlet valve that allows gas or atmospheric air to enter at one end; for anaesthesia this valve is connected with a breathing tube to the vaporizer. This type of bag must always be used with a universal breathing valve, and never with a Heidbrink or a "resuscitation only" valve. Some bags have a port to allow direct connection of an oxygen supply, but, as with the Oxford inflating bellows, this is not recommended for oxygen enrichment; a T-piece and reservoir should be used instead.

With the PAC system, a non-return valve is incorporated in the vaporizer itself and the SIB is mounted on a T-piece limb, which makes it easier to handle than

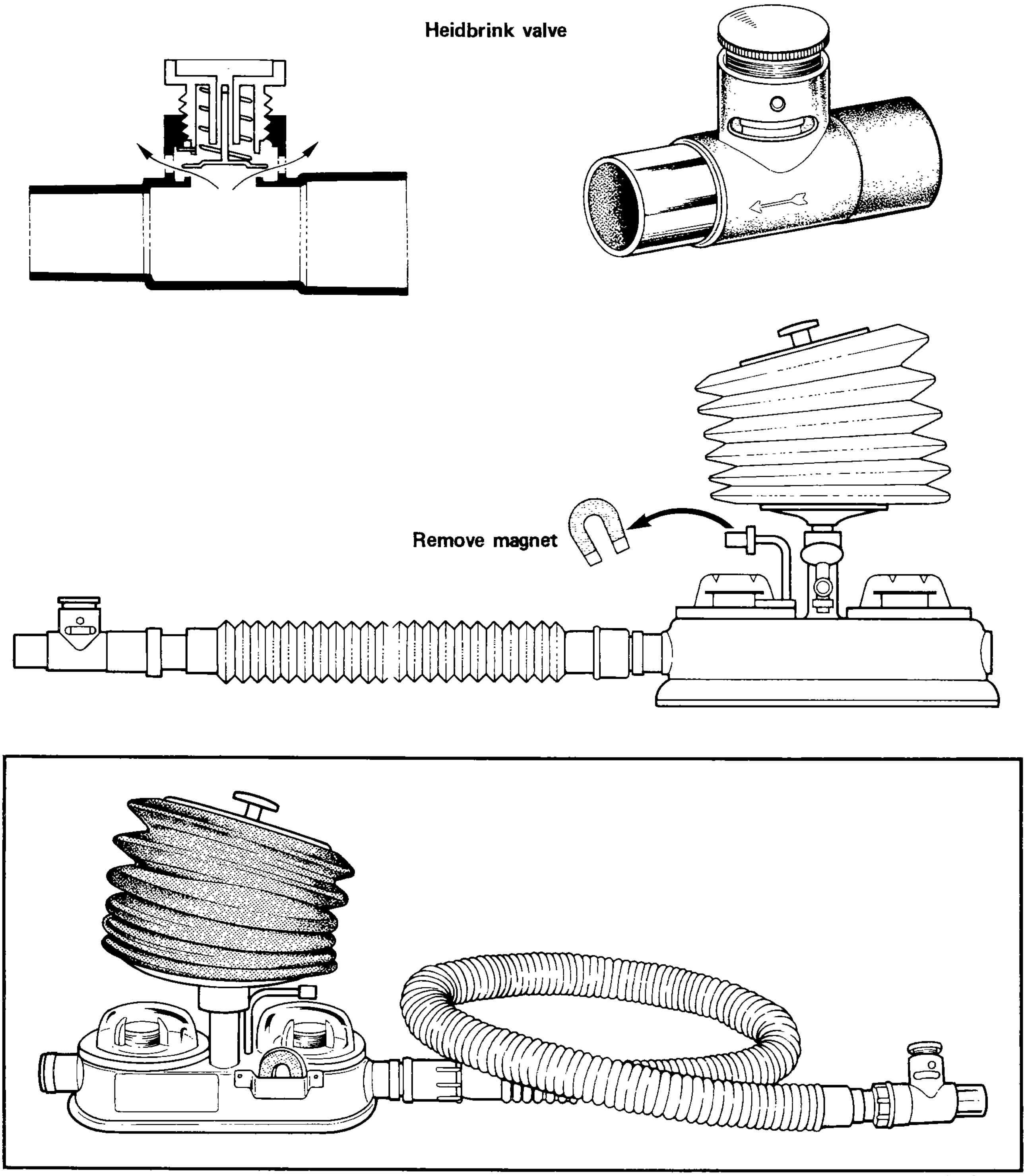


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Fig. 7.8. Use of the Heidbrink valve with the Oxford inflating bellows after removal of the magnet.

an in-line bag (Fig. 7.7). A universal breathing valve must always be used for both spontaneous ventilation and IPPV.

Adding oxygen to the draw-over system

Air contains 20.9% oxygen and is perfectly adequate to oxygenate a healthy patient receiving draw-over anaesthesia, particularly if ether (which stimulates both respiration and cardiac output) is in use or if controlled ventilation is given with light general anaesthesia and a muscle relaxant.

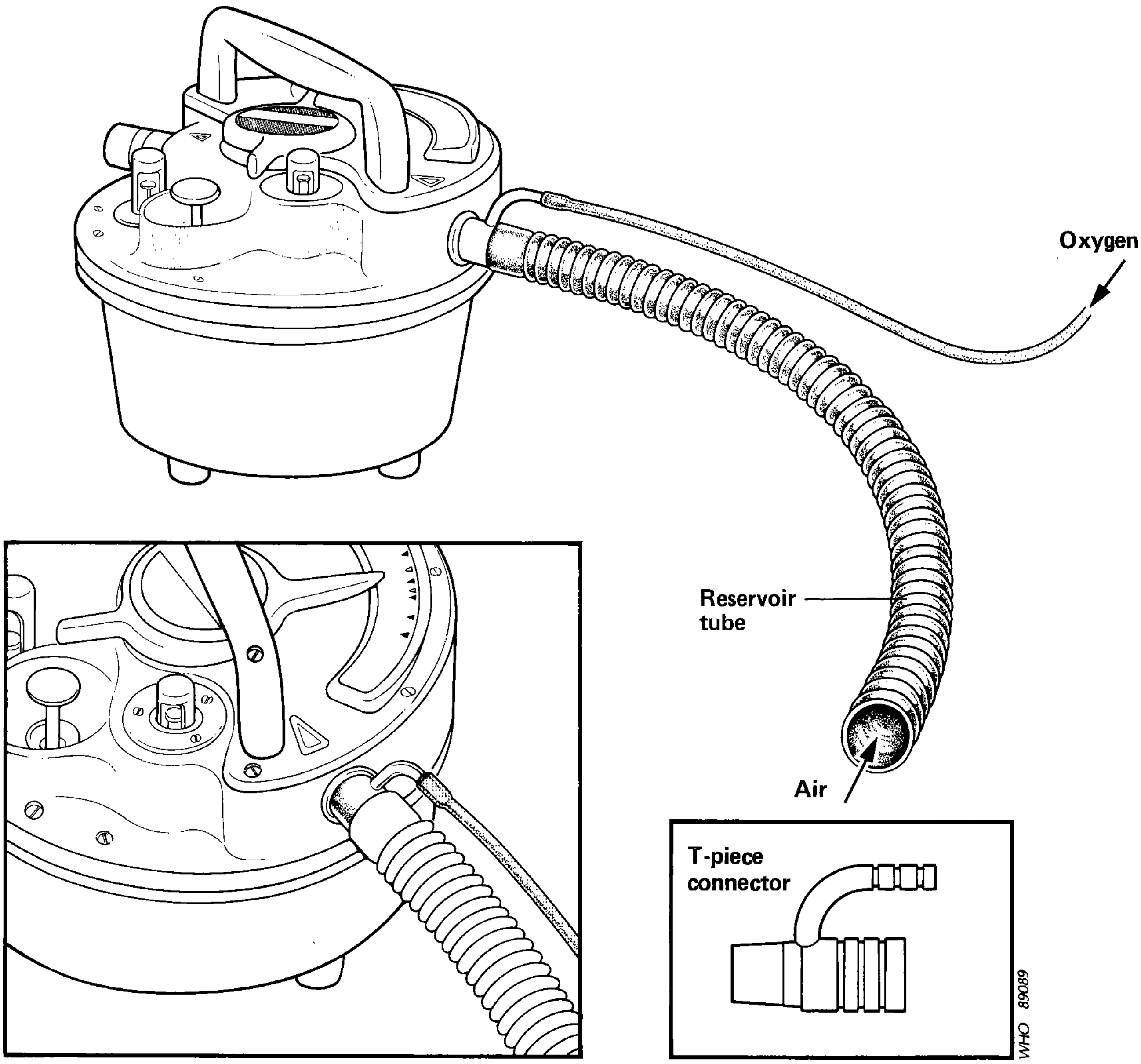


Fig. 7.9. Addition of oxygen with a T-piece and reservoir tube.

Oxygen should always be added

- if the patient is very young, old, sick, or anaemic
- if agents that cause cardiorespiratory depression, such as halothane, are used.

Oxygen is usually available, even if only in limited quantities. Air (the carrier gas) already contains 20.9% oxygen, and oxygen enrichment is very economical in that the addition of only 1 litre/min can increase the oxygen concentration in the inspired gas to 35–40%. With oxygen enrichment at 5 litres/min, a concentration of 80% can be achieved. Industrial-grade oxygen, for example as used for welding, is perfectly acceptable for the enrichment of a draw-over system and has been widely used for this purpose. (Industrial and medical oxygen are both prepared by the same process — the fractional distillation of air.)

To add oxygen to the breathing system, use a T-piece and reservoir tube at the vaporizer inlet (Fig. 7.9). If a ready-made T-piece with reservoir is unavailable, you can easily make an alternative using a small-bore oxygen tube threaded into a large-bore tube (Fig. 2.11B, p. 19). Connect the T-piece and reservoir tube (or your improvised alternative) to the vaporizer inlet and turn on the oxygen supply. In this way the oxygen that flows from the cylinder during expiration is not wasted, but is stored in the reservoir tube for the next inspiration. The reservoir tubing should of course be open to the atmosphere at its free end to allow the entry of air, and it should be at least 30 cm long.

Oxygen concentrators

A full description of oxygen concentrators, which can provide a reliable supply of oxygen from room air using only mains electricity, is given in Chapter 15. Oxygen concentrators are suitable for use in all sizes of hospital and can provide oxygen more cheaply than cylinders, in addition to making oxygen available in hospitals where a regular supply of cylinders is difficult to obtain. It is strongly recommended that only those models meeting the Performance Standard described in Chapter 15 should be purchased for use in district hospitals. An up-to-date list of models currently known to meet the Performance Standard is available on request from Blood Safety and Clinical Technology, World Health Organization, 1211 Geneva 27, Switzerland.

Oxygen concentrators designed for use with individual patients normally give a flow rate of up to 4 litres/min of near-pure oxygen at relatively low pressure. This oxygen can be used in exactly the same way as oxygen from a cylinder — e.g. as the supply for T-piece enrichment into a draw-over system or for use with a nasal catheter, prongs, or face mask to give postoperative or ward oxygen. However, the oxygen from a concentrator is at relatively low pressure and cannot therefore be used in a compressed gas (Boyle's) anaesthetic machine. If there is an electrical power failure the oxygen flow from a concentrator will continue only for about a minute, so make sure you have a back-up system for use in such emergencies — either a generator to maintain electrical supply, or a cylinder of compressed oxygen.

Standardization and identification of oxygen cylinders

An international standard exists for the identification of oxygen cylinders, which specifies that they should be painted white. Unfortunately, the standard is widely ignored. Medical oxygen cylinders originating in the United States of America are normally green, while those originating in Commonwealth countries are usually black with white shoulders. Cylinders of industrial oxygen should also be identified clearly, but this is not always the case. Never use any cylinder to supply gas to a patient unless you are sure of its contents.

Oxygen — fire and explosion risks

All operating theatre staff should be concerned about the possibility of fire or explosion risks in the operating theatre as a result of the use of anaesthetic vapours. It is important to distinguish between gas mixtures that are flammable, i.e. can burn, and those that are explosive. Explosions are much more dangerous to both staff and patients. Of the inhalational anaesthetics mentioned in this book, only one (ether) is flammable or explosive in clinical concentrations.

Mixtures of *ether and air* in the concentrations used for anaesthesia are *flammable*, but there is no concentration of ether that will explode when mixed only with air. However, mixtures of *ether with oxygen or nitrous oxide* are *explosive*.

There is no site within the draw-over apparatus itself where ether combustion could start. The point of risk is therefore the place where the patient's expired gas enters the room, before the ether is diluted by air. If you are using 3–5% ether as an anaesthetic in combination with a muscle relaxant, it is likely that the ether concentration in the patient's expired gas will be less than the lowest flammable concentration (2%). When flammable gases are in use, the most likely source of combustion in the operating theatre is the surgical diathermy machine and other electrical apparatus, followed by static electricity, which is unlikely to start a fire, but can trigger an explosion if an oxygen-rich gas mixture is present. *No potential cause of combustion or source of sparking should be allowed within 30 cm of any expiratory valve through which a potentially flammable or explosive mixture is escaping.* The use of diathermy outside this "zone of risk" is generally acceptable, but if explosive mixtures are in use, for example ether/oxygen or ether/nitrous oxide/oxygen, diathermy should be avoided. It should, of course, never be used inside the mouth or thorax if ether is in use.

What reasonable precautions should you take?

If possible, your operating theatre and equipment should be of the antistatic type. This is important in a dry climate, but less so in a humid one where a natural coating of moisture on objects prevents the buildup of static.

Electrical sockets and switches should either be spark-proof or be situated at least 1 m above floor level.

The patient's expired gases should be carried away from the expiratory valve down wide-bore tubing at least to the floor (ether is heavier than air) or out of the operating theatre. Make sure that no one stands on the hose and that there is nothing that could trigger combustion near the end of this tubing. If you use oxygen enrichment during induction, but not surgery, the patient's expired gas will cease to be explosive within 3 min of stopping the addition of oxygen.

Continuous-flow machines

Continuous-flow anaesthetic machines (commonly known as Boyle's machines or simply gas machines) are in widespread use. They rely on a supply of compressed medical gas, either from cylinders attached directly to the machine or piped from a large bank of cylinders or liquid oxygen supply elsewhere in the hospital. The two gases most commonly used are oxygen and nitrous oxide. Cylinders are attached to the machine by a special yoke that prevents the connection of the nitrous oxide supply to the oxygen port and vice versa — the pin-index system. Some older machines may lack this system; be especially careful with them to prevent incorrect connections. Cylinders contain gas at high pressure, which is reduced to the anaesthetic machine's working pressure, usually 400 kPa (4 atmospheres), by a reducing valve (regulator). Each gas then passes through a needle valve at the base of a rotameter. This valve controls the flow of gas to the breathing system, once the cylinder valve has been opened with a key or spanner (wrench) to allow gas to flow out. The gas passes through the flow meter (rotameter), which measures the gas flow by upward displacement of a bobbin in a tube, and along the "back bar" at the top of the machine, where it may be diverted through a vaporizer for the addition of a volatile anaesthetic agent (Fig. 7.10). A separate switch or tap is usually provided to allow for a high flow of oxygen to be delivered to the patient in case of emergency, bypassing the rotameters and vaporizers. Gas is delivered from the common gas outlet at the top or front of the machine, to which a breathing system is connected.

The vaporizers on a Boyle's machine may be of the calibrated, thermocompensated type (for example Fluotec or Acoma) or simple Boyle's bottles, which are usually used for ether (Fig. 7.11). The Boyle's bottle is uncalibrated, and its output declines as the ether becomes cold. It has two controls: a lever that diverts gas from the back bar down a tube into the vaporizer, and a hood that can be depressed to make the gases pass closer to or even bubble through the liquid ether. Always start with the hood up, increasing the concentration with the lever first, and then lowering the hood if necessary. Never bubble anaesthetic gas through any agent other than ether. Remember that with a Boyle's bottle the

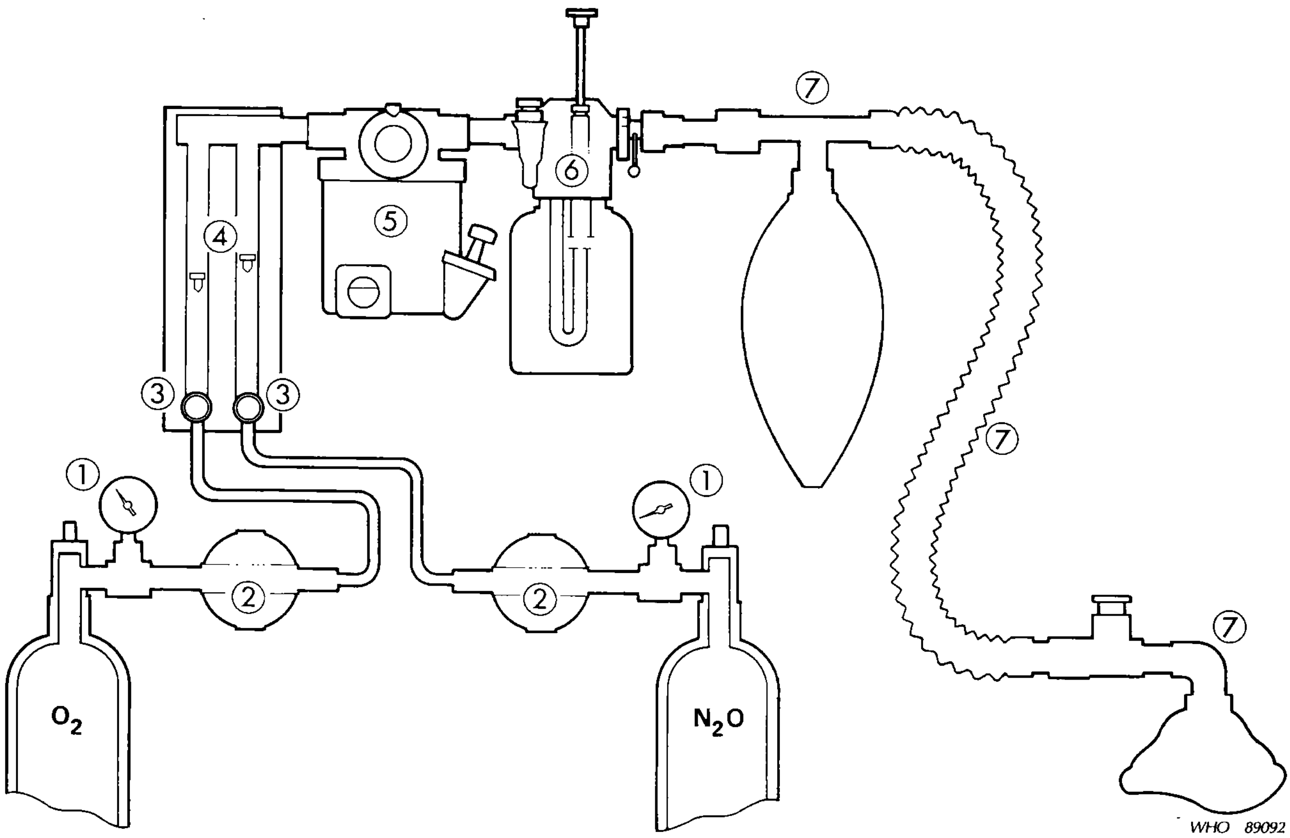


Fig. 7.10. Gas pathway on a continuous-flow (Boyle's) machine with a compressed gas supply. (1) Pressure gauges, (2) reducing valves, (3) flow-control (needle) valves, (4) flow meters, (5) calibrated vaporizer, (6) Boyle's bottle, (7) Magill breathing system.

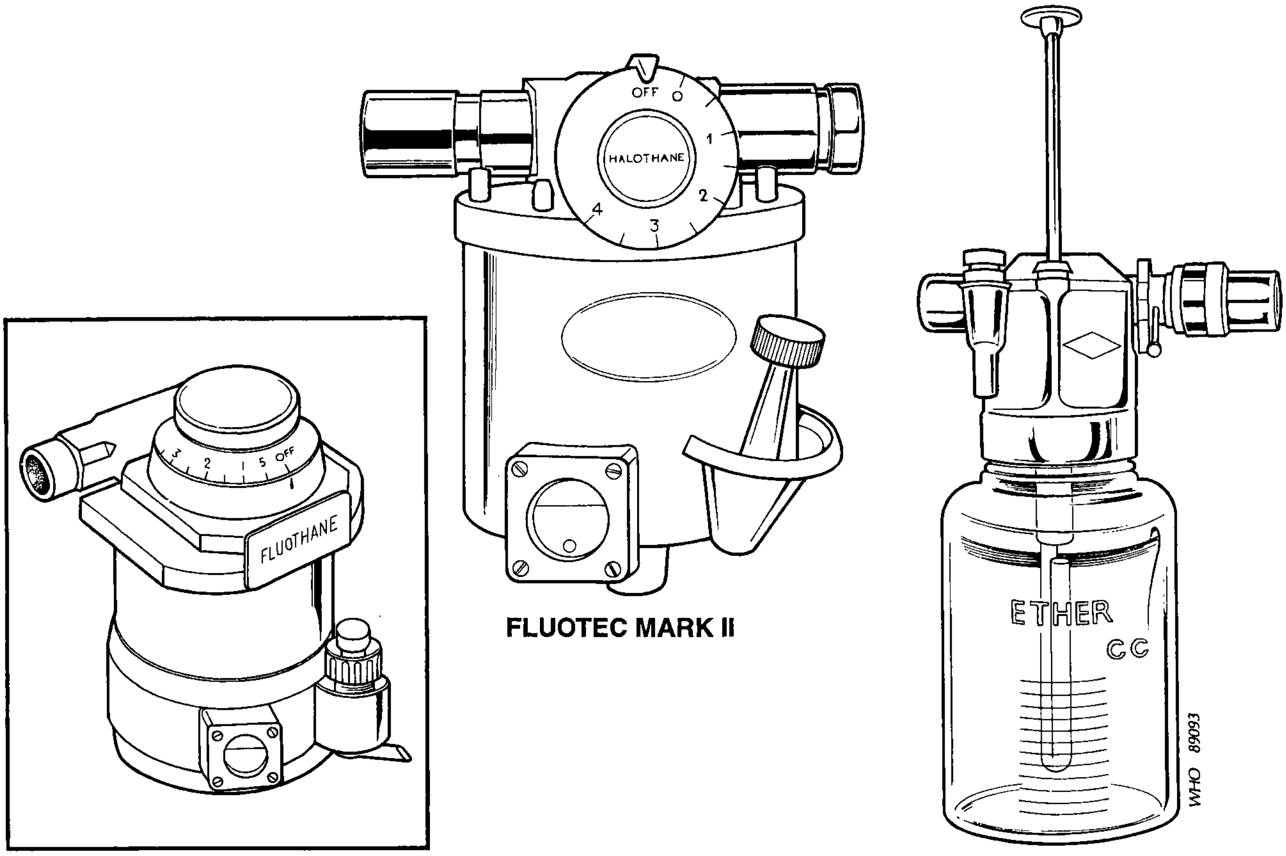
output is neither calibrated nor constant, so you will have to watch the patient with special care. Ether used in a Boyle's machine always produces a potentially explosive mixture.

Because of the danger of giving a patient a hypoxic gas mixture as a result of machine malfunction or human error, it is strongly recommended that an oxygen analyser should always be used with a Boyle's machine to give a continuous display of the inspired oxygen concentration.

The Magill breathing system

This system, which incorporates a Heidbrink valve, is in common use on continuous-flow machines (Fig. 7.12). It is suitable only for spontaneously breathing patients and requires a total gas flow from the flow meters that is approximately equal to the patient's minute volume, for example nitrous oxide at 4 litres/min and oxygen at 2 litres/min for an adult. Always give at least 30% oxygen to provide a margin of safety should there be any leaks or inaccuracy in the flow meters. If you wish to give IPPV with a Boyle's machine, you must use a different breathing system; the Magill system can be modified simply by exchanging the Heidbrink valve for a suitable universal breathing valve such as an Ambu E1 or Ruben valve. Squeezing the reservoir bag will then inflate the patient's lungs. The patient can also take a spontaneous breath from the bag, so the modified system is suitable for both controlled and spontaneous respiration.

DANGER: Do *not* use a Laerdal IV, Ambu Mark III, or other similar valve with low switching-flow in this way, as it will jam on a continuous-flow system.



FLUOTEC MARK II

FLUOTEC MARK III

BOYLE'S BOTTLE

Fig. 7.11. Some vaporizers used on continuous-flow machines with compressed gas supplies.

The circle breathing system

If you have a reliable source of oxygen, you can reduce anaesthetic costs considerably by using a circle system in which some of the patient's expired gas is used again, after removal of carbon dioxide (Fig. 7.13). A special reagent (soda lime) which is a mixture of calcium and sodium hydroxides, is used to absorb the carbon dioxide. When the soda lime is exhausted it changes colour and must be discarded and replaced — 1 kg of soda lime will give about 8 hours' use. Circle systems at district hospitals should not be used with any gases other than oxygen — the source of oxygen can be either a cylinder or a concentrator (with cylinder back-up in case of power failure). Circle systems are relatively complicated and are not recommended for the occasional anaesthetist. For the specialist, full descriptions are to be found in specialist anaesthetic textbooks.

Automatic lung ventilators

For the anaesthetist working without an assistant it can be a great convenience to have a machine provide controlled ventilation of the lungs during surgery — freeing both the anaesthetist's hands for attending to other needs such as monitoring, keeping records, and setting up infusions. Like all machines, ventilators need regular skilled maintenance and attention, and if these are not available it is probably better to use manual ventilation. Many of the ventilators currently available cannot be recommended because of their very high consumption of compressed oxygen (up to 30 litres/min).

The ideal ventilator for a district hospital should:

- use a reliable locally available power source (electricity and/or low flow of oxygen)
- allow any oxygen used for driving purposes to be breathed by the patient
- be easy to understand, use, and repair

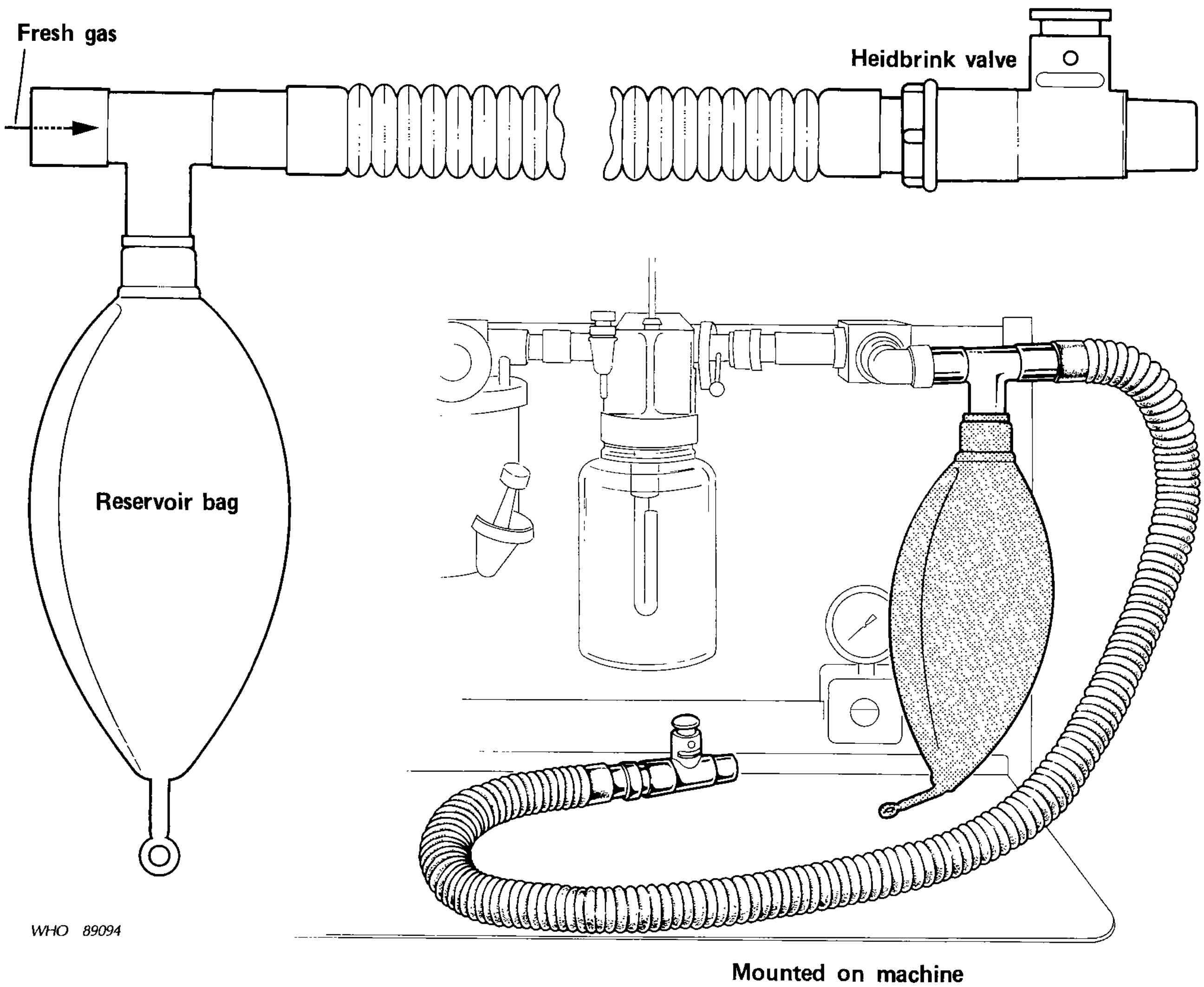


Fig. 7.12. Magill breathing system.

- be capable of ventilating using either draw-over or continuous-flow systems of anaesthesia.

The World Federation of Societies of Anaesthesiologists (8th Floor, Imperial House, 15–19 Kingsway, London WC2B 6TH, England; fax: +41 171 836 5616; e-mail: wfsa@compuserve.com) can advise district hospitals considering the purchase of a ventilator.

Checking your apparatus

Before beginning anaesthesia, you must thoroughly check the machine, with reference to the check-list in Annex 2 (a copy of which should be fixed permanently to your machine). Ensure that you have sufficient compressed gas for the operation, and at least one spare cylinder of oxygen. You must also have an SIB with which to ventilate the lungs should your machine fail. Also check other essential apparatus such as the laryngoscope and sucker. Then assemble the breathing system and test it for leaks by covering the end with your hand and squeezing the reservoir bag. No gas should escape if the Heidbrink valve is closed. (Remember to open it again afterwards!) At least once a month, check the whole machine and any gas hoses for leaks by "painting" suspect areas with soapy water and observing whether bubbles form when you turn on the gas supply. Continuous-

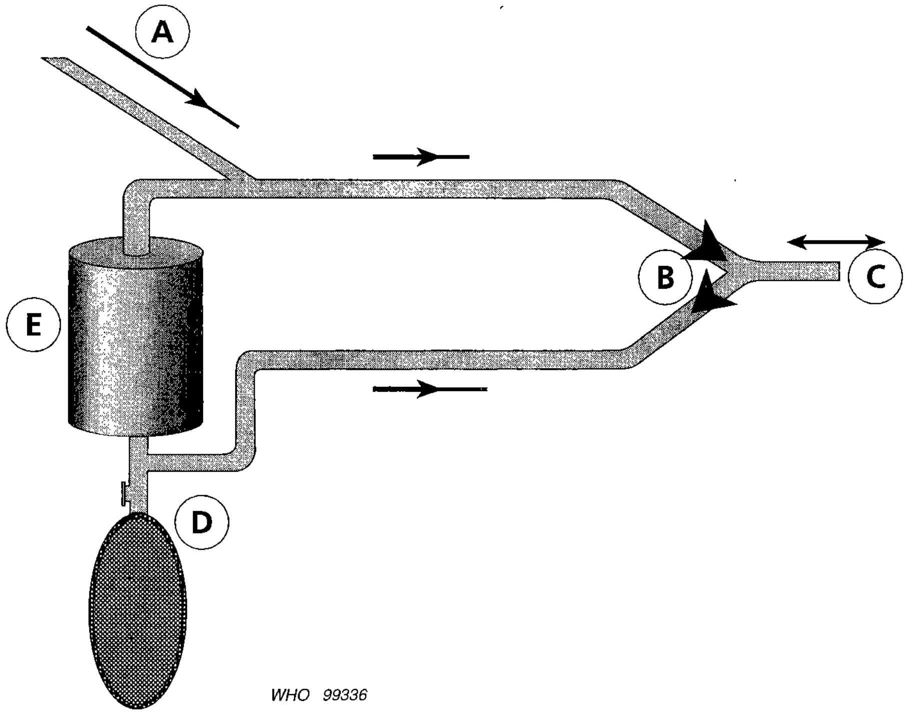


Fig. 7.13. **Diagram of circle breathing system. (A) Oxygen/fresh gas inlet tube, (B) one-way breathing valves, (C) connection to patient, (D) reservoir bag and spill valve, (E) soda lime CO_2 absorber.**

flow machines are prone to leakage because the gases are kept at relatively high pressures inside them.

All types of apparatus should be kept in a clean and dust-free environment, away from extremes of temperature, and covered when not in use. Vaporizers should be drained of anaesthetic if they are unlikely to be used for a week or more. Put a cork or spigot in the end of any gas port or tubing during storage to prevent the entry of insects. Regular cleaning, inspection, and simple maintenance will familiarize you with your equipment, as well as help to keep it in good order. Try to estimate when new parts will be required, and order spares well in advance, before the machine breaks down and leaves you in difficulty.