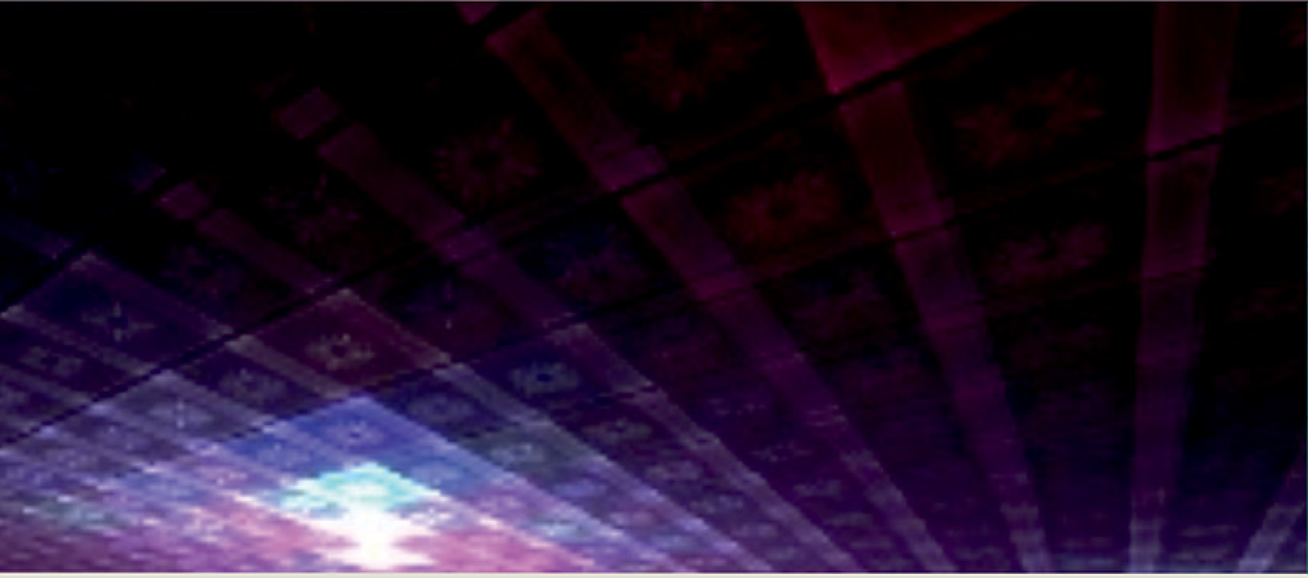
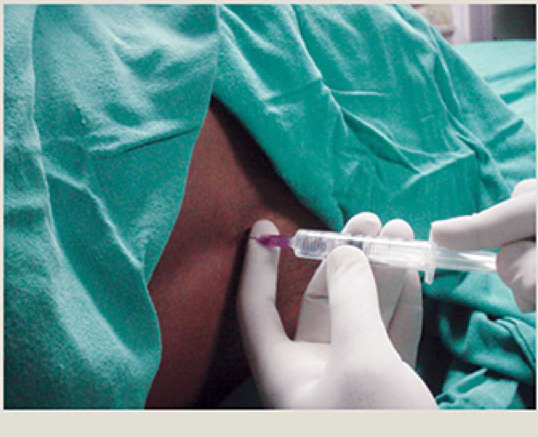



A Primer of ANESTHESIA

Rajeshwari Subramaniam





Forewords

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Chapter 4

The Anesthesia Machine

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- *Functions of the modern anesthesia machine*
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- *Pipelines and their connections*
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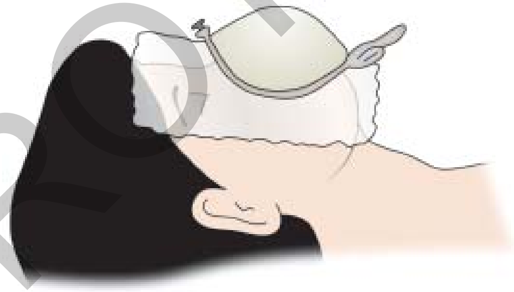


Fig. 4. 1: Schimmelbusch mask

It is important for all physicians to have a working knowledge of the anesthesia machine, breathing circuits and various airway devices. Apart from administration of anesthesia, these are useful for emergency airway management, oxygenation and cardiopulmonary resuscitation (CPR).

The anesthesia machine in use nowadays is termed a 'continuous flow' machine since there is no interruption to gas flow in the respiratory cycle. In earlier times ether or chloroform was dropped on to a wire mask covered with layers of gauze or lint ('**Open-drop anesthesia**' through a Schimmelbusch mask; Fig. 4.1). The concentration of vapor delivered, oxygenation, carbon dioxide elimination and depth of anesthesia were all variable with this technique. The '**draw-over'** apparatus which was more superior consisted of inhalers like the EMO apparatus (Fig. 4.2), where gas flow occurred during inspiration and was dependent on patient effort.

Oxygen (as gas) and nitrous oxide (as liquid) are stored under high pressure in cylinders which cannot be directly administered to a patient owing to the danger of barotrauma. Further, at high pressures flow rates are difficult to control. The modern anesthesia machine overcomes these problems and serves the following functions:

1. Can deliver compressed gases under physiologically safe pressures.
2. Enables the anesthesiologist to adjust flow and composition of inhaled gases.
3. Is capable of delivering accurate amounts of volatile anesthetic agents.

Fig. 4.2: EMO vaporizer

4. Has many features preventing delivery of hypoxic mixtures and therefore enhancing patient safety.

 A typical anesthesia machine can be anatomically divided into two pressure zones:

- The **high pressure system** extending from the cylinder or pipeline inlet up to the flowmeter valve*. A pressure regulating valve reduces the pressure in the oxygen cylinder (2,200 psig) and that in the nitrous oxide cylinder (750 psig) to 45 psig. A conversion factor useful to remember is that 1 kilo Pascal (kPa) = 0.01 bar = 0.1013 atmospheres = 0.145 psig = 10.2 cm H_2O =7.5 mm Hg. The pipeline pressure is normally 50-60 psig, kept 10-15 psig above reduced cylinder pressure so that it is preferentially used even if a cylinder is kept open. [Many machines of the 'Ohmeda' make also have a second stage pressure regulator in the oxygen supply line downstream of the oxygen failure alarms. This reduces the oxygen pipeline pressure to a fixed value of 14-20 psig before it enters the flowmeter valve].
- The **low-pressure system** extends from the flowmeter valves to the common gas outlet.

 The pressures in this area range from 12-14 psig at the needle valves to 2-4 psig at the machine outlet.

In the following text, the structure and function of the components of the anesthesia machine encountered in sequence are described. The safety features of the anesthesia machine are highlighted.

The components are:

1. Source of gas supply: pipelines and cylinders
2. Hanger yoke assembly
3. Pressure reducing/regulating valves
4. Oxygen pressure failure safety/warning devices
5. Oxygen ratio control devices
6. Flow meters
7. Vaporizers
8. Common gas outlet.

Source of Gas Supply

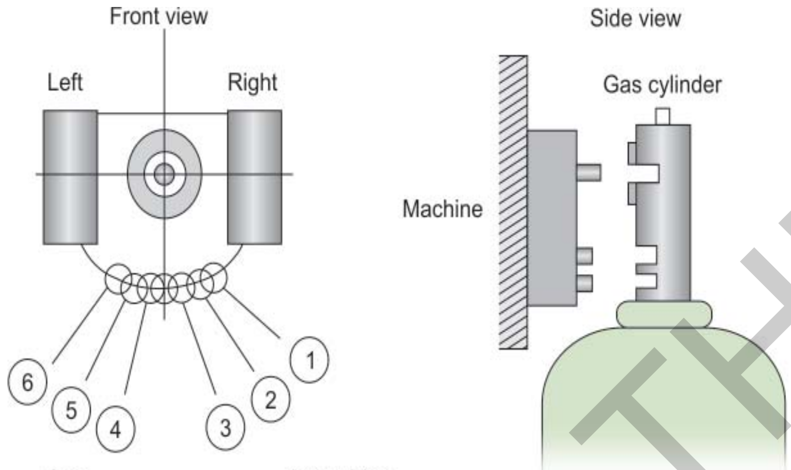
Anesthetic gases are usually supplied in cylinders made of molybdenum steel, an alloy which allows the cylinders to be made thinner and lighter for comparable working pressures.

Medical gas cylinders are **color coded** (Table 4.1) and the name of the gas is also written on the neck of the cylinder. The

Table 4.1: Pressures in, and color of various compressed gases

Gases	*Pressure when full*	*Color Coding*
Oxygen (gas)	2000 psig	Black body with white shoulder
Entonox (gas)	1980 psig	Blue body with white shoulder
Carbon dioxide (liquid)	723 psig	Gray
Cyclopropane (liquid)	64 psig	Orange
Nitrous oxide (liquid)	640 psig	French blue

(* Some textbooks describe the cylinders, yoke blocks and pressure regulators as 'high pressure' area, and the area from the cylinder pressure regulating valves up to the flowmeter valves as 'intermediate pressure' and from the flowmeters up to the common gas outlet as 'low pressure').



Gas	Index Pins
Air	1 and 5
CO_2 mix (CO_2<7%)	2 and 6
CO_2 mix (CO_2>7%)	1 and 6
Cyclopropane	3 and 6
Ethylene	1 and 3
He-O_2 (<80%)	2 and 4
He-O_2 (>80%)	4 and 6
Nitrous Oxide	3 and 5
Oxygen	2 and 5

Fig. 4.3: Pin index safety system for medical gas cylinders

cylinders are hydraulically tested every 5 years. These cylinders are provided with a flush type pin index valve (Fig. 4.3).

The **contents** in a cylinder, if a gas, is indicated by the pressure gauge. A formula that is helpful in determining how long an oxygen cylinder can last is given by:

Approximate remaining time (hours) = oxygen cylinder pressure (psig)/200 × oxygen flow rate (l/min). If the contents are liquid (as with nitrous oxide) the cylinder should be weighed and the empty weight subtracted.

Reserve gas cylinders are fitted to the rear of the machine.That part of the cylinder which is attached to the anesthesia machine is known as the pin index valve block (Fig. 4.4A). It is a solid cuboid with four faces. One face shows the empty weight (tare), the second the symbol for nitrous oxide and the third the pressure of the hydraulic test. It is the fourth side which gets attached to the machine which bears the gas outlet and the pin index safety system (Fig. 4.4B).

The pin index system (Fig. 4.3) consists of seven holes positioned on the circumference of a circle of 9/16 inch radius centered in the port, with a pair of positions designated for each gas (Table 4.2). The two pins projecting from the inner surface of the yoke get inserted into two corresponding holes in the cylinder valve block when the cylinder is suspended on the machine. The arrangement of these pins is specific for each gas and therefore its cylinder. **The pin index system prevents an incorrect cylinder being mounted at the place belonging to another gas**.

Table 4.2: Pin index system

Gas	*Index Pins*
Oxygen	2,5
Nitrous oxide	3,5
Cyclopropane	3,6
O_2-CO_2 (CO_2>7.5%)	1,6
O_2–He (He>80.5%)	4,6
Air	1,5
Nitrogen	1,4
N_2O-O_2 (N_2O 47.5%-52.5%)	7

Fig. 4.4A: Face of pin index block showing tare weight, company and ISI marking

Fig. 4.4B: Face of pin index block of nitrous oxide cylinder showing holes for pins

The pipeline inlets: Oxygen, nitrous oxide and, in some hospitals, medical air are supplied from a central manifold (which contains banks of cylinders) through metal pipelines to the operating room and ICUs. These pipes are **color coded (white for oxygen, blue for nitrous oxide)**. On the wall of the operating room, or the ceiling of the operating theatre, the pipeline from the manifold terminates in the form of self-closing sockets with '**quick coupling' attachments (Fig. 4.5).** The coupling pairs are specific in size and shape for each gas and vary with the manufacturer. These sockets may be present in modern theatres as 'gas columns' and permit only the end of the correct hose to engage in them and open them. At the machine end, the diameter-indexed safety system **(DISS, Fig. 4.6)** permits the attachment of the correct hose only to be screwed on to the machine so that interchangeability is virtually eliminated.

Yoke Assembly

The hanger yoke assembly (Fig. 4.7) orients and supports the cylinder and connects it to the machine. A gas-tight seal is provided with a Bodok sealing washer, made of rubber with a metal periphery. This should be inspected for integrity every time a cylinder is changed. The pins on the yoke (which are part of the Pin Index system) are 4 mm in diameter and 6 mm long. A *one-way check valve* present immediately downstream of the hanger yoke has three important functions:

i. It prevents a cylinder under higher pressure from emptying into one with lower pressure.
ii. It allows change of cylinder on the machine without gas leaking out.
iii. It prevents leaking and emptying of a cylinder left open even if one cylinder is absent from a yoke.

There is usually a single pressure gauge for two similar cylinders hung on the machine downstream of the check valve and it shows the pressure in the cylinder having the higher

Fig. 4.5: 'Quick coupling' attachments

Fig. 4.6: The DISS behind the machine

pressure if both are opened at the same time. Therefore, it may not be possible to determine whether, and if any, of the reserve cylinders is empty unless if they are opened one at a time.

Pressure Regulator

The pressure in a cylinder is high and variable as it changes with the contents and temperature. The cylinder pressure regulator is a pressure-regulating valve which converts the high variable pressure in the cylinder into a **constant working pressure** suitable for use in anesthesia machine, usually 45-47 psig. These regulators work on the principle that high pressure exerted by the cylinder contents over a small area is balanced by reduced pressure exerted over a large area.

Oxygen Pressure Failure Warning Devices

All modern anesthesia machines have an **audible whistle** with a blinking red light when the inlet gas pressure drops below a preset value (20-35 psig). This alarm cannot be disabled till oxygen supply is restored. Another safety feature is cutting off of all gases (except air) when the pressure after the secondary regulator falls below 20 psig. This feature used to be known as **fail-safe or nitrous cut-off valve**. The third kind of device is a proportioning device (also termed

Fig. 4.7: The hanger yoke assembly:shows retaining screw opened (l) and in place (r). note bodok washer and pins

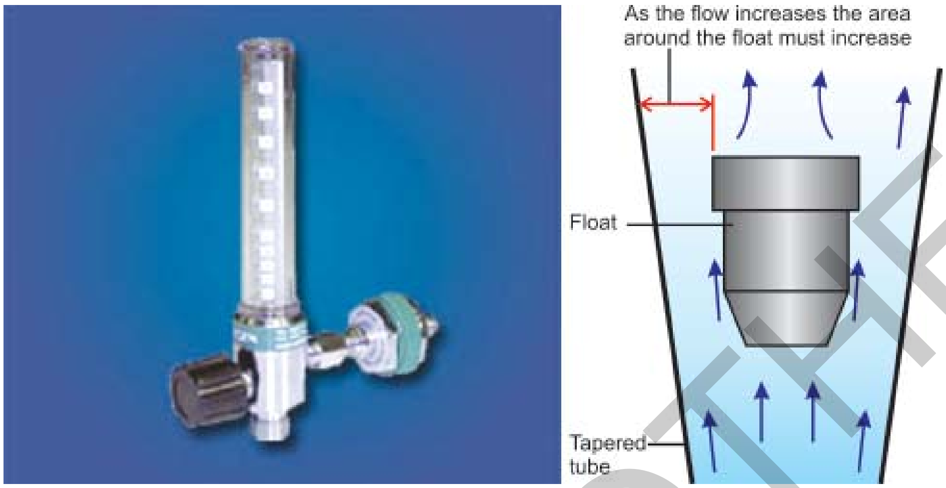


Fig. 4.8: The flowmeter assembly (l) and an enlarged view of the Thorpe tube (r)

oxygen failure protection device) which proportionately reduces the pressure of nitrous oxide as oxygen pressure falls.

Flowmeter Assembly

All the flow meters have a flow control valve, a graduated stem (which is a glass tube) to measure and see the flow and an outlet. The flow meter used in modern anesthetic machines is of the variable orifice type and is made up of a transparent tapered tube known as Thorpe tube (Fig. 4.8). A float which moves up when the gas is turned on and keeps rotating indicates gas flow. The flow control valve is a needle valve or pin valve used to adjust the amount gas entering the flowmeter block. The knob which rotates the needle valve is color and configuration coded; the **oxygen knob is large, fluted and white** and *always* situated towards the gas outlet of the machine (Figs 4.9A to C). This is to prevent escape of oxygen and delivery of a hypoxic mixture in the event of a crack in the flowmeter (Fig. 4.10). Another safety feature of the machine incorporated in the flowmeter assembly is the **flow controller mechanism** whereby the *nitrous oxide is linked to oxygen* flow by a chain-gear system and cannot be independently turned on; this way a minimum of 21-25% oxygen is always present in the gas mixture.

Minimal oxygen flow of 150 ml/min which starts as soon as the machine is switched on is another safety mechanism.

Oxygen Analyser

The use of an oxygen analyzer with an anesthesia system is the single **most foolproof**

Fig. 4.9A: Large, fluted oxygen flowmeter knob

Fig. 4.9B: Oxygen flowmeter situated away from gas outlet in older anesthesia machine

Fig. 4.9C: Oxygen flowmeters on the same side as gas outlet in modern machine

measure to prevent delivery of a hypoxic mixture to the patient. This is because it is **not** dependent on pneumatic or mechanical links, but actually measures the oxygen percentage in the gas mixture either by polarographic method or by using a fuel cell.

Vaporizers

A vaporizer is designed to add a controlled amount of an inhalational agent, after changing

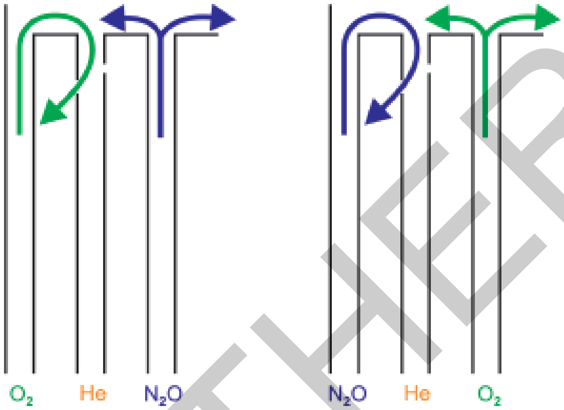


Fig. 4.10: Escape of oxygen when oxygen flowmeter is away from outlet (L)

it from liquid to vapour, to the fresh gas flow. This is normally expressed as a percentage of saturated vapor added to the gas flow, i.e. a 2% vaporizer setting means that 2 ml of vapor is being carried per 100 ml of total fresh gas flow. Most volatile agents in current use are very potent, and accurate, controlled administration through agent-specific vaporizers is needed to avoid overdose and toxicity. Modern vaporizers compensate for the cooling produced by evaporation and are not affected by ambient temperatures or pressures over a wide range. They are usually mounted on the back bar of the machine (Fig. 4.11). When one vaporizer is in use, restraining rods spring out which prevent another vaporizer from being used simultaneously. This is the '**Selectatec' system** which can be considered as a safety feature. Most inhalational agents in current use have boiling points well above room temperatures except desflurane (24°C). For this reason a special heated vaporizer (Tec 6) is required for this agent.

Characteristics of an ideal vaporizer:

1. Performance should not be affected by changes in: (a) fresh gas flow, (b) volume of the liquid agent, (c) ambient temperature, (d) decrease in temperature or pressure due

Fig. 4.11: Vaporizers on back bar of anesthesia machine

Fig. 4.12: Common gas outlet

to vaporization, and (*e*) pressure fluctuation due to the mode of respiration.

2. Should have low resistance to flow.
3. Should be light weight with small liquid requirement.
4. Economy and safety in use with minimal servicing requirement.
5. Have corrosion and solvent resistant construction.
6. A non return pressure relief safety valve is situated downstream of the vaporizers either on the back bar itself or near the common gas outlet. It opens when the pressure in the back bar exceeds about 35 kPa.

Emergency Oxygen Flush

The emergency oxygen flush is usually activated by a non locking button. The flow bypasses the flowmeter and the vaporizer and is derived from an independent pipeline after the pressure regulator. It joins downstream of the high pressure check valve. A flow of about 35-75 l/min at a pressure of about 400 kPa is delivered from this system. Activation of the oxygen flush is frequently required as an emergency, as when one would like to fill the reservoir bag quickly to ventilate a patient. Learn to locate and activate the oxygen flush in the machines in your workspace.

Common Gas Outlet

All machines have a common gas outlet (Fig. 4.12) where the breathing system ('circuit') gets attached. Most machines have an option of selecting the route the gases will take- whether through the sodalime canister and circle system or one of the Mapleson (commonly D or F) systems (termed 'auxiliary'). Before beginning induction it is vital to check which circuit one is using and whether the selector knob has been appropriately turned.

Compressed Oxygen Outlet(s)

One or more compressed oxygen outlets may be available to provide oxygen at about 400 kPa. These can be used to drive ventilators or for manually controlled jet injectors.

THE ANESTHESIA BREATHING CIRCUITS

The breathing circuit is a vital part of anesthesia equipment. This is the interface between the machine and the patient and is the conduit to deliver oxygen, pre-selected gas flows and volatile agents to the patient. The breathing circuit performs another important function of carbon dioxide elimination from the lungs. As we saw earlier, the open drop method is very unreliable both from the point of view of oxygenation as well as CO_2 elimination. A brief description of the circuits used nowadays and their advantages is given below.

Properties of an ideal breathing circuit:

1. Should be simple and safe to use
2. Should permit spontaneous and controlled ventilation.
3. Should be suitable and safe for adults as well as children
4. Should be efficient, requiring low fresh gas flow rates.
5. Should have safety features to protect the patient from barotrauma.
6. Should be sturdy, compact and lightweight in design.
7. Should permit easy removal of waste exhaled gases.
8. Easy to maintain and sterilize with minimal running cost.

The Mapleson Breathing Circuits

The common anesthetic breathing circuits in use were described and analyzed by W.W. Mapleson in 1954. All these circuits have common components- a fresh gas flow inlet, a reservoir bag, an expiratory or pop-off valve, and tubing. They are classified into A, B, C, D, E, F type based on the relative positions of the fresh gas flow and expiratory valve. The efficiency of each breathing system is gauged by the fresh gas flow rate required to prevent rebreathing.

The Mapleson A or Magill circuit (Fig. 4.13) is still present on many old anesthesia machines in the peripheral areas of the hospital. The importance of the Magill circuit lies in the fact that of all the Mapleson circuits, **it is the most efficient for spontaneous ventilation,** requiring fresh gas flow equal to the patient's minute ventilation (MV). However, it is the least efficient for controlled ventilation.

We shall discuss the Mapleson D circuit in some detail as its modified version is commonly used as the 'Bain' circuit (Fig. 4.14). The bain

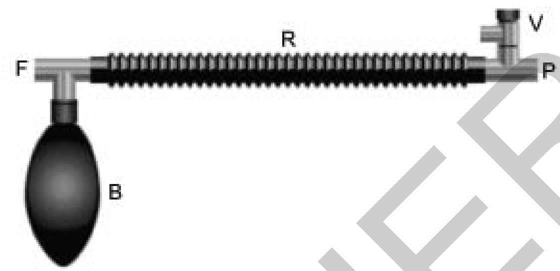


Fig. 4.13: Magill circuit

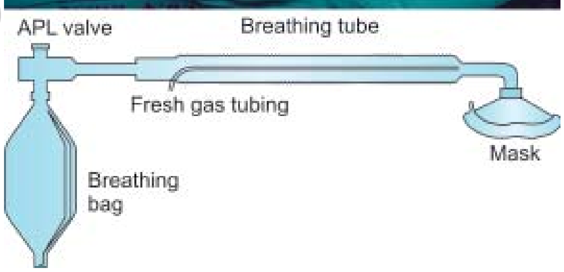


Fig. 4.14: Bain circuit showing co-axial arrangement

circuit is a co-axial circuit. The inner tube carrying the fresh gas flow (FGF) enters the outer expiratory tube at the machine end, travels along the length of the expiratory limb (which is a transparent corrugated plastic tube) and terminates at the patient end. The end of the inner tube is attached to the outer tube at the patient end by three spokes (Fig. 4.15). Thus FGF is actually delivered close to the patient. The patient exhales into the outer tube which

Fig. 4.15: Patient end of Bain circuit. Note inner tube attached to outer by 3 spokes

Fig. 4.16: Jackson-Rees' modification of Ayre's 'T' piece

ends at the reservoir bag and incorporates an expiratory valve at the reservoir bag end. The Bain circuit has many inherent advantages:

1. It is lightweight and convenient to use.
2. It is re-usable and easily sterilizable.
3. It can be used for both spontaneous and controlled ventilation without making any changes in connection, valves, etc.
4. Exhaled gases in the outer tube warm the inspired FGF.
5. Scavenging of exhaled gases is easy due to the expiratory valve being situated away from the patient.

Proper functioning of the Bain circuit should be ascertained by checking the integrity of the inner tube. If broken or kinked it leads to severe hypercarbia. For spontaneous ventilation, FGF needed to prevent rebreathing is 2.5 times the minute ventilation and for controlled ventilation it is 1-2 times the minute ventilation.

The Jackson-Rees' modification of the Mapleson E circuit (Mapleson F, Fig. 4.16) is widely used in pediatric anesthesia. You will notice that it has no valves, which explains the low resistance it offers .It also has advantages of simplicity, allowing spontaneous or controlled ventilation and is lightweight so that there is no drag on the pediatric endotracheal tube. The FGF required to prevent rebreathing for spontaneous ventilation is **2-3 times the minute ventilation**; that for controlled, 2 times the minute ventilation.

We discussed semiclosed systems till now where provision of a designated FGF was required to prevent rebreathing. With increasing awareness to reduce theatre and atmospheric pollution by inhaled volatile anesthetics and for purposes of economy a circuit had to be devised which would absorb the exhaled carbon dioxide and so enable recycling of unused oxygen and volatile agent, thereby minimizing spill and wastage. The answer was the closed circuit (Fig. 4.17). The normal FGF used is 1litre. A sterilizable canister packed with 'high-moisture' soda lime (80% calcium hydroxide, 15% water, 4% sodium hydroxide and 1% potassium hydroxide) is interposed in the circuit. The reaction that occurs in the sodalime canister is as follows:

$$CO_2 + H_2O \rightarrow H_2CO_3$$
$$H_2CO_3 + 2NaOH \rightarrow Na_2CO_3 + 2H_2O + Heat$$
$$Na_2CO_3 + Ca(OH)_2 \rightarrow CaCO_3 + 2NaOH$$

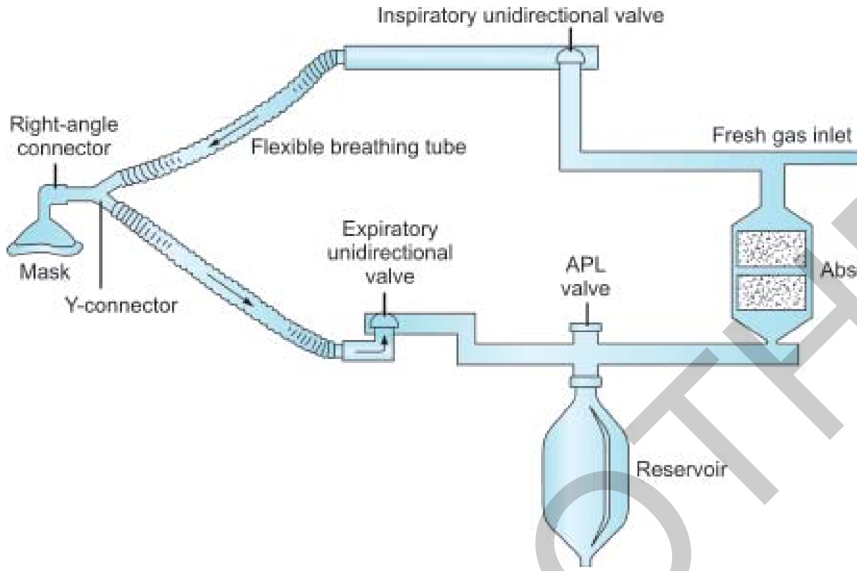


Fig. 4.17: Schematic representation of closed circuit

Use of the closed circuit results in **economy**, **prevention of theatre pollution** and **prevention of chronic exposure** of personnel to inhalational agents, and conservation of heat and humidity in the inspired gases. A detailed discussion of the circuit components is out of the purview of this text. Compounds generated due to the interaction of sodalime with inhalational agents is detailed in the section on inhalational agents.

A Primer of ANESTHESIA

A Primer of Anesthesia is a textbook targeting mainly undergraduates at the threshold of choosing their future specialty. It provides a simplified yet comprehensive coverage of the specialty of anesthesiology. The book is presented in four sections, which take the reader through each aspect of patient care, beginning with the preoperative phase and ending with critical care. Local anesthetics and neuromuscular blockade are covered in detail as they are unique to anesthesiology. Each chapter is generously illustrated to complement the text.

Rajeshwari Subramaniam presently working as a Professor in the Dept. of Anesthesiology and Intensive Care, AIIMS, has been practicing Anesthesiology for the last 26 years ("living and breathing it" as she says). She graduated from LHMC, New Delhi in 1980 and joined AIIMS for her postgraduation, ultimately continuing as faculty. She firmly believes that hands on, patient oriented teaching of undergraduates is essential to demystify the subject as well as to attract potential postgraduates. Ultimately it is these trained doctors who will positively impact patient care and reduce morbidity and mortality, at all levels of health care starting right from PHCs to tertiary level hospitals, both in the Government and Private Sector.

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