

Ministry of Higher Education and Scientific Research

College of Health and Medical Technology

Anesthesia Techniques Department

Subject: practical Anesthesia Equipment

4rd stage

2025-202

Anesthesia machine and anesthesia delivery

- The anesthetic machine receives medical gases (oxygen, nitrous oxide, and air) under pressure and accurately controls the flow of each gas individually.
- A gas mixture of the desired composition at a defined flow rate is created before a known concentration of an inhalational agent vapour is added.
- Gas and vapour mixtures are continuously delivered to the common gas outlet of the machine, as fresh gas flow (FGF), and to the breathing system and patient.



The anaesthetic machine consists of:

1. gas supplies
2. pressure gauges
3. pressure regulators (reducing valves)
4. flowmeters
5. vaporizers
6. a common gas outlet
7. a variety of other features, e.g. high-flow oxygen flush, pressure-relief valve and oxygen supply failure alarm and suction apparatus

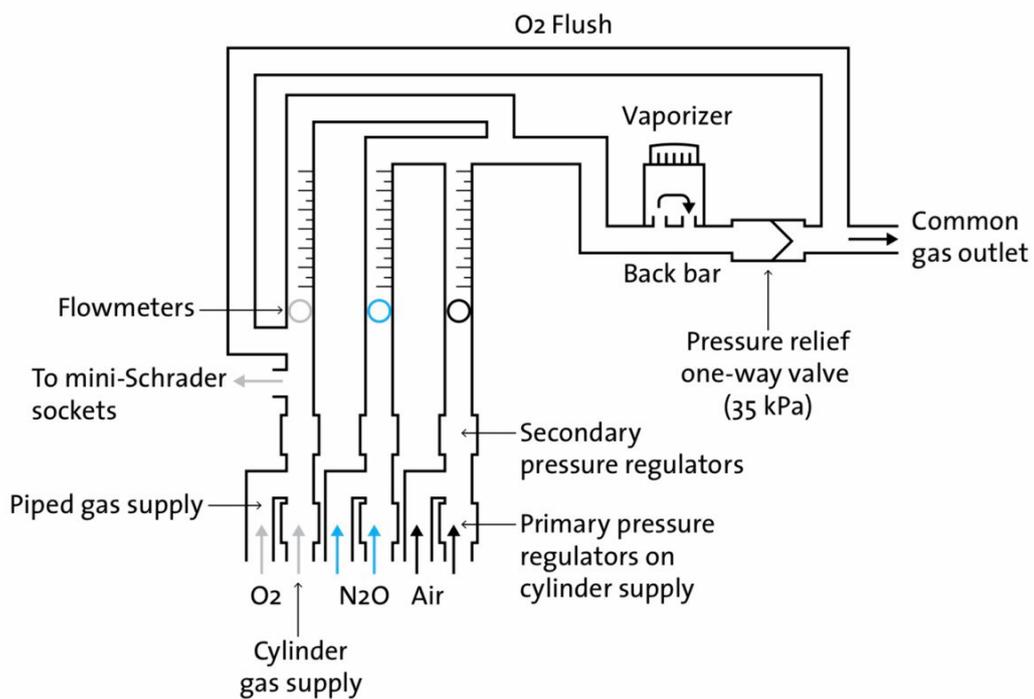
Most modern anaesthetic machines or stations incorporate a circle breathing system and a bag-in-bottle type ventilator

To ensure the delivery of a safe gas mixture safety features of a modern anaesthetic machine should include the following:

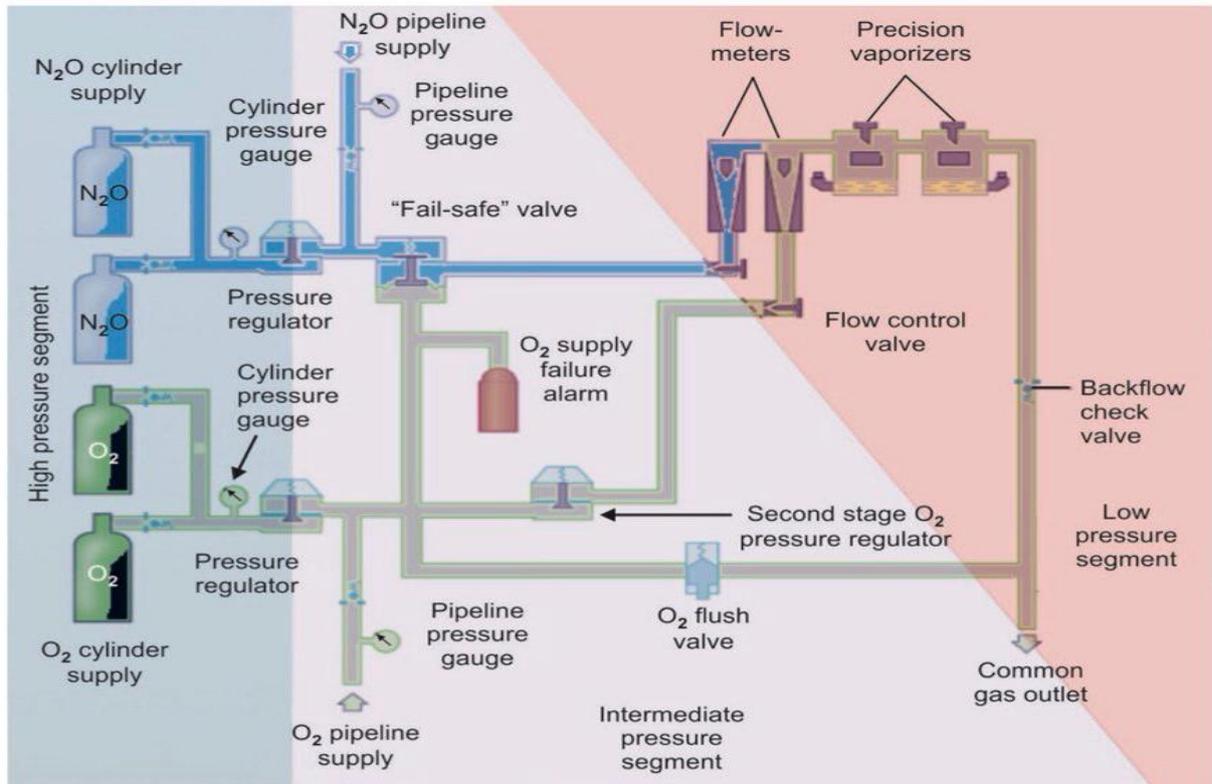
- colour-coded pressure gauges
- colour-coded flowmeters
- an oxygen flowmeter controlled by a single touch-coded knob
- oxygen is the last gas to be added to the mixture
- oxygen concentration monitor or analyser
- nitrous oxide is cut off when the oxygen pressure is low
- oxygen: nitrous oxide ratio monitor and controller



Flow control knobs. Note the colour-coding and the distinctive-shape oxygen control knob.



Anatomy of an anesthesia machine:



Schematic diagram of continuous flow anesthesia machine

We can be divided the Anaesthetic machine into:-

- **High pressure system** which is reduce pressure received from cylinders, make it constant.
- **Intermediate pressure system** which receives gas from regulator or pipeline, deliver it to flowmeter and O₂ flush.
- **Low pressure system** which takes gases from flowmeter to machine outlet enriched with vapourisers.

High-Pressure Section:

- Cylinder P.G. & reg.
- Pipeline inlet & reg.
- Fail-safe.
- Flowmeter valve.
- O₂ flush.

Low-Pressure Section:

- Flowmeter.
- Vaporizer.
- Common gas outlet.

Pressure gauge

This measures the pressure in the cylinder or pipeline. The pressure gauges for oxygen, nitrous oxide, and medical air are mounted in a front-facing panel on the anesthetic machine.

Note: Some modern anaesthetic machine designs have a digital display of the gas supply pressures.



Pipeline pressure gauges for oxygen, nitrous oxide and air.

Gas Supplies	kPa		
	O2	N2O	Air
	3662		
	419	395	396

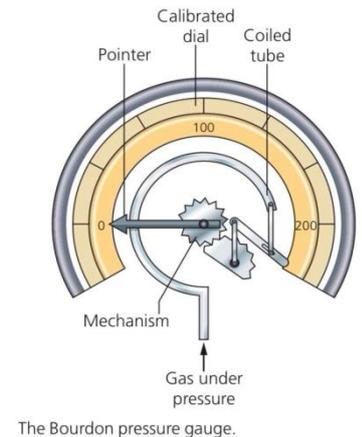
Digital display of pressure gauges for oxygen (cylinder and pipeline), nitrous oxide (pipeline) and air (pipeline).

Components

1. A robust, flexible and coiled tube which is oval in cross- section. It should be able to withstand the sudden high pressure when the cylinder is switched on.
2. The tube is sealed at its inner end and connected to a needle pointer which moves over a dial.
3. The other end of the tube is exposed to the gas supply.

Mechanism of action

1. The high-pressure gas causes the tube to uncoil (Bourdon gauge).
2. The movement of the tube causes the needle pointer to move on the calibrated dial indicating the pressure.



Problems in practice and safety features

1. Pressure gauge is colour-coded for each gas, the pressure measured indicate the content available in the cylinder.
2. The pressure of pipeline must not use to measure pressure of the cylinder and vice versa, otherwise inaccuracy and/or damage to pressure gauge will happen.

Pressure regulator (reducing valve)

Pressure regulators are used because:

- Gas and vapour are stored under high pressure in cylinders. A regulator reduces the variable cylinder pressure to a constant safer operating pressure of about 400 kPa.
- The temperature and pressure of the cylinder contents decrease with use. In order to maintain flow, constant adjustment is required in the absence of regulators.
- Regulators protect the components of the anaesthetic machine against pressure surges.
- The use of pressure regulators allows low-pressure piping and connectors to be used in the machine. This makes the consequences of any gas leak much less serious.



Cylinder pressure regulators (black domes) positioned above the cylinder yokes in the Datex-Ohmeda Flexima anaesthetic machine.

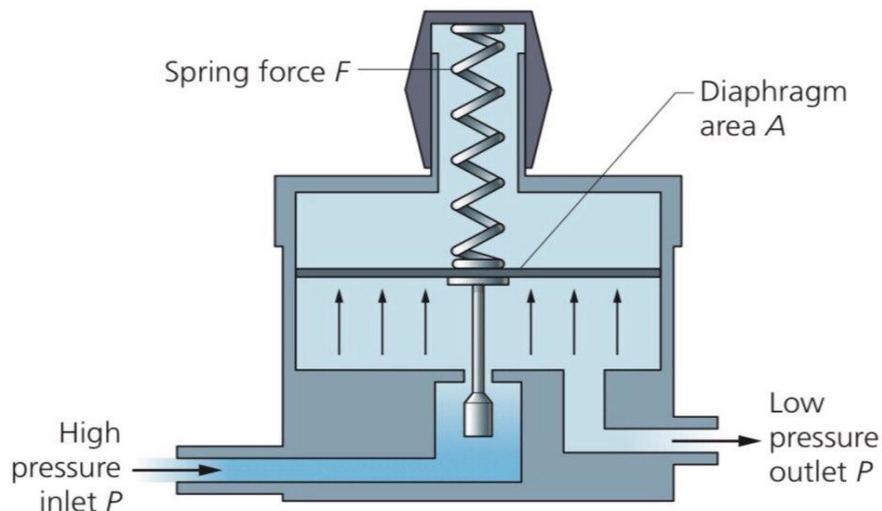


Cylinder pressure regulator (the machine's tray has been removed).

Note: They are positioned between the cylinders and the rest of the anaesthetic machine

Components

1. An inlet, with a filter, leading to a high-pressure chamber with a valve.
2. This valve leads to a low-pressure chamber and outlet.
3. A diaphragm attached to a spring is situated in the low-pressure chamber.



The principles of a pressure regulator (reducing valve).

Mechanism of action

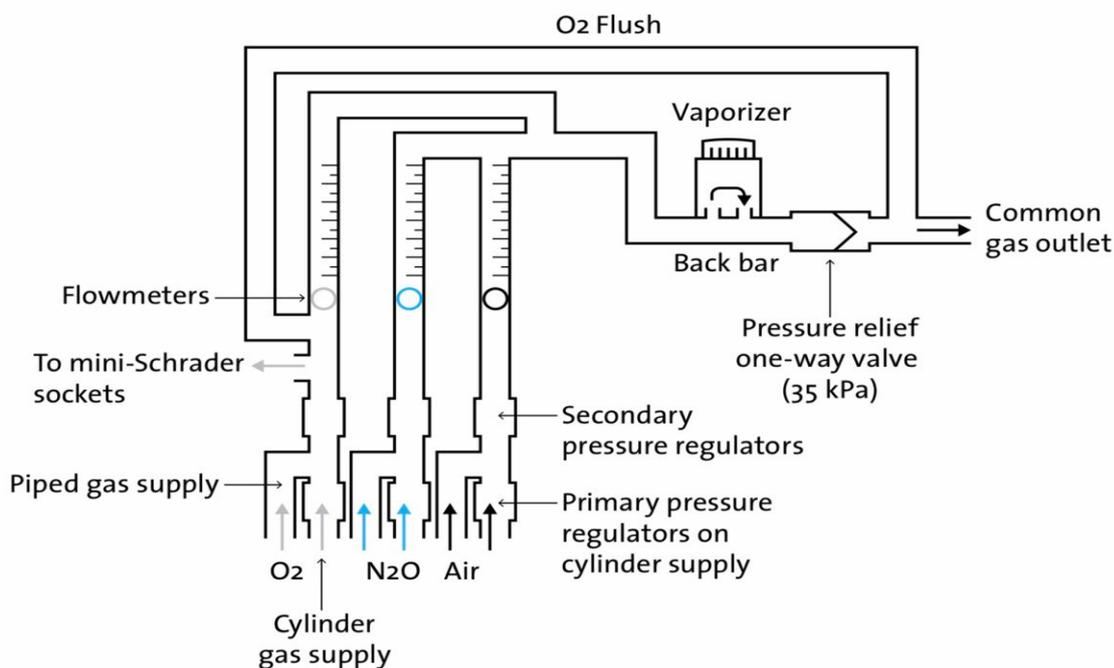
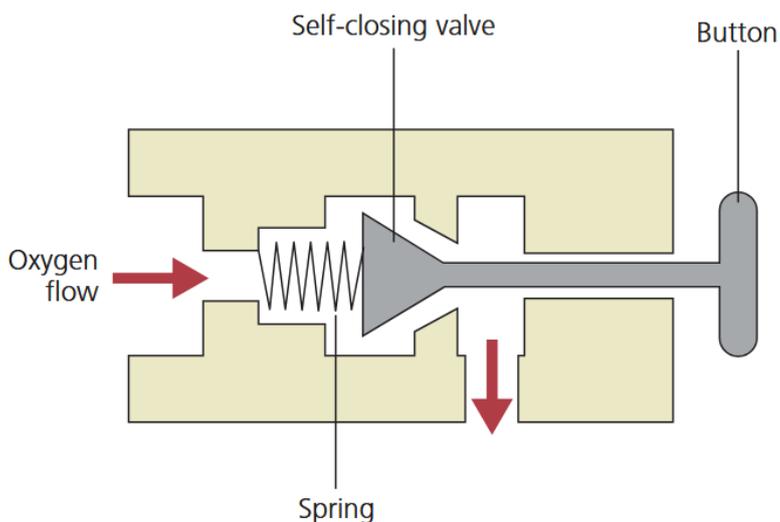
1. Gas enters the high-pressure chamber and passes into the low-pressure chamber via the valve.
2. The force exerted by the high-pressure gas tries to close the valve. The opposing force of the diaphragm and spring tries to open the valve. A balance is reached between the two opposing forces. This maintains a gas flow under a constant pressure of about 400 kPa.

Problems in practice and safety features

1. Formation of ice inside the regulator can occur. If the cylinder contains water vapour.
2. The diaphragm can rupture.
3. Relief valves (usually set at 700 kPa)

Emergency oxygen flush

This is usually activated by a non-locking button. When pressed, pure oxygen is supplied from the outlet of the anaesthetic machine. The flow bypasses the flowmeters and the vaporizers. A flow of about 35–75 L/min at a pressure of about 400 kPa is expected. The emergency oxygen flush is usually activated by a non-locking button and using a self-closing valve. It is designed to minimize unintended and accidental operation by staff or other equipment. The button is recessed in a housing to prevent accidental depression.



Problems in practice and safety features

1. The high operating pressure and flow of the oxygen flush puts the patient at a higher risk of barotrauma.
2. When the emergency oxygen flush is used inappropriately, it leads to dilution of the anaesthetic gases and possible awareness.

Flowmeters

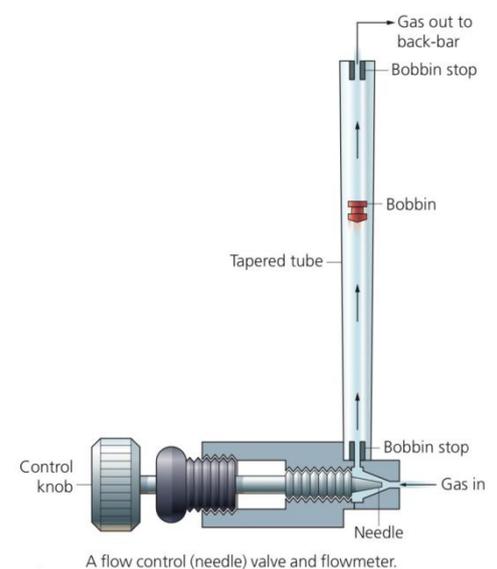
Flowmeters measure the flow rate of a gas passing through them. They are individually calibrated for each gas. Calibration occurs at room temperature and atmospheric pressure (sea level). They have an accuracy of about $\pm 2.5\%$. For flows above 1 L/min, the units are L/min, and for flows below that, the units are 100 mL/min



A flowmeter panel.

Components

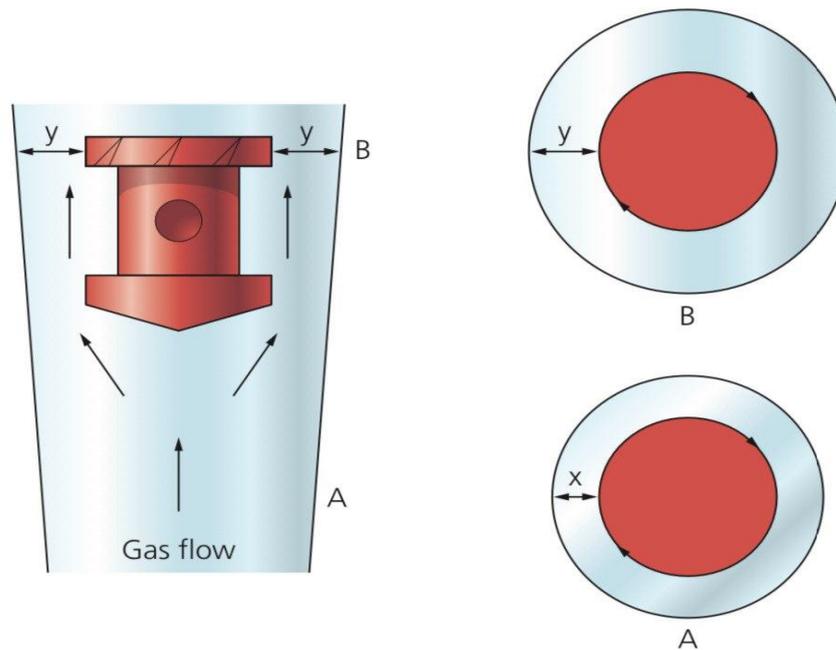
1. A flow control (needle) valve.
2. A tapered (wider at the top), transparent plastic or glass tube.
3. A lightweight rotating bobbin or ball. Bobbin-stops at either end of the tube ensure that it is always visible to the operator at extremes of flow.



A flow control (needle) valve and flowmeter.

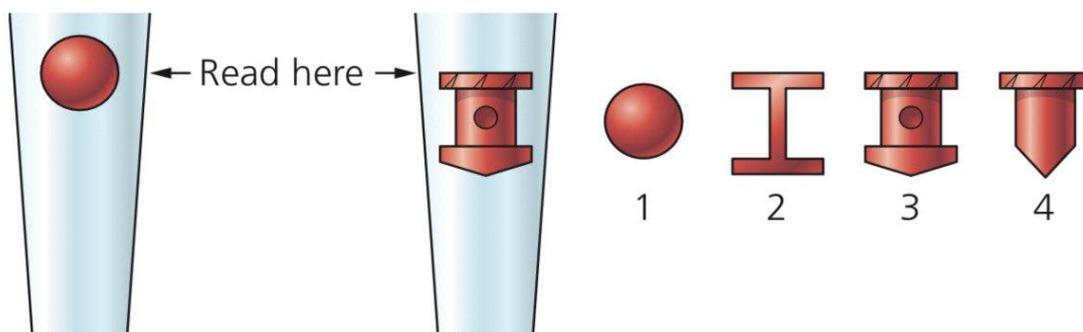
Mechanism of action

1. When the needle valve is opened, gas is free to enter the tapered tube.
2. The bobbin is held floating within the tube by the gas flow passing around it. The higher the flow rate, the higher the bobbin rises within the tube.
3. The effect of gravity on the bobbin is counteracted by the gas flow. The pressure difference across the bobbin remains constant as it floats.
4. The clearance between the bobbin and the tube wall widens as the gas flow increases.



Mechanism of action of the flowmeter. As the bobbin rises from A to B, the clearance increases (from x to y).

5. The top of the bobbin has slits (flutes) cut into its side. As gas flows past it, the slits cause the bobbin to rotate. A dot on the bobbin indicates to the operator that the bobbin is rotating and not stuck.
6. The reading of the flowmeter is taken from the top of the bobbin. When a ball is used, the reading is generally taken from the midpoint of the ball.



Reading a flowmeter (*top*). Different types of bobbin: 1, ball; 2, non-rotating H float; 3, skirted; 4, non-skirted.

7. There is a stop on the oxygen flow control valve to ensure a minimum oxygen flow of 200–300 mL/min past the needle valve. This ensures that the oxygen flow cannot be discontinued completely.

AUXILIARY OXYGEN FLOWMETER

Auxiliary oxygen flowmeters are separate from the back bar flowmeters and the common gas outlet. It is an optional accessory seen on many models of anesthesia machines.

A nasal cannula or other oxygen delivery device can be attached for the delivery of supplemental oxygen



Vaporizers

A vaporizer is designed to add a controlled amount of an inhalational agent, after changing it from liquid to vapour, to the FGF. This is normally expressed as a percentage of saturated vapour added to the gas flow.

Vaporizers can be classified according to location:

1. Inside the breathing system.
2. Outside the breathing system: Example
plenum vaporizer

Uses of plenum vaporizer

For the administration of safe, accurate and precise concentrations of a volatile agent via a continuous flow anaesthetic machine

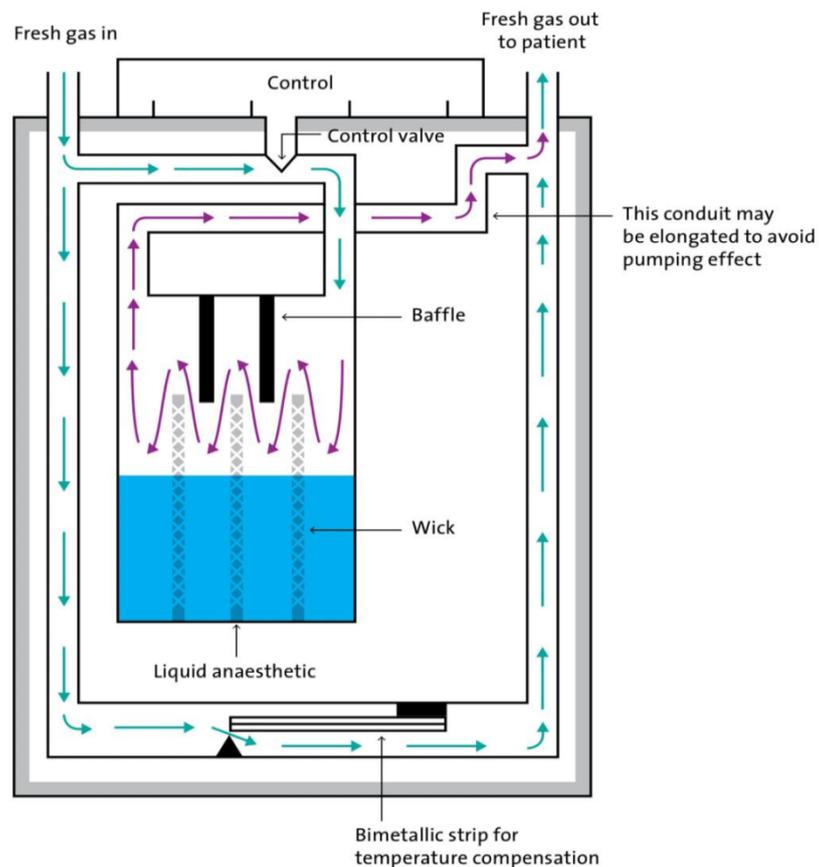
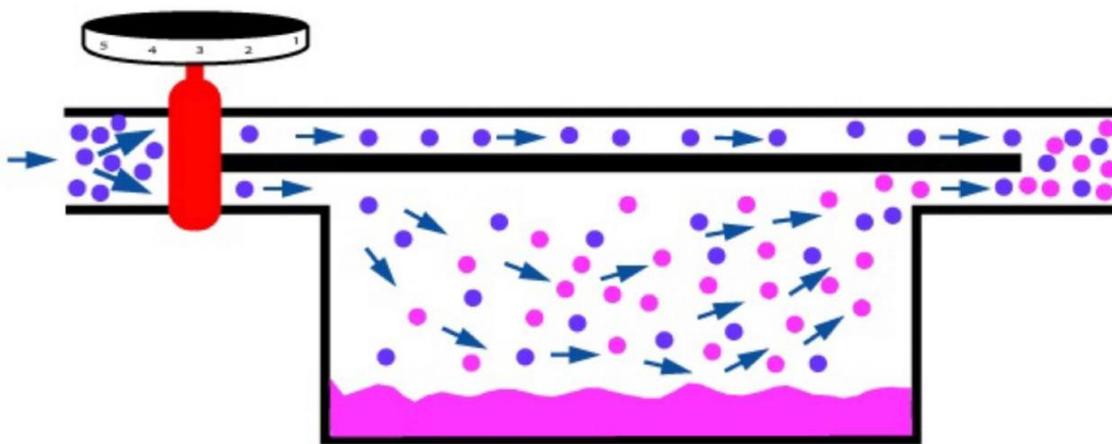


A plenum vaporizer mounted on the back bar of an anaesthetic machine. (Courtesy Philips Healthcare, Guildford, UK.)

Components of plenum vaporizer

1. The case with the filling level indicator and a port for the filling device.
2. Percentage control dial on top of the case.
3. The bypass channel and the vaporization chamber. The latter has Teflon wicks or baffles, cowls or nebulizers to increase the surface area available for vaporization.
4. The splitting ratio is controlled by a temperature-sensitive valve utilizing a bimetallic strip.
5. The vaporizers are mounted on the back bar.

Mechanism of action



A temperature compensated plenum vaporizer.

MAC & colour-coded

The minimum alveolar concentration (MAC) is the minimum concentration of an inhaled anesthetic at a pressure of 1 atm that inhibits skeletal muscle movement in response to surgical incision in 50% of patients.

MAC halothane 0,8 -red-

MAC isoflurane 1,2 -purple-

MAC sevoflurane 2 -yellow-

MAC desflurane 6 -blue-



Vaporizer filling devices

These are agent-specific being geometrically coded (keyed) to fit the safety filling port of the correct vaporizer and anaesthetic agent supply bottle. They prevent the risk of adding the wrong agent to the wrong vaporizer and decrease the extent of spillage.



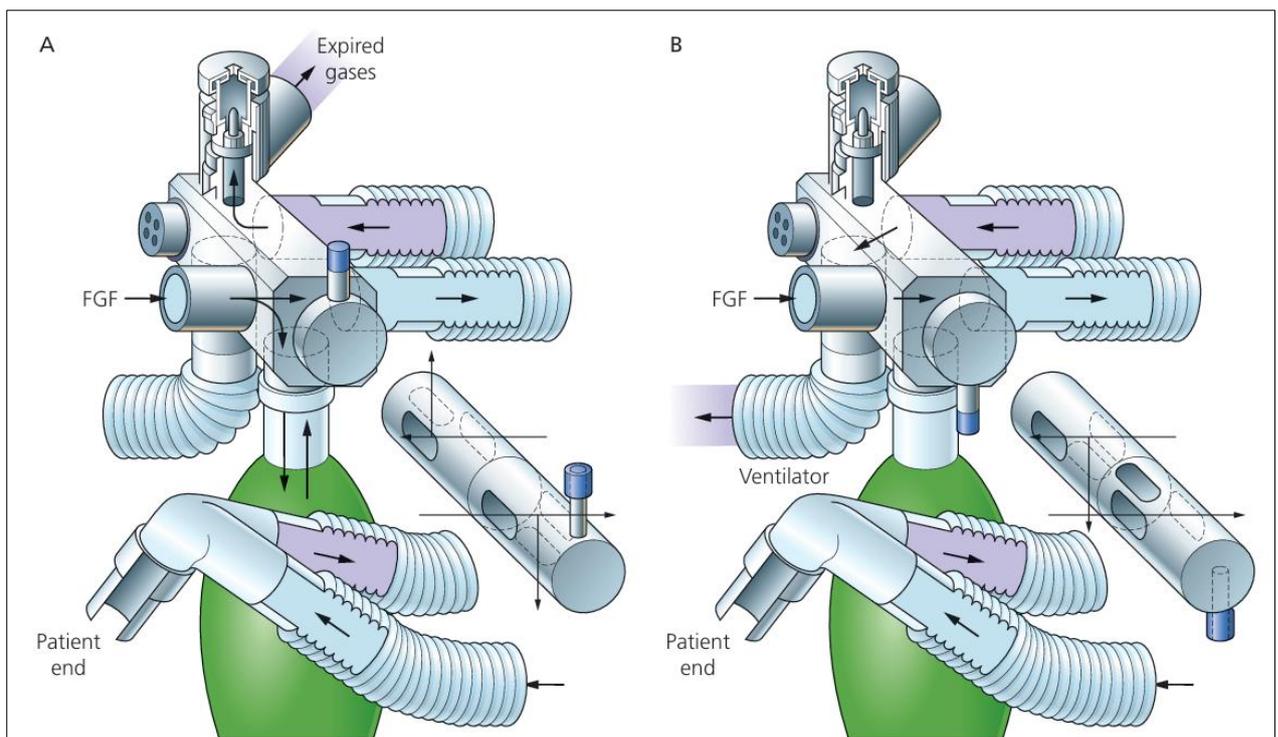
❖ This is one of the latest forms that have been developed for modern Anesthesia machine.

The Humphrey ADE breathing system

This is a very versatile breathing system that combines the advantages of the Mapleson A, D, and E systems. It can therefore be used efficiently for spontaneous and controlled ventilation in both adults and children.

Components

1. **Two lengths of 15 mm smooth-bore tubing.** One delivers the fresh gas, and the other carries away the exhaled gas. Distally, they are connected to a Y-connection leading to the patient. Proximally, they are connected to the Humphrey block.
2. **The Humphrey block is at the machine end and consists of:**
 - An APL valve featuring a visible indicator of valve performance.
 - A 2-liter reservoir bag.
 - A lever to select either spontaneous or controlled ventilation.
 - A port to which a ventilator can be connected.
 - A safety pressure relief valve that opens at pressures in excess of 60 cmH₂O.



Mechanism of action

- With the lever up (**spontaneous mode**), the reservoir bag and APL valve connect to the breathing system like the Magill system.
 - ❖ In adults, FGF is about 50-60ml/kg/min
 - ❖ In children weighing less than 25kg, initial FGF is 3 L/min
- With the lever down (**ventilator mode**), the bag and APL valve are isolated like the Mapleson E system; exhaled gas is routed through the expiratory tubing to the ventilator port and scavenged at the ventilator's expiratory valve.
 - ❖ In adults , FGF is about 70ml/kg
 - ❖ In children weighing less than 25kg, initial FGF is 3 L/min
- The system suits both pediatric and adult patients, featuring narrow, low-volume, smooth-bore tubing that does not significantly increase flow resistance compared with 22 mm corrugated tubing. It permits small tidal volumes and requires less energy to overcome gas inertia.
- The APL valve provides slight PEEP (~1 cmH₂O), benefiting pediatric anesthesia.

The circle breathing system

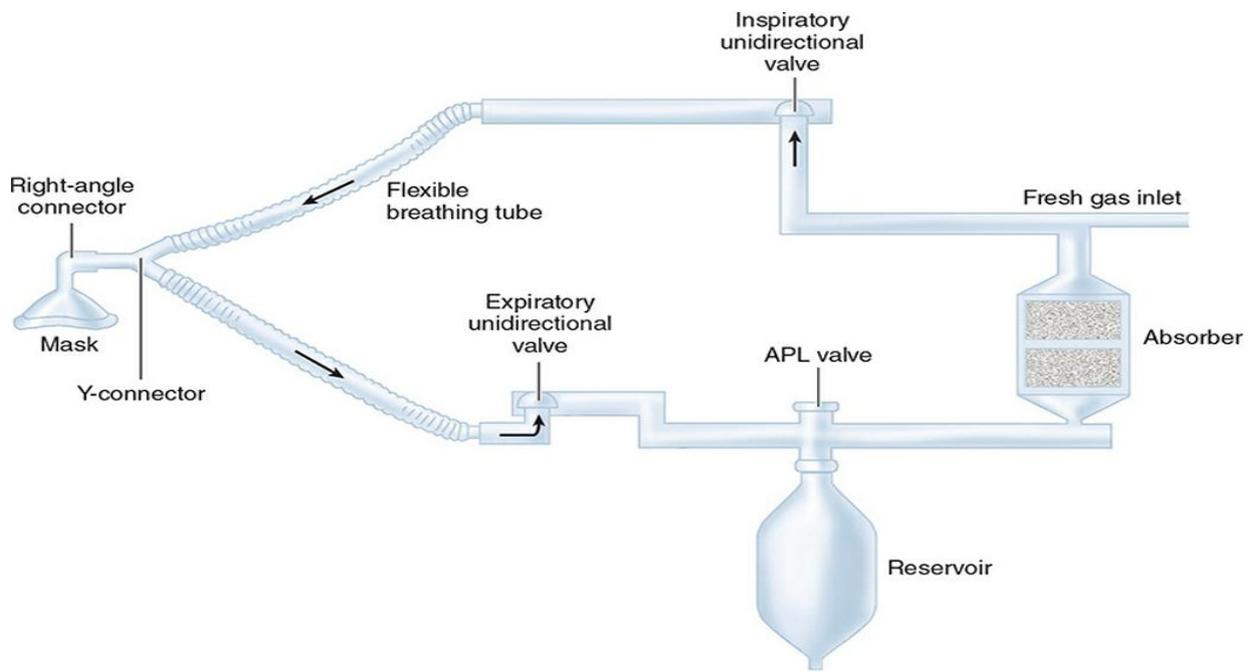
Over 80% of the anaesthetic gases/vapours are wasted when FGF of 5.0 L/min is used. Typically, the reduction of FGF from 3.0 L/min to 1.0 L/min results in a saving of about 50% of the total consumption of any volatile anaesthetic agent.

In this breathing system, **soda lime** is used to absorb the patient's exhaled carbon dioxide. FGF requirements are low, making the circle system very efficient and causing minimal pollution.

This breathing system is particularly **useful for long cases because it efficiently conserves** anaesthetic gases, heat and moisture.

Circle system comprises:

- A fresh gas inlet
- A reservoir bag
- Two one-way valves (one in each of the inspiratory and expiratory limbs)
- A Y-piece connector from the one-way valves to the patient
- An APL valve
- A soda lime canister that absorbs carbon dioxide
- Lengths of corrugated (kink-resistant) tubing to connect the components to one other and the patient.



Soda lime

A CO₂ absorbent canister: A vertically positioned canister containing soda lime, para lime, and ambo sorb.

Soda lime consists of **94% calcium hydroxide** and **5% sodium hydroxide** with a small amount of **potassium hydroxide (less than 0.1%)**. It has a **pH of 13.5** and a **moisture content of 14–19%**.

A dye or colour Indicator is added to change the granules' colour when the soda lime is exhausted. Colour changes can be from **white to violet/purple (ethyl violet dye)**, from **pink to white (titan yellow dye)**, or **from green to violet**. Colour changes occur when the pH is less than 10.

1 kg can absorb more than 120 L of CO₂.



Advantages of the circle system:

- **Economy:** The FGF could be reduced to as low as 500–1000 mL.
- **Humidification:** In the low-flow system, once the equilibrium has been established, the inspired gas will be fully saturated with water vapor.
- **Reduction in atmospheric pollution:** The loss from the system will equal the FGF minus the CO₂ that is absorbed; hence, the reduction in atmospheric pollution.

Disadvantages of the circle system:

- Bulky & complex system, liable for leakage and disconnection
- Real danger of hypercapnia may result from
- An inactive absorber
- Incompetent unidirectional valves and
- Incorrect use of absorber bypass necessitating EtCO₂ monitoring as mandatory.

Use of vaporizers in the circle breathing system

VOC vaporizers are positioned on the back bar of the anaesthetic machine. They are high-efficiency vaporizers that can deliver high-output concentrations at low flows. They have high internal resistance.

VIC vaporizers are designed to offer minimal resistance to gas flow and have no wicks on which water vapour might condense (e.g. Goldman vaporizer). The VIC is a low efficiency vaporizer adding only small amounts of vapour to the gas recirculating through it. Such a configuration is rarely used in current practice.

Ventilators

Ventilators are used to provide controlled ventilation to maintain oxygenation and removal of carbon dioxide. Many of them have the facilities to provide multiple ventilatory modes that can lead to some confusion. They can be used in the operating theatre, intensive care unit, during transport of critically ill patients and also at home (e.g. for patients requiring nocturnal respiratory assistance).

Note: There are many ways of classifying ventilators: method of cycling, method of operation, source of power, suitability for use in theater and/or intensive care, and suitability for pediatric practice.

Ventilators can be classified according to Pressure generation:

1. Positive pressure ventilators:- are overwhelming used in current clinical practice where a positive pressure within the breathing system is created driving the gas into the patient's lungs.
2. Negative pressure ventilators:- mimic the normal physiology by generating a negative intrathoracic pressure allowing gas flow into the lungs but their use in current practice is limited.

The basic variables in any ventilator are

- Tidal volume (mL/ breath), which can be delivered either as a fixed volume (e.g. 500 mL) with variable peak airway pressures or a fixed pressure (e.g. 12– 15cm H₂O) with variable volumes.
- Respiratory rate (breaths/min) can be set either by the ventilator (mandatory breaths) or by the patient (triggered breaths)
- Minute volume is the volume of gas inhaled or exhaled from patient's lungs per minute. It is the product of tidal volume and respiratory rate.
- I: E ratio is the ratio of inspiratory time to the expiratory time.

There are some of the commonly used ventilators

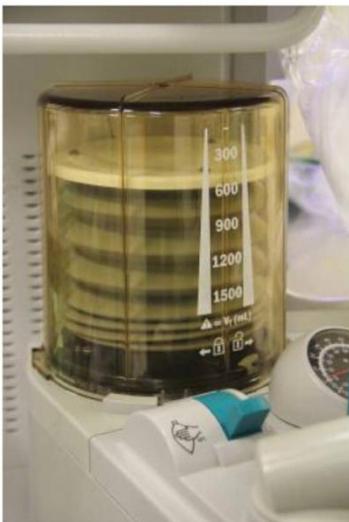
1. Manley MP3 ventilator.
2. Penlon Anaesthesia Nuffield Ventilator.
3. Bag in bottle ventilator.
4. SERVO-U ventilator.



The Manley ventilator.



The Penlon Nuffield 200 ventilator.



A bag in bottle ventilator.



Bag in bottle ventilator

Modern anaesthetic machines often incorporate a bag in bottle ventilator.

Components

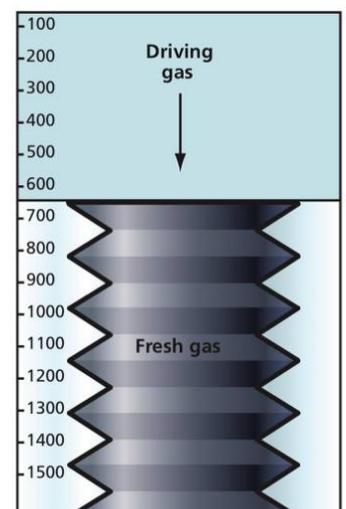
1. A driving unit consisting of:
 - A. a chamber with a tidal volume range of 0–1500 mL (a pediatric version with a range of 0–400 mL exists)
 - B. an ascending bellows accommodating the FGF.
2. A control unit with a variety of controls, displays and alarms: the tidal volume, respiratory rate (6–40 breaths/min), I : E ratio, airway pressure and power supply .



Bag in bottle AV800 ventilator. (Courtesy Penlon Ltd, Abingdon, UK)

Mechanism of action

1. It is a time-cycled ventilator that is pneumatically powered and electronically controlled.
2. The fresh gas is accommodated in the bellows.
3. Compressed air is used as the driving gas . On entering the chamber, the compressed air forces the bellows down, delivering the fresh gas to the patient.
4. The driving gas and the fresh gas remain separate.
5. The volume of the driving gas reaching the chamber is equal to the tidal volume.
6. Some designs feature a descending bellows instead.



Mechanism of action of the bag in bottle ventilator.

SERVO-U ventilator

The SERVO-U is a versatile intensive care ventilator, capable of being used for paediatric and adult patients. It is fully transportable, utilizing at least two 12 V batteries when mains electricity is not available

Components:

1. 'Patient unit' where gases are mixed and administered.
2. 'Graphical user interface' where settings are made and ventilation monitored.

Mechanism of action

1. Gas flow from the oxygen and air inlets is regulated by their respective gas modules.
2. Oxygen concentration is measured by an oxygen cell.
3. The pressure of the delivered gas mixture is measured by the inspiratory pressure transducer.
4. The patient's expiratory gas flow is measured by ultrasonic transducers, and the pressure is measured by the expiratory pressure transducer.
5. PEEP in the patient's system is regulated by the expiratory valve.



SERVO-U ventilator.



Checkout and maintenance of the anesthesia machine and equipment

Nots....

- A checkout procedure is prepared to determine whether the equipment is present, functioning properly, and ready to use.
- Properly checking equipment can reduce equipment-related morbidity and mortality
- Failure to check equipment properly is a factor in many critical incidents
- User manuals that are provided by anesthesia machine manufacturers have detailed directions for checking.
- Many of the newer anesthesia machines provide an electronic checking procedure.

Anesthesia Machine Checkout

1. Emergency Preparedness

❖ Manual Resuscitator (Ambu Bag)

- Inspect for wear, cracks, or tears .
- Test: Occlude the patient port and squeeze; pressure should build rapidly until the bag cannot be compressed .
- Reservoir Test: Attached reservoir bag must inflate when the patient port is occluded and deflate easily when released .

❖ Oxygen Source:

- Ensure a backup O₂ source (pipeline or courtesy flowmeter) is available for the resuscitation bag .

2. Gas Supply & Cylinders

❖ Oxygen Cylinder:

- Check for correct mounting and expiration labels .
- Cylinder Pressure: Turn the valve slowly counterclockwise. Listen for a hiss and observe the pressure gauge .

❖ Pipeline Pressure:

- Ensure connections are tight/quiet. Pressure must be between 345 and 380 kPa .
- Precaution: Close all flow control valves (clockwise) before opening gas sources to prevent indicator damage .

3. Vaporizers & System Power

❖ Vaporizers:

- Check liquid levels, tighten filler caps/drain valves, and ensure they are level and securely mounted .

❖ Master Switch:

- Turn on to enable pneumatic/electronic systems and allow for automated diagnostic self-checks .

4. Flowmeter & Monitor Calibration

❖ Flowmeters:

Indicators must stay at zero (or minimum) when closed. When opened, the float/rotameter must move smoothly and rotate freely .

❖ O₂ Monitor Calibration:

2. Calibrate to 21% in room air (away from gas sources)
3. Reinstall and flush with O₂; reading should exceed 90% .

5. Breathing System Leak & Obstruction Tests

❖ Leak Test (Circle/Mapleson):

1. Set all gas flows to zero, close the APL valve, and occlude the patient port.
2. Pressurize the system to 30 cm H₂O using the O₂ flush.
3. Pressure must remain stable for at least 10 seconds .

❖ Obstruction Test:

Can be detected by having the pt. breathing 100% O₂ through a mask, provided a tight mask fit is achieved. This can also be done by the anesthesia provider wearing a mask. The reservoir bag should inflate and deflate, and the breathing system pressure indicator should show no PEEP. Negative pressure will reveal an obstruction in the insp. Limb. Positive pressure will reveal obstruction in the exp. Limb. While this is being done the capnogram should be checked to make certain that a normal waveform appears.

6. Ventilation & Valve Testing

❖ Manual/Automatic Switch:

Verify the bag/ventilator selector switch functions correctly .

❖ Unidirectional Valves:

Unidirectional valves may be checked by several methods, such as:

Valve tester: this method utilizes a device consisting of a bulb with a 22-mm connector fitting that can be attached to the inspiratory and exhalation ports. To test the inspiratory valve, the compressed bulb is attached to the inspiratory port. It should immediately reinflate. When the bulb is compressed, it should meet firm resistance. To check the expiratory valve, the tester is attached with the bulb inflated. It should be possible to squeeze the bulb, and it should remain deflated.

Notes.....

- All monitor should be turned on. Alarm should be tested, and appropriate limits should be set.
- At the end of the case, flowmeters, vaporizers, and suction should be turned OFF.
- The absorbent should be checked for signs of exhaustion and changed if indicated.