Anaesthesia Machine

- Principles of operation
- construction
- troubleshooting
- preventive maintenance
- safety considerations
- performance monitoring

13.7.1 Maintain an Anaesthesia Machine

Unit B 13.7 Maintaining Ventilation and Anaesthesia equipment

Module 279 18 B Medical Instrumentation I

Function

an·al·ge·sia *noun* \a-nᵊl-ˈjē-zh(ē-)ə, -zē-ə\

medical : the loss of the ability to feel pain while conscious

What is a the purpose of an Anaesthesia machine (or Boyle machine) ?

Anaesthesia units dispense a mixture of gases and vapours/drugs and vary the proportions to control a patient's level of **consciousness** and/or **analgesia** during surgical procedures

Why is it important ?

During most surgical procedures, some form of anaesthesia is used. General anaesthesia is a state of unconsciousness, with an absence of pain sensation over the entire body, produced by anaesthetic agents, often with **muscle relaxants**. By using anaesthesia patients can be operated without feeling pain.

Functions of an anaesthesia machine

- Provide oxygen (O2) to the patient.
- Blend gas mixtures that can include (besides O2) an **anaesthetic vapor**, nitrous oxide (N2O), other medical gases, and air.
- Facilitate **spontaneous, controlled**, or **assisted** ventilation with these gas mixtures.
- Reduce/eliminate anaesthesia-related risks to the patient and clinical staff.

The anaesthesia machine is used by anaesthesiologists, nurse anaesthetists, and anaesthesiologist assistants to support the administration of anaesthesia.

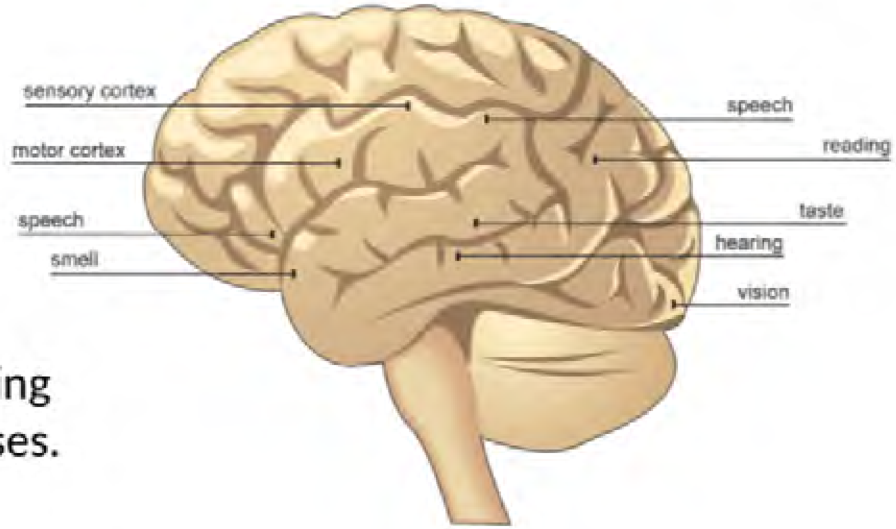
Use: operational room or theatre

There are at least four different types of anaesthesia

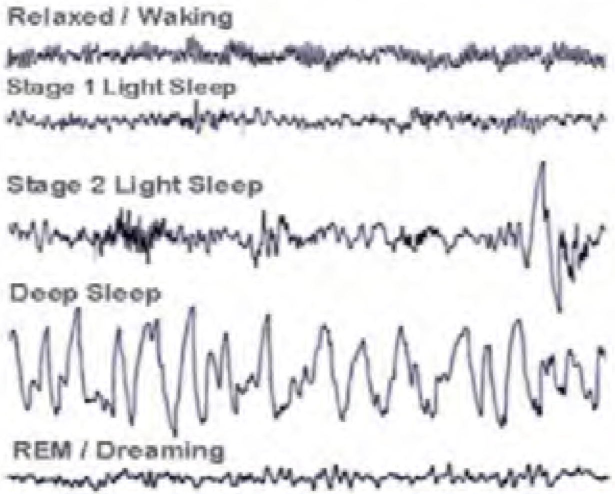
1. **General anaesthesia** is a state of unconsciousness, with an absence of pain sensation over the entire body, produced by anaesthetic agents, often with muscle relaxants. General anaesthesia is administered by inhalation, intravenously, intramuscularly, rectally or via the stomach.
2. **Local anaesthesia** is where a specific area is "numbed" such as in a dentist's office. The patient is awake and may feel some limited pain.
3. **Saddle block anaesthesia** is where the patient is conscious and the area of the body that would touch a saddle is affected. This is accomplished by injecting an anaesthetic agent low in the dural sac and is common for childbirth.
4. **Spinal anaesthesia** is where an anaesthetic agent is injected beneath the membrane of the spinal cord. There is no sensation below that point until the agent wears off.

In this presentation we focus on 1. general anaesthesia, through the use of an anaesthesia machine

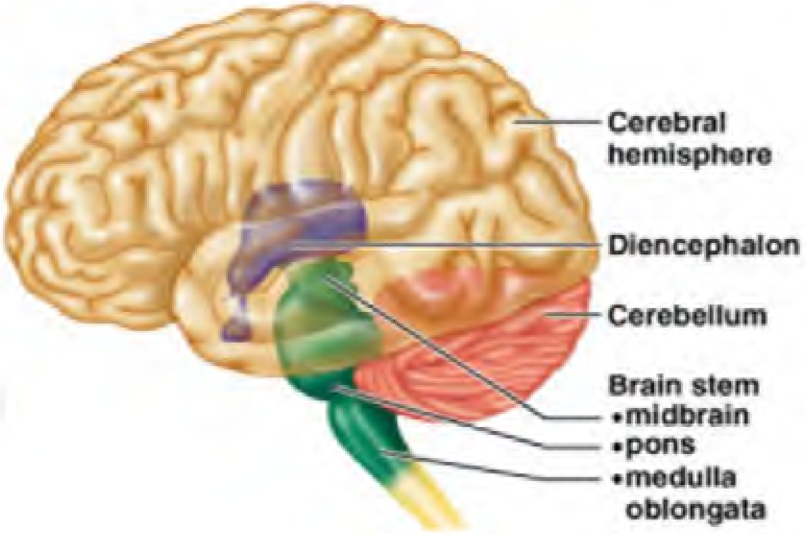
Science: Sleep and Anaesthesia



- **Sleep** is an active process generated in the brain.
- **Memory** and **Consciousness** also reside in the brain. Research is progressing on how exactly the different parts of the brain contribute to these processes.
- Anaesthesia has an impact on some brain structures and results in
  - **unconsciousness**, which is a similar state to sleep.
  - **amnesia**, so that the patient does not store the events in his memory.
- Consciousness and subsequent recall of intraoperative events—known as "awareness during general anaesthesia"—occur in 1 to 2 cases per 1000.



Electroencephalographic (EEG) methods, can be used to monitor anaesthetic depth



Stages of Depth of Anaesthesia

The stages of Depth of Anaesthesia (DoA) defined by Guedel in 1937 are generally accepted:

Stage I (stage of analgesia or disorientation): from beginning of induction of general anaesthesia to loss of consciousness.

Stage II (stage of excitement or delirium): from loss of consciousness to onset of automatic breathing. Eyelash reflex disappears but other reflexes remain intact and coughing, vomiting and struggling may occur; respiration can be irregular with breath-holding.

Stage III (stage of **surgical anaesthesia**): from onset of automatic respiration to respiratory paralysis.

Stage IV: from stoppage of respiration till death, Anaesthetic overdose causes paralysis wit respiratory arrest and vasomotor collapse. Pupils are widely dilated and muscles are relaxed.

Arthur Guedel

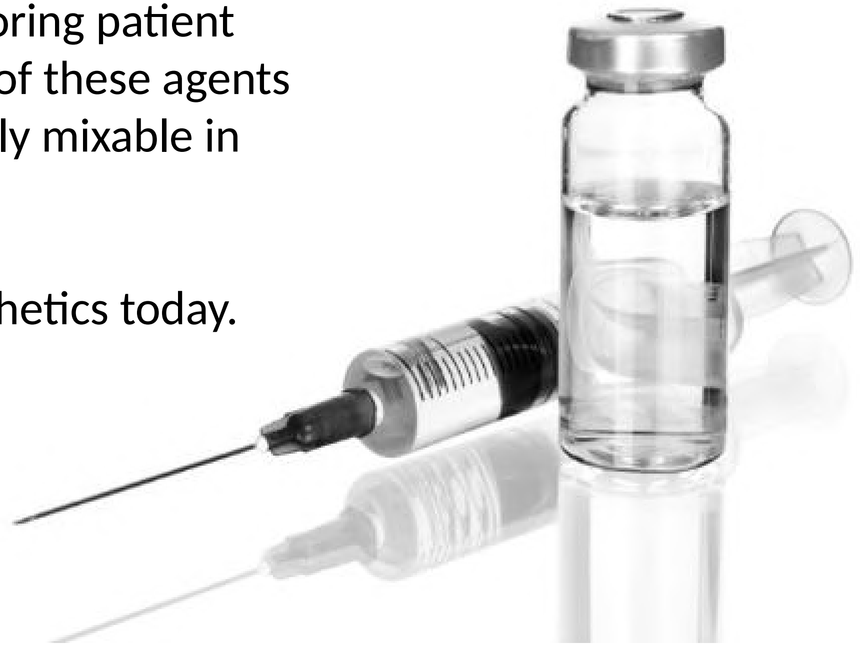
Agents, gases and drugs

Drugs given to induce or general anaesthetic can be either as **gases or vapours** (inhalational anaesthetics), or as **injections** (intravenous anaesthetics or intramuscular). It is possible to deliver anaesthesia solely by inhalation or injection, but most commonly the two forms are combined, with an injection given to induce anaesthesia and a gas used to maintain it.

Inhalational anaesthetic substances are either volatile liquids or gases and are usually delivered using an anaesthesia machine. An anaesthesia machine allows composing a mixture of **oxygen, anaesthetics** and **ambient air**, delivering it to the patient and monitoring patient and machine parameters. Liquid anaesthetics are vaporised in the machine. All of these agents share the property of being quite **hydrophobic** (i.e., as liquids, they are not freely mixable in water).

Desflurane, isoflurane and sevoflurane are the most widely used volatile anaesthetics today. They are often combined with Nitrous Oxide.

Injectable anaesthetics are used for the induction and maintenance of a state of unconsciousness, examples are propofol and etomidate.



Continuous Flow and Draw-Over systems

During anaesthesia using a Boyles machine or **continuous flow system** (figure 1), compressed gases (oxygen and nitrous oxide or air) pass from cylinders mounted on the machine to rotameters (flow meter) and then through the **vaporizer** where a volatile agent such as halothane is added to the gas mixture. The resulting mixture is delivered to the patient via a breathing circuit. This type of anaesthesia system is dependent on a **supply of compressed gases**. If these run out during an operation, so does the anaesthetic!

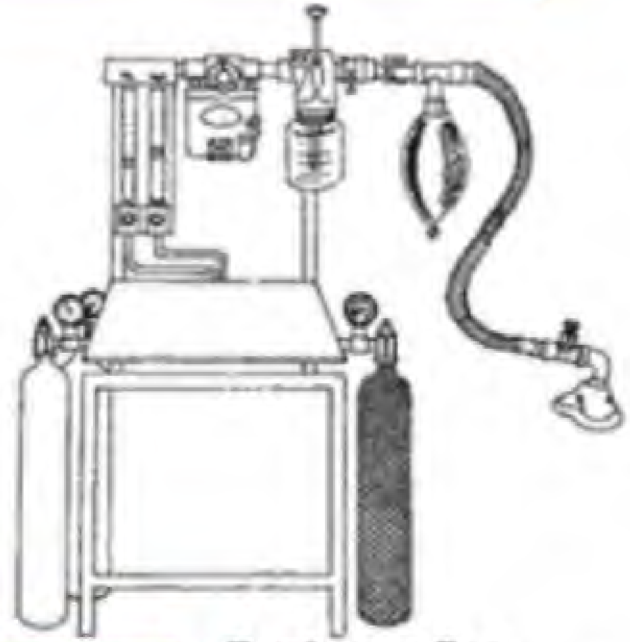
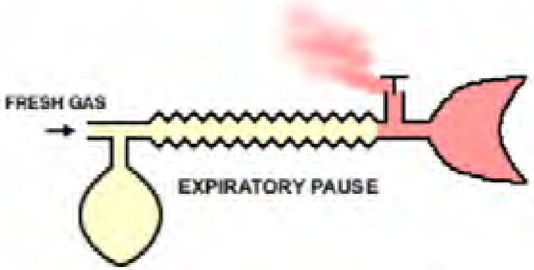


Figure 1 Continuous flow anaesthetic apparatus



classic Magill breathing circuit

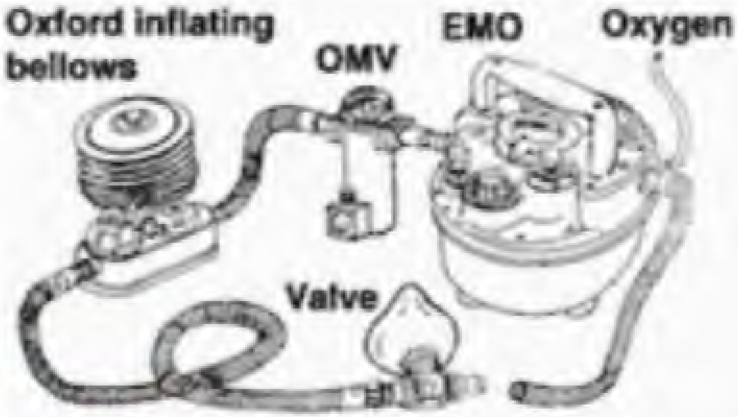


Fig 2 Drawover apparatus

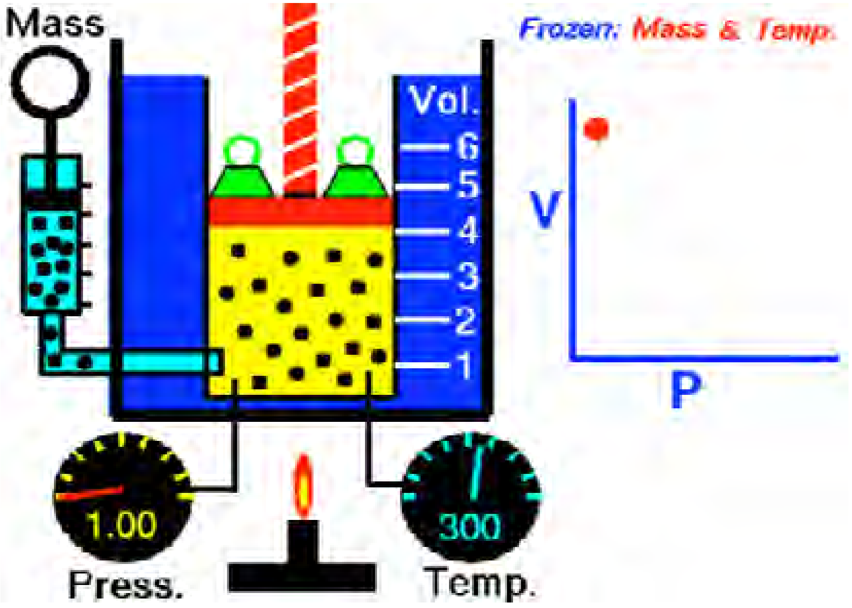
A **Draw-over** system (fig.2) is designed to provide anaesthesia without requiring a supply of compressed gases. Atmospheric air is used as the main carrier gas and is **drawn by the patient's inspiratory effort** through the vaporizer, where the volatile agent, normally ether or halothane, is added. The mixture is then inhaled by the patient via a non-rebreathing valve.

Combined gas law

To understand the functioning of anaesthesia machines and bottled gases it's important understand some gas physics. Boyle's law, Charles's law and Gay-Lussac's law form the combined gas law:

"The ratio between the pressure-volume product and the temperature of a system remains constant"

$$\frac{PV}{T} = k$$



- When the pressure of a closed gas system is increased – at constant temperature - the volume goes down in the same proportion
- When the temperature is increased – with constant volume – the pressure will increase in the same proportion

Anaesthesia system

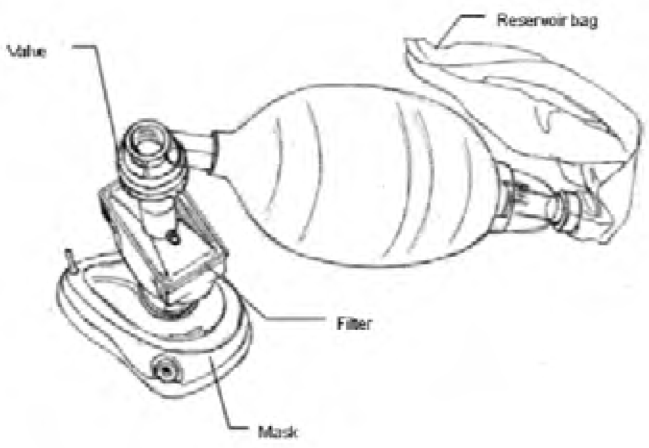
The basic anaesthetic delivery system consists of

- sources of **gases** (O2, N2O, air)
- **flowmeters**
- precision **vaporizers**, which produce a vapour from a volatile liquid anaesthetic
- a patient **breathing circuit** (tubing, connectors and valves)
- a **scavenging** device that removes any excess anaesthetic gases. This is critical, since room pollution with anaesthetic gases may cause health problems.

During delivery of gas anaesthesia to the patient, O2 (N2O, air) flows through the vaporizer and picks up the anaesthetic vapours. The O2-anaesthetic mix then flows through the breathing circuit and into the patient's lungs, usually by spontaneous ventilation (respiration). Occasionally, it is necessary to use assisted ventilation, especially when opening the chest (thoracic) cavity. Assisted ventilation is accomplished by use of a ventilator.

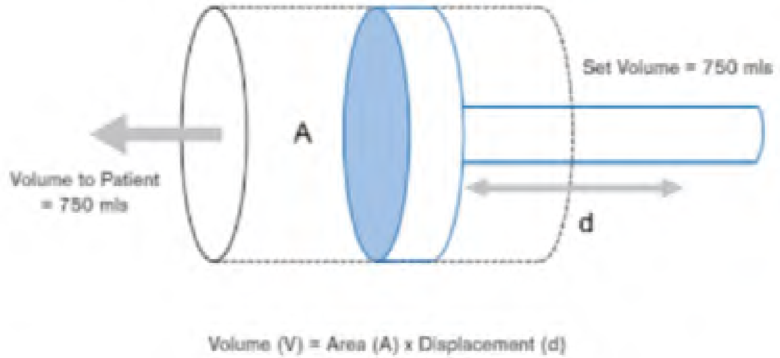
Ventilation is part of the Anaesthesia system

Because normal breathing is depressed by anaesthetic agents and by muscle relaxants administered in conjunction with them, **respiratory assistance** — either with an automatic ventilator or by manual compression of the reservoir bag — may be necessary to deliver the breathing gas to the patient.



Manual compression of a reservoir bag

Bellows

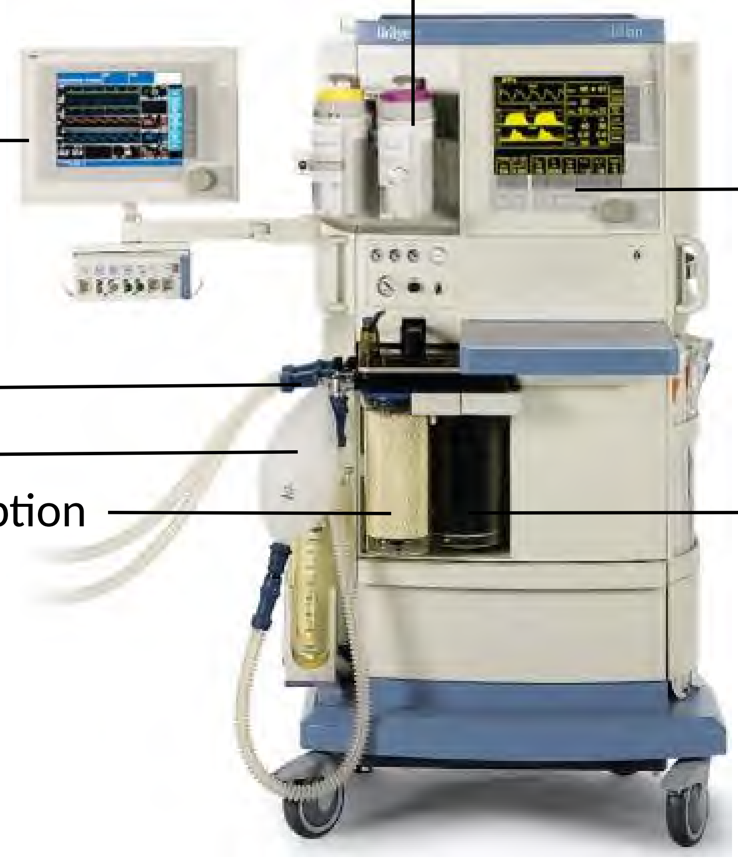


piston based ventilator

Construction, components

Vaporisers

Monitor



Mixing board,
traditionally with with rotameters

Breathing circuit

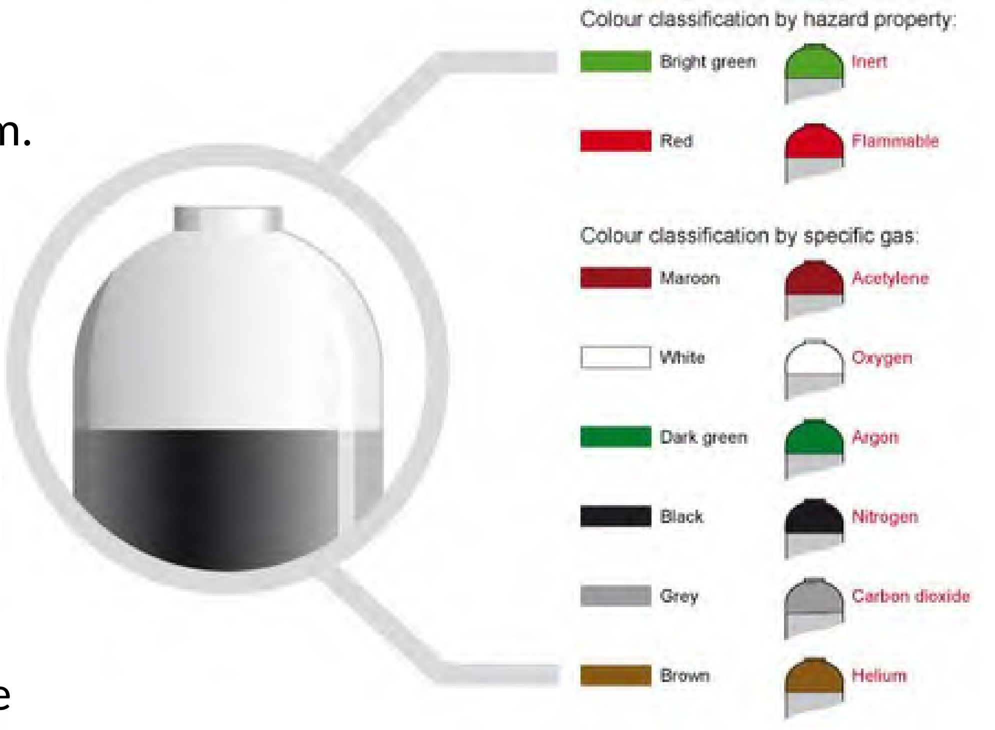
Emergency bag

Soda lime CO2 Absorption

Bellows

Gas supply & Flowmeters

Since cylinders store gas at very high pressure (2,000 PSI~=150bar), a pressure- reducing ***valve or regulator*** is required to reduce the pressure to about 50 PSI~=3.5bar, a level that can be handled by the anaesthesia system.



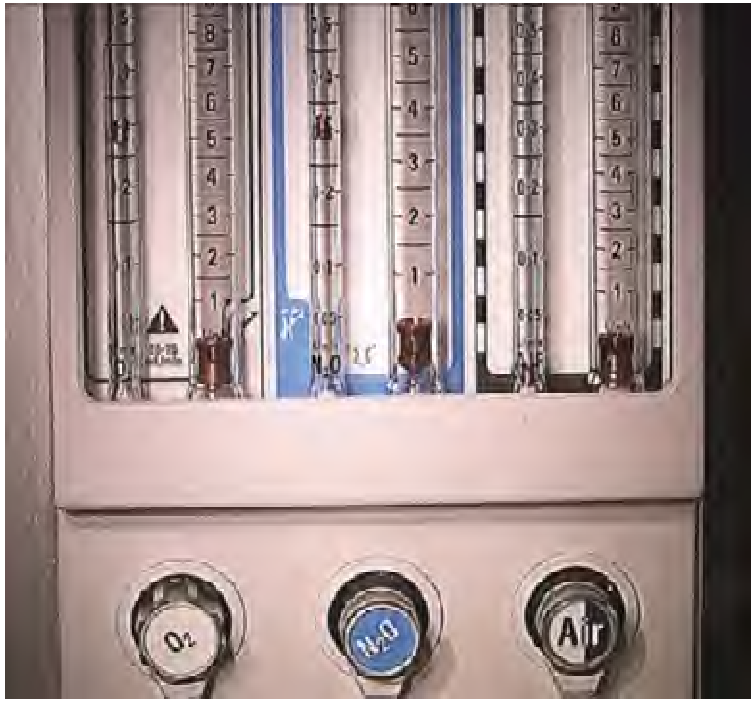
As O2 is consumed during use, the pressure within the cylinders declines. The regulator adjusts automatically when the pressure inside the cylinder falls as the gas is used. When the pressure reaches 500 PSI~=35bar, an "E(mpty)" tank contains approximately 175 L of O2 and should be replaced.

Further reduction in pressure can be achieved by adjusting the flow meter control knob for safe delivery of gas to the patient. The flowmeter uses an adjustable needle valve to deliver the desired flow in ml or litres per minute to the patient circuit.

Most anaesthesia machines have an O2 range up to 10 litres of O2 per minute. Flowmeters are individually calibrated for a specific gas, e.g., oxygen or nitrous oxide.

Mixing board with rotameters

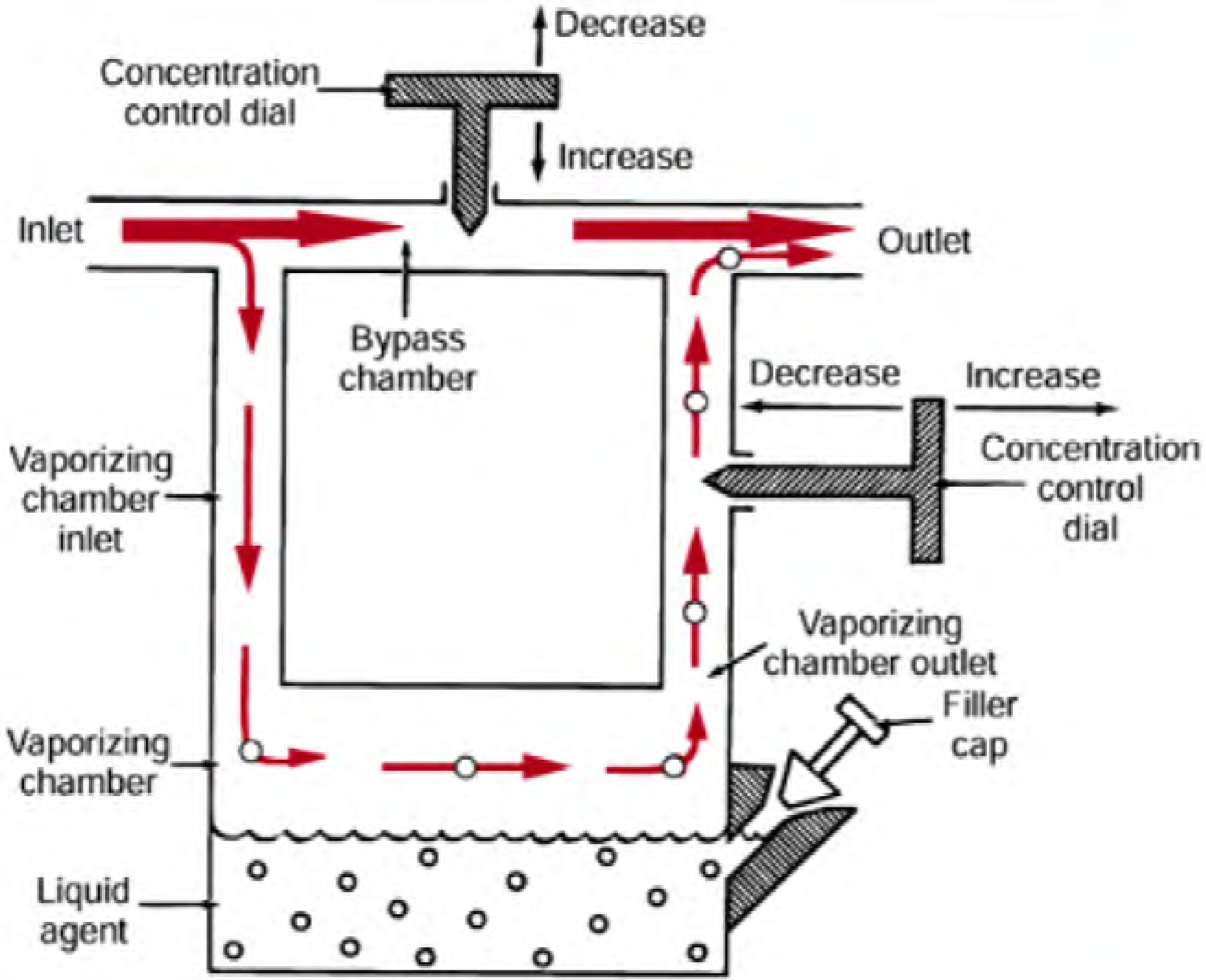
- A mixing board on the anaesthesia machine allows the anaesthetist to mix oxygen, anaesthetic gases and the patients expired air to the desired ratios for delivery to the patient.
- The ratio of the fresh gasses is continuously measured by their flow rates.
- A typical mixing board will contain several rotameters for measuring gas flow.
- Rotameters are calibrated in cubic centimetres (cc) or millilitres (ml) of gas per minute. The amount of each gas entering the mixing board is controlled by needle valves at the base of each rotameter.



The walls of the rotameters are slightly “V” shaped (‘tapered’) so that as the ball rises, more of the gas is diverted around the ball lowering the force upwards on the ball/bobbin. When the force of gravity is just balanced by the force upwards of the gas, the ball will stop moving. As the flow rate increases, the ball moves up and as the flow rate decreases, the ball moves down. Thus, the height of the ball can be used to determine the flow rate of the gas in the rotameter. Flow is read from the indicator/bobbin on the graduated scale.

Vaporiser

- As air enters the vaporiser, it is directed into either the vaporising chambers or a bypass chamber.
- The anaesthesiologist will control the bypass valve to allow more or less of the incoming gases to flow through the vaporising chamber usually via a large knob on top of the vaporiser.
- The liquid anaesthetic agent resides in the lower part of the unit. As the gas moves across the top of the liquid, the anaesthetic agent vaporises and is carried by the gas towards the outlet, where it is blended with the gas that has bypassed the chamber



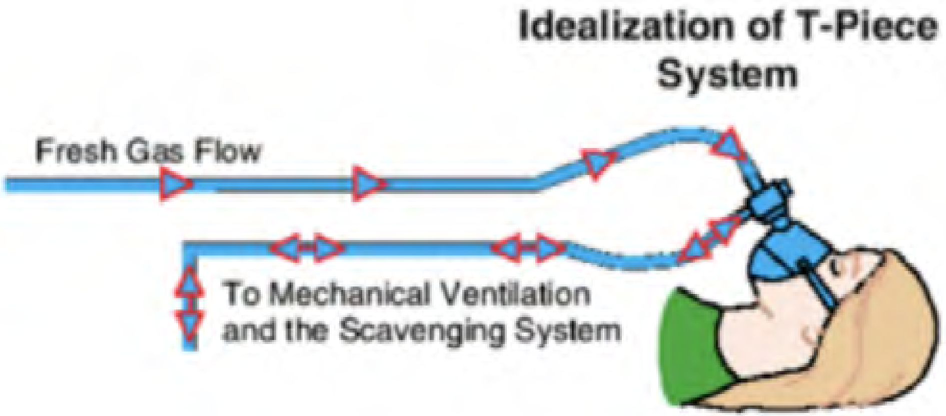
Breathing Circuit

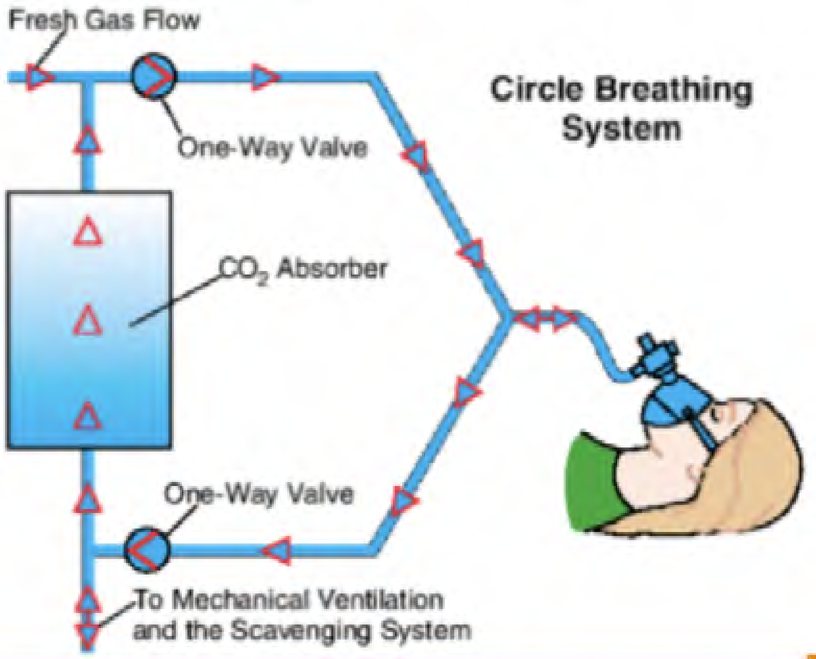
Anaesthetic gas is delivered to the patient via the breathing circuit.

The goals of the breathing circuit are to:

- Deliver oxygen to the patient
- Deliver anaesthetic to the patient
- Remove carbon dioxide that is produced by the patient
- Provide a method for assisting or controlling ventilation, i

The breathing system contains an adjustable pressure limiting valve to limit accidental pressure in the system (safety)





Examples of breathing circuits

Scavenging system

Since the expired gases of the patient contain anaesthetic agents, they must not be allowed to enter the operating room.

In addition to potentially placing the operating staff under the anaesthetics effects, certain agents are flammable, and chronic exposure can cause high fevers and severe liver damage.

To remove this danger, anaesthesia machines contain a **scavenger** (or **scrubber** or **trap**) before venting the expired gas into the room.

In the developing world, the activated carbon filter (consumable !) may not be regularly exchanged forcing the staff to vent the expired gas outside.

passive scavenger system with replaceable filter cartridges to absorb waste gases. Activated charcoal filter absorbs 125% of its own weight.

Further components

CO2 Absorber If (part of) the expired air is to be rebreathed - that is: returned to the patient - then a CO_2 absorber is used. A CO_2 absorber contains a soda-lime (or barium hydroxide lime) filter that strips the expired gases of CO_2.

Bellows Self-inflating bellows are mechanical devices that allow the anaesthetist to **measure** the patient's ventilation. By its movement in a calibrated chamber, a bellows indicates the volume of air that the patient is breathing. The bellows will rise when the patient exhales and will fall when the patient inhales.

Bellows may be part of the ventilator system when pressure applied to the outside of the bellows will force air into the patient lungs at a prescribed rate and volume.

Further components

Reservoir Bag The reservoir bag (0.5-2.0 liter) is made of latex, rubber of plastic. It serves to convert a continuous supply of gas flow into a intermittent breathing/ventilation pattern of the patient. During spontaneous breathing It acts as a breathing monitor (pattern, tidal volume). It may also be used as emergency bag.

Emergency Bag When intermittent ventilation is required, the doctor can use an emergency bag (usually 0.5 liter). The bag allows the doctor to manually push air into the patient's lungs.

reservoir bag

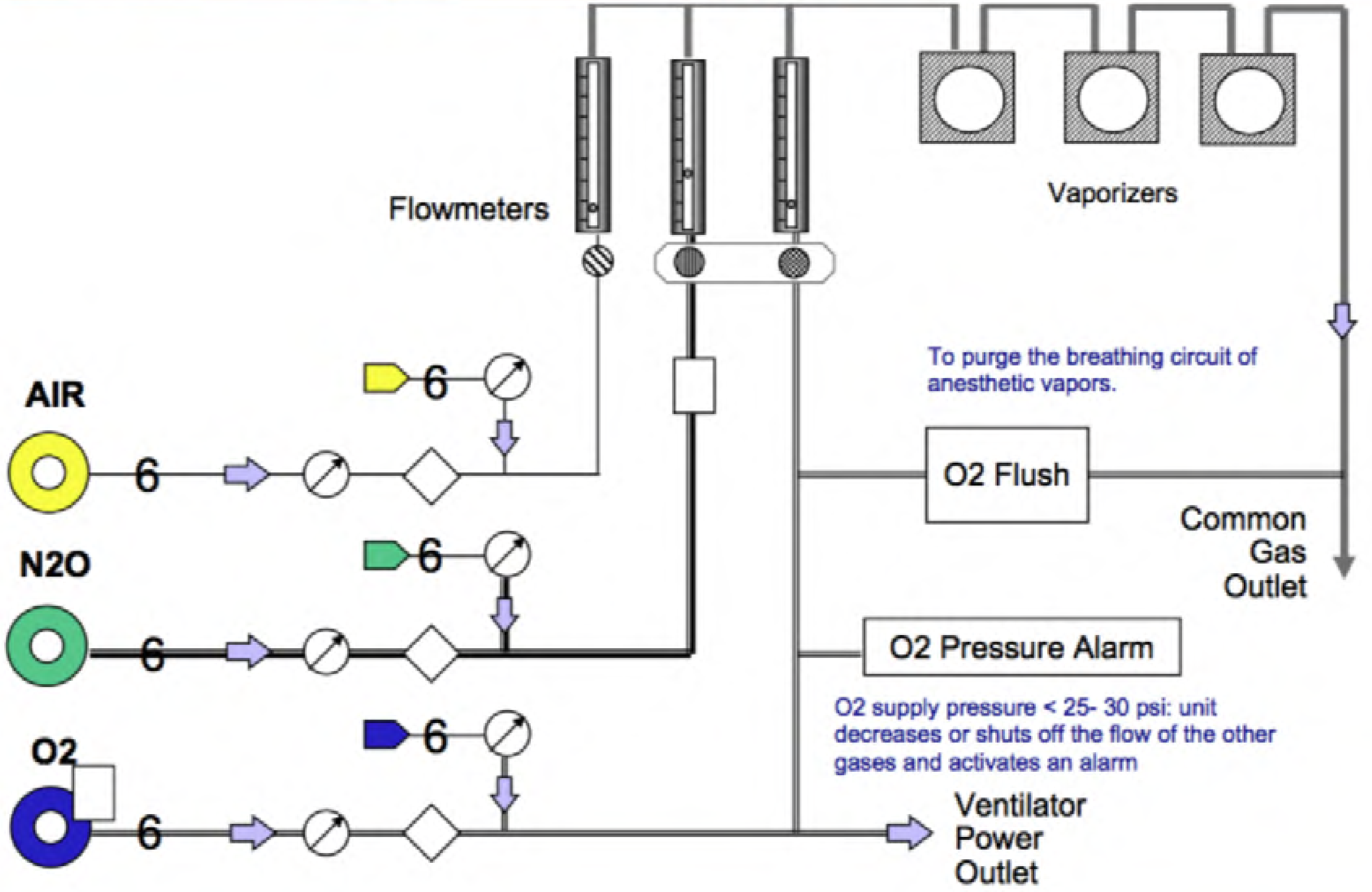
Anaesthesia Monitoring

To meet the minimum standard of care in the United States, the American Society of Anaesthesiologists (ASA) states that anaesthesia systems must continually monitor the patient's

- oxygenation
- ventilation
- circulation
- expired CO2 levels
- temperature

Integrated or stand-alone monitors may be used.

Construction: Gas system diagram



Construction: System diagram

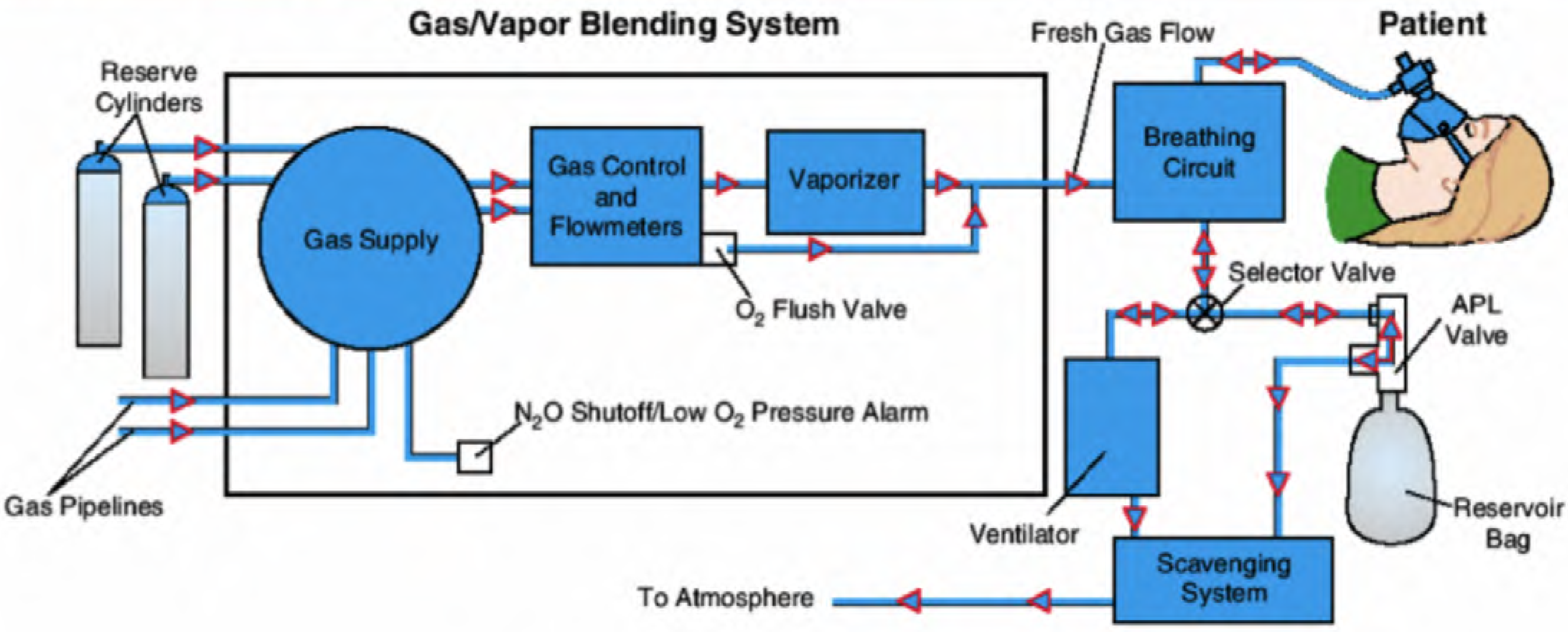


Figure . Continuous-flow anesthesia system

Reproduced from Health Care Product Comparison System, ECRI. 2003 – Anesthesia Units

Trouble shooting: Common faults

As with other pieces of complex medical equipment, **power supply** and **user error** problems account for most of the problems in anaesthesia machines. Drawover machines have fewer problems than other anaesthesia machines, but all machines suffer from **leaks** and **sticky valves**.

Leaks: Tubes tend to deteriorate in hot and humid environments. Also, **re-using disposable materials** causes deterioration. An expiration-side leak occurring before the scavenger is most critical to check, but also the easiest because anaesthetic gases have a distinctive smell which is easily detected. If a leak occurs in the OR, doors to the room should be opened to allow air to flow through the room. A second danger with gas leaks is that some anaesthetic gases are **flammable**. Halothane and ether are two explosive anaesthetic gases.

The tubing often develops leaks in between the **corrugations** ('wrinkles'). You can check for leaks by placing the tubing in a bucket of water, blocking one end, blowing in the other, and looking for bubbles to escape. Repair tubing leaks with epoxy or a silicon sealant. However, this is a temporary repair. It is better to replace the tubing. In some cases, the tubing can be shortened to remove the leaking section. Consult with the anaesthetist before shortening a section of the circuit.

Trouble shooting: Common faults

Other problems

- The needle valves controlling the flow into the rotameters can be sticky or blocked
- The floats in a rotameter can be stuck.

Rotameters and needle valves can be dismounted and flushed with alcohol. Make sure they are completely dry before using again. When taking apart multiple rotameters, floats and needle valves, be sure to put them back together in a set. The float from one gas may not work in the glass tube from another. One simple solution is to disassemble only one rotameter at a time.

If there are valves which appear to be sticky in the circuit, the circuit needs to be replaced. Other sticky valves may be cleaned with water and dried thoroughly before reuse.

If the problem is in the ventilator, CO_2 absorber or vaporizer, and the problem is not a leak, the problem is typically very difficult to repair in the field. It is generally necessary to replace the entire sub-unit with one from another anaesthesia machine.

Preventive Maintenance

In the case of anaesthesia machines, the preventive maintenance and inspection is a detailed examination of the device's **mechanical condition** and a **safety inspection** to insure that the device functions reliably and safely.

There is a single preventive maintenance procedure which is performed **four times per year**. This procedure is a thorough inspection and operational test which is to be performed on each unit. It is designed to identify major and minor deficiencies in a unit which must be corrected for efficient, reliable operation.

Look up the service manual of your anaesthesia machine to find instructions for preventive maintenance. An example of this is presented in the following sheets.

There are 3 elements of inspection:

1. Visual inspection
2. Performance testing
3. Environmental inspection

Preventive Maintenance: Visual Inspection

1. Mounting brackets, wheels, supports, and frames are securely attached, operate correctly and are adequate in strength to support the components mounted on them
2. Nuts, bolts, screws and other hardware will be tight and in good condition
3. Flow meters will be clean, free if all defects and mounted securely
4. Pressure gauges will be clean, free of all defects and mounted securely
5. Controls, mechanical locks and levers will be securely attached to the driven element, properly indexed, free of defects, and functional
6. Cabling, conductors tubing and accessories will be clean, free of cracks or splices, and functional
7. Face masks, rubber tubing and bladder bags will be clean, free of defects and functional
8. Flow check valves will be clean, free of defects and functional, with adequate spares available
9. Vaporisers will be securely mounted and free of visible defects
10. Absorber canister shall be changed when necessary, free of defects and functional
11. Electrical connectors on instruments mounted on the machine will be free of cracks, breaks, and properly attached to the chassis, line cord or cabling.
12. Ground cables, line cords, and transducer leads will be free of splices or frayed insulation.
13. Where applicable cables, clips, studs, and terminals will be free of dirt, dust, corrosion, and will not be worn.
14. The grounding system (both external and internal) will be of an approved type, properly installed and functional

Preventive Maintenance: Performance testing

The performance test for anaesthesia machines combines tests for functional operation and safety. Specifications for each instrument must be **based upon the manufacturer's published specifications** for that particular model and serial number.

In all cases, performance tests must be performed by qualified biomedical engineering technicians or medical equipment repairmen. The performance tests, as set forth in the preventive maintenance and inspection procedures, are minimum-acceptable standards.

Devices failing to meet either the prescribed standard or the manufacturer’s specifications must be reworked until they meet the standard. If a particular unit or component cannot be brought up to standard without excessive expenditure of time/capital, it is to be scheduled for replacement.

Preventive Maintenance: Performance testing

Qualitative tests:
– Chassis/Housing – Mount/Fasteners – Casters/Brakes – AC Plug
– Fittings/Connectors – Filters
– Controls/Switches – Fan
– Line Cord
– Strain Reliefs
– Circuit Breaker/ – Tubes/Hoses
– Cables
– Battery/Charger
– Indicators/Displays – Alarms/Interlocks – Labeling
– Accessories & Bellows

Other checks:
– Gas Supply
– Pneumatic lines (including air filters)
– Gas cylinders (and gauges and regulators, if so equipped)
– Patient Circuit
– Breathing circuit (including filters) – Humidifiers
– Pressure-relief mechanism
– Absorber

Quantitative tests:
– Grounding resistance [≤0.5 Ω]
– Leakage current [≤300 μA chassis]
– Modes and settings [±10% accuracy] – Monitors and Alarms [±10% accuracy]
– Alarms tested:
• Airway pressure • Tidal volume
• FIO2
• Others

Test apparatus and supplies:
– Lung simulator with adjustable compliance or ventilator tester
– Pressure gauge or meter with 2 cm H2O resolution, from -20 to +120 cm H2O
– Various breathing circuit adapters
– Leakage current meter or electrical safety analyzer
– Ground resistance ohmmeter
– Additional items as required for specific manufacturers' procedures

Preventive Maintenance: Environmental inspection

Due to the mobility of the anaesthesia machine, it is difficult to examine every possible location of use. Its point of maximum use, however, can be visually inspected and electrically tested; this is generally one operating room. The following inspection and test factors will be included in this inspection.

1. The electrical distribution will be inspected and tested to insure that:
    a. Voltage level is adequate;
    b. Receptacle polarity is correct;
    c. Receptacle ground is present
    d. Receptacle has mechanical integrity

2. Mechanical clearance between the anaesthesia machine and instruments, apparatus, and other devices.

3. Shelves, cabinets or storage space are clean, mechanically secure and free of obstructions.

Safety Considerations

The major hazard associated with anaesthesia machine is the delivery of an inappropriate oxygen/anaesthesia gas mixture to the patient. There are several modalities where the function of the anaesthesia machine can be lost. These range from **incorrect gas in a marked cylinder to defective or impaired flow meters**.

Incorrect gasses in a particular cylinder sounds like an impossible situation. The only problem is that it happens. Two factors may cause this basic error. The first factor has been hospital staff members who have used an “empty" bottle to store an excess of a particular gas. To prevent this, no technician or anaesthesiologist is to transfer gasses from one full tank to an empty tank unless specifically trained for and assigned to the task of transferring from bulk storage to small cylinders.

The second factor has been errors by commercial suppliers where their personnel accidentally filled cylinders from an inappropriate source. To prevent this from affecting patients, each tank must have a filling tag which is filled out and replaced when the cylinder is charged. If the cylinder colour code does not agree with the cylinder filling tag (either one incorrect), the cylinder is not to be used. It is to be returned to its source, emptied of its contents, and recharged with the appropriate medical gas.

Safety Considerations

Defective or impaired flow meters can only be detected by routine operational tests using appropriate test flow meters. The test flow meters should have an accuracy at least twice that of the anaesthesia machine's flow meters.

Defective or impaired vaporisers should be prevented if they are **removed from service once a year and returned to the manufacturer for cleaning, repair, calibration and test.**

Leaky check valves can also degrade the performance of the anaesthesia machine. They must be cleaned regularly and functionally testes quarterly to prevent deterioration.

Cracked, torn or split rubber anaesthetic tubing and/or face masks can also reduce the effectiveness of the anaesthesia machine. When detected, they must be replaced.

Safety Considerations

Needle valves used to adjust pressures and flows can become damaged, resulting in a reduction of adjustment range. Damaged needle valves must also be replaced.

Most anaesthesia machines utilise **wheels** to provide mobility. When they are moved, they can be tipped over or strike another device and suffer damage. If a unit has been damaged, it must be removed from service and subjected to a preventive maintenance inspection.

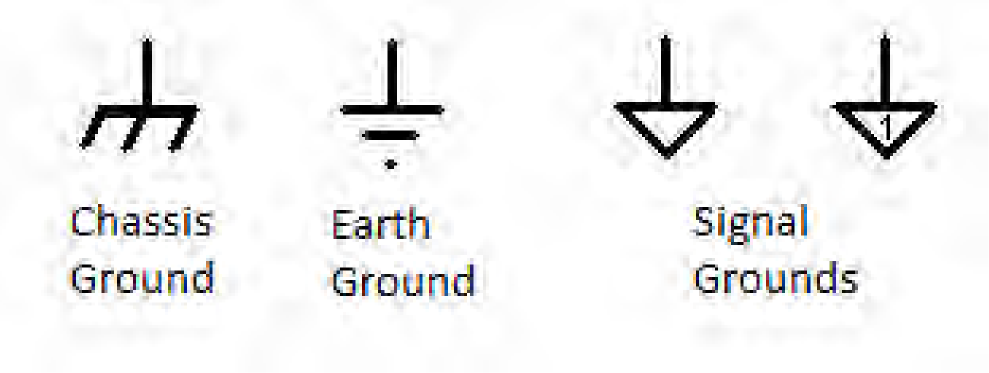
An Anaesthesia machine may appear to be operating correctly after being subjected to stress and yet have sustained sufficient damage to create a serious patient hazard.

Safety Considerations

Explosive gasses are used with most anaesthesia machines. This means that the anaesthesia cart must be constructed of conductive materials including all metal, plastic and rubber parts. Furthermore, a ground lead should be carried out from the cart to the operating room’s ground-equalisation system. When other devices are used with the anaesthesia machine, they should also be **grounded** to the ground-equalisation buss with a separate ground lead. In some instances, it is convenient to mount a ground junction box on the anaesthesia machine's frame and carry the other grounds to the junction box. A single lead from the junction box to the ground-equalisation buss system effectively grounds all the devices.

It must be remembered that an **anaesthesia-gas explosion** during a surgical procedure always kills the patient (ruptures the lungs) and usually severely injures the anaesthetist (propels facemask and fitting into the gut or face). They must be avoided at all cost in terms of both $$ and effort.

If monitors or other electronic instruments are mounted on the anaesthesia machine, they must share a **common chassis ground** with the frame of the anaesthesia cart.

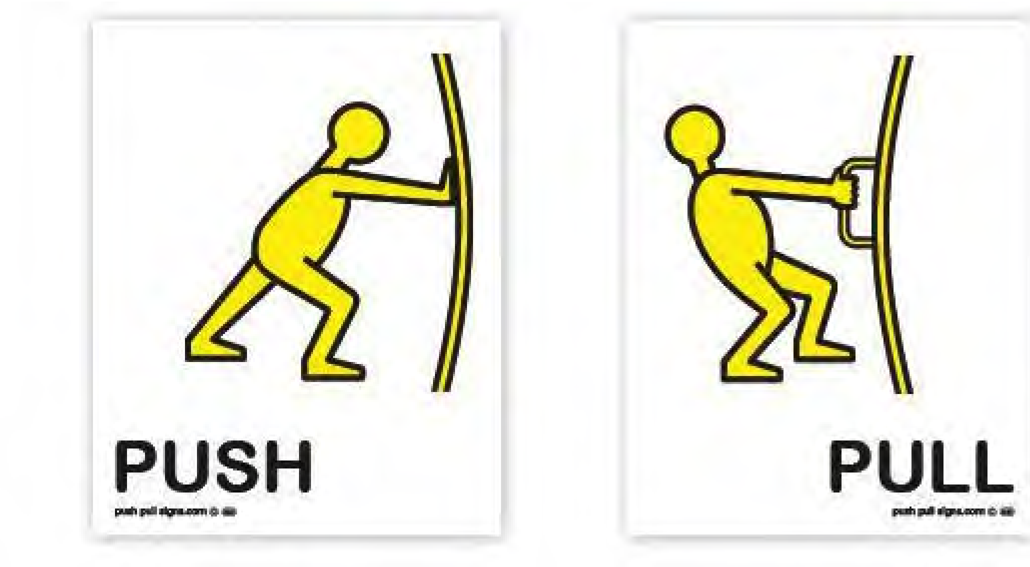


Safety Considerations

The machine is mobile enough so that, even though it's supposed to be used in a particular area, it can, with little notice, be **moved to another area**. The resulting **electrical and explosion hazard** condition is undefined.

To mitigate this situation, the normal handlers of the anaesthesia machines should be show how to:

1. Ground the unit when no standard ground outlet is present
2. Check to see that other devices in contact with the patient are also grounded
3. Operate the instrument with minimum exposure of the patient to hazards
4. Transport the anaesthesia machine by pulling it through doorways, onto and off of elevators and up and down hallways.



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