

## Chapter 1

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# Medical gas supply

## Gas supply

Medical gas supply takes the form of either cylinders or a piped gas system, depending on the requirements of the hospital.

## Cylinders

### Components

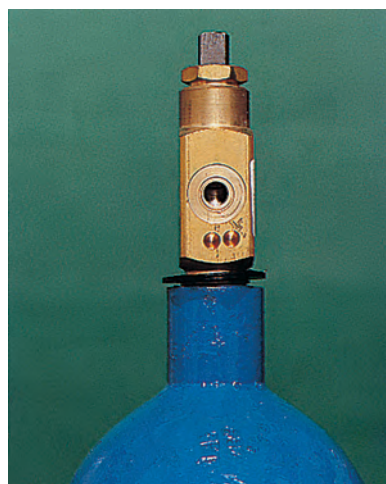
1. Cylinders are made of thin-walled seamless molybdenum steel in which gases and vapours are stored under pressure. They are designed to withstand considerable internal pressure.
2. The top end of the cylinder is called the neck, and this ends in a tapered screw thread into which the valve is fitted. The thread is sealed with a material that melts if the cylinder is exposed to intense heat. This allows the gas to escape so reducing the risk of an explosion.
3. There is a plastic disc around the neck of the cylinder. The year when the cylinder was last examined can be identified from the shape and colour of the disc.
4. Cylinders are manufactured in different sizes (A to J). Sizes A and H are not used for medical gases. Cylinders attached to the anaesthetic machine are usually size E (Figs 1.1–1.4), while size J cylinders are commonly used for cylinder manifolds. Size E oxygen cylinder contains 680 litres, whereas size E nitrous oxide can release 1800 litres. The smallest sized cylinder, size C, can hold 1.2 litres of water while the largest, L, can hold 50 litres.
5. Lightweight cylinders can be made from aluminium alloy with a fibreglass covering in epoxy resin matrix. These can be used to provide oxygen at home or during transport. They have a flat base to help in storage and handling.



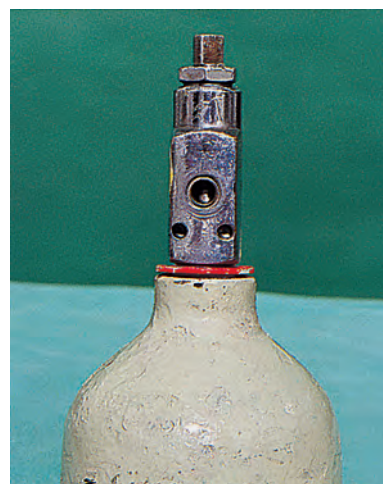
**Fig. 1.1** Medical gas cylinders with plastic wrapping intact. A nitrous oxide cylinder (left) and oxygen cylinder (right).



**Fig. 1.2** Oxygen cylinder valve and pin index.



**Fig. 1.3** Nitrous oxide cylinder valve and pin index.



**Fig. 1.4** Carbon dioxide cylinder valve and pin index.

- **Gas** exits in the gaseous state at room temperature. Its liquefaction at room temperature is impossible, since the room temperature is above its critical temperature.
- **Vapour** is the gaseous state of a substance below its critical temperature. At room temperature and atmospheric pressure, the substance is liquid.
- **Critical temperature** is the temperature above which a substance can not be liquefied no matter how much pressure is applied. The critical temperatures for nitrous oxide and oxygen are 36.5 and  $-118^{\circ}\text{C}$  respectively.

Oxygen is stored as a gas at a pressure of 13 700 kPa whereas nitrous oxide is stored in a liquid phase with its vapour on top at a pressure of 4400 kPa. As the liquid is less compressible than the gas, this means that the cylinder should be only partially filled. The amount of filling is called the **filling ratio**. Partially filling the cylinders with liquid minimizes the risk of dangerous increases in pressure with any increase in the ambient temperature that can lead to an explosion. In the UK, the filling ratio for nitrous oxide and carbon dioxide is 0.75. In hotter climates, the filling ratio is reduced to 0.67.

**The filling ratio** is the weight of the fluid in the cylinder divided by the weight of water required to fill the cylinder.

A full oxygen cylinder at atmospheric pressure can deliver 130 times its capacity of oxygen.

At constant temperature, a gas-containing cylinder shows a linear and proportional reduction in cylinder pressure as it empties. For a cylinder that contains liquid and vapour, initially the pressure remains constant as more vapour is produced to replace that used. Once all the liquid has been evaporated, the pressure in the cylinder decreases. The temperature in such a cylinder can decrease because of the loss of the latent heat of vaporization leading to the formation of ice on the outside of the cylinder.

Cylinders in use are checked and tested by manufacturers at regular intervals, usually 5 years:

1. *Internal endoscopic examination.*
2. *Flattening, bend and impact tests* are carried out on at least one cylinder in every hundred.
3. *Pressure test:* the cylinder is subjected to high pressures of about 22 000 kPa, which is more than 50% above their normal working pressure.
4. *Tensile test* where strips of the cylinder are cut and stretched. This test is carried out on at least one cylinder in every hundred.

The marks engraved on the cylinders are:

1. Test pressure.
2. Dates of test performed.
3. Chemical formula of the cylinder's content.
4. Tare weight (weight of nitrous oxide cylinder when empty).

Labelling. The cylinder label includes the following details:

- name, chemical symbol, pharmaceutical form, specification of the product, its licence number and the proportion of the constituent gases in a gas mixture
- substance identification number and batch number
- hazard warnings and safety instructions
- cylinder size code
- nominal cylinder contents (litres)
- maximum cylinder pressure (bars)
- filling date, shelf life and expiry date
- directions for use
- storage and handling precautions.

#### *Problems in practice and safety features*

1. The gases and vapours should be free of water vapour when stored in cylinders. Water vapour freezes and blocks the exit port when the temperature of the cylinder decreases on opening.
2. The outlet valve uses the pin-index system to make it almost

impossible to connect a cylinder to the wrong yoke (Fig. 1.5).

3. Cylinders are colour-coded to reduce accidental use of the wrong gas or vapour. In the UK, the colour-coding is a two-part colour (Table 1.1).
4. Cylinders should be checked regularly whilst in use to ensure that they have sufficient content and that leaks do not occur.



**Fig. 1.5** Anaesthetic machine cylinder yokes. For the sake of comparison, the Bodok seal is absent from the nitrous oxide yoke (left).

5. Cylinders should be stored in a purpose built dry, well-ventilated and fireproof room, preferably inside and not subjected to extremes of heat. They should not be stored near flammable materials such as oil or grease or near any source of heat. They should not be exposed to continuous dampness, corrosive chemicals or fumes. This can lead to corrosion of cylinders and their valves.

6. To avoid accidents, full cylinders should be stored separately from empty ones. F, G and J size cylinders are stored upright to avoid damage to the valves. C, D and E size cylinders can be stored horizontally on shelves made of a material that does not damage the surface of the cylinders.

7. Overpressurized cylinders are hazardous and should be reported to the manufacturer.

### Cylinders

- Cylinders are made of thin-walled molybdenum steel to withstand high pressures, e.g. 13 700 kPa and 4400 kPa for oxygen and nitrous oxide respectively.
- They are made in different sizes; size E cylinders are used on the anaesthetic machine; size J cylinders are used in cylinder banks.
- Oxygen cylinders contain gas whereas nitrous oxide cylinders contain a mixture of liquid and vapour. In the UK nitrous oxide cylinders are 75% filled with liquid nitrous oxide (filling ratio); this is 67% in hotter climates.
- At a constant temperature, the pressure in a gas cylinder decreases linearly and proportionally as it empties. This is not true in cylinder containing liquid/vapour.
- They are colour-coded.

## Cylinder valves

These valves seal the cylinder contents. The chemical formula of the particular gas is engraved on the valve (Fig. 1.6). Other types of

**Table 1.1** Colour coding of medical gas cylinders, their pressure when full and their physical state in the cylinder

	Body colour	Shoulder colour	Pressure, kPa (at room temperature)	Physical state in cylinder
Oxygen	Black (Green in USA)	White	13 700	Gas
Nitrous oxide	Blue	Blue	4 400	Liquid/vapour
Carbon dioxide	Grey	Grey	5 000	Liquid/vapour
Air	Grey (Yellow in USA)	White/black quarters	13 700	Gas
Entonox	Blue	White/blue quarters	13 700	Gas
Oxygen/helium (Heliox)	Black	White/brown quarters	13 700	Gas



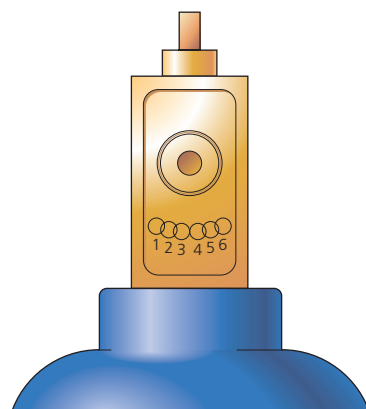


**Fig. 1.6** Chemical formula ( $N_2O$ ) engraved on a nitrous oxide cylinder valve.

valves, the bull nose, the hand wheel and the star, are used under special circumstances.

### Components

1. The valve is mounted on the top of the cylinder, screwed into the neck via a threaded connection. It is made of brass and sometimes chromium plated.
2. An on/off spindle is used to open and close the valve by opposing a plastic facing against the valve seating.
3. The exit port for supplying gas to the apparatus (e.g. anaesthetic machine).
4. A safety relief device allows the discharge of cylinder contents to the atmosphere if the cylinder is overpressurized.
5. The non-interchangeable safety system (**Pix-index system**) is used on cylinders of size E or smaller as well as on F and G-size Entonox cylinders. A specific pin configuration exists for each medical gas on the yoke of the anaesthetic machine. The



**Fig. 1.7** Diagram showing the index positions of a cylinder valve. Oxygen 2 & 5; nitrous oxide 3 & 5; air 1 & 5; carbon dioxide 1 & 6.

matching configuration of holes on the valve block allows only the correct gas cylinder to be fitted in the yoke (Figs 1.7 and 1.8). The gas exit port will not seal against the washer of the yoke unless the pins and holes are aligned.

6. A more recent modification where the external part of the valve is designed to allow manual turning

on and off of the cylinder without the need for a key (Fig. 1.9).

### Mechanism of action

1. The cylinder valve acts as a mechanism for opening and closing the gas pathway.
2. A compressible yoke sealing washer (**Bodok seal**) must be placed between valve outlet and the apparatus to make a gas-tight joint (Fig. 1.10).

### Problems in practice and safety features

1. The plastic wrapping of the valve should be removed just before use. The valve should be slightly opened and closed (cracked) before connecting the cylinder to the anaesthetic machine. This clears particles of dust, oil and grease from the exit port, which would otherwise enter the anaesthetic machine.
2. The valve should be opened slowly when attached to the anaesthetic machine or regulator. This prevents the rapid rise in pressure and the associated rise



**Fig. 1.8** A cylinder yoke and pin index system. Note that a Bodok seal is in position.

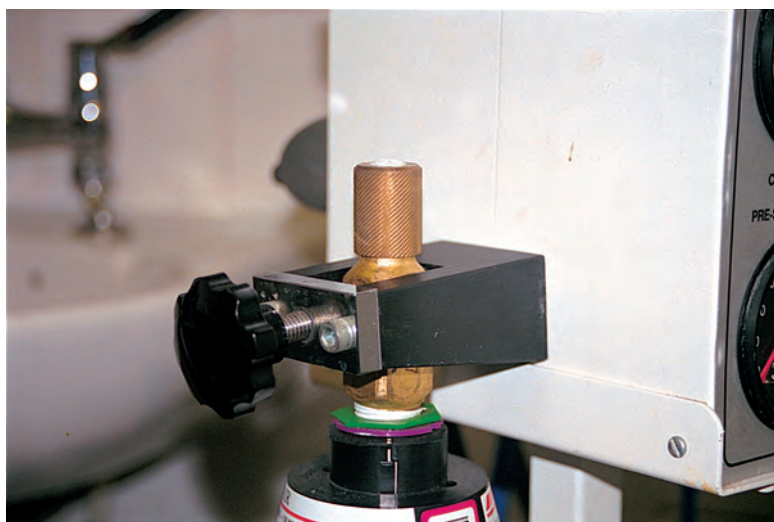


Fig. 1.9 New cylinder valve which allows manual opening and closing.



Fig. 1.10 A Bodock seal.

in temperature of the gas in the machine's pipelines. The cylinder valve should be fully open when in use (the valve must be turned two full revolutions).

3. During closure, overtightening the valve should be avoided. This might lead to damage to the seal between the valve and the cylinder neck.
4. The Bodock seal should be inspected for damage prior to use. Having a spare seal readily available is advisable.

#### Cylinder valves

- They are mounted on the neck of the cylinder.
- Act as an on/off device for the discharge of cylinder contents.
- Pin index system prevents cylinder identification errors.
- Bodock sealing washer must be placed between the valve and the yoke of the anaesthetic machine.
- A newly designed valve allows keyless manual turning on and off.

## Piped gas supply (piped medical gas and vacuum – PMGV)

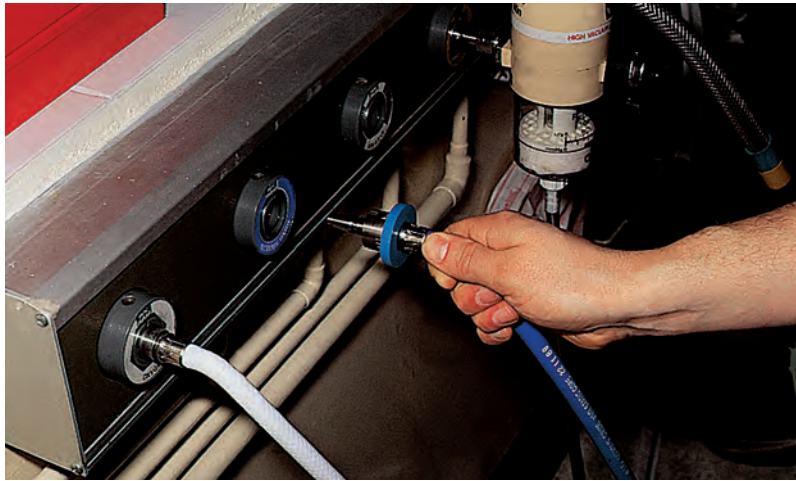
PMGV is a system where gases are delivered from central supply points to different sites in the hospital at a pressure of about 400 kPa. Special outlet valves supply the various needs throughout the hospital.

Oxygen, nitrous oxide, Entonox, compressed air and medical vacuum

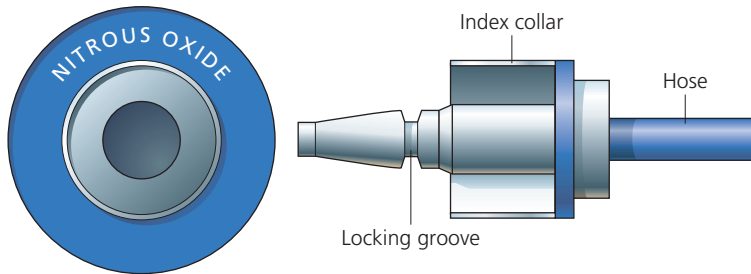
are commonly supplied through the pipeline system.

#### Components

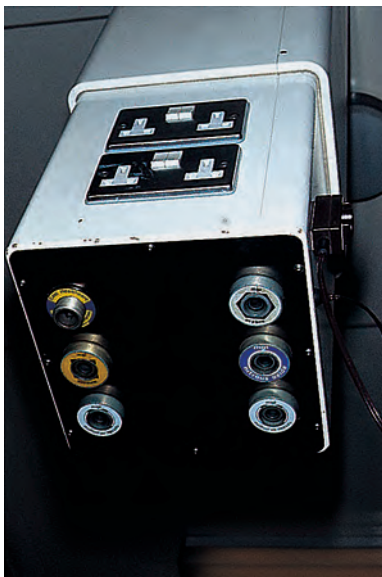
1. Central supply points such as cylinder banks or liquid oxygen storage tank.
2. Pipework made of special high quality copper alloy, which both prevents degradation of the gases it contains and has bacteriostatic properties. The fittings used are made from brass and are brazed rather than soldered.
3. The size of the pipes differs according to the demand that they carry. Pipes with a 42 mm diameter are usually used for leaving the manifold. Smaller diameter tubes, such as 15 mm, are used after repeated branching.
4. Outlets which are identified by gas colour-coding, gas name and by shape (Fig. 1.11). They accept matching quick connect/disconnect probes, Schrader sockets, (Fig. 1.12) with an indexing collar specific for each gas (or gas mixture).
5. Outlets can be installed as flush-fitting units, surface-fitting units, on booms or pendants, suspended on a hose and gang mounted (Fig. 1.13).
6. Flexible colour-coded hoses connect the outlets to the anaesthetic machine (Fig. 1.14). The anaesthetic machine end should be permanently fixed using a nut and liner union where the thread is gas specific and non-interchangeable (non-interchangeable screw-thread, NIST is the British Standard).
7. Isolating valves behind break glass covers are positioned at strategic points throughout the pipeline network. They are also known as AVSUs (Area Valve Service Units) (Fig. 1.15).



**Fig. 1.11** Inserting a remote probe into its matching wall-mounted outlet socket.



**Fig. 1.12** A remote probe and matching outlet socket (not drawn to scale).



**Fig. 1.13** Outlet sockets mounted in a retractable ceiling unit.

*Problems in practice and safety features*

1. A reserve bank of cylinders is available should the primary supply fail. Low pressure alarms detect gas supply failure (Fig. 1.16).
2. Single hose test is performed to detect cross-connection.
3. Tug test is performed to detect misconnection.
4. Regulations for PMGV installation, repair and modification are enforced.
5. Anaesthetists are responsible for the gases supplied from the terminal outlet through to the anaesthetic machine. Pharmacy, Supplies and Engineering departments share the



**Fig. 1.14** Colour-coded hoses with NIST fittings attached to an anaesthetic machine.

- responsibility for the gas pipelines 'behind the wall'.
6. There is the risk of fire from worn or damaged hoses that are designed to carry gases under pressure from a primary source such as a cylinder or wall mounted terminal to medical devices such as ventilators and anaesthetic machines. Because of heavy wear and tear, the risk of rupture is greatest in oxygen hoses used with transport devices. Regular inspection and replacement, every 2–5 years, of all medical gas hoses is recommended.





Fig. 1.15 An Area Valve Service Unit (AVSU).

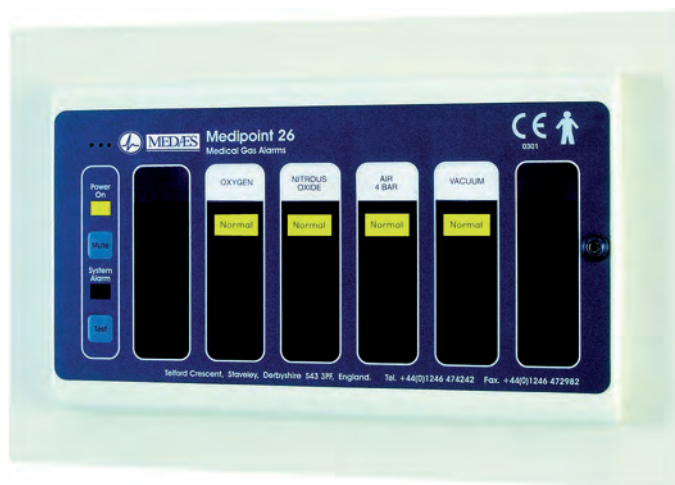


Fig. 1.16 Medical gas alarm panel.

#### Piped gas supply

- There is a network of copper alloy pipelines throughout the hospital from central supply points.
- The outlets are colour- and shape-coded to accept matching 'Schrader' probes.
- Flexible and colour-coded pipelines run from the anaesthetic machine to the outlets.
- Single hose and tug tests are performed to test for cross-connection and misconnection respectively.
- There is risk of fire from worn and damaged hoses.

## Sources of gas supply

The source of supply can be cylinder manifold(s) and, in the case of oxygen, a liquid oxygen storage tank or oxygen concentrator.

### CYLINDER MANIFOLD

Manifolds are used to supply nitrous oxide, Entonox and oxygen.

#### Components

1. Large cylinders (e.g. size J each with 6800 litres capacity) are usually divided into two groups, primary and secondary. The two groups alternate in supplying the pipelines (Fig. 1.17). The number of cylinders depends on the expected demand.
2. All cylinders in each group are connected through non-return valves to a common pipe. This in turn is connected to the pipeline through pressure regulators.

#### Mechanism of action

1. In either group, all the cylinders' valves are opened. This allows them to empty simultaneously.
2. The supply is automatically changed to the secondary group when the primary group is nearly empty. The changeover is achieved through a pressure-sensitive device that detects when the cylinders are nearly empty.
3. The changeover activates an electrical signalling system to alert staff to the need to change the cylinders.

#### Problems in practice and safety features

1. The manifold should be housed in a well-ventilated room built of fireproof material away from the main buildings of the hospital.





**Fig. 1.17** An oxygen cylinder manifold.

2. The manifold room should not be used as a general cylinder store.
3. All empty cylinders should be removed immediately from the manifold room.

## LIQUID OXYGEN

A vacuum-insulated evaporator (VIE) (Fig. 1.18) is the most economical way to store and supply oxygen.



**Fig. 1.18** A vacuum-insulated evaporator (VIE).

### Components

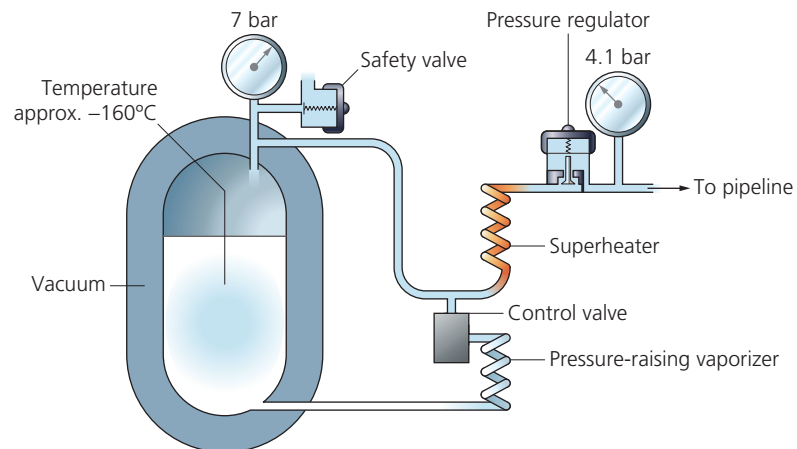
1. A thermally insulated double-walled steel tank with a layer of perlite in a vacuum is used as the insulation (Fig. 1.19).
2. A pressure regulator allows gas to enter the pipelines and maintains the pressure through the pipelines at about 400 kPa.
3. A safety valve opens at 1700 kPa allowing the gas to escape when there is a build-up of pressure

within the vessel. This can be caused by underdemand for oxygen.

4. A control valve opens when there is an excessive demand on the system. This allows liquid oxygen to evaporate by passing through superheaters made of uninsulated coils of copper tubing.

### Mechanism of action

1. Liquid oxygen is stored (up to 1500 litres) at a temperature of  $-150^{\circ}$  to  $-170^{\circ}\text{C}$  (lower than the critical temperature) and at a pressure of 5–10 atmospheres.
2. The temperature of the vessel is maintained by the high-vacuum shell. Evaporation of the liquid oxygen requires heat (latent heat of vaporization). This heat is taken from the liquid oxygen, helping to maintain its low temperature.
3. The storage vessel rests on a weighing balance to measure the mass of the liquid. More recently, a differential pressure gauge which measures the pressure difference between the bottom and top of the liquid oxygen can be used instead. As liquid oxygen evaporates, its mass decreases, reducing



**Fig. 1.19** Schematic diagram of a liquid oxygen supply system (reproduced with permission from Parbrook GD et al., *Basic Physics and Measurement in Anaesthesia*, 3rd edn. Butterworth-Heinemann).

the pressure at the bottom. By measuring the difference in pressure, the contents of the VIE can be calculated. When required, fresh supplies of liquid oxygen are pumped from a tanker into the vessel.

4. The cold oxygen gas is warmed once outside the vessel in a coil of copper tubing. The increase in temperature causes an increase in pressure.
5. At a temperature of 15°C and atmospheric pressure, liquid oxygen can give 842 times its volume as gas.

#### Problems in practice and safety features

1. Reserve banks of cylinders are kept in case of supply failure.
2. A liquid oxygen storage vessel should be housed away from main buildings due to the fire hazard. The risk of fire is increased in cases of liquid spillage.
3. Spillage of cryogenic liquid can cause cold burns, frostbite and hypothermia.

## OXYGEN CONCENTRATORS

Oxygen concentrators extract oxygen from air by differential absorption. These devices may be small, designed to supply oxygen to a single patient (Figs 1.20 and 1.21), or they can be large enough to supply oxygen for a medical gas pipeline system (Fig. 1.22).

#### Components

A zeolite molecular sieve is used. Zeolites are hydrated aluminium silicates of the alkaline earth metals in a powder or granular form. Many zeolite columns are used.

#### Mechanism of action

1. Ambient air is filtered and pressurized to about 137 kPa by a compressor.



**Fig. 1.20** The Oasis home oxygen concentrator (reproduced with permission from Rimmer Alco Ltd).



**Fig. 1.21** The oxyPac 550 anaesthetic machine which has a built-in oxygen concentrator (reproduced with permission from pneuPac Ltd).

2. Air is exposed to a zeolite molecular sieve column, forming a very large surface area, at a certain pressure.
3. The sieve selectively retains nitrogen and other unwanted components of air. These are released into the atmosphere

after heating the column and applying a vacuum.

4. The changeover between columns is made by a time switch.
5. The maximum oxygen concentration achieved is 95% by volume. Argon is the main remaining constituent.

#### Problems in practice and safety features

Although the oxygen concentration achieved is sufficient for the vast majority of clinical applications, its use with the circle system leads to argon accumulation. To avoid this, higher fresh gas flows are required.

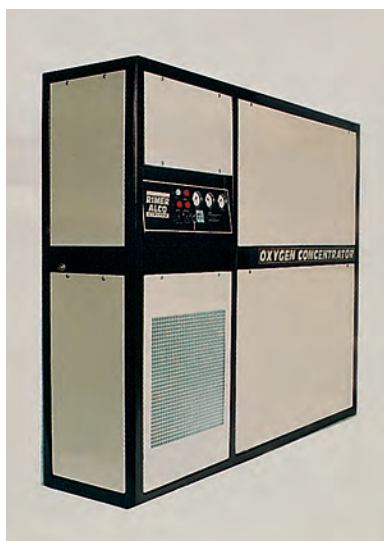
#### Source of supply

- Cylinder manifold: banks of large cylinders, usually size J, are used.
- Liquid oxygen: a thermally insulated vessel at a temperature of  $-150^{\circ}$  to  $-170^{\circ}\text{C}$  and at a pressure of 5–10 atmospheres is used.
- Oxygen concentrator: a zeolite molecular sieve is used.

## Entonox (BOC Medical)

This is a compressed gas mixture containing 50% oxygen and 50% nitrous oxide by volume. It is commonly used in the casualty and labour ward settings to provide analgesia. A two-stage pressure demand regulator is attached to the Entonox cylinder when in use (Figs 1.23 and 1.24). As the patient inspires through the mask or mouth piece, gas flow is allowed to occur. Gas flow ceases at the end of an inspiratory effort. Entonox is compressed into cylinders to a pressure of 13 700 kPa.

If the temperature of the Entonox cylinder is decreased to



**Fig. 1.22** The OC 11 oxygen concentrator (reproduced with permission from Rimmer Alco Ltd).

below  $-5.5^{\circ}\text{C}$ , liquefaction and separation of the two components occur (**Poynting effect**). This results in:

1. a liquid mixture containing mostly nitrous oxide with about 20% oxygen dissolved in it



**Fig. 1.23** An Entonox cylinder and delivery system.

2. above the liquid, a gas mixture of high oxygen concentration.

This means that when used at a constant flow rate, a gas with a high concentration of oxygen is supplied first. This is followed by a gas of decreasing oxygen concentration as the liquid evaporates. This may lead to the supply of hypoxic mixtures, with less than 20% oxygen, as the cylinder is nearly empty.

Rewarming and mixing of both the cylinder and its contents reverses the separation and liquefaction.

#### *Problems in practice and safety features*

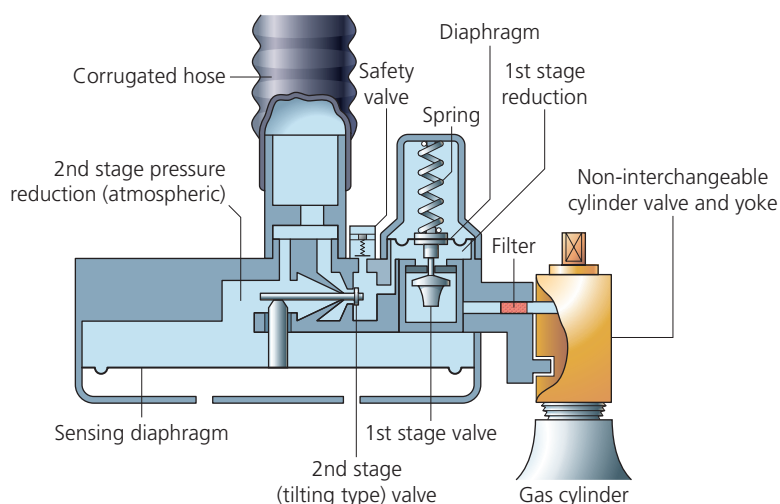
1. Liquefaction and separation of the components can be prevented by:
  - a) cylinders being stored horizontally for about 24 hours at temperatures of or above  $5^{\circ}\text{C}$  before use. The horizontal position increases the area for diffusion. If the contents are well mixed by repeated inversion, cylinders

can be used earlier than 24 hours

- b) large cylinders are equipped with a dip tube with its tip ending in the liquid phase. This results in the liquid being used first, preventing the delivery of an oxygen concentration of less than 20%.
2. Prolonged use of Entonox should be avoided because of the effect of nitrous oxide on the bone marrow especially in the critically ill patient. Adequate facilities for scavenging should be provided to protect hospital staff.

## Compressed air

Medical air is supplied in a hospital for clinical uses or to drive power tools. The former is supplied at a pressure of 400 kPa and the latter at 700 kPa. The anaesthetic machines and most intensive care ventilator blenders accept a 400 kPa supply. The terminal outlets for the two



**Fig. 1.24** The Entonox two-stage pressure demand regulator (reproduced with permission from Aitkenhead R, Smith G. Textbook of Anaesthesia, 3rd edn. Churchill Livingstone, 1996).

pressures are different to prevent misconnection.

Air may be supplied from cylinder manifolds, or more economically from a compressor. Oil-free medical air is cleaned by filters and separators and then dried before use.

## Centralized vacuum system

This system consists of a pump, receiver and a filter. The pump

is capable of creating a negative pressure of  $-53\text{ kPa}$  ( $-400\text{ mmHg}$ ) and can accommodate an air flow of  $40\text{ L/min}$ . It is recommended that there are at least two vacuum outlets per operating theatre, one per anaesthetic room and one per recovery bed.

### FURTHER READING

- Health Technical Memorandum 2022. Medical gas pipeline systems. London: The Stationery Office, 1997.
- Lovell T. Medical gases, their storage and delivery. *Anaesthesia and Intensive Care Medicine* 2004;5(1):10–14.



## MCQs

In the following lists, which of the statements (a) to (e) are true?

### 1. Concerning cylinders

- Oxygen is stored in cylinders as a gas.
- The pressure in a half-filled oxygen cylinder is 13 700 kPa.
- The pressure in a half-full nitrous oxide cylinder is 4400 kPa.
- Nitrous oxide is stored in the cylinder in the gas phase.
- Pressure in a full Entonox cylinder is 13 700 kPa.

### 2. Entonox

- Entonox is 50:50 mixture by weight of  $O_2$  and  $N_2O$ .
- Entonox has a critical temperature of  $5.5^\circ C$ .
- Entonox cylinders should be stored upright.
- At room temperature, Entonox cylinders contain only gas.
- Entonox cylinders have blue bodies and white and blue quarters on the shoulders.

### 3. Oxygen

- For medical use, oxygen is usually formed from fractional distillation of air.
- Long-term use can cause bone marrow depression.
- In hyperbaric concentrations, oxygen may cause convulsions.
- At constant volume, the absolute pressure of oxygen is directly proportional to its absolute temperature.
- The critical temperature of oxygen is  $-118^\circ C$ .

### 4. Oxygen concentrators

- Oxygen concentrators concentrate  $O_2$  that has been delivered from an oxygen cylinder manifold.
- Argon accumulation can occur when oxygen concentrators are used with the circle system.
- They are made of columns of a zeolite molecular sieve.
- They can achieve  $O_2$  concentrations of up to 100%.
- They can only be used in home oxygen therapy.

### 5. Oxygen

- Oxygen is stored in cylinders at approximately 140 bars.
- It has a critical temperature of  $36.5^\circ C$ .
- It is a liquid in its cylinder.
- It may form an inflammable mixture with oil.
- It obeys Boyle's law.

### 6. Concerning cylinders

- The filling ratio = weight of liquid in cylinder divided by the weight of water required to fill the cylinder.
- The tare weight is the weight of the cylinder plus its contents.
- Nitrous oxide cylinders have a blue body and blue and white top.
- A full oxygen cylinder has a pressure of approximately 137 bars.
- At  $40^\circ C$ , a nitrous oxide cylinder contains both liquid and vapour.

### 7. Concerning piped gas supply in the operating theatre

- Compressed air is supplied only under one pressure.
- The NIST system is the British Standard.
- Only oxygen and air are supplied.
- E-size cylinders are normally used in cylinder manifolds.
- Liquid oxygen is stored at temperatures above  $-100^\circ C$ .

### 8. The following statements are true

- There is no need for cylinders to undergo regular checks
- The only agent identification on the cylinder is its colour
- When attached to the anaesthetic machine, the cylinder valve should be opened slowly.
- When warmed, liquid oxygen can give 842 times its volume as gas.
- Cylinders are made of thick-walled steel to withstand the high internal pressure.

## Answers

### 1. Concerning cylinders

- a) **True.** Oxygen is stored in the cylinder as a gas.
- b) **False.** Oxygen is stored as a gas in the cylinder where gas laws apply. The pressure gauge accurately reflects the contents of the cylinder. A full oxygen cylinder has a pressure of 13 700 kPa. Pressure in a half-full oxygen cylinder is therefore 6850 kPa.
- c) **True.** Nitrous oxide is stored in the cylinder in the liquid form. The pressure of a full nitrous oxide cylinder is about 4400 kPa. As the cylinder is used, the vapour above the liquid is used first. This vapour is replaced by new vapour from the liquid. Therefore the pressure is maintained. So the cylinder is nearly empty before the pressure starts to decrease. For this reason the pressure gauge does not accurately reflect the contents of the cylinder.
- d) **False.** Nitrous oxide is stored in the cylinder as a liquid. The vapour above the liquid is delivered to the patient.
- e) **True.** Entonox is a compressed gas mixture containing 50% oxygen and 50% nitrous oxide by volume.

### 2. Entonox

- a) **False.** Entonox is a 50:50 mixture of O<sub>2</sub> and N<sub>2</sub>O by volume and not by weight.
- b) **False.** The critical temperature of Entonox is -5.5°C. At or below this temperature, liquefaction and separation of the two components occurs. This results in a liquid mixture of mainly nitrous oxide and about 20% oxygen. Above the liquid is a gaseous mixture with a high concentration of oxygen.
- c) **False.** This increases the risk of liquefaction and separation of the components. To prevent this, Entonox cylinders should be stored horizontally for about 24 hours at temperatures of or above 5°C. This position increases the area for diffusion. With repeated inversion, Entonox cylinders can be used earlier than 24 hours.
- d) **True.** Liquefaction and separation of nitrous oxide and oxygen occurs at or below -5.5°C.
- e) **True.**

### 3. Oxygen

- a) **True.** Except for oxygen concentrators which use zeolites.
- b) **False.** Long term use of oxygen has no effect on the bone marrow. Long term use of N<sub>2</sub>O can cause bone marrow depression especially with high concentrations in critically ill patients.
- c) **True.**
- d) **True.** This is Gay-Lussac's law where pressure = constant × temperature. Oxygen also obeys the other gas laws (Dalton's law of partial pressures, Boyle's and Charles's laws).
- e) **True.** At or below -118°C, oxygen changes to the liquid phase. This is used in the design of the vacuum insulated evaporator where oxygen is stored in the liquid phase at temperatures of -150 to -170°C.

#### 4. Oxygen concentrators

- a) **False.** Oxygen concentrators extract oxygen from air using a zeolite molecular sieve. Many columns of zeolite are used. Zeolites are hydrated aluminium silicates of the alkaline earth metals.
- b) **True.** The maximum oxygen concentration achieved by oxygen concentrators is 95%. The rest is mainly argon. Using low flows with the circle breathing system can lead to the accumulation of argon. Higher fresh gas flows are required to avoid this.
- c) **True.** The zeolite molecular sieve selectively retains nitrogen and other unwanted gases in air. These are released into the atmosphere. The changeover between columns is made by a time switch.
- d) **False.** Oxygen concentrators can deliver a maximum oxygen concentration of 95%.
- e) **False.** Oxygen concentrators can be small delivering oxygen to a single patient or they can be large enough to supply oxygen to hospitals.

#### 5. Oxygen

- a) **True.** Molybdenum steel or aluminium alloy cylinders are used to store oxygen at pressures of approximately 14 000 kPa (140 bars).
- b) **False.** The critical temperature of O<sub>2</sub> is -118°C. Above that temperature, oxygen can not be liquefied however much pressure is applied.
- c) **False.** Oxygen is a gas in the cylinder as its critical temperature is -118°C.
- d) **True.** Oil is flammable while oxygen aids combustion. Oxygen cylinders should be stored away from oil.
- e) **True.** At a constant temperature, the volume of a given mass of oxygen varies inversely with the absolute pressure (volume = constant × 1/pressure). Oxygen obeys other gas laws.

#### 6. Concerning cylinders

- a) **True.** The filling ratio is used when filling cylinders with liquid, e.g. nitrous oxide. As the liquid is less compressible than the gas, the cylinder should be only partially filled. Depending on the ambient temperature, the filling ratio can be from 0.67 to 0.75.
- b) **False.** The tare weight is the weight of the empty cylinder. This is used to estimate the amount of the contents of the cylinder. It is one of the marks engraved on the cylinders.
- c) **False.** Nitrous oxide cylinders have a blue body and top. Entonox cylinders have a blue body and blue and white top.
- d) **True.**
- e) **False.** At 40°C, nitrous oxide exists as a gas only. This is above its critical temperature, 36.5°C, so it can not be liquefied above that.

7. Concerning piped gas supply in the operating theatre
- a) **False.** Air is supplied at two different pressures; at 400 kPa when it is delivered to the patient and at 700 kPa when used to operate power tools in the operating theatre.
  - b) **True.** This stands for non-interchangeable screw thread. This is one of the safety features present in the piped gas supply system. Flexible colour-coded hoses connect the outlets to the anaesthetic machine. The connections to the anaesthetic machine should be permanently fixed using a nut and liner union where the thread is gas-specific and non-interchangeable.
  - c) **False.** Oxygen, nitrous oxide, air and vacuum can be supplied by the piped gas system.
  - d) **False.** Larger cylinders, e.g. J size, are normally used in a cylinder manifold. E size cylinders are usually mounted on the anaesthetic machine.
  - e) **False.** Liquid oxygen has to be stored at temperatures below its critical temperature,  $-118^{\circ}\text{C}$ . So oxygen stored at temperatures above  $-100^{\circ}\text{C}$  (above its critical temperature) exists as a gas.
8. The following statements are true
- a) **False.** Cylinders should be checked regularly by the manufacturers. Internal endoscopic examination, pressure testing, flattening, bending and impact testing and tensile testing are done on a regular basis.
  - b) **False.** To identify the agent, the name, chemical symbol, pharmaceutical form and specification of the agent, in addition to the colour of the cylinder are used.
  - c) **True.** When attached to an anaesthetic machine, the cylinder valve should be opened slowly to prevent the rapid rise in pressure within the machine's pipelines.
  - d) **True.** It is more economical to store oxygen as liquid before supplying it. At a temperature of  $15^{\circ}\text{C}$  and atmospheric pressure, liquid oxygen can give 842 times its volume as gas.
  - e) **False.** For ease of transport, cylinders are made of thin-walled seamless molybdenum steel. They are designed to withstand considerable internal pressures and tested up to pressures of about 22 000 kPa.