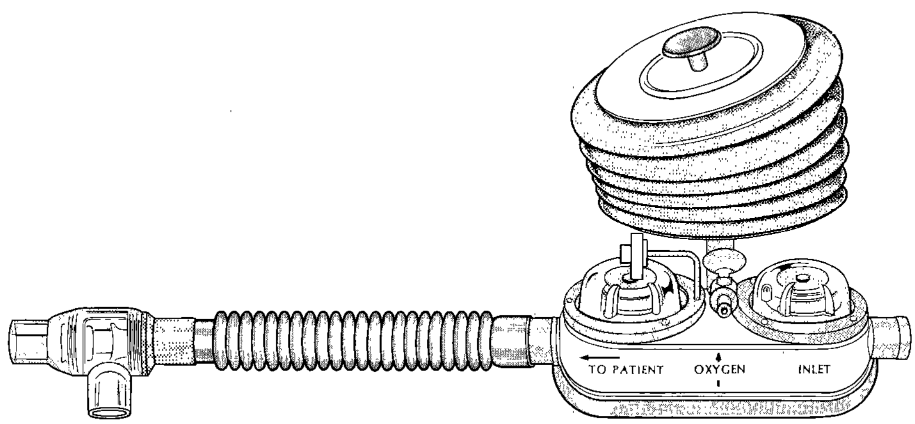
4. Anaesthetic and resuscitation equipment

Breathing machines

Oxford bellows

This is a hand-operated bellows unit for inflating the lungs (Fig. 4.1). It consists of an inlet connection and valve, the bellows in the middle, an outlet valve with outlet connection, and tap. There is a magnet in a holder under the bellows, which is used to immobilize the disk valve when a non-return valve (such as the Ambu) is in use.

Fig. 4.1. Oxford inflating bellows.



Compression of the bellows, during artificial respiration, will produce a full deflection of the flap valve during inspiration. In order to allow the patient to expire to the atmosphere, a small amount of air must pass back up the corrugated tube towards the bellows to reseat the flap valve. If the outlet flap valve of the bellows unit is not immobilized, air will be unable to pass back and the non-return valve will stick in the inspiration position. The magnet referred to above must therefore be fitted, if a non-return valve is being used.

The adult bellows can be exchanged for a paediatric type by unscrewing it from the base. The paediatric bellows has a full-stroke capacity of about 400 ml, making it easier to ventilate children.

The bellows should be inspected regularly. Possible faults in the bellows are listed below.

- *Cracks in the bellows*

Change the whole unit or just the bellows, as appropriate. To replace the bellows, proceed as follows:

1. Remove the bottom plate first, by taking out the four small screws, and then levering off the plate, which is cemented in place with an adhesive.
2. Loosen the inner bottom plate.
3. Access can then be gained to the ball-ended bolt that is attached to the top plate.

4. Holding the bolt with a pair of pliers or spanner, unscrew the knob on top of the bellows, releasing the bolt, spring, and bottom plate. The old bellows can then be pulled off the top plate.
5. Remove all the old cement from the end-plates.
6. Insert the inner top plate into the bellows, apply a small but continuous ring of glue to the groove in the outer top plate, position this on the bellows, and insert the knob.
7. Insert the spring into the bellows from the outer end, apply the ball-ended bolt, and tighten the knob.
8. Glue can then be applied to this thread to seal it. Care must be taken to keep the bellows and the plates concentric during tightening.
9. Stretch the bellows over the inner bottom plate and position the ring on the bellows' edge, in the groove in the plate.
10. Apply glue to the groove in the outer bottom plate and to the threads of the four small screws.
11. Assemble the bottom plate with the screws, again ensuring concentricity of the rubber in the grooved end-plate.
12. Allow the glue to dry for at least 1 hour before testing the bellows for leaks.

- *Cracks in the glass domes*

Replace the glass dome. (Note that the metal clamping rings are not interchangeable between the inlet and outlet valves.) It is advisable to use new gaskets with new glasses, and to tighten the fixing screws in rotation, a little at a time, so as not to stress the glass unevenly. Always ensure that the magnetic disc valve is installed in the outlet valve assembly, after dismantling the valve body.

- *Inoperative magnet*

If the magnet fails to lift the outer valve clear of the valve seating, check that the magnet is functioning, that the disc is the correct one, and that it is magnetic.

- *Faulty outlet valve*

Check the outlet valve by first replacing the magnet in its storage holder; block the inlet port with a cork, and attempt to extend the bellows. It should not be possible to extend the bellows more than 2.5 cm in 1 minute.

- *Leaks in the inlet valve*

To check the inlet valve, block the outlet port with a cork and attempt to compress the bellows. Again, movement should not exceed 2.5 cm in 1 minute. Remove the cork.

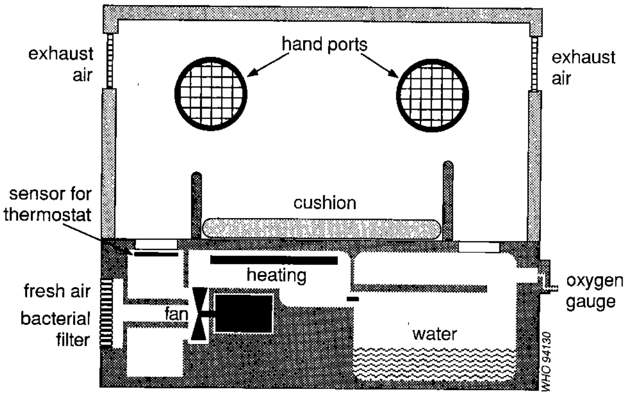
Penlon bellows unit

This is similar to, but simpler than, the Oxford bellows unit. It has a single flap and was designed specifically for use with a non-return valve. It must **never** be used with a simple spring-loaded expiratory valve. The maintenance of these units is similar to that for the Oxford bellows. The commonest site for leaks is at the base of the concertina bellows, where it is connected to the valve unit with a nut and washer. Both bellows are capable of delivering a volume of about 1300 ml; a 10-cm stroke will deliver about 800 ml.

Infant incubators

Infant incubators (Fig. 4.2) are used to keep unwell newborn or premature infants in controlled conditions of temperature, humidity, and oxygen level. Doors are provided in the sides to allow access to attend to the infant. The common types incorporate a low-power heater and a fan to circulate the air. There are warning alarms to draw attention to mains failure or overheating, for example.

Fig. 4.2. Infant incubator.



Maintenance

Day-to-day care involves care of the door catches and seals. Like ventilators and anaesthetic machines, the incubator needs to be thoroughly checked twice a year, and functioning should be checked after each cleaning. Check that:

- it warms up to, and is able to maintain, the set temperature;
- the over-temperature alarm works at the correct setting;
- all dials read correctly.

Also check the electrical safety of the machine. Problems are most likely to be of an electrical nature. If there is overheating, check that the ambient air temperature is not too high, and that the machine is not exposed to the sun. A fan-failure alarm may indicate that the bearings of the fan motor need lubricating or replacing. Correct bearings may be available from a supplier of roller bearings for industrial use.

Do not attempt to repaint the interior surfaces. This can cause serious harm to newborn infants by contaminating the air they breathe. Special repainting procedures are available from manufacturers, upon request.

General cleaning

Cleaning may be carried out with soap and clean water. All the surfaces and corners should be washed and dried thoroughly, using plenty of clean absorbent paper, or clean cloth, to ensure that every corner is completely dry. Any remaining moisture can promote the growth of bacteria. If the canopy is made of Perspex, clean it with soap and water, but do not use abrasive compounds. Finally, wipe the canopy with a little ethanol (70%).

Full disinfection

1. Remove any porous material from the incubator.
2. Place a bowl of formaldehyde solution (formalin) in the incubator (about 250 ml).

3. Turn on the incubator, and leave it to heat with the fan circulating the air, for at least 1.5 hours.
4. Remove the bowl of formaldehyde solution, and replace it with a bowl of 200 g/l ammonia solution. Leave for 1.5 hours with the fan and heating switched on. The ammonia removes the smell of the formalin.
5. Remove the ammonia solution, strip the machine down and clean with soap and water. If after cleaning there is still some residual smell of formalin, leave the incubator running until all the smell has disappeared.

Notes on formaldehyde

A stock solution of formaldehyde in water (370 g/l), generally called formalin, should be available. Prior to disinfection, the equipment should be cleaned of all gross contamination and then arranged to permit a free flow of formaldehyde vapour over all potentially infected surfaces. The properties of formaldehyde make it unsuitable for the disinfection of porous substances such as filters and fabrics, including all bedding material. Any such material should be removed and cleaned by other means. The disinfecting process should take place at a temperature above 20 °C.

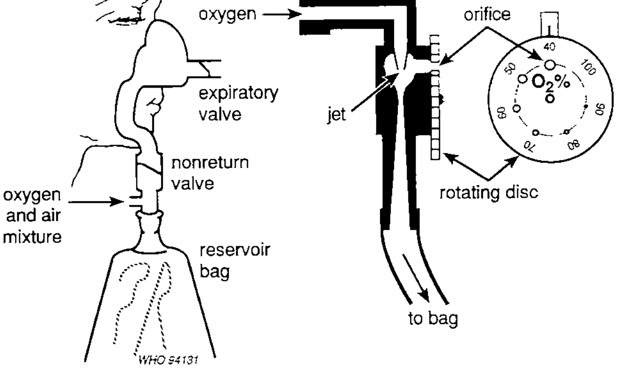
Methanol is often added to formalin as a stabilizer if it is to be stored for long periods. Methanol prevents polymerization. When buying formalin for disinfection, do not select an industrial grade as this may well have up to 10% methanol added. Such a high concentration of methanol can damage some plastics, including Perspex. Buy formalin containing not more than 1% methanol. Always store formalin in a dark-coloured bottle, out of the sunlight.

Oxygen entrainment systems

An entrainer is used to administer an air/oxygen mixture to patients. Fig. 4.3 shows how an entrainer works.

Oxygen from a flowmeter enters the entrainer and draws in air via the air entrainment duct. The duct is covered by a regulator disc, which can be rotated and has holes in it of different sizes. As the disc is turned, different size holes can be lined up with the entrainment duct. In the diagram, the disc has been turned so that the largest hole, marked 40, is against the orifice. At this setting, the flow of oxygen pulls in 3 times its own volume of air, so the mixture administered to the patient is 40% oxygen (because the air also contains some oxygen). The disc can

Fig. 4.3. How an entrainer works.



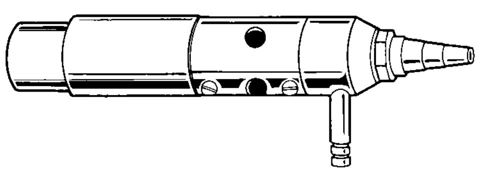
be rotated to a smaller hole, resulting in a higher oxygen concentration being delivered to the patient because less air is taken in. If the disc is turned to 100, the patient will receive 100% oxygen, as there is no inlet for air. Once the disc has been set, the patient will receive a gas mixture with the same proportion of oxygen, whatever the flow rate.

The maintenance of such a basic entrainer is simple, and consists of making sure that the holes in the disc and the jet are not blocked, and that the disc is free to be rotated, though not so free that it can be turned by accident. When checking or unblocking the holes or jet, do not use a drill or wire, as this may alter the size of the hole and thus the amount and composition of gas that is delivered to the patient.

Farman entrainer

This is an entrainer designed for paediatric use (Fig. 4.4). It can be used with an Epstein-Macintosh-Oxford (EMO) machine to vaporize ether, or with an Oxford Miniature Vaporizer (OMV) to vaporize other anaesthetic agents. The entrainer consists of a fine jet through which oxygen passes into a venturi-shaped tube, drawing in air.

Fig. 4.4. Farman entrainer.



The entrainer is plugged into the inlet of an EMO machine and a blood pressure gauge attached to the side-arm. Oxygen from a cylinder is passed through the entrainer, the flow being adjusted until the blood pressure gauge reads 100 mmHg. At this setting, the entrainer will deliver a flow of 10 litres of oxygen-enriched air per minute; the gas mixture will contain about 35% oxygen.

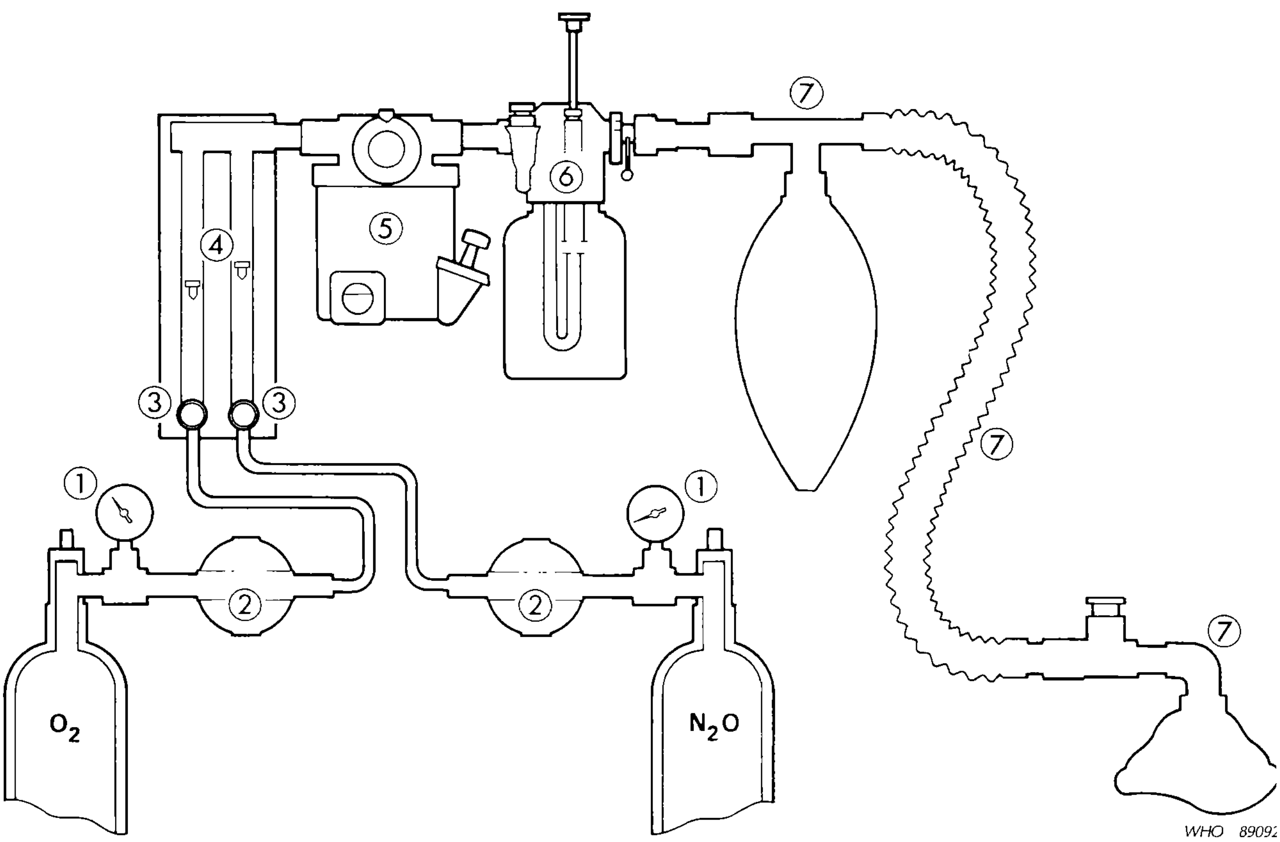
Remember, ether and oxygen mixed in air form an explosive mixture. When testing an entrainer, it is safer to fix it to an empty EMO or carry out the test in a well-ventilated area.

If the outflow of the entrainer is blocked, the high-pressure gas will escape from the air-inlet ports and the maximum pressure in the system will be about 11 mmHg (15 cm H_2O or equivalent on the gauge in use). Thus, if for any reason the gases are prevented from escaping from the breathing circuit, the maximum pressure of gas the patient will receive is about 11 mmHg. A fine filter is provided at the air-inlet port to prevent dust from entering the high-pressure chamber and damaging the jet. Do not clean the jet by probing it with a piece of wire, as this may alter the size of the jet. There is also a wire gauze to protect the air entry port. Make sure the filters are clear and check the jet, which may be removed for cleaning. This entrainer is cheap to buy, economical, safe, and simple in construction; it is easy to maintain (as outlined above) and, if treated with care, will last a long time.

Systems for continuous-flow anaesthesia

Continuous-flow anaesthetic machines (commonly known as Boyle's machines or simply gas machines) are in widespread use. They rely on a supply of compressed medical gas, either from cylinders attached directly to the machine or piped from a large bank of cylinders or liquid oxygen supply elsewhere in the hospital. The two gases most commonly used are oxygen and nitrous oxide. Cylinders are attached to the machine by a special yoke that prevents the connection of the nitrous oxide supply to the oxygen port and vice versa—the pin-index system. Some older machines may lack this system, and extreme care is needed in their use to prevent incorrect connections. The cylinders contain gas at high pressure, which is reduced to the anaesthetic machine's working pressure, usually 400 kPa (4 atmospheres), by a reducing valve. Each gas then passes through a needle valve at the base of a rotameter. This valve controls the flow of gas to the patient, once the cylinder valve has been opened with a key or spanner to allow gas to flow out. The gas passes through the rotameter, which measures the gas flow by upward displacement of a bobbin in a tube, and along the "back bar" at the top of the machine, where it may be diverted through a vaporizer for the addition of a volatile anaesthetic agent (Fig. 4.5). A separate switch or tap is usually provided to allow for a high flow of oxygen to be delivered to the patient in case of emergency, bypassing the rotameters and vaporizers. Gas is delivered from the common gas outlet at the top or front of the machine, to which a breathing system is connected.

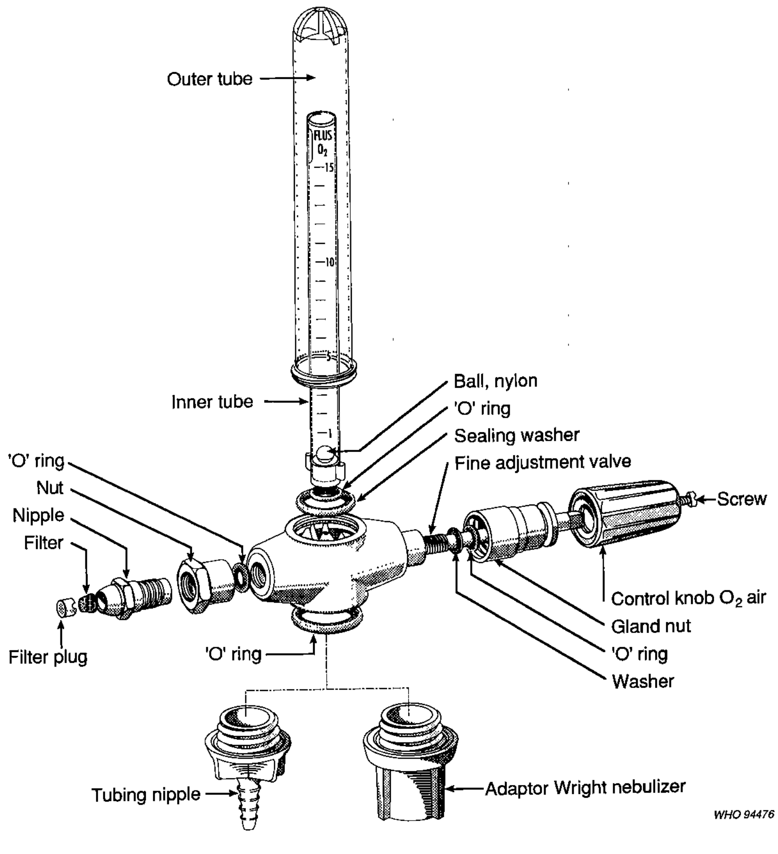
Fig. 4.5. Gas pathway on a continuous-flow (Boyle's) machine with a compressed gas supply: (1) pressure gauges, (2) reducing valves, (3) flow-control (needle) valves, (4) rotameters, (5) calibrated vaporizer, (6) Boyle's bottle, (7) Magill breathing system.



Flowmeter unit

The servicing of a flowmeter, as for example the one shown in Fig. 4.6, is carried out as described below.

Fig. 4.6. Flowmeter.



1. Disconnect the flowmeter from the gas supply and remove the tubing nipple or nebulizer from the outlet of the flowmeter. Inspect the tubing nipple O-ring for damage and replace, as necessary.
2. Hold the flowmeter vertically, unscrew and remove the outer tube and inspect it for dirt and damage. Clean or replace it, as necessary.
3. Remove the inner tube, spider (not illustrated), and nylon ball. Inspect all three parts for dirt and damage, and clean or replace, as required.
4. Examine the O-ring and seal in the body of the unit, and replace them if damaged. Lightly grease with silicone grease. Remove excess grease. Examine the threads in the body of the flowmeter. If they are damaged, do not attempt to repair them, but replace the body.
5. Check the fine-adjustment control valve for smooth operation. If the valve is not smooth through its whole range of movement, proceed as follows:

   – *Ensure that the valve is closed.* Remove the label from the end of the control knob, and check the knob for cracks. Replace if necessary.
   – Remove the screw that holds the control knob to the valve spindle and pull the knob off, then look inside for cracks. Replace the knob if there are any.
   – Unscrew the gland nut and inspect the thread for damage. Replace if there is any. Clean if required.
   – Examine the gland nut packing bush for serviceability, and replace if necessary. For replacement, lightly grease the spindle and bush, and then remove the excess grease.
   – Unscrew and withdraw the valve assembly. Examine the O-ring and seal for serviceability, and replace as necessary. If they are replaced, lightly grease the O-ring and seal, and remove the excess grease.
   – Examine the valve threads for damage, and replace the valve assembly, if necessary.

- Fit the O-ring and seal into the flowmeter body and screw the valve assembly home. Tighten to the torque recommended in the manufacturer's service book.
- Fit the gland nut and tighten sufficiently to maintain a gas-tight seal, but not so tight as to restrict the smooth operation of the fine-adjustment control valve.
- Replace the control knob and secure it to the valve spindle with the screw.

6. Check the inlet adaptor assembly for security of attachment and damage. Replace if damaged. If it is loose, remove the assembly, coat the threads with a suitable liquid for sealing nuts on threads, and screw home.
7. Remove the filter plug and the filter. Examine the filter for dirt, refit or replace, as necessary, and press home the filter plug.
8. Connect the flowmeter to a 300–400 kPa, 300–400 litre oxygen supply, and with a leak-test fluid, such as soapy water, carry out a leak test with the flowmeter pressurized. There should be no leaks. Finally clean the flowmeter.

After-service testing

When servicing and any repairs have been completed, carry out the following tests:

- Connect a gas supply of 400 kPa to the inlet of the flowmeter. Connect a suitable length of tubing to the tubing nipple at the flowmeter outlet, and attach the other end of the tube to an accurate flowmeter. Carry out the checks listed below.
- Check that the two flowmeters agree at the following settings:

  2.0 ($\pm$ 0.5) litres per minute
  5.0 ($\pm$ 0.5) litres per minute
  10.0 ($\pm$ 1.0) litres per minute
  15.0 ($\pm$ 1.0) litres per minute

  All readings must be taken at the centre of the ball.
- Check that each setting is easily obtained and steady.
- If the above flow rates cannot be achieved, check all seals and O-rings, and retest. If the required flow rates still cannot be achieved, replace the inner tube or ball. If the flow rates are still not correct, check the fine adjustment valve again.

Remember that the outer tube is at the pressure of the regulator; do not remove it when the system is pressurized.

Faults

- Unable to obtain full flow:
  - Check and clean the fine adjustment valve.
  - Outlet partially blocked: unblock it.
  - Low cylinder pressure: fit a full cylinder.
  - Regulator pressure set very low: adjust to the correct pressure.
- A small flow showing when the fine adjustment valve is turned off:
  - There may be a crack in the flow-tube outer tube.
  - The outer cover may not be screwed on properly.
- Ball bounces with a popping noise:
  - This is called motor-boating, and is caused by a dirty valve seat.

Rotameter tube

Many machines use a tube called a rotameter to measure the gas flow. A true rotameter tube is made of electrically conductive glass, and has a tapered bore, which is wider at the top than at the bottom. Inside, there is a bobbin with flutes cut out at the top, which make the bobbin spin in the gas flow, showing that it is not stuck. The bobbin is usually made of aluminium, which is light and resistant to corrosion. However, some corrosion may still occur, and it is therefore important that, during the servicing, the tube is taken out. Remove the bobbin, and make sure that every part of it is absolutely dry. If the bobbin has started to corrode, this is what to do:

1. Remove the tube very carefully from the block.
2. Remove the bobbin stop, at the top of the tube.
3. If it is free, tip the bobbin out of the tube. If it is not free, place a thin piece of wood, that is just smaller in diameter than the inside of the tube, into the tube and tap the bobbin with it to try and force it out. This must be done with the greatest of care, as excessive force will crack the tube. If in difficulty, try a little penetrating oil.
4. Once the bobbin is out, clean with very fine abrasive paper, removing all signs of corrosion, and leaving the area smooth.
5. Clean the tube of any corroded material, and dry thoroughly.
6. Replace the bobbin in the tube, and replace the tube in the block.
7. Test the assembly to ensure that the bobbin does not stick in the tube.

The graduations on the tube are calibrated with the bobbin inside. The bobbin has a number on it, and the same number should be on the glass tube. The bobbin should not be changed from one tube to another (except in an emergency) as this will make the graduations slightly inaccurate. Tubes cannot be used for different gases either, as each tube is calibrated only for the gas that is marked on it. In any case, the tubes are often of different sizes and physically will not fit into the wrong place. They should have an accuracy of about $\pm$ 2%.

Other flow indicators

Coxeter dry-bobbin flowmeter

A bobbin floats in a vertical glass tube of uniform bore. Gas enters from below. As the flow increases the bobbin rises in the tube and allows the gas to pass out through a series of holes in the back of the tube. This flowmeter has been largely replaced by more accurate types of rotameter.

Bryce-Smith induction unit

This is a simple and reliable addition to the EMO for delivering limited dosages of halothane. The unit has no controls. Halothane is poured into the measuring dish on the top, which has a capacity of about 3 ml. The wick unit is removed from the bottom and placed in the dish. The wick absorbs the halothane and is then replaced on the bottom of the unit, and will immediately deliver the anaesthetic vapour to the patient. The unit, which is normally left attached to the outlet of the EMO, delivers about 2–4% halothane for 3–4 minutes.

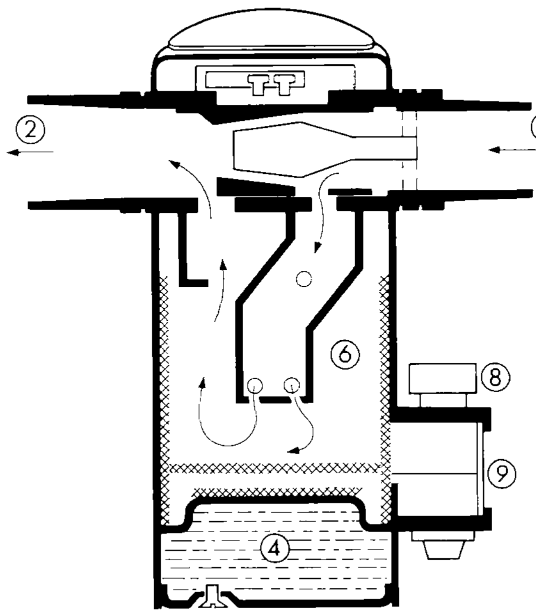
The only maintenance that can be undertaken is to ensure that the wick is in good condition, and that the tapers are not damaged where the unit plugs into the EMO.

Vaporizers

Oxford miniature vaporizer (OMV)

This is a small vaporizer (Fig. 4.7) which can be used to administer anaesthetics. It works in the same way as the larger vaporizers, but does not have a built-in temperature compensation device. However, the base is filled with antifreeze to help stabilize the internal temperature. A number of different versions are available, each of which can be fitted with different scales for use with different anaesthetic agents.

Fig. 4.7. Oxford miniature vaporizer: (1) inlet port; (2) outlet port; (4) water jacket; (6) vaporizing chamber; (8) filling port for anaesthetic; (9) anaesthetic-level indicator.



The volatile anaesthetic liquids contain non-volatile substances such as thymol. These accumulate inside the vaporizer and will adversely affect performance, if present in excessive quantities. Removal of the deposits is therefore an essential part of the maintenance of vaporizers. Simple cleaning can be undertaken quite easily and requires no tools. It should be carried out as soon as any stiffness is noticed in the control pointer. However, major cleaning will require special tools and should only be necessary on rare occasions.

Simple cleaning procedure

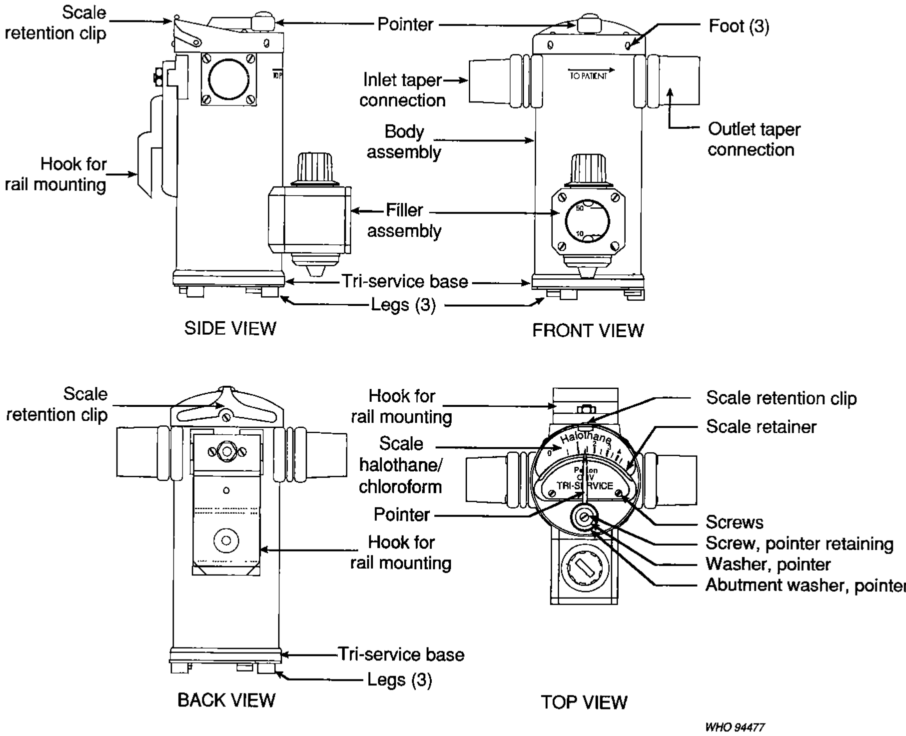
1. Put a rubber bung into the inlet and turn the vaporizer on to its side, with the outlet port pointing upwards.
2. Pour cleaning fluid (methanol or ether) into the outlet, while moving the pointer to and fro.
3. The vaporizer should be completely filled and allowed to stand for 5 minutes before emptying.
4. The vapour of the cleaning fluid that is left in the vaporizer should be completely removed by opening the control fully and blowing air through the vaporizer for 15–20 minutes with an inflating bellows.

Major cleaning procedure

If possible, refer to the manufacturer's service manual.

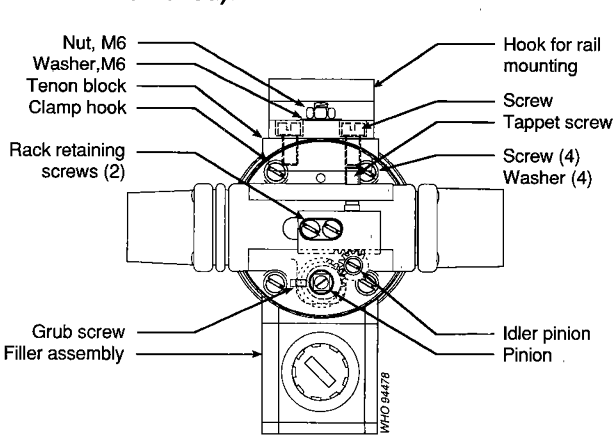
1. Remove the pointer by removing the screw and the washer. Lift off the pointer and abutment washer, and remove the scale (Fig. 4.8).

Fig. 4.8. Detail of the Oxford miniature vaporizer.



2. Take out the three screws from the lid, and lever the lid off the body. **Note**: These screws are rather short and have a fine thread; treat them very carefully, otherwise the thread will be stripped on the screw or on the vaporizer. Should this happen, it will have to be re-tapped, and a bigger screw fitted.
3. Remove the M6 nut and washer, and take off the "off-line" hook (Fig. 4.9). Remove the two screws, and take off the tenon block and clamp.

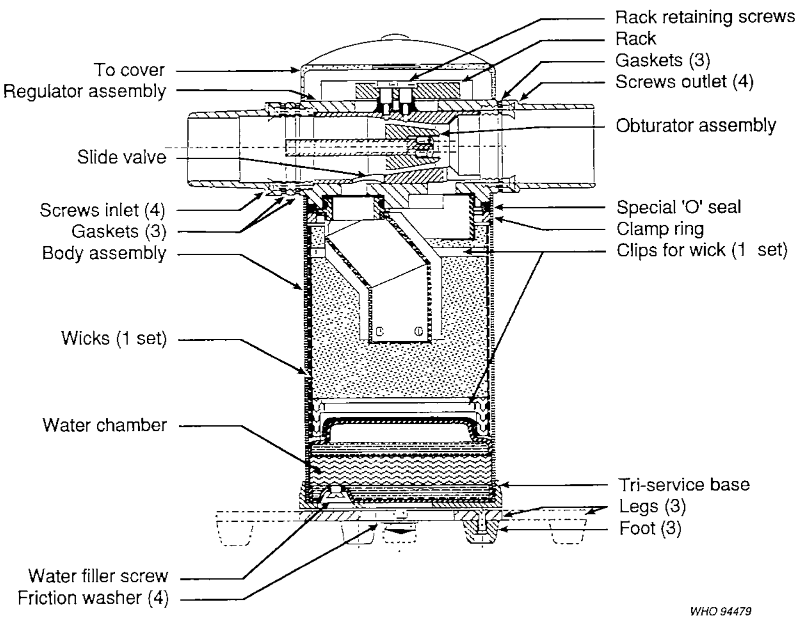
Fig. 4.9. Detail of the Oxford miniature vaporizer: top view (pointer and scale removed).



4. Remove the four screws and washers. Lift out the regulator assembly, O-seal, and clamp ring.
5. Part-fill the vaporizing chamber with cleaning liquid (as above). Shake gently to wet all parts of the wicks. Allow to soak for 2–3 minutes and shake it again; repeat this several times. Discard the liquid. Repeat the process until the discarded liquid appears clean. Invert the chamber and allow to dry completely.
6. If the indicator glass is still dirty after the above process, remove the four screws securing it, lift out the glass and wipe clean. Replace the glass, ensuring that the seals and centring ring are replaced in the correct position.
7. If corrosion is present on the wick, e.g., rusty patches, reassemble the vaporizer and return it to the manufacturer for replacement of the wicks.
8. Dismantle the regulator assembly:

   – Remove the inlet and outlet cones (4 screws each), gaskets, and obturator assembly (Fig. 4.10).

Fig. 4.10. Detail of the Oxford miniature vaporizer: cut view, side.



– Remove the two screws securing the rack. Lift off the rack and spacers. Note that the plastic sleeves inside the spacers must be retained. Also note the relative position of the ports[1] and the direction of the cone of the slider.
– Remove the slide-valve by pushing from the outlet end of the regulator housing. If it is stiff, use a wooden or plastic drift (stick) to push it out. Do not use metal, as this will damage the machined surfaces.
– Soaking the assembly in ether or alcohol will usually dissolve the deposits that are causing the stiffness.
– Wash the slide-valve and regulator housing in cleaning fluid and dry with a clean cloth, paying particular attention to the sliding surfaces. **Never** clean these with abrasive compounds. Metal polish may be used to remove stubborn dirt after first carefully removing the residues and before re-assembly.

[1] Modern versions have markings on the ports so that they can be realigned in the correct position. Older versions may not have these markings, so, before taking the assembly apart, scratch a line with a screwdriver over the connecting parts.

- Refit slide-valve to housing.
- **Do not** use any oil or grease. Check for smooth motion from one end of the housing to the other.
- Check the location of ports and the direction of the cone, and reassemble the rack with spacers and screws, lining up the marked tooth rack between the two marked teeth on the idler pinion, and, at the same time, the marked teeth on the idler and the pointer pinion.

9. Backlash can develop between the rack and idler, or between the idler and pinion.
   - A tappet screw is provided to adjust the engagement of the former.
   - The pinion is mounted in an eccentric bush, and engagement with the idler is adjusted by slackening the lock screw, rotating the eccentric bush, using a 3-mm bar in the hole provided, until the engagement is correct, and then tightening the lock screw.

10. Reassemble the reducing valve assembly body
    - The special PTFE[1]-coated O-ring that seals the assembly must be examined for damage, and repeated if necessary.
    - Separate the clamp ring and regulator housing by removing the four screws and washers.
    - Insert the clamp ring into the body with the four screw-holes at 45 degrees to the reducing-valve housing, in plan.
    - Immerse the O-ring in warm water (40–50 °C) for a few minutes, to soften it.
    - Place the O-ring on top of the clamp ring.
    - Insert the regulator housing assembly using the 3-mm tommy bar to line up the screw holes in the clamp ring and regulator housing. Insert the draw-screws into two diagonally opposite holes to draw the clamp ring into the body (hand-tight only).
    - Insert two screws and washers, remove draw-screws, and insert the two remaining screws and washers.
    - Tighten all four screws evenly and fully, making sure the regulator is pressed home fully into the body without gaps beneath inlet and outlet square section.

11. Examine the obturator assembly to ensure that the adjustment screws are sealed. If the seal is broken it is advisable to return the unit to the manufacturer. Assemble the gaskets, obturator assembly, and inlet connector with four screws to the reducing-valve housing. Check that the obturator is concentric with the slide-valve. Assemble the gasket and outlet connector to the regulator housing.

12. Test the main body seal for leaks:
    - With the slide-valve open, block the outlet connector and apply pressure to approximately 180 mmHg through the inlet connector.
    - Run a small quantity of cleaning fluid (ether or alcohol) into the joints between the regulator assembly and the body.
    - Check for bubbles.
    - Tighten screws or replace O-ring, if necessary, to obtain a leak-free joint.
    - Tip out any surplus liquid, and allow the machine to dry completely.

13. Reassemble the tenon block, clamp, off-line mounting block, lid, and pointer (reverse of dismantling instructions). Do not fit the scale at this stage.

[1] Polytetrafluoroethylene.

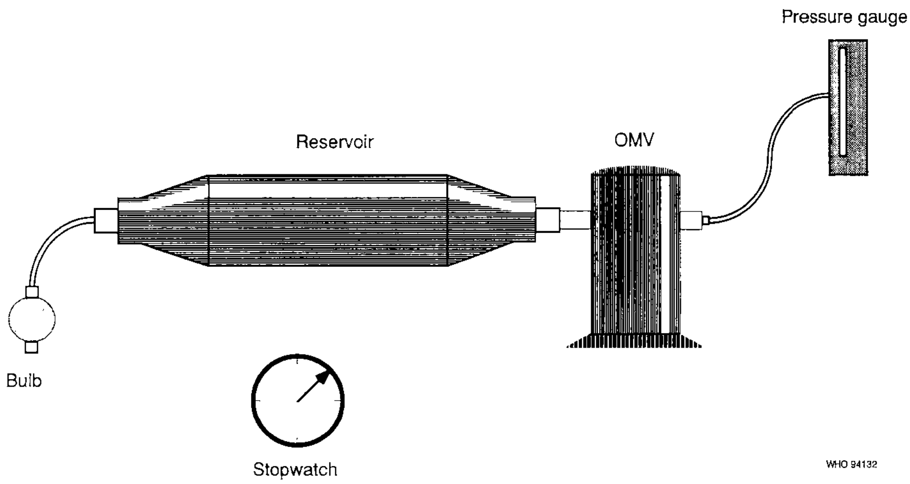
Check pointer setting

Do this by inserting a setting gauge, OMV 1, through the outlet side into the valve port, with the pointer between 50 and 60 on the engraved scale on the lid. Move the pointer towards the left until no further movement is possible. The pointer should then indicate 35 on the engraved scale. A positional error of ± 1 mm is acceptable. If the gear train has been wrongly assembled, an error of 7.5 degrees per tooth will be introduced, so that the errors are easy to detect. Remove the setting gauge, assemble the outlet connector and gasket with four screws, and fit the scale back in place.

Testing for leaks

This procedure should be carried out if the unit is reported to be giving low concentrations or is using excessive quantities of halothane or trichloroethylene. Connect the vaporizer to a reservoir, pressure gauge, and air source, as shown in Fig. 4.11. Pump air into the system until a pressure reading of approximately 210 mmHg (28 kPa) is reached. Clamp off the air-supply line with a pair of forceps. The pressure in the system will fall slowly; use a stopwatch to record the time taken for it to fall from 200 mmHg to 190 mmHg.

Fig. 4.11. Leak test layout.



Carry out the test with:

- The control pointer in the OFF position to test the connectors and the top of the regulator housing. Acceptable value: 30 seconds or more.
- The control pointer in the "3.5" position to test the vapour chamber joints. Acceptable value: 30 seconds or more.
- The control pointer in the OFF position and the filler held open to test the vapour seals. Acceptable value: 15 seconds or more.

If the vaporizer does not pass this test, look for the position of the leak by brushing soap solution around the suspect joints while maintaining the internal pressure. Bubbles will form at the leak site. Do not apply soap solution to the opening around the rack, where it could enter the slide valve (once it dries, it will cause the slider to stick).

Note: There is always a certain amount of leakage from the slide-valve but this can be ignored if the test figures above can be obtained.

Specific repairs

Fitting a new level-indicator glass

Remove the four screws, take off the retainer, the old glass, seals, and centring ring. When fitting a new glass, always use new seals. Glasses vary a little in thickness. Three seals are provided in the spare-parts kit, and sufficient seals should be used to obtain good compression on the glass when the retainer is screwed back into place. Test the unit for leaks after fitting a new level-indicator glass.

Fitting a new drain seal

1. Remove the drain screw.
2. Use a pin spanner to unscrew the old drain-seal assembly from the filler block.
3. Discard the old assembly and seal.
4. Fit a new assembly and seal.
5. Tighten securely.
6. Test for leaks.

Fitting a new back seal

1. If a leak develops between the filler block and body, remove the retaining level-indicator glass.
2. With a screwdriver, lever out the engraved back plate of the level indicator; this will expose the heads of two socket-head screws.
3. If tightening does not cure the leak, remove the screws, lift off the filler block and fit a new seal between the block and the body.
4. Reassemble all parts and test for leaks.

Replacing a folding leg (where fitted)

Remove the screw securing the leg to the base, and fit a new leg and new friction washer. The legs are made of malleable material and will withstand flattening with a soft-faced mallet.

To tighten a loose leg (where fitted)

Remove the screw securing the leg to the base, and replace the friction washer. Reassemble.

Replacing the complete base

The complete base assembly, with its feet, is fixed to the body using adhesive. If this joint should be broken as the result of a fall, a suitable adhesive should be used to refix the base. Clean off the old adhesive before refixing, and ensure that the recess in the base is aligned with the water-filling screw.

Other repairs

Faults requiring the instrument to be returned to the manufacturer or agent:

- broken pointer,
- corroded wicks,
- broken seal on obturator.

The vaporizer should be recalibrated every two years by the manufacturer or agent.

Equipment required for servicing

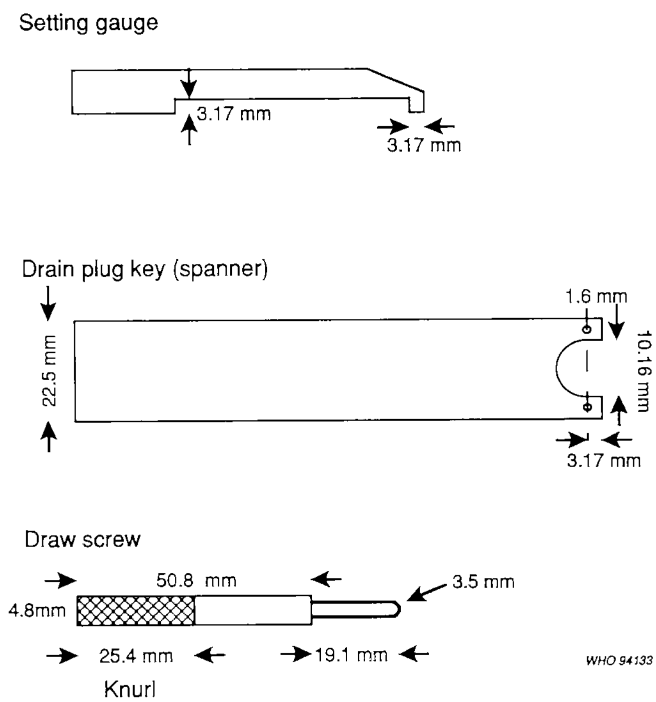
Leak testing

A source of compressed air, at about 200 mmHg (26 kPa). In the absence of a mechanical pump, this may be provided by a blood pressure machine, a hand bulb, or an Oxford inflating bellows.
Rubber bungs to fit the inlet and outlet of the vaporizer, one with a 6-mm tube through it.
A reservoir of capacity 4 litres capable of withstanding a pressure of 200 mmHg (26 kPa).
A pressure gauge to read to 200 mmHg (26 kPa).
Liquid soap solution and a small brush.
Ether or methylated spirit.
A stopwatch.
A pair of clamping forceps.
Rubber or plastic tubing to fit a 6-mm tube.

General servicing equipment (Fig. 4.12)

Setting gauge.
Drain plug key (spanner).
Draw screws.

Fig. 4.12. General servicing equipment.

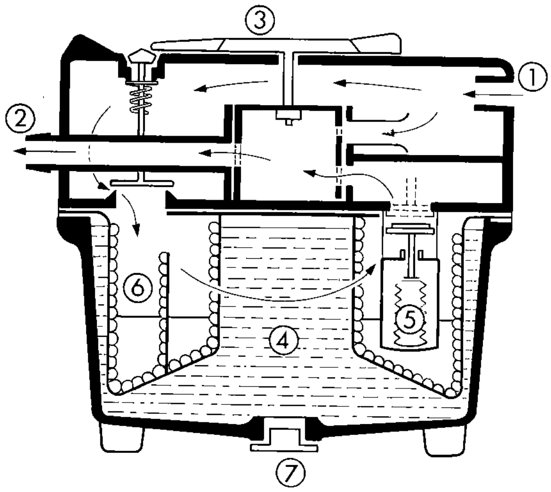


If the manufacturer supplies instructions giving reasons and situations when the equipment should be returned to them or their agent, these should be complied with wherever possible.

Epstein-Macintosh-Oxford (EMO)

The Epstein-Macintosh-Oxford (EMO) (Fig. 4.13) is an anaesthetic vaporizer with low internal resistance, for use with ether and air. It has a water-jacket, which helps to keep the internal temperature constant, and a built-in temperature-compensating valve. The EMO has only two moving parts, the concentration rotor and the temperature compensator. These are set in the factory and should not be altered, except in an emergency, and then only after reading the service manual.

Fig. 4.13. EMO vaporizer: (1) inlet port; (2) outlet port; (3) concentration control; (4) water jacket; (5) thermocompensator valve; (6) vaporizing chamber; (7) filling port for water.

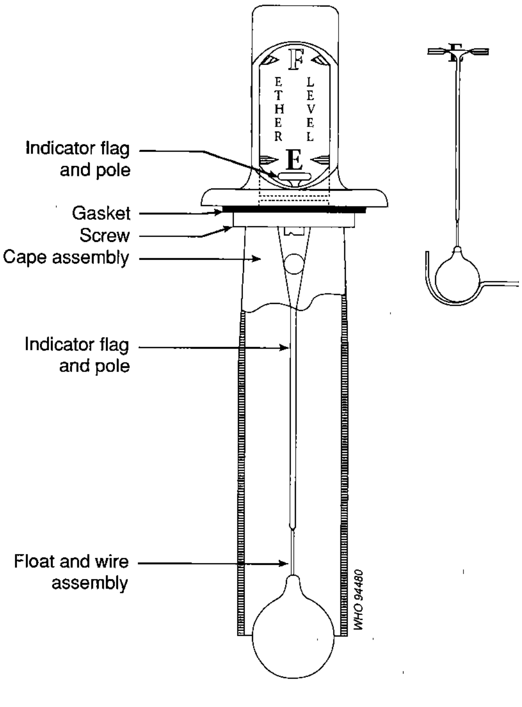


Some simple checks

Level indicator (Fig. 4.14)

With the ether compartment empty, slowly invert the vaporizer and check that the indicator moves freely, falling to the FULL position, and returning to the EMPTY position when the vaporizer is once again upright. When refilling, check that the quantity of ether used complies with the figures given in the instruction book.

Fig. 4.14. EMO: level indicator.



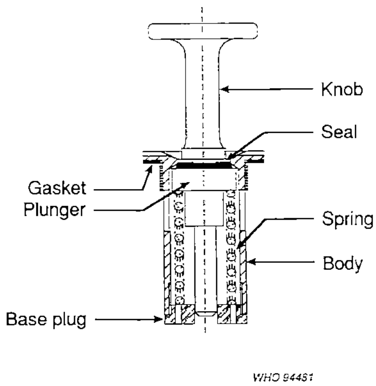
Closing mechanism

Turn the concentration control to the transit position, and connect the outlet of an Oxford inflating bellows, or other ventilating equipment, to the inlet of the EMO. Block the outlet of the EMO, apply gentle pressure to the bellows unit and open the ether filling port. There should be no escape of air through the filling port or through the top of the closing mechanism.

Filling port (Fig. 4.15)

With the bellows still connected to the inlet of the EMO and the outlet blocked, open the control knob to 10, close the filling port, and apply gentle pressure to the bellows; there should be no leakage through the filling port.

Fig. 4.15. EMO: filler unit.



Safety release valve

The safety release valve is combined in the closing mechanism unit. With the control knob set at 2, and with an Oxford bellows connected in the normal position on the outlet of the EMO, block the inlet and check that when the bellows is operated the safety valve operates, drawing air in through the valve.

Temperature compensating unit

The position of the temperature compensating indicator will show whether the unit is in satisfactory working order. The indicator consists of a rod with a black and red band, and a metal top. At 20–25 °C, the metal top and black band should be visible. At temperatures above 32 °C, the red band will begin to show. If only the metal can be seen at 20–25 °C, the compensating unit is faulty and should be replaced.

Water compartment

If the water used to fill the water compartment is thought to contain high concentrations of salts or chlorine, it is advisable to empty and refill the compartment from time to time.

Cleaning and sterilizing

Antiseptic solutions should not be used for cleaning the inhaler. The exterior may be cleaned by wiping with a cloth damped in ether. Sterilizing is not normally necessary as the inhaler is used on open circuit, and protected from contamination by non-return valves. If special circumstances make it necessary to sterilize the instrument, the only suitable method is by the use of ethylene dioxide gas. Excessive heat, such as during boiling or autoclaving, would damage the inhaler.

Fault-finding and rectification

In the event of difficulties in service read the manufacturer's instruction manual carefully. The following notes provide sufficient information for the user to obtain the best possible service from the EMO. It must be stressed that only pure ether should be used in the ether EMO; impurities may cause serious corrosion.

The causes of some of the commoner faults are listed in Table 4.1.

Table 4.1. Common faults with the EMO vaporizer

Fault	Cause	Rectification by user
Concentration control seized	Rotor seized	Return EMO to service engineer or agent
Ether escaping, although control is in "closed for transit" position	Broken level-indicator glass	Replace level-indicator unit
	Broken indicator glass on temperature compensating unit	Replace temperature compensating unit
	Closing mechanism not shutting	Adjust or replace closing-mechanism unit
Concentrations appear to be higher than normal initially, but drop rapidly during use	Temperature compensator not operating	Check the temperature compensating unit and replace if necessary
	Filling port left open	Close filling port
Concentrations appear to be lower than normal	Leak in circuit	Find and rectify
	Relief valve on closing mechanism stuck open	Check the safety release valve Replace closing mechanism unit, if necessary
	Overfilled with ether so that vaporizing surface area is too small	Pour out excess ether and check level-indicator.
	Temperature compensator not operating	Check the temperature compensating unit; if it is suspect replace it
Level indicator fails to rise when ether is added, but moves freely when inhaler is inverted	Broken float	Replace level-indicator unit.
Level indicator sticks at any point and will not move when inhaler is inverted	Float caught by frayed wick	Remove unit, cut away frayed ends of wicks with scissors.
	Caught by collapsed ether compartment, owing to gas build-up in water jacket due to use of impure water.	Return to makers or agent for servicing

Replace defective parts in all cases. Spare parts are readily available from the manufacturer or from the principal agents, some on a service/exchange basis. This arrangement means that the defective part is returned to the firm, and a new or reconditioned one sent in exchange. When ordering spare parts, the serial number of the inhaler should be given, and the defective part returned with the order.

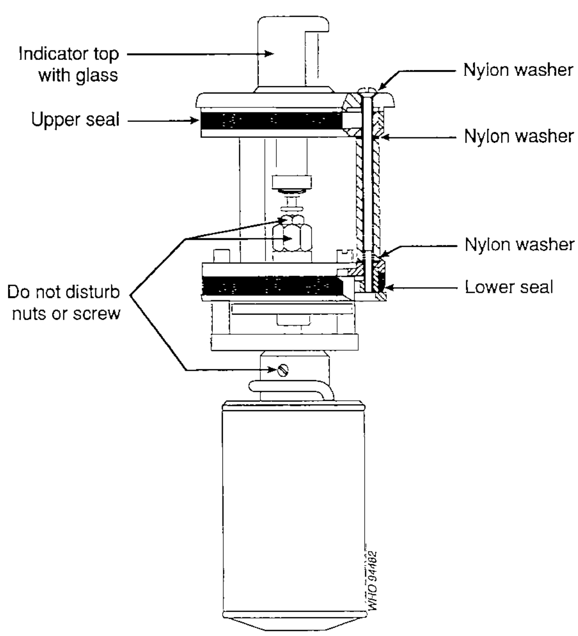
Fitting a new glass float

1. The wire on the glass float is crimped into a tubular form. To release the old wire, squeeze the tube across the direction of crimping, and pull the wire out with a straight pull.
2. Insert the wire on the new float, and crimp the tube lightly with a pair of pliers.
3. Fit the level-indicator assembly into the empty EMO inhaler, and check the position of the indicator when the float is resting on the bottom of the ether chamber. Adjust, so that the indicator is level with the two arrows on either side of 'E', by pulling or pushing the float as required.
4. When the position is satisfactory, crimp the tube in a second place more heavily to secure the float wire.

Temperature compensating unit (Fig. 4.16)

When ordering a replacement unit, specify the part number and the serial number of the inhaler marked on a plate on the back of the body.

Fig. 4.16. EMO: temperature compensating unit.



The unit is retained in the inhaler by three screws which expand rubber sealing sleeves when tightened. To remove the old unit:

1. Slacken all the screws by 3–4 turns.
2. Tap the heads of the screws down flush, using a plastic or wooden block.
3. Grip the top of the unit and twist or wriggle it slightly to break the grip of the rubber seals. You should then be able to lift out the unit.

It may be necessary to repeat steps 1 and 2 if the inhaler has been in use for some time. Do not remove the screws completely, as parts may be lost inside the inhaler. If the screws fall into the inhaler, they may be retrieved by tipping the machine up.

To fit a new unit:

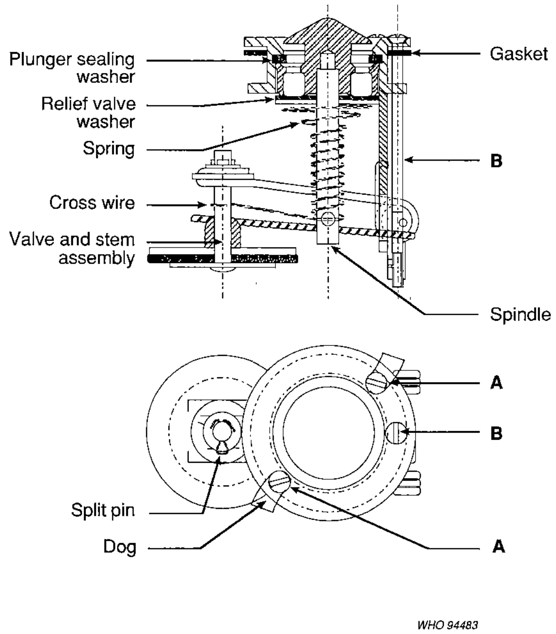
1. Make sure that the well in the inhaler body is clean. Slacken the three screws, and slide the unit into the inhaler body.
2. Check that the top plate fits correctly to the inhaler, without gaps, and tighten the screws.

Note: If the unit is removed for any reason, it is desirable to fit new rubber seals before it is refitted into the inhaler. These are available as: lower sealing ring, upper sealing ring, and nylon washers for screw heads. EMO inhalers made after January 1986 have O-ring seals that replace the lower and upper sealing rings.

Closing mechanism (Fig. 4.17)

The closing mechanism unit is retained in the inhaler by two "dogs" operated by screws (marked A in Fig. 4.17). To release the unit, unscrew these by 2 or 3 turns only, and tap the top of the unit lightly with a piece of wood or plastic to break the grip of the sealing washer. A further turn on each screw should then release the dogs and the complete unit can be lifted out.

Fig. 4.17. EMO: closing mechanism.



To reattach the closing mechanism to the inhaler, make sure that the dogs are turned fully in, and insert the unit into its seating, checking that the tongue provided on the inhaler fits into the slot in the body of the closing mechanism.

Tighten the two screws by one turn, lift the unit to check that both dogs are engaged and then tighten the screws fully.

To fit a new valve assembly:

1. Remove the split pin and small washer. Discard the split pin.
2. Using fine pliers, disengage the spring wire from the hole in the valve stem.
3. Remove the whole valve-stem assembly and fit a new unit by reversing the procedure. Use a new split pin.

To fit a new relief washer:

1. Pull down the spring, and hold the spindle inside it.
2. By pressing the spindle away from the closing-mechanism body, disengage the top end. The washer can then readily be replaced.

To fit a new body sealing washer:

1. Remove the two screws, 'A', and dogs and adjusting screw, 'B'.
2. Remove the old washer by stretching it over the body. Fit the new washer in the same way.

3. Reassemble dogs and screws 'A' and 'B'.
4. Check against Fig. 4.17 for the correct position. The dogs should be a tight fit on screws 'A'.
5. Readjust unit as described below.

Adjustment of unit fitted to inhaler:

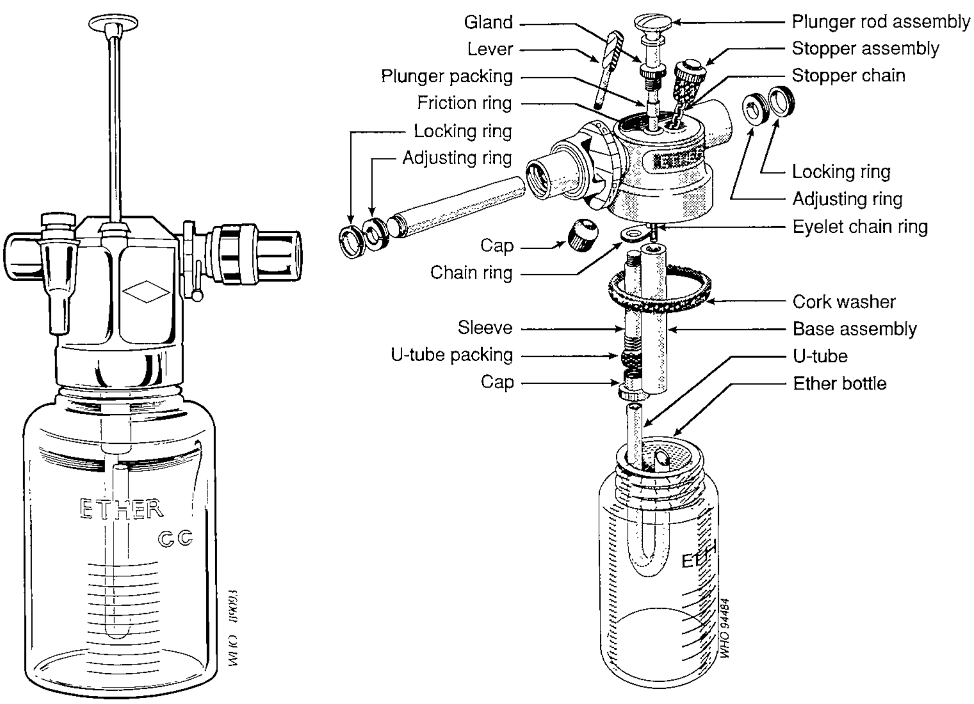
1. After fitting, a new unit may need to be adjusted to ensure correct seating of the valve. Screw 'B' is provided for this purpose. Turning this screw clockwise will increase the closing pressure on the valve.
2. The screw should be adjusted so that the control pointer can operate the closing mechanism without undue force, and the valve closes soundly when checked as described on page 87.

As already stated, the rotor is correctly adjusted before the machine leaves the factory, and should not be interfered with in any way.

Boyle's ether vaporizer

Boyle's ether vaporizer operates through a controllable bypass, which directs the required proportion of anaesthetic gas (0–100%) through a U-tube, to emerge over the liquid ether contained in the glass jar. Vapour concentration may be increased to a maximum by depressing the cowl plunger, thus causing the gas to bubble through the liquid (Fig. 4.18).

Fig. 4.18. Boyle's ether vaporizer.



Servicing

Boyle's ether vaporizer should be serviced as follows:

1. Check that all the apparatus gas supplies are turned off.
2. Remove the vaporizer from the back-bar assembly.
3. Remove the locking nut and adjustment rings from the gas-inlet side of the vaporizer body.

4. Remove the drum-actuating lever and withdraw the drum. (If the drum is seized or cannot readily be withdrawn, remove the locking ring from the gas outlet and turn the adjusting ring in a clockwise direction to force the drum out.)
5. Examine the drum for signs of scoring or corrosion; remove the old grease and apply a film of a suitable grease.
6. Remove the drum-grease injector cap and clean all the old grease from the body assembly.
7. Unscrew the plunger-control-gland packing nut, probe out the packing cotton and regrease it. Replace the cotton and the gland-packing nut.
8. Insert the drum and refit the actuating lever.
9. With the outlet-adjusting ring removed, screw in the inlet adjusting ring, while moving the actuating lever to and fro, until an increase in resistance to lever movement is felt. (**Do not** overtighten the ring to the point of drum seizure, as this will force out all the grease.)
10. Without moving the adjusting ring, fit and tighten the inlet locking ring.
11. Screw in the outlet adjusting ring until it just touches the drum, then back off one-eighth of a turn; fit and tighten the locking ring.
12. Check the drum for freedom of operation.
13. Fill the grease-injector cap with grease and screw in to the grease point.
14. Examine the glass bottle for dirt and damage; replace as necessary.
15. Examine the U-tube and cowl for dirt and damage, and for security of attachment.
16. Examine the bottle-sealing washer for serviceability; replace as necessary.
17. Examine the cork stopper for serviceability and security of attachment to the retaining chain.
18. Refit the vaporizer into the back-bar unit assembly.
19. Using a continuity test-set, or multimeter, check that there is electrical continuity between the drum-actuating lever, the cowl-operating plunger, and the vaporizer body.
20. Test the back-bar for leaks. See p. 94 for the back-bar tests.

Testing anaesthetic machines, ventilators and related equipment

Anaesthetic machines and ventilators should be tested in the room or area where the equipment is situated, if at all possible. Service personnel must wear accepted operating-room clothing in the surgical areas.

Contact the person responsible for operating-room equipment regarding the movement or servicing of any such equipment.

Anaesthetic machines

Tools and materials required

Normal service tools
Silicone grease
Light oil[1]
Service manuals
Watch with a second-hand
Spare parts

[1] Do not use ordinary oil (such as motor oil) to lubricate any parts that come into contact with oxygen.

Mercury sphygmomanometer
Anaesthetic gas analyser (if available)
Device for measuring flow, pressure and tidal volume

Testing procedure

If there is an official service manual, follow the steps outlined in it; otherwise, follow the procedure below (see Fig. 4.5, page 75).

- Check for leaks in the high-pressure system:
  1. Turn off all flowmeters, and disconnect any ancillary equipment such as ventilators and suckers.
  2. Turn on each cylinder in turn and allow the system to pressurize, then turn the cylinder off. Watch the pressure gauge; if the needle drops, there is a leak.
  3. Remove the covers and brush each joint, or suspect point, with soapy water. Do not forget to check inside the back of the pressure gauge. A leak will be indicated by the formation of bubbles. Do this for each cylinder in turn.
- Check the operation of each flowmeter. Make sure the control knob stays where it is set, and is not liable to be turned by mistake.
  1. Close all valves on the machine. Open all cylinder valves one full turn, noting any movement of the flowmeter floats. Float movement indicates a leaky flowmeter valve. If so, adjust the stop so that gas flow ceases 1/8 turn before the knob reaches the stop.
  2. Verify flowmeter accuracy ($\pm$ 2.5% full scale), with the measuring device connected to the common gas outlet.
  3. Check that the needle-valve stems are tight enough to remain where set unless deliberately turned by the operator.
- Check the low-pressure system, which is the part from the control knobs to the outlet.
  1. Check the top and bottom seals on the flow tubes with a low-pressure test.
     - Connect a mercury sphygmomanometer to the outlet.
     - Turn on the oxygen flowmeter very slowly.
     - Pressurize the back-bar to 30 mmHg (4 kPa). When this pressure is reached turn down the flow until the pressure on the gauge remains constant at 30 mmHg (4 kPa).
     - If the flow is less than 100 ml/min, it is acceptable; if it is greater than this, look for a leak.
  2. Check all the joints on the back-bar with a high-pressure test.
     - Pressurize the system to 150 mmHg (20 kPa).
     - Reduce the flow to maintain that pressure.
     - If the flow is 100 ml/ min or less, it is acceptable; if it is greater than this, look for a leak. Brush each suspect point with soapy water; bubbles will appear at the site of the leak.
- Check the correct operation of the oxygen-failure warning whistle (if fitted). Pressurize the intermediate system, turn off the supply, and open the oxygen-flowmeter valve to reduce the pressure slowly. The whistle should sound for a minimum of 10 seconds when the pressure falls to between 180 and 250 kPa. Check that the flow of nitrous oxide is cut off when the oxygen is turned off (if that system is fitted).
- Check the oxygen-flush valve. It should allow a flow greater than 35 litres/min, but not more than 75 litres/min (or as required by local regulations).

- If there are hoses for connection to a wall supply, check these. Check the oxygen flow from the oxygen flow tube when the oxygen probe is plugged in and the nitrous oxide disconnected. Similarly, when the nitrous oxide probe is plugged in and the oxygen disconnected, nitrous oxide must flow from the nitrous oxide flow tube, and nothing from the oxygen flow tube.
- Check the non-return valve on each of the yokes. Pressurize the system, turn off the cylinder, and remove it. There should be no gas leak. If there is a leak, look for the simple non-return valve in the yoke. Dismantle and clean the valve, then reassemble.
- If the anaesthetist has been having difficulty in getting patients to sleep, or waking them up, there may be a problem with the vaporizer. Inspect the mountings and connectors to ensure that they are secure and leak-free. When servicing vaporizers, be sure to keep them in an upright position when they contain liquid anaesthetic. To check the vaporizer, an anaesthetic gas analyser is required. Connect the gas analyser to the common gas outlet. Set the oxygen flow to 3 litres/min, and after zeroing the gas analyser with 100% oxygen, test each vaporizer at each full percentage setting. Determine that there is no concentration of gas when the vaporizers are in the "off" position. Replace any vaporizer for which the concentration is incorrect by more than 0.3% of the reading, or 10% of the measured value, whichever is greater. If an anaesthetic gas analyser is not available, you can only check (*a*) that the vaporizer is off when it is turned off, (*b*) that it gives an output when it is turned on again, and (*c*) that the concentration of gas increases as the control is turned up.
  Check that the control knob turns smoothly. Vaporizers should be returned to the manufacturers, or their agents, for checking every few years. The interval depends upon the model; some models need a check by the company only every 10 years.
- Check the smooth operation of the pressure gauges. The pointer should move smoothly and come to rest before the flow in the flow tube stops. If the movement is not smooth, lubricate the linkage in the back with silicone grease.
- Check the absorber. Check for smooth operation of the controls and for leaks. Change the filling if required.
- Check any other back-bar-mounted equipment.
- Check the output pressure of the regulators. This should be around 390 kPa (or as required by local regulations), and in any case should be about 35 kPa lower than the output pressure from the wall outlet.
- Check all flexible tubing on the machine.
- Check all attached equipment, such as suckers and blood pressure machines.
- Check the drawers, wheels, and the general frame of the machine. Lubricate lightly as required.
- Clean the machine.
- Tick off all tests on the service sheet, and sign it.
- Return the machine to the user. The doctor in charge should test it to make sure that it operates satisfactorily.

Ventilators

Tools and materials required

Normal service tools
Silicone grease
Light oil
Service manuals (if available)
Watch with a second-hand
Spare parts (if available)
Device for measuring flow, pressure and tidal volume

Testing procedure

It is of the utmost importance that all ventilators should work safely, since lives depend upon their correct operation. In addition, ventilators should **never** be used without a correctly adjusted alarm system, which gives a warning, and therefore protects the patient, in case of malfunction or disconnection.

If you do not have the service manual for your machine, make every effort to get one. Make sure a service manual is ordered with every new machine. Even without the manual, it is still possible to ensure that the machine is working correctly, but the proper spare parts must be available. Records are very important when maintaining ventilators and other life-support equipment. All reported faults, repairs, and service details should be noted down, dated, and signed. Machines should be serviced twice a year.

If you are called to look at a machine that has been reported as faulty, check first that it has been set up properly. Most reported faults are caused by operator error. When looking for a fault, start from the beginning. For example, is the electricity turned on? Is the gas on? Investigate the device in a planned manner, looking for the obvious things first. If you have doubts about the machine's safety or correct operation and you are unable to repair it on the spot, take it out of service. If there is no spare machine, the patient must be ventilated with a resuscitation bag while the machine is being repaired.

If it is not possible to repair a machine properly owing to a lack of spare parts, do not be tempted to carry out temporary repairs. Report the problem to the user, ask for the spares, and remove the machine from use.

Do not agree to put a machine back into service against your better judgement. If the personnel on the ward insist, get them to sign the service sheet (with the problem clearly stated).

Follow the steps outlined in the official service book. To carry out a service without the book, follow the steps outlined below:

1. Inspect the outside of the machine, including all tubing, connectors, and any bellows for damage. Replace as required. Lightly rub any antistatic tubing, or bellows, with silicone grease to prevent perishing.
2. Connect up to the electricity and gas supplies, as required. Put a stopper or test lung on the patient connector and start the machine running. Set the controls to normal settings. Watch that the operation is regular and smooth. Listen and check for any unusual noises. It is important to use the same regular settings in each test; in this way, you will get to know the normal movements and sounds of correct operation. Any unusual movements or sounds will alert you to possible problems.
3. Switch off and disconnect the machine from the mains. Remove the covers. Inspect any internal tubing or bellows, lightly rub any antistatic tubing or bellows with silicone grease to prevent perishing. Replace as required. Blow clean, and wipe the insides. If there are electronic circuit boards, check that they are secure and show no damage. Check for wear in any moving mechanical parts. Using a light motor oil, or similar, lightly lubricate any moving pivot points. Clean up any drips.
4. Start the machine running again, taking care not to touch any internal parts; watch any internal movements (bellows, lever, or valve movements) for smooth operation.
5. Try each control in turn and check that it does what is intended; for example, if the breath-rate control says that the machine will do 60 breaths per minute, this must be confirmed. With all these checks, a degree of common sense is

necessary. For example, do not worry if the breath-rate control says 60 and only 58 are delivered. Every machine has a margin of error. If the manual is not available, a degree of discretion should be used.

6. Check that the pressure gauge is accurate by comparing it with a test gauge.
7. Check the correct operation of all lights and indicators.
8. To check the correct operation of the oxygen mixer, an oxygen analyser is needed. If your department does not have one, ask the Anaesthetic Department to provide such an instrument. Note down on the service sheet the output results from 21% to 100%.
9. Check the alarm system.
10. Run the machine again on the normal settings and check that it is still working correctly.
11. If it is a machine that uses electricity, give it a safety check.
12. Fill out the service check-sheet, and sign it.

As you gain more experience in servicing, you will get to know which errors are minor, and can be allowed, and which are unacceptable. For example, an oxygen mixer on a paediatric ventilator **must not** give higher levels of inspired oxygen than indicated. This is because very serious damage can be done to the infant's eyes as a result.

Return the machine to the user; the doctor in charge should test it to ensure that it operates satisfactorily.

Ventilator bellows

Mechanical integrity

Inspect the bellows housing and base for cracks, chips, etc. Check the tubing and control knobs for tightness.

Over-pressure valve

Check the valve, located on the scavenging tee at the back of the control unit, for cleanliness and operation.

Pop-off valve

Remove the housing, bellows, and pop-off valve from the base. Check that the pop-off valve, glass disc, and seat are clean and dry, and that the retaining screw is tight.

Bellows flexibility

Reassemble the ventilator and connect the test gauge to the common gas outlet. Inflate the bellows to 0.1 litre. If the pressure is above 1.75 cm water (1.3 mm Hg) then the bellows should be replaced.

Bellows pressure (low)

Connect the device for measuring pressure to the common gas outlet, open the oxygen flowmeter to 300 ml/min, and allow the bellows to rise to the top. The pressure should be less than 2.5 cm water (1.84 mm Hg or equivalent on the gauge in use), and the bellows should remain full. If the bellows do not remain up, or the pressure exceeds 2.5 cm water, then refer to the ventilator service manual for the necessary repairs.

Bellows pressure (high)

Connect the common gas outlet to the driving gas port on the bellows, and plug the bellows outlet. Pressurize the outside of the bellows to just above 60 cm water

(44 mm Hg) and maintain an oxygen flow of 300 ml/min. The pressure gauge should settle at or above 60 cm water. If the pressure drops below 60 cm water, refer to the ventilator service manual for the necessary repairs.

Ventilator controller

Low-oxygen-supply alarm

Check that the low-oxygen alarm activates before the supply pressure to the ventilator drops below 250 kPa, and resets when the pressure reaches 320 kPa.

Low-airway-pressure alarm

Check that the alarm activates if the pressure measured at the patient port remains below 7 cm water (5 mmHg or equivalent on the gauge in use) for between 20 and 30 seconds.

Safety valve

Check that the relief valve opens when the pressure in the patient circuit exceeds 65–75 cm water (48–55 mmHg or equivalent on the gauge in use).

Flow delivery

Set the ventilator as follows:

minute volume	10
rate	10
inspiratory: expiratory (I:E) ratio	1:1

Start the ventilator; the tidal volume measured with a spirometer, or ventilator tester, should be between 0.9 and 1.1 litres/min. If it is not, first check the rate with a stopwatch and adjust if necessary. Check the I:E ratio with a stopwatch at a very low rate, and adjust if necessary. After confirming that both are correct, reset the ventilator to the above settings and adjust the minute volume to give a 1 litre tidal volume.

Absorbers

Canister

Check for cracks and chips, and check gaskets. Replace as necessary.

Inspiratory and expiratory valves

Inspect the inspiratory and expiratory valves for cleanliness, and for bent or chipped discs.

Bag/ventilator switch (if fitted)

Inspect the valve, clean, and lubricate with silicone grease, as necessary, to maintain free action.

Relief valve

Inspect, clean, and lubricate screw-threads with silicone grease. Check that when the valve is fully open a maximum pressure of 0.3 kPa (2.5 mm Hg) is maintained in the system with the oxygen flowmeter opened to flood measured with the device for measuring flow, pressure and tidal volume at the bag connector.

Drain valve

Inspect and clean as necessary.

Elevating assembly

Check that the push-button operates smoothly; raise and lower the assembly several times to check operation. If it does not operate smoothly, disassemble and clean with alcohol. **Do not lubricate.**

Compound pressure gauge

Test the patient pressure gauge for zero setting and accuracy ($\pm$ 5% of reading) with the pressure-measuring device attached to the bag connector. Calibrate, if necessary, with the adjusting screw located under the plug-screw, inside the absorber head, beneath the screen.

Pressure regulators (reducing valves) and flowmeters

The pressure regulator, or reducing valve, as the name suggests, is used to reduce the pressure of a gas from the cylinder pressure to a pressure that is safe for subsequent delivery to a patient. For example, in the case of oxygen, it is from 14 300 to 420 kPa. A flowmeter can be attached to the regulator to allow a given flow to be set. These assemblies are most common on anaesthetic machines, or on an oxygen therapy unit attached to the top of a gas cylinder.

When used in oxygen therapy[1], there are three parts to the unit:

- a gauge showing the pressure of the contents of the cylinder,
- a regulator to reduce the pressure,
- a flowmeter that indicates the selected flow.

There are a number of different designs of regulator, but generally each unit has one inlet (from the cylinder) and three outlets, one to the pressure gauge, one to the flowmeter, and one to the blow-off valve. It is important to know which one is meant to be connected to the pressure gauge: do not connect any other part to this outlet.

While the proper checking of pressure regulators requires some special test equipment, most problems can be overcome with very little equipment.

Remember that the flow tube is under regulator pressure. Do not unscrew it before the cylinder is turned off and the pressure released.

Setting the output pressure

Make sure that the cylinder contents gauge and the safety valve are connected to the regulator, remove the flowmeter and fit in its place a 0–700 kPa pressure gauge. Connect the regulator to the gas cylinder, and turn on the gas. The test pressure gauge should show a reading of 420 kPa. This is the correct pressure for an oxygen therapy regulator and flowmeter. If it is not 420 kPa, adjust with a socket head key until it is correct. If you are adjusting the pressure downwards, you must release the pressure from the test gauge, turn the adjusting screw out,

[1]Do not use any oil when repairing oxygen regulators. If you use PTFE or plumbers' tape, you should use only special de-greased tape.

reconnect the test gauge, and adjust the pressure up to 420 kPa. On most makes, the adjustment screw will be found at the end of the piece which sticks out at the front; it may be covered with a sticky label.

At this pressure, it should be possible to obtain a flow of up to 55 litres/min out of the unit; this is called the flush flow. In some places, the regulator is not set for pressure but adjusted for a given flow with the control wide open; check what is required before adjusting the setting.

For a regulator attached to an anaesthetic machine, adjust the pressure to about 390 kPa (30 kPa lower than the pressure from the pipeline supply to the machine).

Testing a regulator and flowmeter unit

1. Check for leaks.
2. Check that the pointer on the gauge works smoothly and reaches the stop before the flow falls to zero.
3. Check that the flow goes to its full rate.

Faults

- If a leak is suspected, check as follows:
  - With the flowmeter unit turned off, turn on the gas and allow the pressure to rise. Turn off the gas supply.
  - The system is now pressurized to the full cylinder pressure, but with a very small volume.
  - If there is any leak, the gauge will show a fall in pressure; the bigger the leak the faster the fall.
  - If the pressure falls, brush the unit with soapy water; any leaks will show up as small bubbles.
  - Do not forget to check inside the back of the gauge.
- Leaks around the bull-nose connector are usually caused by a faulty O-ring. Replace the ring.
- Leaks at the blow-off valve:
  - First, check that the regulator is set to the correct output pressure.
  - If the pressure rises to more than it should, yet the regulator is set to the correct output pressure, there is a faulty valve seat (a problem called "creep"). Replace the valve seat.

  The blow-off valve should normally go off at about 640 kPa.
- If the flowmeter makes a popping noise when the flow is turned on ("motor boating"), there is probably dirt inside the valve; the noise may also be caused by a faulty valve seat.
- Low flows: unscrew the needle valve and check that it is clean and undamaged.
- If the ball, or bobbin, shows a small flow even when the unit is turned off, check the flow tube for leaks.
- If the gauge needle does not drop smoothly, remove the back of the gauge and lubricate the movement of the gauge with a light watch oil. Use of oil is acceptable in this case, as there is no oxygen flowing in this part.
- If there is no flow, even when the gauge shows that there is gas in the cylinder, this suggests that the gauge needle is stuck. Check the movement in the back of the gauge, or reposition the needle on the shaft.

Unregulated flowmeters, in which the flowmeter is connected directly to the gas cylinder, are dangerous and should not be used.

Oxygen analysers

Inspection and calibration

Visually inspect the cables and the display unit for signs of wear or deterioration. Check that the sensor membrane is not nicked or otherwise damaged, and that the O-ring seal is intact. Test the calibration by first placing the sensor in a T-adaptor, in a verified 100% oxygen line, and allow the readings to stabilize. If, after 3 minutes, the display has not stabilized, replace the sensor. If it has stabilized, adjust the CAL knob, if necessary, so that the display registers 100%. Remove the sensor from the T-adaptor and expose to room air. A reading of 21% ($\pm$ 2%) should be displayed within 1 minute. If a correct reading is not displayed, replace the sensor.