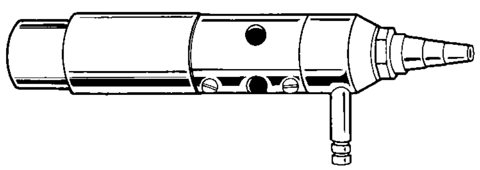
be rotated to a smaller hole, resulting in a higher oxygen concentration being delivered to the patient because less air is taken in. If the disc is turned to 100, the patient will receive 100% oxygen, as there is no inlet for air. Once the disc has been set, the patient will receive a gas mixture with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

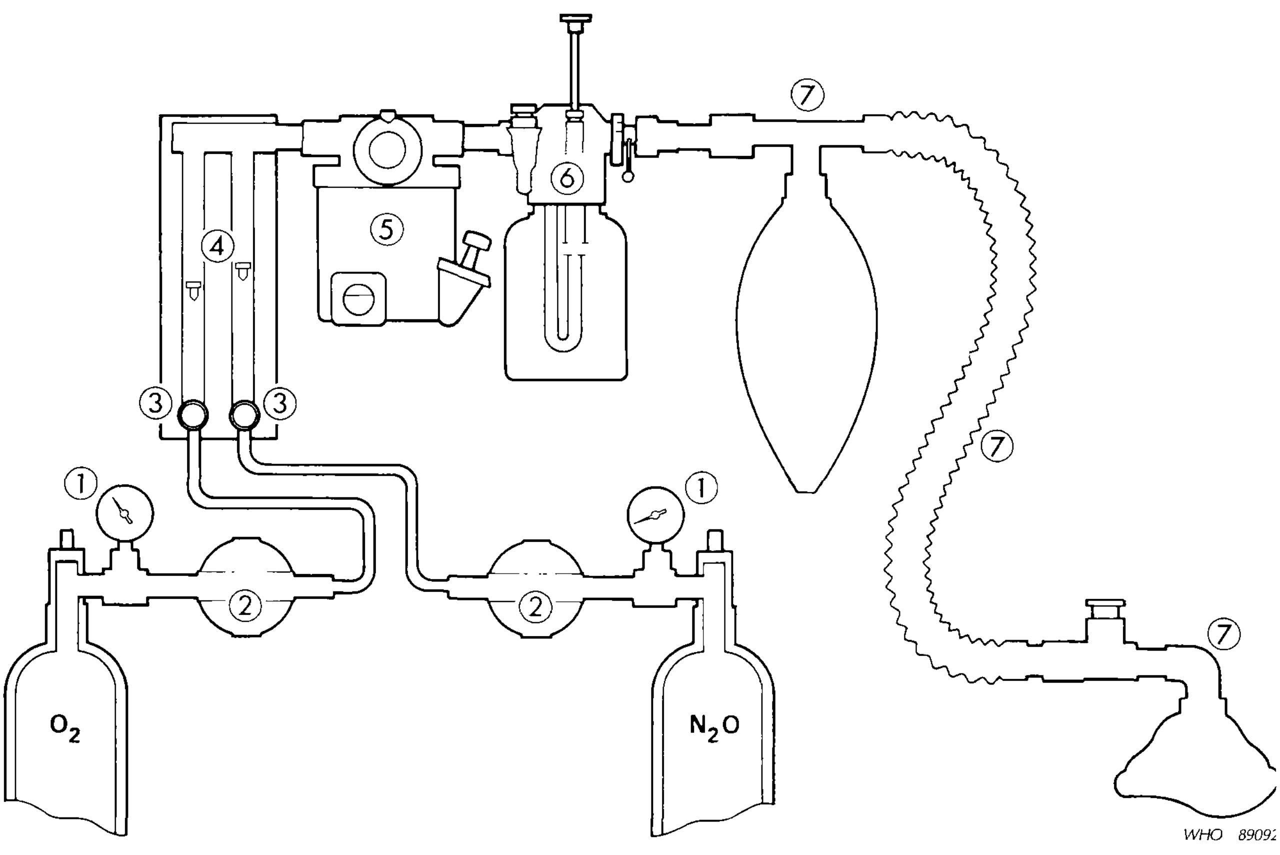
Remember, ether and oxygen mixed in air form an explosive mixture. When testing an entrainer, it is safer to fix it to an empty EMO or carry out the test in a well-ventilated area.

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.

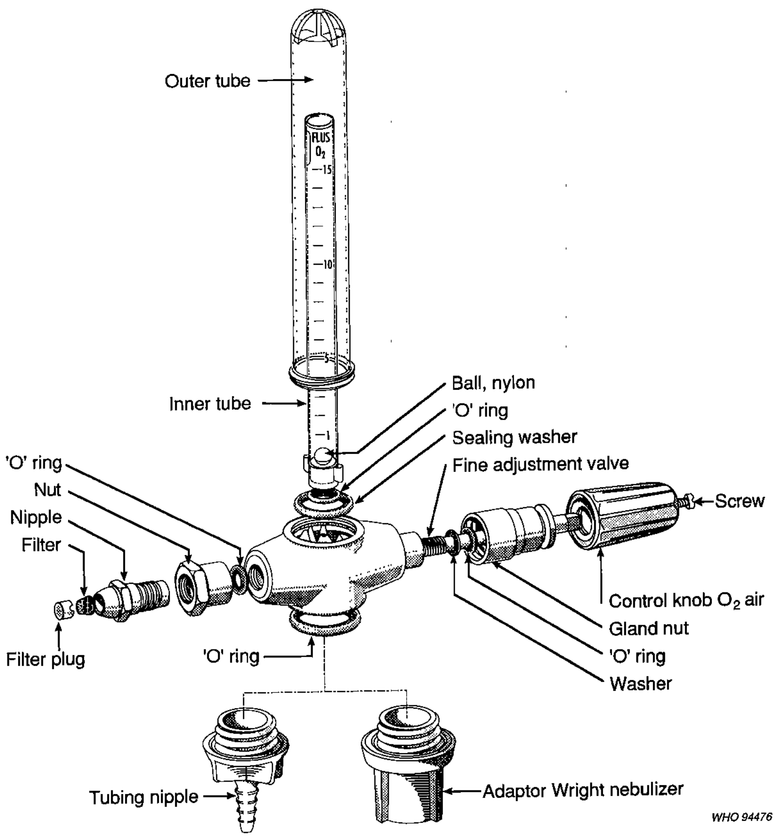
Fig. 4.5. Gas pathway on a continuous-flow (Boyle's) machine with a compressed gas supply: (1) pressure gauges, (2) reducing valves, (3) flow-control (needle) valves, (4) rotameters, (5) calibrated vaporizer, (6) Boyle's bottle, (7) Magill breathing system.



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.