DRY DISPLACEMENT GAS METERS

BY

A. P. ADAMS,* M. D. A. VICKERS, J. P. MUNROE† AND C. W. PARKER
Anaesthetic Department, Royal Postgraduate Medical School, Hammersmith Hospital, London, and Meter Testing Department, North Thames Gas Board, Willesden, London

SUMMARY

The development, working, testing and calibration of the dry displacement gas meter is described. Three models in current use in our laboratory have been tested before and after mechanical overhaul. The dry gas meter is cheap, robust, and accurate enough for measuring gas volumes in most applications.

Anaesthetists are naturally interested in the measurement of gas volumes. Of the instruments used for this, gas meters seem to have been inadequately evaluated, particularly for accurate work. Wet gas meters are heavy, need to work on an accurately levelled surface and be correctly filled with water. Under suitable conditions they are very accurate, particularly at low flow rates. Dry gas meters are more convenient but have been held to be less accurate (Krogh, 1920). Their use in common anaesthetic circuits has been described by Cooper (1959).

The accuracy of domestic gas meters is controlled by statute and Area Gas Boards expect to maintain an accuracy of ±2 per cent under specified conditions. This is more than adequate for most applications in anaesthesia. However, the ease with which they can be read may disguise serious errors and we are probably not alone, therefore, in being concerned with the problems of calibration and usage.

DEVELOPMENT OF GAS METERS

The development of the gas meter parallels the growth of the gas industry which started with the commercial production of town gas in the early nineteenth century. Frederick Albert Winson first organized the distribution of gas in leaden pipes to illuminate one side of Pall Mall on January 28, 1807 (Norman, 1922). The preparation and sale of town gas as a public utility started in 1812 with the sole object of providing artificial illumination (Stewart, 1958).

Initially gas was sold by contract and depended on estimating the number of hours of consumption through lights or burners of a given size. The capacity of meters was originally rated by the number of "lights" they could support. The first suggestion of selling gas by measure was made by Samuel Clegg in 1815. In that year he invented a rotating gas holder which was in fact a volumetric wet gas meter (Gilbert, 1948). These wet meters had many disadvantages. The water was subject to freezing in winter and evaporation in summer and frequent maintenance was necessary, causing inconvenience to both consumer and supplier. In 1820 John Malam patented the first dry meter, and in 1843 William Richards produced a dry meter with two diaphragms, two slide valves and a dial which was the prototype of modern meters (Chandler and Lacey, 1949; Norman, 1922).

In 1840 meters were generally adopted by the London and Westminster Gas Light and Coke Company (Norman 1922). The Gas Act of 1847 allowed gas suppliers to let meters to consumers if desired, but it was not until 1859 that volumetric measurement became the official basis of charge. At that time standards of meter performance were first laid down and since then all meters must be officially inspected, and are stamped if the standards are met. The Gas Regulation Act of 1920 first included the calorific value of the gas in the basis of charge, and the regulations are much the same today, being incorporated in the Gas (Meter) Regulations of 1949 (Statutory Instruments—Gas, No. 790).

* In receipt of a grant from the Wellcome Trust.
† McLaughlin Travelling Fellow, Vancouver General Hospital, Vancouver, B.C.
The first meters had large-bore inlet and outlet connections but were throttled internally by small gasways. Once these were improved the capacity of the meter increased without a concomitant increase in size. Cast iron meters soon gave way to tin which was the mainstay of construction until recently. Most domestic models now being produced are of unit-construction with a casing of plastic or drawn steel. Friction has been reduced by the use of modern synthetic materials which do not need lubrication for the moving parts. The older reciprocating slide valve has been largely superseded by a more mechanically efficient radial pivoted valve. It is interesting that this latter form of valve action was patented in 1875 but the original company failed through lack of support (Gilbert, 1948).

PRINCIPLES OF THE WORKING MECHANISM

A gas meter is a motor whose whole mechanism is driven by the pressure of the gas which is being measured. The energy is supplied by the difference between the inlet and outlet gas pressures. The design aims to keep this pressure loss small and constant.

A horizontal plate, the valve plate, divides the meter into two compartments, the upper of which is called the valve chamber and receives the incoming gas (fig. 1). The space below the valve plate is divided by a vertical division plate into two sections which are identical in construction and operation. On each side of the division plate a bellows is formed by a metal disc surmounted by a leather diaphragm. The diaphragms are usually made from East Indian sheepskin treated with special oils. The bellows together with the space between it and the meter casing on that side comprise two separate measuring chambers. These are in communication with the valve chamber through two sets of ports in the valve plate which form the valve seatings (fig. 2). There are three ports to each set and these take the form of a grid. The inner port of each side connects to the inside of the bellows beneath it and the outer port of each side connects to the corresponding outer measuring chamber. The centre or outlet port of each side of the meter is connected by a duct called the trouser to a common outlet pipe.

The valve cover has a central dome and two flat lateral wings and its dimensions are such that in the dead-centre position the dome exactly covers the outlet port while the wings cover the
inner and outer measuring ports. By sliding to and fro over its seating the valve alternately connects the outlet port with one of the two measuring ports via the dome, and simultaneously exposes the other measuring port to the incoming gas. The outlet port cannot be exposed to the inlet gases in the valve chamber, and gas must first pass through one of the measuring ports to a measuring chamber before it can return at a later part of the cycle under the domed portion of the valve cover and escape to the outlet. Each bellows, controlled by a guide or motion rod to prevent any tendency for either side of the diaphragm to lead during its movement, is attached by a hinge, the flag, to flag rods that pass up into the valve chamber through stuffing boxes or grease seals. These prevent the escape of gas but allow the flag rods to turn freely and transfer the motion by swivel-jointed connecting links (flag arms) to the tangent. The tangent is a lever fixed to a vertical crankshaft. The flag arms of the two sides of the meter are joined together and connected to the tangent by an adjustable tangent pin. When the tangent is revolved by the action of the flag arms the crank revolves with it. Pivoted on the crank are swivel-jointed valve arms, one to each valve cover. The movement of the bellows is thus converted to a circular motion of the crankshaft, and to a push-and-pull action of the valve arms. The valve covers are pivoted at one end and this motion of the valve arms results in a reciprocating radial action of the covers over their seatings.

Let us consider the movement of the left half of the meter in figure 3. Gas from the valve chamber enters the inner measuring chamber through the inner port which is uncovered, and the movement of the bellows outwards causes gas in the corresponding outer measuring chamber to be discharged through the outer port, under the dome of the valve cover, and through the centre port to the outlet pipe (fig. 3A). The movement of the bellows is conveyed by the linkages to the valve covers so that when the bellows is full the valve cover has moved over its seating to the dead-centre position where all ports of this valve are closed (fig. 3B). Further movement of the valve cover over its seating allows incoming gas to pass through the now uncovered outer port into the outer measuring chamber. This now compresses the bellows whose contained gas is discharged through the inner port, under the valve cover, and through the centre port to the outlet pipe (fig. 3C). When the filling of the outer chamber is completed the diaphragm is again reversing at the end of its stroke and the linkages will once again have moved the valve to the dead-centre position (fig. 3D).

**FIG. 3**
Mechanical sequence of the diaphragms and valves in the working of a dry meter.

It can be seen from figure 3 that the movement of the two sides of the meter are 90 degrees out of phase (a quarter of a cycle). Because the movements of the two sides are linked at the tangent this arrangement ensures that whenever a component of one side of the meter is stationary the corresponding component on the other side is moving with maximal velocity. This ensures that the flow of gas through the meter is uninterrupted. The phase difference between the two sides is achieved by arranging the valves at an angle of 45 degrees to a line drawn through the centre of the meter which gives an advance of one valve over the other of 90 degrees. Thus the bellows are never both full nor both empty at the same time and except at dead-centre both sides of the meter pass gas at the same time, although the resulting gasway is in fact only equivalent in area to one fully open port.
The radius of the circle described by the tangent pin is proportional to the movement of the diaphragms. The tangent pin can be shifted along the tangent to alter the radius which changes the stroke of the diaphragms causing a greater or lesser quantity of gas to be displaced per stroke. One revolution of the tangent represents a complete cycle of the system. A worm on the crankshaft gears into a toothed wheel to which is attached the index spindle. This gearing determines the number of revolutions of the crank to one revolution of the index spindle. In some designs a back plate divides the tangent, flag arms and rods from the rest of the valve mechanism and it is then possible to open the meter to adjust the tangent without breaking the gastight seal.

The above description relates in principle to practically all modern English dry meters. It should be mentioned, however, that in the Swedish Nordgas meter the valves are arranged in parallel, the covers being moved over their seatings on a straight push-and-pull arrangement. The crankshaft is placed transversely with a crank at each end of the shaft. The cranks are 90 degrees out of phase. The flag arms of each side are linked to the opposite crank, and adjustment is made independently to each side of the meter by altering the length of this link by a screw thread.

**METER TESTING**

Every meter is embossed by the manufacturer with his name, an identification number, the month and year of manufacture, the maximum hourly capacity of the meter and the volume passed for one revolution of the tangent. This information constitutes the “badge”. The meter is then sent to a Ministry of Power testing station and if it conforms to the statutory regulations a red seal is fixed to the index casing. This constitutes the “stamp”. Test meters in which the pointer can be altered are not stamped. The regulations allow meters to be tested with either gas or air, but at the official testing stations air is always used for reasons of safety and convenience. The permitted standards which are chosen have been arrived at bearing in mind that the meter will in practice be driven by town gas, which has a density of approximately half that of air.

The testing procedures employed cannot all be duplicated in the laboratory, but an understanding of their principles will enable comparable tests to be devised. The test procedures may be viewed as coming under three headings: testing for leaks, testing for resistance, and volume calibration.

**Leaks.**

These may be external or internal. To detect external leaks the meter is subjected to an internal pressure of 20 in. (50.8 cm) water pressure. The inlet and outlet pipes are closed and the meter is left in communication with a manometer. The meter is accepted as sound if the liquid level in the manometer remains constant for 2 minutes.

Such a test will not detect leaks between various chambers which may be due to fissures in the diaphragms, or to slip at dirty valves. These leaks allow gas to pass through the meter without actuating the mechanism. The diaphragms are tested at the time of assembly to withstand a pressure of approximately 15 in. (38.1 cm) water and can be expected to maintain their soundness for many years. Small leaks may only be detectable at low flows, and meters of the capacity encountered in medical work (under 400 cu. ft./hr, 11,327 l./hr) should register flows of 0.5 cu.ft/hr. which is approximately 240 ml/min. The flow is controlled at the meter outlet pipe by a governed orifice disc which has been previously calibrated against a wet displacement test meter. High accuracy is not expected at these extremely low flows but a meter which fails to perform a complete revolution of the tangent when 1½ times the tangent volume has passed at this rate is judged to be passing unregistered gas. It is possible for the medical user to detect the passing of unregistered gas through internal leaks by connecting the meter to an oxygen flowmeter delivering about 250 ml/min for long enough to deliver the volume needed for 1½ revolutions of the tangent.

**Resistances.**

Some resistance is inevitable in the design of the meter but additional resistance develops as a result of deterioration. Any resistance must increase the pressure in at least one of the measuring chambers which will then contain more gas than its apparent volume and the meter will register slow.

The dimensions of the gasways and valve ports determine the inevitable resistance which varies
with the gas flow. The domestic meter is required by statute to be tested at its maximum rated capacity and should pass this flow without the pressure drop across it exceeding 0.5 in. (1.27 cm) water gauge. A test holder provides the flow, which is regulated by a tap on the outlet side of the meter. A test holder is a calibrated gas holder automatically counterbalanced to ensure that the gas within it is at a constant pressure at all levels of the bell. The pressure drop across the meter is measured with an inclined-plane liquid manometer filled with n-dibutyl oxalate (specific gravity 0.988) coloured with Sudan III. The slope of the manometer tube allows these low pressures to be read accurately (fig. 4).

Resistances due to deterioration may be caused by hardening and shrinkage of the leather diaphragms, by wear in the gears and bearings and by dirt in the valve mechanism. Such resistances may occur only in certain parts of the mechanical cycle and cause an oscillation in the pressure drop across the meter. They show up readily on the inclined-plane manometer during the standard test for resistance. (By statute the amplitude of the oscillation must be less than 0.3 in. (0.76 cm) when measured “single-ended” at the outlet.)

Although measuring the pressure drop will present no problem in the medical laboratory, obtaining a test flow equal to the maximum capacity may present problems unless a Rotameter of at least 100 l./min capacity and an air blower are available. If, however, the meter is used solely at flows well below the badged capacity (for example for measuring volumes from collecting bags) it would be permissible to measure the resistance at the fastest rate at which it is to be used, and should be less than 0.75 cm water pressure.

### Volume calibration.

By Act of Parliament meters must register within 2 per cent more or 3 per cent less than the actual quantity passed. The test must be performed at the maximum badged capacity at room temperature and during the test the temperature of the water in the test holder and that of the room must not differ by more than $2^\circ F$ ($0.71^\circ C$). During manufacture the tangent is adjusted by trial and error before the meter is sealed by drawing air through the open meter into the calibrated holder. The tangent has to be set slightly slow to compensate for the fact that pressures in the test system are subatmospheric under these conditions but will be above atmospheric in use. At this stage the meter can be set to an accuracy of ±1 per cent if required. When the meter has been sealed it is calibrated with at least 2 cu.ft (56.6 l.) of air at a pressure of 2 in. (5.1 cm) water at the maximum rated capacity, the flow coming from a counterbalanced calibrated test holder. The holder has been calibrated by water displacement from a Standard cubic foot bottle. The Standard cubic foot bottle contains 62.2882 lb. (avoir.) of distilled water, weighed in air at 62°F and 30 in. mercury barometric pressure.

Area Gas Boards set higher standards than the statutory requirements and require meters to read within ±2 per cent of the true volume, not only at maximum capacity but also at 10 per cent of this flow. Medical users who have their meters tested by Area Gas Board meter departments can expect this level of volumetric accuracy.

Checking the volumetric accuracy presents problems in the medical laboratory unless one has an accurately calibrated spirometer which can pass 60 l. of air at a flow of 100 l./min at a constant pressure of 5 cm H$_2$O. If one already has a correctly calibrated meter it is permissible to calibrate another one “in line” with it. Naturally the errors of the two meters may be additive. However, no additional errors need be expected if the two are compared at 10 per cent of rated capacity and at the highest flow that does not
cause an unacceptable pressure loss provided, that is, that it is subsequently used only between these flows.

Attempting to calibrate a gas meter by water displacement methods cannot be recommended. Water displacement from one jar to another can rarely produce an adequate flow, the pressure head does not remain constant and insufficient volume can be passed to average out enough cycles of the tangent. Volumetric calibration should be performed with at least 2 cu.ft (56.6 l.) of air, and jars of this capacity full of water are not easily managed. Our original attempts to apply this method gave results which professional testing subsequently revealed to be seriously in error.

THE PERFORMANCE OF THREE METERS
(evaluated by C. W. Parker)

Three meters which had been in use for several years were subjected to the statutory tests for pressure absorption and registration. None of the meters was badged, and information as to capacity had to be sought from the manufacturers. As can be seen from table I all three would have been rejected by the Ministry of Power. They were then completely overhauled by the meter department of the North Thames Gas Board. The valves and gratings were cleaned and rebuffed, the linkages and gears were lubricated and the leather diaphragms redressed. The tests were then repeated.

![Fig. 5](image)

Registration errors for four meters (A, B, C, D) measured with 2 cu. ft (56.6 l.) of air from a test holder at flow rates from 5 l./min up to maximum capacity at 10 l./min increments.

**Meter A (Parkinson Cowan Type CDI).** The error in registration was now within 1 per cent for flow rates up to 55 l./min (fig. 5, line A). Poor performance at higher flows was also reflected in excessive pressure loss at maximum capacity (fig. 6, line A).

**Meter B (Parkinson Cowan Type CDI).** The registration of this meter was now exceptionally constant over the entire range of flow. Pressure absorption was less than that quoted by the manufacturers (figs. 5 and 6, line B).

**Meter C (Nordgas Ventilation Gas Meter U2½/D.10).** Diaphragms were not redressed because

<table>
<thead>
<tr>
<th>Meter</th>
<th>At maximum capacity</th>
<th>At 10% of capacity</th>
<th>Pressure absorption</th>
<th>Comment and faults found</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>2.9% fast</td>
<td>10.6% fast</td>
<td>Excessive</td>
<td>(1) Two out of three fixing points of index housing adrift</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(2) Index spindle out of alignment</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(3) Front flag touching panel of meter</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(4) Top flag arms unequally divided</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(5) Commencement of outlet pipe was found to be restricted</td>
</tr>
<tr>
<td>B</td>
<td>1.1% fast</td>
<td>7.3% fast</td>
<td>Satisfactory</td>
<td>No faults found</td>
</tr>
<tr>
<td>C</td>
<td>4.3% slow</td>
<td>0.6% fast</td>
<td>Excessive</td>
<td>No access possible to leather diaphragms (see text)</td>
</tr>
</tbody>
</table>

A = Parkinson Cowan, type CDI.
B = Parkinson Cowan, type CDI.
C = Nordgas Ventilation Gas Meter, type U2½/D.10.
## TABLE II

*Data for some commercially available dry gas meters.*

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Maker's description</th>
<th>Maximum capacity l./hr</th>
<th>Capacity l./min (approx.)</th>
<th>Per rev. of tangent (l.)</th>
<th>Per rev. over dial (l.)</th>
<th>Cost (approx.) (£)</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thomas Glover &amp; Co. Ltd., Gothic Works, Angel Road, Edmonton, London, N.I8</td>
<td>Test meter</td>
<td>2,500</td>
<td>42</td>
<td>2.5</td>
<td>5</td>
<td>20</td>
<td>Very clear 7 in dial calibrated to 0.1 l. on front of meter. Subsidiary dial inset to count up revolutions to 100 l. Backplate models supplied if desired.</td>
</tr>
<tr>
<td>United Gas Industries Ltd., 170 Rowan Road, Streatham Vale, London, S.W.16</td>
<td>D1 Test meter</td>
<td>4,000</td>
<td>70</td>
<td>2</td>
<td>20</td>
<td>18</td>
<td>1.9 cm (3/4 in.) or 2.54 cm (1 in.) connections</td>
</tr>
<tr>
<td></td>
<td>D2 Test meter</td>
<td>8,000</td>
<td>130</td>
<td>4</td>
<td>20</td>
<td>25</td>
<td>2.54 cm (1 in.) or 3.18 cm (11/4 in.) connections</td>
</tr>
<tr>
<td></td>
<td>D4 Test meter</td>
<td>12,000</td>
<td>200</td>
<td>8</td>
<td>20</td>
<td>30</td>
<td>8.18 cm (11/4 in.) or 3.81 cm (11/4 in.) connections</td>
</tr>
<tr>
<td>Most manufacturers</td>
<td>D.07</td>
<td>10,000</td>
<td>160</td>
<td>2</td>
<td>50</td>
<td>30—35</td>
<td>New unit construction domestic meter. Meters will convert for medical use by adding large test dial. Specify two pipe connection.</td>
</tr>
<tr>
<td>Parkinson Cowan Ltd., Talbot Road, Stretford, Manchester</td>
<td>D1 Test meter</td>
<td>5,000</td>
<td>83</td>
<td>2.5</td>
<td>50</td>
<td>31</td>
<td>2.54 cm (1 in.) connections. Incorporates rev. counter</td>
</tr>
<tr>
<td></td>
<td>D4 Lab. Test meter</td>
<td>10,000</td>
<td>160</td>
<td>10</td>
<td>50</td>
<td>66</td>
<td>3.81 cm (11/4 in.) connections. Incorporates rev. counter</td>
</tr>
<tr>
<td></td>
<td>CD1 meter</td>
<td>6,000</td>
<td>100</td>
<td>2.5</td>
<td>10</td>
<td>53</td>
<td>Dial revolves past stationary pointer which can be reset. 2.22 cm (3/4 in.) inlet connection. Outlet fitted with removable non-return rubber flap valve. Brass inlet pipe (to condense water vapour) fitted with drain tap. No way of counting revs.</td>
</tr>
<tr>
<td></td>
<td>CD4 meter</td>
<td>11,000</td>
<td>180</td>
<td>10</td>
<td>10</td>
<td>64</td>
<td>3.18 cm (11/2 in.) connections. Small subsidiary dial registers up to 100 l.</td>
</tr>
<tr>
<td>Akiebolaget Nordgas, Kronobergs gatan 21, Stockholm, Sweden (U.K. distributors Cape Engineering Ltd., Warwick)</td>
<td>U2½/D.10 Ventilator Model</td>
<td>4,500</td>
<td>75</td>
<td>4</td>
<td>10</td>
<td>31</td>
<td>No rev. counter</td>
</tr>
<tr>
<td></td>
<td>D.10/U2½ Research Model</td>
<td>4,500</td>
<td>75</td>
<td>4</td>
<td>10</td>
<td>55</td>
<td>Resettable rev. counter</td>
</tr>
</tbody>
</table>

Pressure cast aluminium; unit construction meters. Large dial on front of meter. 1.9 cm (3/4 in.) connections. Must be returned to Sweden for servicing.
access to the measuring chambers necessitated special tools which were not available. The servicing of the bearings and valves improved the registration somewhat but unacceptable errors remained (fig. 5, line c). A new model of a similar meter (D.10/U21—see table II) was tested and found to be satisfactory (fig. 5, line d).

It will be noted that even after servicing the two CDI meters did not perform similarly. Meter B gave a very steady registration error and this might have been improved by reopening the casing and adjusting the tangent. Meter A had deteriorated beyond the point at which overhaul could restore the stated specification (±0.5 per cent) and should possibly have been serviced much earlier. It would still pass the statutory tests for a domestic meter. Meter C would fail the statutory tests for performance but it must be remembered that it had been in use for some time and the diaphragms were not redressed.

To evaluate the accuracy of meters for intermittent flow a man exhaled through a non-return valve into meter B and thence into a perfectly balanced test holder to a total volume of 50 l. The test was repeated six times. The result was within 1 per cent of the calibrated error for continuous flows on each occasion.

**DISCUSSION**

It will be apparent that gas meters are very accurate if they are correctly calibrated and used; ±0.5 per cent can be achieved when the conditions of use are the same as those of calibration. For any flow between 10 and 100 per cent of maximum rated capacity an accuracy of ±1 per cent is possible. These figures refer to the accuracy that is achieved after several complete cycles of the mechanism. "Within-cycle" measuring errors can be caused by irregularities in the mechanism, but the structure and function of gas meters ensures that equal but opposite errors occur in another phase of the cycle, so that the overall accuracy is regained at the end of any complete cycle. Such "within-cycle" errors appear to be quite large when expressed as a percentage of the volume of one cycle or even when expressed as a percentage of the dial reading, since this is usually only a few cycles in medical meters. These errors become progressively less significant as the volume measured increases. A "within-cycle" error greater than 5 per cent of the cycle volume is unlikely in a well-maintained meter, since these errors are largely a function of the condition of the diaphragms and their linkages. After ten cycles such an error is only 0.5 per cent of the total volume; 2.5 l, being a usual cycle volume, 25 l. represents the total measured volume that attains this level of accuracy.

If volumes smaller than this are to be measured with comparable accuracy, the dial must be calibrated for these "within-cycle" errors. For this it is essential to know how many revolutions of the tangent correspond to one sweep of the dial, or spurious corrections may be attempted. A 2.5 l. cycle geared to a 10 l. dial must result in correct registration at the completion of each quadrant of the dial, unless there are faults in the gearing of the tangent to the pointer. After such calibration the pointer cannot be moved relative to the mechanism without invalidating the calibration. If one uses the facility of setting the pointer to zero one must accept the dial reading as correct and this implies that a volume large enough to minimize "within-cycle" errors must be measured. The accuracy with which the meter can be read depends both on the diameter of the dial and the volume represented by one revolution. This latter depends on the gearing ratio between the tangent and the pointer. The higher this ratio the more difficult it is to discriminate small volumes. Lowering the gearing, however, progressively in-

![FIG. 6](image)

Pressure absorption for three meters (A, B, C) tested with air. Curve D is the maker's specification for a new meter identical with meters A and B. Curve E is the maker's specification for the new unit construction type domestic meter (D.07) for comparison.
creases the need for counting the complete revolutions of the pointer when measuring large volumes. A compromise must be struck in terms of the volumes likely to be measured and the accuracy required. The relevant data for some commercially available meters can be found in table II.

**Correction factors.**

If gas is forced through a meter faster than its rated capacity there will be an excessive pressure absorption and the meter will under-read. At normal atmospheric pressure, an increase of 10 cm water pressure will cause a reduction in volume of approximately 1 per cent. For this reason one should use a meter which has a rated maximum capacity in excess of the flow rate likely to be encountered in the conditions of use. If the meter is to be coupled directly to a patient's exhalations it should pass the peak flow rate.

The meter reading may need to be corrected if the meter is used at a different temperature from that which it was calibrated. At a room temperature of 65°F (18.3°C) a change of 5°F (2.8°C) will alter the volume by about 1 per cent. The reading should also be corrected if the temperature of the gas being measured differs appreciably from that of the meter itself. The mean of the inlet and outlet gas temperatures should be taken. The pressure and temperature corrections referred to above are, of course, additional to any conversion of gas volumes either to BTPS or STPD as the case may be.

If a meter has been tested over the full range of flows and shown to have a constant registration error, as in our Meters B and D, figure 5, it is permissible to apply a correction factor to obtain the true reading. This is more convenient than unsealing the case and adjusting the tangent. A registration error which is similar at both 10 per cent and full flow during the statutory tests does not necessarily mean that the error is constant at all intermediate flows, and routine correction factors should not be used.

**Water vapour.**

The presence of water vapour in the gas does not affect the accuracy of the meter, but if the meter temperature is lower than that of saturated gases reaching it, droplets will be formed. Some laboratory meters have an inlet pipe of high thermal capacity to condense water vapour and are fitted with a drain tap. If there is further condensation within the meter its effect on calibration will depend on where exactly the water droplets are deposited. The gases first pass through the valve chamber and condensation here will not affect the calibration. Water in the outer casing measuring chambers will not affect the calibration unless there is enough to encroach on the space swept by the bellows, but any water in the inner (bellows) measuring chambers will diminish the available volume of that chamber causing over-reading. The thermal conductivity of the casing being greater than the bellows, one can expect that any further cooling of the gases will tend to occur in the outer chambers rather than in the bellows. The meter will dry out if left unconnected at room temperature. Indeed, drying and hardening of the leathers is a common cause of meter deterioration, and it is recommended that both pipes be stoppered if the meter is left unused for long periods.

The deleterious effects of water are minimized by lacquering the inside of the casing and dressing the leathers with castor oil during assembly. Nevertheless, wet gases should not be passed through the meter unnecessarily.

**Economics.**

Table II shows that domestic gas meters compare favourably in price with those sold specifically for medical purposes. Most manufacturers will fit a test dial instead of an index on request, and domestic meters are sold with a two-year guarantee. The dry gas meter is not only accurate but it is cheaper and more robust than many other instruments in current use for measuring gas volumes. As a permanent fixture with a mechanical ventilator it can be expected to give long-term accurate service. If one has doubts about a particular meter it is quite simple to have it tested at any Ministry of Power Stamping Office. The statutory charge is 4s. 3d. The volumetric test will only be performed at maximum rated flow unless the result just complies with the statutory regulations. In this case, or if specifically requested, it will be tested at 10 per cent flow also. If it proves to be defective it should be overhauled by a meter manufacturer. The charge for this should be less than £5.
ACKNOWLEDGEMENTS

We are grateful for the assistance of Miss S. M. Hills and Miss S. Barker of the Department of Medical Illustration, Royal Postgraduate Medical School. Thanks are due to Mr. S. Armitage of Messrs. Parkinson Cowan Ltd. for illustrations from which figure 3 was drawn, and to Mr. J. F. Taylor of Messrs. Alexander Wright & Co. (Westminster) Ltd. for figure 4. We are indebted to Mr. G. A. Tamer of Thomas Glover & Co. Ltd. for the opportunity of seeing all the stages in the assembly and overhaul of gas meters, to Mr. H. Worsley of the Ministry of Power Gas Standards Division (Edmonton Works), and to Mr. A. R. Birch, Manager, Stove and Meter Department, North Thames Gas Board, Willesden.

REFERENCES


PROPRANOLOL DURING CONTROLLED HYPOTENSION

Sir,—I have read with interest the paper by Drs. Hellewell and Potts on this subject in your October issue (*Brit. J. Anaesth.*, 1966, 38, 794), but I do not feel that their polypharmacy is necessary to provide good operating conditions for microsurgery of the ear. Neither do I feel that atropine is a good premedication when hypotension is desired.

Since 1958, by which time halothane had been well assessed, I have found it necessary to use a ganglion blocking agent to produce good and stable hypotensive conditions for aural micro-surgery. The technique used is based on halothane, a high inspired oxygen concentration and controlled respiration under e.g. control and has been referred to elsewhere (Murtagh, 1960; Rollason, 1960).

On occasion, however, a high concentration of halothane is required to maintain the hypotension and this is usually associated with a raised pulse rate and the younger age groups. It is in such cases where small intravenous injections of propranolol (0.5–1.0 mg) may prove useful.

W. N. ROLLASON
Aberdeen

REFERENCES

TROCKENE VERDRÄNGUNGSGASMESSER

ZUSAMMENFASSUNG

Es werden die Entwicklung, Arbeitsweise, Testung und Eichung des trockenen Verdrängungsgasmessers beschrieben. Drei Modelle, die sich gegenwärtig in unserem Laboratorium im Gebrauch befinden, wurden vor und nach mechanischer Ausbesserung geprüft. Der trockene Gasmesser ist billig, robust und genügend exakt zur Messung von Gasmengen bei den meisten Anwendungsverfahren.

CORRESPONDENCE

Drs. Hellewell and Potts replied to Dr. Rollason's letter as under:

Sir,—We are indebted to Dr. Rollason for his observations regarding our paper (*Brit. J. Anaesth.*, 1966, 38, 794) and have no hesitation in acknowledging alternative methods for the induction and maintenance of controlled hypotension for aural microsurgery.

Irrespective of the chosen method for reducing blood pressure we feel that tachycardia should be avoided for the reasons set out in our communication.

Although this may effectively be done using an intravenous injection of propranolol it appears valid to comment that in the un-atropinized patient receiving a high concentration of halothane, as envisaged by Dr. Rollason, ß-adrenergic blockade might result in severe bradycardia (Johnstone, 1966), with a precipitous fall in blood pressure: under these circumstances it would appear prudent to "titrate" with very small doses of propranolol, (of the order 0.25–0.5 mg) and to have atropine available.

J. HELLEWELL
M. W. POTTS
London

REFERENCE