SIMPLIFICATION OF HALDANE'S APPARATUS FOR MEASURING CO₂ CONCENTRATION IN RESPIRED GASES IN CLINICAL PRACTICE

BY

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There is a need for a method of measuring the CO₂ concentration in respired gases which is more accurate than the many simple clinical analysers but which is less complicated than the Haldane and Scholander methods. The ideal instrument for use in the rebreathing method (Campbell and Howell, 1960) should have an accuracy of ± 0.05 – 0.1% together with the following properties: portability, simplicity, speed, ease of servicing, and cheapness. The classical Haldane apparatus was simplified until the present instrument (see Diagram) was obtained; it is similar in principle

Diagram of apparatus.

to the portable apparatus for determining small percentages of CO₂ described by Haldane and Graham (1935). The chief differences from the standard Haldane apparatus are: absence of O₂ absorption pipette; absence of a compensating burette; replacement of the twin-bore tap on the calibrated burette (B) by a three-way tap (T) (this modification simplifies the setting of the liquid level in the absorption pipette (A) to read zero (Z) at atmospheric pressure); replacement of the mercury-levelling bulb with a syringe (SYR).

Other minor alterations include: the use of a cock (C) between the syringe and burette for control of the mercury level; the use of a screw clip (S) between the

cock and the burette for fine adjustment of the mercury level; calibration of the burette so that, provided a fixed volume is introduced, the % CO₂ can be read direct; an expansion (E) of the tubing above the zero level (Z) on the absorption pipette (A) to decrease the danger of drawing the KOH over into the calibrated burette.

The gas burette is normally 10 ml. but can be smaller. It is surrounded by a water-jacket (J) to improve temperature stability.

The only major departure from Haldane and Graham's apparatus is the omission of the compensating burette. This is tolerable because of the speed of the analysis and the lower level of accuracy required for clinical purposes. No originality is claimed for these modifications, many of which have been noted in one form or another in various laboratories.

The Instrument in Use

Preparation.—The instrument is filled with mercury as follows: take the plunger out of the syringe; put about 12 ml. of mercury in the barrel; replace the plunger; lower and invert the syringe to allow air to collect at the nozzle end; eject the air through the burette; place the syringe in a clip on the back board; adjust the volume of mercury by drawing excess off through tap T with a fine catheter and small syringe. The height of the clip which holds the syringe should be so arranged that, with the cock C open, the mercury level in the burette is below the 0 (that is, 10 ml.) mark. The volume of mercury should be such that, with the plunger of the syringe pushed fully home, the mercury is just below tap T. (A short length of rubber tubing (R) round the piston rod of the syringe provides a buffer to ease the arrest of the mercury at this level when the instrument is in use.) The absorber (10%–20% KOH) is poured into the levelling-bulb (L) until the absorption pipette is filled to the zero mark.

Servicing.—The preparation described above need never be repeated. The only regular servicing required is to maintain a trace of acid (such as 5% sulphuric acid containing an indicator) in the gas burette. Should the KOH be drawn over into the mercury the procedure is as follows: with the tap (T), empty the absorption pipette by pouring the KOH off from the levelling-bulb; fill the absorption pipette with dilute acid (for example, 5% sulphuric); turn the tap (T); pass the acid backwards and forwards two or three times; turn the tap (T); pour away the acid and refill with KOH; draw the excess acid out of the gas burette with the catheter and syringe. This cleaning and refilling take less than four minutes. If only a small amount of alkali is drawn over, the burette, tap, and adjoining tubing can be cleaned and acidified, using the syringe and catheter, in even less time.

Analysis.—The instrument should be left with the tap (T) (this prevents alkali diffusing into the gas burette); turn the tap (L) and adjust KOH to zero; turn the tap (T); flush the burette with the gas to be analysed (this is most easily done with a three-way tap attached to the top of the burette); draw the sample down to 0 (10 ml.); disconnect from sample (the extra three-way tap facilitates this); turn the tap (T); check that the zero setting has not changed, and wait a few seconds to make sure that the absorber level does not rise—as it will do if the gas burette is contaminated with alkali; pass the gas

over into the absorber and back 10–15 times; allow the mercury to fall until KOH level returns to zero (this is accomplished by using the cock (C) to regulate rate of fall and the screw clip (S) for final fine adjustment); read the % CO₂ off the burette; repeat passage to check that absorption is complete. The analysis takes less than two minutes from start to finish.

Accuracy.—Serial analyses are reproducible to within $\pm 0.05\%$. Several comparisons both with the standard Haldane and with Lloyd's modification (Lloyd, 1958) gave agreement which was usually within $\pm 0.05\%$ and never outside $\pm 0.1\%$. This degree of accuracy is more than adequate for the purpose for which the instrument is intended.

Modified Instrument

The insert shows an alternative arrangement which, at the expense of the complexity of two taps instead of one, slightly speeds up the analyses and facilitates servicing. The calibrated volume includes the bores of the two taps and the connecting tube. The instrument is left with tap 1 (T) and tap 2 (L); turn tap 2 (←) and adjust KOH level to zero. Tap 2 is then turned (L); the mercury is forced up into the stem of tap 1 and the sample of air is flushed through both taps: tap 1 is turned (→) and the sample is introduced to 0 (10 ml.); tap 1 is turned (←); tap 2 is turned (→); the zero level is checked, and absorption carried out as described above. Cleaning through with acid can be done with tap 2 (L) without needing to empty the KOH from the absorption pipette.

I am grateful to Dr. C. J. Dickinson and Dr. J. B. L. Howell for help in developing this analyser, and to Mr. Richard Neave for preparing the illustration. The instruments have been made for me by Aimer Products, Rochester Place, Camden Town, London, N.W.1.

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A Report on Electrical Accidents and their Causes, 1958 (H.M.S.O., price 5s. net), published on December 30, points out that, although it is just 50 years since the Electricity Regulations were made, they still provide an adequate legal basis for the prevention of accidents on premises covered by the Factories Acts, because it has always been possible to interpret them in terms of the current state of electrical engineering science and practice. "Looking back," the report continues, "to the report of the Chief Inspector of Factories for 1907, the year immediately before the Regulations were drafted, it is interesting to note that there were already 264 accidents during the year, of which eight were fatalities. In 1958 the number of accidents had only risen to 714, including 38 fatalities. This is not unsatisfactory, when one considers the enormous increase in electrical supply, and industrial use since that time." Of the 714 accidents which were reported under the Factories Acts, 127 were welders' conjunctivitis or "eye-flash." "Unfortunately," the report records, "the decrease in the number of accidents in 1957 has not been maintained, and this is particularly noticeable when the figures for electrical accidents excluding eye flash are compared for the two years, there having been 527 accidents in 1957 and 587 accidents in 1958. Tables in the report analyse reported accidents by occupation and by causation." (Ministry of Labour Information Service, December, 1959.)

SIMPLE RAPID METHODS OF ESTIMATING ARTERIAL AND MIXED VENOUS pCO₂

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The aims of this paper are, first, to describe simple rapid methods for estimating mixed venous and arterial pCO₂ and, secondly, to describe an evaluation of their accuracy in clinical disorders in which the carbon dioxide and hydrogen-ion concentration are disturbed.

Physiological and Clinical Significance of Measurements of Blood CO₂ Tension

The arterial CO₂ tension (pCO₂) defines the ratio between metabolism and the effective volume of the breathing—that is, alveolar ventilation.

$$\text{Arterial pCO}_2 \propto \frac{\text{Vol. of CO}_2 \text{ produced}}{\text{Alveolar ventilation}}$$

The ratio between the volume of CO₂ production and alveolar ventilation—and hence the pCO₂—remains relatively constant in health over a wide range of CO₂ production.

If alveolar ventilation is inadequate the pCO₂ rises; if alveolar ventilation is excessive the pCO₂ falls. The arterial CO₂ tension is a much more reliable measure of effective ventilation than respiratory rate, depth or minute-volume, because these only indicate total ventilation, of which the effective (alveolar) portion is a very variable part.

Proof of inadequate ventilation (ventilatory failure) demands an estimation of arterial pCO₂. Similarly, firm conclusions that treatment has improved ventilation can only be justified by estimations of arterial pCO₂.

The arterial pCO₂ also describes the respiratory component of disturbances in hydrogen-ion regulation—the relationship between pH, bicarbonate concentration (which defines the metabolic component), and pCO₂ being expressed in the Henderson-Hasselbalch equation.

$$\text{pH} = \text{pK}' + \log \frac{\text{bicarbonate concentration (mEq/L)}}{0.03 \text{ pCO}_2 \text{ (mm. Hg)}}$$

Respiratory acidosis implies a raised pCO₂ (above 44 mm. Hg). Respiratory alkalosis implies a reduced pCO₂ (below 36 mm. Hg).

The arterial pCO₂ is so informative and unequivocal that it would be measured in the diagnosis and assessment of a wide range of clinical problems were it not for the technical difficulty of its measurement. In this paper we describe a method by which the arterial pCO₂ can be estimated at the bedside in a few minutes by a method requiring little technical skill; and, if necessary, using very simple and inexpensive equipment.

Methods Employed in Estimation of pCO₂

1. *Arterial Blood*, or arterialized blood (Brooks and Wynn, 1959).—The pCO₂ can be measured (a) "directly" by Riley's method (Riley, Campbell, and Shepard, 1957); (b) "indirectly" by measuring the pH and blood CO₂ content and calculating pCO₂ from the Henderson—