A Critical Orifice CO_2 Analyzer Suitable for Student Use

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A simple method for the continuous analysis of carbon dioxide in expired gas has been developed for student use. The following general principle has been used. If a dry gas mixture is passed through a chamber containing a CO_2 absorbent, the volume of gas passing into the chamber in a given time will equal the volume leaving the chamber (under the same conditions of pressure and temperature) if there is no CO_2 in the mixture. If CO_2 is present in the mixture and all of the CO_2 entering the chamber is absorbed, then A, the total volume of gas entering the chamber in a given time will exceed B, the volume leaving the chamber in the same time interval, as related by the equation

$$A = B \times \frac{1}{1 - F_{CO_2}},$$

where F_{CO_2} is the fraction of CO_2 in the entering gas.

In practice the rate of outflow is maintained at a nearly constant level by means of a critical flow orifice (*1*), as shown in Fig. 1. The pressure on the downstream side of the orifice is maintained at less than half an atmosphere by means of a water-jet filter pump. The diameter of the orifice is approximately 0.003 in., permitting a gas flow of about 100 ml/min. The gas sample flows into the chamber through a second orifice of larger diameter (about 0.010 in.). The pressure drop across this orifice is measured and indicates the rate of flow into the chamber. This pressure drop is approximately 10 cm-of-water when dry CO_2-free air is sampled. Since the outflow is maintained at a nearly constant level, the flow through the measuring orifice must increase as the fraction of CO_2 in the test gas increases. For example, if the dry sample contains 5 percent CO_2, the rate of flow through the measuring orifice increases approximately 5 percent from zero CO_2 conditions. In this instance, the measuring orifice pressure drop increases approximately 10 percent, for it varies as the square of the rate of flow through it. To accomplish adequate resolution of such a pressure change, a reservoir manometer is used, slanted at 10° over the operating range and with gauge oil as the fluid (sp. gr. 0.86). The CO_2 absorbent used is Ascarite 8–10 mesh (sodium hydroxide fused on asbestos). Figure 2 is a calibration curve obtained with known mixtures of CO_2 in air. The deflection is approximately 0.05 percent/mm. The response time is approximately 4 min from 0 to 8 percent CO_2. Most of the delay can be attributed to the time required for thermal equilibrium to be established in the CO_2 absorber.

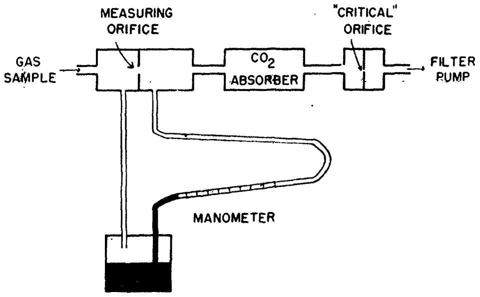

Fig. 1. Schematic diagram of the critical orifice analyzer.

Table 1 shows values obtained by this method and by a standard Haldane gas analyzer on samples of expired air, the range being attained by voluntary hyper- and hypoventilation. If the Haldane determination has an accuracy of ± 0.02 percent, the accuracy of the critical orifice analyzer, as based on these figures, can be taken to be ± 0.05 percent or better.

The analyzer has proved successful in its intended use in student laboratory exercises. Placed in series with a Pauling oxygen analyzer, both dried alveolar gas—as obtained from a Rahn end-tidal sampler (*2*) —and dried mixed expired gas have been analyzed continuously. With 16 students, alveolar CO_2 partial pressure as obtained during quiet breathing ranged from 35 to 42 mm-Hg with a mean value of 38.6. Bohr dead-space volumes for CO_2 in general fell within 10 ml of O_2 dead-space determinations; the greatest difference observed was 17 ml.

A few practical details of the construction and operation should be mentioned. The orifice holes were drilled in 0.002-in. brass shim stock (*3*). Glass filter paper was placed upstream from each orifice to prevent plugging. In order to maintain the same gas temperature at the two orifices, copper coils of length 25 in. and inside diameter 1/16 in. were placed upstream from each orifice. It was found that it was not necessary to place them in a constant temperature bath.

Because of the influence of gas density on the meas-

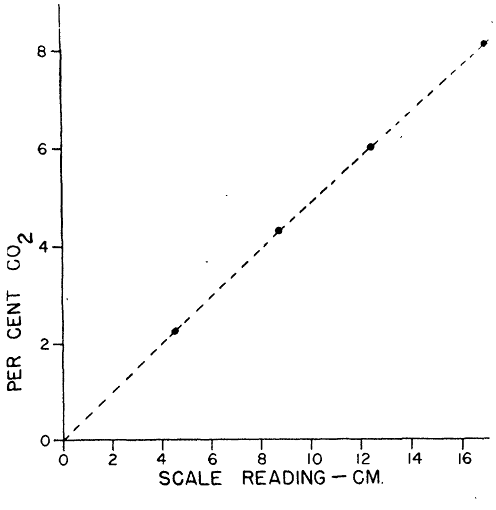

Fig. 2. Calibration curve obtained with known mixtures of CO_2 in air.

Table 1. Comparison of percentage CO_2 obtained by the critical orifice analyzer and the Haldane gas analyzer (seven samples).

Haldane gas analyzer (%)	Critical orifice analyzer (%)	Critical orifice analyzer minus Haldane gas analyzer (%)
2.97	2.94	− 0.03
3.56	3.54	− .02
6.45	6.48	+ .03
1.12	1.08	− .04
6.66	6.73	+ .07
1.37	1.33	− .04
6.80	6.86	+ .06

uring orifice pressure drop, the influence of ambient pressure must be taken into account. It was found empirically, from measurements made over a 19-mm range of ambient pressure (756–775 mm-Hg), that a 1-mm change in pressure was equivalent to about 0.04 percent change in CO_2. By adjusting the reservoir level so that on room air, passed through Ascarite before entering the analyzer, an arbitrary zero point in the scale was maintained, the variation with ambient pressure in the range from 3 to 6 percent CO_2 was reduced to less than 0.008 percent per mm-Hg change in atmospheric pressure. In this way small changes in ambient pressure could be neglected, and a single calibration curve served for a day's run (*4*).

References and Notes

1. R. T. Page, *Ind. Eng. Chem. Anal. Ed.* 7, 355 (1935).
2. H. Rahn and A. Otis, *J. Appl. Physiol.* 1, 717 (1949).
3. The National Jet Co., Cumberland, Md., manufactures microdrilling equipment. They drill holes down to 0.001 in. in diameter in blanks for a nominal cost.
4. I wish to acknowledge the assistance of my father, W. J. Mead, who constructed the manometer, and of Libby Servello, who performed the Haldane analyses. E. M. Landis made possible the use of the analyzer in student exercises and William B. Kinter assisted in supervising its use.

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Auxin Effects on the Utilization of C^{14}-Labeled Acetate by Wheat Roots

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Several years ago we observed production of acetaldehyde by wheat roots incubated in solutions of auxins (*1*). This effect suggests that the search for a specific chemical event underlying auxin action ought to include a study of reactions of the acetyl group, and prompted the work with acetate-1-C^{14} reported here (*2*).

Roots excised from wheat seedlings (White Federation 38) grown for 4 days in distilled water (*3*) were used. For the 2-hr experiment, 19 g of roots were incubated at 21.5°C in 100 ml of 6×10^{4}-M acetate solutions having activities of 242.5 and 229.0 μc, respectively, for the control and experimental treatments. For the 30-min experiment, 3 g of roots were incubated at 23°C in 35 ml of approximately $1 \times 10^{-4}M$ acetate solution having 30 μc of activity. In both experiments, indoleacetic acid (IAA) was used as an auxin at $2.5 \times 10^{-5}M$. Acetate solutions were adjusted to *p*H 4.7 with KOH.

During the experiments, CO_2-free air passed through closed vessels containing the roots, then through a U-tube held at −80°C to trap volatile products, and finally through a gas-washing bottle containing $0.1N$ NaOH to retain CO_2. At the end of the experiment the roots were separated from the solutions and washed. Combined solutions and washings from roots and cold traps were analyzed for C^{14}. These values, together with those for radioactivity in the original solutions and in the CO_2 produced by respiration were used to calculate the total quantity of C^{14} absorbed by the roots in the 2-hr experiment. No measure of C^{14} absorption is given for the 30-min experiment because the decrease in activity of the solution during the course of the experiment was about equal to the analytic error.

Root material in the 2-hr experiment was blended in the cold with water. After filtration this process was repeated three times on the solid material. An aliquot of the combined filtrate (designated "Total water-soluble fraction" in Table 1) was assayed for activity by a wet oxidation procedure (*4*). In this method the organic material is oxidized by chromic acid (*5*), and the gaseous products are carried to an evacuated ion chamber by a stream of CO_2. Activity in the chamber is measured on a vibrating reed electrometer (*6*). Values in Tables 1 and 2 represent averages for two determinations, and in each case duplicate values agree within 3 percent.

Another aliquot of the filtrate was acidified to *p*H 1.0 with sulfuric acid and was extracted for a period of 96 hr with ether. Titration of the ether extract

Table 1. Utilization of acetate-1-C^{14} by wheat roots in 2 hr.

	Control roots (μc)	Roots in IAA $2.5 \times 10^{-5}M$ (μc)	IAA/control times absorption factor*
C^{14} absorbed	214.40	178.97	100
Total water-soluble fraction	121.00	129.50	129
Lipids	1.92	2.15	135
Acidic substances	77.25	89.00	139
Acetic acid (calculated)	71.78	85.65	144
Nonvolatile acids	5.47	3.35	74
CO_2 of respiration	15.70	13.96	101

* Absorption factor equals 100 times the ratio of uptake of C^{14} in the control to that of the auxin treatment.