DETERMINATION OF LUNG VOLUME BY RESPIRATION OF OXYGEN WITHOUT FORCED BREATHING

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Since 1679 when Borelli (1) first endeavored to measure the air in the lungs interest has attached to the physiological and clinical significance of lung volume determinations. That portion of the pulmonary air which can be expired, either by usual or forced expirations, can be readily measured by spirometers. The residual air which remains in the lungs, however, requires other methods.¹

Of these, two types have proven practical, the nitrogen dilution method and the hydrogen mixture method.

In the nitrogen dilution method, which has been reviewed by Lundsgaard and Van Slyke (2), the subject makes 5 or more forced respirations to and from a bag containing a measured volume of 2 or 3 liters of pure oxygen. Thereby the nitrogen of the pulmonary air is diluted with a known volume of oxygen. From the extent to which the nitrogen content of the gas mixture is diluted below the point, 79.1 per cent, found in ordinary pulmonary air, the volume of nitrogen, and hence of air, in the lungs at the beginning of the experiment can be calculated. Such an experiment must be completed in so short a time, that the difference between the volume of oxygen absorbed in the lungs and the volume of carbon dioxide excreted is not sufficient to affect significantly the total gas volume, and that the accumulation of carbon dioxide does not become great enough to make the gas mixture intolerable to breathe. To achieve mixture of the air in the lungs

¹ For a discussion of the various fractions into which authors have divided the total lung volume the reader is referred to Lundsgaard and Van Slyke (2). The two main fractions are the “vital capacity,” which is the volume of air that can be taken in by a maximal inspiration following a complete expiration, and the “residual air” left in the lungs after a complete expiration. The “middle capacity” is the volume of air held in the lungs at the middle of a normal respiration. For measurement of the “middle capacity” as well as the “residual air” the dilution method or some equivalent must be used.
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with the oxygen in the bag in the permissible 20 or 30 seconds, it is necessary to accomplish the mixture in 5 or 6 respirations. These must approach in size the vital capacity of normal subjects, or mixture will not be complete. The simple dilution method is therefore limited in applicability to subjects who can cooperate, and who can make forced respirations of approximately normal extent.

To overcome these limitations Van Slyke and Binger (3) developed the hydrogen mixture method. The subject respires in a normal manner a mixture of oxygen and hydrogen, in which the volume of hydrogen is known, and the amount of oxygen need not be accurately measured, but is sufficient to maintain respiration for the 5- or 6-minute period found necessary for complete mixture of the gases when the respiration is of only ordinary depth. The carbon dioxide is removed by a scrubber. At the end of the period, oxygen and carbon dioxide in a sample of the respired gas are removed by absorption with alkaline pyrogallate, and the ratio $N_2/H_2$ in the residual mixture of these two gases is determined by analysis. From this ratio and the known volume of $H_2$ in the respired gases, the volume of $N_2$ in the lungs is calculated as

$$\text{Vol. } N_2 = \text{Vol. } H_2 \times \frac{N_2}{H_2}$$

and the volume of air is estimated by dividing this volume of $N_2$ by 0.791, the proportion of $N_2$ present in the original pulmonary air.

The hydrogen respiration method can be carried out without cooperation of the subject, and has proved its practicality. Although Van Slyke and Binger used a spirometer, the method can be carried out with only a rubber bag attached to a soda-lime scrubber. The only drawbacks are those necessarily connected with the use of hydrogen for physiological experiments. Every lot of hydrogen must be tested for arsine, since some samples of commercial hydrogen contain this gas in sufficient amount to produce fatal intoxication. Furthermore, one is working with an explosive mixture of hydrogen and oxygen, ignition of which by flame or spark must be guarded against.

To avoid these drawbacks, we have in the present paper devised a technique which permits lung volume determinations without forced breathing, and requires respiration of no extraneous gas other than oxygen. The oxygen is respired from a spirometer, the carbon dioxide being continuously removed by a scrubber. At the end of the period the volume of gas in the spirometer is measured to ascertain the extent to which the pulmonary nitrogen has been diluted. The
The calculation is then performed as in the simple nitrogen dilution method. The difference from the latter is that here the oxygen volume, with which the pulmonary air is diluted, is determined by measurement on the spirometer at the end of the respiratory period, instead of being taken as the oxygen volume measured at the beginning. Hence the respiratory period, as in the hydrogen method, can be prolonged as much as may be necessary to obtain mixture of the gases with ordinary respiration.

Since it is difficult to discuss the technique without referring to the factors involved in the calculation, the latter will be considered first.

Calculation

The basic equation of the dilution method (2) is

\[ V_L = V_{O_2} \times \frac{N_2}{79.1 - N_2} \]

\( V_L \) = volume of air in lungs when the subject is connected to oxygen bag or spirometer; \( V_{O_2} \) = volume of oxygen, from bag or spirometer, with which the pulmonary air is diluted; \( N_2 \) = per cent of nitrogen found in the respired gas mixture at the end of the period; 79.1 is the average per cent of nitrogen found in pulmonary air by Lundsgaard and Van Slyke (2).

When spirometers of the usual types are employed, the total volume of gas in the spirometer is the sum of the volume indicated on the scale plus the volume in the tubing, connections, scrubber, etc., which is not indicated by the scale. If we indicate the volume shown on the scale by \( V_S \) and that held in the dead space as \( V_D \), and substitute their sum for \( V_{O_2} \) in Equation 1, we obtain:

\[ V_L = (V_S + V_D) \times \frac{N_2}{79.1 - N_2} \]

The value of the dead space \( V_D \) is found in independent experiments with the spirometer used. In place of the lungs a bottle containing a known volume of atmospheric air is substituted and this air is mixed with oxygen in the spirometer. (Or oxygen is placed in the bottle and air in the spirometer.) By a rearrangement of Equation 2, \( V_D \) is then calculated, as will be detailed later.

Apparatus

The familiar Roth-Benedict (4) and Krogh apparatuses for determination of basal metabolism can be used without alteration for lung volume by this method. The only disadvantage is the rather
large dead space. Because of it from 12 to 15 washings with oxygen are required before each determination to replace the air in the spirometer completely with oxygen.

To obtain an apparatus which has smaller dead space, and which can be constructed at small cost from ordinary laboratory equipment, one of the writers (S.) devised that shown in Fig. 1.

Z is a three-way stop-cock, one end of which is connected to the vacuum, the other to a high-pressure tank of pure oxygen. The rubber stopper T fits the rubber mouth piece O. The aluminum three-way stop-cock S of 20 mm. bore is made to communicate with the outside air, or through O with the apparatus. I and E are rubber spirometer valves (inlet and outlet), enclosed in glass jackets. X is a 500 to 750 cc. bottle with bottom removed, containing soda-lime. Copper gauze of not too fine mesh, or cotton loosely packed, may be used to keep the particles within the bottle. Running water enters the cooling system at Y, is distributed along the sides of the bottle, and runs off into a funnel. B is a rubber breathing bag, of 5 or 6 liters capacity. R is a press, something like that used for holding tennis racquets. It consists of two pieces of wood large enough in area to cover all but the ends of the bag B. B is also in communication with the Woulfe bottle W of 8 liters capacity, containing water. G is a tube with a millimeter scale. The bottle W is calibrated on the scale G by pouring in measured volumes of water, 300 to 400 cc. at a time, so that definite volumes of gas in W correspond to definite scale readings of the meniscus in G. The points are plotted on a curve, from which scale readings can be converted into liters of gas present in W (1 mm. on the scale of G corresponds to about 30 cc. volume in W). Reading G to 0.5 mm. in such an apparatus gives gas volumes in W to ± 15 cc. The flow of water through a suitable length of rubber tubing (of 32 mm. bore) between
A and W is controlled by the clamp C, placed as near as possible to the volume gage G. M is a water-filled manometer with a millimeter scale, connected with the rest of the system through the stop-cock L, which is of at least 2 mm. bore. All of the connecting tubes through which respired air passes are of heavy-walled glass or rubber tubing, of an internal diameter (23 mm.) sufficiently large to avoid resistance to respiration. In order to make the rubber tube connections at the bottom outlets of A and W, it may be necessary to seal a piece of glass tubing into each outlet. This may easily be done by the use of de Khotinsky cement. No temperature control is necessary, since the change in temperature of the gas contained within the system is so small during the period of a determination that it may be neglected. The zero point at the top of scale G is 3 or 4 cm. below the level of the stoppers in W.

**Determination of \( V_D \), the Dead Space of the Apparatus**

The apparatus is first filled with atmospheric air. If it has contained another gas, it is filled with air and emptied 12 to 15 times to replace other gases entirely with air of atmospheric composition. Then the air content is reduced to that of the dead space, and is mixed with a known volume of oxygen, as follows.

*Krogh or Roth Spirometer.*—The bell is pressed down until the indicator points to the zero mark on the scale so that no air except that in the dead space remains in the spirometer. Then the mouth piece of the spirometer is connected with a gas container holding a known volume of oxygen. An aspirator bottle like A in Fig. 1 serves as such a container. It is provided at the top with a stopper and a cock by which gas can be admitted and let out, and is connected at the bottom with a similar bottle which is filled with water. A mark is made on the stoppered bottle showing the level at which water stands in it when 5 liters of gas are present. The bottle thus calibrated is first filled to the stopper with water, and then pure oxygen is run in until the water has fallen to the 5-liter mark, the level of the water in the connected bottle being kept even with that in the calibrated one. The calibrated bottle is then connected with the spirometer by a short narrow tube bearing a perforated stopper which fits into the hole in the mouth piece of the spirometer. By raising and lowering the other bottle the oxygen is alternately forced into the spirometer and withdrawn from it 15 times, so that a uniform mixture of the oxygen with the air in the spirometer is obtained. A sample of the mixed gas is then analyzed for nitrogen.
In the above procedure, for economy's sake, oxygen is placed in the bottle at the start, and air in the spirometer, instead of vice versa.

The calculation of the dead space is similar to that of lung volume in Equation 1.

\[ V_D = V_{O_2} \times \frac{N_2 - a}{79.04 - N_2} \]

In this case \( V_{O_2} \) represents the volume of oxygen measured into the bottle and then mixed with the air in the spirometer. \( V_{O_2} \) is 5 liters when the technique is carried through as above directed. \( N_2 \) represents the per cent of \( N_2 \) found in the gas mixture by analysis. The per cent of \( N_2 \) present as impurity in the oxygen used is represented by \( a \). The \( N_2 \) content of atmospheric air is 79.04 per cent.

**Sendroy Apparatus.**—After the apparatus (Fig. 1) is washed out with air, the bag \( B \) is pressed in clamp \( R \) and the water in \( W \) is raised till the zero mark on \( G \) is reached, so that all the air except that in the dead space is removed from the apparatus. A bottle containing a measured volume of pure oxygen is attached to the mouth piece, clamp \( R \) is then removed from the bag, and the rest of the determination of \( V_D \) is carried out in the same manner as with the spirometers. In this case, however, the volume of oxygen used is 1 instead of 5 liters, and an aspirator bottle of 3 liters capacity is calibrated to hold the oxygen.

**Lung Volume Determination**

**Preliminary Washing of Gases Other than Oxygen Out of Roth or Krogh Spirometer.**—Either of these instruments is filled as completely as possible with oxygen and emptied 12 to 15 times to remove all nitrogen. Washing of either of these spirometers requires about 90 liters of oxygen.

**Preliminary Washing of Sendroy Apparatus.**—\( W \) is almost filled with water and clamp \( C \) is closed. Then the stopper \( T \) is inserted into the hole in the mouth piece. One outlet of the three-way cock \( Z \) connects with a suction pump and the other with an oxygen tank. Suction is applied through \( Z \) until the bag \( B \) is nearly deflated. Strong negative pressure is not applied because it might start leaks in the apparatus. By turning \( Z \), enough oxygen to fill the gas bag is alternately admitted and withdrawn 10 times. The washing can
thus be completed in 2 or 3 minutes, and requires about 40 liters of oxygen.

*Addition of Oxygen for the Determination.*—With the dead space already filled with pure oxygen, enough more is run into the apparatus to fulfil the requirements of the subject for the duration of the experiment. For a resting subject 3 liters for 5 minutes and 6 liters for 10 provide more than enough.

With the Krogh or Roth apparatus one merely admits 3 or 6 liters of oxygen, measured by the rise of the pointer on the scale, for a 5- or a 10-minute period.

With the Sendroy apparatus the oxygen is admitted as follows. The bag $B$ is flattened by clamping it with $R$. $T$ is then inserted into the mouth piece $S$, and enough oxygen is wasted through cock $S$ into the outer air to wash the air out of this cock. Then oxygen is admitted into the apparatus until the water level in $W$ has fallen to a point indicating that the desired amount of gas has been admitted. (This level can be previously determined and indicated by a mark on bottle $W$.) A reading, $V_s$, is made on scale $G$. Clamp $R$ is then removed from the bag and the latter is filled with gas from $W$. Clamp $C$ is then closed, and bottle $A$ is left elevated above $W$.

*The Respiration Period.*—The determination is carried out in the same way with any of the three types of apparatus.

The subject, with nostrils clamped by a nose piece, is connected to the apparatus by means of the mouth piece, and the cock $S$ is so turned that room air is breathed for several normal respirations. The subject then brings his lungs to the desired position (for residual air he expires as completely as possible), and the cock is turned to connect him with the spirometer or bag. The subject then respires normally for the desired period. 5 minutes are sufficient to obtain a complete mixture for any normal subject. Longer periods may perhaps be needed when the respirations are very shallow. At the end of the period the subject brings his lungs to the same position as at the beginning and the cock $S$ is turned off.

In the Sendroy apparatus it is necessary to admit additional gas into the bag from $W$ at intervals during the period. This is done by opening clamp $C$ and admitting water from $A$ into $W$. So much must
not be admitted at any time that the bag is sufficiently filled to offer resistance to expiration. In particular, when residual air is to be determined, enough space must be left in the bag to receive the final maximal expiration.

**Final Gas Measurements and Sampling.**—In the Krogh or Roth spirometer the gas volume is read on the scale. The total gas volume in the extrapulmonary part of the system is then calculated by adding the volume, \( V_s \), indicated by the scale, to the dead space, \( V_d \), previously determined. A sample of gas from the spirometer is then drawn for gas analysis.

With the Sendroy apparatus the following procedure is used. The bag is compressed in the clamp \( R \) and the gas is thereby completely driven from the bag into \( W \), as it was when the dead space was determined. The volume \( V_s \) is then read on the scale \( G \). During the reading the cock of \( M \) is opened and the bottle \( A \) is set at such a level that the water menisci in the two limbs of manometer \( M \) are at the same level, indicating exact atmospheric pressure in the system.

To obtain a sample the bag is then refilled with gas from \( W \), and the sample is withdrawn from outlet \( K \) of the bag.

**Analysis.**—The nitrogen in samples of the mixed gases is determined as the residual gas left after absorbing, with alkaline pyrogallol or hyposulfite solution, the oxygen and the small amounts of \( \text{CO}_2 \) that may have escaped the scrubber. Any suitable gas burette serves for the measurements. A convenient procedure with use of the manometric apparatus of Van Slyke and Neill, instead of a gas burette, has been described by Van Slyke and Sendroy. It is also especially adapted to determination of the small amounts of nitrogen or hydrogen present as impurity in the oxygen.

**Calculation**

If the oxygen gas used contains no significant amount of impurity in the form of \( \text{N}_2 \) or other inert gas, determinable as \( \text{N}_2 \) by the method of analysis used, the calculation is made by Equation 4.

\[
(4) \quad V_L = (V_s + V_d) \frac{N_2}{79.1 - N_2}
\]
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If, however, the oxygen used contains amounts of nitrogen which significantly affect the result, the calculation must be made by Equation 5, in which allowance is made for such impurity.

\[
V_L = \frac{V_D (N_2 - \alpha) + V_{S2} N_2 - V_{S1} \alpha}{79.1 - N_2}
\]

In these equations the symbols, \(V_L\), \(V_D\), \(\alpha\), and \(N_2\) have the same significance as in Equations 1, 2, and 3. \(V_{S1}\) represents the volume of gas read on the scale of the spirometer at the beginning of the determination, \(V_{S2}\) the volume of gas read on the scale of the spirometer at the end of the period.

Equation 5 is derived as follows. Using the above symbols, and in addition \(V_{N1}\) to express the total volume of nitrogen in the system of lungs + spirometer, we may calculate the values of \(V_{N1}\) at the beginning and end of the respiratory period, respectively, by means of Equations 6 and 7.

\[
(6) \quad V_{N1} = 0.791 V_L + 0.01 \alpha (V_{S1} + V_D)
\]

\[
(7) \quad V_{N1} = 0.01 N_2 (V_L + V_{S2} + V_D)
\]

Since the nitrogen volume, \(V_{N1}\), present in the system is the same at the beginning as at the end of the period, we may equate the right hand members of Equations 6 and 7. Doing so, and solving the resulting equation for \(V_L\), we obtain Equation 5. If \(\alpha = 0\), Equation 5 becomes Equation 4.

From the lung volume calculated by either Equation 4 or 5 a small correction is to be deducted for the dead space in the mouth piece used to connect the subject with the spirometer. This dead space is that contained in the tube between the mouth of the subject and the three-way valve, and is usually less than 100 cc. If the space is cylindrical it may be estimated as \(0.8 D^2 H\) cc., where \(D\) indicates the diameter of the cylindrical section of tubing involved and \(H\) is the length of this section, from the mouth end of the tube to the valve. Or this space may be measured simply by closing the valve on the side towards the mouth piece, and ascertaining the volume of water which must be poured in, in order to fill the space.
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EXPERIMENTAL

Determinations of lung volumes in the same normal subjects have been performed by the present method, and by the two others discussed in the introduction.

The Dilution Method with Forced Breathing.—The technique of Lundsgaard and Van Slyke (2) was followed. The subject breathed 5 or 6 times in and out of a rubber bag previously washed and filled 3 or 4 times with pure oxygen. The results were calculated according to Equation 1, and are given in Table I.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Residual air (liters)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>$V_L = 1.42$</td>
</tr>
<tr>
<td></td>
<td>1.54</td>
</tr>
<tr>
<td></td>
<td>1.42</td>
</tr>
<tr>
<td></td>
<td>1.50</td>
</tr>
<tr>
<td>B</td>
<td>$V_L = 2.29$</td>
</tr>
<tr>
<td></td>
<td>2.10</td>
</tr>
<tr>
<td></td>
<td>2.34</td>
</tr>
<tr>
<td></td>
<td>2.24</td>
</tr>
</tbody>
</table>

The Present Dilution Method without Forced Breathing.—A preliminary experiment was performed to determine the number of washings necessary with oxygen when the dead space in the Benedict-Roth spirometer was initially filled with air. With a dead space of about 5.9 liters, using about 5 liters for each washing, on the assumption that there is complete mixture of all the gases with each washing, one can calculate the number of washings needed to fill the system with pure oxygen. The result of such a calculation is given in Table II, Column 2. The next column indicates the results actually obtained by analysis after washing with tank $O_2$ from the breathing end of the apparatus. The oxygen in the tank had been analyzed and found to contain 0.43 per cent $N_2$. Table II shows that washing is much more efficient than it would be if uniform mixture of each por-
TABLE II
Calculated and Observed Results of Washing Benedict-Roth Spirometer Apparatus with Oxygen Containing 0.43 Per Cent $N_2$

<table>
<thead>
<tr>
<th>No. of washings</th>
<th>Per cent $N_2$</th>
<th>Calculated</th>
<th>Obtained</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beginning</td>
<td>79.05</td>
<td>79.05</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>43.1</td>
<td>8.84</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>43.6</td>
<td>3.75</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>13.0</td>
<td>2.41</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>6.7</td>
<td>2.26</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>3.8</td>
<td>1.31</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>1.0</td>
<td>1.18</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>0.6</td>
<td>0.75</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>0.6</td>
<td>0.8</td>
<td></td>
</tr>
</tbody>
</table>

TABLE III
Determination of Lung Residual Air by the Dilution Method without Forced Breathing. Roth-Benedict Spirometer Used

$V_D = 5.79$ Liters

<table>
<thead>
<tr>
<th>Respiration time</th>
<th>Subject A</th>
<th>Subject B</th>
</tr>
</thead>
<tbody>
<tr>
<td>min.</td>
<td>liters</td>
<td>liters</td>
</tr>
<tr>
<td>1</td>
<td>1.34</td>
<td>1.54</td>
</tr>
<tr>
<td>2</td>
<td>1.24</td>
<td>2.15</td>
</tr>
<tr>
<td></td>
<td>1.37</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>1.41</td>
<td>2.06</td>
</tr>
<tr>
<td></td>
<td>1.42</td>
<td>2.08</td>
</tr>
<tr>
<td>4</td>
<td>1.42</td>
<td>2.05</td>
</tr>
<tr>
<td></td>
<td>1.46</td>
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<td></td>
<td></td>
<td>1.97</td>
</tr>
<tr>
<td>5</td>
<td>1.41</td>
<td>2.17</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.00</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.07</td>
</tr>
<tr>
<td>7.5</td>
<td>1.55</td>
<td>2.09</td>
</tr>
<tr>
<td>10</td>
<td>1.58</td>
<td>2.26</td>
</tr>
</tbody>
</table>
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tion of oxygen occurred with the gas in the dead space, and that 12 to 15 washings suffice to clear the Roth-Benedict spirometer system of almost all nitrogen except that which is introduced with the tank oxygen. Apparently, when oxygen is run into the spirometer it does not rapidly mix with the gas there, but tends to form a layer by itself and to push the previous gas out.

TABLE IV

*Determina tion of Lung Residual Air by the Dilution Method without Forced Breathing.*

*Authors' Apparatus Used*

\[ V_D = 0.89 \text{ Liter} \]

<table>
<thead>
<tr>
<th>Respiration time</th>
<th>Subject A</th>
<th>Subject B</th>
</tr>
</thead>
<tbody>
<tr>
<td>min.</td>
<td>liters</td>
<td>liters</td>
</tr>
<tr>
<td>2</td>
<td>1.45</td>
<td>1.80</td>
</tr>
<tr>
<td>3</td>
<td>1.45</td>
<td>1.85</td>
</tr>
<tr>
<td>4</td>
<td>1.45</td>
<td>2.00</td>
</tr>
<tr>
<td>5</td>
<td>1.50</td>
<td>1.99</td>
</tr>
<tr>
<td>6</td>
<td>1.45</td>
<td>1.95</td>
</tr>
<tr>
<td>7</td>
<td>1.50</td>
<td>2.04</td>
</tr>
<tr>
<td>8</td>
<td>1.47</td>
<td>2.08</td>
</tr>
</tbody>
</table>

In subsequent determinations of \( V_L \) with the Benedict-Roth spirometer, the system was washed 15 times with 5-liter portions of oxygen, and the value of 0.75 per cent \( N_2 \) was used for \( a \) in Equations 3 and 5. Four consecutive determinations of \( V_D \) for this system gave values of 5.74, 5.76, 5.83, and 5.78 liters. Table III indicates the results obtained for residual air.

In using the apparatus shown in Fig. 1, it was found that 10 washings of 4 liters each, with the same oxygen used before, reduced the
nitrogen content of the system to 0.54 per cent. This value was used in Equations 3 and 5, for the calculation of $V_L$ determinations by this apparatus. The $V_D$ values obtained were 0.87, 0.89, and 0.89 liter. The $V_L$ values for the same subjects used in Table III are given in Table IV.

The Hydrogen Method without Forced Breathing

The apparatus of Fig. 1 was tested to determine the practicability of its use in connection with the hydrogen method of Van Slyke and Binger. This has the advantage that no $V_D$ determinations are necessary. It was thought that error might arise from loss of hydrogen by diffusion out of the rubber bag, hydrogen, because of its small molecules, being a rapidly diffusing gas. However, actual measurement showed that within the limit of error in reading the scale $G$, there was no loss of gas over a period of 30 minutes, when the bag and the system were filled with hydrogen.

Three determinations of $V_L$ (residual air) for Subject A were performed. The hydrogen contents of the mixed gases were determined by the combustion method of Van Slyke and Hanke (7). The results, calculated as by Van Slyke and Binger (3), were 1.56, 1.58, and 1.62 liters for 4, 5, and 6 minutes respiration, respectively.

Discussion of Results

The results outlined above indicate good agreement between all of the methods used. Apparently, within the analytical and physiological limits of error, both Subjects A and B were in equilibrium with either the Benedict-Roth or the new apparatus, during the respiration time of 3 to 7 minutes. Subject A was quite remarkably constant over a period of several minutes, by any one of the methods used. That similar results would be obtained with other subjects in all cases cannot be stated. Van Slyke and Binger found that one cannot generalize as to the length of time required to reach equilibrium, since several factors, including the initial volume of oxygen in the spirometer and the depth and rapidity of respirations, are of influence. These authors found, however, that with the hydrogen mixture method
equilibrium was obtained in a few minutes even with decompensated cardiac patients, and the conditions of the present method are so similar that the results of Van Slyke and Binger with regard to this point can apparently be applied.

Compared with the hydrogen mixture method (3) for determination of lung volume without forced breathing, the present procedure has the disadvantage of requiring a spirometer, which must be calibrated and have its dead space determined, while the hydrogen method requires only a rubber bag and a scrubber. However, the dead space can be measured with such accuracy that it does not significantly diminish the precision of the present method. The latter has, over the hydrogen procedure, the advantages that it obviates the necessity for the precautions required for the safe handling of hydrogen, requires the use of only one pure gas (oxygen), and simplifies the final analysis to the determination of only nitrogen, instead of nitrogen and hydrogen. For the subject, one method is as convenient as the other. The choice between them will depend upon the spirometer equipment available, and upon the facilities for handling and analyzing gases.

SUMMARY

A method is described for estimating the volume of air in the lungs by the familiar principle of mixing this air with a measured volume of oxygen, and determining the extent to which the nitrogen of the pulmonary air is diluted. By employing a scrubber to remove carbon dioxide, and by measuring the volume of gas in the extrapulmonary part of the system at the end instead of the beginning of the respiratory period, it is possible to prolong the period to as many minutes as are necessary for complete mixture of the gases, and thereby to carry out the estimation without forced breathing.

The determination can be carried out with the Roth-Benedict or Krogh spirometer, or, more economically, with the simple spirometer, shown in Fig. 1, assembled from ordinary laboratory equipment.

The method gives the same results as the hydrogen method of Van Slyke and Binger (3), and obviates the use and analysis of hydrogen. The relative advantages of the two methods are discussed above.
Dr. Ronald V. Christie has informed us that he has encountered considerable differences in the N₂ content of the pulmonary air of different individuals. A gain in accuracy would therefore be made if this value were determined for each subject, and substituted for 79.1 in the calculation formulae.

BIBLIOGRAPHY