Estimation of the Level of Blood Alcohol from Analysis of Breath

The basic principle underlying all breath alcohol methods is that the distribution of alcohol between blood and alveolar air obeys Henry's Law. This means that there is a constant ratio between the weights of alcohol per unit volume of blood and of alveolar air. Therefore, if one determines the weight of alcohol per liter of alveolar air, the weight per liter, or per cc., of blood follows automatically from the distribution ratio at the temperature controlling equilibrium.

In 1910 Cushny1 reported on the pulmonary excretion of acetone, chloroform, alcohol, etc. by animals receiving various sized doses of these compounds. He concluded, "The exhalation of volatile substances from the lungs is exactly analogous to their evaporation from solutions in water, and the pulmonary cells seem to be purely passive in this process" although his quantitative results are somewhat inadequate for confirming this conclusion. Widmark2 in 1920 and Briggs and Shaffer3 in 1921 reported quantitative studies with animals which indicated that the distribution of acetone between blood and alveolar air obeys Henry's Law. Shaffer and Ronzoni4 in 1923, and Haggard in 19245 showed that the behaviour of ether in the lungs also obeys Henry's Law. That the same principle applies to alcohol in the body was stated by Liljestrand and Linde in 19306 and by Haggard and Greenberg in 19347.

Five breath alcohol methods have been developed. Two employ alveolar air and three use total expired air. The first method using alveolar air was reported by Liljestrand and Linde in 19306. They analyzed samples of blood and alveolar air, taken simultaneously from drinking human subjects, and found that the alcohol ratio of alveolar air: blood was uniformly close to 1:2000. A second method using alveolar air is that of Greenberg and Keator8 which was published in 1941. They call their apparatus an "Alcometer". In their method they adopted the alveolar air: blood alcohol ratio reported by Haggard et al9 which is 1:1300. Seven years earlier, Haggard and Greenberg7 had reported that this ratio is 1:1150.

One of the breath alcohol methods employing total exhaled air was published by Bogen10 in 1927. He was the first to propose breath alcohol analysis for medico-legal purposes. He stated that 2 liters of
expired air contain approximately the same weight of alcohol as 1 cc. of the subject's urine.

In 1931 one of us (R.N.H.)\(^{11}\) reported that the ratio of alcohol to carbon dioxide in expired air can be used to estimate the concentration of alcohol in the blood. Here the per cent of carbon dioxide in the breath sample is used to calculate the fraction of alveolar air in this sample, since Haldane and Priestley\(^ {12}\) had shown that normal alveolar air contains close to 5.5 per cent of carbon dioxide. Our results with this method, plus experiments in vitro, agreed with the finding of Liljestrand and Linde\(^ {6}\) that the correct ratio for alcohol in alveolar air: blood is close to 1:2000. Thus, one simply determines the weight of alcohol which accompanies 190 mgs. of carbon dioxide in the breath, 190 mgs. being the weight of carbon dioxide in 2 liters of any gas containing 5.5 per cent of carbon dioxide. Our results with this method, plus experiments in vitro, agreed with the finding of Liljestrand and Linde\(^ {6}\) that the correct ratio for alcohol in alveolar air: blood is close to 1:2000. Thus, one simply determines the weight of alcohol which accompanies 190 mgs. of carbon dioxide in the breath, 190 mgs. being the weight of carbon dioxide in 2 liters of any gas containing 5.5 per cent of carbon dioxide and at a temperature of 37\(^ {\circ}\).\(^ {8}\) After several years of trial, including comparison of the results with direct analysis of blood, the method was presented more fully in a paper by Harger, Lamb, and Hulpieu in 1938.\(^ {13}\) This paper also described a new reagent for alcohol which is standard permanganate in 16 normal sulfuric acid. This concentration of sulfuric acid is much higher than that formerly used by chemists in analyses with permanganate, and it causes the alcohol to react rapidly and quantitatively with the permanganate at room temperature. We called the portable apparatus for this method a "Drunkometer".

A third breath method using expired air was published by Jetter, Moore, and Forrester in 1941.\(^ {14}\) It employs the same principles as the method of Harger, Lamb and Hulpieu,\(^ {13}\) including the alcohol-carbon dioxide ratio,\(^ {8}\) but the permanganate reagent is replaced by another procedure for determining alcohol. This consists in absorbing the alcohol and moisture from the breath by passing it through a tube containing solid magnesium perchlorate. Subsequently the absorbent is dissolved in water, the alcohol is distilled off, and the distillate is analyzed for alcohol by a dichromate method. Jetter, Moore and Forrester named their apparatus an "Intoximeter".

**Points of Disagreement Among the Breath Methods**

1. While the authors of the five breath methods described above all agree that Henry's Law is followed in the distribution of alcohol between alveolar air and pulmonary blood, they do not agree as to what is the correct ratio for this distribution. Liljestrand and Linde,\(^ {6}\) Harger, Lamb and Hulpieu,\(^ {13}\) and Jetter, Moore, and Forrester\(^ {11}\) all reported a ratio close to 1:2000 for alveolar air: blood. On the other hand Haggard and his colleagues in 1934 stated\(^ {7}\) that the ratio is 1:1150 and then revised it to 1:1300 in 1941.\(^ {9}\)

2. A second point of disagreement is the temperature which controls the final equilibrium between blood and exhaled breath. Haggard et al\(^ {9}\) assumed that it is 38\(^ {\circ}\), although as pointed out by Winslow, Herrington and Nelbach,\(^ {15}\) the temperature

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\(^{8}\) With men, Fitzgerald and Haldane\(^ {28}\) found an average of 5.6 % of CO\(_2\) in dry alveolar air. This would mean 186 mgs. of CO\(_2\) in 2 liters at 34\(^ {\circ}\) and saturated with moisture.

\(^{9}\) In their formula for calculating blood alcohol Jetter, Moore and Forrester use 200 mgs. of CO\(_2\), instead of 190 mgs., as employed by Harger, Lamb and Hulpieu.
of breath leaving the nose or mouth is about 34°. Liljestrand and Linde\(^6\) stated that the temperature at which breath leaves the mouth is 31.°

3. Haggard et al\(^9\) contended that the alcohol-carbon dioxide ratio used by Har­
ger, Lamb and Hulpieu\(^13\) and Jetter, Moore and Forrester\(^14\) gives high results because they claim that the proportion of alcohol to carbon dioxide is higher in the respiratory dead space than it is in the alveoli.

4. Finally, Haggard et al\(^9\) claimed that the collection of breath samples in rubber balloons at room temperature yields low results because a considerable amount of the alcohol is removed by a film of moisture which condenses on the interior of the balloon. On the other hand, Jetter and Forrester\(^16\) found no significant loss of alcohol due to this cause.

In order to obtain further information regarding these four points of disagree­ment we have conducted a number of experimental studies. One of these, which describes in vitro determination of the partition ratio of alcohol between air and water, urine and blood, was recently re­ported by Harger et al.\(^17\) In that study they were unable to confirm the invitro air: blood alcohol results reported by Hag­
gard et al.\(^9\) The results of Harger et al\(^17\) supported the finding of Liljestand and Linde\(^6\) that the ratio for alveolar air: blood at the temperature of the breath as it leaves the mouth or nose should be about 1:2000.

In the present paper we report studies on the following points: (1) the distribu­tion of alcohol between alveolar air, or rebreathed air, and blood of human sub­jects; (2) the temperature at which the breath leaves the mouth; (3) the reliability of the breath alcohol-carbon dioxide ratio for predicting blood alcohol; (4) the pos­sible loss of alcohol from condensed moisture inside the bolloon and (5) the correlation between blood alcohol and al­cohol in a given volume of ordinary exp­ired air. Our experimental procedures and results, together with a discussion of find­ings of other workers, follow.

**Experimental**

1. Distribution of Alcohol between Al­veolar Air, or Rebreathed Air, and Blood of Human Subjects. Thirty-three indi­viduals were used in this study. Each ingest­ed a volume of 90-proof whiskey corres­ponding to 4, or 6, fluid ounces of this liquor for a 150 pound person, or a dosage of 0.61 or 0.92 grams of alcohol per kilo. Most of the subjects received the larger dose. At intervals of 1 hour, 2 hours, and occasionally 3 hours, following ingestion of the whiskey, samples of alveolar air and blood were obtained. The blood was drawn within 3 minutes after the alveolar air was collected. With part of the sub­jects samples of rebreathed air were also collected. The samples of alveolar air and rebreathed air were collected in flexible aluminum bags of the type described by Harger, Turrell, and Miller.\(^18\) The bags were kept in an incubator having a tempera­ture of 40°. Tests showed that breath from alcoholic subjects, stored in these bags, suffered no significant loss of alcohol or carbon dioxide during a period of 1 or 2 hours. The inlet of the bag was connected by means of a 4 inch length of rubber tubing to one limb of a short, rather wide glass T. A second limb of the T was connected to a basketball bladder, part of which was rolled around a thin wooden strip and clamped between two other wooden strips so that it could be in­flated to about 600 cc. At the end of a nor­mal expiration the subject exhaled deeply.
through the open end of the glass T, with the connection to the aluminum bag closed by means of a pinch clamp, until the first 600 cc. were collected in the rubber bag, after which an operator quickly shunted the breath stream into the aluminum bag. This process was repeated several times until somewhat more than a liter of alveolar air was collected. In order to flush out the aluminum bag the first collection was drained out by gentle suction and the collecting process repeated. The glass T and its rubber connections were kept warm during the sampling process. Shortly after obtaining the sample, a portion of it was analyzed for alcohol and carbon dioxide. The latter was determined in order to make sure that the sample was alveolar air. The gas from the aluminum bag was conducted outside the incubator through an internally heated glass tube of the type described by Harger et al., the alcohol was absorbed in cold 50% sulfuric acid and the analysis completed as described by these workers on pp. 198—9 of their paper. The train of tubes for absorbing carbon dioxide (de-hydrite followed by ascarite) was placed between the alcohol absorption tube and the gas burette. The observed volume of gas was corrected to the volume it would have occupied at 34° before removal of the carbon dioxide and saturated with water vapor.

For obtaining rebreathed air, the subject took a deep inspiration, exhaled deeply into the empty aluminum bag, and then rebreathed this gas with five deep inspirations and expirations. The nose was, of course, closed during this operation.

The blood samples were analyzed for alcohol by the dichromate method of Harger, using the slight modifications described by Harger et al. A blank of 0.08 mgs. per cc. was subtracted from all of our blood alcohol results, since it is the average figure given by this method for the volatile reducing substance in normal blood.

The results are shown in Fig. 1, which gives the correlation between alcohol per cc. of blood (a) and alcohol per 2 liters of alveolar air or rebreathed air (b). A ratio of 1:1 for (a): (b) is shown by line A. Line B represents a ratio of 1:1.54 for (a): (b), which is the ratio one would obtain if the weight of alcohol in 1 cc. of blood were contained in 1300 cc. of alveolar air as claimed by Haggard et al. The results certainly do not confirm this 1:1300 ratio because, with one or two exceptions, none of the dots even approach line B. As a matter of fact, the average is a little below line A indicating that the correct alveolar air: blood ratio is perhaps nearer 1:2100.

Our results also indicate that rebreathed air and alveolar air contain essentially the same concentration of alcohol. On this point we are in agreement with the finding of Haggard et al.

2. The Temperature of Breath When it Leaves the Body.

The temperature of expired air at the moment it leaves the mouth or nose has been extensively studied by Liljestrand and Sahlestedt, Perwitzschksy, Seeley and others. These studies have recently been reviewed by Winslow, Herrington and Nelbach, who stated "The temperature of the expired air under normal conditions is 32—35° C; though in very cold atmospheres (Seeley) it may be as low as 25° C".

Using six subjects, we determined the temperature of the breath as it left the mouth. The measurements were made with a copper-constantin thermo-couple of 32-
Fig. 1

Correlation between alcohol per cc. of blood and alcohol per 2000 cc. of alveolar air or rebreathed air.

- Alveolar Air
- Rebreathed Air


B = Line of perfect correlation, Alveolar air : Blood ratio = 1 : 1300.

gauge wire and a sensitive galvanometer* having a short damping period. The reference junction of the thermocouple was placed in water contained in a thermos bottle and having a temperature close to 31°. Bureau of Standards tested thermometers were used for determining the temperature of the water inside the thermos bottle and for calibrating the readings of the galvanometer. The variable temperature junction of the thermocouple was held so that it protruded about ½ inch beyond the inner end of a short length of glass tube, with a diameter of 10 mm., which was held between the lips of the subject, making sure that the thermocouple did not touch any structure within the mouth. The subject inhaled through the nose and then
slowly exhaled deeply through the glass tube, taking about 10 seconds for the exhalation. The observed temperature of the exhaled air was about 31° at the beginning of an expiration and rose to about 35° at the very end of the prolonged expiration. Since these results agreed quite well with those of earlier investigators it was not considered necessary to conduct more extensive experiments.

3. The Use of the Alcohol-Carbon Dioxide Ratio of Expired Air to Estimate the Level of Alcohol in the Blood.

Immediately after obtaining the samples of blood from the 33 subjects mentioned above, samples of ordinary expired air were obtained and analyzed for their content of alcohol and carbon dioxide. With all of the subjects, one sample of breath was
Correlation between alcohol per cc. of blood and alcohol per 190 mgs. of CO₂ of mixed expired air. Samples collected in flexible aluminum bags. Alcohol analysis by dichromate method.

Fig. 3

Collected in a rubber balloon and analyzed at room temperature by the permanganate (drunkometer) method of Harger, Lamb and Hulpieu. In this analysis we used 1 cc. of 0.05 normal permanganate and the color matching tube described by Harger et al. (pp. 206—8 of their paper). With some of the subjects a duplicate analysis by this method was carried out with the balloon and drunkometer kept in the incubator at 40°, and a third breath sample was collected in a rubber balloon kept at 40° and this sample then analyzed by the dichromate procedure employed for alveolar air. (Sec. 1). The passage of breath through the drunkometer or gas scrubber tube was completed within 2 minutes after the balloon was inflated. New rubber balloons were employed which required a pressure of about 22 inches of water for inflation.

Fig. 2 shows the observed correlation between alcohol per cc. of blood and alcohol per 190 mgs. of carbon dioxide in the breath. These data represent 100 consecutive determinations with the 33 subjects. In 63 of these determinations the weight of alcohol which accompanied 190 mgs. of carbon dioxide in the breath was within ±10% of that found in 1 cc. of the sub-
ject's blood. The corresponding deviations for the remaining determinations were: $17, \pm 11\text{--}15$ per cent; $10, \pm 16\text{--}20$ per cent; $3, \pm 21\text{--}25$ per cent; $6, \pm 26\text{--}28$ per cent; and $1, \pm 32$ per cent. The mean deviation was $\pm 9.7$ per cent.

While the deviation between calculated and observed figures for blood alcohol exceeded 20 per cent in one-tenth of the determinations, being $\pm 32$ per cent in one case, the results represent a very considerable improvement over those reported by Harger, Lamb and Hulpieu in 1938.13 Jetter and Forrester16 have also studied the correlation between the alcohol-carbon dioxide ratio of the breath and the level of alcohol in the blood. Their results for 79 determinations, which are shown as Fig. 2 of their paper, agree quite well with ours, the average deviation (Jetter$^{25}$) being $\pm 10$ per cent with a maximum deviation of $\pm 16$ per cent. Fabre and Leheuzey,$^{24}$ from a few determinations, reported similar results.

With part of our subjects we also collected samples of expired air in the aluminum bags of the type we used for alveolar air. These required practically no pressure to inflate. These breath samples were then analyzed for alcohol and carbon dioxide, using the procedure for alveolar air described in Sec. 1. The correlation between alcohol per 190 mgs of carbon dioxide in the breath and alcohol per cc. of blood is shown in Fig. 3. It will be observed that the results for breath average higher than those where rubber balloons were used for collecting the breath sample (Fig. 2), the mean difference being 14 per cent.

The reason for a higher ratio of alcohol to carbon dioxide in the samples of ordinary breath collected in aluminum bags, compared to those collected in rubber balloons, merits further study. The squeezing of the lungs by the muscles of respiration in order to produce the gas pressure of about 40 mm. of mercury required to inflate the balloon, might alter the relative volume of the respiratory dead space. A second factor might be a longer interval between inspiration and expiration. Mackay$^{29}$ found that a prolonged time of expiration resulted in abnormally high values for carbon dioxide of alveolar air.

4. Possible Loss of Alcohol from Condensed Moisture Inside the Balloon.

The criticisms of Haggard et al$^9$ on this point were based on the drop in alcohol content which they observed with air, saturated with moisture at 40° and containing alcohol, when rubber bags containing this air were subjected to lower temperatures. Their results are misleading because, as mentioned previously, breath leaves the mouth at a temperature much below 40°. Furthermore, some of the lower temperatures which they employed are far below the temperature attained by breath during a drunkometer test.

Winslow, Herrington, and Nelbach$^{15}$ stated "The actual moisture content of the expired air under normal conditions is 30—37 grams per cubic meter. In a very hot atmosphere (Seeley) or in a state of fever (Azzi) the value may be greater".

Using five subjects, we determined the moisture content of ordinary breath and of alveolar air. Each sample was collected in an aluminum bag$^{18}$ with the bag and its inlet kept in an incubator at 40°. The sample was then passed through a tube containing dehydrite, followed by a tube containing ascarite, and the gas was collected over water in a burette outside the incubator. From the weights of water and carbon dioxide caught, and the gas burette reading corrected for water vapor, the
moisture content of the breath was then calculated, assuming that it left the mouth at 34°. We ran fifteen analyses with ordinary breath and fourteen with alveolar air. The weight of water found in ordinary breath ranged from 26.5 to 37.8 mgs. per liter, averaging 32.0 mgs. The air saturation temperatures corresponding to these weights of water vapor are, 27.6° to 34.2°; ave. 31.0°. With alveolar air we found 30.1 to 40.2 mgs. of water per liter, with an average of 35.3°. The corresponding saturation temperatures are, 29.7° to 35.3°; ave., 32.6°.

The drop in temperature of 2000 cc. samples of breath collected in rubber balloons was measured by means of a thermometer inserted through a small hole in the balloon wall and tied in place. The tests showed that, during the two-minute interval required for the drunkometer analysis, the temperature within the balloon rarely fell below 27°, except where the room temperature was less than 21°. With the room temperature at 21° to 25° the mean temperature of the air within the balloon during a two-minute period following inflation was about 29°.

If moisture condensation occurs within the balloon containing alcoholic breath, the fraction of the total alcohol absorbed in the liquid phase will be governed by the relative volumes of the two phases and the alcohol partition ratio, \( k_A^W \), for the temperature reached. The concentration of alcohol in the final gas phase will be the same as would result, if, without moisture condensation, the volume of gas was increased by adding a volume of alcohol-free air equal to the volume of water actually formed multiplied by \( 1/k_A^W \).

The mass of water vapor in saturated air at 34° is 37.5 mgs. per liter and at 28° it is 27.2 mgs. per liter. If a liter of breath at 34°, containing alcohol vapor and saturated with moisture, is cooled to 28° its final volume will be 965 cc. The water removed by condensation will be 37.5 — (27.2×0.965) = 11.3 mgs., or approximately 0.0113 cc. At 28° \( k_A^W \) is 0.000266 so that the air equivalent of the condensed water is 0.0113 : 0.000266 = = 42.5 cc. Therefore, the fraction of the total alcohol removed by the water phase will be

\[
\frac{42.5}{42.5 + 965} = 0.0113 
\]

or 4.2 per cent.

A similar calculation will show that if the breath sample were cooled all the way from 34° to 21° the alcohol removed by the condensed moisture would be a little less than 12 per cent.

With 9 of our subjects, immediately after the routine drunkometer analysis at room temperature, we ran a duplicate drunkometer analysis with the balloon and apparatus kept at 40°. We then collected a third breath sample in a balloon kept at 40° after which we analyzed the contents of this balloon for carbon dioxide and alcohol, with the latter determined by the dichromate procedure used for alveolar air. The results of these three types of breath analysis and the alcohol content of the corresponding blood samples are given in Table I. The drunkometer results obtained at room temperature averaged 97.3 per cent of those by this method at 40°, and 93.5 per cent of the results by the dichromate procedure at 40°.

Using breath samples collected in glass flasks, Fabre and Leheuzey observed a drop of 7 per cent in the alcohol per 190 mgs. of carbon dioxide when the breath

\* Calculated from vapor pressure figures given in International Critical Tables, Vol. IV, p. 212.
TABLE I.
Comparison of Drunkometer Results Obtained at Room Temperature
With Breath Analyses Conducted at 40°.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Time after ingestion of alcohol</th>
<th>Blood alcohol</th>
<th>Analysis by Drunkometer</th>
<th>Analysis by dichromate method at 40°</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Hrs.</td>
<td>Mgs./cc</td>
<td>At room temp.</td>
<td>At 40°</td>
</tr>
<tr>
<td>A</td>
<td>1</td>
<td>1,14</td>
<td>0,85</td>
<td>0,96</td>
</tr>
<tr>
<td>A</td>
<td>2</td>
<td>0,92</td>
<td>0,85</td>
<td>0,94</td>
</tr>
<tr>
<td>B</td>
<td>1</td>
<td>1,13</td>
<td>1,03</td>
<td>1,04</td>
</tr>
<tr>
<td>B</td>
<td>2</td>
<td>1,07</td>
<td>1,10</td>
<td>1,19</td>
</tr>
<tr>
<td>C</td>
<td>1</td>
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<td>1,27</td>
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</tr>
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<td>1,03</td>
</tr>
<tr>
<td>I</td>
<td>1</td>
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<td>1,20</td>
<td>1,29</td>
</tr>
<tr>
<td>I</td>
<td>2</td>
<td>0,99</td>
<td>0,83</td>
<td>0,72</td>
</tr>
</tbody>
</table>

was cooled to 20°, and a drop of 14 per cent when it was cooled to 10°. When
they collected the breath in rubber balloons
and calculated the blood alcohol level from
the alcohol-carbon dioxide ratio, the results
were 15 to 16 per cent below their results
from direct analysis of blood and saliva.
However, in their procedure it apparently
took 8 minutes, or longer, to pass the
breath sample through their reagents.

5. The Correlation Between the Concentration of Alcohol in Blood and in a
Given Volume of Breath.

In our 1938 paper we suggested using the weight of alcohol in 4 liters of breath
as an approximate check on the results
from the alcohol-carbon dioxide ratio.
Since we had observed a wide fluctuation
in the carbon dioxide content of 500 cc.
samples of breath, depending on the por-
tion of expired air used and on the time
the breath remained in the lungs, we did
not place much reliance on the results ob-
tained on the basis of breath volume.
Subsequently, results on the volume basis
obtained with hundreds of subjects have
shown a correlation with the results from
the alcohol-carbon dioxide ratio, and with
results of blood alcohol analyses, which
is far better than we had anticipated. Ap-
parently, the reason for this is that, in
Correlation between alcohol per cc. of blood and alcohol per 3200 cc. of CO₂-free mixed expired air measured over water at 25°. Alcohol analysis by drunkometer method.

Inflating a balloon to about 2000 cc., the subject tends to exhale a fairly constant proportion of alveolar air and breath from the respiratory dead space. Our results indicate that the volume of such breath containing the weight of alcohol found in 2000 cc. of alveolar air, and therefore in 1 cc. of blood, averages about 3475 cc. at 34°. This would mean that such a sample of breath is about 58 per cent alveolar air. When the carbon dioxide is removed from this 3475 cc. of breath and the remainder is collected over water at 25° its volume will be 3200 cc. Since the weight of alcohol caught in the drunkometer analysis is always 0.169 mg., a test run with a subject having a blood alcohol of 1 mg. per cc. should yield a volume reading of $3200 \times 0.169 = 541$ cc. of CO₂-free breath measured over water at 25°. Thus, if $V$ is the volume of breath used in a drunkometer test, when measured over water at 25° after removal of carbon dioxide then, $541 : V$ should equal mgs. of alcohol per cc. of the subject's blood.
Using this formula we calculated the blood alcohol from the observed drunkometer volume reading in 90 tests with the 33 subjects used in this study. The correlation between these results and those from direct analysis of blood is given in Fig. 4. It will be observed that this correlation is quite satisfactory. We recommend that this volume procedure be routinely done in all drunkometer analyses, since it can be run simultaneously with the determination of the alcohol-carbon dioxide ratio and because it furnishes a second estimation of the subject's blood alcohol. In those rare cases where the per cent of carbon dioxide in alveolar air is abnormal, the volume result is probably to be preferred to the results from the weight of carbon dioxide caught in the test.

**Discussion**

While the blood alcohol levels of the subjects used in this study do not cover a very wide range, we feel that the data obtained serve quite as well to answer the questions investigated as would higher, or lower, blood alcohol levels. Most of our subjects preferred not to take more than 1 gram of alcohol per kilo.

There are three reasons why one would not expect a perfect correlation between the levels of alcohol in blood and in breath. The first is the inherent fluctuation in the temperature of the breath as it leaves the mouth. While air in the alveolii presumably comes to equilibrium with pulmonary blood plasma at about 37°C, it is cooled to 35°C, or lower, before emerging from the mouth. The latter temperatures control the partition ratio of alcohol between the fluids bathing the upper respiratory tract and the breath exhaled from the alveolii. Studies by a number of investigators, including ourselves, have shown that the temperature of the breath as it leaves the mouth may fluctuate by as much as 2 or 3°C, depending upon the temperature of the inspired air and the manner of breathing. Since a rise or fall of 1°C changes the vapor tension of alcohol about 7 per cent, it is not surprising that the calculated blood alcohol figure may deviate from the true value by as much as ±10 per cent.

A second feature may result in apparent discrepancies when one compares the results from breath with those from peripheral venous blood. It is the fact that the alcohol level in peripheral venous blood is not always identical with the level in heart blood, although the latter level controls the concentration of alcohol in the breath and probably also in the brain. Harger, Hulpieu, and Cole and Forney, Hulpieu, and Harger have shown that, for a short time after ingestion of alcohol, the alcohol level in peripheral venous blood lags considerably behind that of heart blood. The average venous/heart blood ratios which they found for three intervals were: 10 min., 0.72; 15 min., 0.83; and 30 min., 0.91. While almost all of their animals had essentially the same level of alcohol in venous and heart blood at the end of 1 to 3 hours after receiving alcohol, with a few of them the level of alcohol in the heart blood was still 12 to 15 per cent above that of peripheral venous blood. This difference may explain some of our breath figures which were significantly higher than those from venous blood. Our subject in which the breath result deviated most from the blood figure (+32%) certainly exhibited symptoms which corresponded more nearly to the breath figure.

A third factor which may affect the accuracy of methods employing the alco-
hol-carbon dioxide ratio of breath is the fluctuation of the carbon dioxide content of alveolar air. Jetter and Forrester\textsuperscript{16} have estimated that the maximum deviation from the average normal level of alveolar carbon dioxide which might be anticipated is $+16$ per cent. However, as shown by Fitzgerald and Haldane\textsuperscript{28} the mean fluctuation normally observed is less than this.

In spite of the limitations which we have mentioned, the results obtained by ourselves and others to show that analysis of breath will predict the level of alcohol in the blood in a reasonably satisfactory manner. While the precision is less than is required in research, the results are sufficiently accurate for the routine testing of automobile drivers and industrial workers. As a matter of fact, breath analysis appears to predict the level of blood alcohol about as well as does urine analysis, judging from the results of urine analyses reported by Southgate and Carter,\textsuperscript{29} Carlson et al,\textsuperscript{30} Bavis,\textsuperscript{31} and Jetter.\textsuperscript{23}

Greenberg and Keator\textsuperscript{8} state that their alveolar air alcohol method will predict the capillary blood alcohol level with a mean deviation of 0.05 mgs. per cc. and a maximum deviation of 0.15 mgs. per cc. For a blood alcohol of 1 mg. per cc. this would mean an average error of 5 per cent and a maximum error of 15 per cent.

The drunkometer volumetric procedure, employing rebreathed air, appears quite promising and we plan further studies with it. It would eliminate the use of a balance and would permit a much longer interval between collection of the sample and its analysis. Since the rate of heat conduction by aluminum is much faster than by rubber we plan to warm the aluminum bag with a light, electrically-heated blanket. We believe, however, that the alcohol-carbon dioxide pump procedure described by Harger, Lamb, and Hulpieu\textsuperscript{15} should also be available for running tests with subjects who can not, or will not, inflate a breath container.

**Summary**

1. Alcohol analyses of simultaneous samples of blood and alveolar air from 33 persons, 1 hour, and 2 hours, after drinking 0.6—0.9 gr. of alcohol per kg., showed an average alveolar air : blood alcohol ratio of about 1 : 2100. Essentially the same ratio was found for rebreathed air. These results support the findings of Liljestrand and Linde, but not the ratio of 1 : 1300 claimed by Haggard et al.

2. The temperature of the breath as it leaves the mouth was found to vary from 31\textdegree{} to 35\textdegree{}, the higher figure being observed at the end of a prolonged expiration.

3. One hundred consecutive samples of breath from the 33 subjects were collected in rubber balloons analyzed by an improved modification of the ascarite-permanganate method of Harger, Lamb and Hulpieu (drunkometer), and the results compared with direct analyses of simultaneous samples of peripheral venous blood. The average deviation between mgs. of breath alcohol per 190 mgs. of carbon dioxide and mgs. of alcohol per cc. of blood was $+9.7$ per cent, with maximum deviations of $-28$ per cent and $+32$ per cent. Some of the deviations were probably due to discrepancies between the level of alcohol in heart blood and that in peripheral venous blood. This breath procedure will predict blood alcohol about as well as does analysis of urine.
4. Breath samples, collected in flexible aluminum bags requiring practically no pressure for inflation, showed a ratio of alcohol/carbon dioxide averaging 14 per cent higher than that of simultaneous samples collected in rubber balloons. Possible reasons for this difference are discussed.

5. To check the effect of moisture condensation, the results of drunkometer analyses conducted at room temperature were compared with those obtained at 40°. The results at room temperature averaged 97.3 per cent of those obtained at 40°. This slight effect due to moisture condensation is in the order of magnitude which one would calculate from the quantity of water condensed and the partition ratio of alcohol between water and air at the temperature reached.

6. A comparison was made of the weight of alcohol per unit volumes of ordinary expired air and blood in drunkometer tests where the subject collected about 2 liters of expired air in a rubber balloon. The results showed that the weight of alcohol per cc. of blood was contained in about 3400 cc. of the breath, when measured over water at 25° after removal of carbon dioxide, with a correlation which was quite satisfactory. This determination furnishes a second estimation of blood alcohol in the drunkometer procedure.

7. Since rebreathed air contains essentially the same alcohol concentration as alveolar air, we are proposing a simplified drunkometer procedure which involves only the collection of rebreathed air in a warmed, flexible, aluminum bag, with the result calculated from the volume of breath required to decolorize the permanganate reagent.

REFERENCES


