Breath Tests for Determining Alcohol in the Blood

Science-society interactions are seen in microcosm in the use of breath alcohol tests in the courtroom.

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From the point of view of society, science is its handmaiden: science can be no mere intellectual pursuit. As a consequence, the products of science and technology have in large part determined the very structure of modern society. In recent times, society has demanded even more of science. Science, it is said, must contribute to the solution of specific social problems (which, indeed, it may have helped to create). But just how is this to be accomplished? It is not "science" that can act, of course, but individual scientists. Precisely what can they do?

As Weisskopf (*1*) has pointed out, the methods by which scientific efforts may accomplish their intended purposes have not been fully resolved. Various technological "shortcuts" to the solution of particular social problems may not fulfill every expectation (*2*). Conversely, society itself may influence the kinds of scientific input that may be brought to bear. It may therefore be helpful to study the problems of science-society interaction in microcosm. For that purpose, I focus on a particular encounter: the use in the courtroom of breath tests to determine the amount of alcohol in the blood of "drunk drivers."

Such breath tests have been discussed elsewhere (*2*, *3*). That the drunk driver represents a significant social problem scarcely needs reference (the U.S. Department of Transportation estimates that 50 percent of traffic fatalities—of which the National Safety Council estimates 54,800 in 1970—are "alcohol related"). The particular advantage of this example, however, lies in the fact that, for better or worse, the methodology employed in the encounter has been worked out in some detail, through courtroom law.

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The determination of alcohol in the blood is probably considered by the courts more often than any other scientific or technological issue. Not surprisingly, the mechanisms of this encounter have also become the most formalized. Perhaps studying these legal mechanisms in conjunction with their subject matter will yield a better understanding of the more general problem of science-society interactions (*4*).

To examine even this one type of encounter thoroughly, the individual scientist would have to become familiar with the social mechanisms giving rise to the drunk driver (*1*, p. 144). However, by narrowing the issue to that of the science-society interaction itself, only the immediate legal mechanisms need be considered. Of course, some understanding of these mechanisms is required, even by the scientist who wishes merely to act within the system as established.

The legal mechanisms in question have been built around those contributions that it was deemed science and technology could make. It then falls to the scientist to consider whether this edifice has been built on solid ground. For that purpose, I also outline the current state of the art with respect to breath tests for determining alcohol in the blood, including a discussion of the physiological basis for the tests and a description of some commercial breath-testing devices.

Courtroom Procedure

The methodology of science-society interaction involved here is limited by the procedures through which matters are presented to and decided by a court (*5*). The court decides each case on the basis of the law and of the facts. Matters of law are decided by the judge, while the facts are determined by a jury, if there is one. If there is no jury, the judge will act as the fact-finder as well.

The manner in which the facts are presented depends upon the kind of knowledge involved. Matters of common knowledge may simply be noted by the fact-finder and used accordingly. Any scientist on the jury may use his scientific knowledge as well. If the case involves scientific issues, however, the presence of a scientist on the jury is unlikely. Because of the authority the scientist would wield in the jury room, it is generally feared that such issues would then be decided effectively by him alone. Since scientific expertise would be required by some means, however, alternative procedures are provided.

The judge may also instruct the jury that certain matters are to be taken as true. This process of "judicial notice" may again involve either common or scientific knowledge. Unlike the jurors, however, the judge may consult various treatises for his information. The limitation on this procedure is that the information so acquired must be of "verifiable certainty." This test is met by scientific principles that have "general scientific acceptance."

The actual evidence in a case differs from matters of judicial notice in that it is not, of course, simply taken as true. It must be weighed in each case. Treatises that yield scientific information may also enter a case through this route. The rules for admitting such texts then become less stringent, since the jury is free to decide their truth. Even so, the facts sought to be adduced in this manner must pertain to the "exact sciences" (for example, chemistry or physics).

The remaining procedures by which science may enter the courtroom involve actual testimony from witnesses. It is common lore that a witness may testify only as to "the facts," and may not give his opinions thereon. However, that statement is not quite accurate, even as to ordinary witnesses, because some "facts" can only be communicated adequately through opinion. As long as matters of common experience are involved, such opinions are admissible. One matter upon which lay opinion may be received in evidence is whether a person, such as a defendant, was at some particular time intoxicated. That such opinions cannot always be weighed heavily gave the impetus to the search for more scientific methods of determining degrees of intoxication.

The expert witness, on the other hand, can only express opinions. Since the scientist is not allowed to decide the case in the jury room, he will certainly not be allowed to do so in the courtroom. It is his function to speak with authority on scientific matters, but his testimony is restricted to such matters. That is, he is present in court because of his knowledge, not because of his wisdom. Consequently, in his role as expert witness, he can give testimony only on scientific facts of the case (or so the legal theory goes).

The legal mechanism through which the expert witness testifies is the hypothetical set of facts. His opinions will pertain to the scientific consequences of such hypothetical situations, as posed for him by the attorneys for the respective parties. The "facts" alleged must be expressed as hypotheses because it is the province of the fact-finder alone to decide whether or not they are true. Except upon cross-examination of the expert witness, such hypotheses must be based upon matters for which some evidence has been presented—otherwise, an inattentive jury might decide a case on grounds for which there was no proof whatever.

The scientific expert, therefore, serves merely to carry out the necessary scientific reasoning that the court and jury are incapable of performing.

The expert differs from other witnesses in another important respect. Ordinary witnesses are presumed to be competent, and to speak the truth, until the contrary is shown. The issue of truth as sought by the fact-finder should not arise with respect to the expert witness, since he speaks not of "truth," but of scientific consequences. What *is* at issue is his competence to know and apply correctly the scientific principles involved. This competence must be positively shown to the satisfaction of the court.

Expert witnesses may be employed in many areas other than science. In fact, they become necessary whenever the subject matter falls outside the range of common experience. Whether the subject matter is scientific or not, personal experience by the expert is then necessary. Since the court must act upon its faith in what the expert says, it seeks to ensure that such faith is well founded. Before a scientist is allowed to express his opinions with regard to a particular area of science, he will be asked to specify what studies of that subject matter he has made.

This description of the role of the scientific expert has been quite general, but also quite idealized. It neglects, for example, the fact that the scientist who carries out the chemical analyses may end up testifying both as to the facts of the case and as to his scientific opinions. Even without this kind of overlap, however, actual cases may not come so neatly packaged.

The legal theory may become strained, partly because the scientific expert has little understanding of what his role is intended to be. His help is solicited by an attorney not in order that he may be educated in legal procedure, but in order that the attorney may win the case. As was suggested earlier, the responsibility for entering into the science-society interaction in the most appropriate manner may then fall upon the scientist himself.

Partly for such reasons, but mostly because the use of expert witnesses is both costly and time-consuming, the law has seen fit to resolve certain scientific issues before they get to court. Even scientific issues, after all, must lead eventually to the truth or falsity of some ultimate fact. Since a legislature may establish rules for the admissibility of evidence into court, it may also designate the effect such evidence will have.

A legislature may then specify that, when certain facts are properly shown, certain conclusions follow. The scientific issues may be involved both in what constitutes a proper showing and in the drawing of the conclusion. To make such specifications, scientific assistance to the legislature is clearly necessary. In effect, the scientist then acts through the legislature to inform the judge of what scientific conclusions may be noted judicially, for the benefit of the jury. (Any matters peculiar to a particular case, such as whether the requirements for a "proper showing" were in fact met, would still need to be shown by actual evidence.) The dominant example of this procedure is found in the use of breath (or other) tests to determine the percentage of alcohol in the blood.

Implied Consent Laws

A statute that purports to resolve a particular scientific issue should be distinguished from one that merely authorizes the use of some general scientific procedure. That is, various statutes may call for blood tests to determine paternity or the use of narcotics antagonists, or tests for phenylketonuria in the newborn. However, none of these statutes goes as far as those concerned with the "drunk driver"—the so-called "implied consent" laws—in specifying the tests to be made and the conclusions to be drawn therefrom. It was the purpose of these statutes to provide more scientific proof of intoxication, consequently solutions had to be found for three major problems:

1) What scientific measure could be employed?

2) By what scale would this measure be related to the degree of intoxication?

3) How would the evidence for use in individual cases be obtained? (This third problem, it will be seen, raises both scientific and legal questions.)

The scientific-medical community aided in solving each problem. It had long been recognized that it was not the amount of alcohol a person had consumed which determined his degree of intoxication, but rather the amount of alcohol in his bloodstream (*6*). The percentage of alcohol by weight in the person's blood (milligrams of alcohol per 100 mg of blood or, in some jurisdictions, grams of alcohol per 100 cubic centimeters of blood) was then adopted as the measure to be employed.

The problem of relating such values to the level of intoxication was considered in the 1930's by what was to become the Committee on Medico-legal Problems of the American Medical Association and the Committee on Tests for Intoxication (later the Committee on Alcohol and Drugs) of the National Safety Council (*6*, p. 21). Since the concentration of alcohol in the blood had numerical values, but degrees of intoxication did not, some means had to be devised for relating such numerical values to the kind of language used in the statutes to define drunk driving offenses.

Early statutes defined the offense in

terms of "driving while intoxicated" (*6*, p. 2). To obtain conviction, the courts required proof of rather severe inebriation. To avoid such requirements, the statutes were then amended to read "driving under the influence of liquor." The courts responded to the effect that this difference in terminology was merely semantic. Nevertheless, the degree of intoxication that had to be shown in order to obtain conviction was gradually lowered (*6*, p. 4). This change no doubt resulted from an increased awareness of the dangers of drunk driving.

Whatever the language, however, it still remained to link together the language in the statutes and the measurable amounts of alcohol in the blood. The mechanism adopted was that of the legal presumption. That is, if a given percentage of alcohol were found in the blood of the defendant, he could be deemed to have committed (or not to have committed) the given offense, whatever its name. The recommendations of the committees studying the subject were then incorporated into the *Uniform Vehicle Code* (*7*):

1. If there was at that time 0.05 percent or less by weight of alcohol in the person's blood, it shall be presumed that the person was not under the influence of intoxicating liquor.
2. If there was at that time in excess of 0.05 percent but less than 0.10 percent by weight of alcohol in the person's blood, such fact shall not give rise to any presumption that the person was or was not under the influence of intoxicating liquor, but such fact may be considered with other competent evidence in determining whether the person was under the influence of intoxicating liquor.
3. If there was at that time 0.10 percent or more by weight of alcohol in the person's blood, it shall be presumed that the person was under the influence of intoxicating liquor.

The foregoing language, or some close variation thereof, has subsequently been adopted in the statutes of at least half of the states. Judicial notice has been taken of the general validity of using the percentage of alcohol in the blood as a measure of intoxication. Indeed, with increased experience in applying these statutes, a trend has developed to amend them so that lower percentages imply the influence of alcohol (*6*, p. 23).

If the purpose of such legislation is the promotion of safety on the highways, however, one may wonder whether the link it establishes with intoxication is sufficiently strong. Evidence of a defendant's degree of intoxication by way of the subjective judgments of witnesses is still received. Furthermore, the development of a scientific measure of intoxication, in the form of these percentages of alcohol in the blood, might well be wasted if, as is not too hard to imagine, the subtleties of these statutory presumptions are not fully appreciated by many juries.

In at least two states, a more direct link has been achieved. It should be mentioned that any legislation of this type, in which the so-called "police power" of a state is directed toward the protection of its citizens, is subject to a constitutional test of "rational connection." If there exists sufficient reason to connect highway safety to "driving under the influence" to percentage of alcohol in the blood, however, there seems to be no reason why the middle step could not be eliminated. Consequently, in Nebraska and Oregon, at least, driving a motor vehicle on the public highways while the concentration of alcohol in one's blood is 0.15 percent by weight has been made an offense in itself (*8*) (several countries also follow such a practice).

This development suggests that the contributions of the physical sciences to the problem of drunk driving have not been exhausted. That is, speed laws very often specify that a certain fine shall be imposed for each 5 miles per hour by which the speed limit is exceeded. Whether an analogous system linking severity of punishment directly to percentage of alcohol in the blood should be adopted presents a legal problem. It is a scientific question, however, whether the routine accuracy of determinations of alcohol in the blood would be comparable, for example, to that of measuring vehicular speed by radar.

Leaving this problem of the legal application of determinations of alcohol in the blood perhaps only partially resolved, I turn now to the final problem of obtaining the evidence in individual cases. The legal aspects of this problem relate to the manner in which the "implied consent" laws got their name. If the percentage of alcohol in a defendant's blood is to be determined by analysis of his blood, breath, or urine, he must be persuaded to provide a sample. The original theory was that such samples could not be taken without his consent. However, nothing prohibited the use of some leverage to obtain that consent. Acceptance of a driver's license from the state was then deemed to constitute consent to the taking of such samples, should the need arise. If a test for alcohol in the blood was refused by a person when that circumstance arose (that is, upon his arrest on a "drunk driving" charge), his driver's license would be revoked. Since having a driver's license is a "privilege" and not a "right" such revocation would not constitute the taking of property without due process of law.

It was then argued that, even if the state could take the sample, it could not be used in evidence against the person because of the prohibition against self-incrimination. That argument was effectively put to rest by the U.S. Supreme Court case of Schmerber *v.* California (*9*). In that case, distinction was drawn between "testimonial" or "communicative" evidence and "physical" evidence. The latter category, to which the prohibition against self-incrimination is inapplicable, was deemed to include samples of body fluids. (Some courts have then concluded that the "consent" in the implied consent laws is not required.)

Samples of body fluids to be used in determining the percentage of alcohol in the blood are then routinely obtained and analyzed by the police. To protect the defendant, however, standard procedures must be rigorously followed. These are prescribed by another institute of government, usually a state board of health, under the authority of the legislature. (This represents a science-society interaction within the legal system which takes place outside the courtroom.) The implied consent laws will then specify that the results of such analysis shall be admissible in court only if they are obtained in accordance with procedures approved by the particular agency designated.

Procedures that might be adopted would be limited by the available technology or science. In the case of breath tests, additional complications arise from the nature of the respiratory process. A review of the physiology involved is prerequisite to an examination of the measurement technology. Together, these issues define the scientific dimensions of the problem of obtaining specific evidence.

Problems in Physiology

The percentage of alcohol in the blood as a measure of intoxication presents physiological problems beyond that of establishing the numerical values to be incorporated into the statutes. In the courtroom, such problems may include estimates of what concentration can result from drinking the traditional "two beers" or how rapidly the ingested alcohol reaches the bloodstream and then disappears. The nature of breath-blood interaction is involved in the proper taking of breath samples. The alcohol content of the breath must then be related in some way to that of the blood.

As noted, it is the percentage of alcohol in the blood that is significant in measuring intoxication. Consequently, the percentage that might result from ingesting a certain amount of alcohol is not an issue incorporated into the direct application of the implied consent laws. Nevertheless, that issue may become the subject of expert testimony if there is a clear conflict in the evidence. A proper estimate of such resultant percentages may tend to refute the testimony of a defendant concerning the amount of alcohol he had consumed.

Estimates of the percentage of alcohol in the blood are based upon assumed percentages of water in the entire body and of water in the blood itself. It is also assumed that ingested alcohol will become uniformly distributed throughout the water in the body. Consequently, the ratio of the percentage of water in the entire body to the percentage of water in the blood is taken to yield the corresponding ratio (R) of the concentration of alcohol in the entire body to the concentration of alcohol in the blood. Since the percentage of water in the blood is so high, R has a value only slightly higher than the percentage of water in the entire body, and it will vary accordingly.

The normal range for the percentage of water in the body by weight is said to be 55 to 70 in males and 45 to 55 in females (*10*). The major factor causing variation is general body build, since the water content of muscle is quite high, while that of fat is very low. Also, blood volumes are typically 5 liters in males and 3.5 liters in females (*10*, p. 466).

The volume (V) of alcohol that must have been consumed by a person of weight (W) in order to obtain a given concentration of alcohol in the blood (C) (expressed as a decimal) is then given (*6*, p. 299) by the Widmark formula $V = CRW/d$, where the alcohol density (d) serves to convert the resultant weight of alcohol into milliliters. Values for R typically employed in the formula for courtroom purposes are 0.68 for males and 0.55 for females (*11*). Values then calculated for V may be converted into so many beers or drinks, according to their respective alcohol contents by volume.

Because not all of the alcohol ingested will reach the blood, this formula underestimates the amount of alcohol that must actually have been ingested in order to reach a particular percentage of alcohol in the blood. If, in spite of such error, this estimate still exceeds the amount of alcohol the defendant claims to have been ingested, his testimony can be given little weight. An expert with respect to the Widmark formula would then serve the prosecution not by strengthening its own case, but rather by weakening that of the defense.

Legal significance may also attach to the rate at which alcohol is absorbed into the blood. Evidence relating to the percentage of alcohol in the blood, like any other kind of evidence, is subject to a test for "remoteness." That is, a driving offense occurs at a particular time, and all of the evidence used to seek conviction must pertain to the conditions existing at that time. Whether the evidence was too remote in a particular case may depend upon how rapidly the alcohol the defendant drank was absorbed into his blood.

There is, however, no simple formula for estimating such rates. The rate of absorption is affected by the nature and volume of the stomach contents and by the rate at which the stomach empties. The necessary data would not be available in a particular case even if some formula existed. The most that an expert witness could then do is describe the trends in the process. One may see it stated, for example, that absorption may be complete in 40 to 70 minutes, but if the stomach is full, 2 or 3 hours may be required (*6*, p. 283). In many cases, therefore, the issue is never raised explicitly but is left to the imagination of the jury.

While the defendant is interested in suggesting that there was less alcohol in his blood at the time in question than the value measured later, the prosecution may seek to show that, because of metabolic processes, there was more. Some 95 percent of the alcohol absorbed into the blood is oxidized in the liver to acetaldehyde and then to acetic acid (*10*, p. 235). The rate at which this process takes place may become a part of the case for the prosecution.

Unlike the rate at which alcohol is absorbed, the rate at which the concentration of alcohol in the blood decreases is known to be relatively constant at 0.015 percent by weight per hour (*6*, p. 44; *10*, p. 235). Of course, that figure varies somewhat among individuals and may increase following chronic alcohol consumption (*12*). Consequently, this metabolic rate is not a part of the implied consent statutes, nor is it certain enough to be a matter for judicial notice (*13*). The issue is recognized to some extent, however, in some implied consent statutes that require tests to have been performed within 2 hours of the time at which the defendant's state of intoxication must be proved (*6*, p. 48). It seems clear that the purpose is to prohibit too lengthy extrapolations.

Since the prosecution must have an expert witness on the issue of rate of decrease, this issue might be simplified for the witness by determining the rate applicable to the particular case. A series of measurements of the percentage of alcohol in the blood might be made (*6*, pp. 46–47). Of course, such measurements might also show whether alcohol was still being absorbed into the blood. Since present implied consent laws contain no explicit provisions for such an endeavor, however, the legal problems involved in obtaining this evidence would be compounded.

With respect to breath tests, the scientific problems that the statutes do resolve relate to procedures for collecting breath samples and relating their alcohol contents to that of the blood. More exactly, such problems are resolved through administrative acceptance of the measurement techniques devised by the equipment manufacturers. These techniques, in turn, rest upon assumptions concerning the respiratory process.

Effective exchange of gases or vapors with the blood requires that inspired air reach the respiratory sacs, or alveoli, deep within the lungs (*14*). For that purpose, the conducting airways leading to the alveoli represent dead space. This space will amount to some 150 ml of the total volume of some 450 to 600 ml (the so-called tidal volume) filled in a normal breath (*14*, p. 422).

The presence of this dead space must be taken into account in a proper breath-sampling technique, since it is only the remaining volume—that is, tidal volume minus dead space—that represents air which actually came into close contact with the blood (alveolar air). One approach considered, for example, would have the subject "rebreathe" the same air long enough for effectively all of it to ventilate the alveoli (*15*).

The exchange of gases between the alveolar air and the blood has been described in terms of the partial pressures of the gases in the air and their corresponding "gas tensions" within the blood (*14*, p. 432). With respect to alcohol in the blood, this process is more commonly described in terms of Henry's Law (*14*, p. 425; *16*), which establishes a linear relation between the solubility of a gas in a liquid and its partial pressure above the liquid (*17*). Although this usage of the term "Henry's Law" is not nearly as erroneous as its usage in reference to the diffusion of alcohol throughout the water in the body (*6*, p. 12), the term remains misleading in the context of measuring alcohol in the blood.

The solubility in blood of gases such as ethylene does indeed vary linearly with their partial pressures above the liquid, but solubility may also vary considerably with blood composition, particularly lipoid content (*18*). Henry's Law is thus "obeyed," although different values for the proportionality constant in that law would have to be used for different blood compositions. To determine a solubility from a measured partial pressure, the value of the proportionality constant applicable to the particular blood composition would have to be known. For any analytical application of Henry's Law, it would seem that the solubility in question would need to remain finite. Since alcohol and water (in the blood) are completely miscible, to speak of Henry's Law in that context presents an immediate conceptual difficulty.

That difficulty is easily avoided by referring to actual concentrations rather than to ultimate solubilities. A linear relation between the concentration of a gas dissolved in a liquid and its partial pressure in the air above that liquid may perhaps be termed a kind of "Henry's Law." If that linearity is to be used for analytical purposes, however, it remains true that the proportionality constant it contains must be known.

To apply that linearity to determinations of alcohol in the blood by means of breath analyses, there must exist a known, constant ratio between the concentration of alcohol in the breath and the concentration of alcohol in the blood. Such concentrations expressed in terms of weight/volume have been defined as the "Ostwald partition ratio" (*19*). A return to the use of that term would avoid the theoretical implications inherent in Henry's Law.

As noted, the value of that ratio for a particular gas may vary with the composition of the blood (*18*). The samples Grollman employed (*18*) were artificially prepared from the blood of different species of mammals. At least with respect to gases whose water solubility is appreciable, any variations may well result largely from the varying water content of the samples. The wa-

Table 1. Breath alcohol instruments.

Apparatus	Test category	Nature of sample	Volume (ml)	Alcohol indicator	Alcohol quantitation	Alcohol equivalent* per 1 ml of blood
Accutube (*34*)	Sampling	Alveolar breath	2		Laboratory analysis	2100 ml
Indium Tube Encapsulator (*28*)	Sampling	Alveolar breath	0.25		Laboratory analysis	2100 ml
DPC Intoximeter (*28*)	Sampling and screening	Alveolar breath	250	Acid dichromate	Laboratory analysis	2100 ml
Portable Intoximeter (*28*)	Sampling and screening	Mixed expired breath	Varies	Acid permanganate	Laboratory analysis	Alcohol-CO_2 ratio: 190 mg CO_2
SM-2 Sobermeter (*26*)	Sampling and screening	Mixed expired breath	Varies	Acid dichromate	Laboratory analysis	Alcohol-CO_2 ratio: 200 mg CO_2
SM-3 Sobermeter (*26*)	Sampling and screening	Mixed expired breath	3200	Acid dichromate	Laboratory analysis	Alcohol-CO_2 ratio: 200 mg CO_2
SM-7 Sobermeter (*26*)	Sampling and screening	Alveolar breath	2100	Acid dichromate	Laboratory analysis	2100 ml
Drunkometer (*27*)	Analysis	Rebreathed air (mixed expired breath)	Varies (3200)		Acid permanganate	2100 ml (3200 ml or 190 mg CO_2
Photoelectric Intoximeter (*28*)	Sampling and analysis	Alveolar breath	105		Photoelectric, acid dichromate	2100 ml
Alcometer (*35*)	Analysis	Alveolar breath	15 (50)		Photoelectric, iodine pentoxide (acid dichromate)	2100 ml
Breathalyzer (*27*)	Analysis	Alveolar breath	52.5		Photoelectric, acid dichromate, silver nitrate	2100 ml
Alco-Analyzer Gas Chromatograph (*26*)	Analysis	Alveolar breath	10.5		Thermistor detector	2100 ml
Gas Chromatograph Intoximeter (*28*)	Analysis	Alveolar breath	0.25		Flame ionization detector	2100 ml
Intoxilyzer (*36*)	Analysis	Alveolar breath	Multipass reflection		Infrared absorption	2100 ml

* Alcohol equivalent provides the basis for calculating the amount of alcohol in the blood and is explained in the text.

ter content of the blood of living human beings, on the other hand, does not vary excessively among individuals. For whatever reason, the Ostwald partition ratio for alcohol in human blood is reasonably constant at 1 : 2100 (*16*), with 2100 ml of alveolar air containing the same amount of alcohol as 1 ml of blood.

This ratio of 1 : 2100 will not apply, however, if the breath sample contains other than alveolar air. Dead-space air will not take up alcohol from the blood. Alveolar air, on the other hand, takes up other gases as well, including carbon dioxide (CO_2). If the CO_2 content of expired alveolar air were relatively constant, analysis for CO_2 in an expired breath would reveal how much of that air was alveolar. Determinations of alcohol in the blood could then be based simply upon the alcohol-CO_2 ratio (*20*).

Determining a standard CO_2 value introduces again the problem of obtaining a sample of alveolar air (*14*, p. 427). When such sampling is done, it is found that the CO_2 content of such samples is subject to variation among individuals (*14*, p. 428). To apply such CO_2 values to determinations of alcohol in the blood, some modification in procedure would seem to be required.

When determining the amount of alcohol in the blood, one must restrict the breath sample to alveolar air in order to detect individual variation in CO_2 content. Account could then be taken of such medical conditions as respiratory acidosis or alkalosis (*14*, p. 93), which will alter the CO_2 output of the blood. Since it was the amount of alveolar air present in the sample that was sought by the CO_2 analysis in the first place, it may seem that little has been gained.

Other factors, however, may affect the amount of CO_2 found. A basic assumption in Henry's Law (by whatever name) is that a dynamic gas-liquid equilibrium is approximated. To obtain such equilibrium requires both adequate ventilation of the alveoli and sufficient perfusion of the pulmonary capillaries bringing venous blood to the lungs (*14*, pp. 432–433). The extent to which equilibrium can be achieved is measured in terms of the ventilation-perfusion ratio (*14*, pp. 436–437), whose value changes with depth of breath and other factors.

Corresponding changes then occur in the amounts of the various gases that pass from the blood to the alveoli, including O_2, N_2, CO_2, and, no doubt, alcohol. If this were the only effect operating, demonstrated variations in the CO_2 content of alveolar air would not negate its use as a kind of "internal standard," but rather would emphasize its importance. The effective value of the ventilation-perfusion ratio at the time of the breath sampling for a determination of alcohol in the blood could be shown. Correction could then be made, if necessary, to the standard value of 1 : 2100 for the Ostwald partition ratio.

One additional problem, only partly physiological in nature, may be mentioned. If the alcohol content of the blood is to be deduced from that of a breath sample, the sample to be analyzed must be protected from extraneous sources of alcohol. An obvious source of such alcohol would be any that remained in or entered the mouth of the subject tested (*21*). For that reason, there should be a waiting period of at least 15 minutes before the test to permit dissipation of any such alcohol (*22*). Such an observation period has long been required in regulations passed under the implied consent laws. This requirement would apply equally to all instruments analyzing alcohol in the breath.

Breath Alcohol Instrumentation

The term "breath alcohol" is used to emphasize that it is the alcohol in a *breath* sample that the instruments in question analyze. Many of these instruments will read directly in percentage of alcohol in the blood, however, because their design incorporates the physiological factors previously discussed.

These instruments have been evaluated under laboratory conditions and in the field by police personnel (*16*, *23*). Many of the legal defenses that have been used against these instruments have also been described (*6*, *24*). For present purposes, some description of these instruments is necessary.

Breath alcohol instruments may be classified generally into three types: sampling devices, screening devices, and testing devices (*11*, p. B-1). Sampling devices are used simply for the quantitative collection of breath samples for later laboratory analysis. Screening devices incorporate, in addition, a semiquantitative indication of the amount of alcohol in the air collected. Since their design permits recovery of that alcohol for later analysis, they may also serve as sampling devices. The testing devices are intended to yield a true quantitative analysis of alcohol. Some of them permit either field or laboratory use.

Some characteristics of a number of these instruments are summarized in Table 1 (*11*, pp. B-2–B-3; *24*). Some of the instruments mentioned are not in current use, but were included in order to give a more complete description of the measurement techniques that have been employed. For further information on the instruments listed, the manufacturer should be consulted.

In Table 1, the method of alcohol indication refers to the instrument in its capacity as a screening device. For alcohol quantitation, "laboratory analysis" may include use of one of the testing instruments. For example, the sampling devices listed were designed for subsequent analysis by gas chromatography. Similar devices may be sold with some of the testing instruments as a remote sampling feature.

The sampling devices listed employ what has become an accepted technique for obtaining alveolar air. Before the sample is taken, a waste bag must first be filled, presumably with air from the dead space. The breath sample, taken from the same expiration, then represents a portion of the last air to leave the lungs—that is, alveolar air. That there will be no appreciable mixing of these two kinds of air is assumed.

The glass Accutube collects 30 ml of alveolar air, from which 2 ml are drawn with a syringe at the time of analysis. In the Encapsulator, the breath is collected in a tube of indium metal containing three sample spaces with a volume of 0.25 ml each. Such capsules may then be opened within the testing device by puncturing them. The Accutube collects the breath at the temperature at which it leaves the mouth, about 35.5°C (*14*, p. 427), while the Encapsulator is thermostatically controlled at 50°C.

The DPC Intoximeter incorporates a temperature-controlled piston-cylinder assembly. The first portion of expired air fills a waste bag; the remainder, presumed to be alveolar air, then forces the piston through the cylinder until the specified volume has been obtained. The sample may then be discharged into a color-indicating tube, for screening purposes, or through a tube containing anhydrous magnesium perchlorate, where the alcohol is absorbed for subsequent analysis.

An earlier version of this instrument is found in the portable Intoximeter. "Mixed" expired air, from which no separation of alveolar air is attempted, is first blown into a balloon. For screening purposes, a small portion of that air is then allowed to pass through a glass tube containing acid permanganate. The amount of alcohol present is estimated on the basis of the time required for the color of the permanganate to fade. For analytical purposes, the remaining air is passed through a perchlorate tube, to absorb the alcohol, and then through an ascarite tube, to absorb the CO_2.

The ascarite tube is weighed before and after CO_2 absorption. The volume of alveolar air is determined from the net weight of CO_2, assuming that alveolar air is 5.5 percent CO_2. On that basis, 190 mg of CO_2 corresponds to 2 liters of alveolar air. The amount of alcohol distilled from the perchlorate, together with the volume of alveolar air so determined, then yields the concentration of alcohol in the blood by means of the Ostwald partition ratio, 1 : 2100.

The sampling and screening devices also include three versions of the Sobermeter. The SM-2 operates in much the same way as the Intoximeter just discussed, except that the concentration of alcohol is indicated by the color change of acid dichromate in silica gel. Carbon dioxide is absorbed by potassium hydroxide in silica gel, and a factor of 200 mg of CO_2 per 2100 ml of alveolar air (and thus 1 ml of blood) is employed.

The SM-3 Sobermeter seeks to eliminate the effect of variations in the CO_2 content of alveolar air that are caused by acidosis or alkalosis. A fixed volume of 3200 ml of mixed expired air is collected from several breaths, and the CO_2 content is determined as before. That volume is assumed to correspond to 2100 ml of alveolar air, on the basis that 21/32 of a normal breath is alveolar air. A correction factor, using the actual CO_2 content relative to 200 mg of CO_2, is then employed. In the SM-7, a waste bag is used to restrict the sample to 2100 ml of alveolar air, by means of the technique previously described, and CO_2 content is not determined.

The Drunkometer represents an early attempt at quantitative analysis of alcohol in the blood. Mixed expired air collected in a balloon was bubbled through an acid permanganate solution. The concentration of that solution was such that oxidation of 0.169 mg of alcohol should yield an endpoint in reference to two color comparison ampoules. The volume of air taken in at the time that endpoint was reached was measured in a water displacement gasometer. The amount of alcohol that would correspond to 3200 ml of such air, and thus (as in the SM-3 Sobermeter) to 1 ml of blood, was then determined by a simple ratio. Alternatively, absorption of CO_2 by ascarite was used to determine the amount of alveolar air present, as with the DPC Intoximeter. Another version of the instrument simply used a 3200-ml balloon, as does the SM-3 Sobermeter. In a later modification, the balloon was filled with rebreathed air, and the 1 : 2100 ratio was employed.

The Photoelectric Intoximeter serves both sampling and analytical purposes. Two breath samples are collected simultaneously, in separate cylinders. One is discharged into a perchlorate tube for later analysis. The other enters a test ampoule containing an acid dichromate solution, which oxidizes the alcohol to acetic acid. The corresponding reduction of dichromate is measured photometrically. Using the waste bag technique, the instrument collects 105 ml of alveolar air at 33°C. An air pump for flushing the instrument, a thermometer, a gasometer for checking sample volumes, and indicator rods that show piston position are provided. A calibrated, logarithmic scale reads directly in percentage of alcohol in the blood.

In the original Alcometer, determination of alcohol was based upon reaction with iodine pentoxide to liberate iodine. The latter was then measured photometrically as the blue starch–iodine complex. The more recent D-1 Alcometer employs dichromate reduction. A sample chamber operated by solenoid valves traps 50 ml of alveolar air, which is then pumped through a test ampoule. Optical transmittance of the test ampoule is photometrically balanced against that of a reference ampoule. Both a meter and a recorder then read directly in percentage of alcohol in the blood.

The Breathalyzer also employs a balanced photometric circuit to determine dichromate reduction. A movable light source between the test and reference ampoules and their photocells is positioned to yield zero galvanometer current. At this time, a needle that indicates the percentage of alcohol in the blood is also set at zero. After reaction with any alcohol, the galvanometer is set at zero again. The required movement of the light source is mechanically coupled to the needle, and the calibrated result of the analysis is read directly on a linear scale. Sampling in this instrument occurs within a piston-cylinder assembly, with initial breath being vented out the top. Lights indicate whether the sample chamber is empty or full. Flushing of the instrument is accomplished with an atomizer bulb.

In addition to photometric techniques, the methods of gas chromatography have also been adapted for determination of alcohol in the blood. The Alco-Analyzer is a dual-column instrument with inlet ports for both gases and liquids. The port for liquids may be used to determine alcohol in blood or urine directly, while the gas port is used for breath analyses. The gas inlet may also be used for indirect blood or urine analyses by means of "head-space" techniques (*25*). (The liquid sample is placed in a temperature-controlled vessel; when liquid-vapor equilibrium is reached, the enclosed head space above the liquid is sampled.) For direct breath analyses, 10.5 ml of alveolar air is collected, and the percentage of alcohol in the blood is indicated both by peak height on the chromatogram and by a digital readout. Calibration is based upon head-space analysis of standard alcohol solutions in a commercial "simulator" (*26*) or "equilibrator" (*27*).

The Gas Chromatograph Intoximeter (GCI-Mark II) (*28*) is designed for 0.25-ml samples of gas, taken directly or from the indium capsules previously described. Analysis of blood and urine samples is by the head-space technique. An internal chart recorder may operate in either a differential or integral mode, and a digital readout is also provided. Calibration may be accomplished either by head-space analysis of standard alcohol solutions or by injection of a standard alcohol–inert gas mixture.

Breath alcohol analysis in the Intoxilyzer is based upon infrared absorption. A breath pressure indicator monitors the passage of expired air through a sample cell maintained at 55°C. Absorption, at 3.39 microns, is monitored continuously. Maximum absorption is found in the deepest alveolar air. When maximum absorption is reached, the corresponding value for alcohol in the blood is printed out in triplicate. Air blank readings are taken, and calibration may be based upon head-space analysis of standard alcohol solutions. Breath samples collected elsewhere may also be analyzed.

The Limitations of Science

The development of instruments to measure alcohol in the blood might well be regarded more as a matter of technology than of science. Scientific issues are raised, however, in determining how well these instruments function. It is then up to the law, following sound scientific advice, to determine whether or not they function accurately enough.

In arriving at that judgment, the original decision to use the percentage of alcohol in the blood as a measure of intoxication must be considered. At the least, the blood in question might be defined more precisely. For some time after drinking, better correlation is found between the amount of alcohol in the breath and the amount in capillary blood, than between the amount in the breath and the amount in venous blood (*29*). Capillary blood is closer in composition to heart blood than is venous blood, and it is blood from the heart which courses to the lungs and brain (*30*). Without further qualification, the percentage of alcohol in the breath would then give a *better* measure of intoxication than would the percentage in the "blood."

Proposals that the statutes be rewritten to that effect have been noted (*31*). The rational connection required of any statute would surely be present. Such a step would also remove most of the physiological issues that have been discussed from the area of measurement technology and return them, so to speak, to the human body, where perhaps they belong. The question that then arises is whether individual defendants might be unfairly treated as a result.

That question is not new, of course, since it arises as soon as the values that establish presumptions of intoxication are set up. To rationalize those values, it might be noted that some degree of intoxication is usually found when the percentage of alcohol in the blood is 0.08 (*14*, p. 565). That same percentage is said to produce saturation of the enzyme that oxidizes alcohol in the body (*10*, p. 235). Since 0.08 is the point of "physiological significance," this value might then simply be given conclusive legal significance as well (as it has in Canada). However, these values may not be set in so simplistic a fashion.

In medicine, a range of "normal values" is often assigned to bodily functions. Susceptibility to the influence of alcohol must be assigned such a range of values. That is why presumptions are employed, not conclusive proofs, and why the ranges of values over which different presumptions shall operate are defined. To change the legal significance of the highest value in that range—0.15—from a basis for presumption to an offense in itself does not negate this analysis, since it represents a limit beyond which no person remaining unimpaired could be found (*6*, p. 22).

The situation which exists below that value is of the sort that a court has in mind when it says "medicine is not considered as one of the exact sciences" (*32*) (medical textbooks, therefore, are not directly admissible in evidence). This is not intended to deprecate the medical profession, but simply to note that the "material" upon which it works —people—is subject to individual variation. That being the case, the courtroom proof of intoxication begins to appear less and less a scientific proposition.

Courtroom proofs in general, however, represent nonscientific propositions, even under the "beyond reasonable doubt" standards in criminal cases. "Proof beyond a reasonable doubt is not like a physical or chemical property the presence of which can be objectively ascertained" (*33*). Out of necessity, the courts have long been accustomed to accepting the best that they can get. Convictions of drunk drivers were thus being obtained before the system for measuring alcohol in the blood was devised.

If the direct, *breath* alcohol system proposed were adopted, the question of whether any further risk of unfairness might be imposed rests upon the possibility that a particular individual, because of his peculiar physiology, might have a percentage of alcohol that was "illegal" in the breath, but "legal" in the blood. Conceding that possibility, the question of unfairness must be considered in relation to the harm sought to be avoided. In that light, the one approach may be no more unfair than the other. Since actual danger on the highways is difficult to establish until after the accident has occurred, it is the creation of a *risk* of danger that the law seeks to discourage. No driver can predict with accuracy the extent to which his driving may be impaired by a given amount of alcohol; hence, it is the drinking itself that creates the risk. As noted earlier, it is not necessary that a defendant's driving be proven erratic in order to convict him of driving under the influence. Similarly, no driver can predict how much of the alcohol he ingests will be eliminated, metabolized, or passed to the blood, breath, or brain. Consequently, chance variations in one's ventilation-perfusion ratio, for example, should not constitute a defense to the charge. That is a risk that the other drivers on the highway should not be expected to take.

Whatever the validity of this value judgment, the issue is clearly not one that can be solved by physics or chemistry (nor can such sciences contribute anything to the basic question of whether criminal law is the appropriate means of treating the "drunk driver" in the first place). It is thus evident that breath alcohol instrumentation is not the limiting factor in a quest for highway safety. This is not to say that further medical-scientific advances may not be useful. Whatever the level of sophistication that may be reached, however, the legal-sociological questions may not be avoided. The role of the physical sciences as such will then always be limited. The role of the scientist in the courtroom is thus limited as well.

Conclusions

The "drunk driver" represents one social problem that medicine and the exact sciences have been asked to help solve. Once the decision to employ the criminal justice system for that purpose was made, they were asked to provide both a more precise measure of intoxication, in order that criminal sanctions might be brought into play, and means of determining that measure in individual defendants. The use of breath tests in the courtroom to determine alcohol in the blood, along with evidence of related scientific issues, thus serves well to illustrate the mechanisms by which these scientific contributions may enter into the social scheme.

After studying this particular science-society encounter, I note a number of features. The most obvious of these is that it is society (that is, the legal system) which has set the rules of the interaction. At least in this context, the scientist who wishes to add his own contribution must abide by the rules of acceptance that have been established.

As a corollary to that feature, it is apparent that the scientist must learn what those rules of acceptance are. He need not become a legal expert, but he must at least know those rules concerning the admissibility of evidence that have been expressly designed to pertain to him.

With regard to those rules, at least in theory, the scientist has been given a rather tightly circumscribed role. One reason for this is an apprehension, not unjustified, of abuse of the system. Courts are indeed plagued by the "instant expert," who, whether out of a misguided eagerness to earn his fee or an overreaction to his own self-described credentials, may expound quite far-reaching opinions. An unfortunate consequence of that phenomenon has been, on a limited number of occasions, a refusal on the part of the manufacturers of breath alcohol instruments to make their manuals available to anyone other than official government agencies. That, of course, is a bit like the Emperor Caligula inscribing the laws upon pillars so high that none of the citizens of Rome could read them.

Clearly, there can be no such thing as an "official" science. The potential for governmental abuse is not as great as it may seem, however. The prosecutor is bound by the duty to see that justice is done and that the innocent go free. On the other hand, the defense attorney, with respect to his own client and as long as his own actions are lawful, has no duty to see that the guilty are punished. Within this context, it must be remembered that the prosecution and defense do remain as adversaries under our system of law and are obligated to conduct themselves accordingly.

To find those under this system who are not adversaries and who have a duty to remain objective, one must go to the legislature or, in the courtroom, to the judge and jury. To ensure that the *science* is objective and fair, one can only go to the scientists themselves. If the particular encounter discussed has any value as a model for relations in general between science and society, it is this last feature that might earn first consideration. The role intended for science is that of handmaiden to society, not prostitute.

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Project Sanguine

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The United States Navy has announced (*1*) that it has been conducting research and development on extremely low frequency (ELF) communications. The early part of the research program was known as Project Sanguine. The Navy has claimed that the research proved the feasibility of ELF communications as early as 1963.

The Sanguine system, as envisaged by the Navy, is a single transmitter complex able to communicate with American submarines while they are submerged in the ocean at operating depth (*1*). Currently, messages are sent at very low frequency (VLF) by using high-power (megawatt) transmitters with massive aerial structures. Sanguine is supposed to provide the capability of communication (one-way) to submerged submarines from a single buried transmitter site, located in Wisconsin. The technical objective of Sanguine is to launch electromagnetic energy into the free-space cavity formed between the earth's surface and the lower edge of the ionosphere. Such signals will then penetrate below the surface of the sea when the operating frequency is sufficiently low. In this sense, the energy path from transmitter to receiver is up, over, and down, rather than di-