Learning Objectives

After studying this chapter you should be able to:

- Explain how alcohol is absorbed into the bloodstream, transported throughout the body, and eliminated by oxidation and excretion
- Understand the process by which alcohol is excreted in the breath via the lungs
- Understand the concepts of infrared and fuel cell breath-testing devices for alcohol testing
- Describe commonly employed field sobriety tests to assess alcohol impairment
- List and contrast laboratory procedures for measuring the concentration of alcohol in the blood
- Relate the precautions to be taken to properly preserve blood in order to analyze its alcohol content
- Understand the significance of implied-consent laws and the Schmerber v. California case to traffic enforcement
- Describe techniques that forensic toxicologists use to isolate and identify drugs and poisons
- Appreciate the significance of finding a drug in human tissues and organs to assessing impairment

National Science Content Standards

Scientific Inquiry
Science and Technology
Physical Science
Science in Personal and Social Perspective
Life Science
History and Nature of Science

Harold Shipman, Dr. Death

Kathleen Grundy’s sudden death in 1998 was shocking news to her daughter, Angela Woodruff. Mrs. Grundy, an 81-year-old widow, was believed to be in good health when her physician, Dr. Harold Shipman, visited her a few hours before her demise. Some hours later, when friends came to her home to check on her whereabouts, they found Mrs. Grundy lying on a sofa fully dressed and dead.

Dr. Shipman pronounced her dead and informed her daughter that an autopsy was not necessary. A few days later, Mrs. Woodruff was surprised to learn that a will had surfaced leaving all of Mrs. Grundy’s money to Dr. Shipman. The will was immediately recognized as a forgery and led to the exhumation of Mrs. Grundy’s body. A toxicological analysis of the remains revealed a lethal quantity of morphine.

In retrospect, there was good reason to suspect that Dr. Shipman was capable of foul play. In the 1970s, he was asked to leave a medical practice because of a drug abuse problem and charges that he obtained drugs by forgery and deception. However, Dr. Shipman was quickly back to practicing medicine. By 1998, local undertakers became suspicious at the number of his patients who were dying. What is more, they all seemed to be elderly women who were found sitting in a chair or lying fully clothed on a bed. As police investigated, the horror of Dr. Shipman’s deeds became apparent. One clinical audit estimated that Dr. Shipman killed at least 236 of his patients over a 24-year period. Most of the deaths were attributed to fatal doses of heroin or morphine. Toxicological analysis on seven exhumed bodies clearly showed significant quantities of morphine. Convicted of murder, Dr. Shipman hanged himself in his jail cell in 2004.
Key Terms

- absorption
- acid
- alveoli
- anticoagulant
- artery
- base
- capillary
- catalyst
- excretion
- fuel cell detector
- metabolism
- oxidation
- pH scale
- preservative
- toxicologist
- vein
The Role of Forensic Toxicology

It is no secret that in spite of the concerted efforts of law enforcement agencies to prevent distribution and sale of illicit drugs, thousands die every year from intentional or unintentional administration of drugs, and many more innocent lives are lost as a result of the erratic and frequently uncontrollable behavior of individuals under the influence of drugs. But one should not automatically attribute these occurrences to the wide proliferation of illicit-drug markets. For example, in the United States alone, drug manufacturers produce enough sedatives and antidepressants each year to provide every man, woman, and child with about 40 pills. All of the statistical and medical evidence shows ethyl alcohol, a legal over-the-counter drug, to be the most heavily abused drug in Western countries.

Because the uncontrolled use of drugs has become a worldwide problem affecting all segments of society, the role of the toxicologist has taken on new and added significance. Toxicologists detect and identify drugs and poisons in body fluids, tissues, and organs. Their services are required not only in such legal institutions as crime laboratories and medical examiners’ offices; they also reach into hospital laboratories—where identifying a drug overdose may represent the difference between life and death—and into various health facilities that monitor the intake of drugs and other toxic substances. Primary examples include performing blood tests on children exposed to leaded paints and analyzing the urine of addicts enrolled in methadone maintenance programs.

The role of the forensic toxicologist is limited to matters that pertain to violations of criminal law. However, responsibility for performing toxicological services in a criminal justice system varies considerably throughout the United States. In systems with a crime laboratory independent of the medical examiner, this responsibility may reside with one or the other or may be shared by both. Some systems, however, take advantage of the expertise of government health department laboratories and assign this role to them. Nevertheless, whatever facility handles this work, its caseload will reflect the prevailing popularity of the drugs that are abused in the community. In most cases, this means that the forensic toxicologist handles numerous requests to determine the presence of alcohol in the body.

Forty percent of all traffic deaths in the United States, nearly 17,500 fatalities per year, are alcohol related, along with more than 2 million injuries each year requiring hospital treatment. This highway death toll, as well as the untold damage to life, limb, and property, shows the dangerous consequences of alcohol abuse (see Figure 6–1). Because of the prevalence of alcohol in the toxicologist’s work, we will begin by taking a closer look at how the body processes and responds to alcohol.
Quick Review

- Forensic toxicologists detect and identify drugs and poisons in body fluids, tissues, and organs in matters that pertain to violations of criminal laws.
- Ethyl alcohol is the most heavily abused drug in Western countries.

Toxicology of Alcohol

The subject of the analysis of alcohol immediately confronts us with the primary objective of forensic toxicology—detecting and isolating drugs in the body to determine their influence on human behavior. Knowing how the body metabolizes alcohol provides the key to understanding its effects on human behavior. In the case of alcohol, however, the problem is further complicated by practical considerations. The predominant role of the automobile in our society has mandated the imposition of laws to protect the public from the drinking driver. This has meant that toxicologists have had to devise rapid and specific procedures for measuring the degree of alcohol intoxication. The methods used must be suitably designed to test hundreds of thousands of motorists annually without causing them undue physical harm or unreasonable inconvenience, while at the same time providing a reliable diagnosis that can be supported and defended within the framework of the legal system.
Chapter 6

The Metabolism of Alcohol

All chemicals that enter the body are eventually broken down by chemicals in the body and transformed into other chemicals that are easier to eliminate. This process of transformation, called metabolism, consists of three basic steps: absorption, distribution, and elimination.

Absorption and Distribution Alcohol, or ethyl alcohol, is a colorless liquid normally diluted with water and consumed as a beverage. Alcohol appears in the blood within minutes after it has been consumed and slowly increases in concentration while it is being absorbed from the stomach and the small intestine into the bloodstream. During the absorption phase, alcohol slowly enters the body’s bloodstream and is carried to all parts of the body. When the absorption period is completed, the alcohol becomes distributed uniformly throughout the watery portions of the body—that is, throughout about two-thirds of the body volume. Fat, bones, and hair are low in water content and therefore contain little alcohol, whereas alcohol concentration in the rest of the body is fairly uniform. After absorption is completed, a maximum alcohol level is reached in the blood, and the postabsorption period begins. Then, the alcohol concentration slowly decreases until a zero level is again reached.

Many factors determine the rate at which alcohol is absorbed into the bloodstream, including the total time taken to consume the drink, the alcohol content of the beverage, the amount consumed, and the quantity and type of food present in the stomach at the time of drinking. With so many variables, it is difficult to predict just how long the absorption process will require. For example, beer is absorbed more slowly than an equivalent concentration of alcohol in water, apparently because of the carbohydrates present in beer. Also, alcohol consumed on an empty stomach is absorbed faster than an equivalent amount of alcohol taken when there is food in the stomach. The longer the total time required for complete absorption to occur, the lower the peak alcohol concentration in the blood (see Figure 6–2). Depending on a combination of factors, maximum blood-alcohol concentration may not be reached until two or three hours have elapsed from the time of consumption. However, under normal social drinking conditions, it takes anywhere from 30 to 90 minutes from the time of the final drink until the absorption process is completed.

Elimination As the alcohol is circulated by the bloodstream, the body begins to eliminate it. Alcohol is eliminated through two mechanisms—oxidation and excretion. Nearly all of the alcohol (95–98 percent) consumed is eventually oxidized to carbon dioxide and water. Oxidation takes place almost entirely in the liver. Here, in the presence of the enzyme alcohol dehydrogenase, the alcohol is converted into acetaldehyde and then to acetic acid. The acetic acid is subsequently oxidized in practically all parts of the body to carbon dioxide and water.

The remaining alcohol is excreted unchanged in the breath, urine, and perspiration. Most significantly, the amount of alcohol exhaled in the breath is in direct proportion to the concentration of alcohol in the blood. This observation has had a tremendous impact on the technology and procedures used for blood-alcohol testing. The development of instruments to reliably measure breath for its alcohol...
content has made possible the testing of millions of people in a rapid, safe, and convenient manner.

The fate of alcohol in the body is therefore relatively simple—namely, absorption into the bloodstream, distribution throughout the body’s water, and finally, elimination by oxidation and excretion. The elimination or “burn-off” rate of alcohol varies in different individuals; 0.015 percent w/v (weight per volume) per hour seems to be an average value once the absorption process is complete.1 However, this figure is an average that varies by as much as 30 percent among individuals.

**Blood-Alcohol Concentration** Logically, the most obvious measure of intoxication would be the amount of liquor a person has consumed. Unfortunately, most arrests are made after the fact, when such information is not available to legal authorities; furthermore, even if these data could be collected, numerous related factors, such as body weight and the rate of alcohol’s absorption into the body, are so variable that it would be impossible to prescribe uniform standards that would yield reliable alcohol intoxication levels for all individuals.

Theoretically, for a true determination of the quantity of alcohol impairing an individual’s normal body functions, it would be best to remove a portion of brain tissue and analyze it for alcohol content. For obvious reasons, this cannot be done on living subjects. Consequently, toxicologists concentrate on the blood, which provides the medium for circulating alcohol throughout the body, carrying it to all tissues, including the brain. Fortunately, experimental evidence supports this approach and shows blood-alcohol concentration to be directly proportional to the concentration of alcohol in the brain. From the medicolegal point of view, blood-alcohol levels have become the accepted standard for relating alcohol intake to its effect on the body.

**FIGURE 6–2**
Blood-alcohol concentrations after ingestion of 2 ounces of pure alcohol mixed in 8 ounces of water (equivalent to about 5 ounces of 80-proof vodka).
*Courtesy U.S. Department of Transportation, Washington, D.C.*
As noted earlier, alcohol becomes concentrated evenly throughout the watery portions of the body. This knowledge can be useful for the toxicologist analyzing a body for the presence of alcohol. If blood is not available, as in some postmortem situations, a medical examiner can select a water-rich organ or fluid—for example, the brain, cerebrospinal fluid, or vitreous humor—to determine the body's alcohol content to a reasonable degree of accuracy.

**Alcohol in the Circulatory System**

The extent to which an individual may be under the influence of alcohol is usually determined by measuring the quantity of alcohol present in the blood system. Normally, this is accomplished in one of two ways: (1) by analyzing the blood for its alcohol content or (2) by measuring the alcohol content of the breath. In either case, the significance and meaning of the results can better be understood when the movement of alcohol through the circulatory system is studied.

Humans, like all vertebrates, have a closed circulatory system, which consists basically of a heart and numerous arteries, capillaries, and veins. An **artery** is a blood vessel carrying blood away from the heart, and a **vein** is a vessel carrying blood back toward the heart. **Capillaries** are tiny blood vessels that connect the arteries with the veins. The exchange of materials between the blood and the other tissues takes place across the thin walls of the capillaries. A schematic diagram of the circulatory system is shown in Figure 6–3.

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**FIGURE 6–3**
Simplified diagram of the human circulatory system. Dark vessels contain oxygenated blood; light vessels contain deoxygenated blood.

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**Terms**

- **artery**: A blood vessel that carries blood away from the heart.
- **vein**: A blood vessel that carries blood toward the heart.
- **capillary**: A tiny blood vessel that receives blood from arteries and carries it to veins, and across whose walls exchange of materials between the blood and the tissues takes place.
Ingestion and Distribution  Let us now trace the movement of alcohol through the human circulatory system. After alcohol is ingested, it moves down the esophagus into the stomach. About 20 percent of the alcohol is absorbed through the stomach walls into the portal vein of the blood system. The remaining alcohol passes into the blood through the walls of the small intestine. Once in the blood, the alcohol is carried to the liver, where enzymes begin to break it down.

As the blood (still carrying the alcohol) leaves the liver, it moves up to the heart. The blood enters the upper right chamber of the heart, called the right atrium (or auricle), and is forced into the lower right chamber of the heart, known as the right ventricle. Having returned to the heart from its circulation through the tissues, the blood at this time contains very little oxygen and much carbon dioxide. Consequently, the blood must be pumped up to the lungs, through the pulmonary artery, to be replenished with oxygen.

Aeration  In the lungs, the respiratory system bridges with the circulatory system so that oxygen can enter the blood and carbon dioxide can leave it. As shown in Figure 6–4, the pulmonary artery branches into capillaries lying close to tiny pear-shaped sacs called alveoli. The lungs contain about 250 million alveoli, all located at the ends of the bronchial tubes. The bronchial tubes connect to the windpipe (trachea), which leads up to the mouth and nose (see Figure 6–5). At the surface of the alveolar sacs, blood flowing through the capillaries comes in contact with fresh oxygenated air in the sacs.

**FIGURE 6–4**
Gas exchange in the lungs. Blood flows from the pulmonary artery into vessels that lie close to the walls of the alveoli sacs. Here the blood gives up its carbon dioxide and absorbs oxygen. The oxygenated blood leaves the lungs via the pulmonary vein and returns to the heart.
A rapid exchange now takes place between the fresh air in the sacs and the spent air in the blood. Oxygen passes through the walls of the alveoli into the blood while carbon dioxide is discharged from the blood into the air. If, during this exchange, alcohol or any other volatile substance is in the blood, it too will pass into the alveoli. During breathing, the carbon dioxide and alcohol are expelled through the nose and mouth, and the alveoli sacs are replenished with fresh oxygenated air breathed into the lungs, allowing the process to begin all over again.

The distribution of alcohol between the blood and alveolar air is similar to the example of a gas dissolved in an enclosed beaker of water, as described in Chapter 5. Here again, one can use Henry’s law (see pages 177-178) to explain how the alcohol will divide itself between the air and blood. Henry’s Law may now be restated as follows: When a volatile chemical (alcohol) is dissolved in a liquid (blood) and is brought to equilibrium with air (alveolar breath), there is a fixed ratio between the concentration of the volatile compound (alcohol) in air (alveolar breath) and its concentration in the liquid (blood), and this ratio is constant for a given temperature.

The temperature at which the breath leaves the mouth is normally 34°C. At this temperature, the ratio of alcohol in the blood to alcohol in alveolar air is approximately 2,100 to 1. In other words, 1 milliliter of blood contains nearly the same amount of alcohol as 2,100 milliliters of alveolar breath. Henry’s law thus becomes a basis for relating breath to blood-alcohol concentration.

Recirculation and Absorption Now let’s return to the circulating blood. After emerging from the lungs, the oxygenated blood is rushed back to the upper left chamber of the heart (left atrium) by the pulmonary vein. When the left atrium contracts, it forces the blood through a valve into the left ventricle, which is the
lower left chamber of the heart. The left ventricle then pumps the freshly oxygenated blood into the arteries, which carry the blood to all parts of the body. Each of these arteries, in turn, branches into smaller arteries, which eventually connect with the numerous tiny capillaries embedded in the tissues. Here the alcohol moves out of the blood and into the tissues. The blood then runs from the capillaries into tiny veins that fuse to form larger veins. These veins eventually lead back to the heart to complete the circuit.

During absorption, the concentration of alcohol in the arterial blood is considerably higher than the concentration of alcohol in the venous blood. One typical study revealed a subject’s arterial blood-alcohol level to be 41 percent higher than the venous level 30 minutes after the last drink. This difference is thought to exist because of the rapid diffusion of alcohol into the body tissues from venous blood during the early phases of absorption. Because the administration of a blood test requires drawing venous blood from the arm, this test is clearly to the advantage of a subject who may still be in the absorption stage. However, once absorption is complete, the alcohol becomes equally distributed throughout the blood system.

Quick Review

- Alcohol appears in the blood within minutes after it has been taken by mouth. It slowly increases in concentration while it is being absorbed from the stomach and the small intestine into the bloodstream.

- When all of the alcohol has been absorbed, a maximum alcohol level is reached in the blood, and the postabsorption period begins. During postabsorption, the alcohol concentration slowly decreases until a zero level is reached.

- Elimination of alcohol throughout the body is accomplished through oxidation and excretion. Oxidation takes place almost entirely in the liver, while alcohol is excreted unchanged in the breath, urine, and perspiration.

- Breath testing devices operate on the principle that the ratio between the concentration of alcohol in alveolar breath and its concentration in blood is fixed.

Testing for Intoxication

From a practical point of view, the idea of drawing blood from a vein to test motorists suspected of being under the influence of alcohol simply does not provide a convenient method for monitoring drivers. The need to transport the suspect to a location where a medically qualified person can draw blood would be costly and time consuming, considering the hundreds of tests that the average police department must conduct every year. The methods used must be designed to test hundreds of thousands of motorists annually without causing them undue physical harm or unreasonable inconvenience, while providing a reliable diagnosis that can be supported and defended within the framework of the legal system. This means that toxicologists have had to devise rapid and specific procedures for measuring a driver’s degree of alcohol intoxication that can be easily administered in the field.
Breath Testing for Alcohol

The most widespread method for rapidly determining alcohol intoxication is breath testing. A breath tester is simply a device for collecting and measuring the alcohol content of alveolar breath. As we saw earlier, alcohol is expelled unchanged in the breath of a person who has been drinking. A breath-test measures the alcohol concentration in the pulmonary artery by measuring its concentration in alveolar breath. Thus, breath analysis provides an easily obtainable specimen along with a rapid and accurate result.

Breath-test results obtained during the absorption phase may be higher than results obtained from a simultaneous analysis of venous blood. However, the former are more reflective of the concentration of alcohol reaching the brain and, therefore, more accurately reflect the effects of alcohol on the subject. Again, once absorption is complete, the difference between a blood test and a breath test should be minimal.

Breath-Test Instruments

The first widely used instrument for measuring the alcohol content of alveolar breath was the Breathalyzer, developed in 1954 by R. F. Borkenstein, who was a captain in the Indiana State Police. Although the Breathalyzer has undergone several modifications since its development, the basic theory and design of the instrument have not changed. The “Inside the Science” feature on the Breathalyzer explains the working of the device in greater detail.

Starting in the 1970s, the Breathalyzer was phased out and replaced by other instruments for measuring the alcoholic content of alveolar breath. Like the Breathalyzer, they assume that the ratio of alcohol in the blood to alcohol in alveolar breath is 2,100 to 1 at a mouth temperature of 34°C. Unlike the Breathalyzer, modern breath testers are free of chemicals. These devices include infrared light absorption devices and fuel cell detectors.

A fuel cell like the one in “Inside the Science” converts a fuel and an oxidant into an electrical current. In evidential breath testing devices that use this concept, breath alcohol is the fuel and atmospheric oxygen is the oxidant. Alcohol is converted in the fuel cell into acetic acid, generating a current that is proportional to the quantity of alcohol present in the breath.

Infrared and fuel-cell-based breath testers are microprocessor controlled so that all an operator has to do is press a start button and the instrument automatically moves through a sequence of steps that produce a printout of the subject’s test results. These instruments also perform self-diagnostic tests to ascertain whether the instrument is in proper operating condition.

Considerations in Breath Testing

An important feature of breath-testing instruments is that they can be connected to an external alcohol standard or simulator in the form of either a liquid or a gas. The liquid simulator comprises a known concentration of alcohol in water. It is heated to a controlled temperature, and the vapor formed above the liquid is pumped into the instrument. Dry-gas standards typically consist of a known concentration of alcohol mixed with an inert gas and compressed in cylinders. The external standard is automatically sampled by the breath-testing instrument before and/or after the subject’s breath sample is taken and recorded. Thus, the operator can check the accuracy of the instrument against the known alcohol standard.
The Breathalyzer

The Breathalyzer is a device for collecting and measuring the alcohol content of alveolar breath (see Figure 1). The subject blows into a mouthpiece that leads into a metal cylinder. The last portion of breath (alveolar breath) is trapped in the cylinder. The amount of breath collected in this manner is 52.5 milliliters, or 1/40 of 2,100 milliliters.* We have already seen that the amount of alcohol in 2,100 milliliters of alveolar breath approximates that in 1 milliliter of blood. Hence, in essence, the Breathalyzer is designed to measure the alcohol concentration present in 1/40 of a milliliter of blood.

*Actually, the collection cylinder is designed to hold 56.5 milliliters of breath. This is because, having left the mouth at 34°C, the breath will expand when heated to 50°C in the cylinder. Furthermore, added breath is needed to compensate for the air that remains in the delivery tube leading to the test ampoule.

The quantity of alcohol in the trapped breath is measured by passing the breath into a glass ampoule containing potassium dichromate, sulfuric acid, and water. Any alcohol in the breath immediately dissolves in the dichromate solution and is oxidized to acetic acid. In the oxidation process, potassium dichromate is also destroyed. The extent of this destruction is measured by the Breathalyzer and is related to the quantity of alcohol passed into the ampoule.
Inside the Science (CONTINUED)

Basically, the Breathalyzer is a spectrophotometer (see Chapter 5) designed to measure the absorption of light passing through the potassium dichromate solution at a single wavelength. To better understand its operation, let’s examine what is happening in the ampoule when alcohol is converted to acetic acid. Whenever a chemical reaction occurs between two or more substances, chemists use a chemical equation as a shorthand method to describe the changes taking place. The equation serves two purposes: it identifies the participants, and it describes the quantitative aspects of the reaction.

The following equation depicts the chemical reaction taking place in the ampoule:

\[
2\text{K}_2\text{Cr}_2\text{O}_7 + 3\text{C}_2\text{H}_5\text{OH} + 8\text{H}_2\text{SO}_4 \rightarrow 2\text{Cr}_2(\text{SO}_4)_3 + 2\text{K}_2\text{SO}_4 + 3\text{CH}_3\text{COOH} + 11\text{H}_2\text{O}
\]

From this chemical equation, we can see that there is always a fixed relationship between the number of potassium dichromate molecules reacting with the alcohol. Two molecules of potassium dichromate always combine with three molecules of ethyl alcohol. Hence, determining the amount of potassium dichromate consumed is an indirect way to determine the quantity of alcohol originally present. Silver nitrate is also present in the Breathalyzer ampoule; however, this substance acts only as a catalyst to speed up the rate of reaction between potassium dichromate and ethyl alcohol. As a catalyst, silver nitrate undergoes no net change itself during the reaction.

catalyst
A substance that accelerates the rate of a chemical reaction but is not itself permanently changed by the reaction
Inside the Science

Infrared Light Absorption

In principle, infrared instruments operate no differently from the spectrophotometers described in Chapter 5. An evidential testing instrument that incorporates the principle of infrared light absorption is shown in Figure 1. Any alcohol present in the subject’s breath flows into the instrument’s breath chamber. As shown in Figure 2, a beam of infrared light is aimed through the chamber. A filter is used to select a wavelength of infrared light that alcohol will absorb. As the infrared light passes through the chamber, it interacts with the alcohol, which causes the light to decrease in intensity. The decrease in light intensity is measured by a photoelectric detector that gives a signal proportional to the concentration of alcohol present in the breath sample. This information is processed by an electronic microprocessor, and the percent blood-alcohol concentration is displayed on a digital readout. Also, the blood-alcohol level is printed on a card to produce a permanent record of the test result. Most infrared breath testers aim a second infrared beam into the same chamber to check for acetone or other chemical interferences on the breath. If the instrument detects differences in the relative response of the two infrared beams that does not conform to ethyl alcohol, the operator is immediately informed of the presence of an “interferant.”

Detector
Infrared radiation source
Sample chamber
Filter
Breath flows into chamber
Detector
Infrared light beamed through chamber. Alcohol in breath absorbs some infrared light.
Filter selects wavelength of IR light at which alcohol absorbs
Inside the Science (CONTINUED)

(d) Infrared radiation source, Sample chamber, Breath inlet, Breath outlet, Detector converts infrared light to an electrical signal proportional to the alcohol content in breath.

(e) Infrared radiation source, Sample chamber, Breath inlet, Breath outlet, Detector, Breath alcohol content is converted into a blood alcohol concentration and displayed on a digital readout.

FIGURE 2
Inside the Science

The Fuel Cell

A fuel cell converts energy arising from a chemical reaction into electrochemical energy. A typical fuel cell consists of two platinum electrodes separated by an acid- or base-containing porous membrane. A platinum wire connects the electrodes and allows a current to flow between them. In the alcohol fuel cell, one of the electrodes is positioned to come into contact with a subject's breath sample.

If alcohol is present in the breath, a reaction at the electrode's surface converts the alcohol to acetic acid. One by-product of this conversion is free electrons, which flow through the connecting wire to the opposite electrode, where they interact with atmospheric oxygen to form water (see the figure). The fuel cell also requires the migration of hydrogen ions across the acidic porous membrane to complete the circuit. The strength of the current flow between the two electrodes is proportional to the concentration of alcohol in the breath.

The key to the accuracy of a breath-testing device is to ensure that the unit captures the alcohol in the alveolar (deep-lung) breath of the subject. This is typically accomplished by programming the unit to accept no less than 1.1 to 1.5 liters of breath from the subject. Also, the subject must blow for a minimum time (such as 6 seconds) with a minimum breath flow rate (such as 3 liters per minute).

Another feature of these instruments is the slope detector. As the subject blows into the instrument, the breath-alcohol concentration initially will rise steadily as a function of time. The instrument accepts a breath sample only when consecutive breath measurements show little or no rate of change in breath-alcohol concentration. This approach ensures that the breath sample being measured is alveolar or deep-lung breath and thus most closely relates to the true blood-alcohol concentration of the subject being tested.
A breath-test operator must take other steps to ensure that the breath-test result truly reflects the actual blood-alcohol concentration of the subject. A major consideration is to avoid measuring “mouth alcohol” resulting from regurgitation, belching, or recent intake of an alcoholic beverage. Also, the recent gargling of an alcohol-containing mouthwash can lead to the presence of mouth alcohol. As a result, the alcohol concentration detected in the exhaled breath is higher than the concentration in the alveolar breath. To avoid this possibility, the operator must not allow the subject to take any foreign material into his or her mouth for at least 15 to 20 minutes before the breath test. Likewise, the subject should be observed not to have belched or regurgitated during this period. Mouth alcohol has been shown to dissipate after 15 to 20 minutes from its inception.

Independent measurement of duplicate breath samples taken within a few minutes of each other is another extremely important check of the integrity of the breath test. Acceptable agreement between the two tests taken minutes apart significantly reduces the possibility of errors arising from the operator, mouth alcohol, instrument component failures, and spurious electric signals.

**Field Sobriety Testing**

A police officer who suspects that an individual is under the influence of alcohol usually conducts a series of preliminary tests before ordering the suspect to submit to an evidential breath or blood test. These preliminary, or field sobriety, tests are normally performed to ascertain the degree of the suspect’s physical impairment and whether an evidential test is justified.

Field sobriety tests usually consist of a series of psychophysical tests and a preliminary breath test (if such devices are authorized and available for use). A portable handheld, roadside breath tester is shown in Figure 6–6. This device, about the size of a pack of cigarettes, weighs 5 ounces and uses a fuel cell to measure the alcohol content of a breath sample. The fuel cell absorbs the alcohol from the breath sample, oxidizes it, and produces an electrical current proportional to the breath-alcohol content. This instrument can typically perform for three to five years before the fuel cell needs to be replaced. Breath-test results obtained with devices such as those shown in Figure 6–6 must be considered preliminary and nonevidential. They should only establish probable cause for requiring an individual to submit to a more thorough breath or blood test.
Horizontal-gaze nystagmus, walk and turn, and the one-leg stand constitute a series of reliable and effective psychophysical tests. Horizontal-gaze nystagmus is an involuntary jerking of the eye as it moves to the side. A person experiencing nystagmus is usually unaware that the jerking is happening and is unable to stop or control it. The subject being tested is asked to follow a penlight or some other object with his or her eye as far to the side as the eye can go. The more intoxicated the person is, the less the eye has to move toward the side before jerking or nystagmus begins. Usually, when a person’s blood-alcohol concentration is in the range of 0.10 percent, the jerking begins before the eyeball has moved 45 degrees to the side (see Figure 6–7). Higher blood-alcohol concentration causes jerking at smaller angles. Also, if the suspect has taken a drug that also causes nystagmus (such as phencyclidine, barbiturates, and other depressants), the nystagmus onset angle may occur much earlier than would be expected from alcohol alone.

Walk and turn and the one-leg stand are divided-attention tasks, testing the subject’s ability to comprehend and execute two or more simple instructions at one time. The ability to understand and simultaneously carry out more than two instructions is significantly affected by increasing blood-alcohol levels. Walk and turn requires the suspect to maintain balance while standing heel-to-toe and at the same time listening to and comprehending the test instructions. During the walking stage, the suspect must walk a straight line, touching heel-to-toe for nine steps, then turn around on the line and repeat the process. The one-leg stand requires the suspect to maintain balance while standing with heels together listening to the instructions. During the balancing stage, the suspect must stand on one foot while holding the other foot several inches off the ground for 30 seconds; simultaneously, the suspect must count out loud during the 30-second time period.
Quick Review

- Modern breath testers are free of chemicals. They include infrared light absorption devices and fuel cell detectors.
- The key to the accuracy of a breath testing device is to ensure that the unit captures the alcohol in the alveolar (deep-lung) breath of the subject.
- Many breath testers collect a set volume of breath and expose it to infrared light. The instrument measures alcohol concentration in breath by measuring the degree of the interaction of the light with alcohol in the collected breath sample.
- Law enforcement officers use field sobriety tests to estimate a motorist’s degree of physical impairment by alcohol and to determine whether an evidential test for alcohol is justified.
- The horizontal-gaze nystagmus test, walk and turn, and the one-leg stand are all considered reliable and effective psychophysical tests for alcohol impairment.

The Analysis of Blood for Alcohol

Gas chromatography offers the toxicologist the most widely used approach for determining alcohol levels in blood. Under proper gas chromatographic conditions, alcohol can be separated from other volatiles in the blood. By comparing the resultant alcohol peak area to ones obtained with known blood-alcohol standards, the investigator can calculate the alcohol level with a high degree of accuracy (see Figure 6–8).
Another procedure for alcohol analysis involves the oxidation of alcohol to acetaldehyde. This reaction is carried out in the presence of the enzyme alcohol dehydrogenase and the coenzyme nicotinamide-adenine dinucleotide (NAD). As the oxidation proceeds, NAD is converted into another chemical species, NADH. The extent of this conversion is measured by a spectrophotometer and is related to alcohol concentration. This approach to blood-alcohol testing is normally associated with instruments used in a clinical or hospital setting. On the other hand, forensic laboratories normally use gas chromatography for determining blood-alcohol content.

**Collection and Preservation of Blood**

Blood must always be drawn under medically accepted conditions by a qualified individual. It is important to apply a nonalcoholic disinfectant before the suspect’s skin is penetrated with a sterile needle or lancet. It is important to negate any argument that an alcoholic disinfectant may have inadvertently contributed to a falsely high blood-alcohol result. Nonalcoholic disinfectants such as aqueous benzalkonium chloride (Zepiran), aqueous mercuric chloride, or povidone-iodine (Betadine) are recommended for this purpose.

Once blood is removed from an individual, it is best preserved sealed in an airtight container after adding an anticoagulant and a preservative. The blood should be stored in a refrigerator until delivery to the toxicology laboratory. The addition of an anticoagulant, such as EDTA or potassium oxalate, prevents clotting; a preservative, such as sodium fluoride, inhibits the growth of microorganisms capable of destroying alcohol.

One study performed to determine the stability of alcohol in blood removed from living individuals found that the most significant factors affecting alcohol’s stability in blood are storage temperature, the presence of a preservative, and the time of storage. Not a single blood specimen examined showed an increase in alcohol level with time. Failure to keep the blood refrigerated or to add sodium fluoride resulted in a substantial decline in alcohol concentration. Longer storage times also reduced blood-alcohol levels. Hence, failure to adhere to any of the proper preservation requirements for blood works to the benefit of the suspect and to the detriment of society.

The collection of postmortem blood samples for alcohol determination requires added precautions as compared to collection from living subjects. Ethyl alcohol may be generated in a deceased individual as a result of bacterial action. Therefore, it is best to collect a number of blood samples from different body sites. For example, blood may be removed from the heart and from the femoral (leg) and cubital (arm) veins. Each sample should be placed in a clean, airtight container containing an anticoagulant and sodium fluoride preservative and should be refrigerated. Blood-alcohol levels attributed solely to alcohol consumption should result in nearly similar results for all blood samples collected from the same person. Alternatively, collection of vitreous humor and urine is recommended. Vitreous humor and urine usually do not suffer from postmortem ethyl alcohol production to any significant extent.
Quick Review

- Gas chromatography is the most widely used approach for determining blood-alcohol levels in forensic laboratories.
- An anticoagulant should be added to a blood sample to prevent clotting; a preservative should be added to inhibit the growth of microorganisms capable of destroying alcohol.

Alcohol and the Law

Constitutionally, every state in the United States must establish and administer statutes regulating the operation of motor vehicles. Although such an arrangement might encourage diverse laws defining permissible blood-alcohol levels, this has not been the case. Since the 1930s, both the American Medical Association and the National Safety Council have exerted considerable influence in persuading the states to establish uniform and reasonable blood-alcohol standards.

Blood-Alcohol Laws

The American Medical Association and the National Safety Council initially recommended that a person with a blood-alcohol concentration in excess of 0.15 percent w/v was to be considered under the influence of alcohol. However, continued experimental studies showed a clear correlation between drinking and driving impairment at blood-alcohol levels much below 0.15 percent w/v. These findings eventually led to a lowering of the blood-concentration standard for intoxication from 0.15 percent w/v to its current 0.08 percent w/v.

In 1992, the U.S. Department of Transportation (DOT) recommended that states adopt 0.08 percent blood-alcohol concentration as the legal measure of drunk driving. This recommendation was enacted into federal law in 2000. All 50 states have now established per se laws, meaning that any individual meeting or exceeding a defined blood-alcohol level (usually 0.08 percent) shall be deemed intoxicated. No other proof of alcohol impairment is necessary. The 0.08 percent level applies only to noncommercial drivers, as the federal government has set the maximum allowable blood-alcohol concentration for commercial truck and bus drivers at 0.04 percent.

Several Western countries have also set 0.08 percent w/v as the blood-alcohol level above which it is an offense to drive a motor vehicle, including Canada, Italy, Switzerland, and the United Kingdom. Finland, France, Germany, Ireland, Japan, the Netherlands, and Norway have a 0.05 percent limit. Australian states have adopted a 0.05 percent blood-alcohol concentration level. Sweden has lowered its blood-alcohol concentration limit to 0.02 percent.

As shown in Figure 6–9, a person is about four times as likely to become involved in an automobile accident at the 0.08 percent level as a sober individual. At the 0.15 percent level, the chances are 25 times as much for involvement in an automobile accident as compared to a sober driver. The reader can estimate the relationship of blood-alcohol levels to body weight and the quantity of 80-proof liquor consumed by referring to Figure 6–10.
Chapter 6

FIGURE 6–9
Diagram of increased driving risk in relation to blood-alcohol concentration. Courtesy U.S. Department of Transportation, Washington, D.C.

FIGURE 6–10
To use this diagram, lay a straightedge across the suspect’s weight and the number of ounces he or she has consumed on an empty or full stomach. The point where the edge hits the right-hand column is one’s maximum blood-alcohol level. The rate of elimination of alcohol from the bloodstream is approximately 0.015 percent per hour. Therefore, to calculate one’s actual blood-alcohol level, subtract 0.015 from the number in the right-hand column for each hour from the start of drinking.

MyCrimeKit: WebExtra 6.2
See How Alcohol Affects Your Behavior
www.mycrimekit.com
Constitutional Issues

The Fifth Amendment to the U.S. Constitution guarantees all citizens protection against self-incrimination—that is, against being forced to make an admission that would prove one’s own guilt in a legal matter. Because consenting to a breath test for alcohol may be considered a form of self-incrimination, the National Highway Traffic Safety Administration (NHTSA) recommended an implied consent law to prevent a person from refusing to take a test on those constitutional grounds. This law states that the operator of a motor vehicle on a public highway must either consent to a test for alcohol intoxication, if requested, or lose his or her license for some designated period—usually six months to one year.

The leading case relating to the constitutionality of collecting a blood specimen for alcohol testing, as well as for obtaining other types of physical evidence from a suspect without consent, is *Schmerber v. California*. While being treated at a Los Angeles hospital for injuries sustained in an automobile collision, Schmerber was arrested for driving under the influence of alcohol. Despite Schmerber’s objections, a physician took a blood sample from him at the direction of the police. Schmerber was convicted of driving while intoxicated, and he subsequently appealed the decision. The case eventually reached the U.S. Supreme Court, where Schmerber argued that his privilege against self-incrimination had been violated by the introduction of the results of the blood test at his trial. The Court ruled against him, reasoning that the Fifth Amendment prohibits only compelling a suspect to give testimonial evidence that may prove to be self-incriminating; being compelled to furnish physical evidence, such as fingerprints, photographs, measurements, and blood samples, the Court ruled, was not protected by the Fifth Amendment.

The Court also addressed the question of whether the police violated Schmerber’s Fourth Amendment protection against unreasonable search and seizure by taking a blood specimen from him without a search warrant. The Court upheld the constitutionality of the blood removal, reasoning in this case that the police were confronted with an emergency situation. By the time police officials would have obtained a warrant, Schmerber’s blood-alcohol levels would have declined significantly as a result of natural body elimination processes. In effect, the evidence would have been destroyed. The Court also emphasized that the blood specimen was taken in a medically accepted manner and without unreasonable force. This opinion in no way condones warrantless taking of blood for alcohol or drug testing under all circumstances. The reasonableness of actions a police officer may take to compel an individual to yield evidence can be judged only on a case-by-case basis.

Quick Review

- The current legal measure of drunk driving in the United States is a blood-alcohol concentration of 0.08 percent, or 0.08 grams of alcohol per 100 milliliters of blood.

- An implied-consent law states that the operator of a motor vehicle on a public highway must either consent to a test for alcohol intoxication, if requested, or lose his or her license for some designated period—usually six months to one year.
Chapter 6

The Role of the Toxicologist

Once the forensic toxicologist ventures beyond the analysis of alcohol, he or she encounters an encyclopedic maze of drugs and poisons. Even a cursory discussion of the problems and handicaps imposed on toxicologists is enough to develop a sense of appreciation for their accomplishments and ingenuity.

Challenges Facing the Toxicologist

The toxicologist is presented with body fluids and/or organs and asked to examine them for drugs and poisons. If he or she is fortunate, which is not often, some clue as to the type of toxic substance present may develop from the victim’s symptoms, a postmortem pathological examination, an examination of the victim’s personal effects, or the nearby presence of empty drug containers or household chemicals. Without such supportive information, the toxicologist must use general screening procedures with the hope of narrowing thousands of possibilities to one.

If this task does not seem monumental, consider that the toxicologist is not dealing with drugs at the concentration levels found in powders and pills. By the time a drug specimen reaches the toxicology laboratory, it has been dissipated and distributed throughout the body. The drug analyst may have gram or milligram quantities of material to work with, but the toxicologist must be satisfied with nanogram or at best microgram amounts, acquired only after careful extraction from body fluids and organs.

FIGURE 6–11
Scientist analyzing blood samples.
Courtesy Risto Bozovic, AP Wide World Photos
Furthermore, the body is an active chemistry laboratory, and no one can appreciate this observation more than a toxicologist. Few substances enter and completely leave the body in the same chemical state. The drug that is injected is not always the substance extracted from the body tissues. Therefore, a thorough understanding of how the body alters or metabolizes the chemical structure of a drug is essential in detecting its presence.

It would, for example, be futile and frustrating to search exhaustively for heroin in the human body. This drug is almost immediately metabolized to morphine on entering the bloodstream. Even with this information, the search may still prove impossible unless the examiner also knows that only a small percentage of morphine is excreted unchanged in urine. For the most part, morphine becomes chemically bonded to body carbohydrates before elimination in urine. Thus, successful detection of morphine requires that its extraction be planned in accordance with a knowledge of its chemical fate in the body.

Another example of how one needs to know how a drug metabolizes itself in the body is exemplified by the investigation of the death of Anna Nicole Smith. In her case, the sedative chloral hydrate was a major contributor to her death and its presence was detected by its active metabolite, trichloroethanol (see the Case File on page 233).

Last, when and if the toxicologist has surmounted all of these obstacles and has finally detected, identified, and quantitated a drug or poison, he or she must assess the substance’s toxicity. Fortunately, there is published information relating to the toxic levels of most drugs. However, even when such data are available, their interpretation must assume that the victim’s physiological behavior agrees with that of subjects of previous studies. Such an assumption may not be entirely valid without knowing the subject’s case history. No experienced toxicologist would be surprised to find an individual tolerating a toxic level of a drug that would have killed most other people.
Case Files

Celebrity Toxicology
Michael Jackson: The Demise of a Superstar

A call to 911 had the desperate tone of urgency. The voice of a young man implored an ambulance to hurry to the home of pop star Michael Jackson. The unconscious performer was in cardiac arrest and was not responding to CPR. The 50-year old Jackson was pronounced dead upon arrival at a regional medical center. When the initial autopsy results revealed no signs of foul play, rumors immediately began to swirl around a drug-related death. News media coverage showed investigators carrying bags full of medical supplies out of the Jackson residence. Hence, it came as no surprise that the forensic toxicology report accompanying Jackson’s autopsy showed that the entertainer had died of a drug overdose.

Apparently, Jackson had become accustomed to receiving sedatives to help him sleep. On the morning of his death, his physician gave Mr. Jackson a tab of valium. At 2 a.m., he administered the sedative lorazepam, and at 3 a.m. the physician administered another sedative, midazolam. Those drugs were administered again at 5 a.m. and 7:30 a.m., but Mr. Jackson still was unable to sleep. Finally, at about 10:40 a.m., Jackson’s doctor gave him 25 milligrams of propofol, at which point Mr. Jackson went to sleep. Propofol is a powerful sedative whose principal use is the maintenance of surgical anesthesia. All of the drugs administered to Jackson were sedatives that act in concert to depress the activities of the central nervous system. Hence, it comes as no surprise that this drug cocktail resulted in cardiac arrest and death.

Courtesy AP Wide World Photos
Case Files

Accidental Overdose: The Tragedy of Anna Nicole Smith

Rumors exploded in the media when former model, Playboy playmate, reality television star, and favorite tabloid subject Anna Nicole Smith was found unconscious in her hotel room at the Seminole Hard Rock Hotel & Casino in Hollywood, Florida. She was taken to Memorial Legal Hospital, where she was declared dead at age 39. Analysis of Smith’s blood postmortem revealed an array of prescribed medications. Most pronounced was a toxic level of a metabolite of the sedative chloral hydrate. A part of the contents of the toxicology report from Smith’s autopsy are shown here.

**FINAL PATHOLOGICAL DIAGNOSES:**

I. ACUTE COMBINED DRUG INTOXICATION

A. Toxic/legal drug:

Chloral Hydrate (Noctec)

1. Trichloroethanol (TCE)  75 mg/L (active metabolite)

2. Trichloroacetic acid (TCA)  85 mg/L (inactive metabolite)

B. Therapeutic drugs:

1. Diphenhydramine (Benadryl)  0.11 mg/L
2. Clonazepam (Klonopin)  0.04 mg/L
3. Diazepam (Valium)  0.21 mg/L
4. Nordiazepam (metabolite)  0.38 mg/L
5. Temazepam (metabolite)  0.09 mg/L
6. Oxazepam  0.09 mg/L
7. Lorazepam  0.022 mg/L

C. Other non-contributory drugs present (atropine, topiramate, ciprofloxacin, acetaminophen)

Although many of the drugs present were detected at levels consistent with typical doses of the prescribed medications, it was their presence in combination with chloral hydrate that exacerbated the toxic level of chloral hydrate. The lethal combination of these prescription drugs caused failure of both her circulatory and respiratory systems and resulted in her death. The investigators determined that the overdose of chloral hydrate and other drugs was accidental and not a suicide. This was due to the nonexcessive levels of most of the prescription medications and the discovery of a significant amount of chloral hydrate still remaining in its original container; had she intended to kill herself she would have likely downed it all. Anna Nicole Smith was a victim of accidental overmedication.
Collection and Preservation of Toxicological Evidence

The toxicologist’s capabilities depend directly on input from the attending physician, medical examiner, and police investigator. It is a tribute to forensic toxicologists, who must often labor under conditions that do not afford such cooperation, that they can achieve the high level of proficiency that they do.

Generally, with a deceased person, the medical examiner decides what biological specimens must be shipped to the toxicology laboratory for analysis. However, a living person suspected of being under the influence of a drug presents a completely different problem, and few options are available. When possible, both blood and urine are taken from any suspected drug user. The entire urine void (sample) is collected and submitted for toxicological analysis. Preferably, two consecutive voids should be collected in separate specimen containers.

When a licensed physician or registered nurse is available, a sample of blood should also be collected. The amount of blood taken depends on the type of examination to be conducted. Comprehensive toxicological tests for drugs and poisons can conveniently be carried out on a minimum of 10 milliliters of blood. A determination solely for the presence of alcohol will require much less—approximately 5 milliliters of blood. However, many therapeutic drugs, such as tranquilizers and barbiturates, taken in combination with a small, nonintoxicating amount of alcohol, produce behavioral patterns resembling alcohol intoxication. For this reason, the toxicologist must be given enough blood to perform a comprehensive analysis for drugs in cases of low alcohol concentrations.

Case Files
Death by Tylenol

In 1982, two firefighters from a Chicago suburb were casually discussing four bizarre deaths that had recently taken place in a neighboring area. As they discussed the circumstances of the deaths, they realized that each of the victims had taken Tylenol. Their suspicions were immediately reported to police investigators. Tragically, before the general public could be alerted, three more victims died after taking poison-laced Tylenol capsules. Seven individuals, all in the Chicago area, were the first victims to die from what has become known as product tampering.

A forensic chemical analysis of Tylenol capsules recovered from the victims’ residences showed that the capsules were filled with potassium cyanide in a quantity ten thousand times what was needed to kill an average person. It was quickly determined that the cyanide was not introduced into the bottles at the factory. Instead, the perpetrator methodically emptied each of 20 to 30 capsules and then refilled them with potassium cyanide. The tampered capsules were rebottled, carefully repackaged, and placed on the shelves of six different stores. The case of the Tylenol murders remains unsolved, and the $100,000 reward offered by Tylenol’s manufacturer remains unclaimed.
Techniques Used in Toxicology

For the toxicologist, the upsurge in drug use and abuse has meant that the overwhelming majority of fatal and nonfatal toxic agents are drugs. Not surprisingly, a relatively small number of drugs—namely, those discussed in Chapter 5—comprise nearly all the toxic agents encountered. Of these, alcohol, marijuana, and cocaine account for 90 percent or more of the drugs encountered in a typical toxicology laboratory.

Like the drug analyst, the toxicologist must devise an analytical scheme to detect, isolate, and identify a toxic substance. The first chore is to remove and isolate drugs and other toxic agents from the biological materials submitted as evidence. Because drugs constitute a large portion of the toxic materials found, a good deal of effort must be devoted to their extraction and detection. Many different procedures are used, and a useful description of them would be too detailed for this text. We can best understand the underlying principle of drug extraction by observing that many drugs fall into the categories of acids and bases.

**Acids and Bases**

Although several definitions exist for these two classes, a simple one states that an acid is a compound capable of donating a hydrogen ion (or a hydrogen atom minus its electron) to another compound with reasonable ease. Conversely, a base is a molecule capable of accepting a hydrogen ion shed by an acid. The idea of acidity and basicity can be expressed in terms of a simple numerical value that relates to the concentration of the hydrogen ion (H+) in a liquid medium such as water. Chemists use the pH scale to do this. This scale runs from 0 to 14:

\[
\text{pH} = \begin{array}{cccccccccccc}
0 & 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 & 10 & 11 & 12 & 13 & 14 \\
\text{Increasing acidity} & \text{Neutral} & \text{Increasing basicity}
\end{array}
\]

Normally, water is neither acid nor basic—in other words, it is neutral, with a pH of 7. However, when an acidic substance—for example, sulfuric acid or hydrochloric acid—is added to the water, it adds excess hydrogen ions, and the pH value becomes less than 7. The lower the number, the more acidic the water. Similarly, when a basic substance—for example, sodium hydroxide or ammonium hydroxide—is added to water, it removes hydrogen ions, thus making water basic. The more basic the water, the higher its pH value.

By controlling the pH of a water solution into which blood, urine, or tissues are dissolved, the toxicologist can control the type of drug that is recovered. For example, acid drugs are easily extracted from an acidified water solution (pH less than 7) with organic solvents such as chloroform. Similarly, basic drugs are readily removed from a basic water solution (pH greater than 7) with organic solvents. This simple approach gives the toxicologist a general technique for extracting and categorizing drugs. Some of the more commonly encountered drugs may be classified as follows:

**Acid Drugs:** Barbiturates, Acetylsalicylic acid (aspirin)

**Basic Drugs:** Phencyclidine, Methadone, Amphetamines, Cocaine

**Acid**

A compound capable of donating a hydrogen ion (H+) to another compound

**Base**

A compound capable of accepting a hydrogen ion (H+)

**pH scale**

A scale used to express the basicity or acidity of a substance. A pH of 7 is neutral; lower values are acidic and higher values basic.
**Screening and Confirmation** Once the specimen has been extracted and divided into acidic and basic fractions, the toxicologist can identify the drugs present. The strategy for identifying abused drugs entails a two-step approach: screening and confirmation (see Figure 6–12). A screening test normally gives quick insight into the likelihood that a specimen contains a drug substance. This test allows a toxicologist to examine a large number of specimens within a short period of time for a wide range of drugs. Any positive results from a screening test are tentative at best and must be verified with a confirmation test.

**Screening Tests.** The three most widely used screening tests are thin-layer chromatography (TLC), gas chromatography (GC), and immunoassay. The techniques of GC and TLC are described in Chapter 5. The third technique, immunoassay, has proven to be a useful screening tool in toxicology laboratories. Its principles are very different from any of the analytical techniques we have discussed so far. Basically, immunoassay is based on specific drug antibody reactions. We will learn about this concept in Chapter 8. The primary advantage of immunoassay is its ability to detect small concentrations of drugs in body fluids and organs. In fact, this technique provides the best approach for detecting the low drug levels normally associated with smoking marijuana.

**Confirmation Tests.** A positive screening test may be due to a substance’s close chemical structure to an abused drug. For this reason, the toxicologist must follow up any positive screening test with a confirmation test. Because of the potential impact of the results of a drug finding on an individual, only the most conclusive confirmation procedures should be used.

Gas chromatography/mass spectrometry is generally accepted as the confirmation test of choice. As we learned in Chapter 5, the combination of gas chromatography and mass spectrometry provides a one-step confirmation test of unequaled sensitivity and specificity. Figure 6–13 illustrates the process. After being introduced to the gas chromatograph, the sample is separated into its components. When the separated sample component leaves the column of the gas chromatograph, it enters the mass spectrometer, where it is bombarded with...
high-energy electrons. This bombardment causes the sample to break up into fragments, producing a fragmentation pattern or mass spectrum for each sample. For most compounds, the mass spectrum represents a unique “fingerprint” pattern that can be used for identification.

**Detecting Drugs in Hair**

When a forensic toxicological examination on a living person is required, practicality limits available specimens to blood and urine. Most drugs remain in the bloodstream for about 24 hours; in urine, they normally are present up to 72 hours. However, it may be necessary to go further back in time to ascertain whether a subject has been abusing a drug. If so, the only viable alternative to blood and urine is head hair.

Hair is nourished by blood flowing through capillaries located close to the hair root. Drugs present in blood diffuse through the capillary walls into the base of the hair and become permanently entrapped in the hair’s hardening protein structure. As the hair continues to grow, the drug’s location on the hair shaft becomes a historical marker for delineating drug intake. Given that the average human head hair grows at the rate of 1 centimeter per month, analyzing segments of hair for drug content may define the timeline for drug use, dating it back over a period of weeks, months, or even years, depending on the hair’s length.

However, caution is required in interpreting the timeline. The chronology of drug intake may be distorted by drugs penetrating the hair’s surface as a result of environmental exposure, or drugs may enter the hair’s surface through sweat. Nevertheless, drug hair analysis is the only viable approach for measuring long-term abuse of a drug.
Detecting Nondrug Poisons Although forensic toxicologists devote most of their efforts to detecting drugs, they also test for a wide variety of other toxic substances. Some of these are rare elements, not widely or commercially available. Others are so common that virtually everyone is exposed to nontoxic amounts of them every day.

Heavy Metals. One group of poisons once commonly encountered in criminal cases of murder are known as heavy metals. They include arsenic, bismuth, antimony, mercury, and thallium. These days, however, the forensic toxicologist only occasionally encounters heavy metals because severe environmental protection regulations restrict their availability to the general public. Nevertheless, as the following case study makes clear, their use is by no means only a historical curiosity.

To screen for many of these metals, the investigator may dissolve the suspect body fluid or tissue in a hydrochloric acid solution and insert a copper strip into the solution. This process is known as the Reinsch test. The appearance of a silvery or dark coating on the copper indicates the presence of a heavy metal. Such a finding must be confirmed by analytical techniques suitable for inorganic analysis—namely, emission spectroscopy, or X-ray diffraction. These procedures are discussed in more detail in Chapters 11 and 13.

Carbon Monoxide. Unlike heavy metals, carbon monoxide still represents one of the most common poisons encountered in a forensic laboratory. When carbon monoxide enters the human body, it is primarily absorbed by the red blood cells, where it combines with hemoglobin to form carboxyhemoglobin. An average red blood cell contains about 280 million molecules of hemoglobin. Oxygen normally combines with hemoglobin, which transports the oxygen throughout the body. However, if a high percentage of the hemoglobin combines with carbon monoxide, not enough is left to carry sufficient oxygen to the tissues, and death by asphyxiation quickly follows.

There are two basic methods for measuring the concentration of carbon monoxide in the blood. Spectrophotometric methods examine the visible spectrum of blood to determine the amount of carboxyhemoglobin relative to oxyhemoglobin or total hemoglobin; also, a volume of blood can be treated with a reagent to liberate the carbon monoxide, which is then measured by gas chromatography.

The amount of carbon monoxide in blood is generally expressed as percent saturation. This represents the extent to which the available hemoglobin has been converted to carboxyhemoglobin. The transition from normal or occupational levels of carbon monoxide to toxic levels is not sharply defined. It depends, among other things, on the age, health, and general fitness of each individual. In a healthy middle-aged individual, a carbon monoxide blood saturation greater than 50–60 percent is considered fatal. However, in combination with alcohol or other depressants, fatal levels may be significantly lower. For instance, a carbon monoxide saturation of 35–40 percent may prove fatal in the presence of a blood-alcohol concentration of 0.20 percent w/v. Interestingly, chain smokers may have a constant carbon monoxide level of 8–10 percent from the carbon monoxide in cigarette smoke.

Inhaling automobile fumes is a relatively common way to commit suicide (see Figure 6–14). A garden or vacuum cleaner hose is often used to connect the tail-
Case Files

Joann Curley: Caught by a Hair

A vibrant young woman named Joann Curley rushed to the Wilkes-Barre (Pennsylvania) General Hospital—her husband, Bobby, was having an attack and required immediate medical attention. Bobby was experiencing a burning sensation in his feet, numbness in his hands, a flushed face, and intense sweating. After being discharged, Bobby experienced another bout of debilitating pain and numbness. He was admitted to another hospital. There doctors observed extreme alopecia, or hair loss.

Test results of Bobby's urine showed high levels of the heavy metal thallium in his body. Thallium, a rare and highly toxic metal that was used decades ago in substances such as rat poison and to treat ringworm and gout, was found in sufficient quantities to cause Bobby's sickness. The use of thallium was banned in the United States in 1984. Now, at least, Bobby could be treated. However, before Bobby's doctors could treat him for thallium poisoning, he experienced cardiac arrest and slipped into a coma. Joann Curley made the difficult decision to remove her husband of 13 months from life support equipment. He died shortly thereafter.

Investigators also learned that Bobby had changed his life insurance to list his wife, Joann, as the beneficiary of his $300,000 policy. Based on this information, police consulted a forensic toxicologist in an effort to glean as much from the physical evidence in Bobby Curley's body as possible. The toxicologist conducted segmental analysis of Bobby's hair, an analytical method based on the predictable rate of hair growth on the human scalp: an average of 1 centimeter per month. Bobby had approximately 5 inches (12.5 centimeters) of hair, which represents almost 12 months of hair growth. Each section tested represented a specific period of time in the final year of Bobby's life.

The hair analysis confirmed that Bobby Curley was poisoned with thallium. The first few doses were small, which probably barely made him sick at the time. Gradually, over a year or more, Bobby was receiving more doses of thallium until he finally succumbed to a massive dose three or four days before his death. After careful scrutiny of the timeline, investigators concluded that only Joann Curley had access to Bobby during each of these intervals. She also had motive, in the amount of $300,000.

Presented with the timeline and the solid toxicological evidence against her, Joann Curley pleaded guilty to murder. As part of her plea agreement, she provided a 40-page written confession of how she haphazardly dosed Bobby with some rat poison she found in her basement. She admitted that she murdered him for the money she would receive from Bobby's life insurance policy.
Once a drug is found and identified, the toxicologist assesses its influence on the behavior of the individual. Interpreting the results of a toxicology finding is one of the toxicologist’s more difficult chores. Recall that many countries have designated a specific blood-alcohol level at which an individual is deemed under the influence of alcohol. These levels were established as a result of numerous studies conducted over several years to measure the effects of alcohol levels on driving performance. However, no such legal guidelines are available to the toxicologist who must judge how a drug other than alcohol affects an individual’s performance or physical state.

For many drugs, blood concentration levels are readily determined and can be used to estimate the pharmacological effects of the drug on the individual. Often, when dealing with a living person, the toxicologist has the added benefit of knowing what a police officer may have observed about an individual’s behavior and motor skills. For a deceased person, drug levels in various body organs and tissues provide additional information about the individual’s state at the time of death. However, before drawing conclusions about drug-induced behavior, the analyst must consider other factors, including the age, physical condition, and tolerance of the drug user.
With prolonged use of a drug, an individual may become less responsive to a drug’s effects and tolerate blood-drug concentrations that would kill a casual drug user. Therefore, knowledge of an individual’s history of drug use is important in evaluating drug concentrations. Another consideration is additive or synergistic effects of the interaction of two or more drugs, which may produce a highly intoxicated or comatose state even though none of the drugs alone is present at high or toxic levels. The combination of alcohol with barbiturates or narcotics is a common example of a potentially lethal drug combination.

The concentration of a drug present in urine is a poor indicator of how extensively an individual’s behavior or state is influenced by the drug. Urine is formed outside the body’s circulatory system, and consequently drug levels can build up in it over a relatively long period of time. Some drugs are found in the urine one to three days after they have been taken and long after their effects on the user have disappeared. Nevertheless, the value of this information should not be discounted. Urine drug levels, like blood levels, are best used by law enforcement authorities and the courts to corroborate other investigative and medical findings regarding an individual’s condition. Hence, for an individual arrested for suspicion of being under the influence of a drug, a toxicologist’s determinations supplement the observations of the arresting officer, including the results of a drug influence evaluation (discussed next).

For a deceased person, the medical examiner or coroner must establish a cause of death. However, before a conclusive determination is made, the examining physician depends on the forensic toxicologist to demonstrate the presence or absence of a drug or poison in the tissues or body fluids of the deceased. Only through the combined efforts of the toxicologist and the medical examiner (or coroner) can society be assured that death investigations achieve high professional and legal standards.

**The Drug Recognition Expert**

Whereas recognizing alcohol-impaired performance is an expertise generally accorded to police officers by the courts, recognizing drug-induced intoxication is much more difficult and generally not part of police training. During the 1970s, the Los Angeles Police Department developed and tested a series of clinical and psychophysical examinations that a trained police officer could use to identify and differentiate between types of drug impairment. This program has evolved into a national program to train police as drug recognition experts. Normally, a three- to five-month training program is required to certify an officer as a drug recognition expert (DRE).

The DRE program incorporates standardized methods for examining suspects to determine whether they have taken one or more drugs. The process is systematic and standard; to ensure that each subject has been tested in a routine fashion, each DRE must complete a standard Drug Influence Evaluation form (see
DREs must complete the Drug Influence Evaluation form to ensure that each subject has been tested in a routine fashion.

Figure 6–15. The entire drug evaluation takes approximately 30 to 40 minutes. The components of the 12-step process are summarized in Table 6–1.
Table 6–1

Components of the Drug Recognition Process

1. **The Breath-Alcohol Test.**
   By obtaining an accurate and immediate measurement of the suspect’s blood-alcohol concentration, the drug recognition expert (DRE) can determine whether alcohol may be contributing to the suspect’s observable impairment and whether the concentration of alcohol is sufficient to be the sole cause of that impairment.

2. **Interview with the Arresting Officer.**
   Spending a few minutes with the arresting officer often enables the DRE to determine the most promising areas of investigation.

3. **The Preliminary Examination.**
   This structured series of questions, specific observations, and simple tests provides the first opportunity to examine the suspect closely. It is designed to determine whether the suspect is suffering from an injury or from another condition unrelated to drug consumption. It also affords an opportunity to begin assessing the suspect’s appearance and behavior for signs of possible drug influence.

4. **The Eye Examination.**
   Certain categories of drugs induce nystagmus, an involuntary, spasmodic motion of the eyeball. Nystagmus is an indicator of drug-induced impairment. The inability of the eyes to converge toward the bridge of the nose also indicates the possible presence of certain types of drugs.

5. **Divided-Attention Psychophysical Tests.**
   These tests check balance and physical orientation and include the walk and turn, the one-leg stand, the Romberg balance, and the finger-to-nose.

6. **Vital Signs Examinations.**
   Precise measurements of blood pressure, pulse rate, and body temperature are taken. Certain drugs elevate these signs; others depress them.

7. **Dark Room Examinations.**
   The size of the suspect’s pupils in room light, near-total darkness, indirect light, and direct light is checked. Some drugs cause the pupils to either dilate or constrict.

8. **Examination for Muscle Rigidity.**
   Certain categories of drugs cause the muscles to become hypertense and quite rigid. Others may cause the muscles to relax and become flaccid.

9. **Examination for Injection Sites.**
   Users of certain categories of drugs routinely or occasionally inject their drugs. Evidence of needle use may be found on veins along the neck, arms, and hands.

10. **Suspect’s Statements and Other Observations.**
    The next step is to attempt to interview the suspect concerning the drug or drugs he or she has ingested. Of course, the interview must be conducted in full compliance of the suspect’s constitutional rights.

11. **Opinions of the Evaluator.**
    Using the information obtained in the previous ten steps, the DRE can make an informed decision about whether the suspect is impaired by drugs and, if so, what category or combination of categories is the probable cause of the impairment.

12. **The Toxicological Examination.**
    The DRE should obtain a blood or urine sample from the suspect for laboratory analysis in order to secure scientific, admissible evidence to substantiate his or her conclusions.
The DRE evaluation process can suggest the presence of the following seven broad categories of drugs:

1. Central nervous system depressants
2. Central nervous system stimulants
3. Hallucinogens
4. Dissociative anesthetics
   (includes phencyclidine and its analogs)
5. Inhalants
6. Narcotic analgesics
7. Cannabis

The DRE program is not designed to be a substitute for toxicological testing. The toxicologist can often determine that a suspect has a particular drug in his or her body. But the toxicologist often cannot infer with reasonable certainty that the suspect was impaired at a specific time. On the other hand, the DRE can supply credible evidence that the suspect was impaired at a specific time and that the nature of the impairment was consistent with a particular family of drugs. But the DRE program usually cannot determine which specific drug was ingested. Proving drug intoxication requires a coordinated effort and the production of competent data from both the DRE and the forensic toxicologist.
Quick Review

- The forensic toxicologist must devise an analytical scheme to detect, isolate, and identify toxic drug substances extracted from biological fluids, tissues, and organs.

- A screening test gives quick insight into the likelihood that a specimen contains a drug substance. Positive results arising from a screening test are tentative at best and must be verified with a confirmation test.

- The most widely used screening tests are thin-layer chromatography, gas chromatography, and immunoassay. Gas chromatography/mass spectrometry is generally accepted as the confirmation test of choice.

- Once a drug is extracted and identified, a toxicologist may be required to judge the drug’s effect on an individual’s natural performance or physical state.
Chapter Review

- Forensic toxicologists detect and identify drugs and poisons in body fluids, tissues, and organs in matters that pertain to violations of criminal laws.
- Ethyl alcohol is the most heavily abused drug in Western countries.
- Alcohol appears in the blood within minutes after it has been taken by mouth. It slowly increases in concentration while it is being absorbed from the stomach and the small intestine into the bloodstream.
- When all of the alcohol has been absorbed, a maximum alcohol level is reached in the blood, and the postabsorption period begins. During postabsorption, the alcohol concentration slowly decreases until a zero level is reached.
- Elimination of alcohol throughout the body is accomplished through oxidation and excretion. Oxidation takes place almost entirely in the liver, while alcohol is excreted unchanged in the breath, urine, and perspiration.
- Breath-testing devices operate on the principle that the ratio between the concentration of alcohol in alveolar breath and its concentration in blood is fixed.
- Modern breath testers are free of chemicals. They include infrared light absorption devices and fuel cell detectors.
- The key to the accuracy of a breath-testing device is to ensure that the unit captures the alcohol in the alveolar (deep-lung) breath of the subject.
- Many breath testers collect a set volume of breath and expose it to infrared light. The instrument measures alcohol concentration in breath by measuring the degree of the interaction of the light with alcohol in the collected breath sample.
- Law enforcement officers use field sobriety tests to estimate a motorist’s degree of physical impairment by alcohol and to determine whether an evidential test for alcohol is justified.
- The horizontal-gaze nystagmus test, walk and turn, and the one-leg stand are all considered reliable and effective psychophysical tests for alcohol impairment.
- Gas chromatography is the most widely used approach for determining blood-alcohol levels in forensic laboratories.
- An anticoagulant should be added to a blood sample to prevent clotting; a preservative should be added to inhibit the growth of microorganisms capable of destroying alcohol.
- The current legal measure of drunk driving in the United States is a blood-alcohol concentration of 0.08 percent, or 0.08 grams of alcohol per 100 milliliters of blood.
• An implied-consent law states that the operator of a motor vehicle on a public highway must either consent to a test for alcohol intoxication, if requested, or lose his or her license for some designated period—usually six months to one year.

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Quick Lab: pH Test

Materials:

- pH paper with color indicator chart
- Liquid samples of acid and base substances (examples: tap water, bottled water, soda, ice tea, baking soda in water, salt water, lime juice, cleaning solution, liquid soap)

Procedure:

pH can help toxicologists determine what type of toxin may be present in a sample. This activity will allow you to identify the pH of some common substances. Before you begin, write a guess of what you think the pH of each sample will be. Now, take a piece of pH paper and dip into the first sample for a few seconds. Compare the pH paper to the color indicator chart and determine what the pH is of the sample. Record your observations. Repeat this for each sample.

Follow-Up Questions:

1. How many samples did you guess correctly before testing them? Which ones were they?
2. Create a pH chart. Use the labels Acid, Base, and Neutral. Also label where each item you tested would be on your chart.
3. A toxicologist would test samples of what to determine the pH of the toxin in a body?
Review Questions

1. About 95–98 percent of alcohol is oxidized to what two substances?
   a. carbon dioxide and dehydrogenase
   b. water and acetic acid
   c. acetaldehyde and acetic acid
   d. water and carbon dioxide

2. Carbon monoxide combines with what component of blood?
   a. carboxyhemoglobin
   b. hemoglobin
   c. oxyhemoglobin
   d. white blood cells

3. With a blood-alcohol level at 0.15 percent, the chance for involvement in an automobile accident is
   a. 10 times as great
   b. 25 times as great
   c. 50 times as great
   d. 75 times as great

4. Which of the following drugs would not have a pH of increasing basicity?
   a. phencyclidine
   b. amphetamines
   c. cocaine
   d. barbiturates

5. What percentage of alcohol is absorbed through the stomach walls into the portal vein of the blood system?
   a. 20 percent
   b. 70 percent
   c. 1 percent
   d. 10 percent

6. True or False: The role of the forensic toxicologist is limited to matters that pertain to violations of the law.

7. True or False: A breath test, used to measure alcohol, reflects the alcohol concentration in the pulmonary vein.

8. True or False: After a screening test has been used to determine the identity of an abused drug, the confirmation test of choice is thin-layer chromatography.

9. True or False: The concentration of a drug present in urine is an excellent indicator of how extensively an individual's behavior or state is influenced by the drug.

10. True or False: The technique used most widely by forensic toxicologists for detecting alcohol in blood is the gas chromatograph.

11. What is a toxicologist? Name three settings in which a toxicologist often works.

12. What is the most widely abused drug in Western countries?

13. Define metabolism.
14. List and describe the three stages of alcohol's fate in the human body.

15. Name at least three factors that influence the rate at which alcohol is absorbed into the bloodstream.

16. Alcohol that is not oxidized is expelled unchanged in what bodily excretions?

17. The amount of alcohol exhaled in the breath is in direct proportion to what?

18. For a longer total time required for complete absorption, will the peak blood-alcohol concentration be higher or lower?

19. List and describe the functions of the three types of blood vessels in the circulatory system.

20. Through the walls of which organ is most alcohol absorbed into the bloodstream? In what other organ does the remainder of absorption occur?

21. What are alveoli and what role do they play in circulation?

22. What scientific observation forms the theoretical basis for breath testing?

23. Briefly describe how a fuel cell detector measures blood-alcohol concentration.

24. What is mouth alcohol and how does it affect the accuracy of a breath test? Name three potential sources of mouth alcohol.

25. What is a field sobriety test? What two general types of test are included in a field sobriety test?

26. What type of disinfectant must be applied to a subject’s skin before drawing blood? Why must such a disinfectant be applied?

27. What type of container best ensures the preservation of blood samples?

28. What two substances should be added to a blood sample after collection and why?

29. How do each of the following factors affect alcohol’s stability in blood: storage temperature, the presence of a preservative, and the time of storage?

30. When collecting postmortem blood samples for alcohol determination, why is it best to collect a number of blood samples from different body sites?

31. What blood-alcohol concentration is the current legal measure of drunk driving in the United States, as established by the National Highway Traffic Safety Administration?

32. What is a per se law?

33. What is an implied-consent law? Why were such laws implemented?

34. Describe two challenges toxicologists face in detecting drugs and determining their toxicity.
35. What three drugs account for 90 percent or more of the drugs encountered in a typical toxicology laboratory?

36. What is the first task of a forensic toxicologist when establishing an analytical scheme to detect and identify drugs?

37. What are acids and bases? How are they used to extract and categorize drugs?

38. What are the three screening tests most widely used by forensic toxicologists? What is the confirmation test of choice?

39. Which of the following is not classified as a heavy metal?
   a. lead
   b. arsenic
   c. mercury
   d. thallium

40. Explain how inhaling carbon monoxide can cause death.

41. Why is the concentration of a drug present in urine a poor indicator of how extensively an individual’s behavior or state is influenced by the drug?

Application and Critical Thinking

1. Answer the following questions about driving risk associated with drinking and blood-alcohol concentration:
   a. Randy is just barely legally intoxicated. How much more likely is he to have an accident compared with someone who is sober?
   b. Marissa, who has been drinking, is 15 times as likely to have an accident as her sober friend, Christine. What is Marissa’s approximate blood-alcohol concentration?
   c. After several drinks, Charles is ten times as likely to have an accident as a sober person. Is he more or less intoxicated than James, whose blood-alcohol level is 0.10?
   d. Under the original blood-alcohol standards recommended by the NHTSA, a person considered just barely legally intoxicated was how much more likely to have an accident than a sober individual?

2. Following is a description of four individuals who have been drinking. Rank them from highest to lowest blood-alcohol concentration:
   a. John, who weighs 200 pounds and has consumed eight 8-ounce drinks on a full stomach
   b. Frank, who weighs 170 pounds and has consumed four 8-ounce drinks on an empty stomach
   c. Gary, who weighs 240 pounds and has consumed six 8-ounce drinks on an empty stomach
   d. Stephen, who weighs 180 pounds and has consumed six 8-ounce drinks on a full stomach
3. Following is a description of four individuals who have been drinking. In which (if any) of the following countries would each be considered legally drunk: the United States, Australia, and Sweden?
   a. Bill, who weighs 150 pounds and has consumed three 8-ounce drinks on an empty stomach
   b. Sally, who weighs 110 pounds and has consumed three 8-ounce drinks on a full stomach
   c. Rich, who weighs 200 pounds and has consumed six 8-ounce drinks on an empty stomach
   d. Carrie, who weighs 140 pounds and has consumed four 8-ounce drinks on a full stomach

4. You are a forensic scientist who has been asked to test two blood samples. You know that one sample is suspected of containing barbiturates and the other contains no drugs; however, you cannot tell the two samples apart. Describe how you would use the concept of pH to determine which sample contains barbiturates. Explain your reasoning.

5. You are investigating an arson scene and you find a corpse in the rubble, but you suspect that the victim did not die as a result of the fire. Instead, you suspect that the victim was murdered earlier, and that the blaze was started to cover up the murder. How would you go about determining whether the victim died before the fire?

6. Three individuals are stopped at a DUI checkpoint at ten p.m. Before performing the on-site breath test, the checkpoint officer asks each of them about their activities before they were stopped in order to estimate the expected blood-alcohol reading estimation (and to gauge their honesty). Use the testimony of each person that follows and the diagram in Figure 6–9 to estimate the expected BAC (blood-alcohol concentration). Indicate whether this is above or below the legal limit for operating a vehicle.
   a. Larry Questring had a large meal at an Italian restaurant with his wife. He ingested 8 ounces of 80-proof Frangelico between seven p.m. and nine p.m. Larry weighs approximately 180 pounds.
      Estimated BAC at ten p.m.:
   b. Paul Raunetz is driving home from a bar. He drove there after finishing his workday without stopping to eat. At the bar, he had four shots of tequila (1 ounce each, 80 proof) and five shots of whiskey (1 oz each, 80 proof) between six p.m. and nine p.m. Paul weighs approximately 130 pounds.
      Estimated BAC at ten p.m.:
   c. Thomas Wold is returning home after an NFL game that started at six p.m. and ended at nine p.m. While watching the game, he ingested two hot dogs, a hot pretzel, peanuts, cheese fries, two diet sodas, ice cream, and six gin-and-tonics. Each gin-and-tonic contained 2 ounces of 80-proof gin. Thomas weighs approximately 240 pounds.
      Estimated BAC at ten p.m.:
Endnotes

1. In the United States, laws that define blood-alcohol levels almost exclusively use the unit percent weight per volume—% w/v. Hence, 0.015 percent w/v is equivalent to 0.015 grams of alcohol per 100 milliliters of blood, or 15 milligrams of alcohol per 100 milliliters.


4. 0.15 percent w/v is equivalent to 0.15 grams of alcohol per 100 milliliters of blood, or 150 milligrams per 100 milliliters.
