Chapter 13.5: Alcohol

Introduction

Alcohol has been a part of human society for a very long time. Some historians have attributed the rise of civilization to the development of methods for producing alcohol since it allows the storage of a mobile form of calorie-containing nutrition safely for long periods – freeing mankind from the perpetual preoccupation with continually searching for the next meal. Current best guesses place the first widespread preparation of alcohol-containing food-stocks at between 5,000 and 10,000 years ago. Certainly by 700 BC the Greeks had a thriving wine industry that was later refined by the ancient Romans. Historically, wine making was focused in the Mediterranean region while beer production was mostly concentrated in the cooler, northern parts of Europe where it was generally too cold to grow grapes. But human ingenuity has developed alcohol-producing methods using different fermentable materials in virtually every part of the globe.

As much as alcohol has been a stepping-stone in mankind’s freedom to explore beyond the next meal, there have also been societal problems arising from overindulgence of alcohol from the beginning of recorded civilization. Today, alcohol is the number one abused drug worldwide, causing more deaths and injuries than any other compound.

In this section, we begin by briefly exploring the chemistry and production of alcohol, followed by a discussion of its pharmacodynamics and pharmacokinetics.

Alcohol Properties

Organic alcohols are compounds that contain something called a hydroxyl functional group, or an OH group, written in red in Figure 13.5.1.

Three of the most common alcohols (methanol, ethanol and isopropanol) have relatively simple chemical structures consisting of small organic fragments attached to OH units.

Methanol (CH₃OH), sometimes called wood alcohol or wood spirits, is a colorless, low-boiling liquid (b.p. = 65°C) not suitable for human consumption. Its name derives from early methods of burning or distilling certain types of wood to produce it. Methanol is, however, very toxic with a LD₅₀ of only 428 mg/Kg. Biological problems result, however, at levels well below the LD values. For example, ingestion of only 10 mL of methanol can cause permanent blindness by destruction of the optic nerve. It is used primarily as a solvent for chemical reactions, forming plastics, and in cleaning solutions.

Isopropanol (C₃H₇OH), often called rubbing alcohol (although most commercially available “rubbing alcohol” actually contains between 70% and 99% ethanol), is also quite toxic (LD₅₀ = ~ 3500 mg/Kg) and, like methanol, is not suitable for human consumption. As little as 100 mg directly
applied can cause severe eye problems and poisoning can come from ingestion and inhalation as well as direct absorption through the skin. Isopropanol is used in large-scale commercial processes as either a solvent or as a cleaning compound. In the body, it is broken down into acetone and causes depression of the central nervous systems leading to nausea, anesthesia, dizziness, coma, and death.

Ethanol (C₂H₅OH), the alcohol consumed in all alcoholic beverages, is also a clear, colorless liquid (b.p. 78 °C). It is a volatile, flammable, colorless compound that, in pure form, has a slight odor and causes a burning sensation when consumed. Ethanol dissolves in water at all proportions (called “miscible”) and water-ethanol mixtures form something called an azeotrope, meaning that, using normal distillation methods, there is always at least 4% water in distilled ethanol. To obtain pure ethanol (called absolute alcohol), another chemical is added that “denatures” the alcohol, allowing it to be distilled as a pure compound. Denatured alcohol is not suitable for consumption. Ethanol concentrations in beverages are usually referred to as its “proof” which, in the US, is twice the percent composition of the alcohol. For example, a solution containing 50% ethanol is called 100 proof alcohol. Ethanol can be classified as either a poison or a drug (LD₅₀ = 7060 mg/Kg), and it acts as a strong central nervous system depressant.

**Alcohol Production**

While ethanol can be made from petrochemicals and cellulose, by far the most common method for its production for human consumption comes from the fermentation of sugars. Fermentation uses certain strains of yeast to metabolize sugars into carbon dioxide and ethanol:

\[
C₆H₁₂O₆ \text{ (a sugar)} \rightarrow 2 \text{CH}_3\text{CH}_2\text{OH} \text{ (ethanol)} + 2 \text{CO}_2 \text{ (carbon dioxide)}
\]

The fermentation typically occurs under anaerobic conditions – those minimizing the presence of oxygen. The conditions for maximizing the yeast’s production of ethanol are carefully controlled, although the toxicity of the ethanol itself usually limits the highest concentration of ethanol that can be produced before killing the yeast and stopping the process. Typically, the maximum concentration of ethanol from natural fermentation is about 15% ethanol by volume. Nationally, the US ethanol production surmounted 13 billion gallons in 2010 – although the vast majority of this production was directed towards fuel uses. The US per capita annual consumption of alcoholic beverages is about 2.5 gallons per person.

Virtually any source of sugar can and has been used to produce ethanol by fermentation including corn, fruit juices, grains, potatoes, beet and cane sugar, honey. The source of the sugar dictates what type of alcoholic beverage is produced. The flavor, color, and consistency of an
alcoholic beverage comes mostly from other chemicals in the mixture, rather than from the alcohol. These other substances, called congeners, arise primarily as byproducts of the fermentation process but may also simply be present in the drink from the original sugar source.

Beer is probably the oldest alcoholic beverage produced and, worldwide, is the third most commonly consumed drink behind water and tea. Beer is usually produced from the fermentation of grains, most commonly barley that is steeped in water to make it germinate first (called a “malt”). The malt is boiled with hops (flower clusters of the hop plant, Figure 13.5.3) to form a “wort” to add flavor and aroma. The wort is finally fermented by the addition of yeast to produce the beer. Today, beer making is a very complex and carefully controlled multi-step process, as illustrated in Figure 13.5.5. There are a number of types of beer, depending on how the brewing takes place. Beer with a higher alcoholic content is called ale, while a stout is a beer flavored with roasted grain. Lager is a beer that has been allowed to age for a relatively long time. Most beers have an alcohol content ranging between 1% and 6% ethanol (by volume). Curiously, “lite” beer has a lower caloric content primarily because it has a lower alcohol content.

Cider comes from the fermentation of apples, pressed to release the fruit juice. If the fermentation is stopped before all the sugar is consumed, a “sweet cider” results while “sparkling cider” is produced when the carbon dioxide byproduct of the fermentation is trapped inside the bottle (although today, sparkling cider is often prepared by injecting carbon dioxide into the bottle after fermentation has ended).

Wine is most often prepared from the fermentation of grapes and fruits and is often a very complex and carefully controlled process (Figure 13.5.6) – one that generations of producers have developed into an art form. In general,
red wines are produced by fermenting the grapes with the skins left in the fermentation mixture while white wines come from mixtures in which the skins have been removed prior to fermentation. Wine production typically involves a slower fermentation and aging process, often involving months and years. Wines typically have alcohol contents ranging from 9% to 16%.

When alcoholic mixtures are distilled, the alcohol content is increased. Spirits are defined as alcoholic preparations with at least a 20% alcohol content. The distillation process often changes the flavor properties of the beverage by removing or altering some of the congeners found in the liquid.

A variety of other alcoholic beverages are produced and vary by what is used as the sugar source, how it is fermented and processed, how it is aged (or not), and how the final product is bottled and stored. Some common examples are given in the box “Other Alcoholic Beverages”. To avoid a confusion in nomenclature, the term “alcohol” will be used here as it is commonly employed to refer to ethanol.

### Alcohol Toxicology

Alcohol is consumed primarily orally (by mouth), although it can also pass through the skin or be inhaled. Most of the alcohol ingested is absorbed either in the stomach (~20%) or in the small intestines (~80%). Once absorbed, it is very rapidly distributed throughout the body and equilibrated in all body fluids.

The biological effects of the alcohol only occur once the alcohol reaches the blood stream and the body’s tissues. A number of factors influence that rate of alcohol absorption into the blood stream:

- **Gastric Emptying** – refers to the rate at which the contents of the stomach are moved into the intestinal tract. The absorption of alcohol is

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**Other Alcoholic Beverages**

- Brandy is grape wine distilled to increase the alcohol content. Brandy is aged for long periods in wooden casks until it is mature.
- Gin is made from malted barley (germinated barley grain) and rye that is flavored with juniper or other plant flavorings. Gin can also be made from corn or molasses.
- Rum is distilled from fermented sugar cane or molasses and aged in wooden barrels.
- Whiskey is made from fermented grain mash, usually barley, rye, wheat or corn that is aged in wooden casks. Fermentation is usually started by added the residue from previous fermentations.
- Sherry is a “fortified” wine in which brandy is added to the wine to increase its alcohol content to between 15% and 18% ethanol. The term “sherry”, however, can only be used for products originating in the Jerez region in southern Spain – any similar products made elsewhere must simply be called “fortified wine”.
- Many, many other types exist including beverages from native cultures around the world – mares milk, honey drinks, plant infusions of all kinds, including those that are produced by chewing and spitting back into the “mother”.
much faster in the upper portions of the small intestines than in the stomach. Moving the stomach’s contents into the intestines, therefore, speeds up the transfer of alcohol into the bloodstream.

- **Food and Other Drugs** – Alcohol absorption is much faster when the stomach is empty since the alcohol very rapidly passes into the small intestines – faster gastric emptying. This effect is seen in figure 13.5.7, showing the blood alcohol concentration (BAC) on both an empty stomach and after eating a meal. Estimates indicate that the rate of alcohol absorption is about three times slower after eating, especially fatty foods, than when drinking on an empty stomach.

- **Physical Condition/Exercise** – Physical exercise typically slows gastric emptying, mainly by diverting blood supplies to the body’s muscles rather than to the gastrointestinal system. Also, a greater body weight means more fluid volume in the body to dilute the alcohol, leading to lower alcohol concentrations. The presence of some drugs, such as nicotine, marijuana, and others, also modify the rate of gastric emptying.

- **Amount of Alcohol Consumed** – At first, the rate of absorption of alcohol in the stomach is rapid but then quickly falls off, even if the amount of alcohol in the stomach remains high. The rate of alcohol absorption in the small intestines, however, remains high over time.

Once in the body, the alcohol is quickly distributed to all the body’s fluids and organs. Alcohol easily passes across biological barriers, including the blood-brain barrier and the placenta. The behavioral and physical changes arising from alcohol consumption are mainly, however, connected with its effect on brain tissue.

The brain is the terminus of the central nervous system’s millions and millions of nerve cells (neurons). Alcohol interacts with the cell membranes of the neurons, altering the electrical transmission of signals in the brain. While alcohol acts like other drugs in stimulating the “reward pathways” of the brain, it also acts quite...
differently from other drugs by affecting multiple systems of the brain through a combination of stimulation and inhibition. Alcohol generally acts as a depressant and first affects the front of the brain, the frontal lobe responsible for judgment, concentration, and normal inhibition (Figure 13.5.8). As the alcohol level increases, the effects move towards the back of the brain, sequentially affecting language control, motor skills, body orientation, and lastly, the visual center of the brain.

Alcohol use, however, does affect all of the body’s organs, especially when used chronically. A primary target is the liver, the organ responsible for removing most of the alcohol. Many of the byproducts of the liver’s action on alcohol are very toxic to the liver. Their presence can lead to alcoholic hepatitis and scarring (cirrhosis) and represents the leading cause of liver-related deaths. Alcohol also causes damage to other body systems including the gastrointestinal, cardiovascular, endocrine, immune and pulmonary systems.

**Blood Alcohol Concentration (BAC)**

The concentration of alcohol in the body’s tissues dictates its effect on a person’s behavior and physiology. Tissue concentration, in turn, depends directly upon the amount of alcohol initially absorbed into the blood stream. It is rather hard to measure directly the amount of alcohol in a living person’s tissues so we rely upon the next best thing – measuring the amount of alcohol in the blood stream, a measurement called the blood alcohol concentration (BAC).

The BAC is defined as grams of alcohol found in 100 mL of blood (sometimes referred to as milligram percent). For example, a BAC of 0.08% is equal to 0.08 grams of alcohol in

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**Table 13.5.1. Effects of different blood alcohol concentrations on the body**

<table>
<thead>
<tr>
<th>Blood Alcohol Concentration</th>
<th>Changes in Feelings and Personality</th>
<th>Brain Regions Affected</th>
<th>Impaired Activities (continuum)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.01–0.05</td>
<td>Relaxation</td>
<td>Cerebral cortex</td>
<td>Alertness</td>
</tr>
<tr>
<td></td>
<td>Sense of well being</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Loss of inhibition</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.05–0.10</td>
<td>Pleasure</td>
<td>Cerebral cortex +</td>
<td>Coordination (especially fine motor skills)</td>
</tr>
<tr>
<td></td>
<td>Numbness of feelings</td>
<td>forebrain</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Nausea, Sleepiness</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Emotional arousal</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.11–0.20</td>
<td>Mood swings</td>
<td>Cerebral cortex +</td>
<td>Reasoning and depth perception</td>
</tr>
<tr>
<td></td>
<td>Anger</td>
<td>forebrain +</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sadness</td>
<td>cerebellum</td>
<td></td>
</tr>
<tr>
<td>0.21–0.30</td>
<td>Aggression</td>
<td>Cerebral cortex +</td>
<td>Inappropriate social behavior (e.g., obtundation)</td>
</tr>
<tr>
<td></td>
<td>Reduced sensation</td>
<td>forebrain + cerebellum + brain stem</td>
<td></td>
</tr>
<tr>
<td>0.31–0.40</td>
<td>Unconsciousness</td>
<td>Entire brain</td>
<td>Slurred speech</td>
</tr>
<tr>
<td>0.41 and greater</td>
<td>Death</td>
<td>Death</td>
<td>Lack of balance</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Loss of temperature regulation</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Difficulty breathing</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Slowed heart rate</td>
</tr>
</tbody>
</table>

**Table 13.5.2. Selected Legal limits for BAC level when driving.**

<table>
<thead>
<tr>
<th>BAC (0 tolerance)</th>
<th>Russia, Saudi Arabia, Brazil, Canada (new drivers), Hungary</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.02%</td>
<td>China, Poland, Norway, Netherlands, Sweden, Puerto Rico</td>
</tr>
<tr>
<td>0.03%</td>
<td>India, Japan, Uruguay</td>
</tr>
<tr>
<td>0.04%</td>
<td>Canada (provincial)</td>
</tr>
<tr>
<td>0.05%</td>
<td>Austria, Belgium, Denmark, France, Greece, Israel, Italy, Peru, Spain, Thailand, Turkey</td>
</tr>
<tr>
<td>0.08%</td>
<td>Canada (criminal), Mexico, New Zealand, Norway, UK, US</td>
</tr>
</tbody>
</table>

**Figure 13.5.9.** Relative risk of being involved in an automobile crash plotted against blood alcohol concentration (dwiwatch.org/Images/CrashRiskDunlap_x.jpg).
every 100 mL of blood. The effect of a particular BAC level varies from person to person but some typical BAC levels have been associated with certain physiological and behavioral changes, as given in Table 13.5.1. Different countries have varying BAC thresholds for criminal legal action, especially for driving, ranging from anything greater than 0.00% to 0.15%, although most nations fall in the 0.05 to 0.08% range. Some representative values are shown in Table 13.5.2.

The risks associated with driving after drinking are well documented. Figure 13.5.9 shows a plot of the relative risk based upon BAC level.

BAC levels represent a balance between the rate that the alcohol is added to the bloodstream through absorption and how much of it is metabolized away. If the amount added is equal to the amount removed, the BAC will remain relatively constant. If, however, absorption is faster than elimination, BAC will increase. A variety of factors affect an individual’s BAC including:

- The amount of alcohol consumed;
- The rate of consumption;
- The individual’s body weight;
- Gender – women typically have less water and more fat tissue in their bodies – leading to less alcohol absorption by the fat and less fluid to dilute the alcohol;
- The type of drink consumed (alcohol content of the drink);
- Previous drinking history of the individual (chronic alcohol consumption makes the liver more efficient at removing the alcohol until the liver ultimately becomes permanently damaged by the alcohol);
- Genetic background, age, physical condition, and diseases present all can affect how fast the body removes alcohol (an impaired liver is less able to remove alcohol and its function also slows with age);
- Whether the alcohol is taken with or without food, medications or other drugs;

A variety of online and “pocket” calculators for BAC levels are available which allow an estimation of BAC levels based

<table>
<thead>
<tr>
<th>Drinks</th>
<th>100</th>
<th>120</th>
<th>140</th>
<th>160</th>
<th>180</th>
<th>200</th>
<th>220</th>
<th>240</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight</td>
<td>0.0</td>
<td>0.06</td>
<td>0.08</td>
<td>0.10</td>
<td>0.12</td>
<td>0.14</td>
<td>0.16</td>
<td>0.18</td>
</tr>
<tr>
<td>Only Safe Driving Limit</td>
<td>0.00</td>
<td>0.06</td>
<td>0.08</td>
<td>0.10</td>
<td>0.12</td>
<td>0.14</td>
<td>0.16</td>
<td>0.18</td>
</tr>
</tbody>
</table>

Table 13.5.3. Approximate BAC calculation tables for men and women.

Note: one shot contains about 1.25 oz of 80 proof alcohol, the beer is calculated at 5%

(www.honoluludui lawyeronline.com/dui-bac.html)

Figure 13.5.10. Smart phone application of a BAC calculator (iphoneappcafe.com/10-best-iphone-apps-on-a-night-out/bac-calculator-iphone-app-review/).
upon alcohol consumption and their body mass (Figure 13.5.10). One table-based example is given in Table 13.5.3 with separate tables for men and women. For example, from the table, it can be seen that a 180 lb. male reaches the legal driving limit at a little over three drinks in an hour. Consuming one additional drink per hour afterwards would keep the BAC at about the same level, since the liver can metabolize about one drink per hour.

Usually the maximum BAC level is reached between 30 and 90 minutes after consumption, as shown in Figure 13.5.7. This means, of course, that a person’s alcohol level may continue to rise well after they have taken their last drink. This may have dire consequences if a great deal of alcohol is consumed over a short period and the person simply passes out – their BAC may continue to increase to a dangerous, life-threatening level more than an hour after they passed out and may require emergency medical attention instead of simply “sleeping it off”.

**Alcohol Elimination**

Once the alcohol is in the bloodstream, the liver immediately begins to metabolize it. The vast majority of alcohol, therefore, leaves the body after it is oxidized by the liver’s enzymes (~90 to 95%), although some is directly eliminated in sweat, urine, and breath (a central tenant of the “breathalyzer test”, see later).

Once the alcohol enters the liver through the blood, it is converted by an *alcohol dehydrogenase enzyme* into acetaldehyde (CH₃CHO). The acetaldehyde is then converted into acetate (CH₃CO₂⁻, a form of acetic acid) by another set of enzymes (acetaldehyde dehydrogenase), as shown in Figure 13.5.11. Because there are only a fixed number of sites in the liver where this occurs, the rate of alcohol elimination is fixed, typically removing about 0.5 oz. of alcohol (or 1.5 oz. of 80 proof alcohol or 0.015% BAC) per hour. In Figure 13.5.12, the rate of elimination is constant.

### The Cost of Alcohol

- 68 percent of manslaughter cases
- 62 percent of assault offenders
- 54 percent of murders
- 48 percent of robberies
- 44 percent of burglaries
- 39 percent of all fatal crashes


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**Figure 13.5.11.** Metabolic pathway of ethanol (alcohol) in the liver (www.medscape.com/viewarticle/545119_4).

**Figure 13.5.12.** The rate of alcohol metabolism by the liver (alcoholism.about.com/cs/alerts/l/blnaa35.htm).
and the amount of time it takes for different amounts of alcohol to be eliminated is shown. The metabolites of alcohol oxidation in the liver are ultimately eliminated in the urine.

Alcohol use has both short and long-term effects on the body’s physiology. Besides the immediate impairment and intoxication symptoms, a delayed “hangover” can result. A hangover is a collection of symptoms that includes nausea, headache, increased heart rate, excessive thirst, insomnia, dizziness, diaphoresis (sweating) and unsteadiness. These symptoms arise from the effects of the alcohol, its oxidized metabolites, and the congeners present in the drink. Alcohol consumption upsets the body’s water balance, causing the thirst. Alcohol metabolites effectively acidify a person’s blood, a process called acidosis, which causes the body to experience thirst, nausea, and sweating. It also modifies the body’s normal daily rhythms, similar to the effects of “jet-lag”. Some studies have suggested that a major cause of hangover arises from the congeners in the drink and the presence of these additional compounds varies greatly from one type of alcohol to another.

**Blood Alcohol Concentration Testing**

It is often necessary to determine a person’s BAC level and state of intoxication for legal considerations. This testing usually occurs in several “stages”, beginning with a field sobriety test and concluding with an accurate laboratory measurement.

**Field sobriety:** This preliminary form of testing involves a series of behavioral tasks that a person suspected of being intoxicated is requested to perform by a police officer on site. The National Highway Traffic Safety Administration (NHTSA) has developed a battery of three tasks, called the Standardized Field Sobriety Test (SFST), to evaluate impairment as the basis of a probable cause for arrest. These tests include (Figure 13.5.13):

- **Horizontal Gaze Nystagamus** (HGN) – This test examines the involuntary jerking of the eye as a person looks from side to side. Under normal conditions, this jerking occurs only when someone looks far to the side but

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**Figure 13.5.13.** Standardized field sobriety tests (SFST); (Left) *Horizontal Gaze Nystagamus*, (center) Walk and Turn (WAT), and (right) One Leg Stand (OLS) (HNG photo: www.jbmartinlaw.com/pa-dui-lawyer/field-sobriety-tests/.

**Figure 13.5.14.** Structures of the lungs, including the alveoli, responsible for transferring gases between the air and dissolved in the liquid blood (www.graphicshunt.com/health/images/alveoli-271.htm).
when intoxicated, the jerking movement occurs even when a person looks only slightly to the side (less than 45°). Intoxicated people often have difficulty in “tracking” movements smoothly as they try to follow an object, such as a pen or flashlight, with their eyes. The NHTSA study showed that people showing this response had an 88% chance of being at or above to 0.08% BAC level.

- **Walk and Turn** (WAT) – This test is a “divided attention” test that is usually easily performed by a sober person but is difficult for an impaired person. Typically, the person is instructed to walk in a straight line in a “heel-to-toe” fashion for a specified number of steps, turn and walk back to where they started – a series of simultaneous tasks that they must think about (e.g., walking, balance, counting, etc.). An intoxicated person has difficulty doing several actions at once, including listening to multi-step instructions and performing simple tasks.

- **One Leg Stand** (OLS) – In this test, the suspect is asked to balance on one foot while counting until they are told to stop. Signs of impairment include swaying, putting the foot down, and using arms to balance.

**Breath Testing**: Once a person is suspected of being intoxicated, a breath alcohol test is usually administered by the officer, often called a breathalyzer or intoxilyzer test, to more accurately measure the BAC level.  

Alcohol in the blood circulates rapidly throughout the body, including to the lungs. The lungs contain millions of tiny sacs, called alveoli, which provide an efficient way to transfer gases between the air and the circulating blood. In the lungs, oxygen from the air becomes dissolved in the blood and carbon dioxide dissolved in the blood escapes into the air. This exchange process is described by something called **Henry's Law** which states that when a solution containing a dissolved volatile compound, such as O₂, CO₂ or even CH₃CH₂OH (alcohol), is brought into contact with a gas (the air), a fixed equilibrium is established between the amount of the volatile compound in the air and the amount dissolved in the liquid. In other words, at equilibrium, while some of the compound (i.e., ethanol) escapes into the air, some of it is also redissolves in the liquid (i.e., blood). So, at fixed temperature and pressure, once equilibrium is reached, there is a fixed ratio of volatile compound in the air compared to that in the liquid. In the case of alcohol and blood, this ratio is just about 2,100 to 1. This means that, at the temperature of the breath leaving a person (body temperature) and normal atmospheric pressure, there is always the same amount of alcohol in 1 mL of blood as there is in 2,100 mL of expired air. So, if we can determine the concentration of alcohol in a person’s breath, we can directly relate...
this to the amount of alcohol in their blood using the 2,100:1 ratio.

There are several methods currently used to determine the amount of alcohol in a person’s breath, and therefore how much alcohol is in their blood (BAC). The breathalyzer is probably the most common method being used. A breathalyzer works by observing the results of a chemical reaction between the alcohol in a breath and a colored compound. Analysis begins by a person blowing an air sample into a small chamber (Figure 13.5.15). Once in this chamber, the known volume of air in the fixed size chamber reacts with a mixture of chemicals including potassium dichromate and sulfuric acid, with silver nitrate used as a catalyst to speed up the reaction with the alcohol, Figure 13.5.16. Here, the alcohol reacts with the red-orange potassium dichromate, turning some of it into the green chromium sulfate compound, as shown in Figure 13.5.17. The device then electronically compares the color of the solution with a standard, the more green chromium sulfate produced, the more alcohol in the breath. A readout then indicates the person’s BAC level.

Increasingly, this chemical reaction-based system is being replaced by devices that measure the amount of alcohol in the breath directly by using infrared spectroscopy (Chapter 12). This newer process does not require chemical reactions and chemical solutions. The device, called either a breathalyzer or an intoxilyzer, measures the infrared light absorbed by the ethanol molecule to give both the amount of ethanol present (from the amount of light absorbed), and verification of the identity of the intoxicant (from the wavelengths of light absorbed). A schematic diagram of an infrared-based breath-alcohol testing device is shown in Figure 13.5.18.

Other methods for determining the amount of alcohol in blood are also available and

![Figure 13.5.17. Reaction of dichromate with ethanol. Unreacted chromium dichromate (Cr$_2$O$_7^{2-}$)is shown at left. At right, the solution has changed to a green color (chromium sulfate, Cr$^{3+}$) by reaction with ethanol. (Sciencephoto.com ; No. A500/284).](image)

![Figure 13.5.18. A drawing of how an intoxilyzer works based on how much infrared light is absorbed by the alcohol (Note: A = the IR light source, B is the breath inlet, C is the breath outlet, D is the sample chamber, E is the lenses, F is the filter, G is the photocell to measure the light output, and H is the microprocessor to calculate the BAC. (electronics.howstuffworks.com/gadgets/automotive/breathalyzer4.htm).](image)

![Figure 13.5.19. Personal BAC device](image)
becoming more common. One such method uses something called a fuel cell. In these devices, the alcohol in a sample of breath passes over a tiny piece of platinum. The alcohol in the sample is oxidized into acetic acid by the action of the platinum electrode, producing a measurable electrical current. The more alcohol that is oxidized, the greater the electrical current generated. By measuring the current, an estimate of the alcohol-content of a person’s breath can be determined.

Today, personal, pocket-sized BAC measuring devices are available at relatively low cost to consumers to help them estimate their own BAC levels, such as the devices shown in Figure 13.5.19. There are a number of problems with each of these types of alcohol measuring devices, including false positive readings. For example, the infrared-based devices cannot distinguish between ethanol and acetone (among other compounds). Hypoglycemic diabetic people can generate acetone in their blood as part of their condition, leading to false positive alcohol readings. Accurate tests also require “deep-lung”, or alveolar air, where the alcohol in the air and blood are in equilibrium. It is, therefore, important to ensure that “deep-lung” air is sampled. Other problems with breathalyzer devices include difficulties in calibration (standardization of the readings), differences in body temperatures (changing the Henry’s Law calculation), diseases present (e.g., acid reflux, blood diseases), and certain other chemicals present on a person’s breath (e.g., high-alcohol content mouthwashes), among others.

**Laboratory (Confirmatory) Testing:** The definitive test, however, is usually the analysis of the BAC using a gas chromatograph-mass spectrometer tandem (GC/MS, Chapter 12.5). In this method, the amount of alcohol is quantitatively determined by the GC (Figure 13.5.20) while the unambiguous identification of ethanol in the sample is carried out in the mass spectrometer. There are very few interferences with this method and it provides the most reliable and accurate BAC level determinations possible. Sometimes, ethyl glucuronide, a metabolite of ethanol breakdown in the body, may also be analyzed in urine samples.

Finally, sometimes a spectrophotometric method may be useful in determining the BAC level, especially as a second confirmatory test. In this method, the ethanol is first enzymatically converted into acetaldehyde, generating a chemical called

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*Figure 13.5.20. Gas chromatograph for several common alcohols* (www.scribd.com/doc/9732653/GC-Detection-of-Blood-Alcohol-for-Forensic-Methods).
NAD (nicotinamide adenine dinucleotide – a co-enzyme found in all living cells). The acetaldehyde is trapped as a stable compound using hydrazine (N₂H₄) and the amount of NAD formed is measured at 340 nm (ultraviolet region). The more NAD present, the higher the alcohol concentration in the sample.

While there are many things sold claiming to reduce someone’s tested BAC levels, these usually don’t interfere with GC/MS methods (Figure 13.5.20). The only non-medically available “treatment” that is effective in lowering the BAC is simply time – time to allow the liver to process the alcohol out of the blood stream.

Legal Considerations

As described earlier, different countries and states have set varying legal thresholds for BAC levels to be considered in civil or criminal violations. These levels often vary depending upon the tasks being performed: levels are usually set much lower or even zero for a bus driver or pilot as compared to the higher allowed BAC levels for the private individual operation of a vehicle. Some countries have set the BAC for individual vehicular operation, however, at zero – any detected alcohol in the blood is a criminal violation.

The measurement of BAC levels has also been considered by the US Supreme Court. In a landmark 1966 case (Schmerber v. California), a patient was being treated in a hospital for injuries from a car accident when medical personnel took blood samples to measure his BAC levels - over the objections of the patient. The defendant (patient) argued that two of his constitutional rights were violated when the samples were taken over his protests – the right against self-incrimination (5th amendment) and the right against unreasonable search and seizure (4th amendment). The Supreme Court ruled against the defendant on both grounds. The Court ruled that the self-incrimination right only pertained to verbal or written testimony and does not carry over to physical evidence. They also ruled that taking the blood sample amounted to a justified emergency situation since the defendant’s body was destroying evidence – metabolizing away the alcohol – and there wasn’t time for a search warrant to be issued. The decisions noted that the blood samples were taken by medical professionals using safe and accepted procedures. There is also a general recognition that operation of a vehicle on a public road amounts to a person’s acceptance of an implied contract between the person and the state, including permission to police alcohol levels and compliance issues.

Finally, sometimes, it is necessary to determine the amount of alcohol consumed some hours earlier based upon a measured BAC level taken later. When this is required, something called the Widmark equation is used. Simply stated, if you know information such as the person’s body weight, the BAC at the later time, the time between the first drink and the measurement and other

Figure 13.5.21. Far too common occurrence from mixing alcohol or drug use with driving (latimesblogs.latimes.com/lanow/2009/03/littrari-crash-1.html).
information, it is possible to back-calculate the number of drinks consumed at an earlier time. There are, of course, significant limitations in using the Widmark equation, but it has proved useful.