Module 4 -

Alcohol and the Breathalyzer™ Test

MODULE 4 - STUDENT HANDOUT

Spritney Beers Blows it Bigtime

The big news is that celebrity singer, Spritney Beers has been arrested for driving under the influence (DUI). Spritney blew a "0.08%" on the Breathalyzer™ when she was stopped by the police after driving over the center line. This value reflects the blood alcohol concentration (BAC) and, in California, it is the value that legally designates intoxication. Despite considerable evidence that the Breathalyzer™ test gives an accurate approximation of the BAC, there is still much discussion about the validity of this test. While in jail, Spritney used her one phone call to contact her attorney.

A court date has been set for three weeks from today. Paparazzi photographed her as she left the courthouse in a heated discussion with her attorney. Reporters at the scene quoted him saying "I am very suspect of the validity of the Breathalyzer™ test given to my client. I only have to establish reasonable doubt in this case."

Back at school, you are discussing the case with a classmate when your science teacher interrupts and decides that the topic is worthy of a class debate. To prepare for the class debate, you decide to learn how a Breathalyzer™ test is used to determine the BAC so that you can debate whether it is accurate or not.

Spritney Beers' level of alcohol intoxication was assessed by measuring the concentration of ethanol she expelled from her lungs. This technique works because a water-based molecule like ethanol that is absorbed from the gut into the bloodstream will reach the lungs, where it is exhaled as a vapor in the air.

1. Diagram the path that alcohol will take from the gut (stomach & small intestine) to the lungs via the circulatory system. Which membranes will ethanol have to cross? Although some alcohol is exhaled from the lungs, the rest stays in the blood. Where does the ethanol in the blood go once it leaves the lungs?

Ethanol is dissolved in the blood and is distributed to organs around the body. It is a **volatile** molecule and can be vaporized quite easily. In the lung, ethanol is converted from a liquid to a gas, so it can be exhaled in the air.

2. Identify and describe the chemical and physical properties of ethanol that contribute to its volatility. It will help to draw the chemical structure of ethanol.

3. Where in the lung is ethanol vaporized? What role does the lung play in the **vaporization** of ethanol?

The Breathalyzer™ can approximate a person's blood alcohol concentration (BAC) because the concentration of alcohol vapor in the lungs is directly related to its concentration in the blood. Alcohol vaporizes in the air sacs (alveoli) of the lungs and achieves an **equilibrium** with the concentration of alcohol that is still in the blood.

4. What is meant by equilibrium? Are ethanol molecules still moving across the membrane between the capillary and the alveolus?

5. What would happen to the equilibrium if some of the ethanol leaves the alveolar sac by exhalation?

When a person exhales into a breath analyzer such as the Breathalyzer™ tube, the exhaled alcohol reacts with compounds in the Breathalyzer™ chamber to produce a change in color from orange to green. The chemical reaction indicated by the color change involves **oxidation** and **reduction**. Silver nitrate catalyzes the reaction

6. What is **oxidized** in the Breathalyzer™? What is **reduced**? What role does the **catalyst** play in the chemical reaction?

The degree of the color change indicates how much alcohol is present in the expired air and the instrument calculates an actual concentration. However, for the Breathalyzer™ to calculate how much alcohol is present in the expired air sample it must take into account the volume of blood from which the alcohol originated. There is a standard way of describing this relationship; it is called the blood-to-breath ratio or **partition ratio**. The average blood-to-breath ratio is 2100:1 and this is the value used for legal purposes. The ratio assumes that an equilibrium exists between the blood and the alveolar air.

7. Explain what this ratio means in terms of the concentration of alcohol in the blood and the breath. Does the ratio change as one exhales?

Actually, the ratio can vary between 1500:1 and 3000:1 depending upon a number of factors including a person's age, gender, and genetic makeup. In Spritny Beers' case, the reported BAC was 0.08%, based on the 2100:1 ratio. In fact, she may be anywhere in this range from 1500:1 to 3000:1.

8. Calculate the underestimation and overestimation of Spritney's BAC assuming she had a blood-to-breath ratio of 1500:1 and 3000:1. Would Spritney still be considered legally intoxicated based on your answers?

As a point of discussion, consider the advantages and disadvantages of using the Breathalyzer™ test and decide for yourself whether you would prosecute based on the Breathalyzer™ evidence in this case. Is there other evidence to consider?

MODULE 4 - CONTENT

4A - How does ethanol get to the lungs?

Ethanol must first enter the bloodstream

Ethanol is a water soluble compound—it dissolves readily in water-based solutions and once it is swallowed, it moves into water spaces throughout the body, including the bloodstream. Here is a brief review of what happens:

- Molecules of ethanol travel across the membranes made of epithelial cells that line the stomach and small intestine.
- Ethanol molecules move across the membrane via **passive diffusion**.
- Once on the other side of the gut cells, these small ethanol molecules then easily pass through the walls of the tiny capillaries that line the gut.

To review the details about ethanol absorption go to Module 1B.

Learn more about diffusion across a biological membrane.

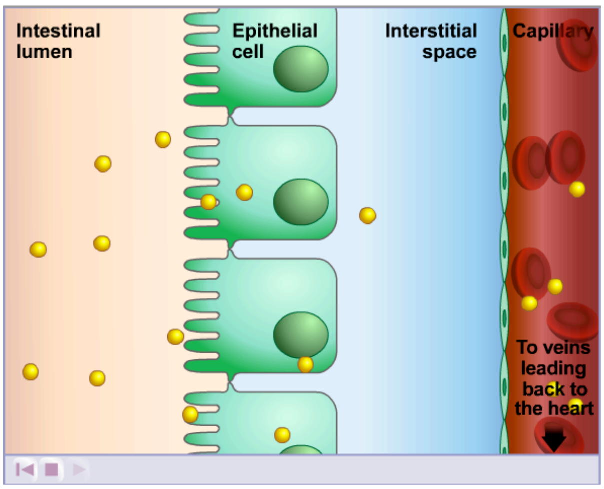

Figure 4.1 Absorption of ethanol from the gut into the bloodstream. Ethanol molecules in the gut diffuse passively across epithelial cells, through the interstitial space, and then into nearby capillaries.

Ethanol travels through the bloodstream to the lungs

Ethanol, in its liquid form, travels in the capillaries to the veins, and then heads up to the lungs. It takes the same route that deoxygenated blood takes to become oxygenated. Refer to Figure 4.2 to follow the route that the ethanol takes to the lungs.

- Ethanol is carried by the venous circulation to the right side of the heart.
- Ethanol enters the right atrium (like a foyer), and then moves into the right ventricle (a pump).
- The right ventricle pumps the venous blood to the lungs.
- In the lungs, red blood cells unload carbon dioxide and pick up oxygen brought in by respiration (breathing).
- Some of the ethanol dissolved in the blood gets eliminated as a gas by the lungs during exhalation.
- Ethanol that remains in the blood returns to the left side of the heart (the atrium).
- The left atrium supplies blood to the left ventricle of the heart, which pumps the blood to the rest of the water-containing compartments and tissues of the body via the arteries.

The branch of the circulatory system that moves blood between the heart and the lungs is called the pulmonary circulation, while the branch that moves blood throughout the rest of the body is called the systemic circulation.

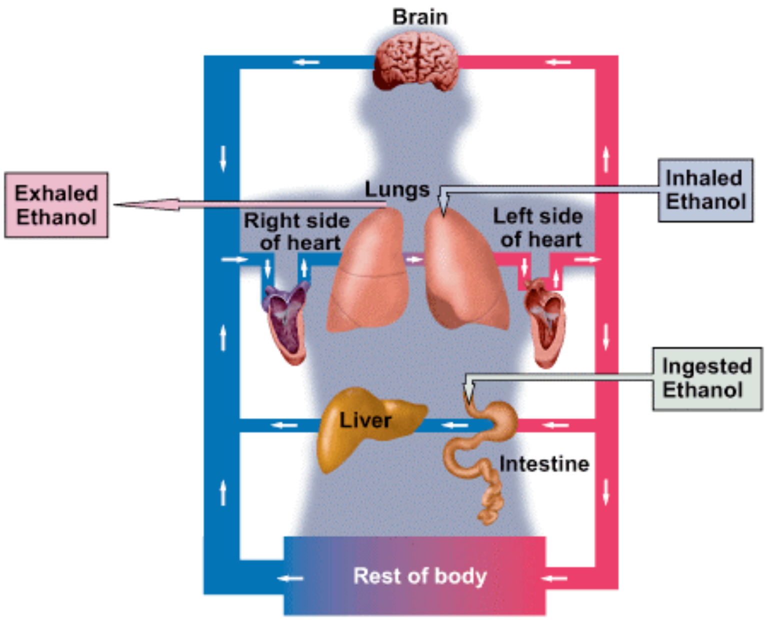

Figure 4.2 Ingested ethanol travels from the gut to the liver before reaching the heart and lungs. Inhaled ethanol travels to the brain before it goes to the liver. Ethanol in the veins travels to the heart, then the lungs, where a portion is exhaled. The arterial side is red, the venous side is blue. Adapted from www.thepepproject.net.

Ethanol moves passively across membranes in the gut into the capillaries, bringing it to the veins, leading to the heart. From there it goes to the lungs where a small portion is excreted. Most of the ethanol goes back to the heart and then to the arteries.

4B - Ethanol vaporizes to a gas in the lungs

In the lungs, ethanol moves by **passive diffusion** from the capillaries into the surrounding air sacs called alveoli. Unlike the process of active transport, passive diffusion requires no additional energy to move molecules. The energy comes from the difference in the concentration of ethanol between the two compartments: blood and lung alveoli (substances move from areas of high concentration to areas of low concentration).

As ethanol diffuses out of the pulmonary capillaries, it contacts a thin water-based mucous layer on the inner surface of the alveolar sacs (Figure 4.3). It is inside the alveolar sacs of the lung—at the interface between the liquid mucous layer and the air—where some of the ethanol changes from a liquid into a gas. The process is known as **vaporization**.

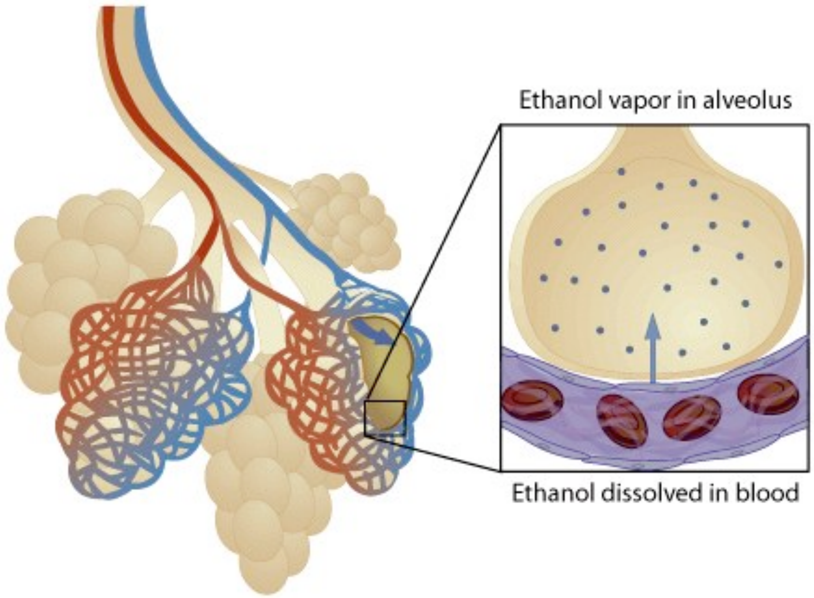

Figure 4.3 Ethanol from the heart reaches the lung capillaries (purple), which surround the alveoli. As ethanol diffuses into the alveoli, it vaporizes to a gas.

 Learn more about the structure and function of the lungs.

How does ethanol vaporize into a gas?

Let's look more closely at the process of ethanol vaporization.

At room and body temperatures, ethanol can exist as a liquid or a gas.

- Liquid - individual ethanol molecules are tethered to one another by two types of chemical forces: hydrogen bonds and **Van der Waals forces**.
- Gas - when liquid ethanol molecules have enough energy to break the hydrogen bonds connecting them together, they escape into the gas state.

Compounds, like ethanol, that can easily change from a liquid to gas are called **volatile** compounds.

Volatility is related to the number of hydrogen bonds. Let's compare ethanol and water. Individual ethanol molecules can only form three hydrogen bonds with neighboring ethanol molecules, while water molecules can form as many as four hydrogen bonds with neighboring water molecules. So, ethanol requires less energy to break three hydrogen bonds (ethanol) than four hydrogen bonds (water). Therefore, ethanol is more volatile than water.

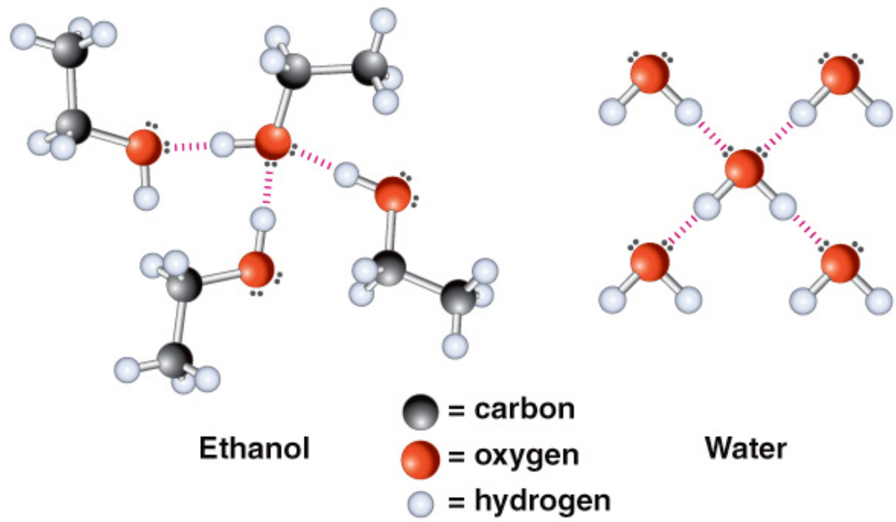

Figure 4.4 Ethanol vaporizes when its hydrogen bonds are broken. This happens more easily compared to water because ethanol molecules are bound to each other with up to three hydrogen bonds, while water molecules are bound to each other with up to four hydrogen bonds.

Learn more about vaporization and the volatility of a compound.

Ethanol volatilizes in the alveoli easily; ethanol has less hydrogen bonds to break compared to water in order to transition from a liquid to a gas.

4C - Ethanol leaves the lungs in the air

As you breathe in, oxygen from the atmosphere enters the lungs and moves into the circulation through the capillary walls that surround the alveoli of the lung. When you exhale, both carbon dioxide and ethanol in the breath are removed from the blood (of course, not all of it!). Let's look at this more closely.

- Ethanol dissolved in the mucous lining of the alveoli is in the liquid phase.
- Above the mucous layer is open space.
- As the ethanol vaporizes, the gas (vapor) expands to fill the air space within the alveolar sac.
- When you exhale, the vaporized ethanol exits the body. This is the same ethanol vapor that is measured by the Breathalyzer™ test to determine whether someone is intoxicated.

So, respiration not only provides the body a steady supply of oxygen, but also provides an exit for toxic waste products, including some **volatile** drugs like ethanol.

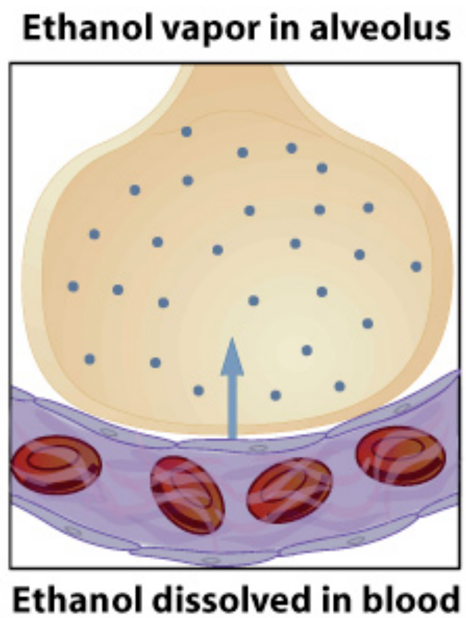

Figure 4.5 As ethanol diffuses into the alveoli, it vaporizes to a gas. Ethanol vapor can be exhaled from the body.

Ethanol can leave the body through exhalation; once the ethanol moves from the liquid to gas phase in the alveoli, it now has an open route to the external environment. Very little alcohol leaves the body through this route, but it’s easy to smell it!

4D - Ethanol in the blood equilibrates with ethanol in the alveolar air.

The ability of ethanol to volatilize in the lungs makes it a good candidate to be detected with breathing devices such as the Breathalyzer™. The Breathalyzer™ test approximates a person's blood alcohol concentration (BAC) because the concentration of alcohol vapor in the lungs is directly related to its concentration in the blood.

Although several devices can be used to test for alcohol in the breath, each one is based on a unique chemical property of alcohol and all are based on the central scientific principle that alcohol in the blood is in **equilibrium** with alcohol in the expired air.

How is equilibrium established?

Shortly after the first sip of beer, the concentration of ethanol in the blood exceeds the concentration of ethanol in the alveoli (which is zero).

Ethanol diffuses into the air sacs until the concentration in blood relative to that in air achieves a constant ratio.

Now, the two compartments are in equilibrium with one another.

- During equilibrium, molecules of ethanol may continue to move freely back and forth between the blood and the alveoli.
- But for each molecule that moves from the air sac back to the blood, another molecule moves from the blood to the air sac; so, no net movement of ethanol occurs across the membrane.

This equilibrium is dynamic because it can react to disturbances within either compartment. For example, when ethanol in the alveoli leaves the body in the breath, the ratio of ethanol concentration between the blood and the alveoli changes. To restore the ratio, more ethanol moves from the blood into the air sacs until the net flow of ethanol between the compartments is zero--equilibrium is restored.

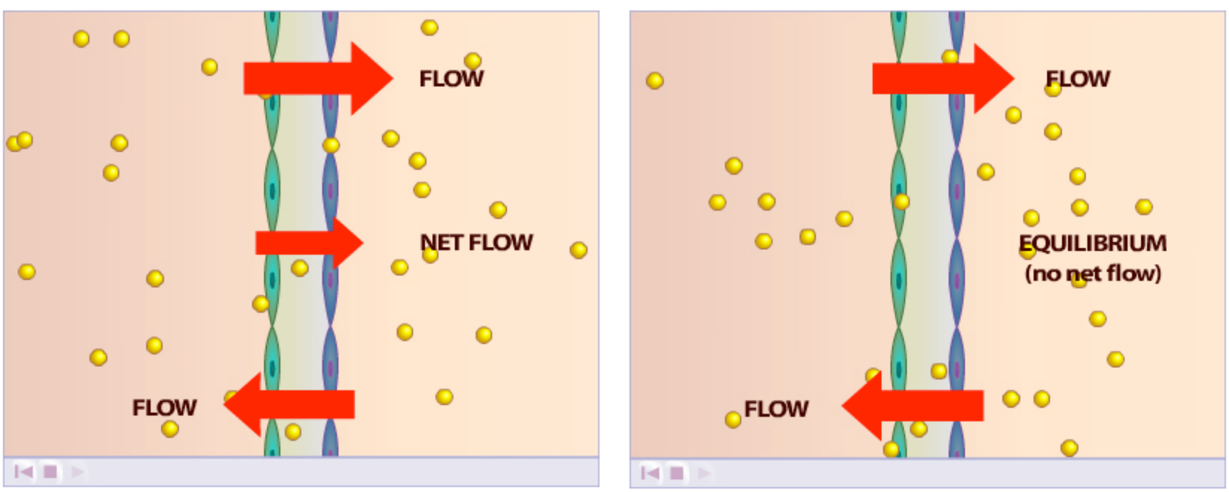

Figure 4.6 After drinking ethanol, it equilibrates between blood and the alveolus (left panel). With each exhalation, the equilibrium is disturbed, and more ethanol moves into the alveolus to reestablish the equilibrium (right panel).

The validity of a Breathalyzer™ test is dependent on the equilibrium of ethanol in the blood and the alveolar air. No net movement of ethanol across the alveolar membrane occurs at equilibrium.

4E - How does the Breathalyzer™ work?

The original version of the Breathalyzer™ included a mouthpiece and two chambers containing liquid connected to a meter that detects a change in color. To use the Breathalyzer™, the subject exhales through the mouthpiece into a test chamber filled with a reddish-orange solution of potassium dichromate ($K_2Cr_2O_7$).

Figure 4.7 An example of a newer version of a breath testing device

In the Breathalyzer™, alcohol reacts with the reddish-orange potassium dichromate solution and turns green. The degree of the color change is directly related to the level of alcohol in the expelled air.

A photocell compares the difference in colors between the reacted mixture in the test chamber and a reference chamber containing unreacted mixture. The difference in colors produces an electrical current, which can be converted into a quantitative value for the BAC. Read on to understand how the chemical reaction produces the color change.

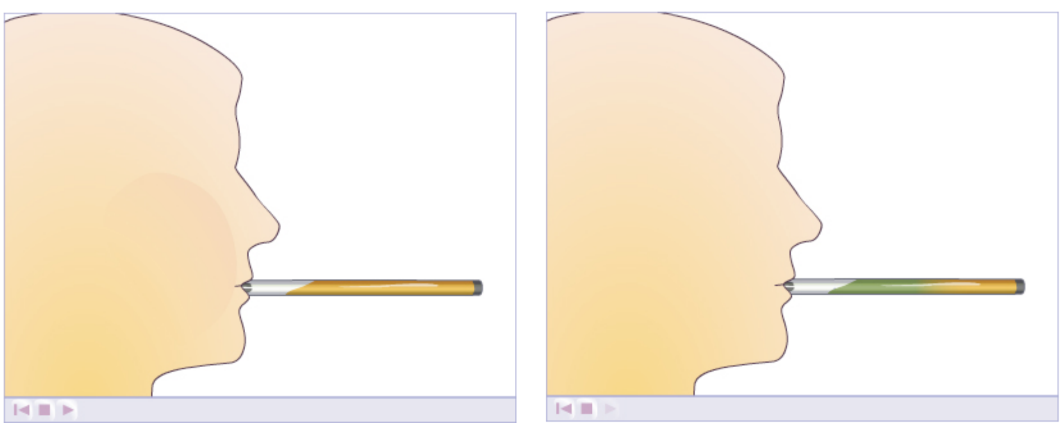

Figure 4.8 The ethanol vapor in the Breathalyzer™ triggers a chemical reaction with the compounds packed inside, turning the chemicals from orange to green. The more ethanol present, the greater the amount of green color is produced.

A description of different types of breath analyzers and how they work can be found at

http://science.howstuffworks.com/breathalyzer3.htm

The original Breathalyzer™ devices relied on the color change of a solution of potassium dichromate from red-orange to green. The more alcohol in the breath, the more the color changes to green, and this is quantified by the device.

4F - Redox chemistry inside the Breathalyzer™

The chemical reaction inside the Breathalyzer™ includes both **oxidation** and **reduction**. The Breathalyzer™ contains a chamber with several compounds to support these reactions. They include:

- Potassium dichromate
- Sulfuric acid
- Silver nitrate

When the potassium dichromate solution in the Breathalyzer™ reacts with ethanol, the potassium dichromate loses an oxygen atom.

- This process is called reduction --when a compound loses oxygen, gains hydrogen, or gains (partially gains) electrons.
- The reduction converts orange potassium dichromate into a green solution containing chromium sulfate.

At the same time dichromate **ion** gets **reduced** to chromium ion, ethanol gets **oxidized** to acetic acid. Oxidation reactions often occur simultaneously with reduction reactions and are commonly abbreviated as redox reactions.

- Oxidation occurs when an element combines with oxygen to give an oxide. For example, the oxide of hydrogen is water.
- Oxidation is the gain of oxygen, the loss of hydrogen, or the loss (or partial loss) of electrons

Silver nitrate serves as a **catalyst** for the reaction to increase the rate at which the dichromate gets reduced.

Sulfuric acid in the test chamber helps to remove the alcohol from the exhaled air into the test solution and to provide the necessary acidic conditions.

Oxidation and reduction (redox) reactions are opposing reactions that occur simultaneously.

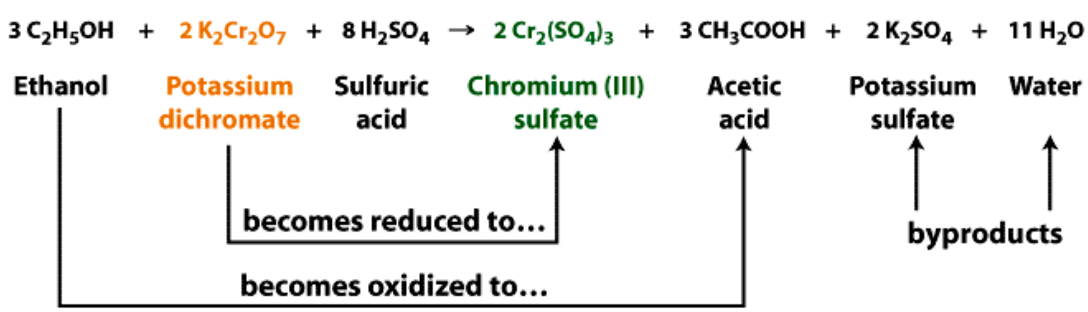

Figure 4.9 This is the balanced equation to show how ethanol is oxidized to acetic acid

 Learn more about redox reactions.

In the Breathalyzer™, ethanol participates in a redox reaction; it gets oxidized as it loses electrons (H atoms) and the potassium dichromate gets reduced as it picks up some electrons.

4G - The Breathalyzer™ assumes a specific blood-to-breath-ratio to calculate the BAC

In a breath test, one must calculate how much ethanol measured from the expired air sample is in the blood. To do this, one must take into account the volume of blood from which the ethanol originated.

First, a few assumptions must be made:

1. The ethanol concentration in the expired alveolar air is directly proportional to the ethanol concentration in the blood. This assumption is based on Henry's Law which states that, at constant temperature, the concentration of gas dissolved in a liquid is proportional to its concentration in the air directly above the liquid.
2. The exhaled alveolar air is in **equilibrium** with the blood. In the case of ethanol, the ratio of concentrations of ethanol in blood to expired alveolar air has achieved a constant value—on average, this is 2100:1.

This relationship is called the blood-to-breath ratio or **partition ratio**.

The blood-to-breath ratio can vary between 1500:1 and 3000:1. The ratio varies:

- among individuals according to age, gender, genetic makeup, and state of intoxication
- within a given individual at different times
- among measuring devices

The 2100:1 ratio is used as a standard conversion factor in determining BAC from the Breathalyzer™ test. It is actually an average based on comparisons of blood and breath samples collected from many individuals using several types of measuring devices.

The variability in the inter-person and intra-person blood-to-breath ratio could under or overestimate the true BAC as measured directly from the blood. This could be acceptable in court if there is proof of a discrepancy.

The average blood-to-breath ratio is about 2100:1. This means that 1 milliliter of blood has 2100 times more ethanol than 1 milliliter of air from the lungs. This value is used to calculate the BAC from the Breathalyzer™ test.

Module 4 - Student Quiz

1) Where does carbon dioxide-rich blood from the capillaries in the gut go?

- **A.** lungs → right side of the heart → left side of the heart
- **B.** right side of the heart → the lungs → left side of the heart
- **C.** left side of the heart → the lungs → right side of the heart
- **D.** lungs → left side of the heart → right side of the heart

2) Ethanol is more volatile than water because it has:

- **A.** fewer hydrogen bonds
- **B.** more hydrogen bonds
- **C.** carbon atoms
- **D.** nitrogen atoms

3) Which of the following statements describes ethanol equilibrium between the blood and the alveoli?

- **A.** The amount of ethanol is the same in the blood relative to the alveoli.
- **B.** The concentration of ethanol is the same in the blood relative to the alveoli.
- **C.** Ethanol stops moving between the blood and the alveoli.
- **D.** There is no net flow of ethanol between the blood and the alveoli.

4) No energy is required for the passive diffusion of ethanol out of the gut and into the bloodstream. If energy is not required, then what drives the diffusion process?

- **A.** ethanol's small molecular size
- **B.** proton pumps
- **C.** the higher concentration of ethanol in the bloodstream relative to the gut
- **D.** the higher concentration of ethanol in the gut relative to the bloodstream

5) When hydrogen is burned it combines with oxygen to produce water molecules. Which describes the state of each atom?

- **A.** Hydrogen is oxidized, Oxygen is reduced
- **B.** Oxygen is oxidized, Hydrogen is reduced
- **C.** Both are oxidized
- **D.** Both are reduced