Chapter 5

Beverages and Poisons

The Use and Abuse of Oxygen

Now it is time to speak of still another type of atom: the *oxygen atom.*

Oxygen is a gas, with a molecule made up of two oxygen atoms. One-fifth of the atmosphere is oxygen gas. Oxygen is not as active as fluorine or chlorine, but it is active enough to keep us alive; and active enough to be very destructive sometimes.

Oxygen atoms combine with the carbon and hydrogen of organic compounds. They continue to do so until the various carbon and hydrogen atoms are hanging on to as many oxygen atoms as they can. At room temperature the process is very slow; so slow, usually, as to be completely unnoticeable. If the temperature is raised, the process speeds up. At a certain temperature, the *ignition point,* the atoms of the organic compound combine with oxygen atoms so rapidly that the energy released can be seen and felt. The organic compound burns. Whether the process is slow enough to be unnoticeable or fast enough to be a fire or even an explosion, it is called an *oxidation.*

When an organic molecule has been completely oxidized, the carbon atoms are all converted to *carbon dioxide.* Its molecule is made up of one carbon atom and two oxygen atoms. The hydrogen atoms of the organic molecule have been converted to water, with molecules made up of two hydrogen atoms and one oxygen atom.

Oxidation goes on continuously in our body, but in a very slow, gentle and controlled way. The energy released by the oxidation is stored in the form of special compounds. When these special compounds (called "high-energy compounds") are broken up, they release the energy as needed. The released energy is then used to run the body machinery.

When we inhale, we pull oxygen into our lungs. From the lungs, oxygen is absorbed into the bloodstream and carried to all parts of the body. This oxygen combines with the organic compounds which have been obtained from the food that has been eaten, digested, and absorbed. The energy is used and the carbon dioxide that is formed is expelled when we exhale.

If, for any reason, our oxygen supply is shut off for as short a time as five minutes, we die. Our life is extinguished just as a fire in a furnace would be if the oxygen supply were shut off for even a short while.

So you see, life depends on controlled oxidation. The usefulness of a furnace, a gas range, or a match also depends on controlled oxidation.

We are all also acquainted with examples of uncontrolled oxidation that can do much harm—forest fires and gasoline explosions, for instance. All civilized communities support a fire department whose special duty it is to keep houses from burning; or to keep damage to a minimum once burning starts.

What a Difference an O Makes

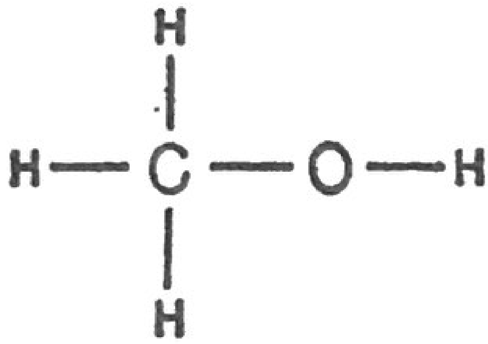
The chemical symbol for oxygen is just its initial, O. The oxygen atom is capable of forming two bonds. It will hook up with two hydrogen atoms to form water. It will also occupy two of the four bonds of a carbon atom while another oxygen atom will occupy the other two. In this way carbon dioxide is formed.

Suppose, though, that an oxygen atom is attached to a carbon atom with one bond and a hydrogen atom with the other. The atom combination would look like this: C-O-H.

Any molecule that contains such a combination is called an *alcohol*. This word is derived from the Arabic and reminds us that during the early Middle Ages, the Arabs (and the Moslem world generally) were far ahead of Europe in science.

The simplest alcohol is one with a molecule containing only a single carbon atom, thus:

Figure 22—Methyl Alcohol



Since this contains a methyl group, it is called *methyl alcohol.*

Methyl alcohol differs from methane because one hydrogen atom of methane has been replaced by an oxygen-hydrogen combination. (This O-H combination is called a *hydroxyl group.*) What a difference that extra oxygen atom makes!

A hydroxyl group in a molecule gives that molecule electrical properties resembling those of water. This means that whereas methane will not dissolve in water, methyl alcohol will. In fact, any amount of methyl alcohol will mix freely with any amount of water so that you could never tell from looking at the mixture that there were two different liquids to begin with. Methyl alcohol and water are, for that reason, said to be *miscible in all proportions.*

A hydroxyl group also makes a difference in the boiling point of a compound. The electrical properties of a hydroxyl group are such that molecules containing them stick together slightly. The molecules of liquid methane, which contain no hydroxyl groups, don't stick together. They are easy to pull apart into a vapor. Even at the frigid temperature of —161° C. there is enough heat present to supply the energy to vaporize methane. Therefore, —161° C. is the boiling point of methane. Each molecule of methyl alcohol, however, has a hydroxyl group which makes it "sticky." To pull those molecules apart and make a vapor out of them takes considerable energy, even though the molecules aren't much larger than those of methane. That is why the boiling point of methyl alcohol is 65° C.—226 degrees higher than the boiling point of methane.

Two hydroxyl groups sticking together form a *hydrogen bond.* It can be written this way —O—H . . . O—H—, with the dotted line representing the hydrogen bond. (Certain other atom combinations can also stick together in this way.) The hydrogen bond is only 5 percent as strong as ordinary bonds between atoms but they are terribly important. The enormous molecules of some of the complicated substances in our bodies are kept from falling apart by the hydrogen bonds that hold different parts of the molecule together.

An early method of preparing methyl alcohol was to heat wood in the absence of air. The complicated molecules in the wood broke up into smaller molecules as a result of the heat. These smaller molecules were given off in the form of vapors. These vapors did not burn since air was absent. They were collected and liquefied and a number of substances, including methyl alcohol, were obtained in this way. Because of this, the common name for methyl alcohol is *wood alcohol.*

The word "methyl" also goes back to that same process. It comes from Greek words meaning "wood wine." Since "methyl" applies to the alcohol with one carbon atom in its molecule, chemists decided to give the name "methane" to the hydrocarbon with one carbon atom in its molecule.[1]

Methyl alcohol is important in industry as a starting point for the manufacture of more complicated molecules. It also has another use, which needs some explaining.

Solid materials react very slowly. When chemists work with these solids they usually want to speed up the reactions. This is particularly true in industrial plants where tons of material may be involved. In order to speed things up, the solid material is dissolved in a liquid. Then, in solution, it can react very quickly.

The trick is to find a liquid that will dissolve the particular solid materials involved; to find a proper *solvent,* in other words. Many solids will dissolve in water and water is the most important solvent we have. However, many organic solids will not dissolve in water, but will dissolve in certain

[1] The official Geneva name for methyl alcohol is *methanol.* The suffix "ol" is given to all alcohols. Other types of compounds should not be given that suffix. Sometimes the aromatic hydrocarbons—benzine, toluene, and xylene—are called "benzol," "toluol," and "xylol." This is a bad habit picked up from the Germans and is frowned upon by American chemists.

organic liquids. Therefore, these organic liquids are also important solvents.

To be really useful, solvents must be abundant and cheap. They must have a fairly low boiling point so that they can be easily vaporized away when they are no longer needed.

Methyl alcohol, with its boiling point of 65° C., is an example of an excellent industrial solvent. Another important industrial solvent, by the way, is benzene, and there are many others as well. Each different solvent has its own particular value. Some solids, you see, may dissolve in one but not in another; a particular reaction may go well in one but not in another. The industrial chemist working with his tons of chemicals must be as particular in his ingredients as the master chef preparing a wedding cake.

The Cup that Cheers

The most famous alcohol of all is the two-carbon variety. Its formula looks like this:

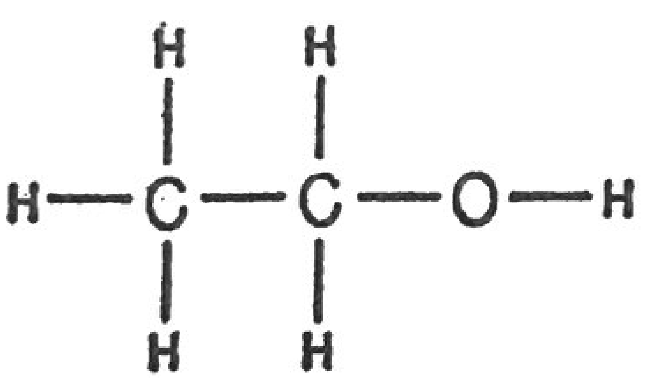


Figure 23—Ethyl Alcohol

Since this compound contains the ethyl group, it is called *ethyl alcohol.* Its official Geneva name is *ethanol.*

Ethyl alcohol is so important that when people (even chemists) say just "alcohol," they always mean "ethyl alcohol" and not any of the trillions of other possible alcohols.

It is difficult to know just what to say about ethyl alcohol. To the chemist, it is a particularly important compound. It is useful in many chemical reactions and, at the same time, quite cheap.[2] It is often important to the layman, too, but for him, it does not always serve a useful purpose.

[2] Ethyl alcohol is cheap, that is, if it is being used for scientific work. When it is used for other purposes, it is usually severely

Man learned about ethyl alcohol thousands of years ago, before civilization had its beginnings. There is no mystery as to how that came about. If fruits, or fruit juices, are allowed to stand about in the open, microscopic living cells (always present in the atmosphere) will fall in. Some will grow in the juice, living on the sugar it contains. The cells change the sugar into ethyl alcohol, using the energy freed by this chemical change for their growth and multiplication.

Fruit juices that are affected in this way are said to be *fermented*. Primitive man, drinking juice that had accidentally fermented, must have liked the taste or the way it made him feel. At least, it is pretty certain that he began to allow fruit juice to ferment on purpose. The earliest civilizations we know already had regular methods for producing fermented drinks.

Fermented fruit-juice, particularly fermented grape-juice, is called wine. Even the Bible shows how ancient the practice seemed even to the ancients, themselves. *Genesis* 9: 20-21 describes how Noah, after the flood, first cultivated the grape-vine and prepared wine. (It also describes the bad effects.)

You mustn't think that you are acquainted with the properties of ethyl alcohol just because you have seen wine. Pure ethyl alcohol is colorless and looks like water. (Chemists sometimes describe this as "water white.") It has a pleasant, sweetish smell, but not very strong. If you mix some with water, the mixture will be almost tasteless. The odor, taste, and color of wines is due not to ethyl alcohol but to other compounds. That is why there are so many different kinds of wine. The taste varies according to the particular juices used to begin with and the particular method by which it is allowed to ferment.

Starchy foods, like the grains, will also ferment, and ethyl alcohol will be produced from the starch. Grains which are allowed to sprout in moist heat (such sprouted grain is called malt) produce beer and ale. Such drinks were so popular and inexpensive in many parts of the world that the common name

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taxed. Most chemical laboratories keep their supply of ethyl alcohol locked away, to make sure it is used for scientific work only.

for ethyl alcohol is *grain alcohol.* One of the most popular grains for the purpose was barley. A grain of barley is called a barleycorn. ("Corn" is really an old-fashioned word for "kernel.") Consequently, alcoholic drinks today are sometimes referred to jokingly as "Old John Barleycorn."

Alcoholic drinks in moderation are found by many people to have a pleasant effect. They are stimulating, warming, seem to make one's self and other people friendlier and happier and so on. However, in greater amounts, they confuse a person's muscular co-ordination, upset his judgment, cause him to do foolish and even harmful things, and make him feel ill for a period of time.

Both the pleasant and the harmful effects can be strengthened by increasing the alcoholic content of the beverage. Ordinary beers and wines can't be more than about 15 percent alcohol. By the time the alcohol builds up to that amount, it kills the living cells that are doing the fermenting. Fermentation comes to a halt.

Man learned how to get around that, however. The boiling point of ethyl alcohol is 78° C., which is lower than that of water. If beer or wine is heated, the alcohol in the beverage evaporates and boils more quickly than the water does. The vapors that come off are richer in alcohol than the original liquor was. If these vapors are trapped and allowed to cool into a liquid again, you have a stronger drink (that is, one with more ethyl alcohol) than you started with.

This process of turning liquid into vapor, then back to liquid, is known as *distillation.* (I spoke of fractional distillation, you may remember, when I discussed petroleum refining.) The stronger alcoholic beverages are therefore called *distilled liquors,* and the equipment used to prepare them are called *stills.* By distillation, wine can be converted into brandy; beer can be converted into whiskey.

A word you may have heard in connection with whiskey is "proof." The proof of an alcoholic drink is a number equal to twice the percent of alcohol present. If a wine contains 18 percent alcohol, it is 36 proof. If a whiskey contains 50 percent alcohol, it is 100 proof.

In the chemistry laboratory, ethyl alcohol is usually used

95 percent pure (190 proof). The last 5 percent of water is hard to get rid of. When it is removed, *absolute alcohol* (100 percent or 200 proof) is obtained. This is quite expensive and must be handled carefully. The least exposure to air will result in its absorbing water vapor from the air and then it will no longer be "absolute."

Ethyl alcohol is a mild antiseptic. For this purpose, a 70 percent solution of alcohol in water (140 proof) is used. Generally, when a doctor or nurse is about to give you an injection, the spot where the hypodermic needle is to enter is first swabbed with a wad of cotton soaked in 70 percent alcohol. This kills skin bacteria which might otherwise enter with the needle and infect you.

Ethyl alcohol will burn. It already has some oxygen in its molecule so it produces only three-fourths of the energy that hydrocarbon will produce when it burns. Ethyl alcohol is also more expensive than gasoline. Still, when the day comes that the oil wells begin to fail us, we may find that our automobiles will have to run on alcohol.

The early chemists who first dealt with liquids that evaporated easily (as ethyl alcohol does) did not quite know what to make of it. They didn't have the equipment to handle vapors. It seemed to them that liquids just vanished when they evaporated. The very word "gas" when it was first invented was taken from the word "chaos" which shows how mysterious the whole thing seemed.

There was something ghost-like and insubstantial about gases to these early chemists. They called liquids that turned into gases easily, "spirits." Methyl alcohol, they called "wood spirit"; ethyl alcohol, "wine spirit." Even today, alcoholic beverages are frequently referred to as "spirits." (Modern Arabs, from whose language the word "alcohol" was taken, call ethyl alcohol "spirit" from the English. This is a queer interchange.)

The Cup that Kills

Ethyl alcohol may be harmful when taken in excess, but the other liquid alcohols are all worse. As little as a third of an ounce of methyl alcohol, for instance, will cause permanent blindness.

For a period of thirteen years, from 1920 to 1933, the United States tried to avoid some of the evils of alcohol intoxication by prohibiting the sale of beverages containing more than 0.5 percent of ethyl alcohol. (This was known as "Prohibition.") The experiment failed because alcoholic drinks were sold illegally in great quantities. Furthermore, a great deal of poor-grade liquor was manufactured in home stills. Sometimes unscrupulous people would add methyl alcohol to the final results, since methyl alcohol could be bought legally and fairly cheaply and it made the liquor "stronger." It also made the liquor poisonous. A shocking number of deaths were brought about by such poison liquor.

Ethyl alcohol can be made poisonous. When ethyl alcohol is used in industry (as a solvent, for instance), poisonous and foul-tasting substances are deliberately added to it. This is done to keep people from drinking it and to avoid increased costs. Drinkable alcohol, you see, is highly taxed, but undrinkable alcohol (called *denatured alcohol*) is not.

Denatured alcohol is sometimes used in automobiles. Ethyl alcohol has a very low freezing point, —117° C. The freezing point of water is 0° C. These two facts become important to the car-owner in the winter. Water is used in the car's radiator to keep the engine from getting too hot as it works. The engine uses up its heat in warming the water which is then circulated through the radiator so that it gives up its heat to the air.

This is all very well, but comes the winter and a cold snap. The car, standing in the street or in an unheated garage, gets cold. The water in the radiator freezes, expands, and cracks the radiator block. Expensive damage is done. For that reason, when winter aproaches, the motorist adds a liquid to the water in the radiator to lower its freezing point. The added liquid is an *anti-freeze*. Denatured alcohol is often used as an antifreeze. Add enough and no winter day will be bad enough to freeze your car. Methyl alcohol can also be used for this purpose.

However, while the engine is working, even on a cold day, the alcohol water mixture gets quite warm and slowly the alcohol evaporates away. If there is a warm snap, it evaporates away that much faster. For this reason, methyl or ethyl alcohol are only temporary anti-freeze compounds and more must be added every once in a while.

Alcohol solutions are often used externally as in *rubbing alcohol* for its effect in toning up the skin and soothing muscular aches. For similar reasons, it is used in hair lotions, after shaving lotions, and so on.

Manufacturers don't like to use ethyl alcohol for the purpose, and they can't use methyl alcohol or denatured alcohol. Instead, they use *isopropyl alcohol.* This is a 3-carbon compound, with the hydroxyl group on the middle carbon. Its action is very similar to ethyl alcohol. It is more poisonous if taken internally than ethyl alcohol is, but it has a harsher taste so people aren't likely to enjoy drinking it. And at least it is not as poisonous as methyl alcohol.

Isopropyl alcohol is sometimes added to gasoline in the winter. There is always a small amount of water in the gasoline, and ordinarily this causes no trouble. During cold snaps, however, the water will freeze into particles of ice. These may clog the fuel lines and stall the car. If a small quantity of isopropyl alcohol is put into the gas tank, it will mix with the water droplets and keep them from freezing. It is also used in de-icing mixtures intended to get ice off automobile windshields.

The Alcohol Properties Vanish

The alcohols with small molecules, such as methyl, ethyl, and isopropyl alcohols, are all miscible with water in all proportions. This is because of the influence of the hydroxyl group. However, in the molecules of alcohols with long carbon chains, the effect of the hydroxyl group is drowned out. The properties of the carbon chain take over.

Butyl alcohol, for instance, is made up of a four-carbon chain with a hydroxyl group attached. If ten ounces of butyl alcohol are added to ten ounces of water, the two liquids will not mix completely. One ounce of the butyl alcohol will dissolve in the water. A similar small quantity of water will dissolve in the butyl alcohol. The main body of the two liquids will remain apart. There will be a definite line of division (a *phase boundary*) between them. If you shake a bottle containing the two liquids, they will mix temporarily, forming bubbles. As the mixture stands, the two liquids separate and form two layers. The butyl alcohol will be on top because it is lighter than water.

Alcohols with still longer carbon chains are even less soluble in water.

The five-carbon alcohols[8] are known as the *amyl alcohols*. They occur in alcoholic beverages and may be responsible for some of the worse effects of alcoholic overindulgence, the so-called "hangover." This longer-chain alcohol portion of the beverage is sometimes referred to as *fusel oil*. (The word "fusel" comes from Greek words meaning "inferior spirits.")

[8] I refer to them in the plural because they occur as a number of isomers. The hydroxyl group can be in various positions on the chain and the chain itself can be branched in several ways.