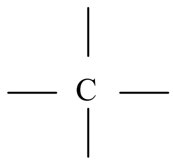
ORGANIC CHEMISTRY

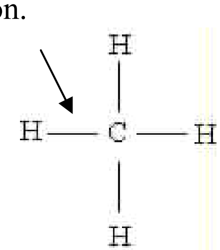
Previously, the chemistry discussed was inorganic chemistry. It is now time to look at the branch of chemistry known as organic. Organic chemistry, somewhat simplistically, is the chemistry of carbon. Organic chemistry is by far and away the largest branch of chemistry. Several hundred new organic compounds are created every year in comparison to 4 or 5 new inorganic compounds. What makes organic chemistry such a large branch? It must be the carbon.

Carbon is element # 6 on the periodic table, therefore it has 6 protons (also 6 neutrons) and 6 electrons in its naturally occurring form. The electron configuration of carbon is $1s^2 2s^2 2p^2$. The outer energy level is the second energy level with 4 electrons. Will carbon give up 4 electrons (to become the +4 cation) or take on 4 electrons (to become the –4 anion)? The answer is it can do both. Carbon can form either the carbon cation or the carbide anion. Given the choice, it will do neither. Carbon prefers to "share" electrons and form covalent bonds. There are 4 locations where carbon may share electrons. These are indicated by lines leading out from carbon.



Each of the above lines represents a sharing of 2 electrons. Carbon provides one electron, and any other atom that wishes to "share" may provide the other electron. For example, hydrogen has 1 electron and it may share that electron with any atom which likes to form covalent bonds. If carbon shares those electrons with 4 hydrogen atoms, the result is CH_4 or methane (CH_4 is the formula of the compound, methane is the name). Carbon thinks it has eight electrons (the octet rule) and each hydrogen thinks it has two (like the noble gas Helium).

Represents two electrons shared: one from hydrogen and 1 from carbon.

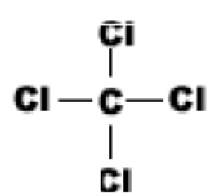


Methane

Methane is a colorless, odorless, flammable gas. It is often referred to as swamp gas or marsh gas due to its presence in those locations. Often any stagnant body of water will have bacteria, called methanogens, which produce methane. However, humans are also capable of producing methane.

Other Compounds of Carbon

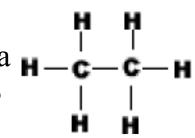
With what else may carbon combine? Any element that wishes to "share" an electron pair can bond with carbon. For example, chlorine has 17 electrons (but only 7 in the outermost energy level). What about sharing an electron with carbon to make eight. Since carbon has 4 locations to share electrons, place chlorine at each of those locations and you form CCl_4. That's the formula for carbon tetrachloride. Carbon tetrachloride was at one time used as a cleaning solution and an agent in fire extinguishers. Today, carbon tet (we often shorten the name when discussing it) is a known carcinogen. We don't use it in chemistry or biology labs for that reason.



Carbon may combine, therefore, with any element that wishes to "share" electrons. However, that's not the beauty of carbon. Carbon not only shares electrons with other elements, it often shares electrons with another carbon atom.

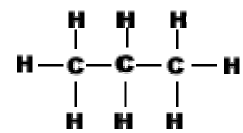
Ethane

If carbon shares electrons with another carbon atom (and then shares with hydrogen at the other possible positions) it forms C_2H_6 or ethane. Ethane is a colorless, odorless, flammable gas, also a component of marsh gas, and also a component of human gas production.



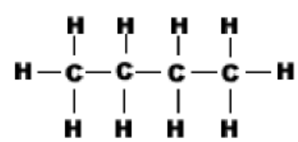
Propane

Continue to add carbons. When you have three carbons together, all sharing additional locations with hydrogen, you have C_3H_8 or propane. Propane is a colorless, *odorless,* flammable gas (but not a component of marsh or swamp gas – nor humans). As you perhaps know, if you have a propane grill, propane has an aroma. What gives? Since propane in its natural condition is odorless, how would you know propane is leaking from the propane tank? We add a "smell" to propane to be able to detect it if it leaks.



Butane

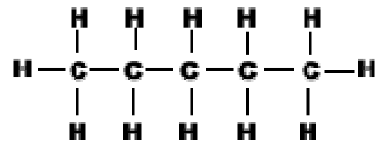
When you add another carbon to propane, you get butane (C_4H_{10}). Butane is colorless, odorless, and flammable. Get the idea? Butane is not used nearly as much today as previously. It was used in heating of homes in rural areas, just as propane is today. However, butane is a heavier gas. When it escapes, it does not go up into the atmosphere, instead, it often settles along the ground, particularly on days when the wind is calm. Leaking butane often caused major fires and explosions. Like propane, butane was given a "smell" in order to detect leaks.



Natural Gas

When you combine methane, ethane, propane and butane, you form the product known as natural gas – a mixture of the previously named gases. Natural gas is often used as a heating and cooking fuel. The United States has vast reserves of natural gas and at current rates of consumption, the reserve of natural gas will not be depleted in your lifetime. A third distinct "smell" is added to natural gas so you can tell the difference between propane, butane, and natural gas by their aromas

Pentane



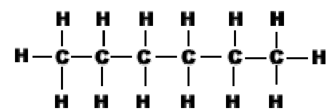
String five carbons together and add hydrogens at the other locations and you have pentane. For the first four compounds discussed earlier, organic chemists came up with unusual names. When they realized it was going to get out-of-hand, they decided to follow the numbering system of the Greeks, *i. e. penta* for five.

Pentane is a liquid at room temperature and flammable. The formula is C_5H_{12}.

Hexane

Six carbons with hydrogens is called hexane, another flammable liquid. The question arises "how many hydrogens"? You can see that if we get up to 40 carbons, it becomes tedious to count the hydrogens. There's a way to determine the number of hydrogens for these compounds.

Hydrocarbons



Methane, ethane, propane, butane, pentane, and hexane are called hydrocarbons. They are composed of but two compounds: carbon and hydrogen. The formula for determining the number of hydrogens in *singly bonded* (where the carbons share 1 pair of electrons between themselves) hydrocarbons is C_nH_{2n+2} where "n" equals the number of carbons. For example, hexane has 6 carbons. Therefore the number of hydrogens would be $C_6H_{2(6)+2}$ or 12.

Other Hydrocarbon Formulas	**Name**
C_7H_{16}	Heptane
C_8H_{18}	Octane
C_9H_{20}	Nonane
$C_{10}H_{22}$	Decane
$C_{11}H_{24}$	Unodecane
$C_{12}H_{26}$	Dodecane

Many of you recognize octane as a component of gasoline. Actually, gasoline (and all petroleum products) come from crude oil. The oil from an oil well is shipped to a refinery where crude oil is pumped into a refining tower. Octane is the most desirable component of gasoline and as such, the refining process is designed to maximize the amount of octane produced. However, gasoline is any hydrocarbon from pentane to dodecane.

The refinery begins heating the crude oil to the boiling point of octane. In that case, pentane, hexane, and heptane all boil with octane. They produce vapors. These vapors rise to the top of the refinery tower and condense to form liquids. They are removed from the tower and further refined.

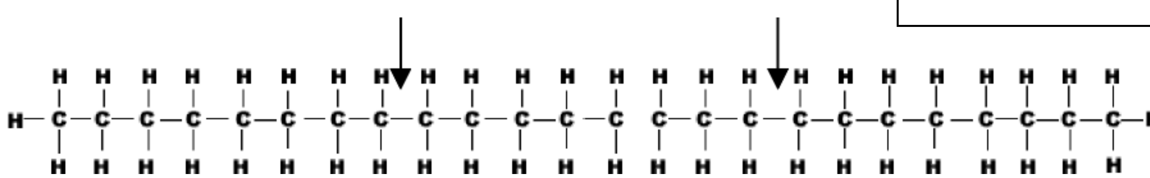
As the refinery continues to increase the temperature, different components of the crude oil mixture begin to boil, vaporize and condense. The next component to come off in the distillation process is kerosene, also called jet fuel. As the temperatures rise, motor oils are pulled off, then waxes and paraffins, and finally, what is left is a black sludge at the bottom of the refinery tower. This is called asphalt with which we pave roads.

Cracking and Polymerization

The problem with oil refineries is they produce as much motor oil, kerosene, waxes, paraffins, and asphalt as they do gasoline. The oil companies can sell a lot more gasoline than they can motor oil. However, if you take $C_{24}H_{50}$ and break it into three equal pieces, add hydrogen at specific locations, it now becomes three molecules of octane.

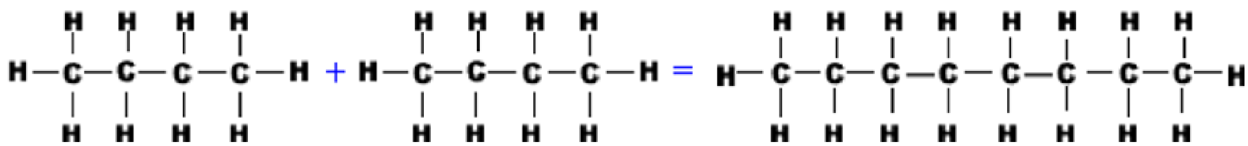
When you fill up at the gasoline pump, you generally purchase your gasoline based on the octane rating. The octane rating of gasoline is a little misleading. Let's say the octane rating of your gasoline is 88. Most people think that means their gasoline is 88% octane. That's incorrect. The next time you fill up, look for the formula $\frac{R+M}{2}$ on the pump.

This formula is used to calculate your octane rating. The octane percent is actually lower than 88. The octane rating is based on a procedure (Research and Motor protocols) comparing the amount of heptane present in relation to octane present (actually isooctane). This is compared against a standard of gasoline of known octane amount.

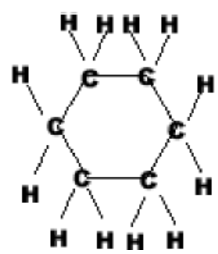


This process of taking a large molecule and breaking it down into smaller molecules is called **cracking**.

Conversely, we have more natural gas reserves than we do oil reserves. Why not take two butane molecules, remove a hydrogen from each and add them to form octane. This process is called **polymerization**. This is where we take two or more smaller molecules and make a larger molecule.



Ring Compounds
Many hydrocarbons fold in on themselves and form ring structures. For example, hexane may form a ring structure. Think of a hexagon. At every bend in the hexagon, place a carbon. Each carbon in the ring is thus sharing two bonds. That means there are two other locations for each carbon to add other bonds. If you place hydrogen at those locations, you form cyclohexane with the formula C_6H_{12}.

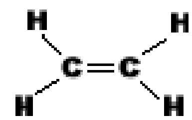


Note that cyclohexanes don’t obey the formulation rule of singly bonded hydrocarbons.

How Many Different Hydrocarbons Are There?
How high can you count? The number of hydrocarbons alone is infinite. All you have to do to create another hydrocarbon is simply add one more hydrogen and additional hydrogens. Organic chemistry is such a large branch of chemistry for this reason.

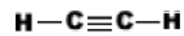
Double Bonds
Carbon is capable of sharing electrons with another carbon atom not one time, but twice. This allows carbon to form a double bond with itself. If you add hydrogen at the other possible locations, you still have a hydrocarbon but one that is different chemically from the singly bonded hydrocarbons.

Ethene



Remember ethane (C_2H_6)? Instead of a single bond between the carbons, remove two hydrogens and allow carbon to share that area also. The result is a compound called ethene. The formula is C_2H_4. This, like ethane, is a gas at room temperature. Think of all the singly bonded hydrocarbons you may form (it's infinite) and then begin inserting double bonds to those every so often and you find hydrocarbon chemistry is now doubly infinite in possibilities of compounds.

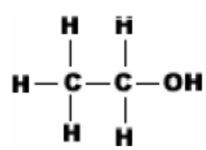
Triple Bonds and Ethyne



Carbon may share electrons with itself three times. For example, ethene may be converted to ethyne by removing another pair of hydrogen atoms and allowing carbon to share that space. The formula for ethyne is C_2H_2. Most people do not call it ethyne; instead they refer to it as acetylene (welder's gas).

Organic Chemistry Redux

So far, the discussion has been about hydrocarbons. There's much more to organic than this one group of compounds. Refer again to ethane. Ethane has the formula C_2H_6. Another way of writing the formula is H_3C-CH_3. On the right side of the molecule, remove one hydrogen and substitute an oxygen bonded to a hydrogen (-OH). -OH as a unit is called a hydroxyl group. (Oxygen is sharing one electron with another element and still has one other location to share, in this case, at the hydrogen.). Adding a hydroxyl group to ethane (with the one hydrogen removed) forms C_2H_5OH,



It is no longer a gas at room temperature, but a liquid. The name is ethanol (also called ethyl alcohol) or booze. Suddenly organic chemistry gets a little more exciting. The hydroxyl group –OH is also referred to as a functional group.

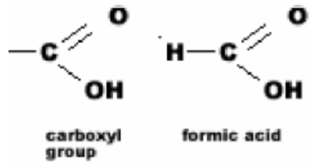
Functional Groups

There are several ways to change the nature of compounds by adding one or more components such as the hydroxyl group. There are many functional groups that are important in biology.

Hydroxyl (-OH)

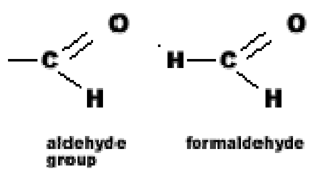
The hydroxyl group (as shown in ethanol) changes ethane from a gas to a liquid (and it also makes humans do peculiar things. Always think in terms of alcohols when you see the hydroxyl group. Caution! Don't confuse the hydroxyl group [-OH] with the hydroxide ion [OH^-] (see bases). They are different.

Carboxyl Group (COOH)
The carboxyl group is carbon doubly bonded to an oxygen (carbon can double bond with other elements) and then a hydroxyl group is added to the carbon. That leaves one space left to bond on the carbon.



If you add a hydrogen to the last position on the carbon, you form the compound called formic acid (HCOOH). When you see carboxyl groups attached to compounds, think in terms of acids.

Aldehyde Group (CHO)
The aldehyde functional group is carbon doubly bonded to oxygen. Add a hydrogen to a third location on carbon. This leaves one location to bond.



A simple aldehyde is to add one more hydrogen (HCHO). This is formaldehyde. This is a known carcinogen, a preservative and sometimes called embalming fluid. It is utilized a great deal in the manufacturing process and is a major component in many fingernail polishes.

Ketone Group (C=O)
The ketone group is carbon doubly bonded to oxygen with two remaining places to add bonds. A simple ketone is

$$\begin{array}{c} O \\ \| \\ H_3C\text{-}C\text{-}CH_3. \end{array}$$

This is dimethyl ketone. (A methyl group is another functional group. It's basically two methanes [CH_4] with hydrogens removed.) Dimethyl ketone is more commonly referred to as acetone (a major ingredient in many fingernail polish removers) also a known carcinogen.

Ether Group (-O-)
An ether group is one where oxygen is found in the middle of the compound. A simple ether is diethyl ether. The ethyl part is simply ethane with a hydrogen removed. The formula for diethyl ether is:

$H_3CH_2C\text{-}O\text{-}CH_2CH_3$.

This compound was used as the first effective anesthesia.

Ester Group (-COO-)
The ester group has carbon doubly bonded to an oxygen and a second oxygen attached to the carbon. An example is pentyl acetate.

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        O
        ||
CH3 -C-O-CH2CH2CH2CH2CH3
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Pentyl acetate is better known as banana. Remember, you only taste four things: sweet, sour, salt, bitter. Banana (or pentyl acetate) is an aroma. You find it naturally in bananas (or it can be made in the chemistry lab – hence artificial flavorings).

Phosphate Group ($-PO_4)^{-3}$
The phosphate group is a phosphorus atom with four oxygens attached. There is still one place to attach another element in phosphorus. (Phosphorus may have five bonds, unlike carbon which has 4 bond sites.) An example is adenosine triphosphate which has three phosphate groups attached.

Amino Group ($-NH_2$)
This is nitrogen with two hydrogens attached. Nitrogen typically has three locations to bond (as opposed to carbons four). An example is an amino acid, the building blocks of proteins.

Thiol or Mercaptan (-SH)
This is a sulfur atom combined with a hydrogen atom and the unit attaches to another element. Whereas esters tend to smell good, thiols (or the older term mercaptan) smell bad. The aroma of a skunk is a thiol group. An example is methyl mercaptan (CH_3SH) an additive in jet fuels and fungicides. It is extremely toxic.

Functional Group	Formula	Example
Hydroxyl	-OH	Ethanol (CH_2OH)
Carboxyl	COOH	Formic Acid (HCOOH)
Aldehyde	CHO	Formaldehyde (HCHO)
Ketone	| C=O |	Dimethyl ketone (H_3CCOCH_3)
Ether	-O-	Diethyl ether ($H_3CH_2COCH_2CH_3$)
Ester	O || -C-O-	Pentyl acetate (CH_3COO- $CH_2CH_2CH_2CH_2CH_3$)
Phosphate	$-PO_4{}^{-3}$	Adenosine triphosphate
Amino	$-NH_2$	Amino Acids
Thiol or Mercaptan	-SH	Methyl mercaptan (CH_3SH)
Methyl	$-CH_3$	Methyl mercaptan (CH_3 SH)
Ethyl	$-CH_2CH_3$	Diethyl ketone ($CH_3CH_2OCH_2CH_3$)
Propyl	$-CH_2CH_2CH_3$	Propyl alcohol ($OH-CH_2CH_2CH_3$)

What do we do with these functional groups. By adding them to other compounds, we can change the nature of the original compound. This course will look at four major compounds important in biology, all of which have functional groups attached to them. The four major compounds are carbohydrates, lipids, proteins, and nucleic acids.