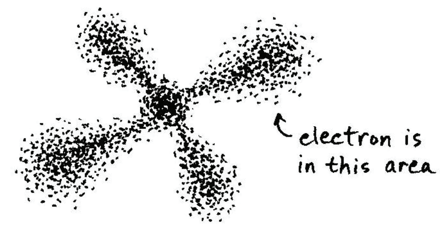
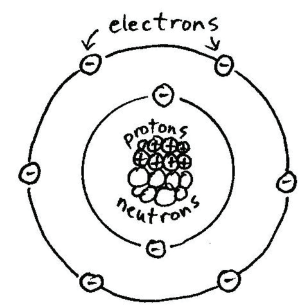
Chapter One: Carbon

The heart of carbon chemistry is, of course, the carbon atom. Like all atoms, the carbon atom is made of only three particles: protons, neutrons, and electrons. There are several ways to represent a carbon atom. Each model has strengths and weaknesses.

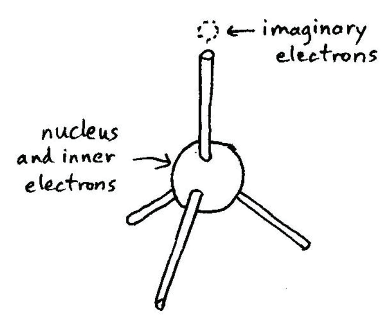
This is called the ***electron cloud model***. It shows how the carbon atom looks under an electron microscope. It is the closest to being an actual "photograph" of the atom. However, it is almost useless when we want to study the orderly arrangement of electrons into shells and orbitals, or when we want to show chemical bonding.

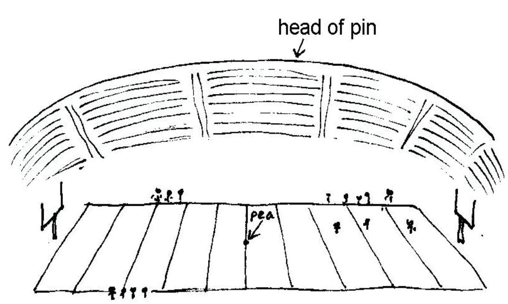


This is called the ***solar system model***. It doesn't look anything like a real carbon atom, but it is a very good model to use for learning about the arrangement of protons, neutrons and electrons. It helps us to understand how the electrons orbit around the nucleus. We can show the arrangement of the electrons into shells. The weakness of this model, however, is that it is very easy to forget that atoms are really three-dimensional, not flat.



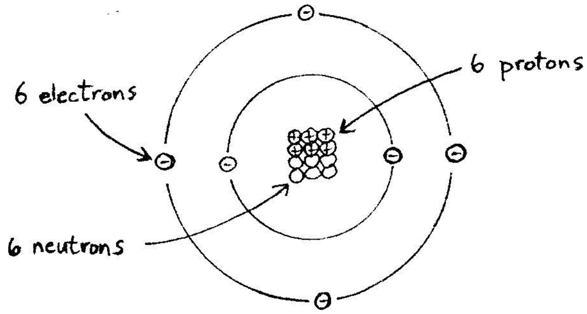
This is called the ***ball and stick model***. It doesn't look anything like a real carbon atom, either. The ball in the center represents both the nucleus of the atom, and any electrons that are in "inner" shells, closer to the nucleus. The sticks represent free electrons on the outside of the atom that are available for bonding with other atoms. This model is very useful when you want to build models of molecules. It does not show the electrons, however; it shows only sticks where the bonds are, and this can be confusing to beginning students. You have to remember that the stick represents an electron or a pairing up of electrons.





A weakness of all these models is that they do not show the relative sizes and distances between the particles. If you imagine that the nucleus of an atom is a marble sitting on the 50 yard line inside a large football stadium, the electrons would be pin heads traveling along the outer reaches of the upper decks. It's hard to believe, but an atom is mostly empty space!

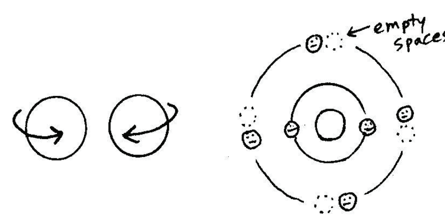
Each element has a unique number of protons. Hydrogen has one proton, helium has two, lithium has three, beryllium has four, and so on through the Periodic Table. An atom's atomic number tells how many protons it has. Carbon's atomic number is six, so it has six protons.



The plus signs in the protons mean that they carry a positive electrical charge. The minus signs in the electrons show that they have a negative charge.

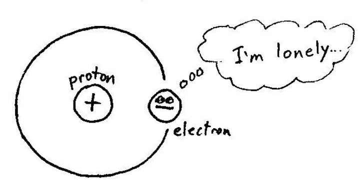
Since atoms must be electrically balanced, this also means that carbon has six electrons. Carbon's electrons are arranged in two layers, or shells. The first shell contains two electrons, and the remaining four are in the second shell. The fact that carbon has four electrons in its outer shell is very significant. Ideally, all atoms would like to have their outer shells filled, and, in the case of carbon, it would like to have eight electrons, not four. Like most of the smaller atoms on the Periodic Table, carbon lives by the motto: ***"8 is great!"***

Electrons form pairs, with one electron spinning one way, and the other electron spinning in the opposite direction. (It's like a very simple dance.) Carbon would like each of its electrons to have a partner, so carbon is out looking for four electron "dance partners" to fill in these empty places.

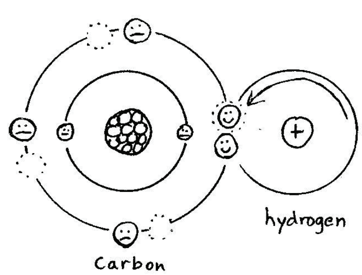


How does carbon find electrons to fill in these empty places? It borrows them from other atoms. It just so happens that there are other atoms out there that have the same problem that carbon does. They have electrons without partners, too. These atoms would love to get together with carbon and share one or more electrons, in an attempt to make pairs of electrons. Let's look at some atoms that would like to share electrons with carbon.

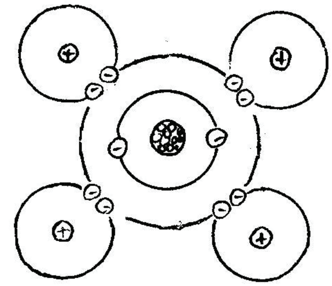
Hydrogen is the smallest atom that exists. It is made of only one proton and one electron. What fun can just one electron have? The proton isn't much company—it can't do the electron dance. So, hydrogen's electron goes out looking for a partner.



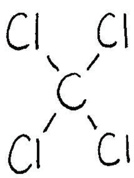
Look! There's a carbon atom! It needs some partners! So hydrogen goes over to carbon and puts its electron into one of carbon's empty slots. Now we have one happy electron couple.



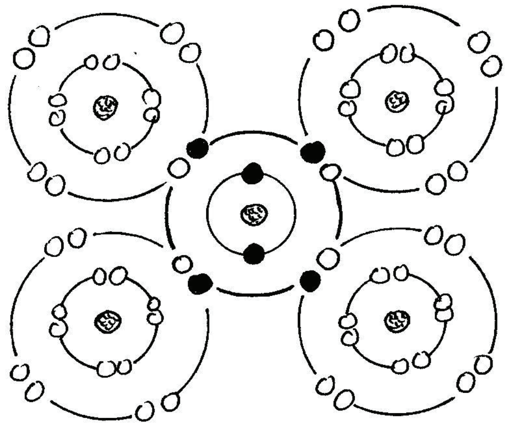
Then the hydrogen atom calls up three of its hydrogen friends and tells them to come on over and fill the other three slots. Now we have a real square dance. Carbon is thrilled to have partners for its four electrons. This works out rather well!

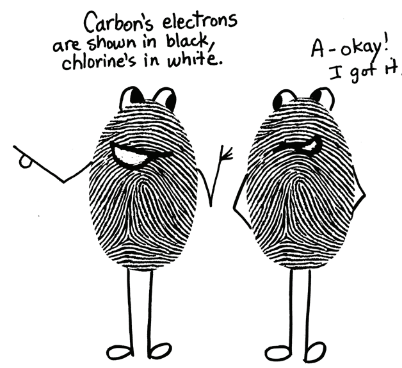


Another atom that can cooperate with carbon is chlorine. Chlorine's problem is that it has seven, not eight, electrons in its outer shell. Chlorine is out looking for a free electron that can pair up with its lonely electron. Can carbon do this? Carbon has four electrons that are looking for partners. One of those electrons could go over and fill in chlorine's empty slot. What if there were four chlorines that were all looking for partners and they were all willing to come over to the carbon and pair up with one of carbon's lonely electrons? Hey—this works out pretty well, too!

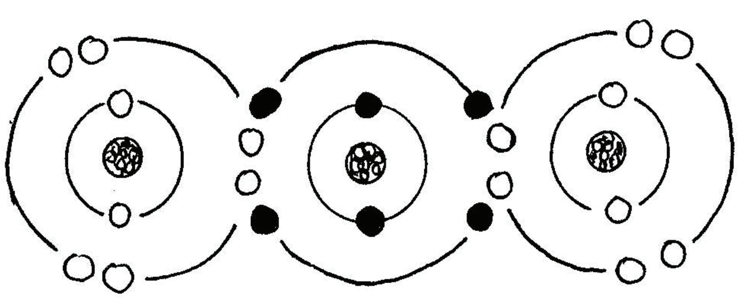


Here is an easy way to draw it.





Life is seldom perfect, even in the atomic kingdom. Sometimes things don't work out so well and carbon must adapt to unusual "dance partners." For example, sometimes carbon has to make do with only two atoms, not four. In the carbon dioxide molecule, carbon pairs up with two oxygens. Since oxygen has two free partners, two oxygens can provide a total of four partners—just what carbon is looking for. All they need to do is slide their electrons over a bit and make them match up. (Electrons don't really "slide" over, but what they do is too complicated to discuss right now.)



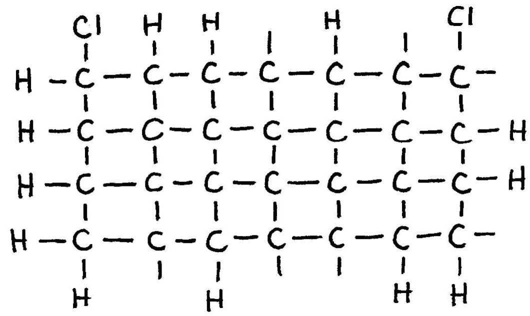
Oxygen pretends two of carbon's electrons belong to it, so it also has eight electrons in its outer shell.

We can draw it like this:

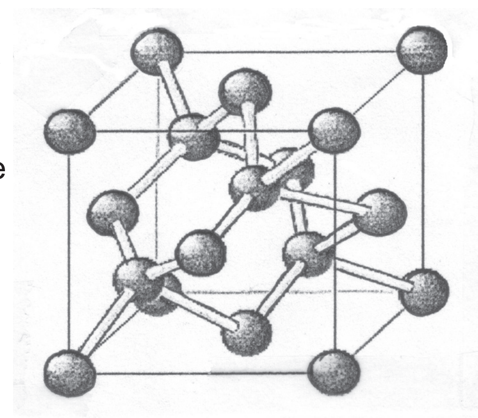
O=C=O

When carbon doubles up like this, we call it a ***double bond.*** That makes sense, doesn't it?

Carbon can also bond with itself. The only problem is that the carbon atoms on the edges will have unpaired electrons hanging off. Nevertheless, carbon does bond with itself. The free electrons dangling on the edges usually pick up a hydrogen atom, or some other atom that happens to be in the area.

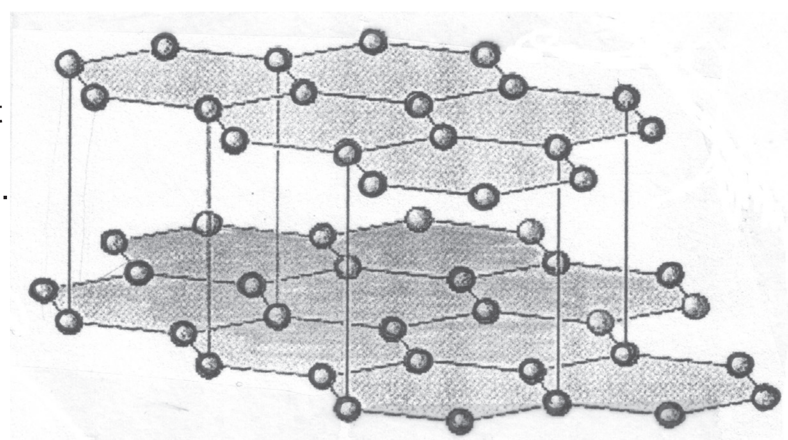


There are basically three ways that carbon bonds with itself. Each of these substances is called an ***allotrope***. The first allotrope of carbon is ***diamond***. Diamonds are made of pure carbon. The bonds between the carbons are extremely strong, making diamond the hardest substance on earth. Diamonds are so hard they can be used on industrial saw blades to cut metal and concrete. This picture shows how the carbon atoms are linked in diamonds.



Historically, the only way to get diamonds was dig them up out of the earth. The largest diamond mines in the world are located in southern Africa, Russia, and western Australia. Some of these mines have treated their workers very poorly, which has caused diamond mining to become controversial. Fortunately, diamonds can now be manufactured artificially, so industries that need diamonds do not need to rely on controversial mining companies. Artificial diamonds often start out as methane, a substance we'll meet very soon. Small, thin diamond plates are put into a high-pressure cooker along with the methane gas. The heat and pressure causes the carbon atoms to stick to the carbon plate and a diamond crystal begins to grow. If you'd like to see some videos about this process, go to www.youtube.com/thebasementworkshop, click on "playlists," then find the "Carbon Chemistry" playlist. (You might have to click on "show all playlists" if you don't see it listed.)

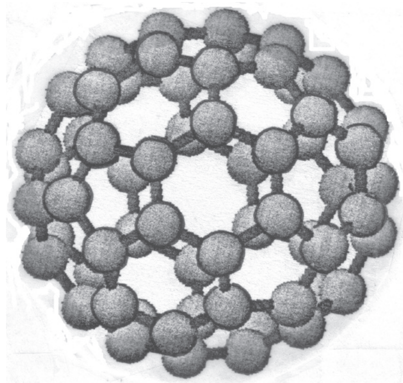
Another allotrope of carbon is ***graphite***. You use graphite all the time; it is the "lead" in pencils. (Real lead is not used anymore, of course, because it was discovered to be dangerous to our health. Graphite is now used instead, but the word "lead" still lingers on.) In graphite, the carbon is arranged in layers.



Each layer is made of a sheet of hexagonal shapes. The layers are loosely bonded to each other and can slide around. This is what makes graphite feel slippery. If you rub your fingers on the end of a pencil, the slippery sensation you feel is the layers sliding back and forth. Because it is slippery, graphite can be used as a lubricant. Some people rub a pencil on the drawer runners in dressers so that the drawers go in and out smoothly. It's hard to believe that graphite and diamonds are made of the same stuff, but if you could squeeze your pencil tip hard enough (which you can't), the atoms would rearrange themselves to form a diamond.

A single sheet of graphite is called ***graphene***. Graphene has recently been discovered to have amazing properties. It has been called the strongest substance in the world, even stronger than diamonds or steel. It the best conductor of electricity and it's also transparent and flexible. Many industries are developing uses for graphene. If it sounds too good to be true, that may indeed turn out to be the case, however. It could also be one of the most destructive substances on earth if it gets released into the environment. We just don't know enough about it yet.

The third allotrope was not discovered until 1985. It was named ***buckminsterfullerene***, after the architect Buckminster Fuller, who was famous for his geodesic dome structures in the 1960's and '70's. Since the name is so long, scientists have come up with a nickname for this substance. They call the molecules ***buckyballs***.



If you think this pattern looks like a soccer ball, you're right—the pattern is the same. There are 20 hexagons and 12 pentagons, with each pentagon completely surrounded by hexagons.

What are buckyballs good for? Some scientists think they might be good for microscopic lubrication, or bearings in a microscope motor. They might be used inside the human body for drug delivery (by putting molecules of medicine inside the buckyballs). If you add a few potassium atoms to the buckyball, it will conduct electricity as well as metal does. At low temperatures, it becomes a superconductor.

Where can you find these weird balls? Buckyballs are a component of black soot—the kind that collects on the glass screen in front of fireplaces. Scientists don't go around collecting soot, however. They manufacture buckyballls in their labs by vaporizing graphite with a laser.

Two more forms of carbon that should be mentioned are ***coal*** and ***charcoal***. They are made of mostly carbon, but often have impurities such as nitrogen, sulfur, salt, or rock and dust particles. (When the sulfur comes out into the air as coal is burned, it can cause major air pollution problems.) In coal, the carbon atoms are not bonded into geometrical shapes. The scientific word for "no shape" is ***amorphous***. ("A" means "without," and "morph" means "shape.") Coal and charcoal are said to be amorphous types of carbon. Coal seems to have come from ancient plants that were buried and then put under extreme pressure. Charcoal is made by burning wood in a low-oxygen environment.

FORMATION OF COAL (under intense pressure)

PLANTS → PEAT *(poor quality)* → LIGNITE *(average quality)* → BITUMINOUS COAL *(good quality)* → ANTHRACITE COAL *(best quality)*

Comprehension self-check

See if you can fill in the blanks and answer these questions, based on what you remember reading. If you have trouble, go back and re-read.

1) All atoms are made of three types of particles: _________, _________, and _________.
2) The three types of atomic models mentioned in this chapter are ________________, ________________, and ________________.
3) Which model gives us the best picture of what an atom really looks like? ____________
4) Which model is the best one to use when making molecule models? ______________
5) Which model is the best for showing exactly what is going on with the arrangement of electrons into shells? _____________
6) Which one is easiest to draw? ____________________
7) Which one is easiest to build out of craft materials? ____________________
8) If we were to make a model of an atom that was proportionately correct, our nucleus would be the size of a _____ in a ___________ and the electrons would be the size of __________ traveling around the ______________.
9) It is the number of __________ that make an atom what it is. This number is called the ___________ number.
10) Most atoms in the top part of the Periodic Table (the smaller, non-metal atoms) live by this motto: "_____________________"
11) If an atom does not have a full outer shell of electrons, what does it do about it? _________ ____
12) When carbon has to double up and share more than one electron with another atom, we call this a _________ bond.
13) Three substances that demonstrate how carbon atoms bond with each other in geometrical shapes are _____________, _____________, and ____________________.
14) A single layer of graphite is called ________________.
15) Two substances that contain mostly carbon but do not demonstrate a geometric shape are: __________ and __________.

On-line Research

Find the answers to the following questions by researching the Internet.

1) What famous scientist invented the solar system model for representing atoms?

2) Diamonds sometimes contain a small number of atoms other than carbon. These other atoms are called "impurities" and they cause the diamonds to have slight tints of color. What colors can diamonds come in?

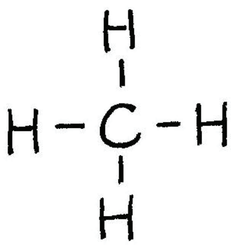
3) Is graphene completely safe?

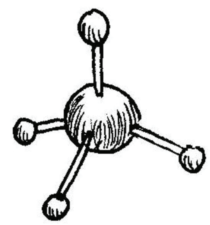
4) What is "activated" charcoal and what it is used for?

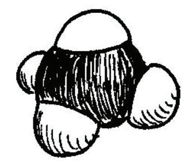
5) Something related to coal is "coke." What is coke?

Chapter Two: Alkane Hydrocarbons

We learned in chapter one that carbon often bonds with hydrogen. When carbon bonds with just hydrogen, they form a molecule we call a ***hydrocarbon***. The simplest hydrocarbon is ***methane***. It consists of one carbon atom and four hydrogen atoms:



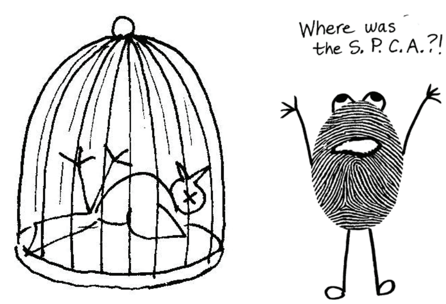




Here are three different ways of drawing the methane molecule. The one on the left is called a "structural formula." It is easy to draw, and because it uses letters to represent the atoms, you always know what the atoms are. However, it does not show the three-dimensional shape of the molecule. The one in the center, the "ball and stick" model, shows how methane really looks in three dimensions. The hydrogen atoms want to stay as far apart from each other as possible, and this "tetrahedral" shape is the result. The model on the right is called a "space-filling" model. It probably comes closest to showing us what a real methane molecule looks like, because real molecules don't have sticks separating the atoms. Space-filling models are easy to make out of clay, but are difficult to draw. We won't be seeing them very much in this book, but it is good for you to have seen a few and understand what they are.

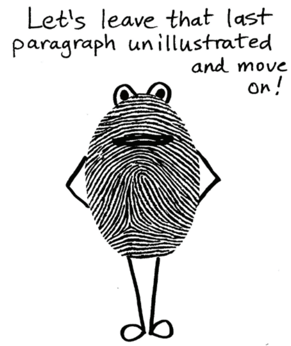
Methane is a small, lightweight molecule that floats around in the air as a gas. You can't see it or smell it. (Gas companies must add a smelly substance to it so that we can smell gas leaks in our homes.) We sometimes call it "natural gas" because it occurs naturally in the earth, often forming in areas where oil and coal are found.

Methane burns easily in the presence of oxygen, and it burns cleanly, without polluting the air. This makes it excellent for use as a fuel, but it also makes it very dangerous for coal miners who run into pockets of methane gas as they are digging. A spark of any kind can ignite the gas and create a deadly mine fire. In the early days of mining, the miners sometimes took caged birds with them into the mines. The birds were very sensitive to the methane gas and would act strangely, or even faint, if there was methane present. By watching the behavior of the bird, the miners would have an early warning signal telling them that methane was lurking in the mine.

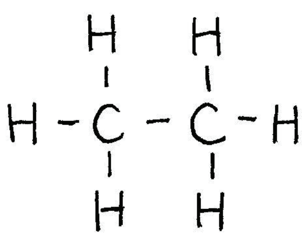


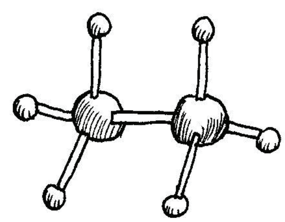
Some types of bacteria produce methane. Farmers know that rotting vegetation can produce both methane and heat. (Not a good combination when you don't want fire!) Fires can start spontaneously in storage silos if enough methane builds up.

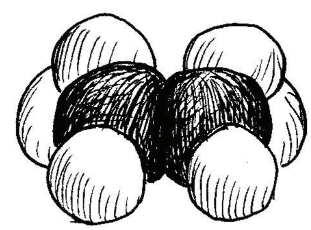
Methane-producing bacteria live in our intestines, also. Yes, gas is really… gas. Healthy intestines have millions of harmless (and beneficial) bacteria living in them. We need these bacteria in our intestines. They aid in digestion and keep us healthy. When certain foods pass through the intestines undigested, the bacteria produce an extra amount of methane and hydrogen. But remember, methane has no odor. The odor we associate with intestinal gas comes from very small amounts of other substances such as hydrogen sulfide. Since methane is flammable, it is fortunate that the methane in our intestines is mixed with other gases such as nitrogen and carbon dioxide, which are not flammable. However, there is enough methane in some intestines to cause problems. Surgeons in the early days of medicine learned the hard way about the flammability of methane when sparks from their operating instruments would occasionally cause small explosions in the patients' intestines!



Methane is the first and simplest member of a whole group of carbon compounds called ***alkanes***. The second member of this group has two carbon atoms in it and is called ***ethane***. This is how it looks:

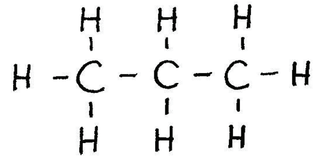

structural formula


the ball and stick model


space filling model

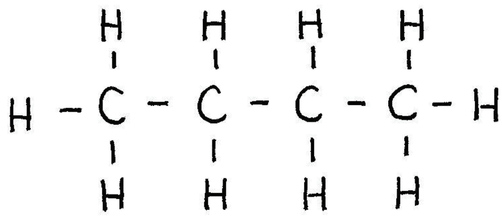
As you can see, ethane is made of two carbon atoms and six hydrogen atoms. We can write it like this: C_2H_6. (This is called the ***empirical formula***.) Both carbon atoms have all four of their free electrons attached to another atom, so this combination works out well. Ethane is also a gas.

If another carbon atom is added on, we make a substance called ***propane*** (C_3H_8).



Undoubtedly, you've heard of propane. You may have a propane tank outside your house, connected to a gas grill.

Add another carbon atom to the string, plus a few more hydrogens, and you have a molecule named ***butane*** (C_4H_{10}). Butane can be found in hand-held lighters.



You can keep on adding carbon atoms and make the string longer and longer. You could have dozens, hundreds, thousands, or millions of carbon atoms in an alkane string. Short strings with 1 to 4 carbon atoms are gases. Strings made of 5 to18 carbon atoms are liquids, and strings with 19 or more carbon atoms are solids.

So where do these names (methane, ethane, propane, butane) come from? What do they mean? An organization called the ***International Union of Pure and Applied Chemistry (IUPAC)*** decides what to name molecules and chemical compounds. Chemists all over the world need to use the same names for things so that they can discuss their work with each other. If a chemist speaks about "methanol" or "ethylene glycol," all the other chemists need to know exactly what substance he is talking about. Sometimes IUPAC decides to go with names that chemists have already been using for a while. Sometimes, IUPAC decides to change the name to something more logical. The goal is to have a naming system with rules that everyone knows, so that there is as little confusion as possible. And confusion is a distinct possibility in a science where there are millions of molecules that could be named!

The first step in naming a carbon compound is to count how many carbon atoms are in it. This is how you count carbons:

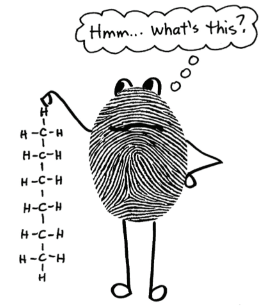
1	2	3	4	5	6	7	8	9	10
meth-	eth-	prop-	but-	pent-	hex-	hept-	oct-	non-	dec-
		(prope)	*(byute)*					*(known)*	*(deck)*

These are the prefixes that come before suffixes like "ane" or "ene" or "yne." In this chapter we are talking about alk*anes*, so each of these prefixes has "ane" after it. "Ane" simply means single-bonded carbons. We have seen methane, ethane, propane, and butane. We can now add pentane, hexane, heptane, octane, nonane, and decane.

You might recognize the word ***octane***. This word is found on gas pumps, where they post "octane ratings." A gasoline that has an octane rating of 87 means that the gasoline is 87% octane and 13% heptane. Inside the engine, the fuels get compressed before they are ignited by the spark plug. Heptane has the unfortunate characteristic of exploding too early, before it is ignited by the spark. This causes something called "knocking" in the engine, which is not desirable. Octane can handle compression much better. So, the more octane, the better. Unfortunately, the higher the octane rating, the higher the price, also! Better things always cost more, don't they?!

Chains of12 to16 carbons give you kerosene fuels. 15 to 18 carbons make heating oil. 20 to 40 carbons give you paraffin waxes and asphalt. Strings of hundreds or thousands of carbons make various kinds of plastics. (Plastics have their own chapter later in the book.)

Number of carbons	Uses
1-4	natural gas (used for fuel)
5-12	gasoline, solvents
13-16	kerosene, diesel fuel, jet fuel, heating oil
17-20	lubricating oils
21--	paraffin, asphalt

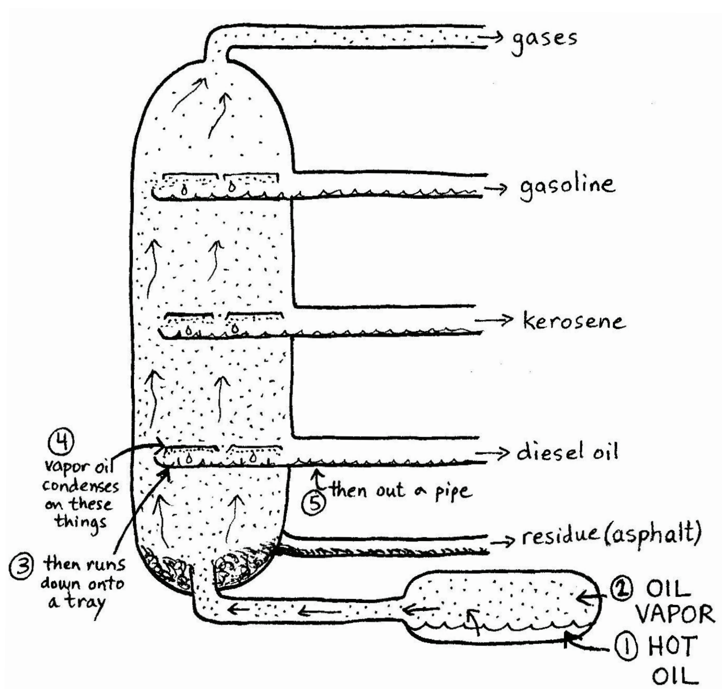


All the products listed above can be made from the same raw material: ***crude oil***. “Crude” just means raw or unrefined-- the natural stuff as it comes up from the ground. Scientists guess that crude oil was formed by the decomposition of plants and animals under great pressure a long time ago. Crude oil is made of alkanes.

A factory called a ***refinery*** can sort out the different lengths of alkanes in crude oil. The refinery uses a process called ***distillation***. You may be thinking of distilled water and wondering if there is a connection. Yes, the process of distillation is similar no matter what you are distilling. ***Distilling*** means heating a substance until it turns to steam, then gradually cooling it. As it cools, it turns into a liquid.

Crude oil is heated until it turns into vapor (at 350^0 C), then this vapor is pumped into the bottom of a very tall tube. The temperature is hot at the bottom, and cooler at the top. The longest hydrocarbon chains turn back into a liquid (condense) onto trays at the bottom of the tube and run into pipes. The next-longest hydrocarbons liquefy at the next level up and run into those pipes, and so on, until the very shortest hydrocarbon chains, such as methane and propane, are collected at the top.

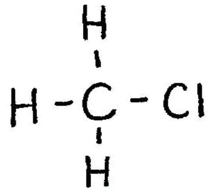
You can see some videos about this on the Carbon Chemistry playlist at www.YouTube.com/The BasementWorkshop.

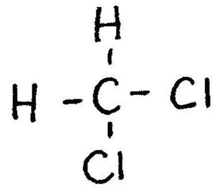


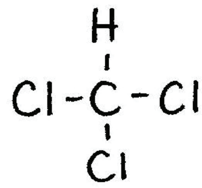
Cracking is a process by which they take medium-sized chains and break them into smaller pieces. The medium-sized chains are heated in the absence of oxygen, and sometimes using chemicals called catalysts, which help the reaction occur. A commonly used catalyst is “zeolite,” a mineral powder made of aluminum, silicon and oxygen. Cracking is often used as a way of producing extra gasoline, a substance which is always in demand.

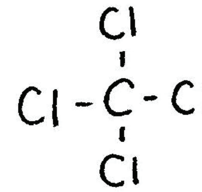
Two more ideas that we need to discuss in this chapter are chlorinated hydrocarbons and isomers. Let’s tackle ***chlorinated hydrocarbons*** first.

As we mentioned in chapter one, carbon can bond with almost any atom that is willing to share an electron. Hydrogen very often does this, but other atoms do, too. Chlorine is an atom that has only seven electrons in its outer shell—three happy pairs and one very unhappy electron that is all alone. Chlorine gladly attaches itself to carbon. Here are four examples of molecules where one or more hydrogens are replaced by chlorine:


methyl chloride


methylene chloride

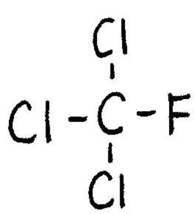

chloroform

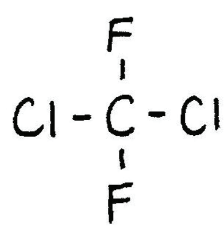

carbon tetrachloride

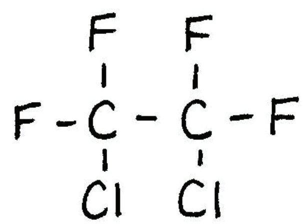
Methyl chloride is mainly used in making silicone substances (sealants, waterproofing materials, artificial body parts, Silly Putty). Methylene chloride is used as a paint remover. Chloroform started out as an anesthetic (putting you to sleep for surgery), but has now been replaced by safer substances. Chloroform is sometimes referred to as “knock-out gas.” (Bad guys in movies soak handkerchiefs in chloroform and put them over the faces of their victims.) Carbon tetrachloride was formerly used in dry-cleaning, but is no longer used because of safety concerns. It can react with water to produce a poisonous gas.

These substances do not dissolve in water, which is a problem when they escape out into nature. ***DDT*** (dichlorodiphenyltrichloroethane) is famous for both its effectiveness as an insecticide (killing insects) and, unfortunately, its ability to harm wildlife such as birds and reptiles (mainly through the birth of deformed babies). DDT was so effective at killing moquitoes, that malaria (a disease carried by mosquitoes) was eliminated in North America. Africa now faces the problem of trying to control malaria without DDT.

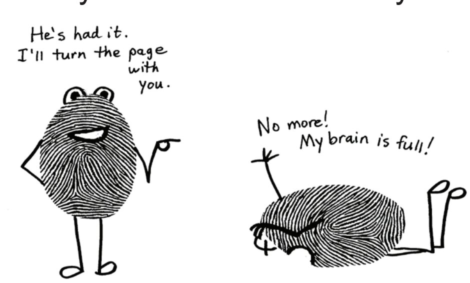
Carbon compounds can contain fluorine along with chlorine. The fluorine atom is in exactly the same state as the chlorine atom, with one unhappy, unpaired electron. Fluorine will gladly attach itself to a carbon.





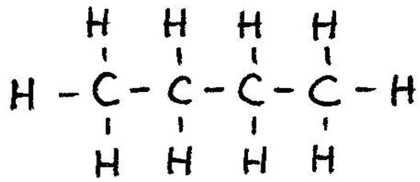


These molecules are called (no big surprise here) ***chlorofluorocarbons***, or CFCs for short. They used to be used as propellants in aerosol spray cans and as coolants in refrigerators. CFCs nontoxic and don’t hurt us directly because they don’t react chemically with anything. They don’t pose any direct health hazards to humans. The problem with them is that when they are released into the air, they float up into the atmosphere where they are changed (by ultraviolet light) into molecules that can damage the protective ozone layer of the atmosphere. In order to protect the ozone layer, most governments have banned the use of CFCs. In some cases, CFCs have been replaced with HFCs, hydrofluorocarbons.

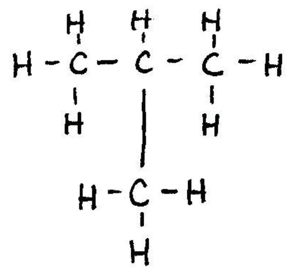


One last topic remains: ***isomers***. The name sounds strange, but the idea is very easy. Isomers are molecules with exactly the same number of atoms but in a different geometrical arrangement. ("Iso" means "same.")

For example, let's look at butane, C_4H_{10}. The most obvious way to arrange the atoms is like this:

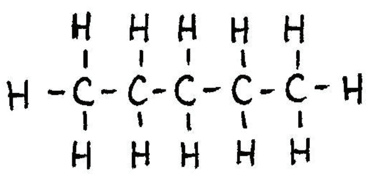


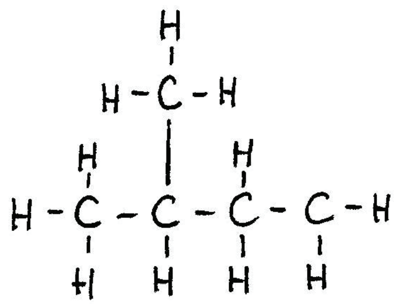
However, you could reshuffle the carbons a bit and make the molecule look like this:

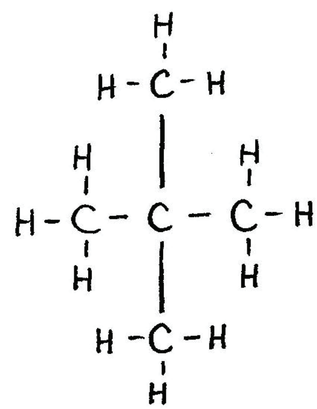


It is still C_4H_{10}, butane. To differentiate it from regular butane, scientists call this "isobutane," an isomer of butane.

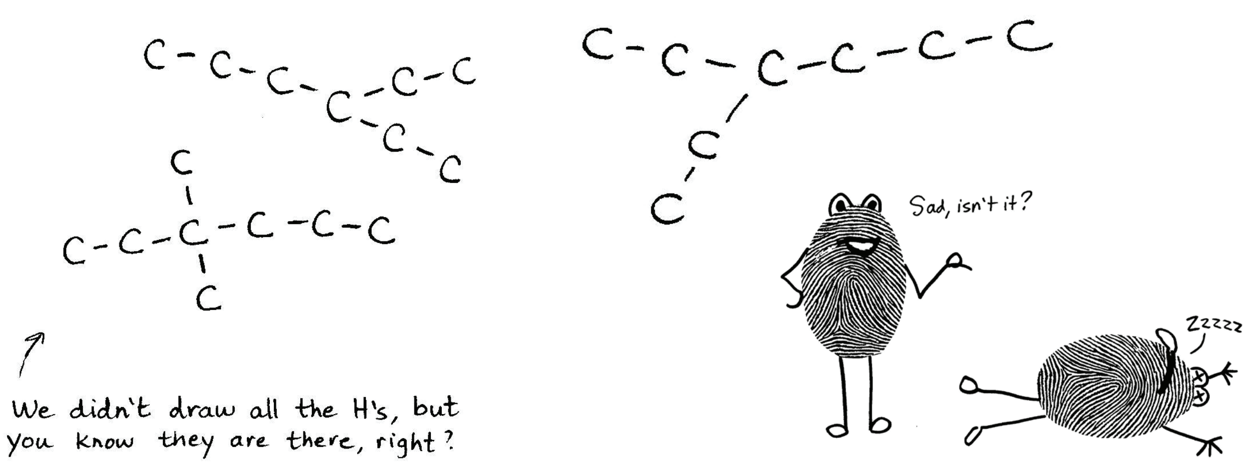
Here are three isomers of pentane, C_5H_{12}.







Why are isomers worth mentioning? One practical use for isomers is in gasoline. Petroleum chemists have found that branched isomers of octane actually burn better than straight octane. Branched nonane and decane are also put into gasoline. The chemists alter the straight alkanes that come from the refinery, adding chemicals that cause them to rearrange into branched isomers.



Comprehension self-check

See if you can fill in the blanks and answer these questions, based on what you remember reading. If you have trouble, go back and re-read.

1) The simplest hydrocarbon is called ___________.
2) Three ways you can draw molecules are _________ _________, ______ ___ ______, _______-_________.
3) Methane is also called ________ gas.
4) Does methane burn easily? ____
5) Where can methane be found in our bodies? ___________
6) Methane, ethane, propane, etc. belong to a group of molecules called __________s.
7) What does the IUPAC do? ________________________________
8) Can you count to ten in carbons?
9) Where can you find octane and heptane mixed together? ____________________
10) Too much heptane and not enough octane causes this problem: ______________.
11) Very short alkanes are ______, medium sized are ______ and longer ones are ________.
12) Raw or unrefined oil is called _______ oil.
13) A factory that processes oil is called a ___________.
14) The primary method factories use to refine oil is called _____________, which is heating then cooling and condensing the oil.
15) Breaking hydrocarbon chains into smaller pieces is called ____________.
16) Name two other atoms, in addition to hydrogen, that will bond with carbon: ______ and _________.
17) CFC's contain these three types of atoms: _______, ________ and _________.
18) DDT was used to kill ____________ but it also killed ____________.
19) What was chloroform used for? _____________________________
20) Molecules that contain exactly the same number of atoms, but in a different geometric arrangement, are called ___________

On-line research

1) Where are the world's largest sources of crude oil? Name at least five places:

2) Name three US states that are known for their coal mining.

3) How long has the IUPAC been in existence?

4) What is ozone?

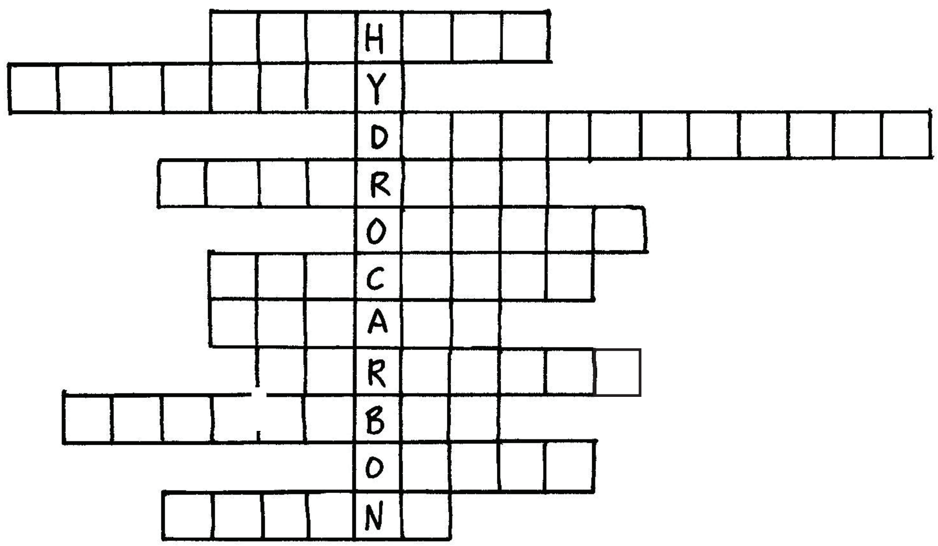
5) What famous scientist invented a safety headlamp for miners?

6) Did miners really take birds into mines, or is this just an "old wives' tale"?

Hydrocarbon puzzle

Here are the clues for the missing words. You have to figure out which goes where!

- A factory where hydrocarbons are processed
- The primary method factories use to process hydrocarbons
- Gasoline is mostly this hydrocarbon
- This hydrocarbon is found in handheld lighters
- This hydrocarbon is found in gas grill tanks
- This atom is the "F" in CFC's
- This is the word for hydrocarbon chains with only single bonds
- Hydrocarbons burn easily. They are highly _________.
- Chlorofluorocarbons destroy the ______ layer of the atmosphere.
- This method is used to break apart hydrocarbon chains.
- This hydrocarbon is natural gas.



"Cross one out" puzzle

1) Which one of these is not a hydrocarbon?
methane gasoline diesel fuel rubbing alcohol kerosene asphalt ethane

2) Which one of these has nothing to do with refining crude oil?
distillation fermentation condensation evaporation

3) Which one of these is not an alkane?
propane butane ethyne nonane decane heptane methane octane

4) In which one of these places will you not find natural gas?
mountain tops grill tanks intestines swamps silos mines

5) Which one of these is not an alkane hydrocarbon?
CH_4 C_4H_{10} C_3H_8 C_2H_2 C_5H_{12}

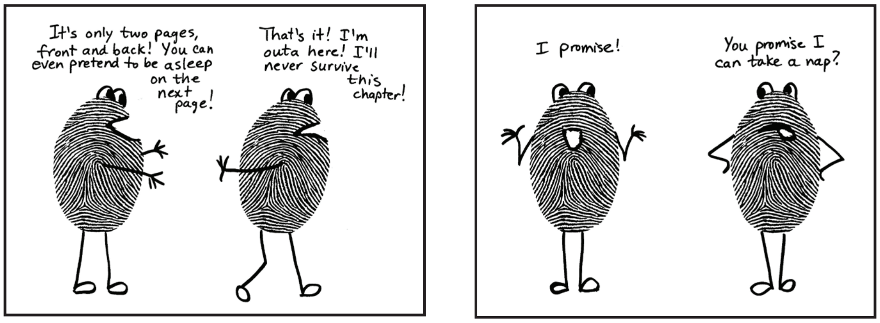
6) Which one of these does not bond with carbon?
chlorine fluorine carbon hydrogen helium

Videos

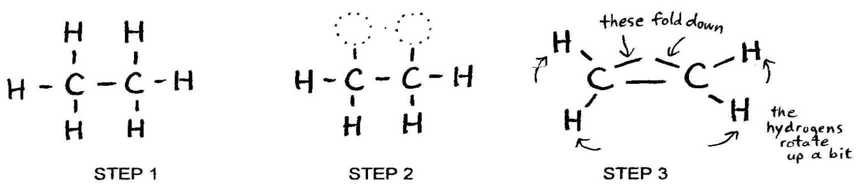
For some fun and information (and short) videos on the topics you've just read about, go to the playlist that was created specially for this course by the author: www.YouTube.com/TheBasementWorkshop, click on SHOW ALL PLAYLISTS, then find CARBON CHEMISTRY.

Chapter Three: “-enes” and “-ynes”

In chapter one, we mentioned that carbon can sometime form what we call a “double bond.” Then in chapter two, we saw nothing but single bonds. Alkanes have only single bonds in them. Now we are going to look at some molecules with double, even triple, bonds in them.



What would happen if we plucked some hydrogens off an alkane? Let’s try it.

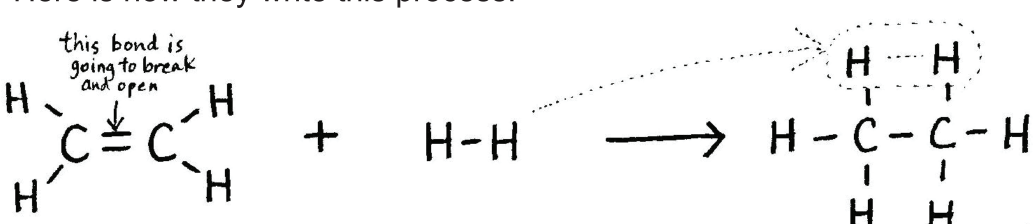


STEP 1 STEP 2 STEP 3

Look at what happened—the carbons tilted themselves a bit so that their unpaired electrons matched up with each other. That seems to work out pretty well. However, we no longer have an alkane, we have an ***alkene***. Alkenes are molecules similar to alknanes, except that somewhere in the molecule there are some carbons forming a double bond with each other.

The alkene shown here, in step three, is called ***ethylene***. Ethylene gas may sound like a poisonous name, but it is a harmless gas produced naturally by ripening fruit. Yes, that bowl of fruit there on the table is giving off ethylene gas. Commercial produce growers have found that they can speed up the process of ripening by steaming their produce in ethylene. Tomatoes, especially, can be “reddened up” by exposing them to ethylene. Unfortunately, the taste does not improve as fast as the color does. “Gassed” winter produce may look good, but it doesn’t taste like that vine-ripened summer stuff. Ethylene gas is also used as an ingredient in automobile anti-freeze (ethylene glycol) and in plastics called polyethylene. We will learn more about these plastics in a later chapter.

Can chemists change ethene back into an ethane by adding some hydrogens? Yes, they can. Here is how they write this process:



ethylene hydrogen ethane

Activity 1.1: Building carbon's allotropes

Background information

The different shapes pure carbon can take (diamond, graphite, buckyballs) are called **allotropes**. Other elements have allotropes, too. Sulfur, for instance, can be found in two different crystal shapes.

You will need:

- One box of Jujubes™ candies
- Two boxes of toothpicks (round or square, not flat)

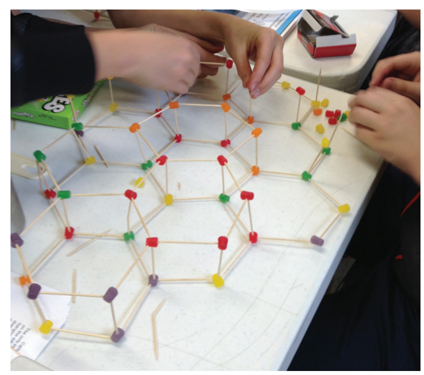
Note: If you can't find Jujubes, you can use small jelly beans. (Gummy bears and marshmallows are not recommended.) Jujubes are good to work with because they are small and hard. The small size keeps the structures from being too heavy, and the hard texture keeps the toothpicks in place. A box of Jujubes contains about 300 candies, which is more than enough to make all three models. (You could probably make two of each model, if the graphite and diamond ones are of modest size.) You will need to buy the sturdier type of toothpick with the square or round center, not the flimsy flat ones. (If you are purchasing for a group, allow three boxes of toothpicks for every one box of Jujubes, four boxes if you anticipate enthusiastic builders who will want large models.)

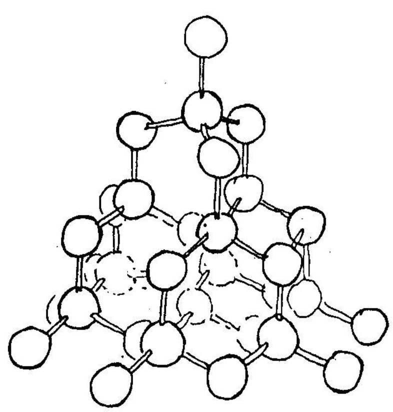
Instructions:

Diamond: Make sure that each carbon atom is connected to four others. The geometry will emerge naturally as a result.

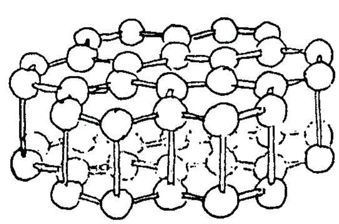
Graphite: You can make several sheets of hexagons, then put them on top of each other, or you can make a flat sheet of hexagons and just build upwards on top of it. (Graphene would be just one layer.)

Buckyball: Start by making 12 pentagons. Each pentagon will contain 5 candies and 5 toothpicks. A buckyball contains 60 carbon atoms, and since 12x5=60, you will not need any more candies. Now use just toothpicks to begin making each pentagon completely surrounded by six hexagons. A pentagon can't touch another pentagon.

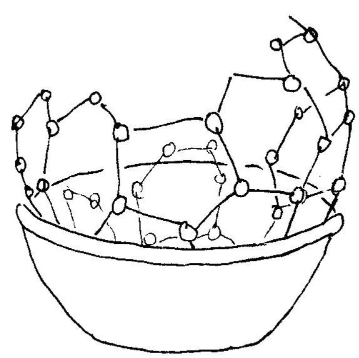




diamond



graphite



A bowl is a big help when making the buckyball!

Activity 1.2: Organic molecules card game

Background information

The molecules you will make in this game may or may not be actual molecules found in nature. There are hundreds of thousands of organic molecules in the world, so your molecules might very well be real ones. If they are not, they will at least be very similar to real ones.

Here is what the letters stand for: H=hydrogen, C=carbon, O=oxygen, N=nitrogen, Cl=chlorine, Br=Bromine, F=fluorine. Notice how many hydrogen cards there are in the game. 90% of all atoms in the universe are hydrogen!

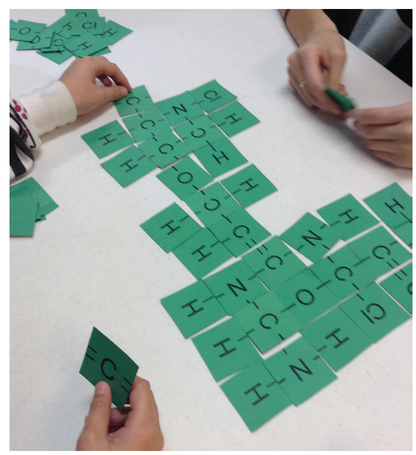
The lines on the cards represent electrons that the atom would like to share with another atom.

You will need:

- copies of the playing card patterns printed onto card stock, then cut them apart into individual squares.

Note: The game can accommodate 2-6 players. If you have more than six students and decide to make more than one copy of the game, you may want to consider making each set of cards a different color. If all of your sets are the same color, there is a high likelihood that cards will get placed into the wrong deck and you will end up with one set having too many cards and another too few, and the only way to straighten them out will be to painstakingly count all the cards and compare each set to the original patterns. Life is too short to spend time counting cards. Make your sets different colors.

Instructions



Give each player 5 cards. The rest go in a draw pile. Put one of the carbons (with no double bonds) face up to be the starter card. The players take turns laying down cards, trying to get rid of all their cards. The first player to get rid of all their cards wins. HOWEVER, the last card he lays down MUST complete a molecule in order to win the game. If a player lays down his last card on an incomplete molecule, he must then draw another card. He may not lay this new card down immediately, but must wait until his next turn to play it.

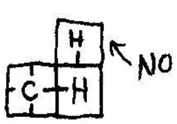
The lines represent bonds. You must match single bonds to single bonds and double bonds to double bonds. The molecule is complete when no bonds are "left hanging." Each bond (line) must have an atom attached to it.

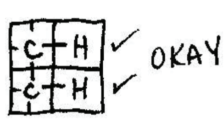
Notice on the double bond O that there are dotted lines. This is so you can turn the card caddy-corner and match the double bond with two single bonds.

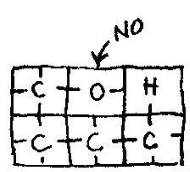
If a player cannot lay down a card, he must take one from the draw pile. He may lay this card down immediately if he can do so.

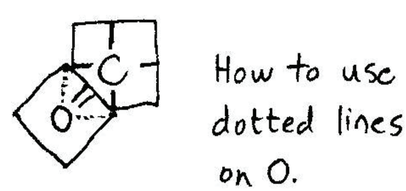
If a molecule is finished and all players are still holding cards, simply begin another molecule. Remember, you must use a single bond carbon (four lines) to begin a new molecule.

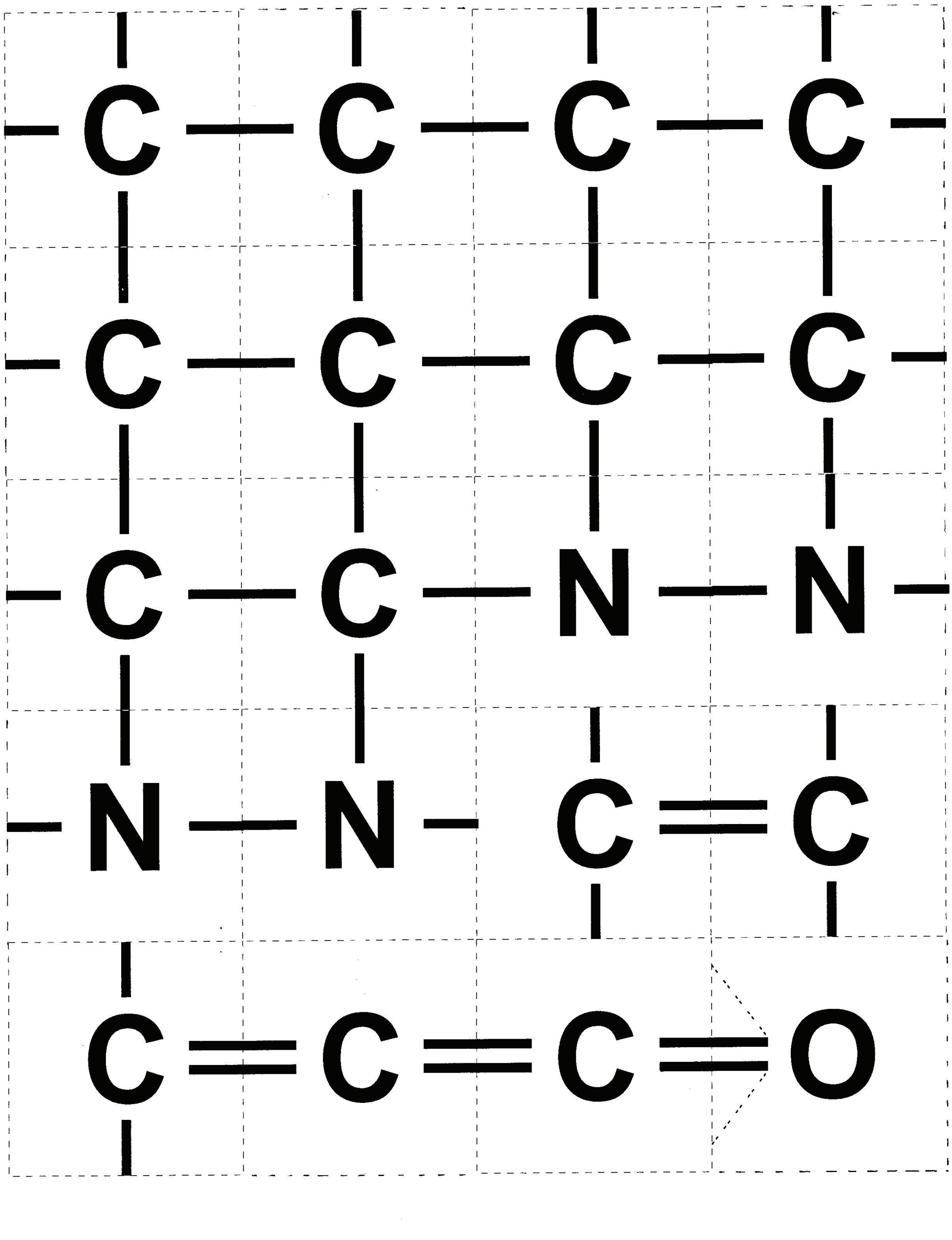
In order to win the game, a player must lay down his last card *as the final atom in a molecule.*







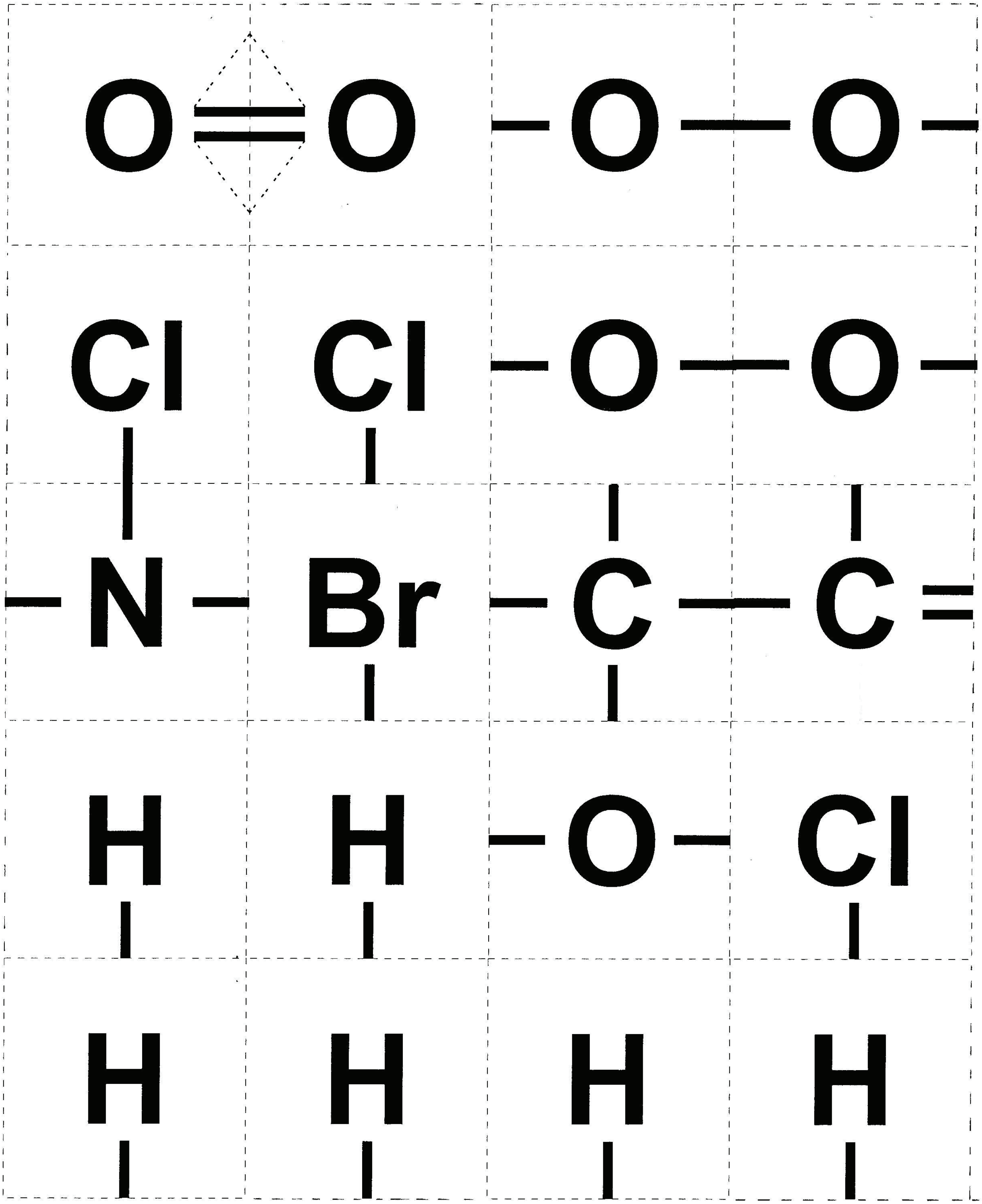




Make one copy (per game) on card stock.
If you are making mulitple copies of the game, make each game a different color (so you can easily tell which cards belong to which set).

H I	H I	H I	H I
H I	H I	H I	H I
H I	H I	H I	H I
H I	H I	H I	H I
H I	H I	H I	H I

Make one copy (per game) on card stock.
If you are making mulitple copies of the game, make each game a different color (so you can easily tell which cards belong to which set).



Make one copy (per game) on card stock.
If you are making mulitple copies of the game, make each game a different color (so you can easily tell which cards belong to which set).

Activity 1.3: Burning contest

Background information

Ancient people learned that if they burned wood in a low-oxygen environment they could make a black fuel that would burn longer than wood and produce more heat with less smoke.

You will need:

- charcoal briquette
- block of wood same size as briquette
- matches
- lighter fluid
- marshmallows to toast, if you want to compare quality of heat
- a safe place to do the burning

Instructions

Burn a charcoal briquette and a piece of wood the same size and compare the duration of burning and the quality of heat.

Can you re-light the charcoal you made from the wood? Why not?

Activity 1.4: Take a tour of a coal mine or refinery

Log on to www.YouTube.com/TheBasementWorkshop and find the Carbon Chemistry playlist. Look for some videos on petroleum refineries and coal mines.

Chapter Two Activities

Activity 2.1: Practice Counting 1-10 Carbons

Background information

Learning to count carbons isn't any harder than counting to ten in Spanish or French. Actually, it is easier because you don't have to worry about your accent. Also, several of the prefixes are the same, or similar, to words you use in math.

You will need:

- The list in chapter two

Instructions

Practice counting a few times. Practice without looking. Practice tomorrow once or twice, and a few times the day after. Bet it won't take you long to rattle them off like a pro! Here's an additional idea: Use the tune of "One Little, Two Little, Three Little Indians" and sing these words:

Meth- little, *eth*- little, *prop*- little carbons,
But- little, *pent*- little, *hex*- little carbons,
Hept- little, *oct*- little, *non*- little carbons,
Dec- little carbon atoms.

Would you like to know more? Here is a list if you would like to continue on counting carbons. You can put "-ane" after each one to name alkanes.

11	undec-	the alkane would be "undecane"
12	dodec-	the alkane would be "dodecane"
13	tridec-	etc.
14	tetradec-	
15	pentadec-	
16	hexadec-	
17	heptadec-	
18	octadec-	
19	nonadec-	
20	eicos-	
21	henicos-	
22	docos-	
23	tricos-	
24	tetracos-	
25	pentacos-	
26	hexacos-	
27	heptacos-	
28	octacos-	
29	nonacos-	
30	triacont-	
31	hentriacont-	
32	dotriacont-	
33	tritriacont-	
34	tetratriacont-	

(If you want a much longer list, there are some available on-line. Just use a search engine.)

Activity 2.2: Build some alkanes

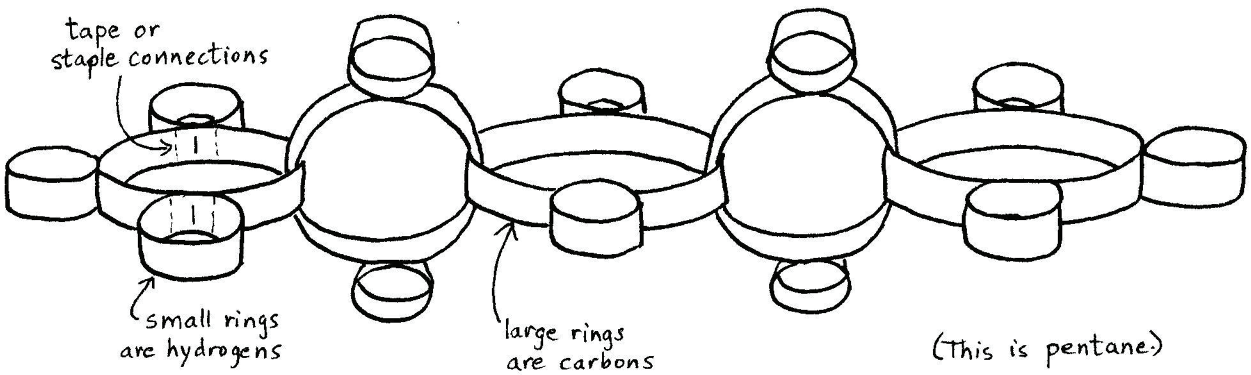
You will need:

- Long paper strips (any colors) cut in two lengths, the shorter length being half the length of the longer one.
- Scotch tape or stapler

Note: You may want to keep these chains (hang them up if you have a classroom, store them carefully if you don't) so that you can use them for the "Polymer Party" on the last day of class.

Instructions

You will be making paper chains similar to the standard type made for parties, only these will be scientific models, as well. We suggest that you use just two colors in your chain, one for carbon and one for hydrogen. To use lots of colors, make lots of chains! Use this drawing as your pattern:



You can make the chains as short or long as you want to. Try to name the alkanes as you make them. Don't forget to put a hydrogen on the ends. Each carbon atom should be connected to four other atoms.

<u>Extra technical note</u>:

It is significant that the paper hydrogens are not all pointing in the same direction. Hydrogen atoms do not like to be next to each other. In fact, if a hydrogen atom is removed, the other hydrogens will shift their positions to get even further away from each other, if possible. Sometimes this creates a bend, or "kink" in the chain. These kinks are not bad, however. The omega-3 fatty acids (fish and flax oil, for example) have one or more kinks at the end of their chains.

Activity 2.3: Build some isomers

You will need:

- Some of the cards from the card game you played in chapter one. You will need all of the H and C cards, plus a couple others (you will be using the backs of these cards, so it doesn't matter which ones you choose)
- A pencil

Instructions

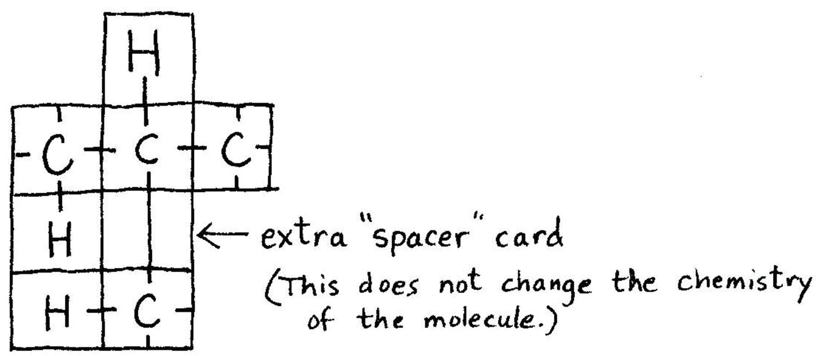
Start by putting out one carbon card. Attach hydrogens. Can you make any isomers of this molecule? *(No.)*

Now lay out two carbons connected to each other. Add the hydrogens. Are there any other ways you could arrange this molecule? *(No.)*

Now add another carbon so you have a chain of three. Add the hydrogens. Are there any other ways you could arrange this molecule? Remember, you have to use all of the atoms and the bonds have to match up correctly. *(You could put the three carbons into an L shape instead of a straight line.)*

Now add a fourth carbon to the chain. Put hydrogens around. Can you rearrange these cards to form a different shape? *(Yes, the carbons could go into a T. They could also go in a "circle," that is, a square circle.)* This circular structure has a special name: cyclobutane. Can you make cyclopentane and cyclohexane?

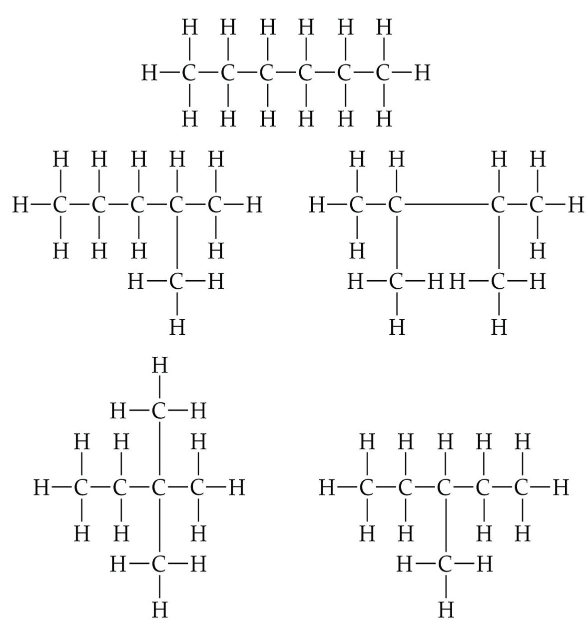
Continue on like this. You may need to make some "spacers" using a pencil on the back of the other cards:



You should have enough cards to make molecules up to decane. (Remember from the text that isomers of octane, nonane, and decane are what gasoline [petrol] is made of.)

If you are working in a class, you could divide up into teams that would work on one alkane each, or you could set it up as a contest to see who could come up with the most isomers or who could rearrange the molecule the fastest.

NOTE: You have to use all of the original cards as you rearrange the molecule. Sometimes students want to rearrange the carbons in such a way that the molecule ends up not needing all of the original hydrogens. If you add or substrate atoms from the molecule, that's not an isomer. Isomers have the same empirical formula, such as C_6H_{14}. If you make C_6H_{13}, that's not an isomer, that's a different molecule.



isomers of hexane

Activity 2.4: Make marbled paper using an alkane

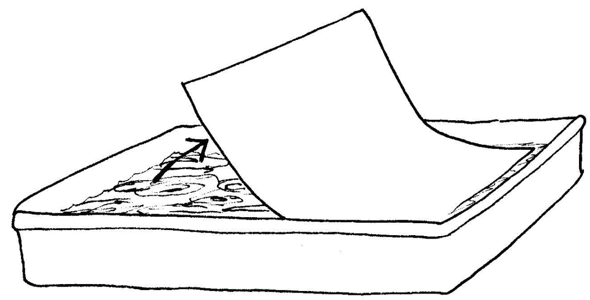
Background information:

"Paint thinner" and "mineral spirits" are two names for the same thing. They are petroleum distillates—liquids that were distilled from petroleum at a refinery. Their chemistry is very similar to that of gasoline (petrol). They are about 9-16 carbons long. Alkanes do not mix with water—they float on the surface because they are non-polar (see explanation at the bottom) and less dense. We can use these chemical properties of alkanes to create some beautiful marbled paper.

You will need:

- Paint thinner (mineral spirits) [not turpentine]
- One or more colors of oil-based paint (oil pigments that come in tubes work well, but you can also use house paint or craft paint as long as it is oil based, not acrlyic)
- A 9x13 pan with an inch or so of water in it
- Sheets of paper
- Some paper cups and spoons for mixing
- Disposable eye dropper of you have one, or a plastic fork

Instructions:



Pour a few spoonfuls of paint into a cup and add just enough paint thinner to make the paint runny. Use the eye dropper or plastic fork to splash some drops lightly onto the surface of the water. (If you want to use more than one color, repeat this process with as many colors as you will use.) When you have your color droplets on top of the water, swirl them around. When the pattern looks nice, take a sheet of paper and lay it on the surface of the water for just a second, then pull it up. The paint will instantly adhere to the paper transferring the beautiful pattern onto it. Lay the paper out to dry. When it is dry, you can draw on it, or use it in a craft project. (It might be so beautiful, though, that you may want to frame it as art!)

<u>Further explanation of the chemistry</u>:

All petroleum products are "non-polar" meaning that they don't have two sides that behave differently. Water, on the other hand, is "polar." Water molecules have one side that is negatively charged and one side that is positively charged. Any substance that is also polar, with a negative and positive side, will be attracted to water molecules. Substances that will dissolve in water, such as sugar and salt, are actually pulled apart by the polar sides of the water molecules. In non-polar substances (oil, grease, fat, petroleum products) the molecules don't have any areas of positive or negative charge, so there is nothing for the water molecules to pull on, therefore they don't dissolve. This is why oil (or mineral spirits) and water don't mix.

Chapter Three Activities

Activity 3.1: Toluene scavenger hunt

Background information:

What kind of activities can you do after a chapter about dangerous chemicals?! Here's one that is safe.

You will need:

- A location with places you can look for cans of solvents, paints, etc. A basement or garage is perfect.

Instructions:

Can you find a product that contains toluene? Look at the labels on cans in a workshop or garage or cleaning closet and see if you can find one that contains toluene. Are there any warnings on the container? What do they say?

Activity 3.2: Smell an alkene (safely)

Background information:

The fumes from naphthalene and paradichlorobenzene are toxic to moths. They are not exactly good for people, either, but one sniff from a distance won't hurt you. To kill moths, the clothing container needs to be air-tight so that the fumes build up enough to kill the moths. Clothes that have been stored in moth balls need to be aired out before they are worn. Being exposed to the fumes for a long period of time isn't healthy.

You will need:

- A moth ball or similar product that contains naphthalene or paradichlorobenzene.

Instructions:

Smell from a safe distance, not with your nose right on the moth balls. (It is never wise to put your nose right up to, or right over, a substance you've not had experience with before!)

Activity 3.3: Burning contest: Alkane versus Alkene

Background information:

All hydrocarbons can be used as fuel. Do they all burn the same?

You will need:

- A propane torch
- An acetylene torch
- A few pennies (other metal objects if you wish, such as an aluminum can)
- Pliers
- Hotpad