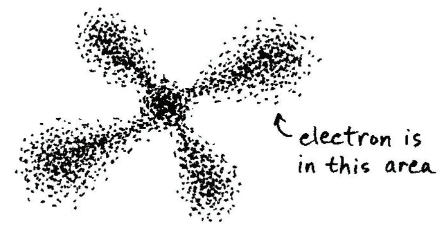
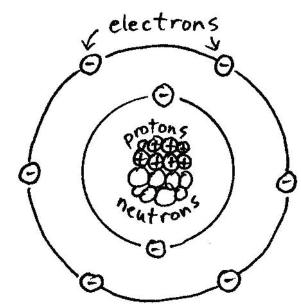
CHAPTER 1: CARBON ATOMS

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.

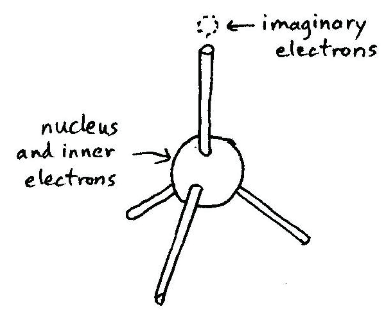
This is called the ***electron cloud model***. It shows the areas where the electrons "live" around the nucleus (center) of the atom. It shows us roughtly what an atom actually looks like. However, it is almost useless when we want to study the orderly arrangement of electrons into shells and orbitals, or when we want to show chemical bonding.

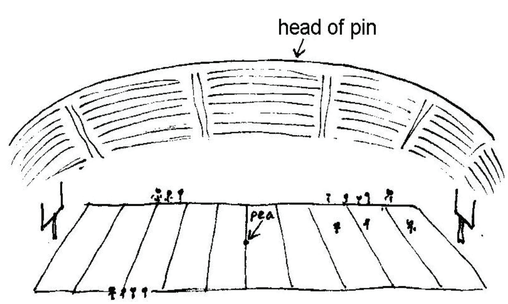


This is called the ***solar system model***. It doesn't look anything like a real carbon atom, but it is a very good model to use for learning about the arrangement of protons, neutrons and electrons. It helps us to understand how the electrons orbit around the nucleus. We can show the arrangement of the electrons into shells and easily count them. The weakness of this model is that it doesn't look at all like a real atom.



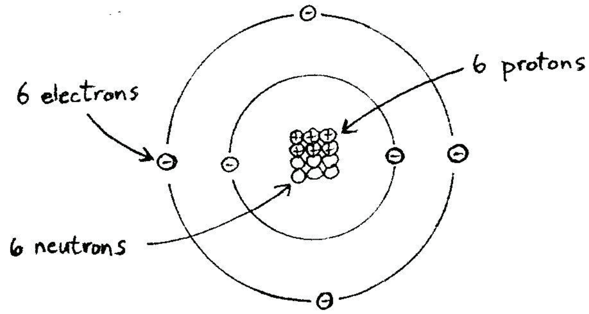
This is called the ***ball and stick model***. It doesn't look like a real carbon atom, either. The ball in the center represents both the nucleus of the atom, and any electrons that are in "inner" shells, closer to the nucleus. The sticks represent free electrons on the outside of the atom that are 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!

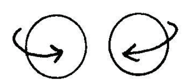
Each element has a unique number of protons. Hydrogen has one proton, helium has two, lithium has three, beryllium has four, and so on through the Periodic Table. An atom's atomic number tells how many protons it has. Carbon's atomic number is six, so it has six protons.

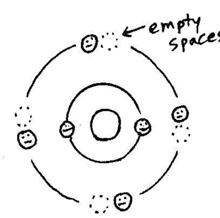


The plus signs in the protons mean that they carry a positive electrical charge. The minus signs in the electrons show that they have a negative charge.

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!"***

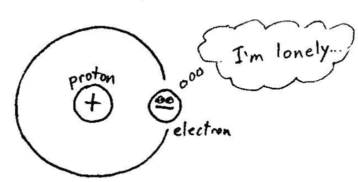
Electrons form pairs, with one electron spinning one way, and the other electron spinning in the opposite direction. (Imagine a very simple dance.) Carbon would like each of its electrons to have a partner, so carbon is out looking for four electron "dance partners" to fill in these empty places.



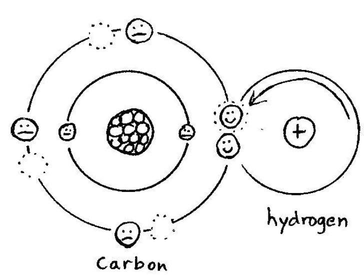


How does carbon find electrons to fill in these empty places? It borrows them from other atoms. It just so happens that there are other atoms out there that have the same problem that carbon does. They have electrons without partners, too. These atoms would love to get together with carbon and share 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.

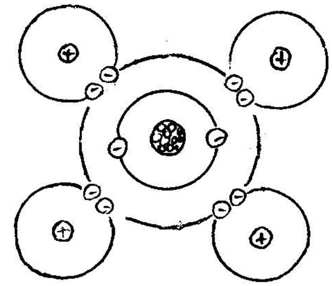
Hydrogen is the smallest atom that exists. It is made of only one proton and one electron. What fun can just one electron have? The proton isn't much company—it can't do the electron dance. So, hydrogen's electron goes out looking for a partner.



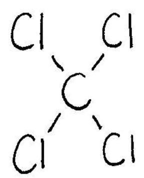
Look! There's a carbon atom. It needs some partners! So hydrogen goes over to carbon and puts its electron into one of carbon's empty slots. Now we have one happy electron couple.



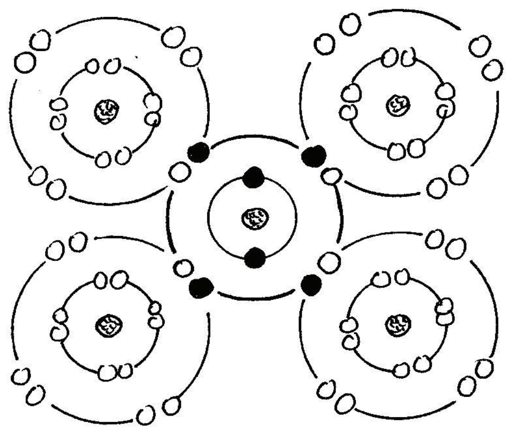
Then the hydrogen atom calls up three of its hydrogen friends and tells them to come on over and fill the other three slots. Now we have a real square dance. Carbon is thrilled to have partners for its four electrons. This works out rather well!

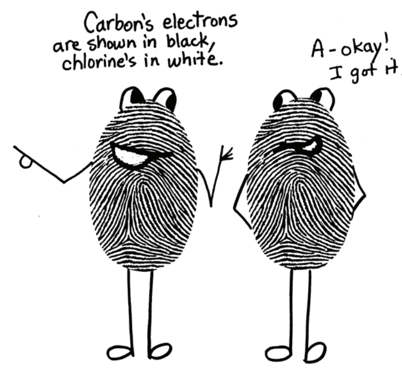


Another atom that can cooperate with carbon is chlorine. Chlorine's problem is that it has seven, not eight, electrons in its outer shell. Chlorine is out looking for a free electron that can pair up with its lonely electron. Can carbon do this? Carbon has four electrons that are looking for partners. 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!

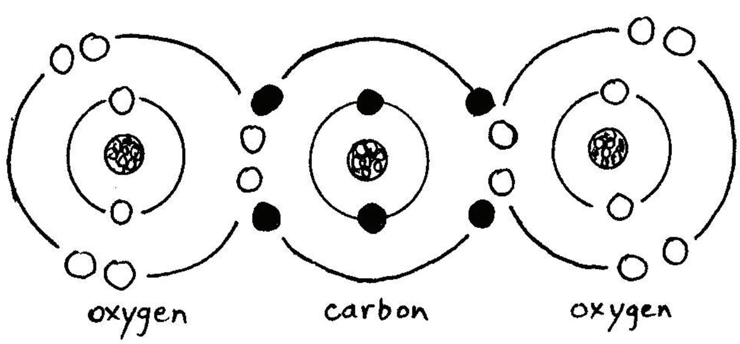


Here is an easy way to draw it.





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 for this discussion.)

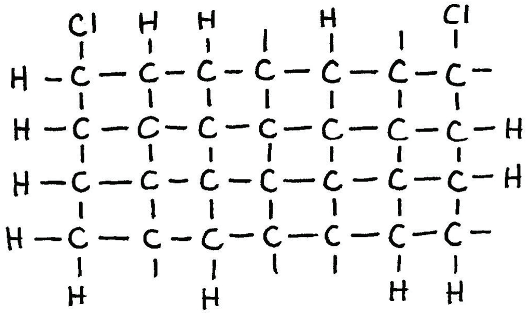


Oxygen pretends two of carbon's electrons belong to it, so it also has eight electrons in its outer shell.

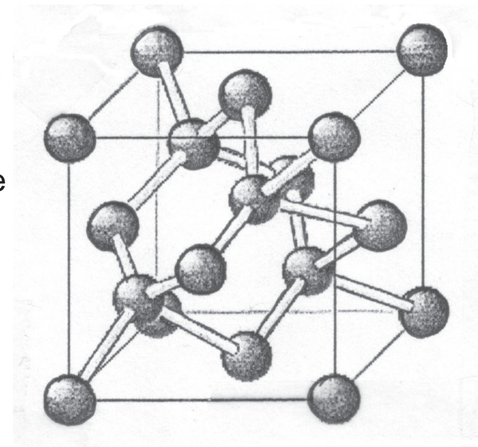
We can draw it like this:

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.

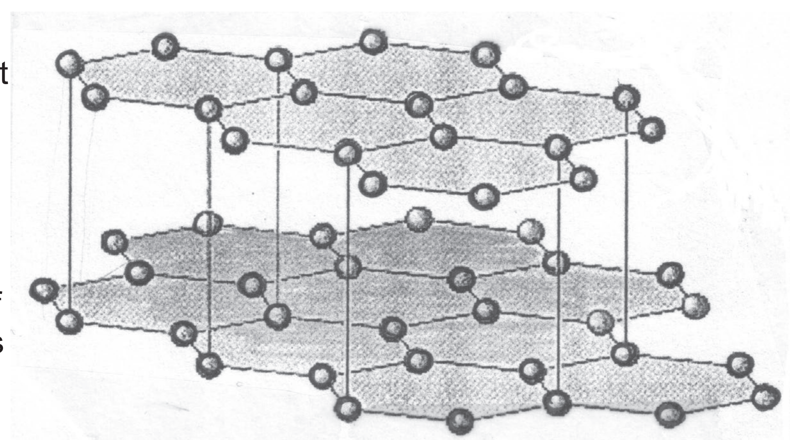


There are basically three ways that carbon bonds with itself. Each of these substances is called an ***allotrope***. The first allotrope of carbon is ***diamond***. Diamonds are made of pure carbon. The bonds between the carbons are extremely strong, making diamond the hardest substance on earth. Diamonds 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.)

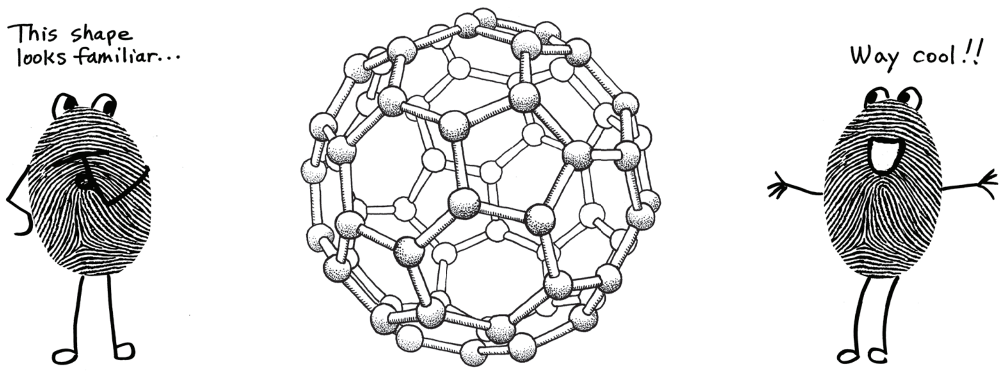
Another allotrope of carbon is ***graphite***. You use graphite all the time; it is the "lead" in pencils. Real lead (Pb on the Periodic Table) is not used in pencils anymore, because it was discovered to be dangerous to our health. You can see that in graphite, the carbon atoms are arranged in layers. 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 graphite layers sliding back and forth. Because it is slippery, graphite can be used as a dry 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 is 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 might turn out be one of the most destructive substances on earth if it gets released into the environment. We 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 1960s and '70s. Since the name is so long, scientists have come up with a nickname for this substance. They call the molecules ***buckyballs***.



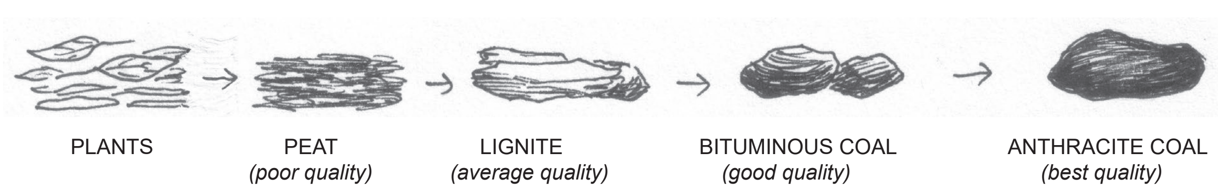
If you think this pattern looks like a soccer ball, you're right—the pattern is the same. There are 20 hexagons and 12 pentagons, with each pentagon completely surrounded by hexagons.

What are buckyballs good for? Some scientists think they might be good for microscopic lubrication, or bearings in a microscopic 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 a fireplace. 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)



Comprehension self-check

See if you can fill in the blanks with the correct words. If you have trouble remembering, go back and re-read that section and find the answer.

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) Name a use for graphite other than in pencils: ___________________________.
15) A carbon "buckyball" is patterned in the same way as a _____________________.
16) A single layer of graphite is called _______________.
17) What does "amorphous" mean? _____________________________
18) Name two amorphous forms of carbon: __________ and __________________
19) Coal is made of _________________ that lived a long time ago.
20) Charcoal is made by burning ____________ in a low-oxygen environment.

A sample from "The Chemical Elements Coloring and Activity Book"

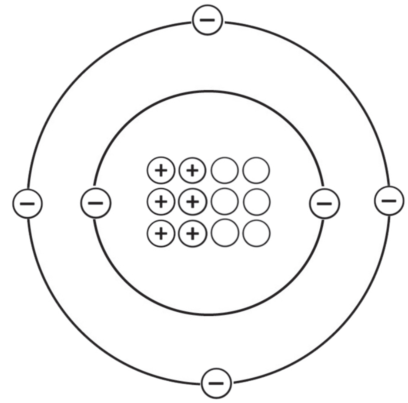
The following two pages are from of this author's advanced coloring book about the elements of the Periodic Table. If you'd like to have all 118 elements, you can find the book by searching ISBN 978-1-7374763-0-6 at your favorite online book store (Amazon, Barnes & Noble, BooksAMillion, BookDepository, etc.).

C

6 protons

6 neutrons
6 electrons

Atomic mass: 12.01



Carbon

From the Latin word for charcoal: "carbo"

Carbon is the most flexible and "friendly" atom on the Periodic Table. It will bond with many other elements, although its favorites are hydrogen and oxygen. If there are no other atoms around to bond with, carbon will bond to itself, forming pure-carbon substances such as diamonds, graphite and coal. That's right, coal and diamonds are made of the same stuff! The most fascinating pure-carbon structure is the buckyball, a hollow sphere of 60 carbon atoms arranged in the same pattern as a soccer ball (hexagons surrounded by pentagons).

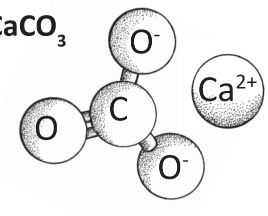
Carbon is found in the air around us as carbon dioxide, CO_2. Vehicles can put both CO_2 and CO (carbon monoxide) into the air as by-products of combustion. CO is very dangerous and many people have CO detectors in their homes if they have a furnace that burns natural gas, CH_4.

Carbon can bond to three oxygen atoms and make the carbonate ion, CO_3^{2-}. If a calcium atom sticks to carbonate, we get calcium carbonate, $CaCO_3$. Calcium carbonate is the main ingredient in the mineral calcite and in the rock known as limestone. Sea shells are a biological form of calcium carbonate.

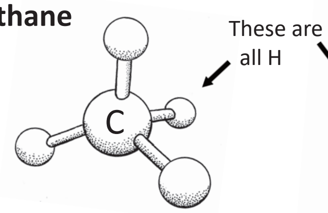
Hydrocarbon molecules are made of just carbon and hydrogen atoms and can be small (CH_4, natural gas), medium-sized (C_8H_{18}, octane, liquid gasoline) or so long we can't even count the carbon atoms (plastics and rubbers). Carbon and hydrogen atoms can also form a ring known as benzene. The benzene ring, or an adaptation of it, is at the heart of thousands of molecules, including polystyrene plastic, Styrofoam®, food preservatives, cholesterol, natural almond flavor, spot removers, moth balls, paints, and medicines.

Many biological molecules have carbon at their core. Proteins, fats and sugars are all carbon-based substances. DNA, the extremely long ladder-shaped molecule that is like a library of information for living cells, has carbon atoms at key points in its structure. Carbon is also at center of many other molecules essential to life, including enzymes.

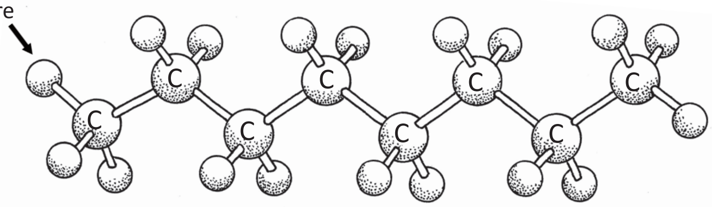
Limestone $CaCO_3$



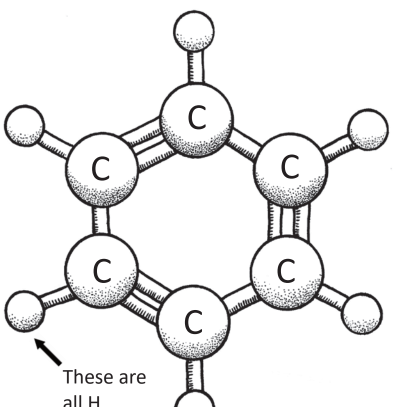
Methane CH_4



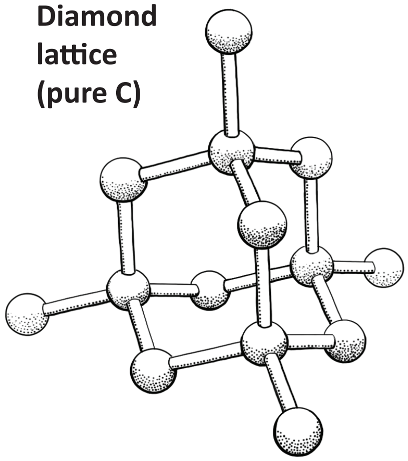
Octane C_8H_{18}

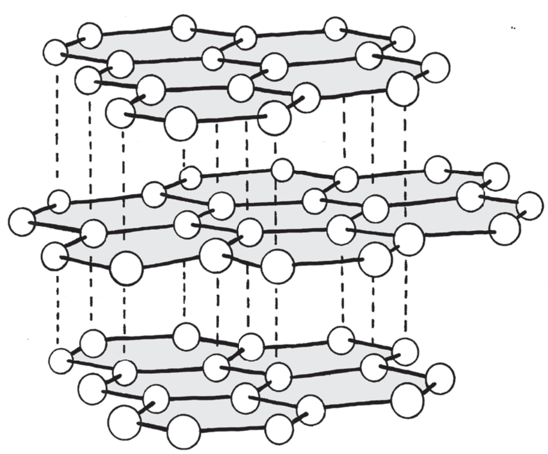


Benzene C_6H_6



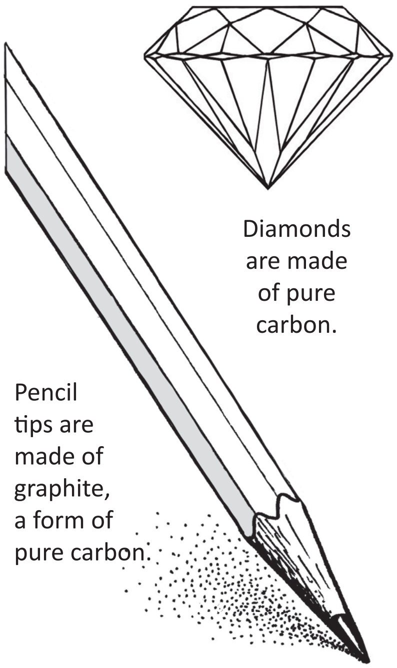
Diamond lattice (pure C)





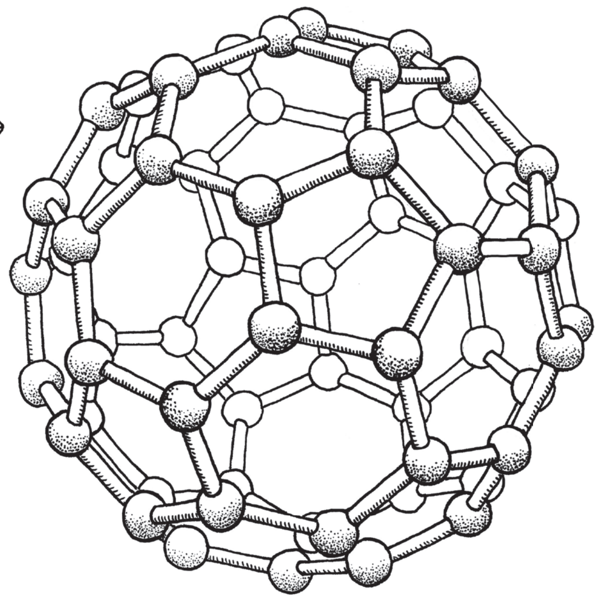
Graphite lattice (pure C)

6 Carbon C



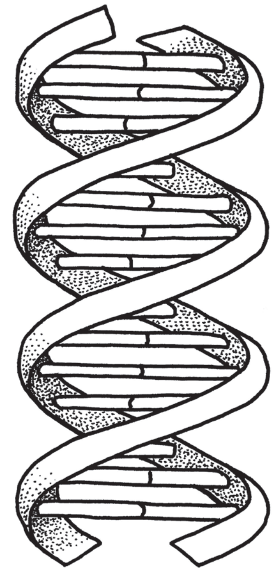
Diamonds are made of pure carbon.

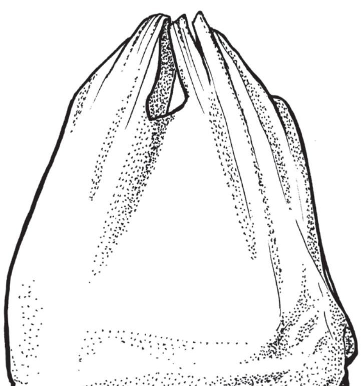
Pencil tips are made of graphite, a form of pure carbon.

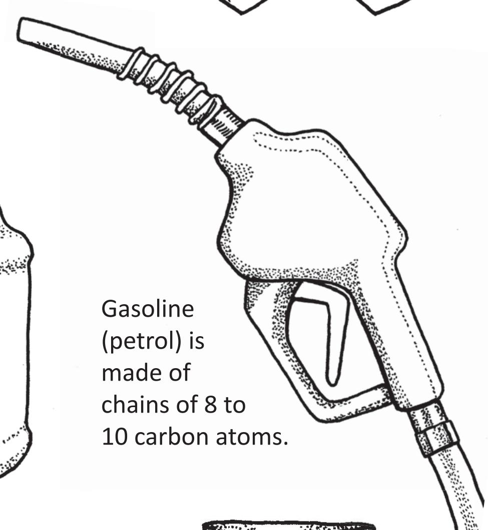


"Buckyballs" are made of 60 carbon atoms.

Carbon atoms determine the structure of DNA.



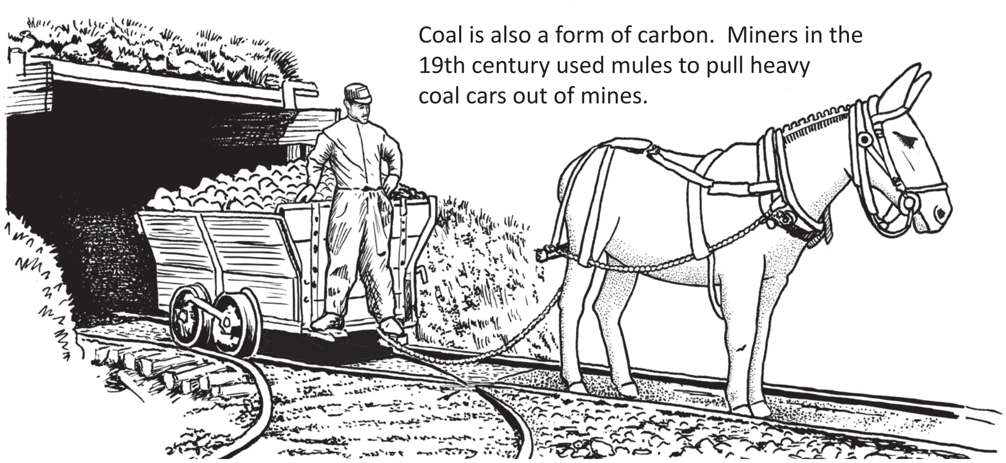


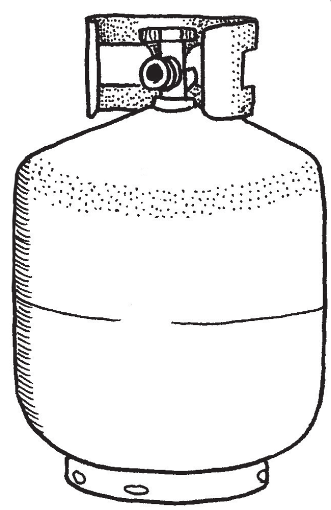


Gasoline (petrol) is made of chains of 8 to 10 carbon atoms.

All forms of plastic are made of long chains of carbon atoms (with hydrogens attached).

Coal is also a form of carbon. Miners in the 19th century used mules to pull heavy coal cars out of mines.

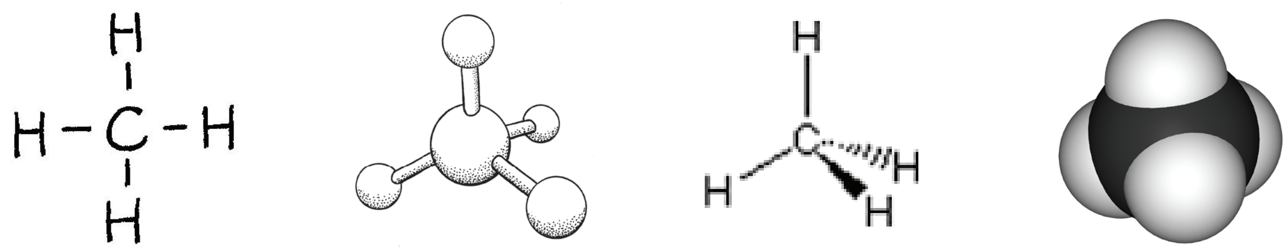




Natural gas (methane) is CH_4.

CHAPTER 2: ALKANE HYDROCARBONS

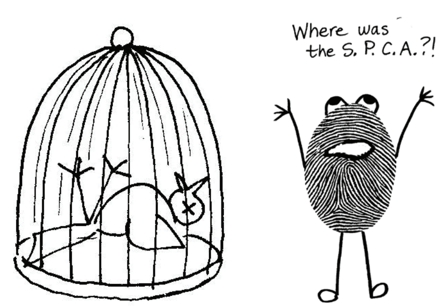
We learned in chapter one that carbon often bonds with hydrogen. When carbon bonds with just hydrogen, they form a molecule we call a ***hydrocarbon***. The simplest hydrocarbon is ***methane***. It consists of one carbon atom and four hydrogen atoms:

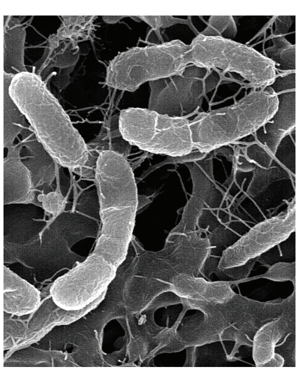


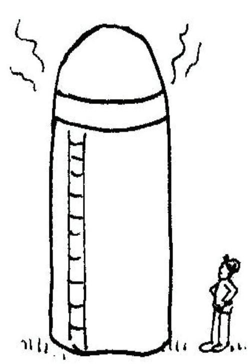
Here are four ways of drawing the methane molecule. The first one (on the far left) is called a “structural formula.” It is easy to draw, and because it uses letters to represent the atoms, you always know what the atoms are. However, it does not show the three-dimensional shape of the molecule. The second one is the “ball and stick” model. The hydrogen atoms want to stay as far apart from each other as possible, and this “tetrahedral” shape is the result. The third model is a hybrid between the structural model and the ball and stick. The last model is a “space-filling” model. It probably comes closest to showing us what a real methane molecule looks like. Space-filling models are easy to make out of clay, but are difficult to draw. We won’t be using them very much in this book, but it is good to have seen one and know what it is called.

Methane is a small, lightweight molecule that floats around in the air as a gas. You can’t see it or smell it. We sometimes call it “natural gas” because it occurs naturally in the earth, often forming in areas where oil and coal are found. Natural gas can be used to heat homes, but the gas companies must add a smelly substance to it so that we will be aware of any leaks in the pipes.

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 coal mining a dangerous job. Miners can run into pockets of methane gas as they work. A spark of any kind could 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.

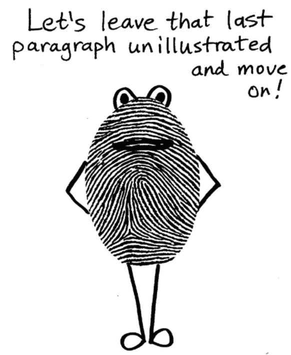




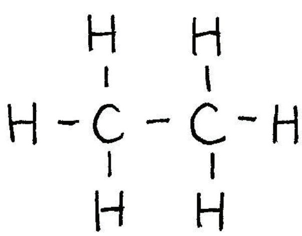


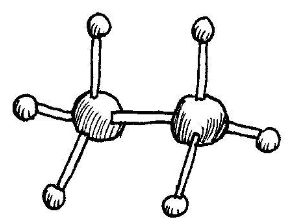
Some types of bacteria produce methane. A good place to find these bacteria is in rotting vegetation. Silos used by farmers to store chopped corn and hay will also contain a healthy population of bacteria that eat the plants and produce methane as a waste product. Care must be taken to monitor how much methane is building up inside the silo. High levels of methane can lead to spontaneous silo fires.

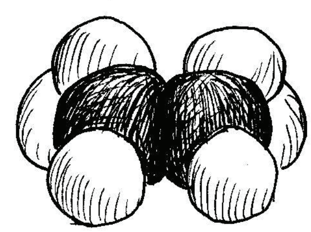
Methane-producing bacteria live in our intestines, also. Yes, gas is really… gas. Healthy intestines have millions of harmless (and beneficial) bacteria living in them. We need these bacteria in our intestines. They aid in digestion and keep us healthy. When certain foods pass through the intestines 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:

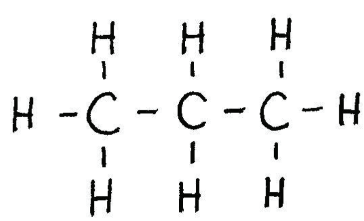

structural formula


the ball and stick model


space filling model

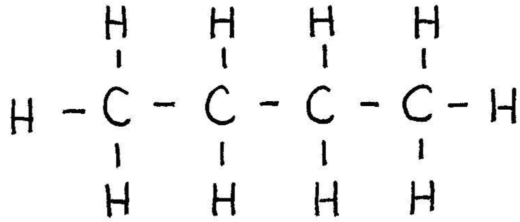
As you can see, ethane is made of two carbon atoms and six hydrogen atoms. We can write it like this: C_2H_6. (This is called the ***empirical formula***.) Both carbon atoms have all four of their free electrons attached to another atom, so this combination works out well. Like methane, ethane is a gas.

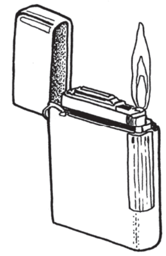
If another carbon atom is added on, we make a substance called ***propane*** (C_3H_8).



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.





Butane is a heavy gas and easily liquified. Butane in lighters and torches will usually be a liquid.

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.

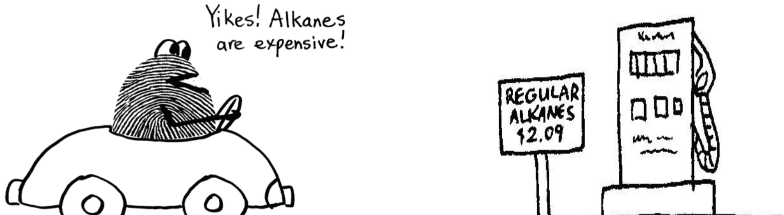
So where do these names (methane, ethane, propane, butane) come from? What do they mean? An organization called the ***International Union of Pure and Applied Chemistry (IUPAC)*** decides what to name molecules and chemical compounds. Chemists all over the world need to use the same names for things 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 is being discussed. Sometimes, IUPAC decides to go with names that chemists have already been using for a while. Other times, 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:

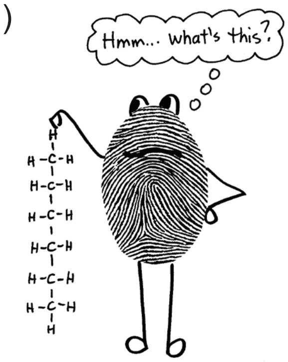
1	2	3	4	5	6	7	8	9	10
meth-	eth-	prop-	but-	pent-	hex-	hept-	oct-	non-	dec-
		(prope)	*(byute)*					*(known)*	*(deck)*

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 the 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?



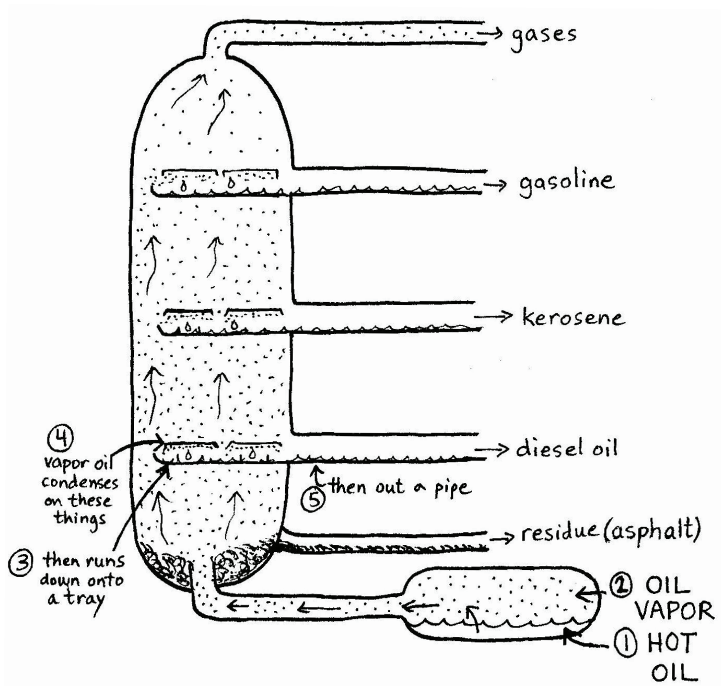
Chains of12 to16 carbons give you kerosene fuels. 15 to 18 carbons make heating oil. 20 to 40 carbons give you paraffin waxes and asphalt. Strings of hundreds or thousands of carbons make various kinds of plastics. (Plastics will have their own chapter.)



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.



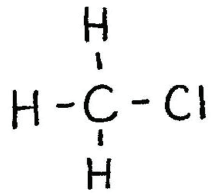
Crude oil is heated until it turns into vapor (at 350^0 C), then this vapor is pumped into the bottom of a very tall tube. The temperature is hot at the bottom, and cooler at the top. The longest hydrocarbon chains turn back into a liquid (condense) onto trays at the bottom of the tube and run into pipes. 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.

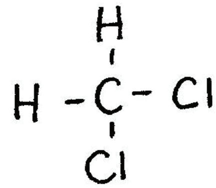
You can see some videos about this on the Carbon Chemistry playlist at www.YouTube.com/The BasementWorkshop.

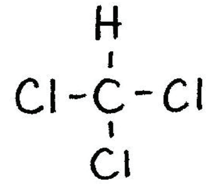
Cracking is a process by which they take medium-sized chains and break them into smaller pieces. The medium-sized chains are heated in the absence of oxygen, and sometimes in the presence of chemicals called catalysts, which help the reaction occur. A commonly used catalyst is "zeolite," a mineral powder made of aluminum, silicon and oxygen. Cracking can produce liquid gasoline (petrol), a substance which is always in demand.

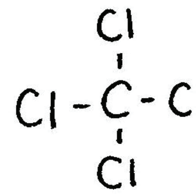
Two more ideas that we need to discuss in this chapter are chlorinated hydrocarbons and isomers. Let's tackle ***chlorinated hydrocarbons*** first.

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

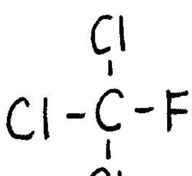

chloroform

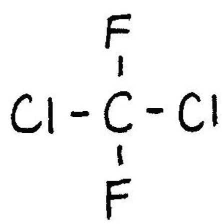

carbon tetrachloride

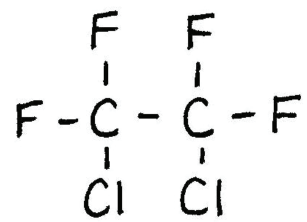
Methyl chloride is mainly used in making silicone substances (sealants, waterproofing materials, artificial body parts, Silly Putty). Methylene chloride is used as a paint remover. Chloroform started out as an anesthetic (putting you to sleep for surgery), but has now been replaced by safer substances. 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*** (di-chloro-di-phenyl-tri-chloro-ethane) 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.

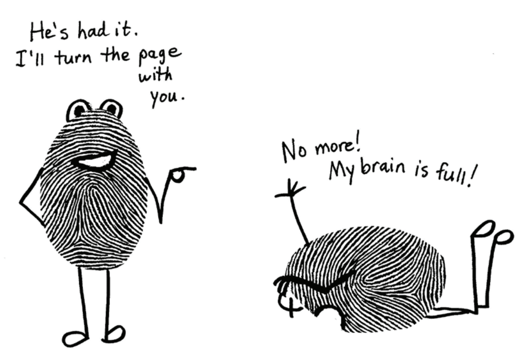
Carbon compounds can contain fluorine along with chlorine. The fluorine atom is in exactly the same state as the chlorine atom, with one unhappy, unpaired electron. Fluorine will gladly attach itself to one of carbon's electrons.





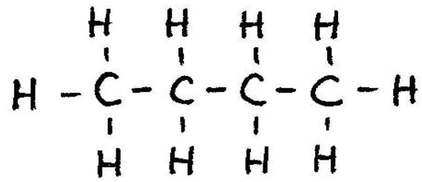


These molecules are called (no big surprise here) ***chlorofluorocarbons***, or CFCs. They used to be used as propellants in aerosol spray cans and as coolants in refrigerators. CFCs are nontoxic and don't hurt us directly because they don't react chemically with anything. They don't pose any direct 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.

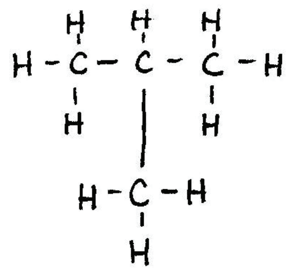


One last topic remains: ***isomers***. The name sounds strange, but the idea is very easy. Isomers are molecules with exactly the same number of atoms but in a different geometrical arrangement. ("Iso" means "same.")

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

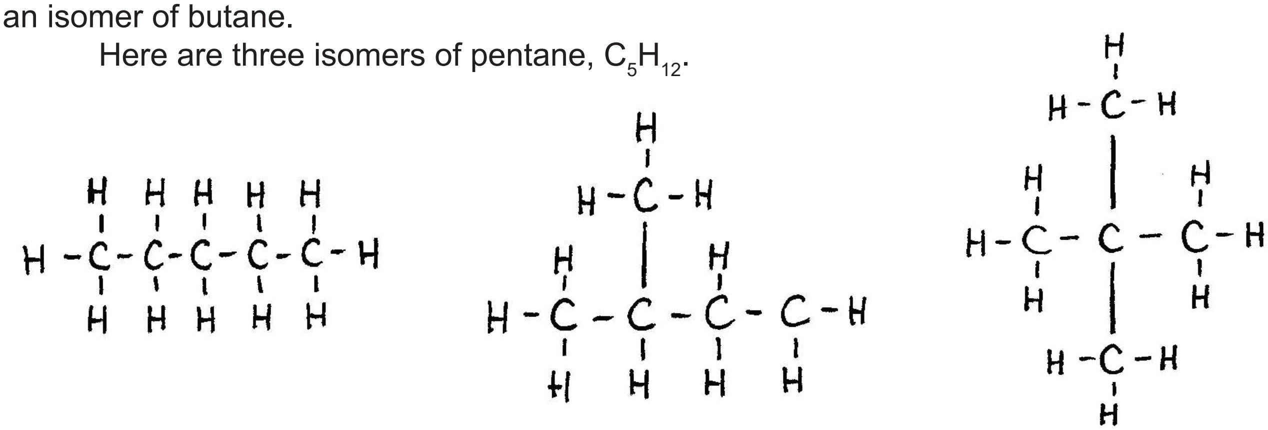


However, you could reshuffle the carbons a bit and make the molecule look like this:

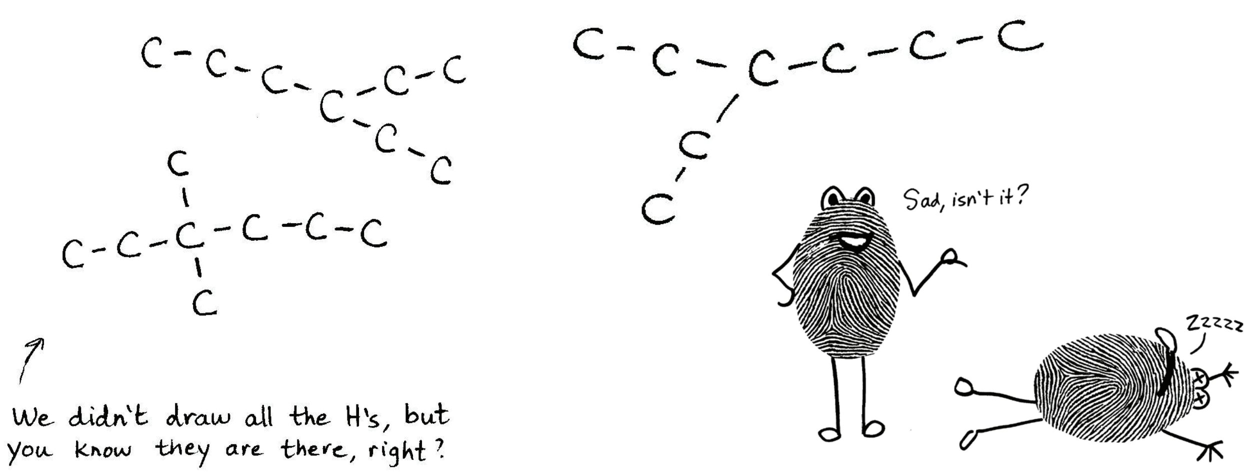


It is still C_4H_{10}, butane. To differentiate it from regular butane, scientists call this "isobutane," an isomer of butane.

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) Methane is also called ____________ gas.
3) Does methane burn easily? ____
4) Is methane smelly? _____
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 put these prefixes in order, from 1 to 6? (but, meth, prop, hex, pent, eth)

________, ________, __________, ________, ________, ________

9) Where can you find octane and heptane mixed together? _____________________
10) Too much heptane and not enough octane causes this problem: ______________
11) Use these words to fill in the blanks. [solids, liquids, gases]

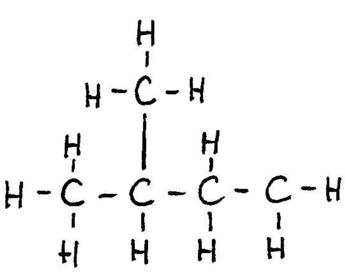
Very short alkanes are _______, medium sized are ________ and longer ones are _________.

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 the oil, then allowing it to cool and condense.
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 first used for? ____
20) Molecules that contain exactly the same number of atoms, but in a different geometric arrangement, are called _______________.

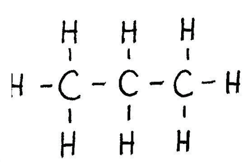
Write the matching letter on each line.

21) methane ___ 22) ethane ___ 23) propane ___ 24) butane ___ 25) octane ___

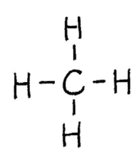
(a)



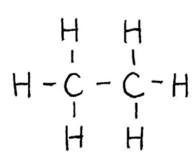
(b)



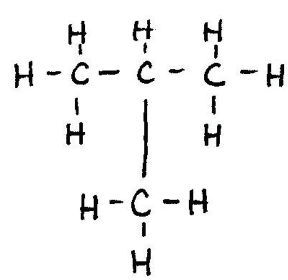
(c)



(d)



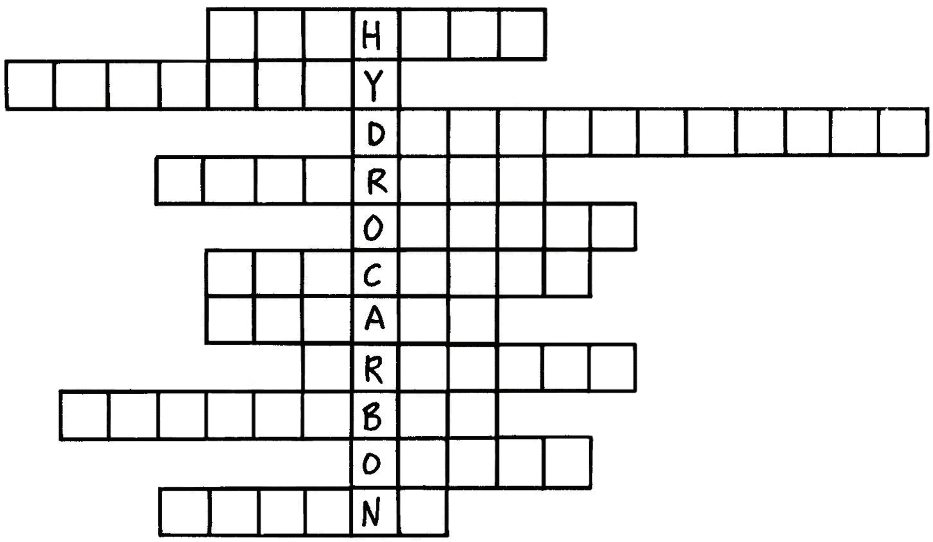
(e)



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 are you least likely to 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}

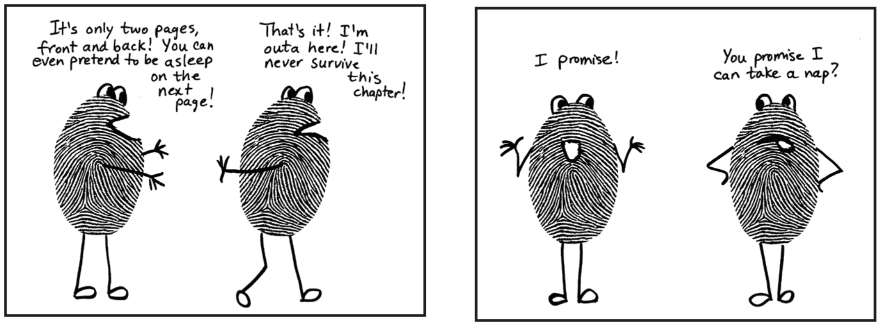
6) Which one of these does not bond with carbon?
chlorine fluorine carbon hydrogen helium

7) Which of these is not considered to be a way of modeling an atom?
empirical formula structural formula space-filling ball and stick

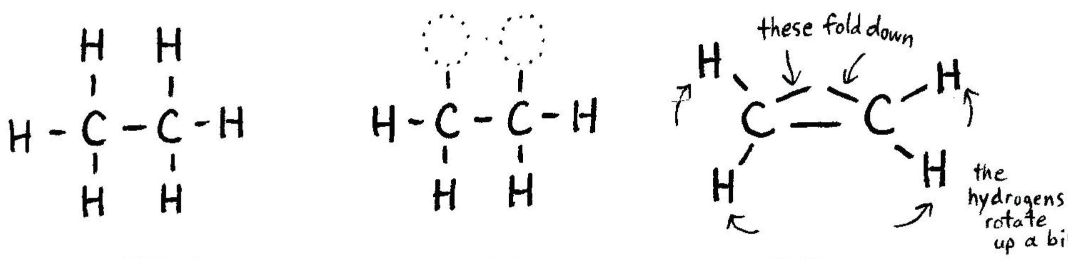
8) Which of these would not come out of an oil refinery?
kerosene gasoline CFCs methane asphalt diesel oil

CHAPTER 3: "-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 molecule have only single bonds. Now we are going to look at some molecules with double, even triple, bonds.



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

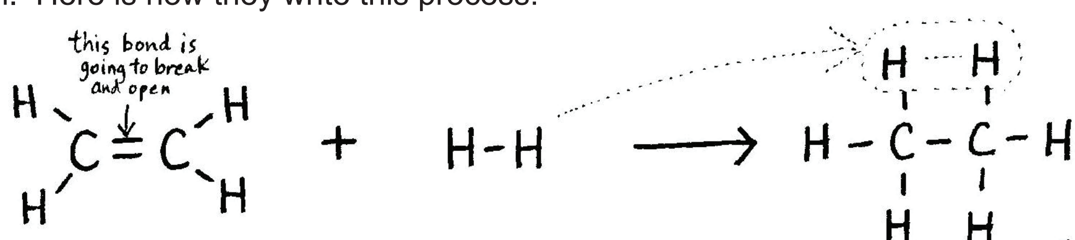


STEP 1 STEP 2 STEP 3

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.

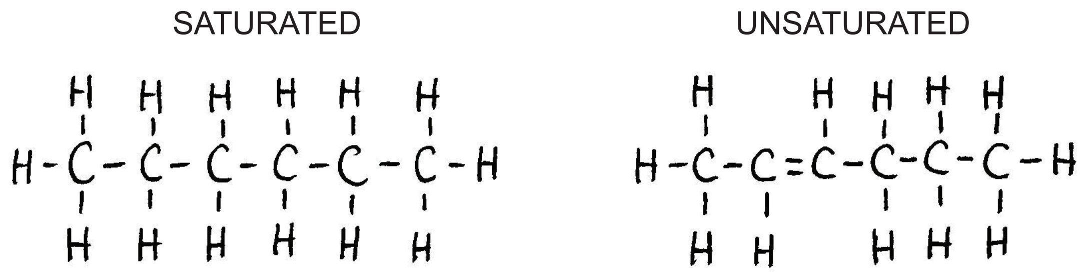
The alkene shown here, in step three, is called ***ethylene***. The name "ethylene" might sound like a poison, but it is actually a harmless gas produced naturally by ripening fruit. es, that bowl of fruit there on the table is giving off ethylene gas. Commercial produce growers have found that they can speed up the ripening process by steaming their produce in ethylene. Tomatoes, especially, can be "reddened up" by exposing them to ethylene gas. 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:

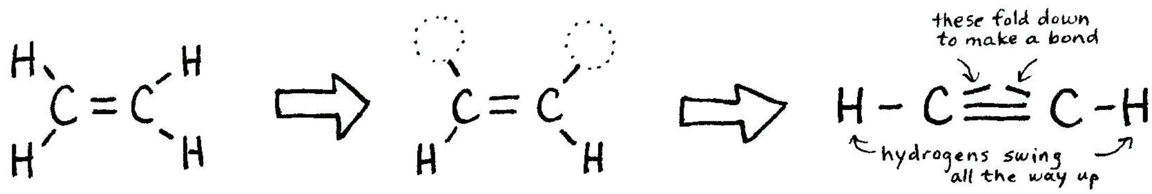


ethylene hydrogen ethane

Alkane molecules are ***saturated*** molecules. Saturated means completely full. When a sponge is saturated, it can't hold any more water. When a liquid is saturated, it can't hold any more of whatever you are trying to stir into it. When your brain is saturated (like our poor little friend's) it can't hold any more information and you need to have a recess or take a nap. When a hydrocarbon is saturated, it has all the hydrogen atoms it can possibly hold on to. The opposite of saturated is ***unsaturated***. If a hydrocarbon has some double bonds that it could open up, then it is unsaturated.



Now, let's look at a molecule with a triple bond. If we pluck off another pair of hydrogens, carbon has no choice but to increase the double bond to a triple bond, sharing not two, but three pairs of electrons. Carbon must feel like a contortionist from an old-fashioned circus! (Contortionists are performers who can bend their bodies in all sorts of unnatural ways.)

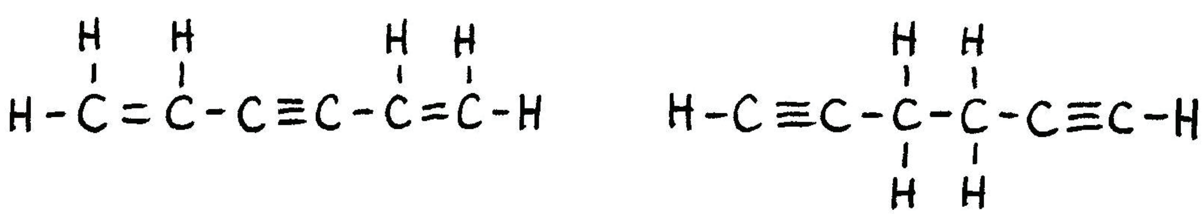


This molecule is the smallest member of the ***alkyne*** group. Alkynes all have at least one carbon with a triple bond. To really confuse you, the name of this chemical is "acetylene," the fuel found in acetylene torches. (Hmm… maybe IUPAC didn't get there in time and acetylene got named by someone not familiar with the ane/ene/yne naming rule.)

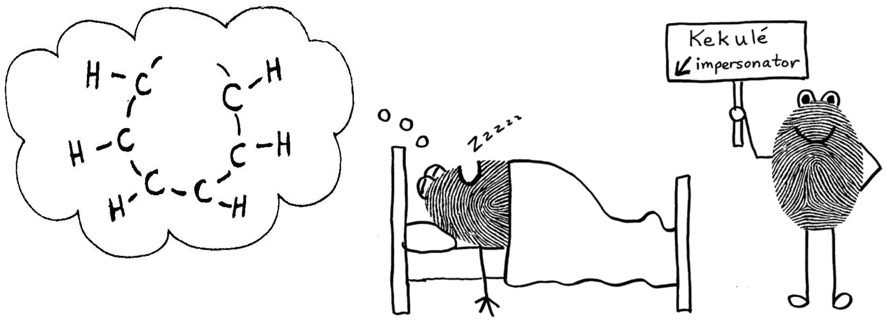
Alkenes and alkynes have many of the same properties as alkanes. Molecules with only 2 to 4 carbons are gases, 5 to18 carbons are liquids, and 19 or more carbons are solids. They do not dissolve in water; they float on water. (Think of an oil spill.)

Another group of molecules that ends in "-ene" is the ***benzene*** group. This group is also called the ***aromatic hydrocarbons*** because the first ones that were discovered had strong aromas (smells). Later on, scientists discovered that not all members of this group have odors, but it was too late—the name had been used for so long that it was impossible to change it.

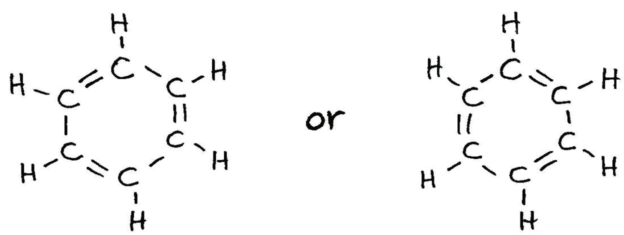
The discovery of the structure of benzene has a famous story attached to it. Benzene's empirical formula, C_6H_6, had been discovered in 1825 by Michael Faraday, a scientist much better known for his work with electricity and motors. Once the ration of carbons to hydrogens was known, many chemists drew up every possible configuration they could think of for C_6H_6. Here are two of them:



All of the configurations contained several double and/or triple bonds. However, chemistry experiments with benzene clearly demonstrated that benzene couldn't have double and triple bonds. What was up? No one could figure it out for 40 years. Then along came a scientist named August Kekule *(keck-u-lay)*. He worked on the puzzle long and hard until it almost drove him crazy. One night he fell asleep thinking about the benzene puzzle. As he slept he dreamed that the straight molecule curved around until its ends touched, forming a ring. (Some versions of the story say that he saw a snake biting its tail.) When he woke up he realized he had solved the puzzle in his sleep. Benzene must be a ring!

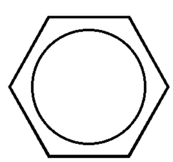


There was more work to do after he woke up, however. This structure still had a bonding problem. If you look at the molecule in his dream bubble and count the bonds attached to each carbon, you will see that there are only three. Carbon atoms always make four bonds. What was happening? This solution was proposed:



The bonds between the carbons alternate back and forth between single and double so fast that they are neither single nor double. The electrons are not tied down to any one place, but are spread around the ring. After deducing that this must be the case, chemists decided to draw the benzene structure like this:

The vertices ("corners") of the hexagon represent the six carbon atoms. There are H atoms at each vertex, but they are rarely drawn.

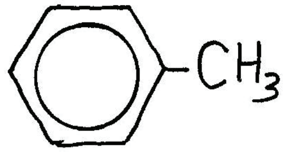


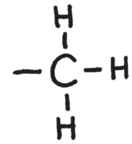
The circle represents the electrons that are being shared back and forth in the single and double bonds.

The benzene ring is a very stable structure. Stable molecules are generally less dangerous than unstable ones. If it were not for your liver, benzene would not be considered poisonous. Benzene would just float through your body, not bothering any of your cells. But when benzene arrives in the liver, the liver starts to disassemble it. The liver is just doing its job— it's supposed to take chemicals apart and get rid of them. This time, however, disassembly is not helpful. But your liver doesn't know this, and it starts messing with benzene, disturbing the stable structure. Now, thanks to your liver, you have an unstable, dangerous substance in your body. Your bone marrow is the body part most affected, and it begins to produce fewer and fewer red blood cells, leading to a condition called anemia, where you feel very tired because you are not getting enough oxygen. Prolonged exposure can also lead to cancers of white blood cells made in the bone marrow.

If you add a CH_3 to one edge of the benzene ring, you get ***toluene*** *(TALL-yu-een)*, a very useful chemical, but a dangerous one. Toluene is more harmful than benzene. Often, a very small change in a molecule can result in very large changes in its behavior.

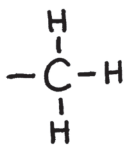
Don't forget that there are H atoms at the other five vertices ("corners"). Chemists don't draw them because they assume everyone knows that they're there.



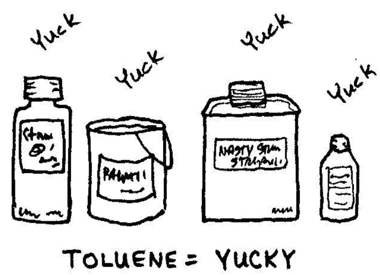


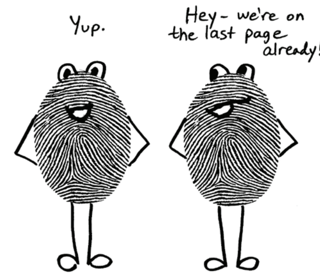
We could draw CH_3 like this. It is usually written "CH_3" just to save space.

Toluene is a clear, fragrant liquid which is used as a solvent in products such as paints, varnishes, cleaning products, pesticides, adhesives and explosives. You almost certainly have products in your home that contain toluene. Toluene is a hazardous chemical and it must not be dumped down drains. It has been proven to cause cancer in laboratory animals. To get rid of it, you must take it to an official hazardous waste collection site. Fortunately, toluene does eventually break down, so it won't stay in the environment forever.



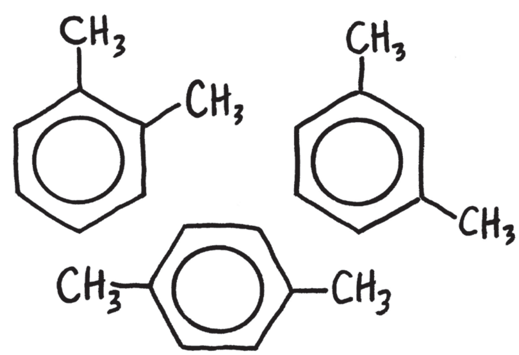
CH_3 is often referred to as the "methyl" group.





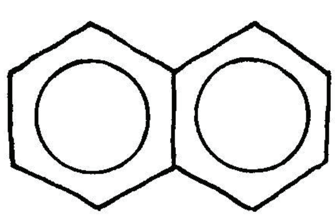
One interesting side note about toluene is that it is produced naturally by the tolu tree. This tree grows in South America and is tapped (like a maple tree) to get the tolu resin, which is used many food and health products. The native peoples use tolu resin to make medicines.

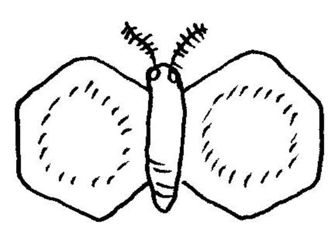
If you take a toluene molecule and add another CH_3 to it, you get **xylene** *(ZIE-leen).* Xylene was first discovered by a French chemist in 1850 as he was pulling chemicals out of wood tar. Since he found it in wood, he used the Greek word for wood, "xylon," to name it. Xylene was found to be useful in labs as a solvent and a cleaning agent because it could dissolve substances like wax and tar. The printing and rubber-making industries soon found uses for xylene. Today, millions of tons of xylene are produced every year for the manufacuring of plastics, especially the type used for plastic bottles and polyester fabrics.



Xylene has three isomers. The CH_3 can be in any of these positions.

If you join two benzene rings together, you get a molecule of ***naphthalene*** *(NAFF-thall-een)*. You know naphthalene as moth balls. Moth balls release a gas that is toxic to the larvae of moths that like to eat clothing made of natural fibers like wool. It's easy to remember that this molecule is the one that kills moths because the molecule actually looks a moth.

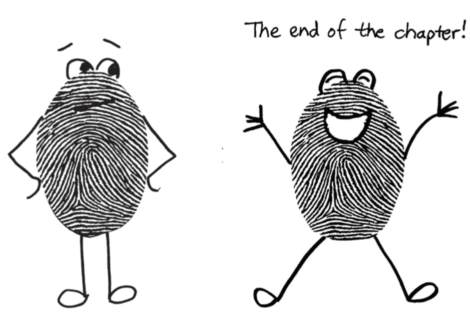




Comprehension self-check

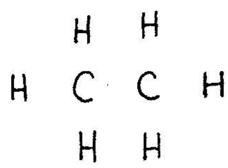
See if you can fill in the blanks and answer these questions, based on what you remember reading. If you have trouble, go back and re-read.

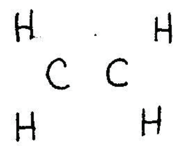
1) Alkanes have ___________ bonds, alkenes have ____________ bonds and alkynes have ___________ bonds.
2) Hydrocarbons that contain just 2-3 carbon atoms are g_____. Large molecules with more than a dozen carbon atoms are s_________.
3) Ethylene gas is produced naturally by _______________________.
4) Hydrocarbons that have the maximum number of hydrogens they can possible hold are said to be s_______________.
5) Hydrocarbons that have double or triple bonds that could be opened up (to allow for the addition of more hydrogens) are said to be u________________.
6) How many carbon atoms are in a benzene ring? _____
7) About how many years did it take for scienetists to figure out the shape of benzene? ______
8) Benzene rings have strange bonds that alternate between _____________ and _________.
9) Molecules that contain at least one benzene ring are called ______________ hydrocarbons because the first examples discovered were smelly substances.
10) Benzene becomes harmful to us when our ____________ starts to disassemble it.
11) Which is more harmful, benzene or toluene? ____________
12) How many benzene rings does toluene contain? ____
13) How many benzene rings does xylene contain? ____
14) Most xylene produced today is used to make __________________________ and ________________________.
15) How many benzene rings does naphthalene contain? ____
16) What household product is made of naphthalene? _______________
17) What does the naphthalene molecule resemble? ________
18) True or false? It's okay to dump toluene down the drain. _____
19) Review: What do you call molecules that have the same empirical formula (such as Cbut differ in their shape? ______________
20) Review: CH_4 is known as _________________ or _________________.

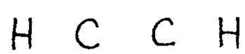


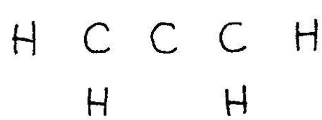
Draw the bonds

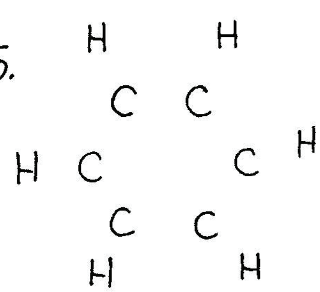
Put all the bond lines between the letters. Make sure that each carbon, "C," has four bond lines going out from it. H's can only have one line sticking out from them and they never attach to each other, only to carbons. A carbon can have more than one H attached to it.

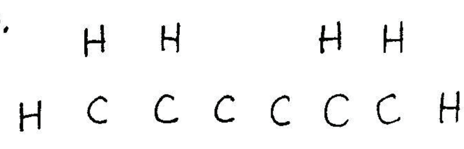
1. 

2. 

3. 

4. 

5. 

6. 

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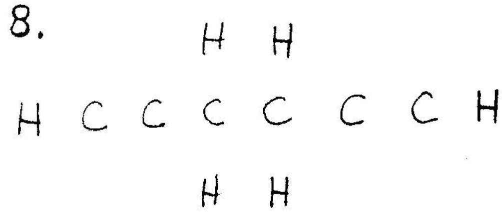
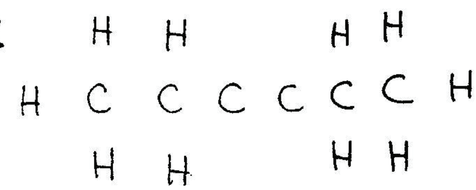
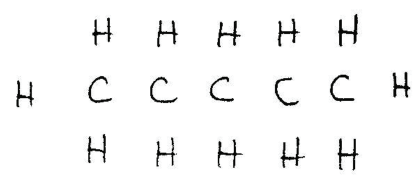
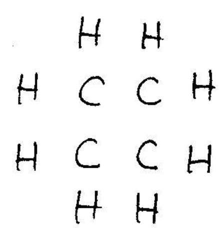
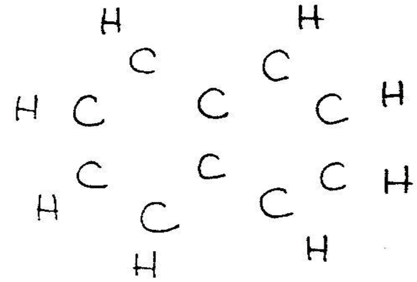
8. 

9. 

10. 

11. 

12. 

The carbons will form two rings that are attached in the middle.