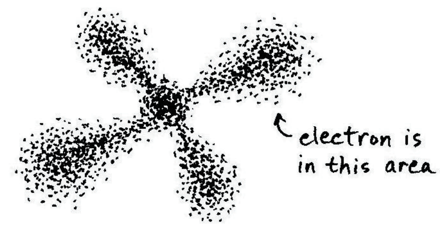
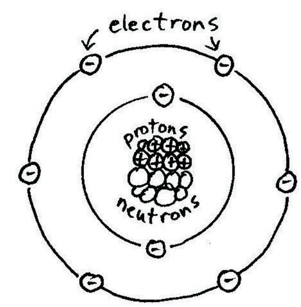
Chapter One: Carbon

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.

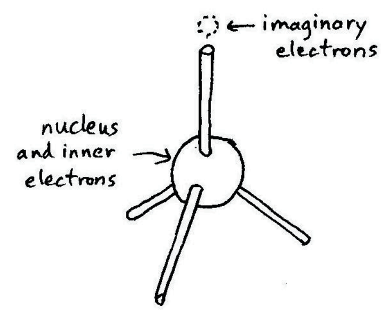
This is called the ***electron cloud model***. It shows how the carbon atom looks under an electron microscope. It is the closest to being an actual "photograph" of the atom. However, it is almost useless when we want to study the orderly arrangement of electrons into shells and orbitals, or when we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

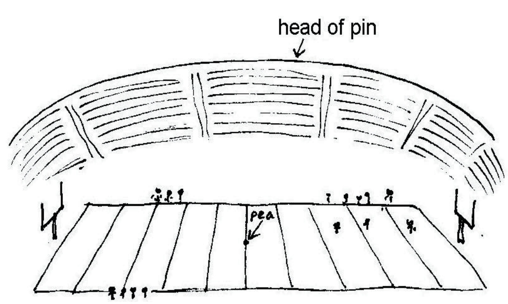


This is called the ***solar system model***. It doesn't look anything like a real carbon atom, but it is a very good model to use for learning about the arrangement of protons, neutrons and electrons. It helps us to understand how the electrons orbit around the nucleus. We can show the arrangement of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



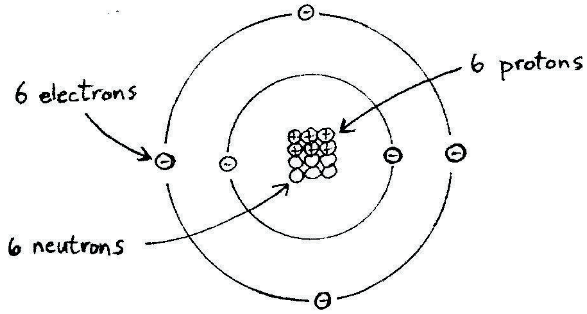
This is called the ***ball and stick model***. It doesn't look anything like a real carbon atom, either. The ball in the center represents both the nucleus of the atom, and any electrons that are in "inner" shells, closer to the nucleus. The sticks represent free electrons on the outside of the atom that are available for bonding with other atoms. This model is very useful when you want to build actual 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 pea 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!!

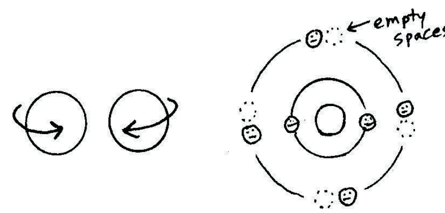
It is the number of protons that determines what an atom is. Each element has a unique number of protons. Hydrogen has one proton, helium has two, lithium has three, beryllium has four, and so on through the Periodic Table. An atom's atomic number tells how many protons it has. Carbon's atomic number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



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

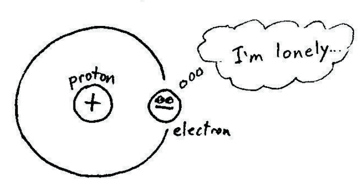
Since atoms must be electrically balanced, this also means that carbon has six electrons. Carbon's electrons are arranged in two layers, or shells. The first shell contains two electrons, and the remaining four are in the second shell. The fact that carbon has four electrons in its outer shell is very 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.

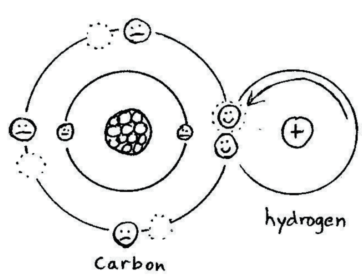


How does carbon find electrons to fill in these empty places? It borrows them from other atoms. It just so happens that there are other atoms out there that have the same problem carbon does. They have electrons without partners, too. These atoms would love to get together with carbon and share one or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

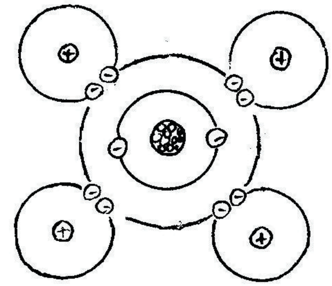
Hydrogen is the smallest atom there is. It is made of only one proton and only one electron. What fun can just one electron have? The proton isn't much company. It can't do the electron dance. So, hydrogen's electron goes out looking for a partner.



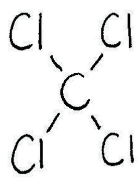
Look! There's a carbon atom! It needs some partners! So hydrogen goes over to carbon and puts its electron into one of carbon's empty slots. Now we have one happy electron couple!



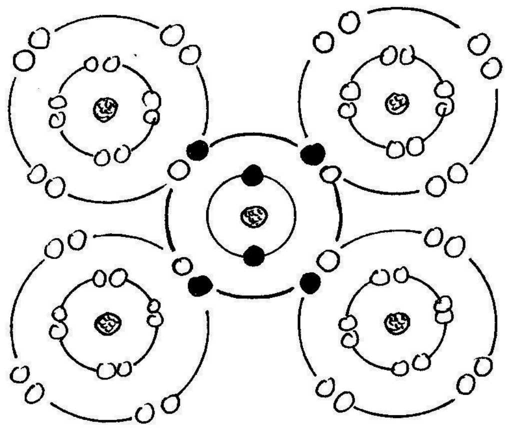
Then hydrogen calls up three of its hydrogen friends and tells them to come on over and fill the other three slots. Now we have a real square dance! Carbon is thrilled to have partners for its four electrons. This works out rather well!

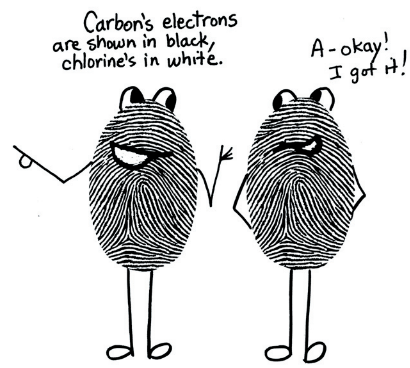


Another atom that can cooperate with carbon is chlorine. Chlorine's problem is that is has seven, not eight, electrons in its outer shell. Chlorine is out looking for a free electron that can pair up with its lonely electron. Can carbon do this? Carbon has four electrons that are looking for partners.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

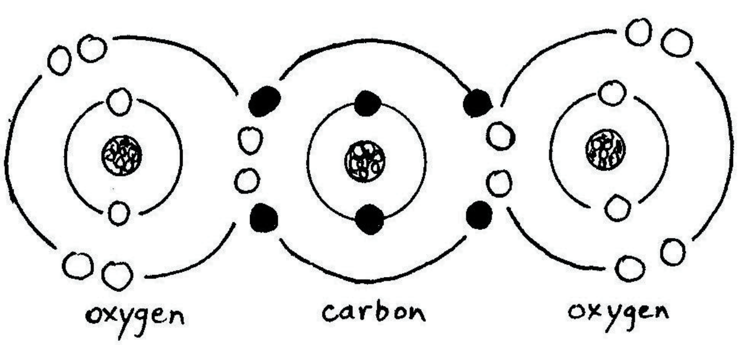


Here is an easy way to draw it.





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.



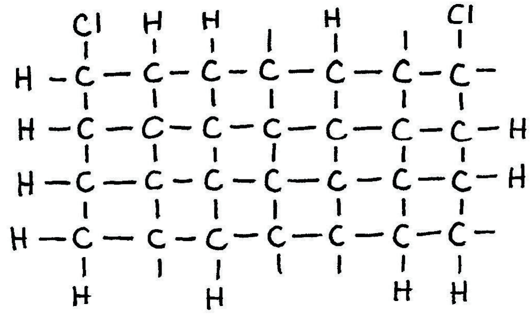
Oxygen pretends two of carbon's electrons belong to it, so it also has eight electrons in its outer shell.

We can draw it like this:

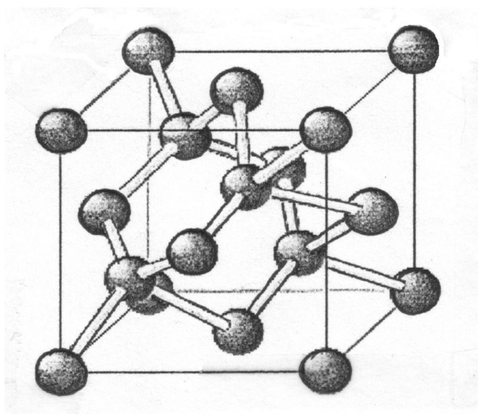
O=C=O

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

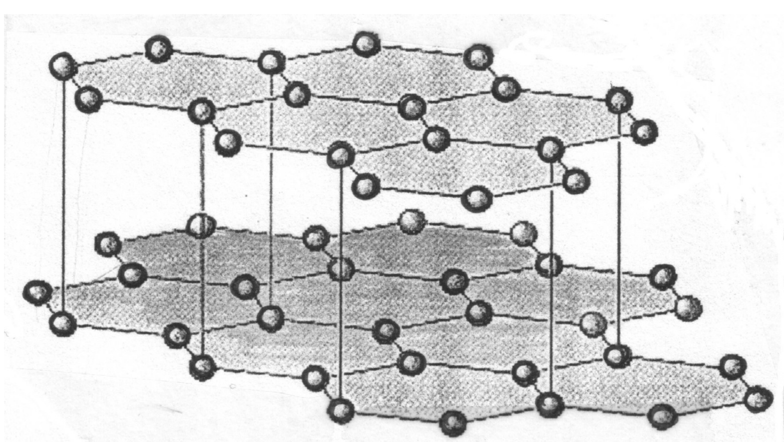
Carbon can also bond with itself. The only problem is that the carbon atoms on the edges will have unpaired electrons hanging off. But, nevertheless, carbon does bond with itself. The free electrons dangling on the edges usually pick up a hydrogen atom, or some other atom that happens to be in the area.



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 very, very 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 is how the carbon atoms are linked in diamonds:

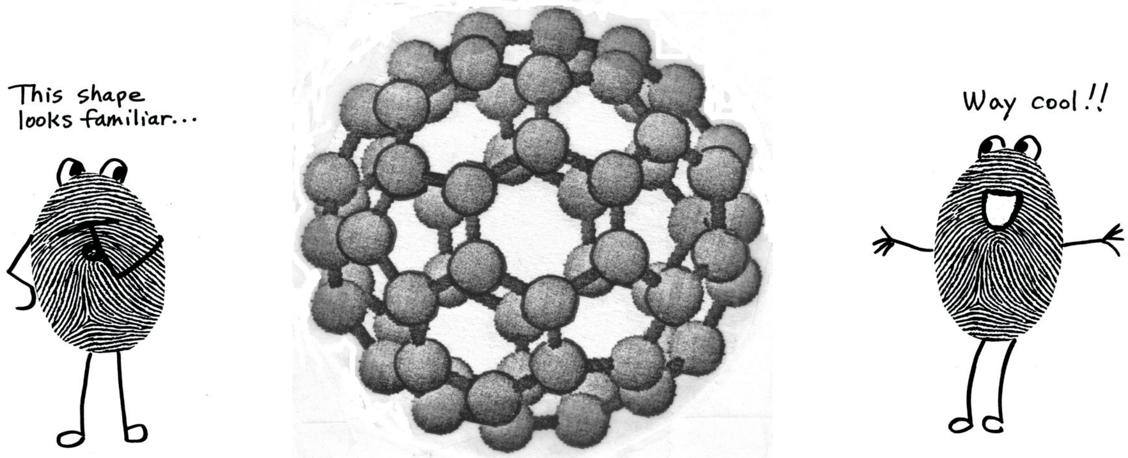


Another allotrope of carbon is ***graphite***. You use graphite all the time. It is the “lead” in pencils. (Lead is not used anymore, of course, having long ago been discovered to be dangerous to our health. Graphite is now used in pencils, but the word “lead” still lingers on.) In graphite, the carbon is arranged in layers, like this:



Each layer is made 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. 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 graphite hard enough, the atoms would rearrange themselves and form a diamond!

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 are absolutely right. The pattern on a soccer ball is exactly the same as a buckyball. 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. Maybe they can be used inside the human body for drug delivery (by putting the drug molecules inside the bucky balls). If you add a few potassium atoms to the buckyball, it will conduct electricity as well as metal does. A 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 the carbon atoms are not bonded in 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. There are also small amounts of other types of atoms mixed in with the carbon. Coal comes from ancient plants that were buried and put under extreme pressure. Charcoal is made by burning wood in a low-oxygen environment.

FORMATION OF COAL (over time and with increasing 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) Which one of these substances has a molecular structure than looks like a soccer ball? ____________________
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?

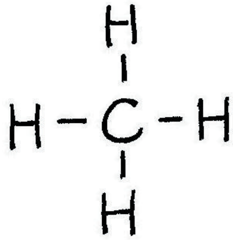
3) Who was the first person in history to make an artificial diamond?

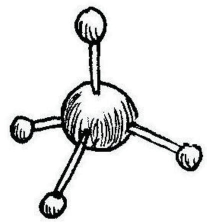
4) What is "activated" charcoal and what it is used for?

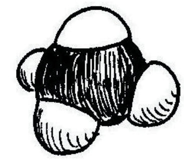
5) Something related to coal is "coke." What is coke?

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:



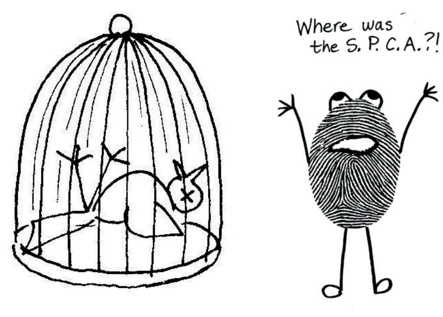




Here are three different ways of drawing the methane molecule. The one on the left is called a "structural formula." It is easy to draw, and because it uses letters to represent the atoms, you always know what the atoms are. However, it does not show the three-dimensional shape of the molecule. The one 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.

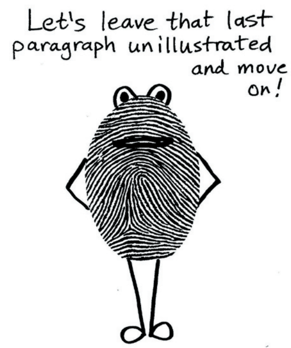
Methane is a small, lightweight molecule that floats around in the air as a gas. You can't see it or smell it. (Gas companies must add a smelly substance to it so that we can smell gas leaks in our homes.) We sometimes call it "natural gas" because it occurs naturally in the earth, often forming in areas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

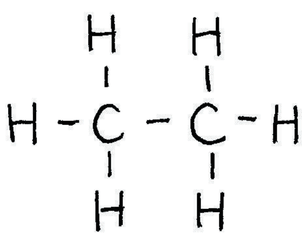


Some types of bacteria produce methane. Farmers know that rotting vegetation can produce both methane and heat. (Not a good combination when you don't want fire!) Fires can start spontaneously in storage silos if enough methane builds up.

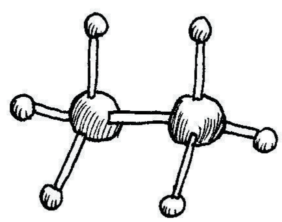
Methane-producing bacteria live in our intestines, also. Yes, gas is really… gas. Healthy intestines have millions of harmless (and beneficial) bacteria living in them. We need these bacteria in our intestines. They aid in digestion and keep us healthy. When certain foods pass through the intestines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



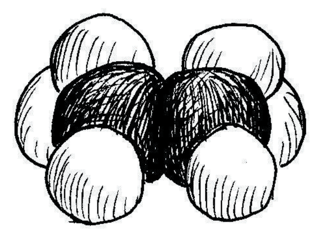
Methane is the first and simplest member of a whole group of carbon compounds called ***alkanes***. The second member of this group has two carbon atoms in it and is called ***ethane***. This is how it looks:



structural formula



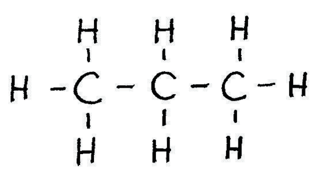
the ball and stick model



space filling model

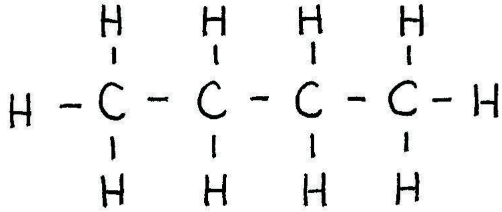
As you can see, ethane is made of two carbon atoms and six hydrogen atoms. We can write it like this: C_2H_6. (This is called the ***empirical formula***.) Both carbon atoms have all four of their free electrons attached to another atom, so this combination works out well. Ethane is also a gas.

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.

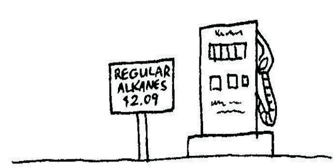
So where do these names (methane, ethane, propane, butane) come from? What do they mean? An organization called the ***International Union of Pure and Applied Chemistry (IUPAC)*** decides what to name molecules and chemical compounds. Chemists all over the world need to use the same names for things 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)*

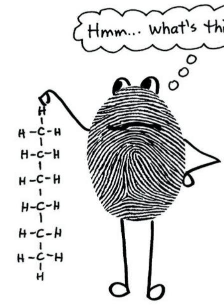
These are the prefixes that come before suffixes like "ane" or "ene" or "yne." In this chapter we are talking about alk*anes*, so each of these prefixes has "ane" after it. "Ane" simply means single-bonded carbons. We have seen methane, ethane, propane, and butane. We can now add pentane, hexane, heptane,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

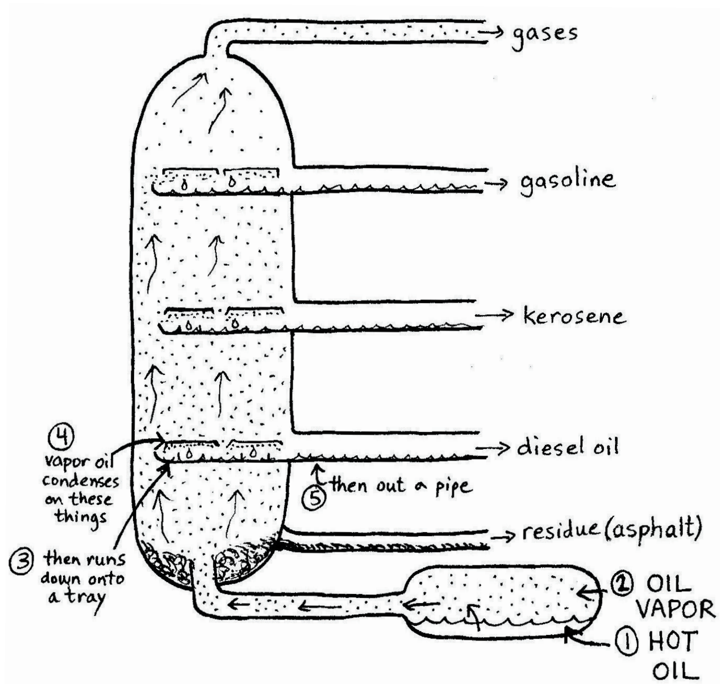
Number of carbons	Uses
1-4	natural gas (used for fuel)
5-12	gasoline, solvents
13-16	kerosene, diesel fuel, jet fuel, heating oil
17-20	lubricating oils
21--	paraffin, asphalt



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. (A world-wide flood would certainly have provided the right conditions for the formation of crude oil.) 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.

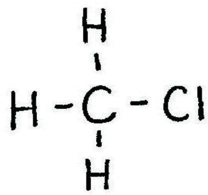
Crude oil is heated until it turns into vapor (at 350^0 C), then this vapor is pumped into the bottom of a very tall tube. The temperature is hot at the bottom, and cooler at the top. The longest hydrocarbon chains turn back into a liquid (condense) onto trays at the bottom of the tube and run into pipes.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

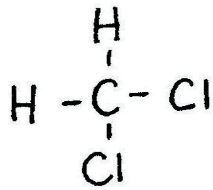


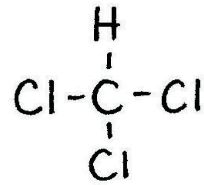
Cracking is a process by which they take medium-sized chains and break them into smaller pieces. (That's easy to remember!) Cracking is done by heating the medium-sized chains in the absence of air (and sometimes using chemicals called catalysts, which help the reaction occur). Cracking is often used as a way of producing extra gasoline, a substance which is always in demand.

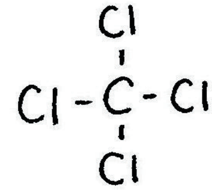
Two more ideas that we need to discuss in this chapter are chlorinated hydrocarbons and isomers. Let's tackle chlorinated hydrocarbons first.

As we mentioned in chapter one, carbon can bond with an 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

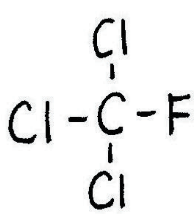

chloroform

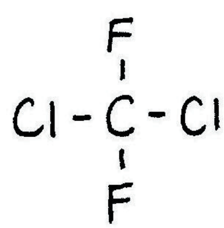

carbon tetrachloride

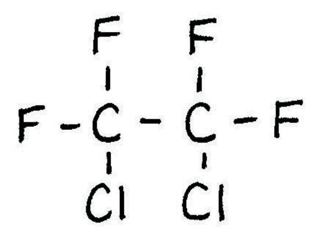
Methyl chloride is mainly used in making silicone substances (sealants, waterproofing materials, artificial body parts, Silly Putty). Methylene chloride is used as a paint remover. Chloroform started out as an anesthetic (putting you to sleep for surgery), but has now been replaced by safer substances. 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 (it did a great job!) and, unfortunately, its ability to destroy wildlife such as birds and reptiles (it did a great job at that, too!).

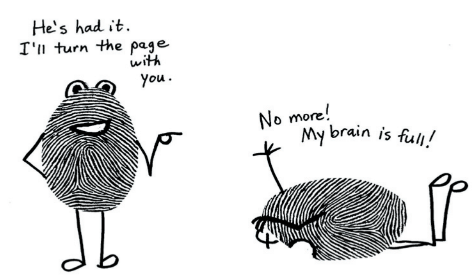
Carbon compounds can contain fluorine along with chlorine. The fluorine atom is in exactly the same state as the chlorine atom, with one unhappy, unpaired electron. Fluorine will gladly attach itself to a carbon.





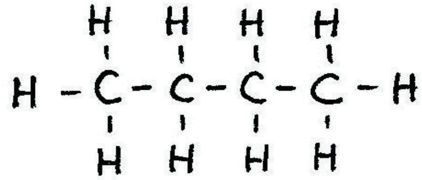


These molecules are called (no big surprise here…) chlorofluorocarbons, or CFC’s for short. They are used as propellants in aerosol spray cans. The CFC’s don’t hurt us directly because they don’t react chemically with anything. The problem with them is that they diffuse up into the atmosphere where they are changed into molecules that can damage the protective ozone layer in the atmosphere. CFC’s are no longer used in most countries.

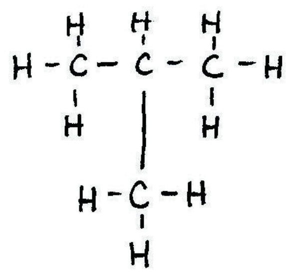


One last topic remains: ***isomers***. The name sounds strange, but the idea is very easy. Isomers are molecules with exactly the same number of atoms but in a different geometrical arrangement.

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

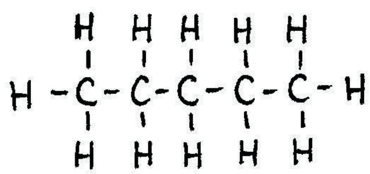


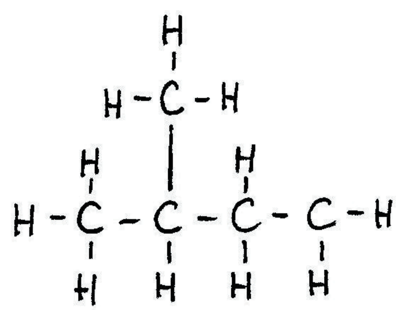
However, you could reshuffle the carbons a bit and make the molecule look like this:

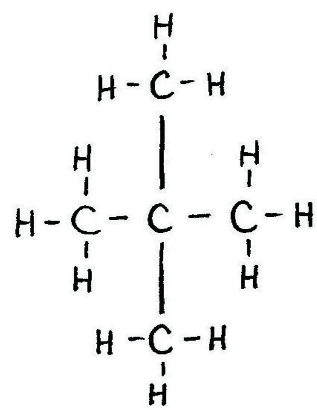


It is still C_4H_{10}, butane. To differentiate it from regular butane, scientists call this "isobutane," an isomer of butane.

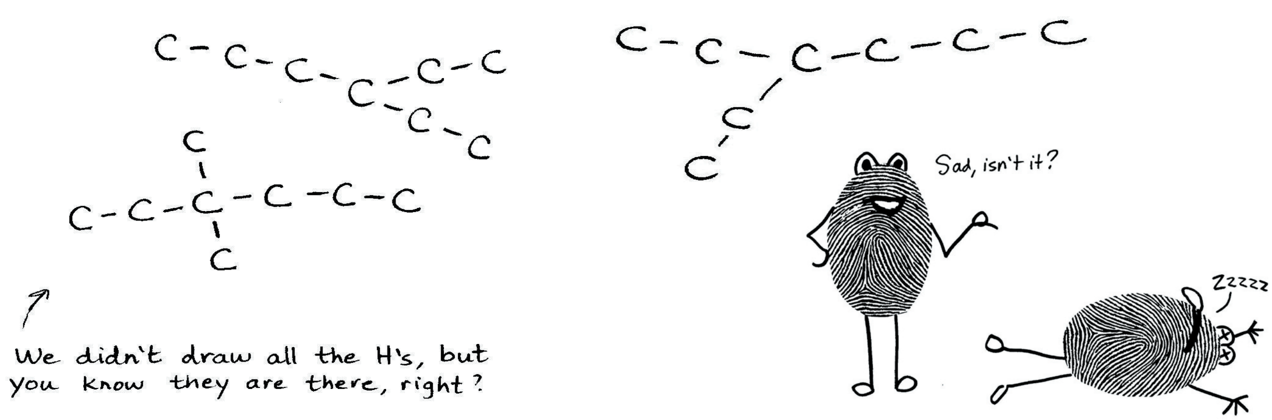
Here are three isomers of pentane, C_5H_{12}.







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?

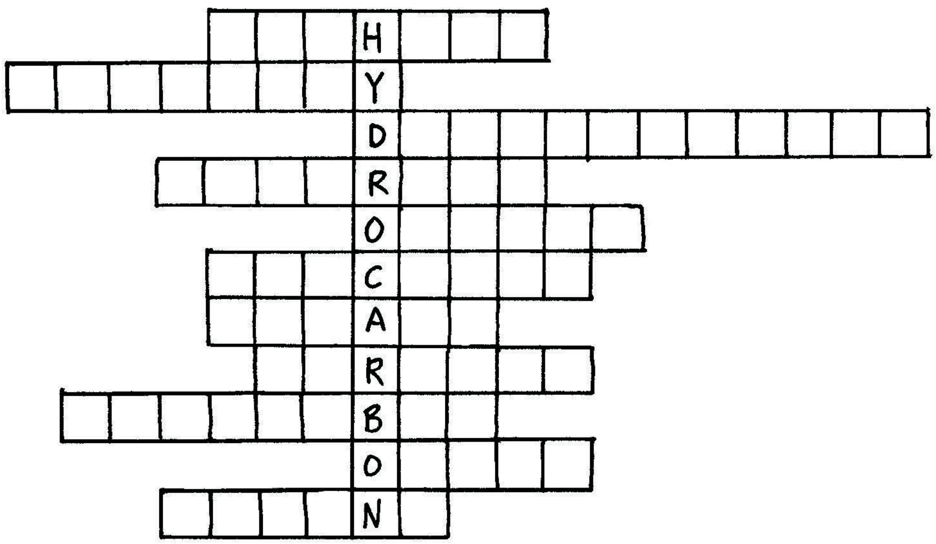
5) What famous scientist invented a safety headlamp for miners?

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