HOW TO BUILD MOLECULAR MODELS

The atom models have been added to the Gilbert Chemistry set in order to help you better understand the make-up of chemical substances and their relation to the formulas.

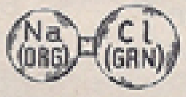
All matter which occurs naturally on the earth's surface can be broken down into one or more of about 92 different basic materials, called elements. These individual substances cannot be further broken down into anything more basic by ordinary chemical means. For example, ordinary table salt can be broken down into the two elements, sodium and chlorine. It is for this reason that it is also called sodium chloride.

Now each of the elements are known to be made up of very small units called atoms. They are so small they cannot even be seen with a microscope. A speck of dust contains an almost countless number of atoms. The atoms of a particular element are all the same, and at the same time, different from the atoms of any other element. Atoms are usually imagined as being somewhat rounded in shape and of different sizes for different elements. The models chosen for this set have also been made of different colors in order to help in recognizing one element atom from another, even though, in reality, it is not possible to associate color with an atom. The fact that the atom of one element is different from the atom of another element is illustrated by the different size and color of the beads, according to the following table.

TABLE I

Element	*Color Code*	*Chemical Symbol*	*Molecular Formula*
Carbon	Black	C	C
Oxygen	White	O	O_2
Sulfur	Yellow	S	S
Nitrogen	Blue	N	N_2
Chlorine	Green	Cl	Cl_2
Hydrogen	Red	H	H_2
Sodium	Orange	Na	Na
Calcium	Purple	Ca	Ca

If you wish to represent a molecule of sodium chloride, take a sodium atom model and join it to a chlorine atom model. Its formula is NaCl.

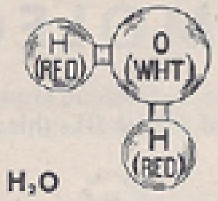
NaCl 

A molecule of a substance is the smallest unit of a substance that retains the chemical properties of that substance. It is made up of one or more atoms of the same or different elements. For example, a molecule of sodium chloride as you have seen, contains one atom of sodium and one atom of chlorine joined together. A molecule of sodium is just an atom of sodium itself, however, a molecule of the gases hydrogen, oxygen, nitrogen or chlorine, is two atoms of the element joined together. For example, if you take two of the hydrogen atom models and join them you have a hydrogen molecule. Its formula is written H_2.

H_2 

When there is more than one *atom* of a particular element in a molecule, the number present is indicated by a subscript indicating the number of atoms present. If you wish to symbolically indicate more than one *molecule* of a substance, then you indicate the number of molecules by putting the number in front of the symbol. For example, two molecules of hydrogen, H_2, would be $2H_2$. See if you can form the molecules for the other gases and write down their formulas.

Water has the formula H_2O. The chemical name is hydrogen oxide. In this case you see that the molecule contains two atoms of hydrogen and one atom of oxygen. It is known to have a shape something like that shown in the drawing.



H_2O

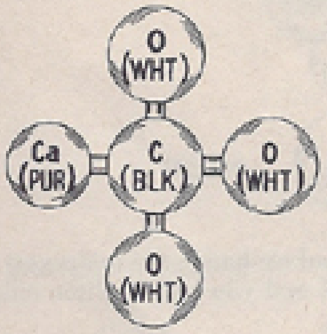
Water is known as a binary compound because it only has two kinds of atoms in its molecule.

Now that you see the general principle involved in making a representation of a molecule it should be possible for you to construct a model of many different kinds of molecules. Try making models for the following binary compounds.

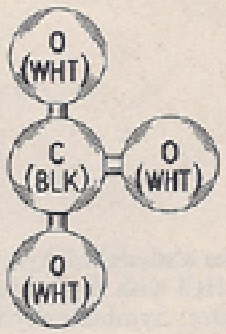
Sodium Oxide	— Na_2O
Sodium Sulfide	— Na_2S
Hydrogen Sulfide	— H_2S
Hydrogen Chloride	— HCl
Calcium Oxide	— CaO
Calcium Sulfide	— CaS
Calcium Chloride	— $CaCl_2$
Carbon Dioxide	— CO_2
Nitrogen Dioxide	— NO_2
Sulfur Dioxide	— SO_2
Methane	— CH_4
Ammonia	— NH_3

All the compounds thus far considered have been binary compounds. Let us consider compounds containing more than two elements, such as Calcium Carbonate, $CaCO_3$.

A model of such a molecule might look like this:



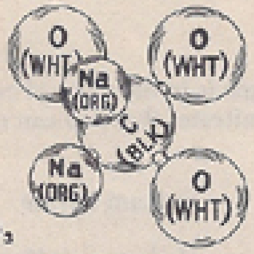
$CaCO_3$



(CO_3) Radical

This introduces us to what is known as chemical radicals, in this case the carbonate radical CO_3. These radicals have the property of retaining their form and identity in certain chemical reactions but do not have an existence independent of the compound or reaction. Other examples of compounds containing the carbonate radical are:

Sodium Carbonate	— Na_2CO_3
Carbonic Acid	— H_2CO_3
Sodium Bicarbonate	— $NaHCO_3$



Na_2CO_3

In an experiment in your Gilbert Chemistry Manual, solutions containing calcium chloride, $CaCl_2$, and sodium carbonate, Na_2CO_3, are mixed and a white solid (precipitate) appears. In effect, what has happened is that the sodium and calcium have exchanged places. That is, the 2 sodium atoms of the sodium carbonate, Na_2CO_3, changed places with the calcium atom of the calcium chloride, $CaCl_2$. Now the calcium carbonate which forms in this reaction is insoluble in water so it settles out in a solid form and leaves a solution of sodium chloride. Make up a model of calcium chloride, $CaCl_2$, and sodium carbonate, Na_2CO_3. Now exchange the calcium and sodium atoms. Now what molecule do you have and how many of each kind? The Chemist symbolizes what you have just done in the following way:

$$\underset{\text{1 molecule}}{Na_2CO_3} \overset{\text{(plus)}}{+} \underset{\text{1 molecule}}{CaCl_2} \xrightarrow{\text{(goes to)}} \underset{\text{2 molecules}}{2NaCl} \overset{\text{(plus)}}{+} \underset{\text{1 molecule}}{CaCO_3} \downarrow \text{(insoluble)}$$

The mixture of an acid and carbonate solution produces carbon dioxide. See experiments 2-22a and 2-43b or 2-43c in your Gilbert Chemistry Manual. For example, putting hydrochloric acid, HCl, and sodium bicarbonate, $NaHCO_3$ together, produces carbon dioxide, CO_2; water, H_2O; and sodium chloride, NaCl. Make up a model of HCl and $NaHCO_3$. Now by exchanging the sodium of the $NaHCO_3$ with the hydrogen of the HCl you have the NaCl and H_2CO_3. H_2CO_3 is unstable at normal temperatures and pressure, and breaks up into water, H_2O, and carbon dioxide, CO_2. The Chemist writes this symbolically as:

$$\underset{\text{1 molecule}}{HCl} \overset{\text{(plus)}}{+} \underset{\text{1 molecule}}{NaHCO_3} \xrightarrow{\text{(goes to)}} NaCl \overset{\text{(plus)}}{+} H_2CO_3$$

and

$$\underset{\text{1 molecule}}{H_2CO_3} \xrightarrow{\text{(goes to)}} \underset{\text{1 molecule}}{H_2O} \overset{\text{(plus)}}{+} \underset{\text{1 molecule}}{CO_2} \uparrow \text{gas}$$

or, combining both equations, we have:

$$HCl + NaHCO_3 \longrightarrow NaCl + H_2O + CO_2 \uparrow$$

One of the important facts to notice in the reactions we have represented thus far is that you end up with the same number of atoms after a reaction as you had before the reaction. The atoms are simply rearranged into different combinations. For example, if you were to represent the reaction of the acid with sodium carbonate, Na_2CO_3, instead of sodium bicarbonate, $NaHCO_3$, you would have to write:

$$\underset{\text{2 molecules}}{2HCl} + \underset{\text{1 molecule}}{Na_2CO_3} \longrightarrow \underset{\text{2 molecules}}{2NaCl} + \underset{\text{1 molecule}}{H_2O} + \underset{\text{1 molecule}}{CO_2} \uparrow$$

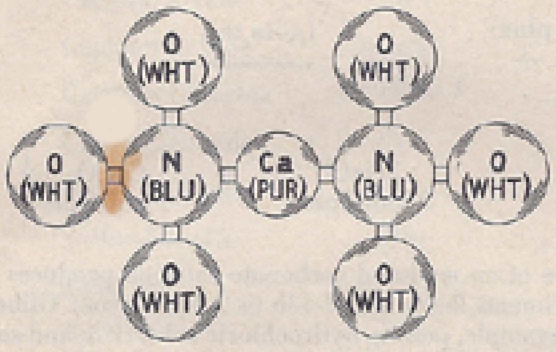
So you would have to make 2 molecules of hydrochloric acid to react with sodium carbonate in order to have enough hydrogen atoms to make the water molecule which forms in the reaction.

The principle just outlined is one of the most important fundamental principles in chemistry. That is, that all matter is conserved in a chemical reaction. There is only a rearrangement of parts (atoms).

So much for the carbonate radical. Other radicals retaining their identities in a chemical reaction are the sulfate, SO_4; sulfite, SO_3; and nitrate, NO_3, radicals. The sulfite and nitrate radicals look the same as the carbonate radical except that sulfur is in the place of carbon in the sulfite radical, and nitrogen is in the place of carbon in the nitfate radical. Examples of sulfites and nitrates that you can make with your models are:

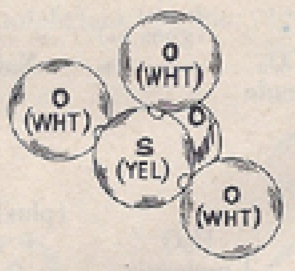
Na_2SO_3	Sodium Sulfite
H_2SO_3	Hydrogen sulfite or sulfurous acid
$CaSO_3$	Calcium sulfite
$NaNO_3$	Sodium nitrate
HNO_3	Nitric acid
$Ca(NO_3)_2$	Calcium nitrate

Notice that calcium has two nitrate radicals attached to it. Its model might look like this:



$Ca(NO_3)_2$

The sulfate radical, SO_4, we will consider to look like this:

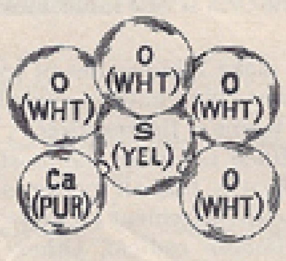


(SO_4)

Examples of sulfates that you can make with your models are:

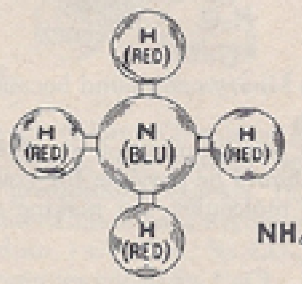
$CaSO_4$	Calcium sulfate
Na_2SO_4	Sodium sulfate
H_2SO_4	Hydrogen sulfate or sulfuric acid

According to the scheme to which the models in this set have been designed, calcium sulfate would look like this:



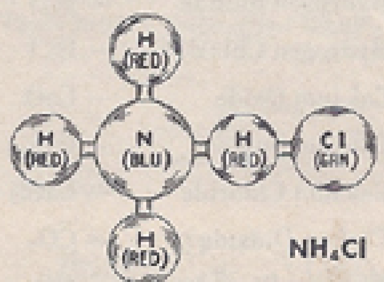
$CaSO_4$

One more radical of quite a different kind is the ammonium radical, NH_4. This radical may be said to look like this:



NH_4 (Radical)

When the ammonium radical is joined with chlorine in ammonium chloride, NH_4Cl, it would look like this:



NH_4Cl

Other examples of ammonium compounds are:

NH_4NO_3 Ammonium nitrate $(NH_4)_2SO_4$ Ammonium sulfate

$(NH_4)_2S$ Ammonium sulfide

See if you can make them.

One more radical of great importance in chemistry is the hydroxide, OH, radical. When this is present in a soluble compound it is said to be a base and is the part of a base which turns phenolphthalein pink. It is the chemical that will neutralize an acid because the hydrogen atoms of the acids join with the hydroxide of the bases to form water. An example of a base is sodium hydroxide, NaOH. Its model might look like this:

NaOH

Make a model of hydrochloric acid and exchange the hydrogen atom of the HCl with the sodium of the NaOH and you have sodium chloride and water. Symbolically this is written:

$$\underset{\text{1 molecule}}{HCl} + \underset{\text{1 molecule}}{NaOH} \longrightarrow \underset{\text{1 molecule}}{NaCl} + \underset{\text{1 molecule}}{H_2O}$$

The acid and the base have changed to a salt and water. Other hydroxides are:

NH_4OH Ammonium hydroxide $Ca(OH)_2$ Calcium hydroxide

Try putting acids with these and see what forms.

Now that you have the general idea of how to make Molecular Models, as you proceed with experiments in the manual you can represent some of the reactions involved. For example, in Experiment 3-29e the making of sulfur dioxide, SO_2, can be represented with your models. Symbolically the reaction is written:

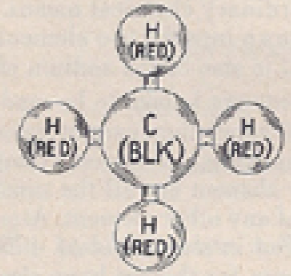
$$\underset{\text{1 molecule}}{NaHSO_4} + \underset{\text{1 molecule}}{NaHSO_3} \longrightarrow \underset{\text{1 molecule}}{Na_2SO_4} + \underset{\text{1 molecule}}{H_2O} + \underset{\text{1 molecule}}{SO_2}$$

You can show this with your models.

So far we have considered the class of compounds called inorganic compounds. There is another class called organic compounds, which have as their main constituents carbon and hydrogen.

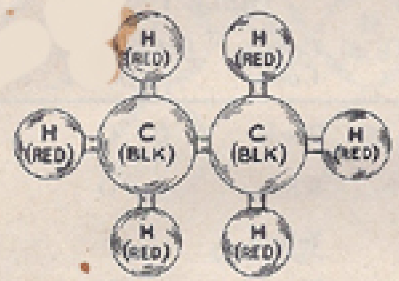
We will restrict our discussion here to a specific group, that is, the petroleum series and a few of their derivatives.

The first of this class is called methane, CH_4. Its model looks something like this:



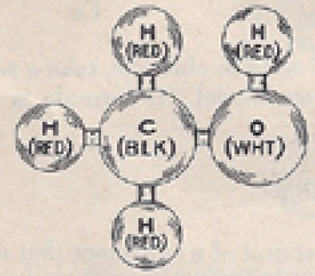
CH_4

The next in this series is ethane, C_2H_6, which looks like this:

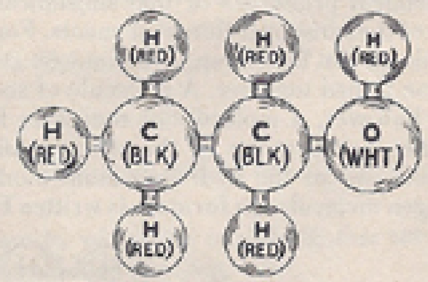


C_2H_6

Two common derivatives of these two molecules are methyl and ethyl alcohol.



CH_3OH



C_2H_5OH

Now that you see how the atom models may be used to build molecules, see if you can make up models of molecules other than those already mentioned. In order to include other elements recode your atoms as to color. For example if you wish to make up a strontium compound let your calcium atoms be the Strontium atom. Keep on going and have fun.

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Structure of the Atom

All elements are made up of atoms. Several elements, when joined together, form compounds. To better understand how this is made possible, we must know something about the structure of the atom.

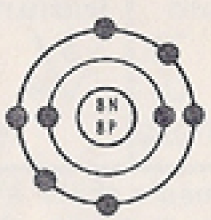
An atom is the smallest piece that an element can be broken into and still retain the character of the element. Each atom is divided into several parts, three of which will be considered here.

An atom can be thought of as a tiny solar system, much like the Sun with its planets revolving around it. The nucleus is made up of neutrons and protons. The protons have a positive electrical charge. The neutron has no charge and is equal in mass to the proton. The number of protons in the nucleus determines the number of electrons. The electron has a negative electrical charge and revolves or orbits around the nucleus. The mass of the electron is small compared to the nucleus.

Since the proton has a positive charge and the electron is negative, we can consider a normal atom to be neutral electrically.

The atomic number of an element is equal to the number of protons in its nucleus. The atomic weight is equal to the sum of the weights of the protons and neutrons in the nucleus. The weight of the proton is called a unit. Since an atom is too small to be weighed, scientists have developed a system of relative weights by comparison, using the element oxygen as a standard. Since oxygen has eight protons and eight neutrons in its nucleus, and eight electrons in orbit, its atomic number is eight and its atomic weight is sixteen. See Fig. 1.

Fig. 1.



OXYGEN

HYDROGEN

Fig. 3.

Hydrogen is 16 times lighter than oxygen, has one proton in its nucleus and one electron in orbit, therefore, its atomic number is one and its atomic weight is one. See Fig. 3.

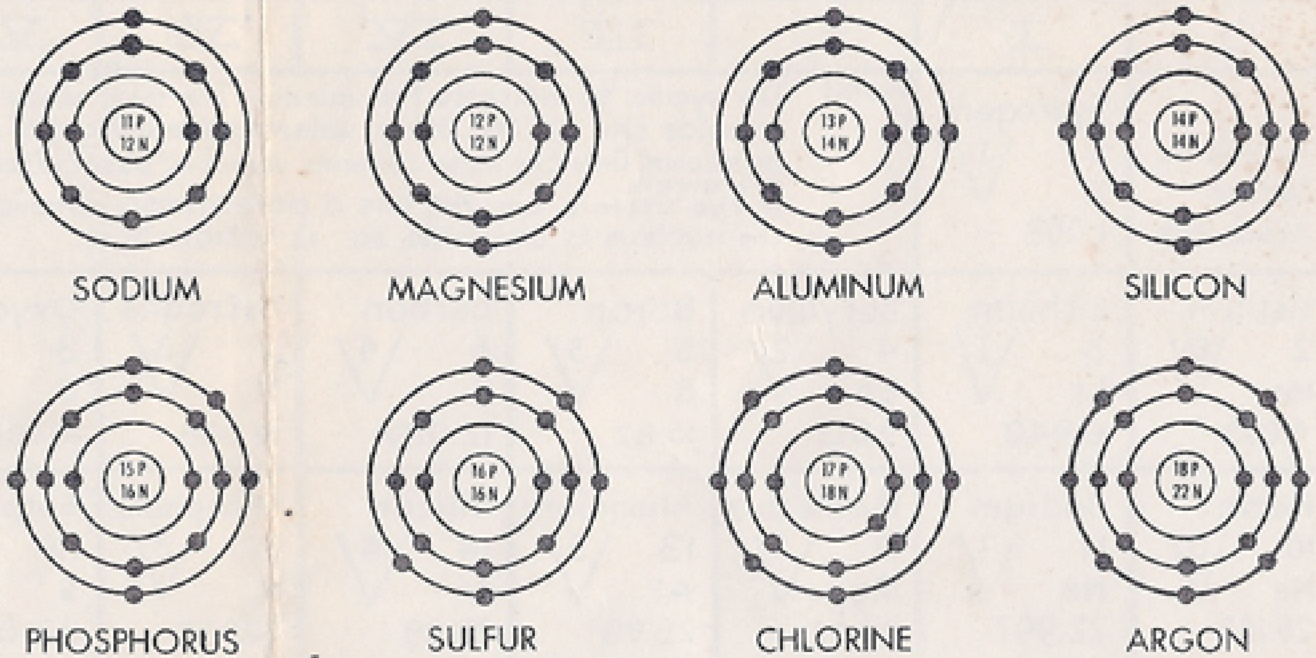


Figure 2

Sodium has 11 protons and 12 neutrons in its nucleus which gives it an atomic weight of approximately 23 and since it has 11 protons it follows that it has 11 electrons and its atomic number is 11.

The number of electrons in orbit around the nucleus determines the chemical properties of an atom and how it will react with other atoms. Therefore, there is a definite relationship between the chemical properties of an element and its atomic number.

The electrons orbit around the nucleus in shells or rings. These rings are designated by the letters K-L-M-N-O. Each ring can have a maximum number of electrons in it. The K ring can have 2 electrons, the L & M rings, up to 8, the N ring, up to 18 and O ring, up to 32.

Atoms with a full compliment of electrons are stable and, therefore, inactive or inert. Atoms with other structures tend to gain or lose electrons to form a stable structure. This causes chemical action to take place. The easier an atom gives or loses an electron the more active it is.

Atoms of elements can be arranged in groups and periods according to their atomic weights and numbers. An arrangement of this kind is called a periodic table of chemical elements. Such a table is printed on the reverse side of this sheet.

The ability of an element to combine with any other element is called valence. The elements listed vertically under group O on the chart, have a full compliment of electrons in the outer shell. They are considered to be inert and will not combine with any other element. Those in group I have a valence of one. Those in group II have a valence of two and so on.

Figure 2 shows a diagram of elements in Period Three starting with Sodium which has one electron in the third ring and ending with Argon, an inert gas, with a full ring of eight electrons. An example of how two elements combine to form the chemical compound is sodium chloride which is common table salt. Sodium chloride consists of chlorine and sodium. Sodium has one electron in the third or outer ring. Chlorine needs one more electron to complete its outer ring. Since sodium has only one electron in its outer ring it will tend to give up this electron quite easily. Chlorine which has seven electrons in its outer ring will have a tendency to gain an electron, when this occurs the two atoms combine to produce Sodium Chloride. Thus it follows that each molecule of sodium chloride consists of one atom of sodium and one atom of chlorine.

Due to the more complex nature of the electron structure at the higher atomic numbers the periods become longer and the possibility of more than one valence for an element arises, although the basic idea just outlined still applies. Notice that the beginning and end of each of the periods is still much the same chemically as in the shorter periods.

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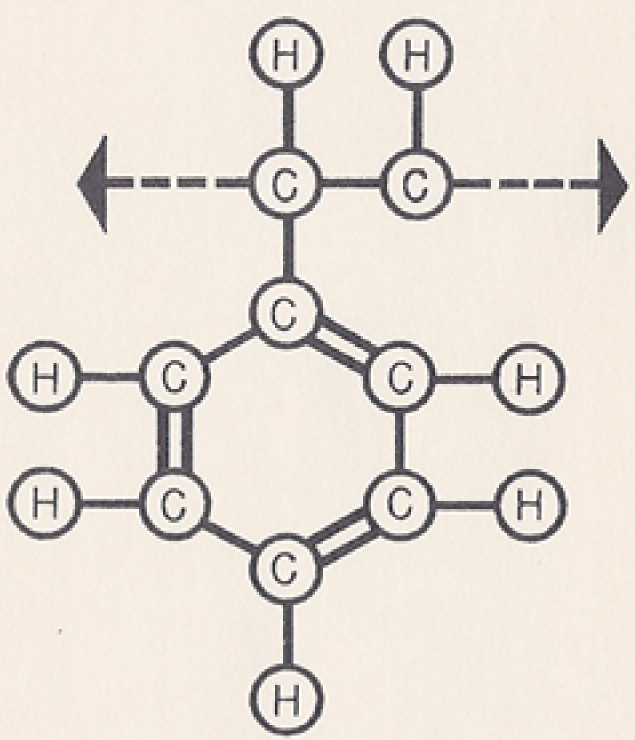
GROUP	O	I	II	III	IV	V	VI	VII	VIII		
PERIOD 1	Atomic No. Symbol Atomic Wgt	Hydrogen 1 H 1.008 ∨ 1	VALENCE — The symbol ∨3 indicates the valence. The most stable or common valence is inside the symbol. Other valences are indicated outside the symbol as shown. Only the more common valences associated with the element are given. If the atomic weight has a parenthesis around it, this means the nucleus is unstable so is radioactive.						RARE EARTH SERIES 58 Cerium Ce 59 Praseodymium Pr 60 Neodymium Nd 61 Promethium Pm 62 Samarium Sa 63 Europium Eu 64 Gadolinium Gd 65 Terbium Tb 66 Dyprosium Dy 67 Holmium Ho 68 Erbium Er 69 Thulium Tm 70 Ytterbium Yb 71 Lutetium Lu		
PERIOD 2	Helium 2 He 4.003 ∨ 0	Lithium 3 Li 6.940 ∨ 1	Beryllium 4 Be 9.013 ∨ 2	Boron 5 B 10.82 ∨ 3	Carbon 6 C 12.010 ∨ 4	Nitrogen 7 N 14.008 ∨ 3, 5	Oxygen 8 O 16.0000 ∨ 2	Fluorine 9 F 19.00 ∨ 1			
PERIOD 3	Neon 10 Ne 20.183 ∨ 0	Sodium 11 Na 22.997 ∨ 1	Magnesium 12 Mg 24.32 ∨ 2	Aluminum 13 Al 26.98 ∨ 3	Silicon 14 Si 28.09 ∨ 4	Phosphorus 15 P 30.975 ∨ 3, 5	Sulphur 16 S 32.066 ∨ 2, 6	Chlorine 17 Cl 35.457 ∨ 1, 5, 3			
PERIOD 4	Argon 18 A 39.944 ∨ 0	Potassium 19 K 39.100 ∨ 1	Calcium 20 Ca 40.08 ∨ 2	Scandium 21 Sc 44.96 ∨ 3	Titanium 22 Ti 47.90 ∨ 4, 3	Vanadium 23 V 50.95 ∨ 5, 4, 3	Chromium 24 Cr 52.01 ∨ 3, 2, 6	Manganese 25 Mn 54.93 ∨ 2, 7, 4	Iron 26 Fe 55.85 ∨ 3, 2	Cobalt 27 Co 58.94 ∨ 2, 3	Nickel 28 Ni 58.69 ∨ 2, 3
		Copper 29 Cu 63.54 ∨ 2, 1	Zinc 30 Zn 65.38 ∨ 2	Gallium 31 Ga 69.72 ∨ 3	Germanium 32 Ge 72.60 ∨ 4, 2	Arsenic 33 As 74.91 ∨ 3, 5	Selenium 34 Se 78.96 ∨ 2, 4, 6	Bromine 35 Br 79.912 ∨ 1, 5, 3			
PERIOD 5	Krypton 36 Kr 83.80 ∨ 0	Rubidium 37 Rb 85.48 ∨ 1	Strontium 38 Sr 87.63 ∨ 2	Yttrium 39 Yt 88.92 ∨ 3	Zirconium 40 Zr 91.22 ∨ 4	Columbium 41 Cb 92.91 ∨ 5, 3	Molybdenum 42 MO 95.95 ∨ 6, 3	Technetium 43 Tc (99) ∨ 7	Ruthenium 44 Ru 101.70 ∨ 3, 4	Rhodium 45 Rh 102.91 ∨ 3, 4	Palladium 46 Pd 106.70 ∨ 2, 4
		Silver 47 Ag 107.880 ∨ 1, 2	Cadmium 48 Cd 112.41 ∨ 2	Indium 49 In 114.76 ∨ 3	Tin 50 Sn 118.70 ∨ 4, 2	Antimony 51 Sb 121.76 ∨ 3, 5	Tellurium 52 Te 127.61 ∨ 2, 4, 6	Iodine 53 I 126.92 ∨ 1, 5, 3			
PERIOD 6	Xenon 54 Xe 131.30 ∨ 0	Cesium 55 Cs 182.91 ∨ 1	Barium 56 Ba 137.36 ∨ 2	Lanthanum 57 La 138.92 ∨ 3	Hafnium 72 Hf 178.60 ∨ 4	Tantalum 73 Ta 180.88 ∨ 5, 3	Tungsten 74 W 183.92 ∨ 6, 4	Rhenium 75 Re 186.31 ∨ 7, 4, 6	Osmium 76 Os 190.20 ∨ 4, 6	Iridium 77 Ir 193.10 ∨ 3, 4	Platinum 78 Pt 195.23 ∨ 4, 2
		Gold 79 Au 197.20 ∨ 1, 3	Mercury 80 Hg 200.61 ∨ 2, 1	Thallium 81 Tl 204.39 ∨ 3, 1	Lead 82 Pb 207.21 ∨ 2, 4	Bismuth 83 Bi 209.00 ∨ 3, 5	Polonium 84 Po (210) ∨ 2, 4	Astatine 85 At (211)	The elements of the 6Th period of atomic numbers between 57 and 72, called the rare earths, are seldom encountered and are not included in this table.-List is above.		
PERIOD 7	Radon 86 Rn (222) ∨ 0	Francium 87 Fr (223) ∨ 1	Radium 88 Ra (226.05) ∨ 2	Actinium 89 Ac (227) ∨ 3	Thorium 90 Th (232.12) ∨ 4	Protactinium 91 Pa (231) ∨ 5, 3, 4	Uranium 92 U (238.07) ∨ 6, 4	Neptunium 93 Np (237) ∨ 5	Plutonium 94 Pu (242) ∨ 4, 3	Americium 95 Am (243) ∨ 3, 4	Curium 96 Cm (243) ∨ 3

Read and study the back of this sheet.

POLYSTYRENE

ETHYLENE + BENZENE
(from petroleum) (from petroleum or coal)

The Styrene Building Block



RED PLASTIC

Kitchen Items

Wall Tile

Toys

Radio Cases

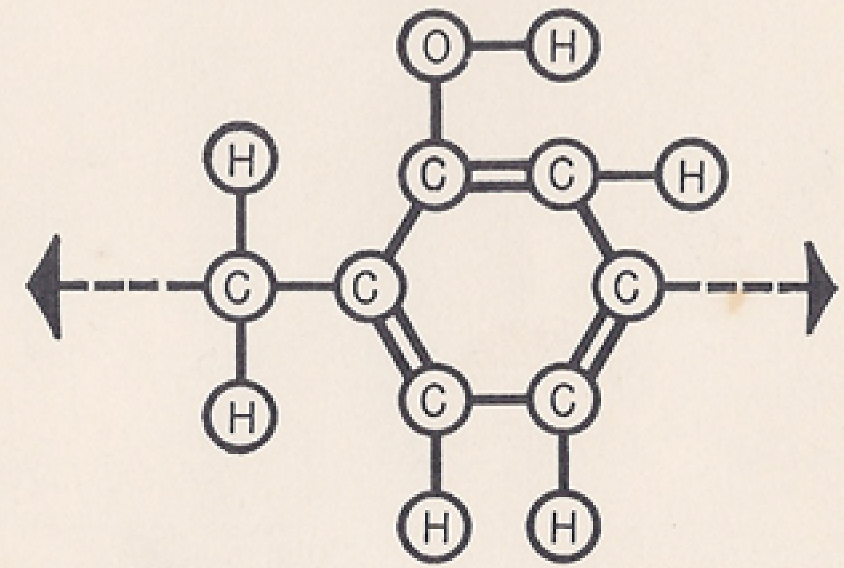
OUTSTANDING PROPERTIES

Hard and Rigid
Easily Molded (thermoplastic)
Good Electrical Insulator
Crystal clear or colored
Resists Water

Phenol-Formaldehyde

PHENOL + FORMALDEHYDE
(from coal or petroleum) (from coal and water)

The Phenol-Formaldehyde Building Block



BLACK PLASTIC

Used in the manufacture of
TV Cabinets Telephones Handles
Radio Cabinets Electrical Parts

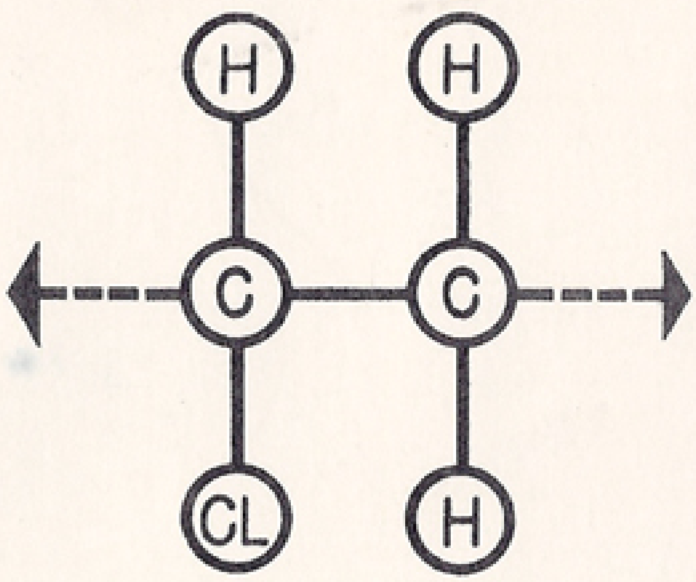
OUTSTANDING PROPERTIES

Hard, Strong and Rigid
Resists Heat Very Well (thermosetting)
Good Electrical Insulator

Polyvinyl Chloride

VINYL CHLORIDE
(from Hydrochloric acid plus coal and limestone or natural gas)

The Polyvinyl Building Block



GREEN PLASTIC

Used in the manufacture of

Wading Pools **Floor Tile** **Shower Curtains**
Garden Hose **Raincoats** **Wire Covering**

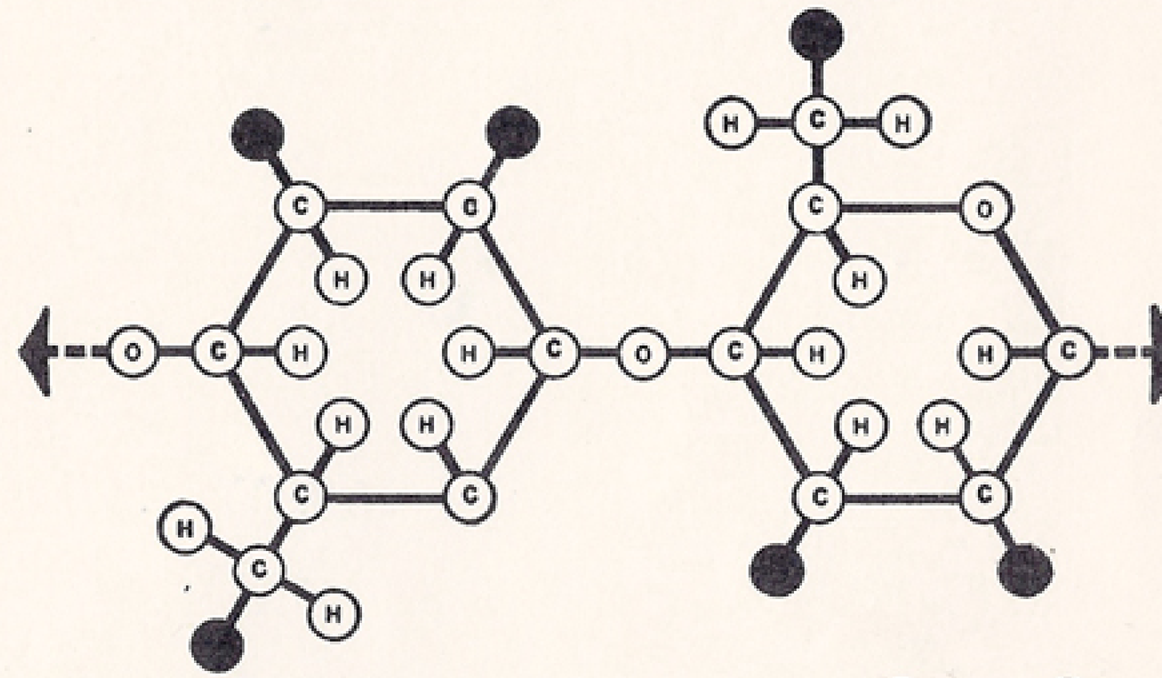
OUTSTANDING PROPERTIES

Tough and Strong
Can be Bent without Breaking (flexible)
Easily Molded (thermoplastic)

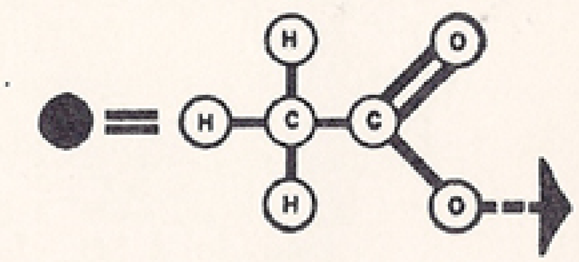
Cellulose Acetate

CELLULOSE + ACETIC ACID
(cotton) (from natural gas or coal + limestone)

The Cellulose Acetate Building Block



This shows structure of ACETATE molecule represented by solid black molecule.



BLUE PLASTIC

Used in the manufacture of:

Toys **Films** **Plastic combs** **Vacuum Cleaner Parts**

OUTSTANDING PROPERTIES

Very Strong and Tough **Electrical Insulator**
Beautiful colors or Clear **Easily Molded (thermoplastic)**

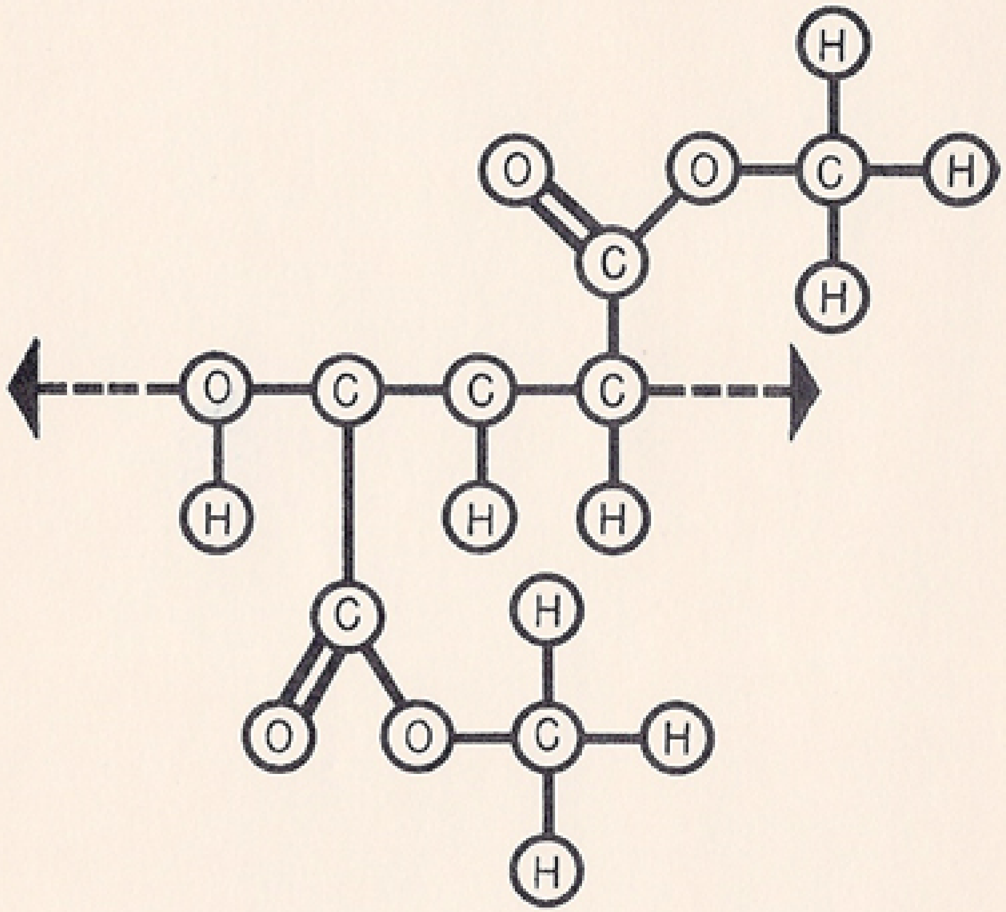
PLASTIC IDENTIFICATION CHART

METHACRYLATE

METHYL + ACRYLATE

(from coal, petroleum, air and water)

The Methacrylate Building Block



CLEAR TRANSPARENT PLASTIC

Used in the manufacture of

Lenses Salad Bowls Outdoor Signs
Airplane Windows

OUTSTANDING PROPERTIES

Very Clear
Strong and Rigid
Can Stand Sharp Blows
Resistant to Weather
Thermoplastic

PLASTIC IDENTIFICATION CHART

POLYETHYLENE

ETHYLENE

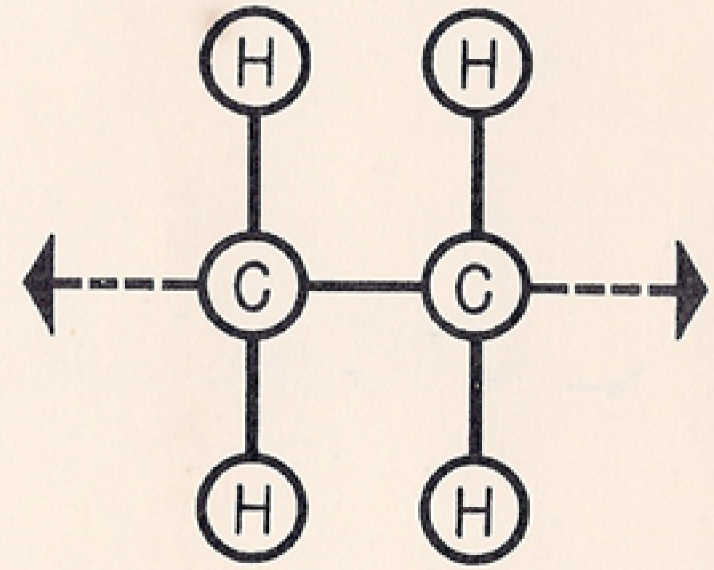
(from petroleum)

The Polyethylene Building Block

MILK WHITE PLASTIC

Used in the manufacture of:

Refrigerator Dishes
Pipe and Tubing
Wire Coating
Bags
Squeeze Bottles
Tumblers



OUTSTANDING PROPERTIES

Bends Easily without Breaking
Not Affected by Foods
Very Good Electrical Insulator
Thermoplastic