Chapter 4

The Salt-Formers

Introducing New Atoms

UNTIL NOW, I have been talking about organic compounds with molecules made up of only carbon and hydrogen atoms. Now it is time to introduce other kinds of atoms.

To begin with, there is a group of elements called the *halogens*. There are four important members of this group: *fluorine, chlorine, bromine,* and *iodine*. Fluorine is a pale-green gas, very poisonous and very active. In fact, fluorine is the most active chemical known. It will tear away at almost any molecule with which it comes in contact, substituting its own atoms for some of those already in the molecule.

Chlorine is a yellow-green gas, also active and poisonous, though less so than flourine. Bromine is a dark-red liquid and iodine is a slate-grey solid.[1]

Although these substances are poisonous in themselves, their atoms can form part of the molecules of non-poisonous compounds. An atom of chlorine, for example, will combine with an atom of sodium[2] to form *sodium chloride,* or *table salt*. Sodium chloride is certainly not poisonous. Quite the contrary. It is essential to life.

Fluorine, bromine, and iodine also combine with sodium and each forms a compound that has the appearance of salt. (These other "salts" are more or less poisonous, however.) The very word "halogen," in fact, comes from Greek words meaning "salt-former."

In organic compounds, the various halogen atoms behave

[1] You may be familiar with something called "iodine" which is a brown-red liquid. That is actually "tincture of iodine." It is iodine dissolved in a mixture of alcohol and water.

[2] *Sodium* is a soft, silvery metal. It is very active and is dangerous in itself but forms part of very common, useful compounds. A metal very like sodium which I will also have occasion to mention now and then is *potassium.*

much like hydrogen atoms. Like the hydrogen atom, each can form a bond with only one other atom.

The chemical symbols for fluorine and iodine are the initial letters of the names. Fluorine is symbolized as F, iodine as I. Unfortunately, we can't do the same for chlorine. The symbol, C, represents carbon. The symbol for chlorine must be something different, and it is Cl. The letter B is the symbol for the element, boron, so the symbol for bromine must be different. It is Br.

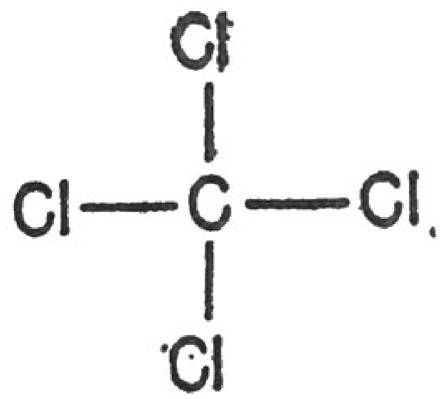
Most elements, as a matter of fact, have symbols made up of two letters. The first is generally the initial letter of the name (usually of the English name, sometimes of the German or Latin name). The second letter comes from the body of the name. The first letter is always capitalized; the second is always lower-case. The symbol for chlorine, for instance, is never CL or cl. It is always Cl.

Of the four halogens, chlorine is the most common and its occurrrence in organic compounds has been most studied.

Safe, but Dangerous

Let's begin with something simple. Suppose all the hydrogen atoms in a methane molecule are replaced by chlorine atoms, thus:

Figure 20—Carbon Tetrachloride



This is *carbon tetrachloride.* (The prefix "tetra" is from the Greek word for "four.") Sometimes the compound is called "carbon tet" for short.

Carbon tetrachloride is different from methane in some ways, thanks to those chlorine atoms. Methane is a gas at room temperatures, but carbon tetrachloride is a liquid. Hydrocarbons in general are only about four-fifths as heavy as water, but carbon tetrachloride is 1½ times as heavy.

The most important fact is this: as chlorine atoms replace hydrogen atoms, the compound becomes less inflammable. Carbon tetrachloride, with no hydrogen atoms in the molecule, will not burn at all. In fact, carbon tetrachloride is used in some kinds of fire extinguishers. When carbon tetrachloride is sprayed on a fire, the heat of the flame easily converts the liquid to a vapor.[8] This vapor is over five times as heavy as air so it doesn't blow away easily. It hugs the fire and keeps oxygen away. Since the carbon tetrachloride will not burn and will not support the burning of other substances, the fire must go out.

There is one catch, however, carbon tetrachloride vapors are quite poisonous. For this reason, using it as a fire-extinguisher in a poorly ventilated room is risky.

Carbon tetrachloride will mix with fatty substances as easily and quickly as hydrocarbons will. It, too, can be used as a dry cleaner and spot remover, and it frequently is. The most common trade-name for carbon tetrachloride dry cleaner is Carbona. Carbon tetrachloride is more expensive than petroleum ether or other hydrocarbon dry cleaners. But it has the great safety advantage of being non-inflammable, and can be used without fear of fire or explosion. However, you must remember that it is dangerous in another way. Watch out for the vapors. Make sure there is good ventilation when you are removing grease spots.

Not all the hydrogen atoms in methane need be replaced by carbon atoms. Suppose only three are, thus:

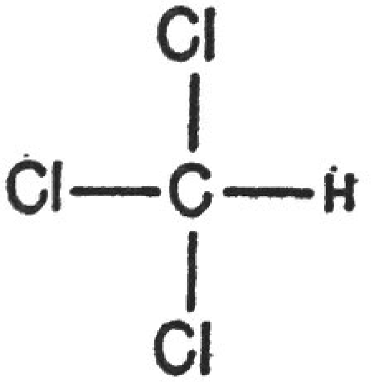


Figure 21—Chloroform

[8] Scientists use the *Centigrade scale* in measuring temperature. On this scale, the freezing point of water is zero degrees; written 0° C. Room temperature is about 25° C. and the boiling point of water is 100° C. The boiling point of carbon tetrachloride is 77° C. so you see that it will boil and become a vapor more easily than water will. Temperatures lower than the freezing point of water are written with a negative sign. Thus, methane boils at a

This is *chloroform,*[4] and it is perhaps the most familiar chlorine-containing compound, at least by name, to the general public.

Almost all of us have read adventure stories in which someone is knocked out by having a handkerchief soaked in chloroform forced over his or her nose. This is not just make-believe. Chloroform is a powerful anesthetic and has been used as such for over a century. A British physician, James Simpson, first used it on patients in 1847. Later on, he used it on Queen Victoria to ease the pains of childbirth for her. There was some opposition to this because a number of people thought that God meant human beings to suffer pain and that it was wicked to interfere with His plans. They quoted the Bible to prove this since in *Genesis* 3:16, God tells Eve: "In sorrow thou shalt bring forth childen."

However, Dr. Simpson pointed out that when God created Eve out of Adam's rib, He used a kind of anesthesia: "And the Lord God caused a deep sleep to fall upon Adam, and he slept: and he took one of his ribs, and closed up the flesh instead thereof." (*Genesis* 2:21.) This won the argument and the fact that Queen Victoria used anesthesia went a long way toward making its use respectable.

However, chloroform didn't remain respectable even if anesthetics in general did. Its great advantage over other anesthetics is that it is practically non-inflammable. Its great disadvantage is that it is quite poisonous, more so than most other anesthetics. Nowadays, it is practically never used if any other anesthetic is available. Doctors prefer to take the

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temperature 161 degrees below the freezing point of water and this is written −161° C. The common method of measuring temperature in this country is the *Fahrenheit scale.* Sometimes, for the sake of familiarity, I will put the Fahrenheit temperature in parentheses. Thus, the boiling point of water is 100° C. (212° F.) and the boiling point of carbon tetrachloride is 77° C. (171° F.).

[4] You may have noticed that I don't always tell you where the name of a compound comes from. Sometimes, I don't know myself; or I know but don't think the details are worth explaining. At other times, the name cannot be understood completely until other compounds are discussed later on in the book. This is true of chloroform and a few other compounds I have mentioned before this.

chance of explosions and fires rather than risk the damage chloroform might do to the patient.

Freezing Skin and Killing Bugs

Any hydrocarbon can have its hydrogens replaced by chlorine atoms. Ethane, for instance, can have one hydrogen atom in its molecule replaced by a chlorine atom. The resulting compound is *ethyl chloride*.[5]

Ethyl chloride is a low-boiling liquid. Its boiling point is only 13° C. (55° F.). This means that it is a liquid in winter and a gas in summer.

Doctors keep ethyl chloride in little vessels with narrow sealed tips to keep it from evaporating. When they want to use it, they open a special valve. The heat of the doctor's hand then turns some of the liquid into a gas and the gas pressure forces the rest of the liquid out through the valve in a fine spray.

This spray is directed onto a spot on the patient's skin where some minor infection requires a moment of surgery. The liquid boils at once as it touches the warm skin. It boils so quickly that it withdraws a great deal of heat from the skin.[6] The skin undergoes a kind of frost-bite, turns white, and loses all feeling temporarily. If the doctor then works quickly, before the skin has a chance to warm up again, he can cut into the infected area and do what needs to be done, with the patient feeling no pain. A substance that causes a part of the body to lose feeling without affecting the rest of the body is a *local anesthetic*.

Aromatic compounds can also contain chlorine atoms. A

[5] I have already said that methane minus a hydrogen atom is called a methyl group. The same can be said about any hydrocarbon. Ethane minus a hydrogen atom is an ethyl group. In the same way you can have a propyl group, a butyl group, an isobutyl group and so on.

[6] It takes heat to convert a liquid to a gas; that is, to make it evaporate. Put a drop of water on your skin and blow on it. Some of the water evaporates, taking the heat from your skin for the purpose. The skin under the drop of water will feel colder than the dry skin about it. If, instead of water, you use a liquid that evaporates more quickly, like carbon tetrachloride, your skin will feel still colder. Ethyl chloride carries things to an extreme.

molecule of benzene can contain a chlorine atom in place of one of its hydrogen atoms, or in place of all six for that matter. A benzene molecule minus one hydrogen atom is referred to as a *phenyl group*[7] and one minus two hydrogen atoms is a *phenylene group*. Therefore, a benzene ring with two chlorine atoms replacing hydrogen atoms at opposite ends of the ring is called *para-phenylene dichloride*.[8] (The prefix, "di," is from a Greek word meaning "two.") Para-phenylene dichloride is an *insecticide*; that is, an insect-killer.[9] The housewife is familiar with it these days since it has largely replaced naphthalene as the substance out of which mothballs or mothflakes are made.

A more famous insecticide is the compound familiarly known as *DDT*. This was first put out as an insecticide by a Swiss firm in 1942 and since World War II it has become very common. Insect sprays used in the house nowadays almost always contain this compound. (DDT is poisonous to humans as well as to insects so it must be used carefully. It is not as poisonous, however, as old-fashioned insect sprays that contained lead or arsenic. By 1947, however, houseflies were developing resistance to DDT and newer insecticides had to be used.)

The term DDT is an example of how people, even chemists, abbreviate the long chemical names of compounds when they have to use those names frequently. (It's like saying UN instead of United Nations or USA instead of United States of America.) A longer name for DDT is *dichlorodiphenyltri-*

7 You might expect it would be called a "benzyl group" but it isn't. A *benzyl group* is the name given to a molecule of toluene with one hydrogen atom missing from its side-chain. This doesn't sound logical, but I must admit that chemists are sometimes illogical and nothing can be done about it.

8 It can also be called *para-dichlorobenzene*, which is another logical name for it. It often happens that a chemical compound can be called by more than one name. Chloroform, for instance, could be called "trichloromethane." Chemists get used to this situation just as you do to hearing our country called "The United States," "America," "Columbia," and "Uncle Sam."

9 Insects aren't the only things we want to do away with. Mankind now makes use of chemicals to kill weeds, rats, and other forms of life that are harmful for one reason or another. Such chemicals are given the general name of *pesticide*.

chloroethane. Do you see where the abbreviation comes from? *D*ichloro*D*ipheny*T*richloroethane.[10] (In the last few years, more and more chemicals with complicated names are getting to be known by initials. The trend is going too far, perhaps, and some chemists are rather sarcastic about what they call "alphabet soup" names.)

You may feel quite satisfied with the initials. Why use the jawbreaker when the initials do just as well?

However, the name tells us something the initials don't. It tells us what the molecule looks like. The long name ends with "ethane" so we can start with the ethane molecule. It is "trichloroethane" so three of the hydrogen atoms of ethane must be replaced by chlorine atoms. (The prefix "tri" comes from a Greek word meaning "three.") The name further says that two other hydrogen atoms are replaced by chlorophenyl groups, which are benzene rings with one hydrogen atom missing and another replaced by a chlorine atom. So there you are.[11]

Do you wonder why it is important to know the formula?

Remember, it is only by knowing the formula that a chemist knows how to manipulate a compound properly. He can't change one substance into another unless he knows the formula; at least he can't do it intelligently. He can work by the hit-and-miss method, but that's very inefficient.

Some useful organic substances are *natural compounds;* that is, they are obtained from the tissues of some living

[10] One of the things that make chemical names look so complicated is the way they are always run together to form one long word. The name for DDT would look better to our eyes if it were written: dichloro-diphenyl-trichloro-ethane. However, until World War I, organic chemistry was almost entirely a German science. In the German language, words are often run together to make one long word and the Germans don't seem to mind at all. English and American chemists picked up the habit, alas, even thought this is not the way of the English tongue. Now it is too late to do anything about it.

[11] Actually, this is not the whole story. Which hydrogen atoms are replaced by chlorine atoms and which by chlorophenyl groups? The full Geneva name of the compound is: 1, 1, 1-trichloro-2, 2-(*bis*-p-chlorophenyl) ethane. A name such as this may look horrible but it describes the chemical formula at a glance to the chemist. With a little practice it would do the same for you.

organism; or from the action of some living organism on its surroundings; or from the remains of some once-living organism. Other organic substances do not exist in nature, but are manufactured by chemists. These are *synthetic compounds.* (The word "synthetic" comes from two Greek words meaning "put together.") DDT is an example of a synthetic compound.

Our daily life now depends on thousands of synthetics. (Think how an insecticide like DDT helps increase our food supply by killing insects that feed on our crops; how it cuts down the death rate from diseases like malaria and typhus which are carried by insects.)

As another example, consider *Saran.* This is a synthetic compound which is seen most often as a thin, transparent film. It is sold in rolls and is used in the kitchen to wrap food, cover dishes, and so on. It is made of long-chain molecules like polyethylene except that every other carbon atom is bonded to either one or two chlorine atoms. Still another example is *Neoprene,* an artificial rubber. This consists of a hydrocarbon chain with a chlorine atom attached to every fourth carbon atom. It is built up from a compound like isoprene but with a chlorine replacing the branched carbon atom. This compound is called *chloroprene.*

Synthetics such as these are built up purposely by chemists who know how to force atoms together in some particular pattern. They must also have a good idea, in advance, of what kind of properties such a pattern is likely to have. This cannot be done without considerable knowledge of the atomic structure of organic molecules.

So it is all very well to use names like DDT or Saran. Most of us don't need to know any more than that. Still, there must always be some people who know the full name that goes with the initials or with the trade-name, and what it means structurally, or all of us will be the worse for it.

Refrigeration and Hospital Smell

It is only rather recently that useful compounds containing fluorine have been developed. The most familiar is *dichlorodifluoromethane,* which is better-known under the trade-name

Freon. As you can tell from the chemical name, the molecule of Freon consists of methane with all four hydrogen atoms replaced, two by chlorine atoms and two by fluorine atoms.

Freon is a *refrigerant*; that is, it can be used to keep things colder than the surrounding temperature. A substance, to be used as a refrigerant, must be a gas which can easily be made liquid by pressure. (Its boiling point must not be too far below 0° C., in other words.)

If such a substance is put through pipes under pressure, so that it is liquid, and the pressure is then removed, the liquid turns into a gas. In so doing, it removes heat from whatever it is in contact with. (This is similar to the way in which evaporating water cools the skin, or evaporating ethyl chloride freezes it.) The gas is liquefied and allowed to evaporate over and over again. Heat is removed and removed and removed (and carried away either by the air or by running water). In this way, the contents of a refrigerator, of a room, or even of a large box-car can be kept well below room temperature, or even well below freezing.

The ordinary liquids used for this purpose are the inorganic compounds, ammonia (boiling point, —33° C.) or sulfur dioxide (boiling point, —10° C.). Both are quite cheap and are still used in large industrial refrigerating equipment. In smaller units, such as home refrigerators, or room air-conditioners, it is Freon that it being used more and more. Its boiling point is —28° C.

Although more expensive than the inorganic refrigerants, Freon has several very important advantages. Ammonia and sulfur dioxide have very irritating and unpleasant odors and are quite poisonous. An accidental leak in the freezing coil would be most unpleasant and could be fatal. Furthermore, both ammonia and sulfur dioxide will corrode many metals. Freon, on the other hand, is odorless, non-poisonous, and non-corrosive. Unlike most organic compounds, it is completely non-inflammable so that we are spared even the danger of fire and explosion.

Organic compounds that contain fluorine show promise for the future. Chlorine, bromine, and iodine are rather large atoms and they sometimes can't replace all the hydrogen atoms in an organic compound. If they try, they get in their own way. Fluorine, however, takes up little room in a molecule. (In fact, the only atom that takes up less room is the hydrogen atom.) For that reason, it can easily replace all the hydrogen atoms. Compounds made up of carbon atoms and fluorine atoms only are called *fluorocarbons.*

Fluorocarbons are much more stable than the hydrocarbons. They are less affected by chemicals or by heat. They won't dissolve in water and will hardly dissolve in anything else. Long fluorocarbon chains can be made into interesting plastics. One such has been prepared by Dupont under the trade-name, *Teflon.* It is also called *Fluon.* It is unaffected by the strongest acids or by heat up to 325° C. It is also an excellent electrical insulator.

Fluorocarbons of different types are now coming into use as artificial rubbers, as lubricants and as fire extinguishers. They are also placed in cans under pressure, so that upon release, they can force out whip cream, shaving soap or any of dozens of other articles.

The most important hydrocarbon containing bromine is *ethylene dibromide.* This is a two-carbon compound with a bromine atom attached to each carbon atom. Ethylene dibromide is added to leaded gasoline to take care of the lead. Ordinarily, the lead atoms in the burning gasoline would settle out in the engine and ruin it. With ethylene bromide around, lead atoms combine with the bromine atoms to form lead bromide. At the temperature of the working engine, lead bromide turns to vapor. It is expelled through the exhaust and the lead atoms are gone.

A compound with a more old-fashioned use is *iodoform.* This is a yellow solid that has a certain ability to kill germs. In other words, it is a mild *antiseptic.* At one time, doctors used iodoform freely to dust on wounds and bandages. Iodoform has a strong odor and hospitals and doctors' offices used to smell strongly of it. It is the "hospital smell" many people remember. Partly because of this odor, iodoform has gone out of fashion. Another reason is that other and better ways of guarding against infection have been discovered.