

## Chemical Compounds

On the preceding pages, we got to know the characteristics of the **elements**. Now we shall look at the conditions under which these combine to make chemical **compounds**. Based on what has already been said, it is clear that the elements only combine with one another when there are very fixed weight relationships, so that for example two parts of hydrogen always unite with sixteen parts of oxygen to form water. Only after long efforts by means of most careful examinations did chemists gain insight into the fact that in every compound the components are always and in every circumstance in the same quantitative relationship to one another. At the end of the last century, it was still thought that the quantitative relationship between the components in a compound depended on the amount of the elements used, so that if we mixed a large amount of hydrogen with a relatively small amount of oxygen and let both substances unite to form water, the water produced contained more hydrogen than if we had done it the other way around.

But now we know with certainty that all the components of a compounded substance are always in the same quantitative relationship to one another, that this relationship cannot be changed no matter what the conditions under which the respective substance is produced. And we also know that the amount of every element contained in the most varied compounds must always be according to its atomic weight, for example that in any compound oxygen can only be present with sixteen parts or with a multiple of sixteen parts (2 x 16, 3 x 16, etc.).

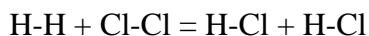
But what are the conditions under which chemical compounds are produced? Before we discuss the various conditions, it must be said first that a compound or any chemical change in any substance is only possible when the molecules of these substances can come into very direct contact with one another. When solid objects are mixed, such a contact between the molecules hardly takes place, or if it does, this occurs to a very insignificant extent. Even when the solid substances that are supposed to have a chemical effect on one another are mixed together in the form of extremely fine powder, the individual grains of powder are much too far away from one another to make molecular contact possible. The force of chemical attraction works in a very different way to that of the attraction of masses. Even though it decreases with increasing distance, the force of the latter radiates at any distance, whereas the chemical attraction of the atoms to one another absolutely does not work over a distance, but only when the atoms can come absolutely close to one another. Now they can only fulfill this condition when the molecules are very mobile, which means nothing other than that the substances that are supposed to affect one another are mixed in a liquid or gaseous state.

This knowledge is so old that already in the Middle Ages the alchemists said: “*corpora non agunt nisi fluida*” – only in a liquid state can substances affect one another chemically.

Among the chemical changes in the broadest sense, we must distinguish above all: 1) the creation of new substances from the components of the same, the formation of substances, **synthesis**, and 2) the dismantling of substances into their components, the **analysis**. The production of compounds out of the elements and the dissolution of the compounds into the elements contained in them are to be considered special cases of these two forms of chemical change.

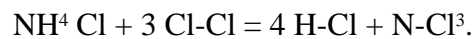
In most cases, the production of compounds from the elements is only successful at higher temperatures, on condition that at least one of the components is in a liquid or gaseous state. Higher temperature is nothing other than the molecules' more intense state of oscillation and as we can now add, that of the atoms within the molecules. And it seems that everywhere, the higher temperature is greatly conducive to moving the atoms to new molecules, which is to say to forming new substances. The further away two elements are from one another in the groupings shown in the above table, the easier it is for them to combine to a compound. Thus chlorine already unites at normal temperatures with all metals and with the elements in the first group, sodium, potassium, rubidium, cesium while producing fire. But chlorine also combines directly with most non-metals such as sulfur, selenium, tellurium, phosphorus, arsenic and antimony (with the latter three also while producing fire), however not with oxygen, nitrogen, carbon, although compounds of chlorine with these elements can be produced indirectly.

This peculiarity that compounds can be produced from some elements indirectly but not directly is easy to understand if we look at the essence of the chemical processes in somewhat greater detail. As we know, chlorine combines directly with hydrogen forming hydrochloric acid. The chemical process for this unification becomes most clear when we base it on the following chemical formula:



That is to say that one molecule of hydrogen enters into interaction with one molecule of chlorine. As soon as these molecules come into close contact with one another under appropriate conditions, which is to say at a high temperature or in sunlight, the force of attraction of the chlorine atoms to the hydrogen atoms comes into play. Now the hydrogen atoms in the hydrogen molecules and the chlorine atoms in the chlorine molecules attract one another. But since the force of attraction of the chlorine atoms to the

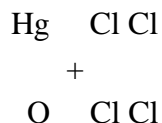
hydrogen atoms is greater than the mutual attraction of the chlorine atoms and the hydrogen atoms among themselves, the hydrogen atoms as well as the chlorine atoms are torn away from one another. Following the greater force, they mass together into new molecules in such a way that one chlorine atom sticks to one hydrogen atom respectively and is thus transformed into a molecule of hydrochloric acid. If however we were to assume that the force of attraction of the chlorine atoms to the hydrogen atoms were not as great as the sum of the forces of attraction between the hydrogen atoms on the one hand and the chlorine atoms on the other, a changeover of the atoms to form hydrochloric acid molecules would of course be impossible. Chlorine would not be able to combine directly with hydrogen. Nevertheless, by a simple thought process, we can imagine that a connection between both elements would occur immediately if we succeeded in bringing together not the hydrogen **molecules** and the chlorine molecules, but the individual hydrogen **atoms** and the chlorine molecules. Let us choose a correct example right away. We learned above that chlorine cannot combine directly with nitrogen, that is to say, when we bring nitrogen molecules and chlorine molecules together, the atoms do not move to form new molecules, because the force of attraction between the nitrogen atoms and the chlorine atoms is not great enough to overcome the mutual attraction between the nitrogen atoms in the nitrogen molecules and at the same time that of the chlorine atoms in the chlorine molecules. But if we place chlorine in an ammonium solution, the compound nitrogen chloride is formed. The ammonium is  $\text{NH}_4\text{Cl}$ . As soon as three chlorine molecules meet one ammonium molecule, the following change occurs:



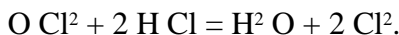
That is to say, because of the strong force of attraction between the chlorine atoms and the hydrogen atoms, above all hydrochloric acid will strive to form. But that is only possible if the four hydrogen atoms in the ammonium are torn away from the nitrogen atom; one of them remains united with the chlorine atom and the other three strive to unite with three chlorine atoms. In the same way, in order to form hydrochloric acid, the chlorine atoms in three chlorine molecules respectively are torn apart; thus we have for an instant one free nitrogen atom on the one hand, and on the other, three free chlorine atoms that are now able to unite, since there are no other forces of attraction that need to be overcome.

With all chemical changes, the unification of two elements with one another is much easier if these elements meet the moment they are freed from another compound, so the moment they are present as free atoms, not as complete molecules. This moment is called the state of birth, the *status nascens*. The following are instructive examples of how capable the elements are to unite with one another as soon as they are in the “state of birth”.

There is very little force of attraction between chlorine and oxygen. There are no conditions under which these two elements can unite directly. But if we conduct chlorine gas through mercury oxide (HgO), the strong relationship between chlorine and mercury becomes apparent, since chlorine combines very easily with all metals; so first of all mercury chloride is produced. In this way, the oxygen is freed, and in the “state of birth” it unites with the chlorine, which by the way is also in the “state of birth”, as can be seen in the following formula:

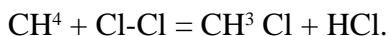


The two atoms of chlorine that are freed from two chlorine molecules unite with the freed oxygen atom to become chlorine oxide. But this chlorine oxide is so unstable that it is immediately dismantled by hydrochloric acid. Its oxygen thereby unites with the hydrogen of the hydrochloric acid to become water, thus producing free chlorine molecules:



Moreover, we are not able to make chlorine unite directly with carbon. Nevertheless, we can produce a very large number of chlorine compounds containing carbon.

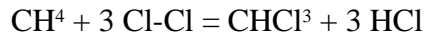
Because carbon has the value of four (C), carbon’s simplest hydrogen compound is that which contains four hydrogen atoms to one carbon atom, CH<sup>4</sup>. This is a gas that is found in coal mines and that at times causes violent explosions there; it is called methane. If this gas mixed with chlorine gas is left in sunlight, hydrochloric acid is formed. For every molecule of hydrochloric acid that is produced, one atom of chlorine is freed, which in turn immediately unites with the carbon that has a free force of attraction because an atom of hydrogen has torn away; the carbon then fills this freed force of attraction with the chlorine atom. Because the process of forming hydrochloric acid is a slow one, we are able to interrupt it at every point, and in this way we can produce a series of carbon compounds with chlorine that at the same time still contain hydrogen. Thus, from one molecule of methane and one molecule of chlorine, is formed first of all one molecule of hydrochloric acid and simply chlorinated methane:



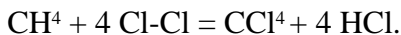
From one molecule of methane and two molecules of chlorine, doubly chlorinated methane is produced:



When three molecules of chlorine gas are used, triply chlorinated methane is produced, which is the well-known chloroform that can be produced more easily by other means:



Only when four molecules of chlorine are used with one molecule of methane, all four hydrogen atoms in the methane unite with four chlorine atoms and a free carbon atom is produced, which unites with the other four chlorine atoms from the four chlorine molecules:



This digression will occupy us again later, because it gives us deep insight into the causes of chemical changes. But now let us return to our topic. We saw above that chlorine is able to unite directly with almost all elements. Of course this unification occurs according to the value of the various elements. Thus, other than hydrogen, all the elements in the first group listed in the preceding table will unite with 35.5 weight units, with one atom of chlorine; one atom of the elements with a value of two will unite with two chlorine atoms, etc. However, only in relatively few cases will we produce the chlorine compound of any element through the direct effect of the chlorine on the respective element. Thus, nobody would think of making larger amounts of sodium chloride, for example, by conducting chlorine gas through sodium metal. Nature gives us such enormous amounts of sodium chloride in rock salt and in salt water that we will only use the already formed sodium chloride, at most purifying it first. In addition, we will also not make chlorine compounds with most metals in this way. The chlorine metals are salts, and all salts can be produced by bringing together the base, that is the metal hydrate or the metal oxide, and the acid, which in our case is the hydrochloric acid. So we will only make use of the possibility of producing chlorine compounds by uniting chlorine with another element when no other way is available to us or when this method is the easiest. Thus, we do produce the chlorine compounds with sulfur, selenium, tellurium, phosphorus and arsenic and finally with the precious metals gold and platinum by means of this method.

Bromine behaves exactly like chlorine and iodine is almost the same. It is not necessary to discuss in detail the production of these elements' compounds; what was said above about chlorine is also true for them.

When used in a dry state, oxygen does not unite with any other element at normal temperatures. On the other hand, at a higher temperature it is able to combine with almost all elements. With many elements, this unification occurs while producing such great heat that it is enough to warm a small part in order to bring about the unification of the whole mass, usually while producing light. We say that such elements are combustible. For what we call the **combustibility of a substance** in ordinary life is nothing other than the ability of the same to combine easily with the oxygen in the air while developing great heat even to the point of giving off light. "Hydrogen is combustible" means nothing

other than this: if we heat a small part of hydrogen to the point of glowing by bringing it into contact with a burning candle, so with an extremely hot object, the heated part unites with the oxygen in the air that is in its direct vicinity. By means of this chemical process such great heat is in turn produced that the hydrogen flowing in afterwards is also heated immediately to the point of glowing and thus also becomes able to unite with the oxygen in the air surrounding it. Thus, if we produce hydrogen by means of zinc and sulfuric acid or by any other means, then let it flow through a pipe into the air and bring it into contact with a glowing hot object, the hydrogen will be set on fire and burn as long as there is still oxygen present with which it can combine. The amount of heat produced by one gram of burning hydrogen is so great that it can heat 34,000 grams of water by one degree; hydrogen produces 34,000 units of heat when burned. If we mix hydrogen (two volumes) and oxygen (one volume) and heat only a very small part of the mixture to glowing point by letting an electric spark go through it, the unification of all of the hydrogen with the oxygen occurs in an almost immeasurably short time with tremendous energy, while developing such great heat that an extremely violent explosion takes place with a deafening bang because of the sudden expansion of the gas (resulting from the great increase in heat). That is also why a mixture of hydrogen and oxygen [oxyhydrogen] has been called [in German] *Knallgas* ["bang gas"].

In the same way, coal for example burns up because as soon as it is heated to glowing point, it easily combines with oxygen while developing great heat. Here again it is only necessary to warm a small part of the coal to glowing point, because the neighboring parts are warmed by means of the heat developed through the unification of this part of the coal with the oxygen, and thus they also become able to combine with the oxygen until finally the whole mass of coal begins to burn. As everyone knows, we use the heat developed by burning coal, which is to say by means of the unification of coal with the oxygen in the air, exclusively as our source of heat in daily life, to heat rooms, to cook our food, for various commercial purposes, etc.

Because burning objects in the air is so important for our daily life, we want to look at this more closely. As was already mentioned, it is only the oxygen in the air that makes the burning of combustible substances possible. But since our atmosphere consists of only about 1/5 oxygen and on the other hand of 4/5 nitrogen, and because the latter has no part in the burning of objects, it is clear that all combustible substances burn with far greater energy in pure oxygen than in ordinary air. For in air a large part of the heat produced by burning is used to heat the large mass of nitrogen that is there.

Moreover, it is easy to perceive great differences in the way various objects burn. Some objects, as for example hydrogen, sulfur and others, burn with a bluish flame that hardly

glows; others such as petroleum, oil etc. burn with a flame that glows strongly and even produces soot; yet others such as charcoal etc. burn without any flame. Whence these differences? First of all it should be mentioned that when coal burns, the compound of one atom of carbon with two atoms of oxygen is always produced,  $\text{CO}_2$ , a compound that has been given the not entirely appropriate name of carbonic acid gas.

Here, the first principle is that all objects that burn with a flame are gaseous when they reach burning temperature, so in the strong heat that results from the burning and that causes them to glow. For then the entire ascending column of gas begins to burn at the same time, and such a burning column of gas is called a flame. Thus, not only hydrogen that is already gaseous at ordinary temperatures, but also sulfur, phosphorus, etc. burn with a flame because these substances become gaseous at high temperatures. Among our ordinary types of fuel, only coal burns without a flame, because even in the highest temperatures that we are able to produce, carbon does not pass into a gaseous state. All the other fuels that we use partly for heating, partly to give light, are compounds of carbon with hydrogen and in many cases of carbon with hydrogen and a little oxygen. Burning occurs when both the carbon and the hydrogen combine with the oxygen, one atom of carbon with two atoms of oxygen forming carbonic acid gas (carbon dioxide), and two atoms of hydrogen with one atom of oxygen producing water. Many of our fuels already contain oxygen, though always far less than is required to form carbon dioxide with all the carbon and water with all the hydrogen contained in them. But because of this, the more oxygen they already contain, the less they will need from the air. Similarly, it is easy to understand that the heat produced through burning will be all the less, the more the burning object already contains oxygen, and vice versa. Now all the carbon compounds that we use in our daily life for burning pass into the gaseous state at high temperatures (some of course while being radically decomposed); consequently, they all burn with a flame. Only when wood and hard and brown coal are burned, which are not at all pure types of coal, a decomposition occurs at high temperatures in such a way that coal itself is produced along with gaseous compounds. Thus, these fuels first burn with a flame, and when only the coal is burning, finally without a flame. But all carbon compounds decompose into their elementary components, carbon and hydrogen, in a flame that has an extremely high temperature, while the oxygen that is present forms both carbon dioxide with part of the carbon and water with part of the hydrogen, both of which escape as gas. Oxygen from the surrounding air only reaches the area of the flame bit by bit, so that gradually the freed carbon and hydrogen can also burn. Now if the burning object contains relatively little carbon, the small amount of freed carbon will very quickly find enough oxygen to unite with it and form carbon dioxide. But if the burning object is rich in carbon, part of the latter will find a sufficient amount of oxygen in the flame to combine with it only after some time. Thus, this part of the extremely fine

solid particles of excreted carbon will have to remain unburned for some time in the area of the flame, and during this time it will become so hot from the flame's high temperature that it glows white. We will thus get a flame that is filled with glowing white solid particles, and the flame thereby becomes **glowing white**. If we hold a cold object such as a porcelain dish into the flame, we can easily recognize that in fact our glowing flames owe their glowing simply to the carbon particles that are floating in them. The dish rapidly becomes covered with soot, and the soot is nothing other than coal. The more coal particles are in the flame, the greater will be the flame's glow. But if the flame contains too many coal particles, these latter cannot burn in the time they need to float upwards, because not enough air gets to the flame to give a sufficient amount of oxygen for the burning. Then a more or less large part of the coal particles leaves the flame's region unburned and the flame is sooty. Up to a certain limit, we can prevent the flame producing soot by making a strong draft so that as much fresh air as possible reaches the flame. An example of this is our petroleum, which causes quite a lot of soot when it burns; but by surrounding the flame with a cylinder it can be made to burn without soot. The cylinder is meant precisely to bring about a strong draft.

If we look more closely at the ordinary flame of a candle (**Figure 56**), we will notice first of all how the stearin that is melting because of the radiating heat of the flame draws upwards in the wick; then we will see that around the dark point of the wick there is an area that is not glowing and that is surrounded by a white glowing "cloak". This white glowing cloak carries the flame's glow strength, but it in turn is surrounded by a quite thin cover, a bluish layer that burns without glowing. It will not be difficult to understand this phenomenon if we remember that the candle's stearin is first being changed into the gaseous state. The interior dark cone surrounding the end of the wick contains the gaseous stearin. Inside this cone, burning does not occur; there is no air inside it, which is to say no oxygen that enables burning to take place. The air that causes the burning is in the glowing cloak into which it penetrates from the surroundings. The main burning occurs inside this glowing cover; here, the temperature is so high that the gaseous stearin decomposes into its elementary components, carbon and hydrogen, while at the same time the oxygen contained in the stearin produces water and carbon dioxide from part of the hydrogen and carbon. Part of the excreted carbon begins to glow white in this region of the flame and causes the latter to glow, while another part of it burns up. Now as we saw, the product brought forth by carbon when burned is carbon dioxide. But when carbon dioxide comes into contact with glowing coal, it is transformed into carbon monoxide (CO). So since the conditions are present, carbon monoxide must be produced in the flame's glowing area. But as soon as this carbon monoxide leaves the real area of the flame, it comes into contact with superfluous air while it is still burning hot and it



burns with a blue flame. The thin cloak burning with a blue light that surrounds the flame's glowing core is nothing other than burning carbon monoxide.

As was mentioned above, our ordinary fuels only burn with a glowing flame because the carbon that is excreted at the flame's high temperature does not find oxygen fast enough to burn immediately when it is excreted. Accordingly, the idea suggests itself to try and see if by giving more air, we could succeed in taking away all light from an otherwise glowing flame or even from one that produces soot while burning.

In fact, quite a while ago Bunsen already solved this problem in the simplest way possible by not lighting our coal gas directly, but rather by first mixing it with air and then burning it. The gas lamps that were named after him have the form shown in **Figure 57** and can be dismantled into two parts (**Figure 58**). The coal gas flows through the extension pipe **A** into the lower part of the lamp and then out of the small round opening **c** into the pipe **B**. The pipe surrounding the point **c** where the gas flows out has two openings **O**. Through the upwards flow of the coal gas, air is sucked through these openings into the pipe **B**. The air is mixed with the coal gas, and when we light the mixture flowing out of the pipe's upper opening, it burns with a blue flame that does not glow. Such flames that do not glow are used to heat objects, since they obviously do not leave any soot (coal) on the cold object. That is why our common gas cookers are constructed in this way (**Figure 59**). The gas flows through the extension pipe **A** and the small opening **c** into the pipe **B**, which has two holes **O** where **c** is, so that the air going through the holes **O** into the pipe **B** can mix with the gas. The mixture exits from the plate **D** that is full of holes and when it is lit, it burns with a bluish flame that does not glow.

In order to understand the daily occurring phenomena, it was necessary to discuss in some detail the processes that take place when elements unite with oxygen. Having done so, we can now be brief as regards the creation of compounds from the other elements.

At higher temperatures, **sulfur** combines directly with almost all elements. In particular, it easily combines with metals, and the heavy metals are so very important because, from among very many valuable metals, they are almost the only compounds from the respective metals that nature offers us. Most of the valuable ores are sulfuric metals, and their transformation into the metals themselves, their smelting usually occurs by heating, roasting them in the open air, for in this way they are burned up. Sulfur is burned up by uniting with two atoms of oxygen and thus forming  $\text{SO}_2$ , the so-called sulfurous acid which is used to produce sulfuric acid, while the roasting transforms the metals

themselves into metal oxides. The roasted ores, so the metal oxides, are then soldered together with coal. The coal thereby combines with the oxygen in the metal oxides forming carbon dioxide or carbon monoxide, and the metal is freed.

**Nitrogen** is characterized by the fact that it can only combine directly with very few other elements and even then only at high temperatures. As regards the ability to combine directly, it is perhaps the most indifferent element. The elements that are close to nitrogen, **phosphorus**, **arsenic** and **antimony** combine directly with oxygen, with the halogens (chlorine, bromine, iodine) and with the metals, but not with hydrogen, although hydrogen compounds with all three elements are well known. Carbon and silicon finally really only unite directly with oxygen. Almost all metals, finally, can combine with one another; the compounds that are thus created of course maintain the elements' metallic nature and their characteristics situate them between the components of which they consist. The metal compounds among themselves, which are always produced by melting the components together and which in most cases are nothing other than solutions of the one metal with the other without being in a constant compound relationship, are called **alloys**. Metal alloys play an outstanding role in commerce. Thus precious bronze is nothing other than an alloy of copper and tin; common bronze, which is now used for crafts, the *cuivre poli*, is an alloy of copper and zinc; the so-called nickel silver is an alloy of copper, zinc and nickel. All of our silver and gold utensils are alloys of these precious metals with copper, and in fact our coins contain one part copper to every nine parts precious metal, while the silver and in particular gold utensils contain far more copper. It is interesting that until a very short time ago, the marking of how much precious metal our utensils contain came from long lost medieval systems of weighing. Thus the content of silver in silver utensils was calculated according to the old *mark*, which corresponded to about 250 grams. The mark was formerly divided into 16 *lot* [between 15.5 and 16.6 grams], and the stamp on the utensils (12) said that the amount of silver used is "twelve *lot*", which is to say that in every mark there were 12 *lot* of silver and 4 of copper to every 16 *lot* of the alloy; thus the mixture consisted of  $\frac{3}{4}$  silver and  $\frac{1}{4}$  copper. Gold utensils are based on an even older system of weighing; it is also the mark of course, but at a time when it was not yet divided into 16 *lot* but into 24 karats, and until most recently the gold content of a utensil was indicated by saying how many karats of pure gold were contained in one mark of the alloy used for the utensil. 14-karat gold is gold consisting of 14 parts gold and 10 parts copper (all together 24 parts = 1 mark).

Of all the elements, carbon is the most interesting. In spite of its inability to combine directly, it is capable of forming an incalculable number of compounds, and stands out precisely because it is the most integrating component, the basic element in all substances

that bear organic life, plant and animal bodies. Precisely carbon is so basic an element in all the substances forming organisms that carbon compounds in general have been called organic compounds. Already in ancient times it was possible to separate quite a large number of substances contained in the plant and animal world from these compounds, thus bringing them into a pure state. But only in our century have we been able not only to study the composition of these compounds, not only to separate a very large number of new substances from plant and animal bodies, not only to produce by chemical means a number of new compounds from the substances given us in organic nature, but above all to show that we are capable of reproducing artificially, by purely chemical means, a large part of the substances that are formed by nature in the life process of plants and animals. In addition, we have succeeded in putting the many thousands of substances into a system that is simple and easy to understand, so that with little effort we are able to recognize them and to explain how they came to be. At the start of being able to separate the organic substances and to determine their composition, attempts were also made to produce them artificially, but of course without success at first. The experiment's lack of success was not blamed on our own inability nor on the fact that the conditions for their coming into existence were not known and therefore could not be obeyed, but rather it was assumed that a mysterious force, the **life force**, was at work in nature. This of course was not available to us in our laboratory work and it would forever prevent us from creating out of the elements the substances produced by nature with the help of this life force. Much thinking and work were wasted in search of this life force, and as was already mentioned above, Galvani also believed that his experiment with frog legs that became so famous was a manifestation of the life force. But on the day that saw the success of making an organic compound out of inorganic substances, the assumption of a mysterious life force also disappeared, and the credit of having brought down this barrier to free research goes to a German chemist, Friedrich Wöhler. Wöhler made artificially a compound that is produced in animal organisms and that can be found in the urine of animals, the so-called urea. Since then, various organic substances have been made artificially, and gradually a clear notion has developed that will be discussed on the following pages and that allows us in many cases to recognize the nature of a substance from its composition and vice versa.

Starting with the simplest carbon compounds, it was discovered that almost all changes undergone by organic substances through chemical means, whether these be produced in the organisms of the plant and animal world through the life process or in the chemist's laboratory, can be interpreted in a simple way by assuming that every carbon atom has the value of four. That is to say, it is assumed that one carbon atom is capable of binding to itself four atoms of one element or of various elements with the value of one, two atoms of elements with the value of two, etc. Moreover, it is assumed that precisely

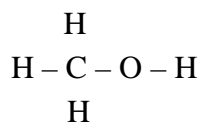
carbon has to a high degree the characteristic that two or more atoms bind one another with part of their four powers of attraction so that what remains is available to bind itself to other elements.

Let us explain this by means of a few examples. One carbon atom can unite with four hydrogen atoms to produce the compound  $\text{CH}_4$ , and in the same way it can attract four chlorine atoms to form the compound  $\text{CCl}_4$ . With four bromine atoms, carbon can make the compound  $\text{CBr}_4$ , and with four iodine atoms the compound  $\text{CJ}_4$ . However, it is also clear that one carbon atom can bind three hydrogen atoms and one chlorine atom, as well as two hydrogen atoms and two chlorine atoms, one hydrogen atom and three chlorine atoms, so that the compounds  $\text{CH}_3\text{Cl}$ ,  $\text{CH}_2\text{Cl}_2$ ,  $\text{CHCl}_3$  are produced. Instead of chlorine, the compound can contain bromine or iodine for every atom, and if for the present we look only at the four elements with the value of one, hydrogen (H), chlorine (Cl), bromine (Br), and iodine (J), we reach an imposing number of compounds that are not only possible but that have almost all been produced:

1.  $\text{CH}_4$ ; 2.  $\text{CCl}_4$ ; 3.  $\text{CBr}_4$ ; 4.  $\text{CJ}_4$ ; 5.  $\text{CH}_3\text{Cl}$ ; 6.  $\text{CH}_3\text{Br}$ ; 7.  $\text{CH}_3\text{J}$ ; 8.  $\text{CH}_2\text{Cl}_2$ ;
9.  $\text{CH}_2\text{Br}_2$ ; 10.  $\text{CH}_2\text{J}_2$ ; 11.  $\text{CHCl}_3$ ; 12.  $\text{CHBr}_3$ ; 13.  $\text{CHJ}_3$ ; 14.  $\text{CH}_2\text{ClBr}$ ;
15.  $\text{CH}_2\text{ClJ}$ ; 16.  $\text{CH}_2\text{BrJ}$ ; 17.  $\text{CHCl}_2\text{Br}$ ; 18.  $\text{CHClBr}_2$ ; 19.  $\text{CHCl}_2\text{J}$ ; 20.  $\text{CHClJ}_2$ ;
21.  $\text{CHBr}_2\text{J}$ ; 22.  $\text{CHBrJ}_2$ ; 23.  $\text{CHClBrJ}$ ; 24.  $\text{CCl}_3\text{Br}$ ; 25.  $\text{CCl}_2\text{Br}_2$ ; 26.  $\text{CClBr}_3$ ;
27.  $\text{CCl}_3\text{J}$ ; 28.  $\text{CCl}_2\text{J}_2$ ; 29.  $\text{CClJ}_3$ ; 30.  $\text{CBr}_3\text{J}$ ; 31.  $\text{CBr}_2\text{J}_2$ ; 32.  $\text{CBrJ}_3$ ; 33.  $\text{CCl}_2\text{BrJ}$ ;
34.  $\text{CClBr}_2\text{J}$ ; 35.  $\text{CClBrJ}_2$ .

In all these cases, four atoms of elements with the value of one are united with one carbon atom with the value of four. But instead of four atoms of elements with the value of one, two atoms of elements with the value of two, such as oxygen and sulfur, can combine just as well with one carbon atom, so that we get the compounds  $\text{CO}_2$  (which is the well known carbon dioxide),  $\text{CS}_2$  (that is, the carbon disulphide that is greatly used in commerce), or finally  $\text{COS}$ , so a substance that saturates the carbon atom's four affinities by means of two affinities of an oxygen atom and two affinities of a sulfur atom. But the variation becomes very much greater when we take into consideration that the four powers of attraction in the carbon atom can be partly replaced by elements with the value of one and partly by elements with the value of two, so that compounds such as  $\text{CH}_2\text{O}$ ,  $\text{CH}_2\text{S}$ ,  $\text{CCl}_2\text{O}$  and  $\text{CCl}_2\text{S}$ , etc. can also exist. Finally, elements with the value of three can also be united with carbon, though of course with one carbon atom only if one atom of an element with the value of one is combined at the same time, thus for example the nitrogen in the compounds  $\text{CHN}$  (which is the well known hydrocyanic acid),  $\text{CClN}$ ,  $\text{CBrN}$ ,  $\text{CJN}$ , etc.

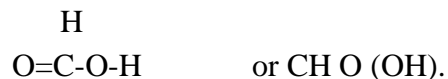
In spite of the great variety of compounds containing a carbon atom and that can come about like the cases seen so far, we have only become acquainted with a small fraction of the carbon compounds that actually exist, the molecules of which contain one C. For aside from the fact that a considerable number of compounds that are theoretically possible have so far not been produced, we now know a little about several hundred such objects. This at first glance somewhat remarkable fact can be easily understood if we take into consideration that elements with a value of two or more can also be combined with the carbon by only one affinity while they saturate the rest of their affinities with other elements. Thus, as can be seen from the following schema, oxygen can be united with carbon by one force of attraction, and its second force of attraction can be satisfied by a hydrogen atom:



Precisely such compounds, which we can abbreviate by writing  $\text{CH}^3$  (OH),  $\text{CH}^3$  (ONa), are the most important ones. We shall now elaborate on some of them.

Already the compound  $\text{CH}^3$  OH is highly interesting. Aside from the fact that it is possible to produce it artificially though indirectly, it is formed along with many other products when wood is heated. It is contained in the fluid that floats on wood tar, which consists mainly of water and is called wood vinegar because of its high content (about 6 %) of acetic acid, and it has been given the name wood spirit. It is very similar to ordinary spirit, alcohol, and is therefore also called an alcohol (methyl alcohol); it is now used often for the denaturization of spirit.

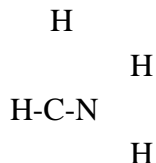
Moreover, an acid that is frequently present in nature is the compound containing only one hydrogen atom combined with a carbon atom, and in addition one oxygen atom with its two affinities and a second oxygen atom with one affinity, so that the latter's second affinity is saturated by one hydrogen atom – as becomes visible in the following schema:



It can be found first of all in ants and has been called formic acid. This is also the substance contained in stinging nettles, which gives them their well known characteristic of causing small wounds that burn and form blisters on the skin. It is present in a quite concentrated form in the large red ants, and these have so much of it that formic acid was formerly extracted from them. Still today “ant spirit” is sometimes produced by distilling red ants with diluted alcohol. If we let these ants walk over blue litmus paper, they draw red lines on it.

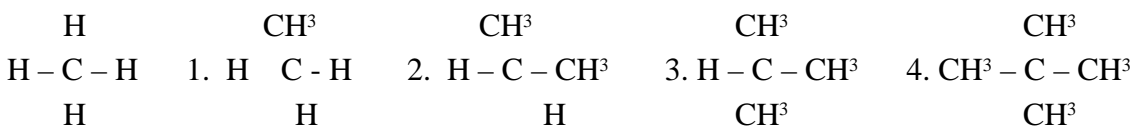
Corresponding to the oxygen compounds mentioned there are sulfur compounds that contain sulfur instead of oxygen.

Just as the oxygen with a value of two can be bound to a carbon atom with one affinity if its second affinity is saturated by means of an element with the value of one, nitrogen with the value of three can also be bound to carbon with one affinity if its other two affinities are neutralized by other elements, for example hydrogen. Thus we would get a compound



or  $\text{CH}^3 (\text{NH}^2)$ . We see immediately that this compound is nothing other than ammonia  $\text{NH}^3$  in which the one hydrogen atom has been replaced by a carbon atom, the other three affinities of which have been filled with hydrogen. And in fact this compound still has all the characteristics of ammonia.

In these few examples, we can already see the great variety in the composition and of course also the characteristics of the compounds containing one single carbon atom in their molecules. And yet this number is very small compared to the incalculable number of substances whose molecules contain more than one carbon atom. We saw above that in methane  $\text{CH}^4$ , one hydrogen atom can be replaced by elements having a value of more than one (on condition that the other forces of attraction in these elements with a value of more than one are also saturated). Now if we use carbon itself as one such element having a value of more than one, according to our experience so far, we can hardly doubt that one hydrogen atom in the methane can be replaced by one carbon atom whose other three affinities are saturated by something else. The simplest example is that the carbon atom's three affinities are saturated by means of hydrogen atoms and that this group of atoms  $\text{CH}^3$  joins the methane's C instead of the individual hydrogen atoms in the methane. We would then arrive at the following four compounds, which by the way are all known:



The compound 1 consists of two carbon atoms and six hydrogen atoms and could therefore also be written more briefly as  $\text{C}^2 \text{H}^6$ ; the compound 2 consists of three atoms C and eight atoms H and can be written  $\text{C}^3 \text{H}^8$ ; the compound 3 consists of four C and ten H, so is  $\text{C}^4 \text{H}^{10}$ ; finally, compound 4 is  $\text{C}^5 \text{H}^{12}$ .

The atom group  $\text{CH}_3$ , which can replace one hydrogen atom extraordinarily often in organic compounds, has been given the name methyl. We can therefore call the compound  $\text{C}^2 \text{H}^6$ , which we can also write as  $\text{CH}_3 \text{CH}_3$ , methylated methane or dimethyl; the compound  $\text{C}^3 \text{H}^8$  is doubly methylated methane, the compound  $\text{C}^4 \text{H}^{10}$  is triply methylated methane, etc.

These compounds consist only of carbon and hydrogen and are therefore called hydrocarbons; in each of them, the hydrogen atoms can be replaced by any other elements in the same way as we saw for methane. So the compounds that are produced from these hydrocarbons by replacing the hydrogen atoms with other elements are far more numerous than those compounds that are derived from methane and contain only one carbon atom in their molecules. And this already high number is increased considerably by the fact that compounds with completely different characteristics can have the same components. That is to say that they can contain the same elementary components in the same quantity. The following two examples can serve as an explanation.

If two hydrogen atoms in the dimethyl  $\text{CH}_3 \text{CH}_3$  are replaced by two chlorine atoms, this exchange can occur both in a methyl, so that there is only one H left in it while the second methyl remains whole, thus resulting in the compound  $\text{CH}_3 \text{CHCl}_2$ . Or the two chlorine atoms can join each of the carbon atoms instead of one H each; then two H would remain with each carbon atom, and the result is the compound  $\text{CH}_2 \text{ClCH}_2 \text{Cl}$ . These two compounds  $\text{CH}_3 \text{CHCl}_2$  and  $\text{CH}_2 \text{ClCH}_2 \text{Cl}$  are exactly the same in their composition. They both contain 24 weight units (two atoms) of carbon, four weight units (four atoms) of hydrogen, and 71 weight units (two atoms) of chlorine per molecule. They can both be expressed by the symbol  $\text{C}^2 \text{H}^4 \text{Cl}^2$ , but because the atoms are not distributed equally in them, they must both be different. And just like chlorine, every other element replacing two hydrogen atoms in the dimethyl will result in two compounds being formed that are made up in the same way but are different from one another. When instead of the two chlorine atoms one oxygen atom replaces two H in the dimethyl molecule, either the compound  $\text{CH}_3 \text{CHO}$  or the compound  $\text{CH}_2 - \text{CH}_2$  can be formed.

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In doubly methylated methane, already the replacement of a single hydrogen atom by any other element causes the formation of two different compounds. For depending on whether in the doubly methylated methane - that we express in the formula  $\text{CH}_3 \text{CH}_2 \text{CH}_3$  - one H of the two methyls or one H from the middle carbon atom is replaced by chlorine, for example, the result is one of the two compounds  $\text{CH}_3 \text{CH}_2 \text{CH}_2 \text{Cl}$  or  $\text{CH}_3$

CH Cl CH<sup>3</sup>, both of which consist of C<sup>3</sup> H<sup>7</sup> Cl, but they are different from one another. And if in the hydrocarbon CH<sup>3</sup> CH<sup>2</sup> CH<sup>3</sup>, two hydrogen atoms are replaced by two atoms of another element with the value of one, for example chlorine, or by one atom of an element with the value of two, for example oxygen, already four different compounds are possible:

1. Two hydrogen atoms in a methyl are replaced, for example CH<sup>3</sup> CH<sup>2</sup> CH Cl<sup>2</sup>.
2. Both hydrogen atoms at the central carbon atom are replaced, for example CH<sup>3</sup> CCl<sup>2</sup> CH<sup>3</sup>.
3. One hydrogen atom of each of the methyls is replaced by chlorine: CH<sup>2</sup> Cl CH<sup>2</sup> CH<sup>2</sup> Cl.
4. One hydrogen atom in a methyl and one H at the central carbon atom are replaced: CH<sup>3</sup> CH Cl CH<sup>2</sup> Cl.

All of these compounds are also known, and we can easily understand how exceptionally great the number of such compounds must be as soon as the molecule contains a larger number of carbon atoms.

For by replacing the four hydrogen atoms in methane with four methyls we have by no means reached the limit of compounds containing only carbon and hydrogen. Rather, in each of the hydrocarbons mentioned above, in C<sup>2</sup> H<sup>6</sup>, in C<sup>3</sup> H<sup>8</sup>, in C<sup>4</sup> H<sup>10</sup> and in C<sup>5</sup> H<sup>12</sup> we can again exchange the hydrogen atoms with methyl (CH<sup>3</sup>), and the resulting compounds - of which many, particularly in the higher rows, are made up in the same way but are different from one another - can in turn exchange the hydrogen with chlorine, bromine, oxygen, sulfur, nitrogen, etc. And yet with this tremendous growth in the number of compounds we have so far only become acquainted with one class.

For it is also possible to replace two hydrogen atoms of methane with one carbon atom, which in turn has saturated its other two affinities with other elements (for example hydrogen), thus producing a compound CH<sup>2</sup> CH<sup>2</sup>. But in this compound the hydrogen atoms can of course again be exchanged, and if we look at only one case in which one after the other the four H are replaced by methyls, we come to the compounds CH<sup>2</sup> CH CH<sup>3</sup> = C<sup>3</sup> H<sup>6</sup>; CH<sup>2</sup> C (CH<sup>3</sup>)<sup>2</sup> = C<sup>4</sup> H<sup>8</sup>; or CH (CH<sup>3</sup>) CH (CH<sup>3</sup>) = C<sup>4</sup> H<sup>8</sup>; CH (CH<sup>3</sup>) C (CH<sup>3</sup>)<sup>2</sup> = C<sup>5</sup> H<sup>10</sup>; C (CH<sup>3</sup>)<sup>2</sup> C (CH<sup>3</sup>)<sup>2</sup> = C<sup>6</sup> H<sup>12</sup>. We hardly need mention that in the compounds thus formed the hydrogen atoms can again be exchanged with chlorine, oxygen, methyls, etc.

In addition, three hydrogen atoms in methane can be replaced by one carbon atom that only contains one other H, so that the compound CH CH = C<sup>2</sup> H<sup>2</sup> results. From this



compound we can again produce an extraordinarily great number of other compounds, for example  $\text{CH}_2\text{C}(\text{CH}_3)$  and  $\text{C}(\text{CH}_3)_2\text{C}(\text{CH}_3)$ , etc.

Precisely this last compound  $\text{CH}_2\text{C}(\text{CH}_3)$ , which by the way is gaseous and is contained in our coal gas, has a characteristic that made it highly interesting for chemistry. In particular at very high temperatures, three of its molecules can come together to form one molecule so that the more complex compound  $\text{C}_6\text{H}_6$  (so three times  $\text{C}_2\text{H}_2$ ) is produced. We shall soon return to this compound. But first we want to discuss another point: how it has become possible to get a very simple and understandable overview of the almost endless number of compounds.

If we again summarize the compounds that we got to know above and that can be produced from methane by exchanging one hydrogen atom with methyl, we learned that these can be shown as follows:



If we further take into consideration that in the compounds thus formed, the hydrogen atoms can again be replaced by methyl, that instead of an H a  $\text{CH}_3$  enters the compound, the new substance must differ from its substance of origin by one carbon and two hydrogen atoms more in its content. In the construction of the whole series, every member grows by the atom complex  $\text{CH}_2$ , and since the first member of the series, the methane, contains 2 H along with  $\text{CH}_4$ , every member must be made up of any number of carbon atoms, let us say  $n\text{C}$ , and twice as many plus two hydrogen atoms, so  $2n\text{H} + 2\text{H}$ . Thus, the composition of all the members in the series can be expressed in the general symbol  $\text{C}_n\text{H}_{2n+2}$ . All the members in the series are very similar to one another. At ordinary temperatures, the lowest members are gasses and the higher members are liquids, the boiling point of which is all the higher, the more carbon atoms are contained in the molecule; at ordinary temperatures, the still higher members are solid objects that are all the harder to melt, the more complex their molecule is; but those are the main differences. For the rest, they resemble one another entirely. In passing let it be said that from the methane to the compound  $\text{C}_5\text{H}_{12}$  (which is simply called pentane), the individual members are gaseous; from  $\text{C}_6\text{H}_{14}$  (hexane) to  $\text{C}_{20}\text{H}_{42}$ , they are liquid, and those that are still higher are solid. The middle (liquid) members of the entire series are the main component of our petroleum, the higher members are those of paraffin. They are all easily inflammable and burn with a more or less bright flame (of course by uniting with the oxygen in the air and giving out carbon dioxide and water); they are not soluble in water and are lighter than the latter, so that they float on it, and it is difficult to transfer them to other compounds. The whole series is called **saturated hydrocarbons** or paraffins.

A second series of compounds corresponds to this series of hydrocarbons. It is derived from the compound  $\text{CH}_2\text{CH}_2$  mentioned above in exactly the same way as the different types of paraffin are derived from methane, which is to say that any one hydrogen atom of one of the members is replaced by methyl, thus producing a compound that is enriched by one carbon atom and two hydrogen atoms. Thus the following can be produced from one another:



In this series of compounds, every member contains exactly twice as many hydrogen atoms as carbon atoms. Thus, if we call the number of carbon atoms contained in the molecule by the letter n, we can sum up this series in the general symbol  $\text{C}_n\text{H}^{2n}$ . These compounds are very similar to the various kinds of paraffin; like them, they are easily inflammable, they are not soluble in water and are lighter than water, but they are in general somewhat heavier than paraffin; they are different to paraffin in that they easily unite with chlorine, bromine, etc. and easily transfer to compounds derived from paraffin. They can also be found in petroleum, and in general they are in the same state as the various kinds of paraffin.

In addition, a series of compounds is derived from hydrocarbon  $\text{CH}_2\text{CH}_2$  or  $\text{C}^2\text{H}^2$  in the same way, which is to say by replacing hydrogen with methyl, and thus compounds like  $\text{C}^3\text{H}^4$ ,  $\text{C}^4\text{H}^6$ ,  $\text{C}^5\text{H}^8$ ,  $\text{C}^6\text{H}^{10}$ ,  $\text{C}^7\text{H}^{12}$ , etc. are formed, which is to say compounds with molecules that always contain two hydrogen atoms less than the corresponding member of the previous series and that can therefore be summed up with the general symbol  $\text{C}_n\text{H}^{2n-2}$ .

But there are also hydrocarbon series containing even less hydrogen. However it would go too far to discuss them here.

All series containing the same number of carbon atoms but fewer hydrogen atoms than the corresponding members of the paraffin series are called **unsaturated compounds**. They can all be easily transferred to saturated compounds.

The oxygen compounds derived from the hydrocarbons are far more important for organic nature's household as well as for commerce than the hydrocarbons themselves.

Above, we got to know a substance containing a further oxygen atom united with one H instead of a hydrogen atom; we called this wood spirit:

$\text{CH}_3\text{H}$  is methane;  $\text{CH}_3(\text{OH})$  is wood spirit. It makes sense that the same change can occur in every member of hydrocarbons derived from methane. Already the compound

$\text{CH}_3\text{CH}_2\text{OH}$  derived from dimethyl  $\text{CH}_3\text{CH}_3$ , is the universally known ethyl alcohol, *spiritus vini*, which is produced when objects containing sugar ferment and is now simply called spirit. Alcohol, the Arabic alchemist name for spirit, was then given to the entire class of objects, which like alcohol *par excellence* contain an oxygen atom combined with hydrogen instead of one H found in any paraffin. Most alcohols are liquids that boil at temperatures that are all the higher the more carbon atoms they contain in a molecule; only those containing more than 7 C are at times solid at ordinary temperatures. It is very easy to calculate the composition of these alcohols as soon as you know how many carbon atoms are in a molecule, for they have only one atom of oxygen more than the hydrocarbons and can therefore be summed up under the general symbol  $\text{C}_n\text{H}_{2n+2}\text{O}$ , e.g.  $\text{CH}_4\text{O}$ ,  $\text{C}_2\text{H}_6\text{O}$ ,  $\text{C}_3\text{H}_8\text{O}$ ,  $\text{C}_4\text{H}_{10}\text{O}$ ,  $\text{C}_5\text{H}_{12}\text{O}$ ,  $\text{C}_6\text{H}_{14}\text{O}$ , etc. But we must not forget that in the members of the series that are richer in carbon there must always be several alcohols with the same composition that are however different to one another. Thus we actually know of two alcohols that are composed of  $\text{C}_3\text{H}_8\text{O}$ , four alcohols with the composition  $\text{C}_4\text{H}_{10}\text{O}$ , eight alcohols with the composition  $\text{C}_5\text{H}_{12}\text{O}$ , and with the increase of the carbon content, the number of alcohols with the same composition but differing from one another goes up extraordinarily fast. It deserves to be mentioned that one alcohol,  $\text{C}_3\text{H}_8\text{O}$ , one with the composition  $\text{C}_4\text{H}_{10}\text{O}$ , two alcohols  $\text{C}_5\text{H}_{12}\text{O}$ , and at least one  $\text{C}_6\text{H}_{14}\text{O}$  are formed along with the real wine spirit, though in small quantities, when a liquid containing sugar ferments, and these give it an unpleasant smell and taste and probably also very considerably increase its effects that are detrimental to health. They are commonly called hooch, bad liquor.

But it also makes sense that in the higher hydrocarbon series, one OH can also replace one H with two or more carbon atoms and that in their most essential characteristics, the compounds thus composed will behave like the alcohols mentioned so far. Here only two of these “polyvalent” alcohols will be mentioned because of their outstanding importance, glycerin and mannite. Glycerin is a component of all fats, and we will soon learn more about its nature. It is gained from fats as a by-product for producing stearin and recently also for producing soap. Its molecule contains three carbon atoms, eight hydrogen atoms, and three oxygen atoms, so its composition is  $\text{C}_3\text{H}_8\text{O}_3$  or  $\text{CH}_2(\text{OH})\text{CH}(\text{OH})\text{CH}_2(\text{OH})$ , which is to say that in it three H of the hydrocarbon  $\text{CH}_3\text{CH}_2\text{CH}_3$  have been replaced by three OH. The second alcohol, mannite, is the main component of the dried juice [called *Manna* in German] that is exuded when the [*Manna*] ash, that is cultivated in southern Europe, is accidentally or deliberately injured. It is solid and tastes sweet and is closely related to the various kinds of sugar. Its molecule contains six carbon atoms, fourteen hydrogen atoms and six oxygen atoms,  $\text{C}_6\text{H}_{14}\text{O}_6$ . It is an alcohol with the value of six.

All alcohols have the ability to unite with acids while giving off water in the same way as the bases, and they can produce compounds that are to be situated alongside of the salts. Of course these compounds, which have been given the name acidic ether, are only formed when the alcohol and the respective acid are both brought together in a highly concentrated form. But aside from the fact that there are many easy methods for producing these acidic ethers, a number of them can be found in organic nature, and there they play an outstanding role; others that have been produced artificially are already being used commercially in many ways. Thus by carefully mixing glycerin with most concentrated nitric acid, nitroglycerin is produced, an oily fluid that stiffens in lower temperatures and that in its solid state already explodes violently when it receives a blow. It can be drawn from silica (**?-Kieselguhr – Infusorienerde**), a very loose earthy mass made of the shells of pebbles (**?-Kieselpanzern**) from (**Infusorien**), in order to make the well known dynamite. In making dynamite, the only purpose of silica **?-Kieselguhr** is to make the nitroglycerin explode by means of a blow already at ordinary temperatures, so in a liquid state, because the whole mass behaves like a solid object. Adding silica **?-Kieselguhr**, which has no part in the explosion, is simply a necessary evil. Recently, by dissolving cotton sprouts (**???-Schießbaumwolle**) in warm nitroglycerin, it has been possible to produce a mass that becomes solid when cooled off and that explodes with even greater violence than dynamite; it is called **gelignite**.

All real fats that are contained in every plant and are of great importance in animal food also belong to the class of acidic ethers, as shall be developed further on; however, their alcohol is always glycerin.

In addition, under certain conditions the alcohols can easily be oxidized, most easily when along with the oxygen atom, there are also two hydrogen atoms on the same carbon atom. During oxidation, these two hydrogen atoms unite with one oxygen atom to form water, which is secreted, and another oxygen atom takes the place of the two hydrogen atoms. Here, let us give ordinary wine spirit as an example; as we know, its composition is  $\text{CH}^3 \text{CH}^2 (\text{OH})$ . If after diluting the wine spirit itself with a lot of water, it is then heated with acidic chrome or with a solution of overly acidic manganese potassium, by taking on two oxygen atoms and discharging water it undergoes oxidation:



The latter compound is the acid contained in vinegar, **acetic acid**. Oxidation occurs in exactly the same way in all alcohols that are chemically similar to wine spirit, e.g. the alcohols that as a whole are called hooch or bad liquor. In this process, acids are always produced.

It is surely not without interest to say here that the vinegar of which we produce so much is obtained by means of two entirely different processes. The one is that wood is heated to glowing point in long and wide sealed clay cylinders that do not allow air to enter, which would cause burning. The gasses that develop thereby are conducted through a long row of upright iron pipes in order to let the glowing gasses cool off and to allow for the compression of all the products that are not gaseous at ordinary temperatures. The remaining gaseous substances, mainly carbonic acid, carbon oxide, hydrogen, methane, etc., are flammable with a brightly glowing flame. These are conducted under the cylinders in order to be used as fuel for heating the cylinders, whereas the compressed substances are collected in containers under the iron pipes and divided into two layers. The lower, dark brown-black, very thick fluid layer is called wood tar; the upper layer, which is somewhat lighter but still brown-black, more fluid and consisting for the greater part of water, is called wood vinegar and contains about 6% acetic acid as well as wood spirit and other compounds. In its raw state, wood vinegar is only used to a small extent for medicinal purposes, but pure acetic acid containing no water and wood spirit are produced from it. For since, as we learned earlier, acetic acid is an acid and therefore unites with bases to form salts, it is easy to separate the acid from all the other substances contained in the raw wood vinegar by adding carbonic sodium, i.e. soda, for so long until the liquid begins to turn red litmus paper blue. At the same time, it will fizz and carbonic acid will escape, while acetic sodium is formed, which remains dissolved in the large amount of water that is present. The liquid is then distilled. The wood spirit and the other non-acidic substances contained in the raw wood vinegar distill with the water, while the acetic sodium remains as a solid mass of salt. This salt residue is carefully heated further until it melts, and the high temperature that is required to melt the acetic sodium at the same time destroys some non-liquid substances that make the latter impure. The salt residue is then dissolved in water, the solution is again evaporated, and the remaining salt residue is once more heated until it melts. The salt that has cooled off after this melting is mixed with concentrated sulfuric acid in order to make the acetic acid containing no water, whereby sulfuric sodium and free acetic acid are formed, and the latter is distilled. At a low temperature, the acetic acid free of water solidifies to a mass with large crystals that is similar to ice; it is called ice vinegar. It has a very strong sharp smell and causes blisters on skin.

The second method used to produce vinegar is based on the oxidation of wine spirit. But in order to bring about this oxidation, chemicals such as chrome acid or other similar substances are not used, but rather the life activity of a small mushroom, the vinegar fungus. Its shoots are just as widespread as those of the yeast fungus, so that liquids containing wine spirit such as wine, beer, gradually become sour of themselves, which is to say that they let an oxidation of wine spirit to acetic acid occur. But in producing vinegar, one does not wait for these shoots to fall into the liquid containing wine spirit; rather, the vinegar fungus is added directly to it. First of all, so-called mother vinegar, i.e. a liquid from an old barrel of vinegar that is rich in vinegar fungus, is trickled through large barrels filled with carefully rolled beech wood shavings. Above their real lower floor, these barrels also have a sieve-like lower floor full of holes as well as a sieve-like upper ceiling full of holes. Diluted wine spirit is then constantly added. Because very much oxygen is used in this process of oxidizing the wine spirit, a strong draft through the barrels is produced by boring a wreath of holes just above the lower and just below the upper sieve-like panel. Thus air can enter into the barrel through the lower row of holes and can leave the barrel through the upper row. Ordinary table vinegar contains about 3-5% of acetic acid, vinegar alcohol 6-7%.

The other acids similar to the acetic acids are produced by means of the oxidation of the alcohols corresponding to them insofar as they cannot be found in nature (e.g. as a component of the fats).

We learned above that the alcohols unite easily with acids to form acidic ethers. For example, if acetic acid or better yet, acetic acid sodium is mixed with wine spirit and sulfuric acid, the mass is heated and the well known **vinegar ether** with its refreshing smell is distilled. Together with the in themselves unpleasant alcohols that have a suffocating smell, the acids that can be produced from the bad liquors by means of oxidation with chrome acid form acidic ethers that are outstanding because of their pleasant fruity scent. These acidic ethers are produced on a large scale for use both in perfumes and in particular as surrogates that are called essences (essence of pear, essence of pineapple, and such like), to make liqueurs, etc.

As already mentioned above, the most important acidic ethers are the fats. In animals, these are always in a liquid state as very small drops that are surrounded by a covering that resembles the white of an egg and seals tightly; when the animal dies, these stiffen more or less easily. For all fats found in nature are a mixture of at least three kinds of fat, which is to say of the glycerin compounds of three acids with a complicated composition. Of these three types of fat, two are solid at ordinary temperatures and the third is liquid. The relationship of the three to one another changes greatly. In the kidney fat of cattle

and sheep, the liquid type of fat is present only in small amounts, whereas there is a considerable quantity of it in the fat in the spinal region of pigs. Therefore, the greater or lesser ease with which the fat can be melted, and connected with this also the greater or lesser degree of its hardness, depend only on the mixture's proportions.

All acidic ethers disintegrate when they are cooked in caustic potash solution or sodium hydroxide, whereby the salt of the respective acid and free-state alcohol are created. For example, if vinegar ether is cooked with sodium hydroxide, an acetic acidic sodium and wine spirit are formed. If a fat is cooked with sodium hydroxide, the sodium salts of the acids making up the fats and glycerin are produced. If we call all the acids contained in the fats fatty acid, we can describe the process by which the fats disintegrate by means of caustic potash solution or sodium hydroxide more briefly by saying: Glycerin and fatty acid salt are formed. For a long time now, fatty acid potassium and fatty acid sodium are being produced on a large scale; they are both called **soap**. Fatty acid potassium, i.e. the mixture of the potassium salts contained in the various acids to be found as glycerin ether in every fat, has a soft greasy consistency and is therefore called soft soap, whereas fatty acid sodium is hard and forms our hard soap. Like caustic potash solution and sodium hydroxide, all bases have a disintegrating effect on acidic ethers and in accordance with their nature also on fats. However, all fatty acid salts, with the exception of the potassium and sodium salts, are completely insoluble in water; but our soaps are valuable precisely because of their solubility in water. Thus for example, the fats can also be disintegrated by cooking them with lead oxide and water. Along with glycerin, fatty acid lead is thereby formed, and that is our ordinary sticking plaster. Because all fatty acid salts except potassium and sodium salt are insoluble, if a soap solution is added to a calcium salt solution, sediment is formed. As was shown earlier, the water in our wells contains a small amount of dissolved calcium with sulfuric acid and carbonic acid (as is known, these both make the water hard); consequently, well water in a soap solution produces sediment (calcium salts of the fatty acids). When soap solution is needed in large amounts, as for laundry, water that is as soft as possible is therefore used.

Just as acids are derived from the real alcohols that resemble wine spirit, they can also come from the alcohols with a multiple value that contain in their molecule either once or several times an oxygen atom instead of the two hydrogen atoms of alcohol. We shall only mention the alcohol  $\text{CH}_2\text{OHCH}_2\text{OH}$  as an example. Two acids can come from this through oxidation, the first by oxidizing the one  $\text{CH}_2\text{OH}$  into  $\text{COOH}$ , and the second by bringing about this oxidation twice. The two acids would then be composed as follows:  $\text{CH}_2(\text{OH})\text{COOH}$  (or  $\text{C}_2\text{H}_4\text{O}_3$ ) and  $\text{CO}(\text{OH})\text{CO}(\text{OH})$  (or  $\text{C}_2\text{H}_2\text{O}_4$ ). The second of these two acids occurs in all plants as potassium salt and calcium salt; in particular, a large amount of the sour potassium salt is contained in wood sorrel, which is why it has

simply been called sorrel salt, and the acid itself is called acidic sorrel or oxalic acid (derived from oxalis, i.e. sorrel). In passing let it be said that this acid was produced for a while by cooking sugar with saltpeter acid, and because of this it has the false commercial name sugar acid. By the way, sorrel acid is an acid with a double base.

In the plant kingdom there are many such acids with multiple bases and the most varied compositions. Here let us just remember the apple acid contained in apples, pears, etc., the tartaric acid found in grapes, and the citric acid in the various kinds of citrus fruit.

Finally, as we have seen, alcohols are derived from the saturated hydrocarbons by replacing one or more hydrogen atoms with one oxygen atom united with one H atom, and from these acids are then derived. Let it now be mentioned briefly that alcohols and acids are also derived from unsaturated hydrocarbons. However, because discussing these would lead us too far, these will now be left out.

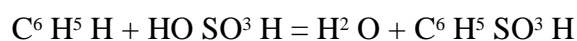
In accordance with nature, there are very many methods used to produce the various compounds. Nevertheless, the majority of them can be summed up under a few aspects. Almost always the strong power of attraction of individual elements or atom complexes on one another is used, and thus a movement of the atoms to new molecules is brought about. Thus for example, potassium, sodium, silver and a few other metals have a strong power of attraction to chlorine, bromine and iodine. So if for example acetic acid sodium and methyl chloride ( $\text{CH}_3\text{Cl}$ ) are heated together, sodium chloride and acetic acid methyl are formed. Or if methyl chloride is heated with potassium hydrate, potassium chloride and methyl hydrate  $\text{CH}_3\text{OH}$  are produced, which is nothing other than wood spirit.

It was mentioned above that the gaseous hydrocarbon  $\text{CH}_2 = \text{C}_2\text{H}_2$  has the capacity under certain conditions, that is by means of very high temperatures, to mass together to a molecule that is three times as large and that at ordinary temperatures can produce a liquid compound  $\text{C}_6\text{H}_6 = 3\text{C}_2\text{H}_2$ . Now this latter compound has become highly significant in recognizing a very large number of extremely important substances, some of which can be found in nature and some of which are produced artificially. For it has been discovered that the latter can be produced either directly or indirectly from the former, and that on the other hand, the latter can again be changed into the former. They must be understood as derivatives of the compound  $\text{C}_6\text{H}_6$ . A large number of these derivatives are outstanding because of their pleasant scent, and the whole class of these compounds has therefore been called **aromatic** compounds. The aromatic substances can be derived from the compound  $\text{C}_6\text{H}_6$  in a similar way to the substances derived from methane that have already been mentioned. The basic substance  $\text{C}_6\text{H}_6$ , which was originally called benzol or benzine, now only has the name benzol, since the second

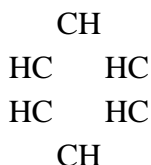


name has been taken to designate the lighter volatile components of petroleum. It was first found among the products formed when benzoic resin is heated with lime, and later when it was discovered to be a significant component of coal tar, it became very important to industry because through simple chemical processes a large number of beautiful dyes known as aniline dyes are made from it. Benzol, which is a liquid that boils at 80° centigrade, is completely insoluble in water and does not smell pleasant, differs very substantially from the hydrocarbons discussed so far by the fact that the individual hydrogen atoms contained in it can very easily be replaced by other substances. Thus benzol, which is lighter than water and floats on the latter, dissolves in strong saltpeter acid when heated, and if after a time one adds water to this solution, a heavy oil is secreted that sinks to the bottom. This oil has a bitter almond-like smell that is no longer in any way reminiscent of benzol, and it is used for perfumes as a surrogate for the oil of bitter almonds; it is called **Mirbanöl**. For by adding saltpeter acid to benzol, one hydrogen atom of the latter is split off, which combines with one oxygen atom and one hydrogen atom of the saltpeter acid to form water, and the remainder of the saltpeter acid molecule takes its place. As was shown above, the saltpeter is HNO<sup>3</sup>; if we take HO away from that, what remains is NO<sup>2</sup>, one atom of nitrogen combined with two oxygen atoms. On the other hand, when one hydrogen atom has gone out of the benzol C<sup>6</sup> H<sup>6</sup>, the molecular remainder is C<sup>6</sup> H<sup>5</sup>, and this combines with NO<sup>2</sup> forming C<sup>6</sup> H<sup>5</sup> NO<sup>2</sup>. This compound can very easily again be changed by zinc and hydrochloric acid, tin and hydrochloric acid, in short by all mixtures that are able to develop oxygen. It is changed in such a way that the two oxygen atoms unite with hydrogen to form water, and the nitrogen in turn unites with two other hydrogen atoms forming NH<sup>2</sup>, so that the result is the compound C<sup>6</sup> H<sup>5</sup> NH<sup>2</sup>. And this compound is nothing other than the well known **aniline**. It is a liquid that is colorless when just formed and when standing in the light it soon becomes yellow and finally brown; it smells unpleasant and simmers at 183°. Under certain conditions it can be transferred into dyes.

Moreover, when benzol is shaken together with strong sulfuric acid, it gradually dissolves in this liquid. If water is then added to the clear solution, nothing is discharged. For a peculiar, in water easily soluble acid has thereby been produced, C<sup>6</sup> H<sup>5</sup> SO<sup>3</sup> H. Since sulfuric acid is made up of H<sup>2</sup> SO<sup>4</sup>, the formation of the acid mentioned occurs in exactly the same way as the creation of the C<sup>6</sup> H<sup>5</sup> NO<sup>2</sup> from benzol and saltpeter acid: one of the benzol's hydrogen atoms leaves its molecule, unites with oxygen and hydrogen from the sulfuric acid to form water, and lets the remainder of the sulfuric acid molecule (SO<sup>3</sup> H) take its place:



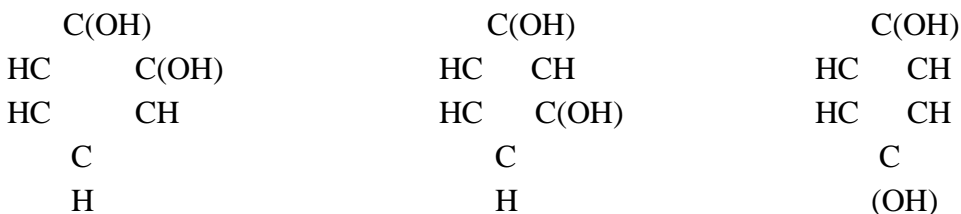
We can see that the hydrogen atoms in the benzol can very easily be replaced by other substances, and it is therefore understandable that a very large number of other compounds can be produced from benzol. In order to better understand these compounds, let it be mentioned here the idea that chemists have today of how the six carbon atoms are strung together with their six hydrogen atoms in the benzol molecule. For it is assumed that each of the six carbon atoms is combined with one hydrogen atom, so that there would be a perfectly uniform distribution of the six H in the molecule and the six C in turn would be connected with one another in the form of a ring, as the following schema shows:



This means that every carbon atom is connected with two neighboring atoms in such a way that it is connected with one of them simply and with the other doubly. But we may not forget that this schema is only meant to give a picture of the characteristics found in the substances produced from benzol and not that the benzol molecule really has such a form. For we know absolutely nothing about the shape of molecules. The schema shows us the six hydrogen atoms as completely equal, so that if one of the six H is replaced by any other element or by any other atom complex, e.g. by Cl, OH, NO<sup>2</sup>, SO<sup>3</sup>, H, CH<sup>3</sup>, etc. etc., it is completely immaterial which of the six H undergoes this exchange. That is to say that one and the same compound always results from this. There can therefore be only one C<sup>6</sup> H<sup>5</sup> Cl, just as there can only be one C<sup>6</sup> H<sup>5</sup> OH, one C<sup>6</sup> H<sup>5</sup> NO<sup>2</sup> and so forth, and in spite of most eager searching, it has so far only been possible to produce only one derivative of benzol respectively by replacing one hydrogen atom with various groups of atoms.

The case is already different when two hydrogen atoms of the benzol are replaced by two other elements or groups of atoms. For in so doing, three cases are possible.

1) Two neighboring carbon atoms, or 2) two carbon atoms that are separated by one C, or 3) two opposite carbon atoms allow their two hydrogen atoms to be replaced by any one element or group of atoms. As an example, let us assume that the two hydrogen atoms are replaced by OH. We can see the three possibilities in this exchange in the following schema:



In fact, three such compounds  $C^6 H^4 (OH)^2$  are known, and among hundreds of benzol derivatives in which any two atoms or groups of atoms have replaced two benzol hydrogen atoms, for each of them three different compounds are known that have the same composition but different characteristics.

The same is repeated as soon as three or four hydrogen atoms in the  $C^6 H^6$  are replaced by something else, except that as soon as this exchange occurs with one and the same group of atoms, there are always three different compounds, whereas otherwise far more compounds with the same composition but different characteristics are possible.

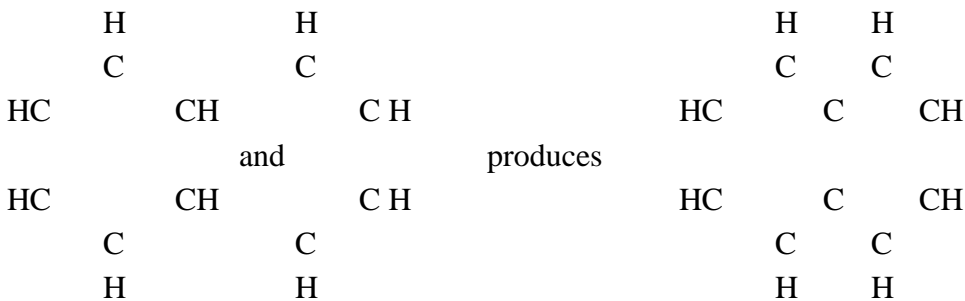
It is interesting that the compounds corresponding to the alcohols discussed earlier, i.e. those in which OH is found instead of one or more hydrogen atoms of the benzol, have characteristics that are entirely different to those of the alcohols. In particular, they differ in that they behave like weak acids, so can easily unite with bases to form salts. Thus the first such substance,  $C^6 H^5 OH$ , is the universally known carbolic acid, which has gained such great importance for medicine because of its power to disinfect. It is possible to gain carbolic acid from benzol indirectly, but since it is contained in abundance in coal tar, it is much easier to produce it from the latter. It hardly needs to be mentioned that the three equally composed compounds  $C^6 H^4 (OH)^2$  as well as carbolic acid have mildly sour characteristics as do the compounds containing three OH instead of three benzol hydrogen atoms. Of the latter, one is called pyrogallic acid or pyrogallol and is much used in photography.

Just as with the rows of compounds discussed earlier, the fact that the hydrogen atoms of benzol can very easily be replaced by methyl, ethyl, etc. is important for the construction of compounds that are rich in carbon. Such compounds (methyl benzol  $C^6 H^5 CH^3$ , dimethylbenzol  $C^6 H^4 (CH^3)^2$ , trimethylbenzol  $C^6 H^3 (CH^3)^3$ , up to hexamethylbenzol  $C^6 (CH^3)^6$ , as well as ethyl benzol  $C^6 H^5 C^2 H^5$  etc.) have been produced artificially in great number, but in part they can also be found in coal tar along with benzol. Several methods are used to produce it, of which only two shall be mentioned here. If e.g. benzol bromine,  $C^6 H^5 Br$ , which is very easy to obtain by letting benzol stand together with bromine, is mixed with methyl iodine and the liquid is heated together with metallic sodium, sodium bromine and sodium iodine and methyl benzol are formed, as can be understood easily from the equation  $C^6 H^5 Br + CH^3 J + 2 Na = Na Br + Na J + C^6 H^5 CH^3$ . One can also use iodine ethyl instead of the iodine methyl and thus produce ethyl benzol, etc. However, one can get these hydrocarbons even more easily when benzol is mixed with aluminium chloride and heated with methyl chloride, ethyl chloride, etc.

It hardly needs to be mentioned that in the hydrocarbons thus gained, both the hydrogen atoms that were still present in the original benzol and those in the methyl, ethyl, etc. can again be replaced by any other element or atom complex, so that the number of substances produced from benzol in this way is extremely high.

We learned above that benzol itself is constructed by stringing together three CH CH to form one molecule, the benzol. Now it seems that precisely the CH groups participate to a very great extent in producing the most varied and important organic substances, at least insofar as the compounds are produced at high temperatures. But apparently this is also true under the conditions that are valid for organic nature. It is worth mentioning that carbon and hydrogen are only able to unite directly under very particular circumstances and only at exceptionally high temperatures, which is to say when an electric arc of flame is produced between two carbon points in a hydrogen atmosphere. And thereby only one compound is formed, which is nothing other than C<sup>2</sup> H<sup>2</sup> or CH CH.

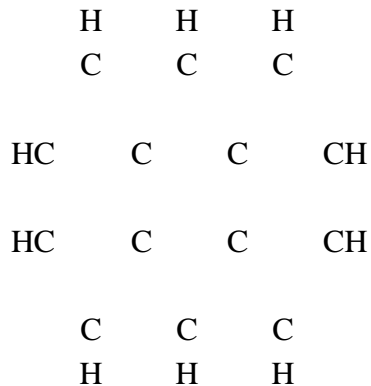
If hydrocarbons of the methane row such as petroleum, paraffin, are conducted through very strongly glowing pipes, these compounds disintegrate while discharging hydrogen to form compounds with less hydrogen. It seems that in this process there is the tendency to produce precisely such hydrocarbons that consist of a number of CH groups and in which a part of the hydrogen atoms are again replaced by CH groups. Let us imagine e.g. that two H in a benzol molecule are replaced by the atom group 4 (CH), which is equal in value. This can be seen in the following schema:



Thus we get a compound, the inner structure of which is very similar to that of benzol. It is constructed from one benzol and one piece of benzol that have been welded together. This compound must have characteristics that are very similar to those of benzol and its hydrogen atoms will exchange with others with the same ease. And this compound, which has ten carbon atoms and eight hydrogen atoms in its molecule, in fact is formed in great abundance when an extremely high number of organic compounds are greatly heated. It is therefore present in tar in very great quantities. It is the **naphtaline**, which in recent times is often used by many names because of its power to drive away insects. At ordinary temperatures it is solid and crystallizes in beautiful, very shiny sheets; it doesn't

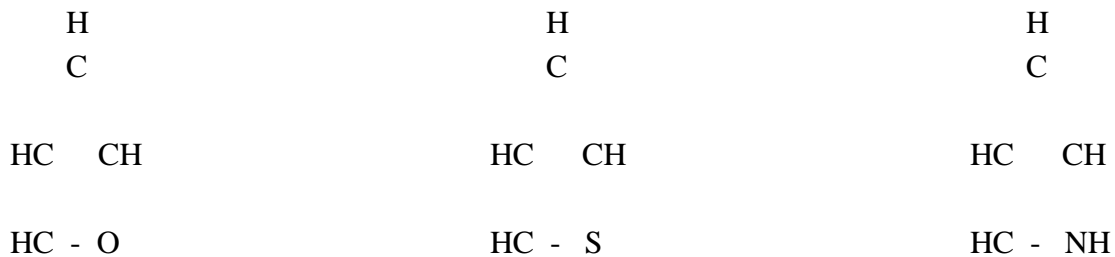
melt until 80° and distills only at 218°, but it evaporates so easily at ordinary temperatures that it gets into gas pipes in considerable amounts along with coal gas and quite often causes the gas meters to become stopped up.

In addition, in each of two benzol molecules two hydrogen atoms can be replaced by the atom group CH CH, and the hydrocarbon thus formed would consist of



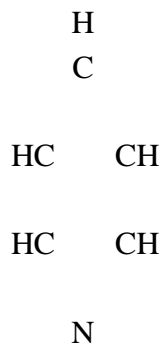
or C<sup>14</sup> H<sup>10</sup>. This object can be found in coal tar, though not in great quantity. It is called anthracene and is very important because very many substances found in the plant kingdom are derived from it. The most outstanding of these is the beautiful red contained in the madder plant, alizarine. It is a dye that is now produced exclusively from anthracene and no longer from the madder plant.

The number of aromatic substances is further increased considerably because within the benzol molecule, the CH itself can also be replaced. For it is not necessary for three CH CH to mass together to form a benzol molecule; rather, with two CH CH or four CH, elements with a value of two or atom complexes can unite to make a molecule, as can be seen in the following three examples:

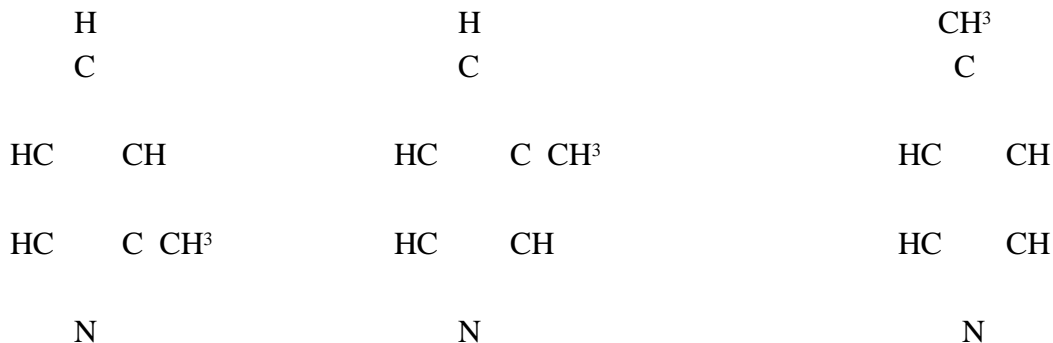


Thus compounds are formed that in their most essential characteristics are very similar to benzol. But yet another modification is possible, and precisely the compound that is thereby produced is to be seen as the basis for a very large class of medically extremely important substances, just as benzol is the basis for aromatic substances. This

modification is that one CH of the benzol can be replaced by nitrogen, and the compound that results can be shown by the symbol

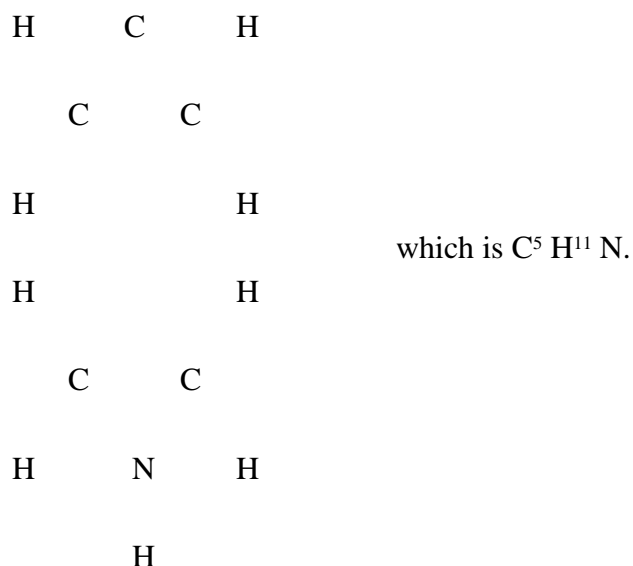


Thus this compound is made up of  $\text{C}^5 \text{H}^5 \text{N}$  and differs from benzol in that it is a strong base and unites with all acids to form salts. It has been given the name **pyridine** and is a colorless liquid that has a strange smell and boils easily. It can be found in small quantities in coal tar and in somewhat larger quantities in the very badly smelling tar-like products that are gained by heating animal substances such as meat, skin, horn, etc. Of course the five hydrogen atoms contained in it can be replaced, but already when one single H is replaced by any other element, three differing though similarly composed substances can be formed, depending on whether one of the two H atoms next to the nitrogen or one that is separated by an H or finally the H opposite it in the above symbol has undergone the exchange. This can be seen from the three following figures, in each of which one H has been replaced by  $\text{CH}^3$ :



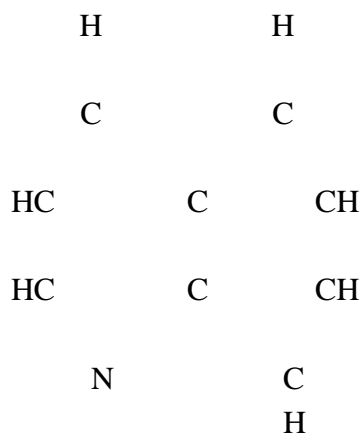
In addition, under appropriate conditions the pyridine and the compounds derived from it by replacing one or more hydrogen atoms with elements of the value of one or with atom complexes can easily take in six further hydrogen atoms as soon as they come into contact with hydrogen in *statu nascente*. For the double links can easily be dissolved into simple ones, so that one hydrogen atom can connect with each of the five carbon atoms and with the nitrogen atom:





Such derivatives of pyridine containing more hydrogen can be found in nature, for example precisely C<sup>5</sup> H<sup>11</sup> N is a compound in pepper. In poison hemlock, *conium maculatum*, a liquid called conine is what contains the plant's very poisonous characteristics. It is made up of C<sup>8</sup> H<sup>17</sup> N and can be expressed with the formula C<sup>5</sup> H<sup>10</sup> (C<sup>3</sup> H<sup>7</sup>) N, which is to say that it is C<sup>5</sup> H<sup>11</sup> N in which one H has been replaced by the atom complex with the value of one C<sup>3</sup> H<sup>7</sup> ("propyl"). The substance in tobacco with the narcotic effect (*nicotiana tabacum*) is somewhat more complicated, but it nevertheless belongs to this class of compounds; it is called nicotine and is C<sup>10</sup> H<sup>14</sup> N<sup>2</sup>.

Moreover, just as in benzol, two hydrogen atoms in pyridine can be replaced in such a way that compounds are formed that by their structure are connected with naphthaline etc. In particular, the compound corresponding to naphthaline



is important, because the effective substances contained in cinchona bark, above all quinine itself, are derived from it. This compound  $C^9 H^7 N$  was first produced from quinine and was therefore called **quinoline**. Now of course, quinoline is produced chemically, synthetically.