Chemical Phenomena

So far, we have spoken only of molecules, that is to say, the smallest free particles that are in constant movement, of which all matter consists and which possess perfectly the characteristics of the entire substance. However, the molecules themselves are in turn usually very complicated little bodies and consist of even smaller particles, which from now on will be our main topic. Most of the substances that exist in nature, as well as those produced in the chemist's laboratory, are objects made up of various elements, and it is possible to dismantle these objects by means of various methods, some of which will be discussed later. Now since every tiniest particle of the substance, its molecule, also possesses perfectly its characteristics, the molecules of the substances that are made up of various elements must also be made up of various elements, that is to say, of particles of the substances of which they consist. The components of the molecules are called **atoms**. The name "indivisible" (the word "atom" means indivisible) was chosen because with our present instruments, we are not able to dismantle these even further. However, we do not link this fact with the claim that the atoms have to be the ultimate smallest particle of all matter. More recent research has shown that the atoms in turn are probably again compounds made up of even smaller particles. However, this circumstance in no way takes away from the following conclusions.

Before moving on to discuss the laws that govern the movement of atoms, we have to talk about **electricity**, at least as regards its basic characteristics – the force of nature that we completely disregarded in our earlier considerations. Since ancient times, it has been known that when amber (which the Greeks called electron) is rubbed, it can become capable of attracting small, light objects such as bits of paper, little bits of the flesh of elderberries, etc. and then repelling them, again attracting them and repelling them, and so on, and this characteristic has been called electricity.

In addition to amber, all resins as well as glass and other objects have the ability to become electric through rubbing, and around the middle of the last century, a machine was first built for electrifying through rubbing and the electric sparks were observed. At about the same time (1752), **Franklin** proved that lightning is nothing but a powerful electric spark, and that thunder is simply the sound produced by the shaking of the air following the lightning's striking. On the other hand, in the year 1727, **Gray** discovered that metal rods do not show electricity when they are rubbed, only because all the electricity produced is conducted through the hand and body of the person experimenting, but that these same rods easily become electric when they are rubbed without being directly touched. Thus, the difference between good and bad electricity conductors was discovered, and it was found that all metals are more or less good conductors, that all resins, glass, rubber, gutta-percha and the air are bad ones, and that wood, the human body, etc. are quite bad conductors.*

* As with heat and light, it was assumed that electricity as well was an incalculable substance that was united with material objects, or rather, as can be seen in the following, that it consisted of

Yet another phenomenon drew the attention of researchers. For it was observed that a rod of sealing wax that has been rubbed and thus electrified and that is then brought close to a little bit of the flesh of elderberries hung up on a silk thread, first attracts the latter so that it flies to the rod and remains stuck to it. But as soon as the rod is removed and brought close to the bit of elderberry a second time, the latter is repelled and moves ever farther away from the rod. But if a glass rod that has been electrified by rubbing it with a piece of silk is brought close to the bit of elderberry, the latter is immediately attracted very strongly. The attempt was made to explain this phenomenon by assuming that the rod of sealing wax passed on its electricity to the bit of elderberry touching it, with the result that the latter was in turn electrified. But that the electricity in the sealing wax (and in all resins) generally had the same effects, but that it differed from the electricity in the glass in one respect, this being that it repelled the electricity in resins (and thus in light objects loaded with electricity from resins), but that it attracted the electricity in glass. The electricity in resins was called negative electricity and that in glass positive electricity, and the phenomenon discussed above was explained by means of the general theorem: Those kinds of electricity bearing the same name (positive and positive, as well as negative and negative) repel one another, whereas those kinds of electricity with dissimilar names (positive and negative) attract one another.

In addition, it was discovered that when two equally electrified objects, one of which has positive and the other negative electricity, touch one another, both objects immediately cease to be electrified. It was said that positive and negative electricity equalize one another, flow into one another.

In addition, the phenomenon observed by **Galvani** in 1789 in the famous experiment with frog legs, which seemed to belong to an entirely different area, was soon correctly interpreted by **Volta**. Galvani explained the fact that the fresh frog legs hanging on copper wires twitched as soon as they were touched with a zinc rod at the same time as they were touching the copper wires, as an expression of the force of life. For until then, attempts had been made in vain to produce synthetically some substance that exists in the body of a plant or animal, and it was thus assumed that some special secret force was creatively at work in the organic world, which was entirely different to the forces governing inorganic nature (the spirit of the earth in *Faust*), and this strange force was called the force of life. But soon afterwards, Volta showed that when a copper rod is touched by a zinc rod, a small amount of positive electricity is immediately produced at the other end of the copper rod, and of negative electricity on the zinc rod, that these two kinds of electricity equalize one another as soon as a second place of contact is created between the zinc rod and the copper rod by introducing a conducting object between them, and that the twitching of the frog legs was nothing but the consequence of the equalization of the electricity.

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two opposite incalculable substances, and all the names for electric phenomena come from the period of time, when this assumption was the only valid one. Thus it is said that electricity is "passed on" from one object to another, it "flows through" an object, it "spreads" through an object, etc. But even though this is hardly ever assumed now, we are nevertheless still very much in the dark as to the essence of electricity, for we have not yet been able to put its phenomena down to some form of movement, perhaps that of world ether, in a simple way.

However, since the condition needed to produce electricity, i.e. the contact between the zinc and the copper rods, is still present, it follows that in the next instant after the different kinds of electricity first produced have been equalized, positive electricity in the copper rod and negative electricity in the zinc rod must be produced, and if the equalization of both of them can occur without interruption, it must also occur continuously, so that we have the conditions necessary for the production at every moment and the continuous equalization of the different kinds of electricity flowing back and forth, that is to say, an electric current. The amount of electricity produced at every moment will be much greater if the two metals do not touch one another directly but are separated by a layer of fluid, whereby the fluid becomes the mediator for the production of electricity.

So as soon as two different metals that are separated from one another by a layer of fluid are connected to one another in the parts that protrude from the fluid by means of a conductor, an electric or galvanic current is produced. In **figure 52**, **a** is a glass of water that is about ¾ full. A zinc rod **Z** and a copper rod **K** are lowered into the glass. Both rods are connected to one another by means of a wire **l**. In this apparatus, electricity flows uninterruptedly from the copper rod into the wire, through the wire into the zinc rod, from the zinc rod through the water again into the copper rod; because at every moment positive electricity is produced at the zinc rod and negative electricity at the copper rod, and these two are equalized again at every moment. The strength of the current depends on the nature of the two metals, so that for example, under otherwise entirely equal conditions, a zinc and a copper rod do not produce as much electricity as a zinc and a platinum rod or a zinc and a carbon rod. In addition, the strength depends on the fluid's ability to conduct and on the connection created between the two metals outside of the fluid. The most commonly used apparatus is that shown by **Bunsen**, as seen in **figure 53**. In **glass a** there is a porous clay vessel **b**, through which fluids can penetrate. Between the glass and the clay vessel, there is a zinc cylinder **Z** that is lowered into diluted sulfuric acid, while a carbon rod **K** in the clay vessel is in strong nitric acid. As soon as the end of the zinc cylinder protruding from the fluid is connected with the carbon rod, a galvanic current flows from the carbon rod to the zinc cylinder through the conductor wire. We call a vessel that has been made to produce a galvanic current a **galvanic element**. If we connect several galvanic elements with one another, we get a galvanic battery, as in **figure 54**, where the carbon rods of the four elements are bolted to the zinc cylinders by means of short metal strips.

After getting to know the means for producing a galvanic current in the preceding pages, we will now discuss the effect of such a current on a few substances. If, with the help of the apparatus shown in **figure 54**, we insert the ends of the two wires (the two poles) into water, to which we have added 6 – 8% sulfuric acid so that it will be a better conductor, we will observe a strange phenomenon. The apparatus consists of four Bunsen elements **ABCD**, in which the end of the zinc cylinder **Z** in vessel **A** is connected with the carbon rod **K** of vessel **B**, that of the zinc cylinder **B** with the carbon rod of **C**, that of the zinc cylinder **C** with the carbon rod of **D**, while copper wires are fixed to the carbon rod of **A** and to the zinc cylinder of **D**. These wires may not touch one another at any point. If we connect the ends of the two copper wires with the two small platinum wires **p** that have been inserted opposite each other into the glass tube **R**, which is filled with water and placed upside down into the glass dish **W**, we can immediately observe that small bubbles are produced; these grow fast, rise up and cause the water to become effervescent. The water rapidly sinks in the tube; apparently air has collected above the water. However, we get a better understanding of what happens with the water when electricity flows through it, if we change our apparatus slightly. Let us replace the tube **R** with two tubes, each of which is infiltrated with a platinum wire **p**, as in **figure 55**. Here again, as soon as we have connected the two copper wires with the two platinum wires, small bubbles begin to form in both tubes; these rise up and collect above the water, so that the level of the water gradually falls. At the same time, the water virtually maintains its original temperature. Thus, what collects in the top part of the two tubes certainly cannot be steam; it has to be a gaseous substance at a normal temperature, such as the air that surrounds us. Thus, a kind of air, a gas has been produced in both of the two tubes, and as a closer examination easily shows, a special gas that is different to the air of the atmosphere has been produced in each tube. What we first notice is that the level of the water does not fall equally in the two tubes, so that the amount of gas produced at every moment in one of the tubes (of which the platinum wire is connected to the zinc cylinder in the battery) is far greater than that in the other tube; and if we know exactly what the two tubes contain, we see that there is always exactly double the amount of gas in the one tube as compared to the other. For example, if two cubic centimeters of gas have collected in the one tube, there are four cubic centimeters in the other; if after a few minutes, the amount of gas in the first tube has increased to three cubic centimeters, in the same amount of time, the quantity of gas in the second tube has risen to six cubic centimeters, and so on. Moreover, if after interrupting the current, we lift the two tubes out of the water, having sealed their open lower side with our finger, and if we turn them around and immediately place a burning candle to the opening of the tubes, the gas in the tube containing the greater amount of gas catches fire and burns with a bluish, hardly glowing flame, whereas the gas in the other tube does not catch fire. In contrast, this second kind of gas manifests another characteristic, which makes it easily recognizable; if you place an extinguished but still smoldering candle inside the tube, immediately the candle will begin again to burn brightly and with far greater intensity than in ordinary air. These two gasses were produced from the water; they must have been in the water. Every amount of water, even the smallest, whether it is in a solid, liquid or gaseous state, produces these two gasses as a result of the influence of an electric current. It follows that these gasses must be present in every water molecule, they must be components of these. The inflammable gas has been called hydrogen, and the second one oxygen, because **Lavoisier**, who gave this gas its name (oxygen, producer of acid) mistakenly believed that it was a component of all sour substances, of all acids.

From this example we can see not only that we are capable of changing the water molecules even more, but also that the relation between the volumes of the gaseous components of water molecules is very simple: for every one volume of oxygen, two volumes of hydrogen are produced from the water; thus, for every one volume of oxygen there must also be two volumes of hydrogen in the water, or rather, in every water molecule.

However, not only water but all compounded liquid and gaseous substances can be split, if it is at all possible for electricity to flow through them, and two components of these substances are produced respectively, by discharging one component at the one end of the conducting wire, the one "pole", and the other component at the other one. Thus, if we can carry out the experiments in the same way as when we take apart the water, which is to say that the two results produced by taking apart the submitted substances can be collected separately from one another, we are already able to split in this way a very large number of substances into two simpler components. For the sake of understanding better, we shall give a few examples.

We shall use first of all hydrochloric acid, which is used for so many commercial purposes and thus generally known as a liquid with a penetrating smell, which when exposed to air, forms a mist; even after being strongly diluted with water, it still has a strong sour taste. This liquid is nothing other than a solution of hydrochloric acid in water. For pure hydrochloric acid at ordinary temperatures is a gaseous object with a penetrating smell; it is colorless and therefore not visible, but as soon as the container holding it is opened, so as soon as it comes into contact with atmospheric air, it forms thick white mist. In addition, it is extremely easy to dissolve in water, so that when a vessel filled with hydrochloric acid is opened under water, the water rushes into the vessel with as much force as if the vessel had been vacuous. Because hydrochloric acid gas is easily dissolved in water, what is used is always the watery solution of the gas, and for our experiment, we can also use watery hydrochloric acid.

If we let a strong galvanic current flow through an apparatus that is very similar to the one we used to split the water and that is filled with hydrochloric acid diluted in water, in this case too, we can see that little gas bubbles soon rise up in each of the two tubes, but in contrast to what happens when we split the water, we see 1) that the amounts of gas collecting in the two tubes always remain equal, and 2) that only the one gas is colorless, whereas the other is yellowish-green. If we interrupt the experiment and examine the gasses, we can immediately recognize the colorless gas to be hydrogen because of its inflammability, so the same gas that we also obtained from water; on the other hand, with the second gas we are faced with a new substance, which because of its color was given the name chlorine (*chloros* means yellowish-green). Thus, hydrogen and chlorine must have been present as components of hydrochloric acid. With the help of the galvanic current, we have split the hydrochloric acid into hydrogen and chlorine.

In the same way, we are able to split the liquid that is commercially usually called ammonia by means of an electric current. For in its pure state, ammonia is a gaseous substance, but like hydrochloric acid, it is so easily dissolved in water, that we can use such a watery solution instead of the gas itself, not only in its every-day use, but even in our case. Incidentally, ammonia is sufficiently characterized by its strange and very penetrating smell. If we now let an electric current flow through the two tubes shown in **figure 55** that are filled with a solution of ammonia, we will again observe that gas bubbles rise up in both tubes. But at the same time, we will observe that the gasses collecting in the upper part of the tubes are both colorless, and that in the one tube there is three times as much gas collected as in the other tube. For as soon as six cubic centimeters of gas have collected in the one tube, there are only two cubic centimeters in the second tube, and so forth. If we examine the contents of the two tubes after the electric current has had enough time to work, so after a sufficient amount of the two gasses has been formed, the gas that has been produced in a triple quantity is immediately recognizable as hydrogen because it is easily inflammable, whereas the gas in the second tube is neither inflammable nor does it cause a smoldering candle to burn brightly; it even causes a burning candle that is held into it to go out completely and immediately. When this gas, which is colorless and has no smell, was discovered, it was observed that animals immediately suffocate in it, so it was called nitrogen (*translator's note: the German name* Stickstoff *means literally suffocating substance*). Thus, ammonia must contain the components hydrogen and nitrogen.

But by means of a galvanic current, we can also split substances that are solid at normal temperatures, on condition that we have previously somehow transformed them into a liquid state. For example, if we heat our ordinary cooking salt until it is red hot, it melts to a colorless fluid, and if then, while observing certain precautionary measures, we let a galvanic current flow through the molten salt, gas bubbles rise up at the positive pole, and we can easily recognize these to be chlorine because of the yellowish-green color and the suffocating smell that causes us to cough. At the same time, small, shiny metallic little spheres stick to the negative pole; because of the high temperature, these are molten, but at normal temperatures they are solid. In humid air, these spheres rapidly lose their shine, and when thrown onto water, they immediately begin to rotate violently, then melt and gradually disappear. But if they cannot begin to rotate so rapidly in the water, for example because rubber slime was used instead of pure water, they catch fire after a short time and burn with an intensively yellow color. This substance, which is obtained from cooking salt by means of the galvanic current, is in every way recognizable as a metal and has been called sodium. Thus, the components contained in cooking salt are gaseous chlorine and metal sodium.

In the same way, for example, we can dissolve in water the corrosive sublimate used particularly for medicinal purposes, thus transforming it into a liquid state, and then conduct the galvanic current through the solution. In this experiment, we would again see small gas bubbles rising up at the positive pole, which we could easily recognize as chlorine because of their color and smell, and at the negative pole we would see a liquid metal being discharged, which we could immediately recognize as mercury. Thus, chlorine and mercury are obtained from the sublimate, which means that these two substances must be components of the sublimate.

As we can see from all these examples, with the help of a galvanic current (we will get to know other methods later), we are able to change a large number of substances in such a way that the molecules of the substances are totally transformed. We call this kind of change in the objects' state, which causes the essential characteristics of these objects to undergo a complete change, **chemical** phenomena, in contrast to the physical phenomena in which the substances' molecules remain intact.

Thus, by means of the effect of a galvanic current, we have become acquainted with a method that allows us to split a large number of substances into their components, as soon as these substances are in a liquid state.

Now all substances that by some means can be split into several different objects are called **compounds**. By far the majority of substances that can be found in nature and that the chemist produces synthetically in the laboratory are compounds. However, compared to the infinitely great number of different substances, there are a number of substances – and these are not really very numerous - that people have so far not succeeded in splitting further. These substances, which include oxygen, hydrogen, nitrogen, chlorine, sodium and mercury, are called simple substances that cannot be taken apart, **elements**. Thus, the concept "element" has been taken up by the science of chemistry and has received an entirely different meaning to the one it had before. For natural science, elements are those substances that, with the methods available to us today, are considered to be simple objects that cannot be split into other components. But in saying this, there is certainly no intention to deny that it might be possible in the future to split all elements or perhaps some of them into even simpler substances.

The use of a galvanic current allowed us to cause a kind of chemical change, that is, the **splitting of substances into their components**. But in most cases, the opposite path, that is the production of compounds from their components, is also open to us. For example, if we mix hydrogen and oxygen with one another in the same proportion as we obtain from water, that is, with two parts hydrogen to one part oxygen, and if we set the mixture on fire, they produce water in a most violent explosion and with a deafening bang. Because of the violence of the explosion in which hydrogen and oxygen unite to become water, we may only ever set on fire a few cubic centimeters of this mixture.

From this example we see that hydrogen and oxygen are the only components of water, for they are enough to produce water; moreover, we see that we are not only able to split the water into its components, but we are also able to assemble it from its two components, to produce it synthetically. In the same way, we are able to synthetically produce hydrochloric acid from hydrogen and chlorine, cooking salt from sodium and chlorine, and the sublimate from mercury and chlorine, but we are not able to synthetically produce ammonia from nitrogen and hydrogen.

However, already early on a very surprising law was recognized in the unification of the elements making up the compounds, and of course also in the splitting of the compounds into their elementary components, and this law gives deep insight into the nature of the substances. Not just any arbitrary amount of hydrogen is able to connect with any arbitrary amount of oxygen; rather, what unites is always only two volumes of hydrogen with one volume of oxygen. Of course, we can produce a mixture of hydrogen and oxygen in any relation to one another. For example, if we prepare a mixture of 10 cubic centimeters of hydrogen and 10 cubic centimeters of oxygen, so a mixture of equal volumes of both gasses, and if we set this mixture on fire, for example by means of an electric spark in a closed space, we will obtain water by means of the explosion, but at the end of the experiment, we will find five whole cubic centimeters of oxygen as such, which is to say that, together with the 10 cubic centimeters of hydrogen, the water produced used up only five cubic centimeters of oxygen, so only half of the volume of the hydrogen. Consequently, under all circumstances, even when the two gasses have been mixed in arbitrary proportion to one another, the formation of water out of its two components hydrogen and oxygen always occurs in such a way that one volume of oxygen unites with two volumes of hydrogen. Both in splitting water into its components and in forming water out of its components, the proportion of the two components is perfectly constant, unchangeable.

The same is true of hydrochloric acid, cooking salt, sublimate, yes, of the almost innumerable substances that have been studied to date.

The regularity under discussion can be seen even more clearly if we examine the weight of the elements that unite with one another.

However, where this is concerned, we must begin with a short comment. The weights that are valid for us in our daily dealings refer to a unit that was chosen arbitrarily. There is no absolute weight unit, and since the weight of an object is nothing other than the size of the force with which the respective object is attracted by the earth, in other words, the pressure exerted by the object on its base, we use any object, the weight of which we compare with the weight of the object to be studied. But in order to be better able to compare the weights of the various substances in our daily dealings, an arbitrary weight was chosen as the unit, and at various times and in various countries, differing units of weight were accepted. In Germany, almost every small State had a special pound weight until the French Revolution, when a commission of scholars suggested the weight of a cubic centimeter of water at its greatest density, at 4.1°, as the unit. This unit of weight, which was accepted not only in France, but in almost all Latin peoples and now also in Germany, is the **gram**. However, for the needs of the chemist, in observing the proportions of elementary substances that unite in compounds, it turned out to be far easier to use not the gram as the basic unit of weight, but rather the weight of one volume of hydrogen. Thus for example, oxygen is sixteen times as heavy as hydrogen, chlorine 35.5 times, nitrogen 14 times as heavy as an equal volume of hydrogen that is weighed under the same pressure and at the same temperature. Thus, in the examples discussed above, when water, hydrochloric acid, and ammonia were split, we can also express the quantitative relations by saying as follows:

> When water is split, for every two weight units of hydrogen, 16 weight units of oxygen are produced (since each volume of oxygen weighs 16 times the weight of the same volume of hydrogen, and in splitting water, for every volume of oxygen, two volumes of hydrogen are produced). Also, when hydrochloric acid is split, for every weight unit of hydrogen, 35.5 weight units of chlorine are produced (because in splitting hydrochloric acid, exactly the same volume of hydrogen and of chlorine is produced, and chlorine is 35.5 times as heavy as hydrogen). Finally, in splitting ammonia, for every three weight units of hydrogen, 14 weight units of nitrogen are produced.

In the same way, two weight units of hydrogen always unite with 16 weight units of oxygen to make water, one weight unit of hydrogen unites with 35.5 weight units of chlorine to make hydrochloric acid, etc.

The weight of the water that has been obtained from two weight units of hydrogen and 16 weight units of oxygen is exactly 18 weight units, just as the weight of hydrochloric acid, which is formed from one weight unit of hydrogen and 35.5 weight units of chlorine, is exactly 36.5 weight units. In the same way, it was discovered with all compounded substances that the weight of the compounded substances made up of the elementary components always equals the sum of the weight of all the components that form it, just as the sum of the weight of all the components obtained from a compound always equals the weight of the substance that was split. This fact, which seems so obvious at first sight, has become as important to our understanding of nature as it is obvious, because it shows us that with all the changes that the substance undergoes, its mass is neither diminished nor increased, the substance as a whole always remains the same in its mass; only its form changes. We could call this fact **the law of the preservation of matter**. From this law follows that matter as such is everlasting.

We get an even clearer insight into the essence of chemical occurrences if we compare the relationship between the space occupied by a gaseous compound and the space taken up by the components in a gaseous state. One spatial volume (or one weight unit) of hydrogen unites with one spatial volume (or 35.5 weight units) of gaseous chlorine to form 36.5 weight units of gaseous hydrochloric acid. Measured under the same conditions as its components, this amount of gaseous hydrochloric acid fills exactly two spatial volumes. Accordingly, there is absolutely no change in the space occupied when the mixture of chlorine and hydrogen unites to become hydrochloric acid. Two spatial volumes of gaseous hydrochloric acid weigh 36.5 times as much as one spatial volume of hydrogen, or the gaseous hydrochloric acid weighs 18.25 times as much as its equal volume of hydrogen.

If on the other hand, two spatial volumes (that is to say, two weight units) of hydrogen unite with one spatial volume (that is to say, 16 weight units) of oxygen to form water, the water produced from three volumes of the mixture, occupies the space of two volumes as a gas; in the unification of the two gasses, a contraction occurs. Thus, since the 18 weight units of water only fill two volumes when they are steam, the gaseous water is nine times as heavy as its equal volume of hydrogen, when both are measured under the same pressure and at an equal temperature.

Moreover, although we are not able to produce ammonia from hydrogen and nitrogen, it is easy to split completely the gaseous ammonia by persistently letting an electric spark flow through it. When we do this, we see that after its complete splitting, the volume of the gaseous ammonia has doubled. But as we know, the gas produced in this way is a mixture of one volume of nitrogen with three volumes of hydrogen, and these four volumes of the gaseous mixture were produced out of two volumes of ammonia. So here, too, the volume of the compound was two, although the sum of the volumes of its components equaled four.
From this we see that in gaseous elements that unite to form a compound, the amount of space occupied is in a simple and constant relation to one another, but that the relations can be different in the various substances, since with hydrogen and chlorine, the spatial relationship is 1:1, with hydrogen and oxygen it is 2:1, with hydrogen and nitrogen 3:1. In contrast, we see in the same way that in all three examples, the spatial volume of the compounds formed is the same, so of gaseous hydrochloric acid, steam from water, gaseous ammonia, that is to say, double the amount of chlorine, oxygen, nitrogen.

On the other hand, we learned above that when gaseous substances are contained in equally large spaces, the same number of molecules is present. It follows, that the same number of molecules of hydrochloric acid are produced from one volume of chlorine and one volume of hydrogen, as are produced from one volume of oxygen and two volumes of hydrogen, and finally as from one volume of nitrogen and three volumes of hydrogen. If we now assume that in every molecule of hydrochloric acid there is one weight unit of hydrogen, it follows that there must also be 35.5 weight units of chlorine in every molecule; in the same way, every molecule of water must contain two weight units of hydrogen and 16 weight units of oxygen, and every molecule of ammonia, three weight units of hydrogen and 14 weight units of nitrogen. Moreover, the following important theorem follows from the assumption that every molecule of hydrochloric acid contains one weight unit of hydrogen: Every molecule of hydrochloric acid fills two volumes, and since with gaseous substances, the same number of molecules are present in an equal space, it follows that:

> In the gaseous state, the molecules of all substances fill two volumes, when one volume of hydrogen is taken to be the weight unit.

It is completely immaterial how large or small the weight unit is and thus the volume of the hydrogen, since we are dealing with nothing but a relative weight between hydrogen and the other objects.

As has been said, in every molecule of hydrochloric acid there are 35.5 weight units of chlorine. But we know an extraordinarily large number of substances, of which chlorine is a component along with a great variety of other substances. After transforming these compounds into a gaseous state, the amount of chlorine was determined in two spatial volumes respectively, which is to say, according to an equal number of molecules. In so doing, it was discovered that in all the compounds studied (in two volumes), there were either 35.5 or 71, so twice 35.5, or 106.5, so three times 35.5 weight units of chlorine, etc. Expressed in a generalized way: these compounds always contain either 35.5 or a multiple of 35.5 weight units of chlorine. So it was very natural to come to the conclusion that 35.5 weight units are the smallest amount of chlorine that can be found in a compound.

Similarly, we know of thousands of compounds that contain oxygen along with other elements. And all of these compounds, insofar as they have been studied in a gaseous state, always contain in every two volumes either 16 or 32 or 48, etc. weight units of oxygen, so either 16 weight units or a multiple of this amount. It follows that we are forced to conclude that 16 weight units of oxygen are the smallest indivisible amount that can be contained in any compound.

From this developed the idea that the molecules consist of small elementary mass particles that have a specific unchangeable weight; their form is just as unknown to us as that of the molecules, but we can discover their weight in relation to one another. These elementary mass particles are called **atoms**.

We will take the weight of an atom of hydrogen as a unit. Now since a molecule of hydrochloric acid contains 35.5 weight units of chlorine for every one weight unit of hydrogen, or for every atom of hydrogen, which is the same thing, and since we also saw that all substances containing chlorine as a component always have 35.5 weight units of that element or a multiple of this amount, we can take 35.5 weight units of chlorine to be an indivisible whole; thus, we must also consider 35.5 weight units of chlorine to be one atom of chlorine, that is to say, we are justified in assuming that every atom of chlorine weighs 35.5 times as much as one atom of hydrogen.

By means of the same deduction, where oxygen is concerned, we reach the conclusion that every atom of oxygen has a weight of 16, that is to say, it is 16 times as heavy as a hydrogen atom.

In the same way it has also been found that every atom of nitrogen, that is, the smallest indivisible amount of this element that can be in any compound containing it, weighs 14 times as much as a hydrogen atom.

But we express these relations more simply by saying that the weight of the hydrogen atom, or also its compound weight, equals one, that of chlorine equals 35.5, that of oxygen equals 16, that of nitrogen equals 14.

If we apply this new way of seeing to the three examples we discussed previously, the compound relations of the four elements hydrogen, chlorine, oxygen and nitrogen in hydrochloric acid, water and ammonia can be expressed more briefly:

> Every molecule of hydrochloric acid consists of one atom of hydrogen and one atom of chlorine; every molecule of water consists of two atoms of hydrogen and one atom of oxygen; every molecule of ammonia consists of three atoms of hydrogen and one atom of nitrogen.

However, before discussing the consequences of these conclusions, we must first explain how we can determine the weight of a molecule, of course always in relation to hydrogen. We just accepted to take an arbitrary volume of hydrogen as the weight unit; on the other hand, we also want to fix the compound weight of hydrogen as one. Thus, an arbitrarily small volume of hydrogen will have to be a hydrogen atom. On the other hand, such a volume (or atom) of hydrogen united with an equal volume of chlorine produces two volumes of hydrochloric acid, and since in every molecule of any compound there must be at least one atom of every elementary component, it follows that the molecule of hydrochloric acid must fill a space twice the size of the space occupied by the hydrogen atom; every molecule of hydrochloric acid must occupy two volumes, if one hydrogen atom takes up one volume. Furthermore, since with gaseous substances in equally large spaces, the same number of molecules are present, the molecules of all gasses must fill two volumes. Thus, all we need to do is determine the weight of any volume of any substance in the gaseous state, compare this weight with that of an equally large volume of hydrogen, and double the number resulting from this in order to find the molecular weight of the respective substance. Thus for example, one liter of gaseous hydrochloric acid at 0° centigrade and under the pressure that is on the earth's surface, so under the pressure of a mercury column of 760 millimeters, weighs 1.6350 grams. One liter of hydrogen under the same conditions weighs 0.0896 grams; accordingly, the hydrochloric acid weighs 18.25 times as much as the hydrogen. Double the last number gives 36.5, a number that in fact corresponds with the molecular weight of hydrochloric acid. One liter of steam from water at 100° centigrade and under the pressure of 500 millimeters of a mercury column weighs only 0.3362 grams, one liter of hydrogen under the same conditions only 0.03735 grams; accordingly, the steam from water is nine times as heavy as hydrogen, its molecular weight is thus 2 x 9 = 18.

With the help of the hypothesis first set up by **Avogadro,** that with gasses in equally large spaces an equal number of molecules are present, we are able to determine accordingly the weight of the atom of a large number of elements, on condition that a sufficiently large number of gaseous compounds containing the respective element are known. The best example for this is coal, or rather, as chemists call it in its pure state, carbon.

For when it is closed off from air, no amount of heat can transform carbon into a liquid state, and even less into a gaseous one. But thousands of compounds are known that contain carbon as a component and that are gaseous, either at ordinary or at higher temperatures. All of these compounds contain in every two volumes either 12, or 24 = 2 x 12, or 36 = 3 x 12, or 48 = 4 x 12 weight units of carbon. We can therefore assume that the smallest weight of carbon that can be contained in any compound is no less than 12, in other words, that the carbon atom weighs 12 times as much as the hydrogen atom.

We can make another interesting deduction by means of Avogadro's hypothesis. Starting with the assumption that one hydrogen atom should have the weight 1, we have discovered that the weight of the oxygen atom is 16, that of nitrogen 14, that of chlorine 35.5, and at the same time, we saw that one volume of each of these four gasses respectively has the weight stated. But on the other hand, we have discovered that every molecule fills two volumes, from which follows that every molecule of hydrogen must consist of two hydrogen atoms, every molecule of oxygen of two oxygen atoms, every molecule of nitrogen of two nitrogen atoms, and finally, every molecule of chlorine of two chlorine atoms. Thus, the molecules of the elements named each consist of two atoms that are connected to one another, but that are identical to one another. Whereas in every molecule of hydrochloric acid, one hydrogen atom and one chlorine atom are united, every molecule of chlorine is made up of one chlorine atom united with one chlorine atom, and every molecule of hydrogen of one hydrogen atom united with another hydrogen atom. So we see that the difference between simple objects and compound ones is merely that in compounds, the atoms that are united to form a molecule **differ** from one another, whereas in elements, the atoms united to form a molecule are **identical** with one another. In order to get even a somewhat rough idea of what atoms looks like, let us imagine them as small spheres, and in order to characterize these better, we shall give them a letter. Thus we could visualize every molecule of hydrogen by means of the sign H H , every molecule of chlorine as Cl Cl , whereby we accept that the little sphere shown by H (H) means a hydrogen atom, that by Cl (Cl) a chlorine atom; then the formation of hydrochloric acid out of hydrogen and chlorine could be visualized by means of the following image: H H and Cl Cl give H Cl and H Cl . But that means nothing other than that when, under suitable conditions, hydrogen molecules encounter chlorine molecules, the hydrogen atoms separate from the hydrogen atoms in the hydrogen molecules, and at the same moment, the chlorine atoms separate from the chlorine atoms in the chlorine molecules, to produce a molecule of hydrochloric acid. Or in other words: in every hydrogen molecule (H H), two hydrogen atoms are linked to one another with a certain force, the strength of which we of course do not know, just as in every chlorine molecule, two chlorine atoms are bound to one another with a certain force; if the hydrogen molecules meet with the chlorine molecules under suitable conditions, for example in sun light, the force of attraction between the hydrogen atoms and the chlorine atoms manifests itself. Now this force is greater than the force of attraction between the hydrogen atoms among themselves and the chlorine atoms among themselves, so that a transfer of the atoms occurs, and new molecules are formed (hydrochloric acid).

In exactly the same way, we can explain the formation of water from hydrogen and oxygen as being simply a transfer of the atoms to new molecules. If we call an oxygen atom O (O), then every molecule of oxygen must be called O O. Every molecule of water consists of two atoms of hydrogen and one atom of oxygen, so that we have H H / H H and O O resulting in H H O and H H O. The sign H H O signifies a molecule of water. This image shows us that under suitable conditions, the hydrogen atoms from two molecules of hydrogen and at the same moment, the oxygen atoms from one molecule of oxygen tear themselves free and in the next moment they have all transferred in such a way as to produce two hydrogen atoms with one oxygen atom each, thus forming a new molecule.

As our examples so far have shown us, chemical or substantial changes are changes in which the atoms in the molecules separate from one another in order to regroup as new molecules. And such a transfer of atoms from the molecules that meet one another to new molecules occurs when the force of attraction between the atoms of the molecules of the various substances is greater than the force of attraction of the atoms among themselves in the existing molecules. But in saying this, we must take into consideration that the force of attraction between the atoms, or as we can call it more appropriately, the chemical force of attraction, can only take effect if the molecules of the various substances can approach one another up to an infinitely tiny distance. Thus, chemical transformations also only occur if the molecules of the various substances can move easily. For if we mix two solid objects, even when they are the finest of powders, the individual grains are much too far from one another for the chemical forces of attraction to become effective. Such a chemical transformation can only occur with fluid and gaseous substances that are mixed together, if the other conditions for a transfer of atoms are present. That is why already the ancient alchemists set up the theorem: *corpora non agunt nisi fluida*, objects effect one another only in a liquid state, whether this be the liquid state that can form drops or the liquid state in the form of air. We can transform solid objects into the fluid state both by melting them through heating and also by dissolving them in some fluid that does not at all have to participate in the chemical transformation, in the chemical reaction. The purpose of the fluid is merely to give the molecules of the solid object the easy mobility that is necessary for the chemical transformation.

We recognized that the most essential cause for a chemical transformation to occur is that the attraction of the atoms in the molecules of the one substance to the atoms in the molecules of the other substance is stronger than the attraction of the atoms within the molecules to one another. It therefore goes without saying that such chemical transformations can occur not only between the molecules of substances that are elements, as the formation of hydrochloric acid from hydrogen and chlorine molecules and that of water from hydrogen and oxygen molecules shows, but also between the molecules of an element and those of a compound, as well as between the molecules of two compounds. And in fact, most chemical changes occur in this way. For example, as we saw above, cooking salt is a compound from chlorine and the silvery white, very shiny metal sodium. If we throw a little piece of this metal, that for technical reasons is produced in large quantities, onto water, it remains on the surface, because it is lighter than water, and after a very short time it melts, gathers together into a ball and rolls back and forth with extraordinary speed while becoming smaller and smaller and finally disappearing entirely. If we prevent the ball of sodium from rolling around by using tough rubber slime instead of pure water, the sodium begins to burn after a short time, and it burns up with a yellow flame and spreads white smoke. What becomes of the sodium in the one case and the other? Why does the metal become so hot that it melts and even begins to burn as soon as it meets with the water? We easily get information on this if, after throwing the sodium onto the water, we quickly press it underwater with a spoon that has holes like a sieve and place a glass pipe over it that is filled with water, closed at the top and open at the bottom. Then, while the water sinks ever further down, the pipe rapidly fills with a gas that we can easily recognize as hydrogen because of its inflammability. So as soon as the sodium comes into contact with the water, hydrogen is produced by the metal, of course from the water. If we then turn the water into steam, what finally remains is a white solid mass that tastes very strongly of lye, feels greasy, has a strong corroding effect and is known as caustic soda or soap stone, although of course soap stone is produced by other means. Caustic soda is a compound made of sodium with oxygen and hydrogen, and we now understand the chemical process that occurs when sodium thrown on water disappears while forming hydrogen. If, as we did above, we again imagine the water molecule, as a conglomeration consisting of three small spheres, one of which is oxygen (O) and the other two hydrogen (H), and the sodium molecule as a conglomeration consisting of two small spheres of atoms (Na Na), the process can be shown in the following image: as soon as Na Na , that is to say, a molecule of sodium, meets with H H O / H H O , so with two molecules of water, the force of attraction of the oxygen to the sodium takes effect, as it is far greater than the force of attraction of the oxygen atoms on the hydrogen atoms and of the sodium atoms among themselves, and for a moment, the sodium atoms separate from one another, as does one hydrogen atom from the oxygen atom in the molecule of water. The sodium atom settles in place of the hydrogen atom that is tearing itself away, while two hydrogen atoms unite to form a molecule, so that the next moment we have one molecule of hydrogen H H and two molecules of caustic soda Na H O / Na H O before us. However, the molecules of caustic soda easily dissolve in water, of which a very great amount is present in our experiment, and the hydrogen molecules are gaseous, so that they escape, which is why we see the sodium that was thrown onto the water disappear gradually, which is to say, at the same speed at which the transformation progresses.

If we throw a piece of iron into water, no chemical phenomenon occurs; the iron sinks down into the water, at first without any further change. But if we heat the iron in a porcelain pipe until it is red hot, and if we let steam from water flow through the pipe, the water will be corroded by the iron, gaseous hydrogen is produced, which is easily recognized by its inflammability, and the water's oxygen compounds with the iron to form a solid black mass. Thus, whereas sodium is able to split the water already at an ordinary temperature, that is to say, to cause the hydrogen to tear away from the oxygen, and to then settle in its place in the water molecule, iron only becomes able to do this when it is red hot; only when it is very hot does the power of attraction of iron to oxygen become great enough to be able to overcome the attraction of hydrogen to oxygen.

But if we place a piece of iron into a water solution of hydrochloric acid, the fluid immediately becomes quite effervescent, a large amount of gas develops, and we can again recognize it as hydrogen because it is easily inflammable; at the same time, the iron gradually disappears in the fluid while coloring it light green. We will now easily understand that the iron unites with the chlorine in the hydrochloric acid, and we will have to accept that this compound of iron with chlorine is present in the fluid. And if we transform the fluid into steam after the iron has disappeared, what remains is in fact a light green mass that is a chemical compound of chlorine and iron. We hardly need to show this chemical process again in an image.

Furthermore, if we pour a watery solution of hydrochloric acid into a solution of caustic soda or soap stone, very great heat is produced even to the point of boiling, and if we transform the fluid, which had remained clear, into steam, we obtain neither hydrochloric acid nor caustic soda again, provided we did not use too much or too little hydrochloric acid. Rather, when most of the water has turned into steam, small cubes finally separate, which we can easily recognize as cooking salt by their taste and because of all their other characteristics.

What change took place here with the caustic soda and the hydrochloric acid? No matter how close the relationship between sodium and oxygen might be, as we saw above, sodium's force of attraction to chlorine is even greater. So if we remember the form of the caustic soda molecule $Na\ H\ O$, as well as that of hydrochloric acid molecules $H\ Cl$, we will easily understand that the sodium atoms tear away from the oxygen atoms in the molecules of caustic soda as soon as the caustic soda molecules meet with the molecules of hydrochloric acid, and at the same time, the hydrogen atoms tear away from the chlorine atoms; in the next moment, they all resettle in such a way that the sodium atoms join with the chlorine atoms and the hydrogen atoms with the oxygen atoms, so that instead of having $Na\ H\ O$ and $H\ Cl$, we now have $H\ H\ O$ and $Na\ Cl$ in the fluid, that is to say, merely water molecules and sodium chloride molecules. And the latter is nothing other than ordinary cooking salt.

However, before continuing with further discussion of our reflection on chemical changes, we first want to touch on something that, when looked at superficially, has a deterring effect on people who are not chemists, because it seems to be difficult. And yet, it belongs to the simplest, clearest and most easily understood matters in chemistry. That is the chemical sign language or rather, chemical stenography. For as soon as it had been recognized that the make-up of all compounds is constant, that is to say, that the elements in any compound are always contained in the same quantitative proportions in the compound, so for example that hydrochloric acid always contains 35.5 weight units of chlorine to one weight unit of hydrogen, water always contains 16 weight units of oxygen to two weight units of hydrogen, etc., and when scientists had been forced to acknowledge the existence of the smallest indivisible particles of a substance, of atoms, the necessity was also felt of expressing this fact in a precise way in writing. Thus, chemical shorthand was invented. It expresses all chemical processes in such a simple and clear way that, without hesitation, chemical shorthand can be called one of the best and most elegant forms of shorthand that was ever used for any purpose. For every element was called by the first letter of its name, whereby this was limited, so that the letter always means the smallest amount of that element that is present in compounds, in other words, the amount that corresponds to an atom of the respective element. For us Germans, this way of naming the elements is of course complicated by the fact that we use the same letters for naming the elements as the other nations, so that the first letters used are not those of the German names, but of the international names.

We must also take into consideration that we now know some seventy substances that cannot be divided, so that there are almost always a larger number of names of elements that begin with the same letter. That is why the first letter alone has only been used for the most important of the elements beginning with a particular letter, whereas for the other elements, in addition to the first letter of the element's name, a second letter, usually but not always the second letter, is used to signify it. Thus for example, the sign for iron is Fe, derived from the Latin word ferrum, but for silver it is Ag, from the Latin argentum, and not Ar. Thus, the most important elements of which the German names are immediately recognizable as translations of their international names, are symbolized by letters that have no relationship to the German word.

The German word for hydrogen [*Wasserstoff* = water substance] is a translation of the word hydrogenium, which means the substance that is produced from water or also that produces water; that is why hydrogen is signified by the letter **H**. Oxygen – oxygenium – means the substance producing acids, and among all peoples it is symbolized by the letter **O**. Nitrogen [in German suffocating substance] is the translation of the word formed by Lavoisier to signify this gas, **azote**, which is to say the substance that annihilates life, that brings about death through suffocation, and until today, the chemical sign **Az** is still used in France to symbolize it. But another international name for nitrogen has been accepted far more, and that is nitrogenium, which is to say, the substance produced from saltpeter (niter), and therefore the sign **N** is used for nitrogen. Now, none of the other elements are difficult. Thus, chlorine is signified by the letters **Cl**, iodine by the letter **J**, sulphur by the letter **S**, phosphorus by the letter **P**, carbon by the letter **C**, sodium [in Latin natrium] by the two letters **Na**, etc. But as was already mentioned, these letters do not mean just any amount of the respective element, but rather always the amount with which the element enters into its compounds. Thus the chemical sign **H** always means one weight unit of hydrogen, the sign **O** always 16 weight units of oxygen, the sign **N** always 14 weight units of nitrogen, the sign **Cl** always 35.5 weight units of chlorine, the sign **Na** always 23 weight units of sodium, the sign **C** always 12 weight units of carbon, etc.

The importance of this shorthand only becomes apparent in the way compounds are symbolized. We already know for example, that hydrochloric acid consists of one weight unit of hydrogen and 35.5 weight units of chlorine, and the symbol for hydrochloric acid is therefore HCl, that is to say, without any more ado, we place the letters signifying the two elements next to one another. The symbol HCl shows us first of all that we have before us a compound and not a simple substance, and then that this compound consists of hydrogen and chlorine, and that it contains 35.5 weight units of chlorine to every one weight unit of hydrogen. Thus we write cooking salt as NaCl and recognize from this that cooking salt is a compound of the metal sodium with chlorine and that in it, 23 weight units of sodium are compounded with 35.5 weight units of chlorine.

Moreover, the chemical sign for caustic soda is NaHO, that is to say, caustic soda consists of three elements, the metal sodium, hydrogen and oxygen, and for every 23 weight units of sodium, it contains one weight unit of hydrogen and 16 weight units of oxygen.

On the other hand, those compounds that contain more than one atom of one or more elements - such as water, for example, of which we know that every molecule contains two atoms of hydrogen for every one atom of oxygen – are written in such a way as to indicate the number of atoms of the respective element by means of a small numeral written after the element’s letter, either under or above the line. The chemical symbol for water is H^2O, that is to say, every molecule of water contains two atoms or two weight units of hydrogen (H^2) to one atom or sixteen weight units of oxygen. Of course, we could also write the symbol for water as HHO, but in particular with the more complicated compounds, writing them in this way would take away from their simplicity and thus from their clarity.

Already to write ammonia, which as we know consists of three weight units of hydrogen and 14 weight units of nitrogen (we express 14 weight units of nitrogen by means of the symbol N), this latter way of writing – which would be HHHN - would become awkward; it is therefore far more concise and just as understandable to write ammonia by means of the symbol H^3N.

After what has been said, we will easily understand the symbol, the formula C^2H^6O. It signifies a compound, the elements of which are carbon (C), hydrogen (H), and oxygen (O); and every molecule of this compound contains 2 x 12 or 24 weight units of carbon (for according to what was said above, every C stands for 12 weight units of carbon), six weight units of hydrogen, and 16 weight units of oxygen. This compound is nothing other than ordinary alcohol or alcohol without water.

From what has been said so far it can be seen how important it is for recognizing and understanding compounds to not only study the elementary components, but also the size of the atoms, to know the weight of the elements’ atoms, so to know the amount of minimum weight of the respective element that must be contained as indivisible in any compound. It is easy to find the size of the atom if we know a large number of compounds containing the element that are gaseous either at ordinary temperatures, or that can be transformed into a gaseous state through heating. All we have to do then is to determine the molecular weight of these compounds by seeing what their weight is in a gaseous state compared to the weight of hydrogen at the same temperature and under the same pressure, and calculating how many weight units of the element, the weight of which we want to determine, are contained in the amount of weight representing one molecule, that is to say, the double volume of all these compounds. It is then easy to find the amount of weight that is present either as such or double its amount or triple, etc. in the compounds. The greater the number of gaseous compounds formed by the respective element, the greater will be the certainty with which the weight of the element's atom can be deduced.

Already of the 74 elements known to us now, there is a considerable number that do not form a single compound that can be transformed into a gaseous state. Where these elements are concerned, we would be completely ignorant as to the size of their atoms, if another method had not been discovered that allows us to determine with certainty the weight of their atoms. And precisely the most important metals such as copper, nickel, silver, gold, platinum are such elements. Compounds containing these metals and oxygen, for example, are known, and in them 16 weight units of oxygen, which is the equivalent of one atom of oxygen, are combined with 63.5 weight units of copper, 59 weight units of nickel, 216 weight units of silver, 131.3 weight units of gold, and 97 weight units of platinum. Do these amounts of weight also signify the weight of the atoms in the five metals mentioned, so that one atom of the respective metal is combined with every atom of oxygen? Or are the weights of the atoms of these metals only half the size of the weights mentioned above, so that to every atom of oxygen there would be two atoms of each of the five metals? Or is the weight of the metals' atoms twice as great as the weight indicated, so that with every atom of metal two atoms of oxygen are combined? Or finally, has one atom of one of the metals united with one atom of oxygen, whereas one atom of another metal has united with two atoms of oxygen, etc.? From the facts mentioned so far, we have not gained the slightest clue for deciding on these questions. In order to understand better, let us take one metal, for example copper. Since 63.5 weight units of copper are united with 16 weight units of oxygen in the copper-oxygen-compound, if 63.5 were not the weight of one atom of copper, but this was rather perhaps half of that (31.75), two such atoms (2 x 31.75 = 63.5) would have combined with one atom of oxygen; and if the double weight (127) were the "indivisible" weight of an atom of copper, one such atom would be united with 2 x 16, with two atoms of oxygen, and so on.

We now have an excellent aid to find the size of the atoms of these elements. In order to be heated, every object needs a certain amount of heat with which it must be supplied from the outside. For example, if we want to heat a piece of copper from 0° to 10°, we have to supply it with ten times the amount of heat that would be able to heat the same piece of copper from 0° to 1°. But the amount of heat that could raise the temperature of one pound of copper by 10° would not also heat one pound of lead or one pound of silver or one pound of iron by 10°; rather, we need an entirely different amount of heat in order to raise the temperature of the pound of lead, again a different amount to raise that of the pound of silver, and so on. Now it has been determined for a very large number of substances how much heat is required to heat them (mostly from about 10° to 100°), and this amount of heat has been compared with the amount used to heat an equal amount of water; the amount of heat resulting has been called the **specific** temperature of the substances. The simplest method used for this purpose was that an exactly weighed out quantity of any substance, for example iron, was heated in a space to 100° and then dropped into a vessel with water. Obviously, the amount and the temperature of the water were exactly determined. So let us assume that we used 200 grams of iron, and after heating these to 100°, they were dropped into 600 grams of water at a temperature of 12°. Through the hot iron, the water was heated to 15.2°, and consequently, the iron cooled from 100° to 15.2°, so it gave up 84.8° degrees of its warmth in order to heat three times the amount of water by 3.2°. Hence, the iron would heat a quantity of water equal to its own by three times 3.2°, so by 9.6°, in that it cooled by 84.8°; or in other words: the amount of heat used to raise the temperature of water by 9.6° is able to raise the same weight of iron by 84.8°. If we call the amount of heat that is able to raise the temperature of 1 kilogram of water by one degree a **heat unit**, then 1 kilogram of iron would need 9.6/84.8 heat units, or "**calories**" to be heated by 1°; 9.6/84.8 = 0.113. Hence, iron needs 0.113 heat units. This amount of heat is called the **specific** temperature of iron. Thus, for the five metals named above as examples the specific temperature is: copper: 0.09515, nickel: 0.108, silver: 0.0570, gold: 0.0324, platinum: 0.03243; that is to say that one kilogram of water requires the same amount of heat in order to raise its temperature by one degree as 10.51 kilograms of copper, 9.26 kilograms of nickel, 17.54 kilograms of silver, 30.82 kilograms of gold, and 30.84 kilograms of platinum.

On the other hand, the specific temperature of sulfur, for example, was found to be 0.188, that of phosphorus 0.202, and that of arsenic 0.0814. Many gaseous compounds of these three elements are known, so that it was easy to determine the size of their atoms. The weight of one atom of sulfur is 32, that of phosphorus 31, that of arsenic 75. If we now multiply the numbers mentioned as the specific temperatures of these three elements with the weight of their respective atoms, strangely enough we get almost the same numbers:

	Weight of atom		Specific temperature	
sulfur	32	x	0.188	= 6.016
phosphorus	31	x	0.202	= 6.26
arsenic	75	x	0.0814	= 6.105

Hence, the product resulting from the weight of the atom and the specific temperature is a constant. But that means nothing other than: in order to heat 32 kilograms of sulfur, the same amount of heat is required as for 31 kilograms of phosphorus or for 75 kilograms of arsenic, which is about 6.2 heat units or the same amount needed to heat 6.2 kilograms of water by the same number of degrees. Now 32 kilograms of sulfur contain exactly the same number of sulfur atoms as the number of phosphorus atoms contained in 31 kilograms of phosphorus, as the number of arsenic atoms contained in 75 kilograms of arsenic. So that means that the law of nature we mentioned is nothing other than this: For all elements, an equal number of atoms require an equal supply of heat in order to have their temperature raised by an equal number of degrees. The heat of the elements' atoms is about 6.2.

With the help of this new law with which we have become acquainted, we are able to determine the size of the atoms of all elements, and we shall use this law right away in order to find out the weight of the atoms of the five metals used above as examples.

With 16 weight units or with one atom of oxygen are connected:

1) 63.5 weight units of copper; the metal's specific temperature is 0.09515, the product of both is 6.042. We can see immediately that this is the constant mentioned above. Therefore, 63.5 weight units are the amount of copper that corresponds to one atom of the metal, the weight of an atom of copper equals 63.5. The symbol for copper (cuprum) is **Cu**. Thus, in using the symbol **Cu**, we will always express 63.5 weight units of copper, and we will have to write the compound of copper with oxygen **CuO**.
2) In addition, 59 weight units of nickel are compounded with 16 weight units of oxygen; the specific temperature of nickel is 0.108, the product of both is 6.372. Here we again see right away that in fact 59 weight units correspond with one atom of nickel, that the weight of one atom of nickel, the symbol of which is **Ni**, equals 59, and that the compound of the same with oxygen consists of one atom of nickel to one atom of oxygen and must be written **NiO**.
3) 216 weight units of silver are connected with 16 weight units; the specific temperature of silver is 0.0570 and the product of both is 12.312. We see immediately that this number is twice the amount of the constant (about 6.2), which is to say that this amount of heat corresponds to that required by two atoms of silver, that 216 weight units represent not one but two atoms of silver, and hence that half of 216, or 108 is the weight one atom of silver. Therefore, the

symbol for silver **Ag** (argentum) always means 108 weight units of silver, and with every 16 weight units or one atom of oxygen, two atoms of silver (2 x 108 = 216) are united in the oxygen compound; thus the oxygen compound with silver must be written **Ag^2O**.

4) Moreover, 131.3 weight units of gold are connected with 16 weight units of oxygen. The specific temperature of gold has been found to be 0.03244 and the product of the two numbers is 4.26. As can be seen at first sight, this number is two thirds of the constant (about 6.2), that is to say that 131.3 weight units of gold are the amount that corresponds to two thirds of an atom of gold; every atom of gold must weight 3/2 x 131.3 or 196 times the weight of every atom of hydrogen. The symbol for gold (aurum) **Au** therefore means for us 196 weight units. Now since 131.3 weight units of gold are connected with 16 weight units of oxygen, 196 weight units or one atom of gold is united with 24 weight units, that is to say with 3/2 atoms of oxygen. But as we know, atoms cannot be divided; all its compounds must contain either 16 weight units of oxygen or 2 x 16, 3 x 16, 4 x 16 and so on. We are therefore forced to assume that every molecule of the gold-oxygen compound contains at least 48 (3 x 16) weight units of oxygen. Of course, 2 x 196 weight units of gold are united with 48 (2 x 24) weight units of oxygen; thus every molecule of gold's oxygen compound would consist of at least two atoms of gold and three atoms of oxygen, and it must be written **Au^2O^3**.
5) Finally, we learned above that 97 weight units of platinum are united with 16 weight units of oxygen. As the experiment taught us, the specific temperature of platinum is 0.03243 and the product of the two numbers if 3.14. This number is again half that required by the warmth of an atom of platinum, so the weight of an atom of platinum, the symbol of which is **Pt**, must also be double, that is, it must be 2 x 97 = 194. Every 194 weight units of platinum require the amount of heat 6.28. But in this metal's oxygen compound, 2 x 16, so 32 weight units of oxygen are united to every 194 weight units of platinum, so that we have to write this platinum-oxygen compound **PtO^2**.

Let it be noted in passing that the specific temperature of compounds also manifests this same law. We can take water as the simplest example. We took water's specific temperature to be a unit. Every molecule of water (H^2O) has the weight 18. It goes without saying that 18 weight units of water require 18 units of heat if the temperature is to be raised by one degree. However, every water molecule contains three atoms (two hydrogen atoms and one oxygen atom); it follows that for every one of the three atoms, the required amount of heat is six heat units.

With the help of this law, the attempt has been made to determine the size of all the elements' atoms.

The table below lists the elements that we know so far – insofar as they have already been given a name – along with their chemical symbol and the weight of their atom.

	Chemical symbol	Weight of atom
Aluminum	Al	27.3
Antimony (Stibium)	Sb	122
Arsenic	As	75
Barium	Ba	137
Beryllium	Be	9.4
Bismuth	Bi	208
Boron	Bo	11
Bromine	Br	80
Cadmium	Cd	112
Cesium	Cs	133
Calcium	Ca	40
Carbon	C	12
Cerium	Ce	141.6
Chlorine	Cl	35.5
Chrome	Cr	52
Cobalt	Co	59
Copper (Cuprum)	Cu	63.5
Didymium	Di	145.4
Erbium	Er	166
Fluorine	Fl	19
Gallium	Ga	69.8
Gold (Aurum)	Au	196
Hydrogen	H	1
Indium	In	113.4
Iodine	J	127
Iridium	Ir	192.7
Iron (Ferrum)	Fe	56
Lanthanum	La	139
Lead (Plumbum)	Pb	207

Lithium	Li	7
Magnesium	Mg	24
Manganese	Mn	55
Mercury (Hydrargyrum)	Hg	200
Molybdenum	Mo	92
Nickel	Ni	59
Niobium	Nb	94
Nitrogen	N	14
Osmium	Os	192
Oxygen	O	16
Palladium	Pd	106.6
Phosphorus	P	31
Platinum	Pt	194.5
Potassium (Kalium)	K	39
Rhodium	Rh	104.4
Rubidium	Rb	85.4
Ruthenium	Ru	104.4
Samarium	Sm	?
Scandium	Sc	44
Selenium	Se	79
Silicon	Si	28
Silver (Argentum)	Ag	108
Sodium (Natrium)	Na	23
Strontium	Sr	87.5
Sulphur	S	32
Tantalum	Ta	182
Tellurium	Te	126
Terbium	Tb	148
Thallium	Tl	204
Thorium	Th	231
Thulium	Tu	?
Tin (Stannum)	Su	118
Titan	Ti	48
Tungsten (Wolfram)	W	184
Uranium	U	240
Vanadium	Vd	51.5
Ytterbium	Yb	173

Yttrium	Y	89.5
Zinc	Zn	65
Zirconium	Zr	89.6

Of the 72 elements listed here, some, such as hydrogen and oxygen as components of water, but also potassium, sodium, calcium, iron etc., can be found everywhere and in huge amounts, mostly of course in compounds; however, others are both very rare and can be found in such small quantities as impurities in some products of nature that they could only be discovered very recently by means of perfected research methods. The more important elements have been written in bold.

It is just as easy to understand the chemical names of the compounds as it is to understand the chemical way of writing them. Every compound that consists of only two different elements is named in such a way as simply to place the names of the two elementary components next to each other. Thus for example the name hydrochloric acid, and cooking salt, which consists of chlorine and sodium (NaCl), is called sodium chloride; a compound of iodine with potassium is called by these names (KJ), a compound of iron with sulfur is called iron sulfide, and so on. [*Translator's note: unfortunately, these examples don't always work in English.*] Only the oxygen compounds are named according to the international name of oxygen, so they are called oxides: copper oxide, iron oxide, mercury oxide. Accordingly, water should also be called hydrogen oxide. However, this kind of appellation would be drawn-out in naming compounds consisting of three and more elements, which is why it is used more rarely. Mostly, such substances were named according to another criterion. Let it suffice here to say that, just as the oxygen compounds were given names including **oxide**, so also all chlorine compounds have been gathered together with the common name **chloride**, all sulfur compounds with the name **sulfide**, etc. Thus cooking salt has also been called sodium chloride, iodine with potassium has been called potassium iodide, and iron with sulfur has been called iron sulfide. Moreover, a compound with gold, chlorine and sodium has been called sodium-gold-chloride, and one of platinum, chlorine and potassium has been given the name potassium-platinum-chloride. However, with by far the greatest number of compounds, the name they were given was based on an entirely different principle, inasmuch as these substances did not already have old names that had no connection at all with their composition, such as alum and vitriol. We shall now be introduced to this principle.

On the preceding pages, we had occasion to mention hydrochloric acid, a substance with a very strong sour taste, even after it is very strongly diluted with water. Little by little, we have become acquainted with a very large number of substances with an equally strong sour taste as hydrochloric acid and that share a number of other characteristics with hydrochloric acid, which will soon be discussed. Thus, we know a substance that can hardly be distinguished from hydrochloric acid. It is a compound consisting of the element bromine with hydrogen (HBr); it is gaseous, forms a very thick mist in the air, has an acrid sour smell, is very easily soluble in water – in short, it has all the characteristics that we encountered in hydrochloric acid. This compound is called bromine-hydrogen acid. Two other such compounds are known that are gaseous at ordinary temperatures, form a thick mist in the air, and are easily soluble in water; one of them is a compound of hydrogen with the element iodine, the other is a compound of hydrogen with the element fluorine; these are called iodine-hydrogen acid and fluorine-hydrogen acid respectively. In addition, a fluid with an intense sour taste has been known for a long time, which in its pure state produces an almost odorless oily fluid that was formerly gained from vitriol and was therefore called oil of vitriol, whereas it is now produced from sulfur and bears the name sulfuric acid. Its composition is quite complicated and consists of 32 weight units (one atom) of sulfur, 2 weight units (2 atoms) of hydrogen, and 64 weight units (4 atoms) of oxygen, so that its chemical symbol is H^2SO^4. In addition, for a long time now, a fluid with a very sour taste has been obtained from saltpeter, which was already used during the Middle Ages to separate silver from gold because it is able to dissolve the silver, but not the gold; goldsmiths therefore called it “separating water” (*aqua fortis*), whereas it is now generally called nitric acid. Let it be said in passing that it consists of one weight unit of hydrogen, 14 weight units (one atom) of nitrogen, and 48 weight units (3 atoms) of oxygen, so that its chemical symbol is HNO^3.

In addition, when phosphorus is burned in damp air, a fluid with a sour taste is produced; in its pure state it is solid, but it is so easily soluble in water and so eager to dissolve in water that it attracts humidity from the air and dissolves. By the way, this compound consists of 31 weight units (one atom) of phosphorus, 3 weight units (3 atoms) of hydrogen, and 64 weight units (4 atoms) of oxygen, so that its chemical symbol is H^3PO^4. Its name is phosphoric acid.

Thus in addition, an almost incalculable number of such compounds are known, and they have been gathered together under the common name of **acids**. As we can see, the above principle of naming these substances by stringing together the names of their components is only used when they are made up of only two elementary components, such as bromine-hydrogen acid, iodine-hydrogen acid, fluorine-hydrogen acid; however, when they are made up of more than two elements, their composition is not taken into account and they are named after the substance from which they are made, such as sulfuric acid, nitric acid [in German: saltpeter acid], phosphoric acid.

On the other hand, in the above we got to know cooking salt as a compound of chlorine with the metal sodium, consisting of 35.5 weight units (1 atom) of chlorine and 23 weight units (1 atom) of sodium; it is therefore symbolized as NaCl. But already in ancient times, a very large number of substances were known that were very similar to cooking salt, both because of how they looked and because of their (salty) taste, and these substances were therefore given the common name of **salts**. Saltpeter, for example, is such a salt; it consists of 39 weight units (1 atom) of the metal potassium, 14 weight units (1 atom) of nitrogen, and 48 weight units (3 atoms) of oxygen, and we can thus express its composition in the symbol KNO^3. The substance that was introduced by the famous doctor **Glauber** into the treasury of medications (in the year 1658) and that is named **Glauber Salt** after him, is also characterized as salt already by its name. It consists of 46 weight units (2 atoms) of sodium, 32 weight units (1 atom) of sulfur, and 64 weight units (4 atoms) of oxygen, so that its chemical symbol is Na^2SO^4. However, it is very easy to produce these salts from the acids. We already learned that when a watery solution of hydrochloric acid is mixed with the same kind of solution of caustic soda, a strong heating of the fluid occurs, and both the sour taste of the former solution and the pungent, salty taste of the latter disappear completely, and when the solution is evaporated, all that remains is cooking salt. We also learned how cooking salt is formed in this process. The caustic soda, a compound consisting of 23 weight units (1 atom) of sodium, 1 weight unit (1 atom) of hydrogen, and 16 weight units (1 atom) of oxygen, so NaHO, together with the hydrochloric acid HCl, is converted in such a way as to form cooking salt NaCl and water H^2O. As can be seen at first sight, caustic soda NaHO differs from water HHO in that every molecule of the former contains one atom of sodium instead of one atom of hydrogen; it can therefore be considered to be sodium water, and it was also given a similar name, sodium hydroxide (from *hydor*, derived from the Greek translation of the word water). So: as soon as hydrochloric acid is mixed with sodium hydroxide, cooking salt and water are produced.

In the same way, we can easily make saltpeter.

For a compound of the metal potassium with hydrogen and oxygen corresponds with sodium hydroxide; its molecule consists of one atom (39 weight units) of potassium, one atom (1 weight unit) of hydrogen, and one atom (16 weight units) of oxygen and is therefore written KHO and called potassium hydroxide. As soon as a solution of potassium hydroxide, which has an even stronger pungent and salty taste than a solution of sodium hydroxide, is mixed with the sour tasting solution of nitric acid, the composition of which is HNO^3, as we learned above, the fluid becomes very hot and gradually takes on a salty taste. If, after adding a sufficient amount, the fluid is evaporated, what remains is pure saltpeter. The chemical process here is the same as when cooking salt is produced from sodium hydroxide and hydrochloric acid. The potassium atoms in the potassium hydroxide molecules and the hydrogen atoms in the nitric acid molecules trade places, as the following setup shows:

Potassium hydroxide	KHO
and nitric acid	HNO^3
produce	
saltpeter	KNO^3
and water	HHO.

Finally, Glauber Salt can also be made very simply by mixing a solution of sodium hydroxide or caustic soda with sulfuric acid. But since sulfuric acid, as we know, is a compound, H^2SO^4, so contains two hydrogen atoms in every molecule, and since on the other hand, Glauber Salt is made up of Na^2SO^4, we can see that both hydrogen atoms in the sulfuric acid are exchanged with two sodium atoms in order to form Glauber Salt. Thus, the chemical process in this transformation can be shown as follows:

Every 2 molecules of sodium hydroxide	2 NaHO
and every 1 molecule of sulfuric acid	H^2SO^4
produce	
1 molecule of Glauber Salt	Na^2SO^4
and 2 molecules of water	2 HHO.

Potassium and sodium are two metals that, because they change easily when exposed to air, are of no great technical importance as metals, even though their compounds are extremely important, and this is why in ordinary life, they are rarely mentioned as metals. But aside from these two, there are a considerable number of elements that we are already acquainted with in daily life, such as iron, lead, copper, zinc, silver, mercury, and others. All of these elements, as well as various others that can easily be recognized as metals because of their odd way of shining and because of their excellent ability to conduct heat and electricity, form compounds with oxygen and hydrogen that are similar to potassium hydroxide and sodium hydroxide and are therefore called **hydrates**. And all metal hydrates, as soon as they are brought together with salt, very easily produce salts, along with intense heat. That is why in former times, metal hydrates were considered to be the foundation, the basis for salts, and they were simply called **bases**, which made it possible to formulate the theorem: As soon as an acid and a base come together, salt and water are produced. Of course, even more simply, we can consider the salts to be compounds, the molecules of which contain metal instead of the hydrogen of the acids, and equally, we can consider the acids to be compounds that always contain hydrogen and that easily exchange this hydrogen for metal as soon as a base is added.

Thus we have become acquainted with three large classes of compounds: **acids**, **bases**, and **salts**. **Acids** are understood to be compounds of hydrogen with one or more other elements that are characterized by their ability to replace this hydrogen very easily with metal; this exchange occurs immediately when acids are mixed with bases, and salt is then produced. **Bases** are understood to be compounds of metals with oxygen (metal oxides) or with oxygen and hydrogen (metal hydroxides) that immediately produce salt when joined with acids. And finally the **salts** themselves are nothing other than the compounds in which some metal has taken the place of the hydrogen of the acids.

But with that, let us immediately clarify another important point. We learned above that in hydrochloric acid, one atom of chlorine is united with one atom of hydrogen; in water, one atom of oxygen is united with two atoms of hydrogen; and in ammonia one atom of nitrogen is united with three atoms of hydrogen. Thus, the individual elements do not have the same quantitative ability to unite with hydrogen. While one atom of chlorine can attract at most one atom of hydrogen, every atom of oxygen can become connected with two atoms of hydrogen, every atom of nitrogen can even unite with three atoms of hydrogen. The ability of the various elements to connect per atom with varying numbers of hydrogen atoms is called the chemical value of the respective elements. Thus, for example, chlorine is considered to have the value of one, oxygen has that of two, nitrogen that of three in relationship to hydrogen. However, this is not at all meant to express the size of the force of attraction as such; the chlorine atom with the value of one, for example, has a far greater force of attraction towards hydrogen than the nitrogen atom, which has the value of three, so that when we bring the hydrogen compound with nitrogen, i.e. ammonia, together with chlorine, the hydrogen atoms immediately tear themselves away from the nitrogen atoms in order to unite with the chlorine atoms as hydrochloric acid, and the nitrogen atoms have to unite among themselves as molecules. But of course, for every nitrogen atom, three chlorine atoms are required to unite with the three hydrogen atoms of every molecule of ammonia so as to form hydrochloric acid; every atom of nitrogen requires three atoms of chlorine so as to be driven out of its hydrogen compound. In the same way, chlorine is able to decompose water. If chlorine gas is discharged into water, every liter of water is able to dissolve about 3 liters of chlorine gas, and because of the chlorine, a green fluid smelling strongly of chlorine is produced, which is called hydrochloride and used for medical purposes. If such a chlorine solution is left in sunlight for a few hours or in daylight for a few days, the green color and the suffocating smell gradually disappear, and the fluid that has become colorless no longer contains any trace of chlorine, but rather of hydrochloric acid. Under the influence of sunlight, the chlorine was able to decompose a corresponding amount of water, it united with the hydrogen to form hydrochloric acid, and it allowed free oxygen to be produced. Now in order to decompose, every molecule of water requires two atoms of chlorine that form two molecules of hydrochloric acid, and the water molecule sets free one atom of oxygen (that of course does not remain in a free state, but rather in the next instant unites with a second atom of oxygen that has been set free from another water molecule and becomes a molecule of oxygen). So we see that every three atoms of chlorine are able to drive out one atom of nitrogen and to replace it, and that every two atoms of chlorine can do the same to one atom of oxygen, or expressed more generally, every three atoms of an element with the value of one replace one atom of an element with the value of three; two atoms of an element with the value of one are required in order to drive out one atom of an element with the value of two, etc. Equally, one atom of an element with the value of one can only unite with one atom of another element with the value of one; one atom of an element with the value of two can only unite with two atoms of one or various elements with the value of one, or also with one atom of an element with the value of two; one atom with the value of three can only unite with three atoms of one or various elements with the value of one, or also with one atom of one element with the value of two and with one atom of an element with the value of one. As examples, we can refer to the following compounds that we encountered in the preceding pages: HCl, HBr, HJ, so hydrochloric acid, bromine-hydrogen acid, iodine-hydrogen acid for compounds containing only elements with the value of one; H^2O, NaHO, $FeCl^2$, $HgCl^2$, CuO, so water, sodium hydroxide, iron chloride, mercury chloride, copper oxide for compounds containing one atom of an element with the value of two together with two atoms of one or two elements with the value of one or one atom of an element with the value of two. H^3N, NOCl, ammonia and nitrogen-oxygen-chloride as compounds containing one atom of an element with the value of three and three atoms of an element with the value of one, or one atom of an element with the value of two and one atom of an element with the value of one. Thus, if we know the value of the elements, we can easily recognize the composition of a compound of that element. Thus for example, a compound of silver, which has the value of one, with oxygen, having the value of two, can only be Ag^2O, and with chlorine, having the value of one, it must be AgCl. However, the relationships become far more complicated, because not only the value of an element can vary, though within narrow limits, but in addition, the elements with a value of more than one are also able to unite themselves with two or more atoms, using part of their force of attraction, so that only what remains of their force of attraction is available to the other elements. Let us illustrate the elements' forces of attraction by means of small hyphens, so for hydrogen with the symbol H-, for chlorine with the symbol Cl-, for oxygen with the symbol –O- or O-, for copper with the symbol –Cu- or Cu-, for nitrogen with the symbol –N- or N-, etc. Then the hydrochloric acid molecule would be expressed by means of the symbol H-Cl, the water molecule as H-O-H, the ammonia molecule as H-N-H-H, the copper oxide molecule as Cu-O, and the nitrogen-oxide-chloride molecule as N-Cl-O. But two atoms of oxygen can also unite together by means of their own respective force of attraction, which we can express by means of the symbol –O-O-, and in that case, for both atoms together, only two forces of attraction would remain, so that for example a compound H-O-O-H = H^2O^2 would be the result, which is the so-called hydrogen-super-oxide, or also [O-O-O] O^3, a molecule of oxygen consisting of three atoms of oxygen, which is the well-known ozone. Moreover, in relationship to hydrogen, nitrogen always has the value of three, that is to say, each of its atoms can only attract three atoms of hydrogen, no more and no less, but in relation to oxygen, it can be found as having a value of one, of two, of three, of four, even of five; in other words, it is able to attract varying amounts of oxygen atoms, and for example, the following oxygen compounds of nitrogen are known: N^2O, the so-called nitric oxygen, a gas which, when inhaled for a short time, brings about a loss of sensitivity and which dentists use to cause unconsciousness when pulling teeth; then NO, the so-called nitric oxide, an extremely poisonous gas that is colorless, but as soon as it comes in contact with air, it immediately unites with oxygen and becomes red; then N^2O^3 and NO^2, a red gas, and finally N^2O^5, a compound that immediately turns into saltpeter when it joins with water. Only later will we look more closely at these facts, which complicate the elements' relationship to one another in compounds and detract from their transparency.

Now when a metal replaces the hydrogen in acids, if we know the chemical value of the metal, we are able to deduce *a priori* the composition of the salt that is produced. For the principle is valid for all cases in chemistry: only equal amounts of elements can replace one another. That is to say:

A metal with the value of one, for example potassium or sodium, replaces one atom of hydrogen with one atom. Thus if the acid concerned contains only one hydrogen atom in every molecule, as is the case in hydrochloric acid, bromine-hydrogen-acid and iodine-hydrogen-acid, the salt is formed by replacing the H in an acid molecule with an atom of the metal. For example:

HCl – NaCl; HBr – KBr.

If on the other hand, the acid molecule contains two atoms of hydrogen, as for example sulfuric acid, H^2SO^4, two atoms of an element with the value of one (or of two elements with the value of one) will be required to replace the two hydrogen atoms. For example:

$$H^2SO^4 – Na^2SO^4 \text{ or also } NaKSO^4$$

(in the latter case, the two H's of the sulfuric acid molecule were exchanged for two different metals with the value of one, sodium and potassium).

If every molecule of an acid contains three atoms of hydrogen, as for example phosphoric acid, H^3PO^4, three atoms of one or more metal atoms with the value of one will be required, for example H^3PO^4 – Na^3PO^4, etc.

Expressed generally, the law is: To replace the hydrogen atoms in acids, exactly the same number of atoms are required of metals with the value of one as there are hydrogen atoms, symbolized by H.

However, there are also metals with the value of two, of which we have already become acquainted with copper (Cu) and nickel (Ni); in fact, the majority of metals have the value of two. Now such an atom of a metal with the value of two can always only replace two atoms of hydrogen in the acids. So if every molecule of an acid has exactly two atoms of hydrogen, as is the case with sulfuric acid, H^2SO^4, then these two atoms can be replaced by one such atom of a metal with the value of two, and sulfuric acid H^2SO^4 will have to be transformed into salt $CuSO^4$, $NiSO^4$, etc. If on the other hand, the molecule of the respective acid contains only one atom of hydrogen, such as hydrochloric acid HCl, bromine-hydrogen-acid HBr, saltpeter acid HNO^3, then two acid molecules are always required that together exchange their two H with one atom of the respective metal with the value of two in order to produce salt. For example, in order to replace the hydrogen in the hydrochloric acid with copper, two HCl must be present, and then $CuCl^2$ is produced; similarly, nickel salt, for example, is produced from saltpeter acid when in two HNO^3 the two H are replaced with one atom of Ni, so that we obtain Ni $(NO^3)^2$. From this last symbol, we can also see how a larger number of atoms, an atom complex, that is contained several time in the molecule of a compound, can be expressed in the chemical way of writing the compound in question, that is, by writing the atom complex in brackets and placing a numeral after the brackets. The symbol Ni $(NO^3)^2$ means that twice the atom complex NO^3 is united with one atom of nickel.

If on the other hand a molecule of acid contains three atoms of hydrogen, these can only be exchanged with a metal with the value of two when there are three atoms of the metal with a value of two in every two molecules of acid, which then contain six H. Thus for example, calcium salt is produced from phosphoric acid H^3PO^4 (every atom of calcium has the value of two) when three Ca take the place of six H in two H^3PO^4, thus uniting with two PO^4 and enabling the compound Ca^3 $(PO^4)^2$ to be produced. Let it be said in passing that this “phosphor-acidic calcium” is the main component in the bones of all vertebrates.

Finally, an atom of metal with the value of three can only replace three atoms of hydrogen in acid molecules in order to produce a salt. Thus for example, bismuth (Bi = bismuthum) and gold (Au – aurum) are metals with the value of three; therefore, three molecules of an acid containing only one atom of hydrogen that can be exchanged with metal will be required in order to form a salt with such a metal; the saltpeter acidic bismuth will have to have the composition Bi $(NO^3)^3$, and chloride gold that of $AuCl^3$.

However, just as the various hydrogen atoms in an acid containing more than one H in its molecule, so of a multiple acid, as it is called, can be replaced with various metals, so it is also possible to replace only part of the hydrogen atoms with metal. Thus sulfuric acid H^2SO^4 is not only able to replace both hydrogen atoms with metals in order to form salts, but it can let one atom be replaced and keep the other without replacing it. For example, salts of sulfuric acid are known with the composition $KHSO^4$, $NaHSO^4$, etc. Among other similar ones, the following important salts are known that come from phosphoric acid H^3PO^4: KH^2PO^4, NaH^2PO^4, as well as K^2HPO^4, Na^2HPO^4, etc. That is to say that either all three of the three hydrogen atoms in phosphoric acid, or only two of them, or finally, even only one atom H can be exchanged with metal.

These salts are strange compounds. Since they still contain a part of the hydrogen that can easily be exchanged with metals, they are at one and the same time salts and acids, and they are called by the common name of **acidic salts**. With the triple based phosphoric acid, in which two series of acidic salts exist, the salts in which there are still two hydrogen atoms that can be replaced by metals (KH^2PO^4, NaH^2PO^4) are called **doubly acidic salts**, “doubly acidic phosphoric acidic potassium”, etc. On the other hand, the salts K^2HPO^4, Na^2HPO^4 are **simple acidic salts**, “simple acidic phosphoric acidic sodium” etc. But for the sake of brevity, they are also called primary, secondary, etc. salts. KH^2PO^4 is primary phosphoric acidic potassium, Na^2HPO^4 is secondary phosphoric acidic sodium, and the real or neutral salt Na^3PO^4 is the real or neutral salt, in which finally all the hydrogen in the phosphoric acid is replaced by the metal sodium.

Therefore, a distinction is made between **neutral** and **acidic** salts; the former are those in which all the hydrogen atoms in an acid molecule that can be exchanged with metals have been replaced by one or more metals, whereas the second group of salts are those in which a part of the replaceable hydrogen atoms are still present.

So far, we have only derived the salts from acids, and we have become acquainted with them as those compounds that contain metal atoms in the place of all or part of the hydrogen in the acids. But we are equally justified in also deriving the salts from the bases. In so doing, we reach the same goal while proceeding in the opposite direction.

Above, we got acquainted with bases as the hydroxides of the metals, so they are all compounds with oxygen, in which half of the oxygen is united with a metal and the other half with hydrogen. Since every atom of oxygen has the value of two, and since one of its values is claimed by the connection with a hydrogen atom, always only one value remains for the connection with the respective metal. For the metals with the value of one, to which potassium (K), sodium (Na), and silver (Ag) belong, this one value is enough to bind a complete atom of metal, so that the hydroxides must be composed of K O H, Na O H, etc. For the metals with the value of two, for example calcium (Ca), copper (Cu), zinc (Zn), etc., this one force of attraction of the oxygen is not able to fill the two forces of attraction of the metal atom. Therefore, every one atom of metal must be replaced by two atoms of oxygen (each at the same time with one atom of hydrogen) in order to produce the base's molecule in such a way that all the forces of attraction on the one side are kept in balance by an equal number on the other side. For example, H-O-Ca-O-H = Ca $(OH)^2$, calcium hydroxide, which is our ordinary slaked lime; H-O-Cu-O-H – Cu $(OH)^2$, copper hydroxide; Zn $(OH)^2$, zinc hydroxide. So we can see that the hydroxides of the metals with a value of two contain two OH. The atom complex OH has been given the name **hydroxyl**.

It hardly needs to be explained that a metal with the value of three, such as bismuth (Bi) must unite with three OH, with three hydroxyls, in order to produce a hydroxide: $Bi(OH)^3$. In addition, we can recognize from this that the atom complex OH, the hydroxyl, works in exactly the same way as an element with the value of one, which is to say that one OH unites with a metal atom with the value of one, two OH unite with a metal atom with the value of two, three OH unite with one with the value of three. If we know the value of the metals, we can easily determine the composition of the bases from this, just as it is possible to deduce the value of the metal from the composition of the base.

Now we know that when a base is mixed with an acid, a salt is always produced, while at the same time water is formed: KOH and HNO^3 produce KNO^3 and HOH; that is to say, potassium hydroxide and saltpeter acid immediately produce saltpeter and water. Now we can understand this process in the sense that in place of the hydroxyl in the potassium hydroxide, the rest of the saltpeter acid molecule unites with the potassium, while the hydroxyl in turn connects with the hydrogen in the saltpeter acid to produce water. Thus a salt is produced, because the hydroxyl of the base is exchanged with the remainder of an acid molecule, so with an **acid radical**. In forming salt in this way, we above all again have to pay attention to the value of the acid radical in order to reach correct conclusions concerning the composition of the salts that are produced. The hydroxyl works in exactly the same way as an element with the value of one, as we just learned. Now the acid radical has the value of one, when it contains all the atoms of the acid molecule minus one H, for example NO^3 from HNO^3, HSO^4 from H^2SO^4, etc. It has the value of two, when it contains the atoms of the acid molecule minus two H, for example SO^4 from H^2SO^4, HPO^4 from H^3PO^4. Finally, it has the value of three, when it contains the atoms of the acid molecule minus three H, and so forth.

Only an acid radical with the value of one can replace one hydroxyl in order to produce salt. Examples of this with NaOH are $NaNO^3$, $NaHSO^4$, NaH^2PO^4. Two acid radicals with the value of one or one acid radical with the value of two can replace two hydroxyls. The two acid radicals with the value of one can be either the remains of two molecules of the same acid or two different acids. Examples: from Cu $(OH)^2$ are produced $CuCl^2$, $Cu(NO^3)^2$, $CuClNO^3$, as well as $CuSO^4$, $CuHPO^4$, etc.

Three acid radicals with the value of one (with every possible variation) and one acid radical with the value of three can replace three hydroxyls of a base. For example, from Bi $(OH)^3$ are produced Bi $(NO^3)^3$, $BiCl^3$, $BiPO^4$, etc. On the other hand, two molecules of such a base are required in order to replace its hydroxyls with acid radicals with a value of two, and three acid radicals with a value of two are needed in order to give an equivalent replacement to the six OH that are then present, so that for example salt $Bi^2(SO^4)^3$ can only be produced from two Bi $(OH)^3$ and three (H^2) SO^4.

We learned of the acids with more than one base, which is to say, those that contain more than one replaceable hydrogen atom, that not all hydrogen atoms must be replaced by metals, that part of the H atoms can remain without a replacement, and that this then produces the so-called acidic salts. In exactly the same way, it is not necessary to exchange all the hydroxyls in the bases containing several hydroxyls, i.e. the **multiple acidic** bases, with acid radicals when producing salt. Rather, the hydroxyls can be partly replaced by acid radicals and partly remain without a replacement, so that for example, we can obtain a saltpeter acidic salt with the composition Cu (OH) No^3 from copper hydroxide Cu $(OH)^2$, a saltpeter acidic salt Bi $(OH)^2$ NO^3 from bismuth hydroxide Bi $(OH)^3$, and so on.

Such compounds, which at one and the same time can be considered to be salts and bases, are called **basic** salts.

Thus we see that in forming salts from acids and bases, always exactly as many values of a metal (or of an acid radical) come in place of the hydrogen (or hydroxyl) as there are hydrogen atoms being replaced. Now the principle that any element is always only replaceable by the **equivalent** amount of another element is a fundamental theorem that is valid for all chemical conversions.

However, the simple theorem that only equivalent amounts of atoms can replace one another, is complicated by the fact that the value of most of the elements is not unchangeable. It is true that all elements that unite with hydrogen do have a constant value in relation to it: chlorine has only the value of one, oxygen has only the value of two, nitrogen has only the value of three, carbon has only the value of four in relation to hydrogen; which is to say that one atom of chlorine can only unite with one atom of hydrogen, one atom of oxygen only with two atoms of hydrogen, one atom of nitrogen only with three, one atom of carbon only with four atoms of hydrogen. On the other hand, the value of some elements already fluctuates in relation to chlorine. Thus for example, one atom of phosphorus is able to unite both with three and with five atoms of chlorine forming the compounds PCl^3 and PCl^5. Thus, if we consider chlorine to have the value of one, phosphorus not only has the value of three, but also that of five. And precisely the element that can unite with the other elements to form the most numerous and the most important compounds, i.e. oxygen, within certain limits, causes strong fluctuations as to the chemical value. However, every element manifests a **maximal value** in relation to oxygen; this value does not have to be reached, but it cannot be surpassed. Thus nitrogen can form five compounds with oxygen, and in them it has a value between one and five; and chlorine forms oxygen compounds, in which it works both as an element with the value of one, as well as three, four, five and even seven. However, there are only a few elements, the forces of attraction of which fluctuate this strongly in relation to oxygen, so that the uncertainty in predetermining the composition of an oxygen compound is relatively small.

The Relationship between the Weight of Atoms and the Elements' Characteristics

Among the 74 elements known so far, almost always several are very similar to one another insofar as their compounds with the same other elements not only have the same composition, but above all, their effect on other substances has the same characteristics. Thus for example, chlorine, bromine and iodine are very similar to one another in their compounds; potassium, sodium and the more rare metals lithium, rubidium and cesium form very similar compounds; in fact, the potassium, rubidium and cesium compounds are so similar to one another, that it is almost only possible to distinguish them from one another by means of spectral analysis, which will be discussed later. In the same way, the phosphorus, arsenic and antimony compounds are very similar to one another, as are the sulfur, selenium and tellurium compounds, the calcium, strontium and barium compounds, etc. And so, already very early scientists became aware of a strange regularity in the weight of the atoms of elements that were close to one another in this way. For example, the weight of an atom of chlorine = 35.5, that of bromine = 80, that of iodine = 127; thus the difference between the weight of the chlorine atom and that of bromine = 44.5, between that of bromine and that of iodine = 47. Moreover, the weight of an atom of lithium = 7, that of sodium = 23, that of potassium = 39, that of rubidium = 85.4, that of cesium = 133; thus the difference between the weight of the lithium atom (7) and that of sodium (23) = 16, between sodium (23) and potassium (39) = 16, between potassium (39) and Rubidium (85.4) = 46.4, between rubidium (85.4) and cesium (133) = 47.6, so the difference in the weight of the atoms of the last three elements is close to 3 x 16. The weight of an atom of phosphorus is 31, that of arsenic = 75, that of antimony = 122; thus, the difference = 44 and 47, so both are almost equal to one another. In the same way, the differences between the weights of an atom in the above mentioned groups of similar elements are almost equal. Thus the difference between sulfur (weight of the atom = 32) and selenium (weight of the atom = 79) equals 47, between selenium and tellurium (weight of the atom = 126) it is 47. Moreover in the calcium group, that between calcium (weight of the atom = 40) and strontium (weight of the atom = 87.5) is 47.5, and between strontium and barium (weight of the atom = 137) is 49.5. But as we can see, these differences are not almost equal only within one and the same group of similar elements, but everywhere this difference equals either about 16 or a multiple of 16. However, the deviations from these numbers are so great that they cannot be blamed on inexactitude in determining the weights of the atoms, and so this fact remained conspicuous without scientists being able to recognize a real law, until a general law was recognized by various people and in particular by **Mendelejeff** in 1872. For if you put the elements into order according to the weight of their atom, you discover that after every seven elements, the eighth is similar to the first, the ninth to the second, the tenth to the third, and so on. But even more: after every 14 elements, the fifteenth has even greater similarity with the first, the sixteenth with the second etc. than the eighth had with the first, the ninth with the second, etc. And so every seven elements were called a small period, every 14 elements a large one, and the total order of the elements was named the **periodic system**. However, in this system, there is a group of four elements at the end of every large period that have a weight that is virtually equal to one another, and their last member is at the same time the first member of the following period and thus leads on to it. When the elements are put in order in this way, the following laws occur:

1) All elements of one and the same group have the same chemical value in relation to the other elements. Group I has the value of one in relation to oxygen; that is to say that at least two atoms of every element in this group unite with every atom (16 weight units) of oxygen. The elements in Group II have a value of two in relation to oxygen, so that one atom of the respective element unites with one atom of oxygen. The elements in Group III have a value of three in relation to oxygen, so that two atoms of the respective element unite with three atoms of oxygen. But this relationship does not always have to prevail. Every one of these elements has at most the value of three, and most of them can also have the value of one, as it is possible, for example, to produce such compounds with gallium, indium and thallium. The elements in Group IV mostly have a value of four in relation to oxygen, but here too, the value of four is only the maximum force of attraction manifested by the respective element, the upper limit; they can also occur with a value of two. The elements in Group V have a value of five in relation to oxygen (and also a value of three). The elements in Group VI have a value of six, but most of them can also occur with a value of four, three and even two. The elements in Group VII have a value of seven (but also of five, three and one). Finally, the elements in Group VIII have a value of eight. But if we perceive a regular increase in the value of the elements in Groups I to VIII in relation to oxygen, their behavior in relation to hydrogen is the opposite. First of all, let it be noted that the elements in Groups I – III do not unite with hydrogen at all, and that the value of the elements in Groups IV – VIII in relation to hydrogen always remains the same, as was already said above. Thus, the elements in Group IV always have a value of four in relation to hydrogen, the elements in Group V always have a value of three, the elements in Group VI always have one of two, the value of those in Group VII is one, and finally those in Group VIII have a value of only one half, which is to say that one atom of hydrogen unites with two atoms of the elements in this group.

But a whole row of other relations has been found in this ordering of the elements according to the weight of their atoms. Thus we see that those elements with the most characteristics of a metal, such as lithium, sodium, potassium, rubidium, cesium, are the first members of the periods, whereas those elements that are opposite the metals, such as fluorine, chlorine, bromine, iodine, are the last members of the periods. While the compounds of the first members with hydroxyl are the strongest bases, the compounds of the last members with hydrogen are already strong acids. And the members in between in each period at the same time form a passage from the one extreme to the other.

In addition, it was observed that the specific weight of the elements, which is to say the space filled by the mass, is in close relationship to the weight of the atoms. In the individual periods, either a regular increase or decrease of the specific weight occurs from one member to the next, so that from the specific weights of its two neighbors, it is possible to calculate almost exactly the specific weight of any element. Thus for example, the specific weight of sodium is 0.97, that of aluminum is 2.56, and that of magnesium, which is between them, is 1.74, which is virtually 0.97 + 2.56 / 2. The specific weight of copper is 8.8, that of gallium is 5.96, and that of zinc, which is between them, is 7.15, which is virtually 8.8 + 5.96 / 2.

Finally, regularities were also discovered as regards the greater or lesser ease with which the elements can be melted or transformed into gas, and these regularities again are connected with the weight of the atoms. But it would take us too far to go into detail about this here. A different topic, which has already been common for quite some time now, can follow on the one we just discussed concerning the ordering of the elements according to the weight of their atoms, and that is the formation of the most important classes of compounds, the salts. As was shown above, a salt is formed when an acid meets with a base. Now the elements have been divided into those that are particularly able to form bases, and these were called **metals**, because the metals that have been known since the most ancient times, iron, zinc, lead, copper, etc. belong to this class of elements. The metals were placed opposite the elements that do not produce bases, the compounds of which on the other hand are acids, when they contain hydrogen. These elements are called **non-metals**.

To the latter class belong the four elements, the compounds of which with only hydrogen are already acids, and accordingly their compounds with metals belong to the salts. These four elements are fluorine (Fl), chlorine (Cl), bromine (Br), and iodine (J). These four elements, which by the way have the value of one in relation to hydrogen and to the metals, are therefore called salt formers, halogens or also haloids (derived from the Greek word *hals*, salt). All other non-metals are not able to form any acids with only hydrogen or any salts with only metals. On the other hand, their oxygen compounds, insofar as they also contain hydrogen, are acids. In addition to oxygen (O), other elements belonging to these elements are sulfur (S), selenium (Se), tellurium (Te), as well as nitrogen (N), phosphorus (P), arsenic (As) and antimony (Sb = Stibium), then carbon (C) and silicon (Si). It goes without saying that the halogens are also able to unite with oxygen, and these compounds are also acids insofar as they also contain hydrogen.

Of the elements that have been named, the halogens form a small group of elements that are very similar to one another; in the same way, the three elements sulfur, selenium, and tellurium form a closed group of substances that are very similar to one another. In relation to hydrogen and to the metals, they all have a value of two, in relation to oxygen they have a value of six. Their compounds with these other elements are extraordinarily similar in their chemical composition, in their external shape, in the way they behave towards other substances, etc.

In the same way, the three elements nitrogen, phosphorus, and arsenic are very similar to one another. All three have a value of three in relation to hydrogen, in relation to oxygen they mainly have a value of five, and their compounds with these other elements are in very great accordance with one another.

Finally, although not to an equally high degree, the last two elements, carbon and silicon, are also very similar to one another. Both have a value of four in relation to hydrogen and to carbon, etc.

The elements that form bases, the metals, to which all other elements belong, are far greater in number, but here we shall only mention the most important ones. Among them, there are also small closed groups, the members of which manifest surprising similarities with one another both in a free state and particularly in compounds. Thus, the first group, which includes potassium, sodium (lithium, cesium, rubidium), was already given a special name early on. For the hydroxides of this group were called **alkalis** and the metals themselves alkali metals. The alkalis, which all dissolve extremely easily in water, whereas the hydroxides of all the other metals are either very difficult or even impossible to dissolve in it, are the strongest bases, which is to say that among all the hydroxides, they have the strongest urge to unite with acids in order to form salts. We shall later have occasion to discuss the consequences of this.

The alkali metals are joined by three metals that are very similar to one another: barium, strontium and calcium. Their hydroxides, which are difficult to dissolve in water, have been given the name of **alkali clays**.

In addition, the following groups of metals are worth mentioning: magnesium, zinc and cadmium; copper, mercury and silver; aluminum, iron, chrome, manganese, cobalt and nickel. In this connection, we must underline that the metals of the sixth and seventh groups in the table, in particular chrome and manganese, which can have a value of six or seven respectively in relation to oxygen, that is to say, which are able to unite with 3 and 3½ atoms of oxygen per atom, produce acids in these compounds that are very rich in oxygen. Thus we know of acidic chrome, acidic manganese, and super acidic manganese salts.