The Connection between Chemical and Physical Phenomena

On the preceding pages it was shown that the movement of molecules can produce physical phenomena. Thus sound comes about through the oscillation of the molecules in solid, liquid or gaseous objects, and it continues in these substances until it reaches our ear. And heat and light are nothing other than an extremely rapid oscillation of molecules that continues through the world ether until it reaches us. On the other hand, chemical phenomena are produced by the movement of atoms in such a way that the atoms separate from one another in order to come together immediately as molecules in another grouping, according to their mutual powers of attraction. It is easy to understand that the atoms within the molecules are not at rest, but that they in turn are in constant movement. If it be permitted to compare these infinitely tiny components of all substances with the heavenly objects that almost surpass our thinking power, the movement that is present everywhere in space would give us a more comprehensible example. For then we could compare the fixed stars, the firmament's suns, with the molecules and the planets that go around their suns with the atoms. The atoms not only participate in the movement of the molecules; rather they themselves move in a way that is perhaps also complicated. Whatever the movement of the atoms within the molecules may be like, it is clear that their holding together must be seen as due only to their mutual attraction. However, this attraction is decreased by the molecules' very intense oscillations, which is why most chemical transfers only occur at high temperatures. And more: when the temperature is very high, i.e. when the intensity of the molecules' oscillation becomes very great, the mutual attraction of the atoms in the molecules ceases entirely. Consequently, if the temperature is high enough, every compounded object must disintegrate into its elementary components solely because of the heat. Since from the start the mutual attraction of the atoms differs greatly in the various compounded objects, the temperature at which the various compounds separate into their elements must also vary greatly. Thus e.g. gold chloride disintegrates into chlorine and gold already at about 250°, whereas water separates into hydrogen and oxygen only at about 3000°. But in any case, above a certain temperature, which we can assume to be between 3000 and 4000°, no chemical compound is possible anymore. Thus in our sun, the temperature of which has been estimated to be about 8000°, all substances must be alongside one another in their elementary state, hydrogen alongside oxygen alongside chlorine, etc. In the sun there is absolutely no chemical compound. But we shall soon show in greater detail that the sun consists of the same elements as our earth.

We learned earlier that the molecules of the elements, of hydrogen, oxygen, nitrogen, etc. also consist of several atoms that mutually attract one another. The so-called simple substances only differ from the compounded substances by the fact that in the former the molecules are made up of identical atoms, while the latter consist of atoms that differ from one another. Now how do the molecules of the elements themselves behave in very high temperatures? By logical deduction, we must assume that at sufficiently high temperatures, the atoms in the molecules of the elements also entirely lose their mutual attraction and thus must separate from one another in order to oscillate alongside one another as free atoms. And that is in fact the reality. Of course, because of the difference in the mutual attraction of the various elements' atoms, the temperature at which the molecules disintegrate into their individual atoms will vary greatly. It has been known for a long time that the molecules of some metals, the molecular size of which could easily be determined, do not consist of two atoms like hydrogen, oxygen, etc., but of one atom. It was possible to discover this because the respective metals such as mercury, cadmium, zinc, evaporate at a temperature that is not very high and thus, after their passage into the gaseous state, their specific weight could be determined. Formerly, this peculiarity of the metals examined was considered to be an inexplicable exception, until it was recently discovered that at moderately high temperatures, other elements as well such as bromine and iodine and in particular the latter, have molecules consisting of two atoms each, as the specific weight of these substances in the gaseous state showed. But at very high temperatures, these molecules gradually change in such a way that they split into individual atoms. Unfortunately, we do not have the means to produce sufficiently high temperatures to determine this for all elements, for what we use as fuel is nothing other than the heat of burning, the heat of compounding, that is produced when carbon and hydrogen are united with oxygen. Thus, we naturally cannot produce such a high temperature that the molecules of all elements finally split into their atoms. But because we know that compounded objects separate into their components at very different temperatures, we are justified in assuming that the simple substances will also separate into their components at various temperatures. However, the simple substances consist of molecules that in turn are made up of identical atoms. For some elements, such as mercury, cadmium, zinc, the disintegration of these molecules into their individual atoms requires a relatively low temperature; for others a very high, at present unattainable temperature is needed.

We must finally conclude that in the ball of the sun there are not only no compounded substances, but also that the sun's substances are not present as molecules, like on the earth, but as free atoms.

Not only an increased **intensity of oscillation**, so heating within certain limits, can cause the atoms in the molecules to move to new molecules, i.e. to produce chemical phenomena as we saw above, for example where burning is concerned, oxygen can unite with carbon and with hydrogen only in glowing heat. Strong light, so an increase in the **speed of oscillation**, can also sometimes cause chemical changes. Thus for example chlorine unites with hydrogen immediately and with a strong explosion when a mixture of the two gasses is exposed for just a moment to direct sunlight. And in this case it is precisely the light rays that can be refracted the most, that is to say those in which the particles of the world ether oscillate the fastest, that cause this chemical effect. But not only the formation of some compounds occurs through the influence of the light rays; some disintegration also occurs because of the effect of the light. And as was shown previously, here again it is above all the violet and ultraviolet light rays that have this kind of a chemical effect. That is why this effect is caused above all through direct sunlight, which is very rich in violet and ultraviolet rays. It is caused to a somewhat lesser degree by electric light, by magnesium light, and it occurs only minimally through the light of a lamp, because the latter is rich in yellow and red rays but poor in violet and in particular ultraviolet rays. The disintegration of silver chloride, silver bromide, and silver iodine through light has become extremely important for industry and science. It was already known in the last century that the pure white silver chloride secreted immediately as cheesy flakes when an acidic saltpeter silver solution was mixed with a salt solution, changed color in a short time when left in the light, finally turning dark violet. And already towards the end of the last century there were repeated attempts to use this characteristic of silver chloride to produce drawings by covering copper plates with a thin layer of silver and then exposing them to chlorine vapors. In this way a thin layer of silver chloride was formed on the plate. Such a completely white plate was covered with a piece of paper on which there was a drawing, and it was then exposed to sunlight. Some light, though greatly weakened, penetrated the paper to the plate, but not to where the lines of the drawing were, so that gradually everything under the white paper became dark, while the lines of the drawing remained white on the plate. But once the paper was removed, a drawing produced in this way on a plate that was sensitive to light had to be preserved in a way that gave it greatest protection against light. And yet, from these first raw beginnings our photography gradually developed. For by chance **Daguerre** discovered that silver chloride that was “exposed” even when put into light for a short time, so that no direct effect of the light could be perceived, becomes capable of attracting and of holding on to finely spread mercury (mercury vapors) and finely spread metallic silver. Thus, when a plate covered with silver chloride on which the sun has shone for a short time is exposed to mercury vapors, or when a solution of acidic saltpeter silver is poured over it and by some means metallic silver is produced from this solution, after being washed the plate keeps the mercury or silver in those places on which the sunlight has had an effect. Now since all metals look black when they are most finely spread, the places on the plate that have been hit by the light look dark. Now silver chloride is easily soluble in a solution of sub-sulfuric acidic sodium. Thus when a solution of sub-sulfuric acidic sodium is poured over a silver chloride plate after "producing the picture" in this way, all the silver chloride is removed from it and only the picture remains. Now the plate is no longer sensitive to light. Later it was discovered that silver bromide and silver iodine are even more sensitive to light than silver chloride. And in most recent times it has become possible to produce plates that are so extremely sensitive to light that an exposure of less than 1/100 of a second is enough to get a sharp picture. This is not the place to enter into the details of photography; after discussing the principle, let us here mention only briefly the method that leads to producing the picture.

A gelatin solution containing extremely finely spread silver chloride is put on glass plates. As slowly as possible, the gelatin is dried and thus plates that are very sensitive to light are obtained. Of course the silver chloride gelatin and the drying and storing of the plates are done in darkness. In the darkroom, the picture of an illuminated object is thrown onto these plates by means of achromatic lenses and then a saltpeter acidic silver solution together with a solution of pyrogallic acid is poured over them. From the saltpeter acidic silver, the pyrogallic acid produces metallic silver, which precipitates over the whole of the plate's surface and is extremely finely spread, but it only sticks in the places that have been exposed to the light. The plate is then rinsed with water. This is how the picture is "called forth", and it is dark on a light background. When the picture has emerged clearly enough, a solution of sub-sulfuric acidic sodium is poured over the plate, and all of the silver chloride is thereby dissolved; the plate is well washed, allowed to dry, and then for its protection covered with a varnish. From this so-called negative, the positive picture is produced on paper plates covered with silver chloride.

In the preceding, we saw that heat and light produce compounds from the respective components, and vice versa, that compounds can be decomposed by means of these two physical forces.

But what is far more important is the fact that by means of chemical forces, physical phenomena can be produced. Almost every chemical change is connected with heat development. If we dissolve a solid object in a liquid, as was discussed previously, the liquid cools off because in dissolving, the solid object in turn becomes liquid, and all objects use up heat when going from the solid to the liquid state. As soon as no heat is supplied from the outside, they take this heat from the liquid surrounding them. Thus, for example, water cools very considerably when we dissolve crystallized calcium chloride in it. It is extremely easy to dissolve calcium chloride in water, and when it gradually crystallizes from the water, it contains considerable amounts of crystal water **?-Krystallwasser**. By heating the salt to about 300°, it is possible to remove this latter again completely. But if calcium chloride that has thus been freed completely of water is dissolved in water, the water is not cooled off but heated. That is because when the water-free calcium chloride is dissolved, it first of all again combines chemically with the appropriate amount of water (for every molecule of salt, six molecules of water) and then dissolves. And through this chemical unification of the calcium chloride with water, such a considerable amount of heat is produced that it comes to bear in spite of the heat used in the process of liquefying the solid salt. For the heating that occurs when the water-free calcium chloride is dissolved in water only corresponds to the surplus heat produced by the chemical reaction over against the heat used for liquefying the solid salt.

Moreover, all acids unite with bases to form salts while producing heat. But in particular, all elements develop heat when they unite with one another. And almost all of our methods for producing heat, our artificial sources of heat are based on chemical reactions. Our ovens are heated simply because of the heat that develops when our fuels are burned, which is to say, when carbon and hydrogen unite with oxygen to form carbon dioxide and water.

On the other hand, it is known that mechanical work is accomplished by means of heat, especially when water is transformed into steam through heating. By its pressure, the steam causes the movable wall (the retort) of the entirely enclosed space containing it to move. Thus, through the increased intensity of the molecules' movement, masses can be brought into motion. On the other hand, heat can be produced through the movement of masses, as when two objects rub against one another. So we see that the movement of the atoms (chemical movement) can be transformed into the movement of the molecules (physical movement), which in turn can be transformed into the movement of masses (mechanical movement), and vice versa.

All that we still need to do now is to discuss in somewhat greater detail a phenomenon that was mentioned earlier. As was shown there, when sunlight is made to pass through a narrow gap and then through a prism, a broad colored strip (the spectrum) can be observed rather than the narrow image after passing through the gap, and this strip is interspersed with many dark lines. These dark lines obviously signify nothing other than the fact that in sunlight there are rays that are refracted differently, or at least not with the same intensity as the others. That is why the image has dark lines in various places.

On the other hand, when sunlight or artificial light passes through colored glass or colored liquids and then through a prism, it can be observed that part of the spectrum is either entirely cancelled, or that it is visible in its full breadth but with broad dark lines going through it in certain places. Now that means nothing other than that the colored glass or liquids are not only transparent for light of one color and opaque for all other light rays, but rather that they are opaque for a series of rays, but transparent for the other components of white light present in sunlight. And in the transparent colored substances, we only see the mixed color that is produced by all the latter rays. It is exactly the same with every other colored object. For such an object reflects only a fraction of all the rays that fall on it, while it absorbs the other part of those rays. And what we get is never simple light of one color.

But it is entirely different when, under certain conditions, we heat gasses to the point of glowing strongly, so to the point when they themselves glow. Thus for example, it is universally known that the spirit that burns with a blue non-glowing flame immediately begins to burn with an intensely yellow flame as soon as some common salt is placed on the spirit lamp's wick. Not only the salt (sodium chloride) but also sodium sulfuric acid, soda (sodium carbonic acid), borax (sodium boron acid), in fact all sodium salts show this same characteristic. If we look at such a yellow flame through a prism, it appears as diverted, but no other colors can be observed; even after its rays have passed through a prism, it remains purely yellow. If the rays from the yellow flame are then passed through a narrow gap followed by a prism, what can be seen is not a color spectrum but a bright narrow yellow line, the image from the gap. Thus, the yellow sodium flame really does contain nothing but simple light that can not be separated further into other colors. If a small amount of the more rare metal lithium's chlorine compound is added to the non-glowing flame in the Bunsen lamp (cf. above), the flame can be seen to have a bright red color, and seen through a prism, this light also has only one color. However, we do not have many means to produce such light with one color. But even if such colored flames usually do not contain only one color, they are nevertheless always a mixture of relatively few colors. That is why, when their light is made to pass through a narrow gap and then through a prism, only a few bright lines of various colors are perceived; these are the images from the gap and they appear in various places according to the refraction of the rays. As can be seen in **figure 60**, the spectrum of the colored flames appears as made up of individual lines. **Figure 60** shows the spectrum of a flame that got its color from calcium salt; the lines **a** to **g** are various shades of red, orange and green, **h** is violet. In the course of a few years, the spectra almost all the elements' flames were examined, and it was discovered that, with the exception of very few elements, the bright lines that can be seen in their flames are in exactly the same places as the dark lines in the sun's spectrum. Thus for example, iron that is evaporated in the arc of flame of electric light appears with about 300 bright lines in the spectrum and they all correspond exactly to the dark lines in the sun's spectrum. Lead, on the other hand, evaporated in the same way, has a number of bright lines in its spectrum, of which not a single one corresponds with the Fraunhofer lines. That is surely no a coincidence. Then another optical fact was discovered, and it suddenly made it possible to give a simple explanation for this conspicuous phenomenon. For it was seen that every flame allows all types of rays that it does not itself radiate to pass through it without obstacle, but it completely absorbs all the types of light rays that it does radiate. In other words, every flame is entirely opaque for those kinds of rays that it radiates itself, and for all others it is entirely transparent. For example, let us place a spirit flame soaked in common salt, which only radiates a weak light of the one color, yellow, between a very intense source of light such as electric light - which is white and thus radiates rays that can be refracted in every way - and the gap that can be seen through a prism. In this case, all the rays of the electric light reach the gap through the flame soaked in common salt except the yellow rays, which the flame with salt itself radiates, and a very bright spectrum with all the colors from red to violet can be seen. But no light from the electric flame reaches the place where only a bright yellow line would be seen if it were illuminated by the flame mixed with common salt; rather, here there is only the weak light from the flame with salt. Therefore this spot is far less bright than the neighboring parts of the spectrum and it appears as a dark line on a bright background, exactly as in the sun's spectrum. This solved the puzzle as to where the dark lines in the spectrum of the sun's light come from. The sun consists of a very brightly shining white hot (probably liquid) ball. The various elements that, because of the extremely high temperature are all in a free state in the sun, evaporate from the sun's surface and surround the ball of the sun as a glowing gas cover, as a shining atmosphere. Therefore, the sunlight that reaches the earth must first penetrate this glowing atmosphere of the sun that shines with a far weaker light. But in it, all the light rays with the same refraction as the light it radiates itself are absorbed, and when the white sunlight is separated through a prism into the individual types of colored light, we get rays with very different intensity. Those that the ball of the sun itself sends us and that penetrate the sun's atmosphere without hindrance are very intense. On the other hand, those that only come from the sun's atmosphere are far weaker. The latter will therefore be much darker in the spectrum than the former, and we will see dark lines on a bright background (cf. the previous discussion). By means of the Fraunhofer lines in the sun's spectrum, we are thus capable of determining exactly which elements are contained in the sun's atmosphere and that is to say ultimately also which ones are in the ball of the sun.

A thorough examination has been done of the position of the brightly colored lines that appear in the spectrum when looking at flames in which some substances in the form of steam have been brought to glow. This examination also led to the discovery of a great number of new elements. For since only a certain spectrum can be obtained from every element, it is clear that when a mixture of various substances in the gaseous state is brought to glow, and when the light is observed through a prism, all the lines of the individual elements will appear next to one another in the mixture's spectrum. As soon as these lines cannot all be explained as coming from elements that are already known, the supposition suggests itself that the new lines are due to one or several elements that are not yet known. Thereupon, the attempt is made by means of the most varied methods to isolate these new elements from the mixture. Since applying Bunsen's and Kirchhoff's spectrum analysis, Bunsen himself succeeded in finding and isolating two elements that are very similar to potassium; they are rubidium and cesium. Crooks could do the same for thallium, Richter for indium, Lecoq de Boisbaudran for gallium, etc.

In the course of time, another purely optical phenomenon, the turning of the level of polarization discussed above, also proved to be closely connected to the chemical nature of the substance that causes the turning. For in the very many organic compounds that, in a liquid state - the solid substances when they are dissolved in any liquid - are able to divert the level of polarization towards the right or left, a common characteristic of the atoms' reciprocal binding in the molecules was discovered. That is that they all contain at least one carbon atom, the four powers of attraction of which are neutralized by four different elements or atom complexes. Thus for example the acid contained in tartar along with all its salts revolves to the right; the acid is made up of $C^4 H^6 O^6$ or

O-C-O-H
H-C-O-H
H-C-O-H
O-C-O-H

If we look at each of the two central carbon atoms more closely, we find that one of its powers of attraction is saturated by hydrogen: -H, a second one by: -O-H, a third by: O-C-O-H, and the fourth finally by the complex:

H-C-O-H
O-C-O-H

On the other hand, if we look at the following compound, which is only slightly different from tartaric acid, the difference in the four powers of attraction's saturation dwindles immediately:

O=C-O-H

H-C-H
H-C-H
O=C-O-H

This is the acid that is found in amber, succinite acid C^4 H^6 O^4. Here, for every central carbon atom two powers of attraction are neutralized by hydrogen, so in an identical way. Therefore, succinite acid cannot influence the level of the polarized light.

Thus we see how the oscillation of the molecules can cause the movement of the atoms to the point of causing them to regroup. Physical phenomena can cause chemical changes; and physical phenomena are at times dependent on the chemical nature of the substances, both of the elements (in the spectral phenomena) and of the compounds (in the phenomena of polarization). And if at the same time we consider the slight change in the movement of atoms into the movement of molecules and that of the latter into the movement of masses, which is to say of chemical force into physical and mechanical force, we can easily recognize that the essence of the force in itself lies in movement. That is why it is not possible to gain or lose anything of the force, even though the force can be used to greater or lesser advantage for our purposes. A ball weighing 100 kilograms can be rolled away more easily than an equally heavy plate can be dragged away. But the greater force that we must use to move the plate and that seems to get lost when the plate rubs the ground, is changed into heat, which in this case of course we cannot use. But for the total view of the forces at work in nature, the fact that we cannot use it is irrelevant.

In this small book, one force of nature has not been taken into greater consideration because we do not yet know its essence with certainty, and that is **electricity**. But the effects of this force show that it has great energy and that this energy extends as far as the atoms in the molecules. For if we let an electric current go through any compound of which the molecules are easily movable, so that is liquid or gaseous, this always brings about a decomposition of the substance. A liquid or gas that is not decomposed by the electric current also does not let the current pass through it. In this decomposition, one of the compound’s components always separates to one of the points at which the electric current enters the liquid and the second component separates to the other point. For example, if we place a copper rod and a zinc rod into a glass filled with a solution of common salt in such a way that they jut out over the liquid and do not touch one another in the liquid, as soon as the two rods outside of the liquid are brought into contact with one another by means of a metal strip, an electric current is produced. At the same moment, the salt decomposes with a speed that corresponds to the intensity of the current; chlorine is thereby formed on the zinc plate and sodium on the copper plate. Of course in this case we can find neither the one nor the other component as such in a free state, because every chlorine atom that is discharged onto the zinc rod immediately unites with the zinc to form zinc chloride, and in the same way, because every sodium atom is in contact with the water in the salt solution, it decomposes this and produces hydrogen. But we can easily change the experiment in such a way that we can in fact get the components from the compound in a free state.

Thus we see that electricity produces chemical phenomena, so it must also be based on a movement of the atoms. But until now we know nothing about this movement's nature in the origin of this force and in its continuation; nor do we know whether it continues by means of the world ether or by some other means. That is why the essence of this force was not discussed in more detail. It is situated between the purely physical and the purely chemical forces, while being essentially different from both.

To conclude, it can be said again: As far as we are able to know their essence so far, all phenomena in nature, all changes are caused by changes in movement. The movement can include the entire mass of an object, it can be a movement of the molecules or of the atoms. But in every case, the one can easily be changed into the other, and we can therefore say with confidence: **There is only one elemental force that causes all natural phenomena, and that is movement** – the movement that is present in space, that can pass from the masses to the molecules and from these to the atoms and vice versa. And we owe all natural phenomena to transformation in the form of movement. The task of the natural sciences is precisely to discover the conditions under which the form of movement can change.