Physical Phenomena

As we saw, the form in which a mass appears, its state, depends first of all on the intensity of the molecules' movement in the mass. Already the most important physical phenomena, sound, light, and as is assumed, very probably electricity, are based on the movement of the molecules. Let us imagine that a steel rod, which is fixed at one end (**figure 18**), has been taken out of its position of equilibrium (**ac**) and put into the position **a'c**; because of its elasticity, it will move with ever greater speed to the position of equilibrium, and because of its inertia, it will move beyond this with ever less speed to the position **a''c**; then it will again swing from **a''** to **a'** and so forth. If these oscillations are very slow (as for example in a pendulum), we can follow them with our eyes and we can observe the rod's position at every moment. If the oscillations become faster, the rod's momentary position becomes invisible to our observation, and all we see is a wide band from **ca'** to **ca''**. This is because every impression of light on our eyes continues to have an effect for some time, so while we believe that we can see the rod in a particular position, it has already completed its oscillation and is already on its way back to the same position. Every impression of light works on our eyes for 1/13 second. Accordingly, if the rod swings back and forth 13 times in one second, so needs 1/13 second for every oscillation, we see it in all its positions during the oscillation at one and the same time. But if the speed of the oscillations continues to increase, after a short time a very deep tone resounds in our ear – as soon as the rod swings back and forth at least sixteen times in one second. If the speed of the rod's oscillations increases still further, we hear this movement as an ever higher and stronger tone that in the end becomes ever weaker and completely disappears when the rod swings back and forth about 36,000 times every second. If we now imagine that the oscillations continue to increase in speed even more, for a long time they are no longer perceptible to our senses. Only when the rod oscillates about 200 trillion times each second will our senses begin to notice it: close to the rod it gets warm, the rod radiates warmth. With an increase in the speed of the oscillations, the warmth increases, and after a relatively small increase in the speed of oscillations, the rod begins to shine with a dark red light. But now, with an increasing speed of oscillation, the shining of the rod increase rapidly; the rod soon becomes a shining yellow, then a shining blue, and then gradually darker again. As soon as its oscillations occur about 800 trillion times a second, it completely disappears from our eyes. Our senses are again incapable of perceiving its oscillations directly, but we can recognize them indirectly by the fact that a sheet covered in silver chloride quickly becomes dark when close to it. But soon, this phenomenon also no longer occurs, and now we seem to lack any possibility of making such extraordinarily rapid oscillations perceptible, unless an entirely new characteristic of the rod becomes apparent, which is electricity. However, this is something we do not yet know. Of course, we will never ever be able to bring a rod into oscillation at such a high speed, one which is unimaginable for us. But we are able to supply the molecules that as such are always in extremely rapid oscillation with so much strength that, for the first moment, the speed of their movement reaches this degree that is so confusing for our senses.

Sound, warmth and light (perhaps also electricity) are nothing other than forms in which we become aware of the movements of the masses and of their molecules. Tones are produced by means of the regular oscillations of solid, liquid or gaseous objects when these oscillations are faster than 16 times and slower than 36,000 times a second. Because of its elasticity, if we take a drawn string (of a musical instrument) out of its position of equilibrium **AmB** and put it in the position **AnB** (**figure 19**), it will swing from **AnB** to **AoB** and back, and the tighter the string is drawn, the faster will be the oscillations. The height of the tones depends on the rapidity of the oscillations, as is generally known, whereas the strength of the tone depends on the size of the space between **n** and **o**, the amplitude of the oscillations.

On the other hand, like warmth, light phenomena are nothing other than the consequence of the oscillations of an object's molecules. Of course, we don't know what kind of oscillation this is, but that is secondary when explaining the phenomena. What is more important for the latter is the explanation of how sound, warmth and light spread. Their spread to the point of our sensory organs, through which the phenomena reach our consciousness, also occurs by means of oscillations, in a so-called undulation. But right from the outset, we must distinguish here between the spread of sound and that of warmth and light. For sound can spread through the movement of molecules in solid, liquid or gaseous substances, and it does so all the more easily, the more dense the substance is through which it spreads. If someone gently taps on one end of a long bar with his finger, a second person holding his ear close to the wood at the other end of the bar hears the tapping very clearly, whereas someone much closer to the person tapping, but who does not hold his ear to the wood, will not perceive it. So sound spreads far better through wood than through air. In contrast, sound will not spread at all in a vacuum. We are in no way able to perceive the strongest, loudest explosions that occur above our atmosphere.

It is different with warmth and light. Warmth can communicate itself directly from one object to another, can spread through a pipe, but both warmth and light are also able to reach us through space by means of radiation. For we receive all warmth and all light on our earth from the sun, and the space between the earth and the sun is certainly not filled with material objects. It was therefore assumed in times past that warmth itself was a substance, different from our ordinary, earthly substances, of course, in that it was completely weightless and so fine that it could penetrate the pores of even the most dense substances and so to speak surround the molecules of normal objects. It was also believed that this weightless warmth substance was hurled away in small particles at infinitely great speed and that it penetrated cold objects it encountered, etc. However, it was gradually noted that with this assumption it was not possible to explain a great number of phenomena of warmth, and so it had to be given up.

In the same way, **Newton** tried to explain the spread of light through space by assuming that there was a light substance. He believed that every shining object hurled away infinitely small particles of this substance at extremely great speed; when these particles reached our eyes, they then called forth the feeling of light. But even though, because of **Newton**'s authority, this assumption remained the dominant one over a long period of time, it gradually had to be abandoned entirely, since the number of facts that could no longer be explained by it increased constantly.

So we came to the point of recognizing another assumption as the more correct one. It was first set up by **Huyghens**, the inventor of the pendulum clock, and says that the spread of light occurs in the same way as that of sound, or like that of the wavy circles caused by throwing a stone into still waters. And later, it was also seen to be necessary to explain the spread of rays of warmth in exactly the same way. But in order to do so, a second assumption had to be made, which was that all of space is filled with an extremely fine and extremely light substance, a substance that we cannot perceive directly with our senses, but which not only fills the empty spaces between the heavenly bodies, but also the spaces between the molecules in solid, liquid, and gaseous objects. This substance that fills space was called **world ether** or simply **ether**. In the spread of sound, the molecules of solid, liquid or gaseous substances themselves are made to oscillate, in the spread of warmth and of light, what oscillates are the ether particles.

We shall now try to show what kind of oscillations these are.

If you throw a stone into still water, you immediately see rapidly growing, moving wavy circles. But the water particles themselves do not participate in this movement, as you can easily see if you lay a piece of wood onto the water. You only see the wood bobbing up and down, but it remains in the same place. When a stone was thrown into the water, the water particles in the place that was hit were pressed down and at the same time to the side. Because of the water's elasticity, these particles try to return to their position of equilibrium, and as was previously shown several times, they reach their position of equilibrium at a certain speed and then, because of their inertia, they swing beyond it in the opposite direction as far as the stone had taken them away from it. Then they swing back again and would continue this game without interruption with the same strength if there were no impeding force, which is to say friction, that gradually returned them to a position of rest. These particles oscillate in the form of a circle, as can be seen in **figure 20**. But as soon as each of these particles has covered a small distance in its oscillation, it causes (in water because of the mutual attraction) all of its neighboring particles to begin this movement as well. For the sake of simplicity, we shall only look at the neighboring particles to the right of **a** in **figure 21** and assume that the particle **b** just begins to move when **a** has completed a quarter of its oscillation, so is in the position **a**^{1}. In **figures 21A** to **H**, which show the circular movement of the individual water particles by means of small dotted circles and at the same time, the respective position of the particles (**a** to **h**) by means of a thicker connecting line, **figure 21A** shows us their respective positions so long as the water's surface is smooth, which is to say as long as there is a state of rest. In **figure 21B** we see the beginning of movement. The particle **a** has completed one quarter of its oscillation and in this instant causes the particle **b** also to move out of its position of equilibrium. At this moment, the particle **a** is in the position **a**^{1}. As soon as **a** has progressed a further quarter of its oscillation and has reached **a**^{2}, as in **figure 21C**, **b** has completed one quarter of its oscillation and has reached **b**^{1}, and in the same way it now causes the particle **c** to move away from its position of equilibrium. After yet another quarter of **a**'s oscillation, when the latter is in **a**^{3}, as in **figure 21D**, **b** has reached **b**^{2}, and during this time, **c** was forced in the same way as **b** before, to go to **c**^{1} and to force its neighboring particle **d** to give up its position of rest. The next moment (**figure 21E**), the particle **a** has returned to its original position of rest, and at the same time, **b** has gone from **b**^{2} to **b**^{3}, **c** in turn has gone from **c**^{1} to **c**^{2}, and finally, **d** has reached **d**^{1} and the particle **e** is just beginning to leave its position of rest. At this moment, the five particles **a,b,c,d,e** are in their respective positions as indicated by the thick line. However, as shown in **figure 21F**, **a** now again swings to **a**^{1}, **b** moves from **b**^{3} to **b**, that is to say, to its original position of equilibrium, **c** moves from **c**^{2} to **c**^{3}, **d** from **d**^{1} to **d**^{2}, and finally, **e** to **e**^{1}. Their respective positions are expressed by means of the thick line in **figure 21F**. After yet another quarter of an oscillation, the position of the individual particles is that shown in **figure 21G**, and so on. So during the time in which the particle **a** completes just one oscillation, the movement is communicated as far as particle **e**; particle **a** begins its second oscillation the same instant that **e** is preparing to begin its first one. When **a** has completed its second oscillation, **e** has just gone through its first one (**figure 21J**) and is now also at its original place, and the movement has been reproduced as far as **i**; particle **i** just wants to begin its first oscillation. And thus it continues. Every particle only moves in the small circle that is shown by dots in **figures 21A** to **J**; but since every particle following begins to oscillate an instant later, the respective positions of the particles are greatly changed. When we see the wavy movement of the water, we are not seeing the oscillations of the individual particles, but rather only the respective positions of the particles on the surface. The surface no longer appears to be smooth, as in **figure 21A**, but rather, in **a**^{3} and **e**^{3} it shows heights, and in **c**^{1} and **g**^{1} depths. The heights are called the crest of the wave and the depths are the wave trough. The distance from one crest of a wave to another or from one wave trough to another is called a wavelength. If we look at two particles that vary from one another by just one wavelength, as for example **b** and **f** in **figure 21F**, we see that both are in exactly the same state of oscillation, at this moment both are striving with the same speed and in the same direction (towards the left) from the position **b**^{1}**, f**^{1} to the position **b**^{2}**, f**^{2} (**figure 21G**). In contrast, two particles that are half a wavelength from one another are in opposite states of oscillation. Thus the particles **b** and **d**. While **b** is swinging towards the left and upwards, at the same moment the particle **d** is moving towards the right and downwards. This correspondence in the states of oscillation of two particles that are a whole wavelength away from one another occurs at every point in the oscillation. They hasten through the position of equilibrium, they reach the deepest point in the wave trough and the highest point in the crest of the wave at the same moment, and again go through the position of equilibrium at the same moment. In the same way, two particles that are separated from one another by half a wavelength are always in opposite states of oscillation. When one is going through the position of equilibrium, the other is at the same height, but it is moving forwards in the opposite direction, and as soon as the one reaches the highest point of the crest of the wave, the other is at the lowest point of the wave trough, etc.

The speed at which the waves progress, which is to say, the point to which the oscillations spread within one second, how far they distance themselves from the point of departure, in no way depends on the speed at which the individual particles cover their circles or on the size of the circles, but rather it is determined solely by the nature of the substance. So in our case with waves of water, the progress of the waves always remains the same. But in mercury, the waves progress faster than in water. The size of the circles covered by the individual particles determines the greater or smaller height and depth of the waves, their intensity. Finally, the rapidity with which the individual particles oscillate, so the length of time they need to complete one oscillation, determines the length of the individual waves. If we assume that the waves progress 100 meters every second and every particle needs 1/300 second for each oscillation, the wave would progress by 1/3 meter during this time. As soon as the particle begins its second oscillation, a particle that is 1/3 meter away from it begins its first oscillation. Since all oscillations of the individual particles in the same wavy movement occur at the same speed, this particle that is 1/3 meter away must be in the same state of oscillation as the first particle one wavelength away. So every wave is 1/3 meter long. If the speed of the waves' reproduction were 300 meters per second and every oscillation of the individual particles lasted 1/20 second, the length of the individual waves, so the distance between two particles in the same state of oscillation, would be 300/20 or 15 meters.

Sound, warmth and light spread in the same way as waves in water, sound through material objects, warmth and light through ether. We shall now look at the spread of sound in air, but again for the sake of simplicity, we shall only discuss their spread in one direction. Let us think of a number of air particles 1 – 20 that are all at the same distance from one another (**figure 22**). Let us now imagine that by some power, the first was made to move somewhat to the right and then drawn back again. In this case, because of the elasticity of air, the neighboring particle will also move to the right and then swing back again, in short, it makes the same movement as the first particle, except that it begins its movement an instant later. Similarly, this particle causes its neighboring particle to oscillate in the same way, and it in turn begins its movement an instant later and again causes particle 4 to oscillate. In **figures 22B – E** we can see the positions of the 20 particles after ¼, ½, ¾ and a complete oscillation of particle 1. Near particle 15 in **figure 22D** we see a compression of the air, and near particle 1 a dilution.

If we now imagine that this spread occurs at the same speed in all directions, compressions and dilutions of the air will be produced at the same distance from the point that was first made to oscillate, so in a spherical expanse, and they will spread at a certain speed. Such compressions and dilutions are produced when sound spreads.

Thus with sound, like with the wavy movement of water, the movements of the individual particles, which take place within very narrow limits, must be clearly distinguished from the spread of sound; the latter occurs to the extent to which the sound can be heard, that is to say, to which a transmission of the oscillations is still so strong that our ear-drum can also be made to oscillate by means of the oscillations of the air.

As already mentioned, the height of a tone depends on the individual particles' speed of oscillation. As soon as the number of oscillations per second reaches 16.5, we hear these as the deepest tone (it is subcontra C). Thus, the length of oscillation for the deepest tone is 1/16.5 second. Every tone oscillates twice as often per second as the next deeper octave and half as many times as the next higher octave. The fifth of a tone is produced when every three oscillations need the same length of time as two oscillations of the root. The following simple numerical relationship occurs as regards the length of time required for the oscillation of an individual tone: in the same length of time in which the tone C oscillates 24 times, the following number of oscillations occur for the other notes: D – 27, E – 30, F – 32, G – 36, A – 40, B – 45, c – 48, d – 54, e – 60, f – 64, g – 72, a – 80, b – 90, etc. Or while C oscillates once, the following number of oscillations occur for the other notes: D – 9/8, E – 5/4, F – 4/3, G – 3/2, A – 5/3, B – 15/8, c – 2, d – 9/4, e – 5/2, f – 8/3, g – 3, a – 10/3, b – 15/4.

But in one and the same substance, for example in air, all notes spread at the same speed, otherwise the harmony of the tones during a concert would turn into a cacophony for everyone who was not at a certain distance from the orchestra. The speed at which sound waves spread in air is 333 meters per second. In other gaseous substances the distance is all the greater, the lighter the gas is, and all the smaller, the heavier it is. Thus, the speed is the following in these gasses:

Oxygen, specific weight 1.1026	317 meters
Carbonic acid, specific weight 1.542	262 meters
Hydrogen, specific weight 0.0688	1270 meters

In liquid and solid objects, it is considerably greater and amounts to:

Water	1453 meters
Alcohol	1157 meters
Mercury	1484 meters

In wood, iron, glass it is about 16 times greater than in water. But it would take us too far to study the methods used to find the speed of sound in the various substances here. However, the speed at which sound waves spread in air was found in a very simple way: on two hills in Paris that are about 18 kilometers from one another, canons were shot and people then watched to see how much time went by between the flash and the boom from the shot fired from the opposite hill.

We still have to discuss briefly what occurs when the waves of sound in air hit a solid or liquid object. Through the oscillations of the air particles, some of the particles in the wall that the waves encounter also begin to oscillate. Thus, the sound will partly spread by going through the wall; but partly, the air particles that bounce off the wall will cause a wavy movement in the opposite direction. The sound is thrown back, reflected onto the other part. It goes without saying that the same laws apply here as with all elastic objects:

the direction of the reflected rays of sound has exactly the same inclination towards the reflecting surface as the rays of sound that crash into it. In the special case when the rays of sound are directed vertically onto the reflecting wall, they are reflected to the point whence they came. And when the wall is far enough away for the sound to require the time needed to say one, two or more syllables for it to reach the wall and to return to its point of departure, an echo of one, two or more syllables will be heard. Since it takes about 1/7 second to say one syllable, and since the sound must cover the distance to the wall and back to the ear of the person calling, an echo will be heard as soon as the wall that is throwing back the tone is at least 1/14 of 333 meters away from the caller, so about 24 meters. If it is more than twice that far away, a two-syllable echo will be heard, and so forth.

Just as sound waves in solid, liquid and gaseous substances spread by means of the oscillation of the molecules within narrow confines, the light and heat waves spread through the oscillation of the ether particles. Here too, the spread occurs in such a way that every oscillating particle of ether causes its neighbors to oscillate in the same way and that these neighboring particles begin their oscillations just the tiniest amount of time later than the preceding particle. But there is one difference between the oscillations by which sound spreads and those that spread light and heat through space. For in the former, the direction of the individual molecules' oscillation is the same as that of the rays of sound, but in the latter, the ether particles oscillate vertically to the direction of the rays of light or heat. We can compare this way in which a wavy movement progresses with the movements that can be caused in a long, taut rope that is fixed at one end and that is moved back and forth quickly at the other. The rope takes on the form of a serpentine line while each of its particles only covers a short distance that is vertical to the rope's direction.

Let us imagine a row of ether particles (**figure 23**) 1 to 20 in a horizontal line, with each particle oscillating from top to bottom and back (for the sake of simplicity, this oscillation itself is written in a straight line) in such a way that particle 5 begins its oscillation when particle 1 has just reached its deepest point (**figure 23B**), that is to say, when it has completed one quarter of a complete oscillation (back and forth), just as particle 10 begins to move one quarter of an oscillation after the fifth particle. Then **figure 23C** shows us the respective positions of the particles after half an oscillation of particle 1, **figure 23D** after ¾ of an oscillation, **figure 23E** after a complete oscillation.

As for the reflection of heat and light rays, the same basic principle is true as for the rays of sound, that is, the angle formed by the ray with the surface as it falls onto any surface must be equal to the angle formed by the reflecting ray with the same surface. For reasons of expediency, we begin with the angle formed by the invading ray and the vertical that is directed to this point, for example in **figure 24**, **AB** is a ray falling onto the surface **MN**, and **CB** is the vertical; then the inclination of **AB** to **BC**, angle **a**, is the so-called angle of incidence. The ray **AB** is reflected by the surface **MN** at the point **B** in such a way that it continues in the direction **BD** when the inclination of **BD** to **BC**, which is to say the angle **b**, the "angle of reflection", is exactly equal to angle **a**. Let us now assume that **MN** is a mirror surface and that our eye is at the point **D.** We then see the point **A** in the mirror at **E**. For we are used to seeing light always in a straight line, and in addition, to estimating its distance instinctively. We do the same with light that has been deflected from the straight path by some cause. Now in our example, the distance between point **A** and our eye equals the length of the sum of the two lines **AB** and **BD**. Through an unconscious mental conclusion, we therefore transfer the light in the direction **BD** so far as corresponds with the length mentioned, that is to **E**, if **BE** is just as long as **AB**. Thus we see the image of the light behind the mirror, and as can easily be understood, just as far behind the mirror as it is in front of it. All we have to do is connect **A** with **E** in our figure, and we see that **AM**, that is to say the distance of the light from the mirror, equals **ME**, that is the distance of the image from the mirror surface. Such an image of an object, that in reality does not exist (for in point **E** there is in fact not a trace of an image of the light), but that we think we can see in the respective place because of unconscious mental activity, is called an apparent or virtual image. Because through the reflection of light rays, we can also bring forth objective, real images. For let us be clear about how we can see at all. Without discussing the internal arrangement of our eye, let us just mention here that a shining or illuminated object enters our perception because part of the light rays that every single point of the object radiates in all directions enters the eye and again unites at one point on the inside back wall of the eyeball, on the retina. This stimulates the extremities of the visual nerve that are spread out on the retina, and in a mental activity of which we are not conscious and which does not interest us here, we pursue the light rays back again to the point from which they came, that is to the shining or illuminated object. Thus, if light rays go out from a point and partly hit our eye, we see the respective point. When in addition, light rays go forth from a shining point in such a way that, with some kind of help, they again unite to a large extent at a point, continue on from there in a diverging path and only then hit our eye, by means of our mental activity, we of course will not transfer the shining point to the place where it in fact is, but rather to the place where the rays that hit our eye were last united. Thus for example, according to the fundamental principle that the angle of reflection is always equal to the angle of incidence, concave mirrors that can be seen as pieces of hollow spheres mirroring from within, are able to unite again in one point the light rays coming from a shining or illuminated object that is outside of the focal length and that hit the mirror. In **figure 25**, **SP** is a concave mirror and **L** a shining point. Of the infinite number of light rays that **L** sends forth in all directions, a large part hits the concave mirror and is reflected by it in such a way that the reflected rays all go through point **B**. An eye that is beyond **B** and which the rays reach will see the shining point in **B**. If instead of the shining point we take an unbroken row of shining points, that is to say a shining object **LM** (**figure 26**), all the rays going forth from **L** that hit the mirror unite in **B**, all those going forth from **M** unite in **C**, and all those going forth from **N** unite in **D**; the rays sent forth by the points between **L** and **M** meet in the part between **B** and **C**, and so forth. In short, we get an unbroken row of points in **BDC**, every one of which sends forth a large number of rays. On a dark screen set up in **BC**, the reverse image of the arrow **LM** appears in most clear outline. If we compare the **BC** image in front of the concave mirror with the image discussed in connection with **figure 24** that appears in image **E** behind the flat mirror, the difference between the two is immediately clear. In **BC** we in fact have light rays that go forth from every point, whereas in **E** (**figure 24**) we cannot speak of the presence of light rays. In our present case a **real** image appears, whereas the upright image that appears behind the flat mirror only **seems** to be there.

As with sound waves, we must also carefully distinguish in light and heat waves between the speed of the individual ether particles' oscillations and the speed of the oscillations by which the wavy movement spreads. Just as with sound, the latter depends on the nature of the substance in which the spread occurs. As is generally known, this spread occurs in space at the speed of virtually 42,000 geographic miles per second, but where the ether particles are influenced by the presence of material molecules, so in the air, in liquid and in solid objects, the distance covered is less. When light rays go through a transparent object, they move in the respective object all the more slowly, the more dense the object is, so for example through water more slowly than through air, through glass more slowly than through water, etc. Of course the speed of the light rays' spread is so extremely great even in the densest of substances, that this difference in the speed at which light passes through air or through water could only be proven experimentally by means of very usefully constructed instruments. But another phenomenon is based on this difference in the speed at which the rays spread in various substances; it is the possibility of refracting light rays when they pass from one substance into another. Everyone knows the odd phenomenon that occurs when you dip a rod into water in a diagonal position. The rod seems to be bent at the point at which it is dipped into the water, as can be seen in **figure 27**. The rod **ABC** appears in the form **ABD**. This phenomenon can easily be explained.

For as soon as light rays reach water from the air, or vice versa, reach the air from water, they are refracted. In **figure 28**, the hatched expanse is water and the line **aN** is a ray of light. As soon as the light ray enters the water, it does not continue in the same direction, but instead in the direction **NP**. There is a very simple law regarding the direction of the refracted ray. For if at the point **N** a vertical line **RS** is drawn, and if on the other hand a circle is drawn with **N** at its center, the vertical line **ab** that is placed on **RS** at the point of intersection of **aN** with the circle is about 4/3 the length of the vertical line **cd** that is placed on **RS** at the point of intersection of **PN** with the circle. Whatever the angle might be that is formed by **aN** and the line **RS**, the direction of the refracted ray is always easy to find by means of this construction. It goes without saying that a ray having the direction **NP** in water, would be refracted in such a way when leaving the water that it would take on the direction **MN** (**figure 29**). But since we always follow the rays in the direction in which they finally reach our eye, we will see the ray **NP** in the direction **MQ** in figure 29. If we now return to our example of the rod that is half dipped into water in a diagonal position, it is easy to understand that we will see the half that is above the water in its true direction **AB** in **figure 30**, and we will see the half **BC** that is dipped underwater, the rays of which are refracted in the direction **BE,** in the extension of this direction **BD**. Thus the rod **AC** appears to be bent at **B**; we see its upper half in the direction **AB** and its lower half in the direction **BD** (**figure 31**).

The speed at which the light rays spread will be slowed down ever more, the more dense the substance is through which they hasten; that is to say, the refraction of the rays is all the greater, the greater the difference in density is between the two transparent substances. Thus, as we have seen, the refraction of the rays in passing from air to water is in a relation of 4:3; rays that pass from air into glass are refracted in such a way that the relation of the two lines discussed above (**ab** and **cd** in **figure 28**) is about 3:2.

But whenever the light rays go from a weaker substance to a denser one, they will always be refracted in such a way that they form a smaller angle with the vertical line placed on the surface border, and vice versa, when they go from a denser substance into a weaker one, they will be refracted in such a way that they form a larger angle with this vertical line after the refraction, and the more the rays are refracted, the greater is the difference. In the two **figures 32** and **33**, the hatched parts are glass, the white parts are air, the line **ab** is the vertical line on the bordering expanse **MN**; so the angle **w** in **figure 32**, formed by the light ray **lp** with the vertical line, is larger than the angle **v**, which the ray **pq** forms with the same vertical line, and in **figure 33** the angle **w** is smaller than the angle **v**.

Consequently, we could easily have the case that, as in **figure 34**, the angle **w**, formed by the light ray with the vertical line at the surface border of the denser substance, is so large that the angle **v** of the refracted ray is 90°, that is to say that it leaves the weaker substance parallel with the surface border or that it is even greater than 90°. But that is impossible. In other words,

> “those light rays that pass from a denser substance into a weaker one, can do so only if their inclination to the vertical line of the surface border is small enough so that this inclination after the refraction is smaller than 90°; otherwise they cannot reach the weaker substance at all and are totally reflected at the surface border.”

The angle at which this impossibility of the rays passing over into the weaker substance occurs, so the angle that is so large that the angle of the refracted ray would be 90°, is called the angle of limitation, and it is all the smaller, the larger the difference in density is between the two substances. Thus for example, the angle of limitation in the passage of rays from water into air is reached at 48° 35’, from crystal glass into air at 37° 36’, from diamond, which is the object that refracts the most, into air already at 23° 53’. We can easily watch the total reflection in glass prisms used as decorations on chandeliers, etc., if we hold these with their broader side downwards and let a bright object such as a window mirror on the lower surface. This lower surface will then appear as a wonderful mirror, because all the rays that penetrate through the side **AB** (**figure 35**) into the prism reach the lower surface **AC** at an angle that is below the angle of limitation and thus cannot pass downwards into the air but are totally reflected towards the side **BC**, whence they reach our eye **O**. By the way, the beautiful play on color that can be seen in diamonds comes from their great ability to refract light.

Let us briefly discuss one extremely important fact here. With our eyes, we do not perceive light rays with one single speed of oscillation, but rather, as with sound though to a lesser extent, we see rays with various speeds of oscillation, or in other words, of various wave lengths. It is only rare that we perceive light rays with one single speed of oscillation; the rays sent to us by the sun or by artificial light are a mixture of rays of greatly varying wave lengths. Simple light, which is to say, light that sends forth only rays of a very precise wave length, also has a certain color, whereas the highly composite light, so light containing rays of all those wave lengths that we are at all capable of perceiving, is white light. For example, our sun sends forth white light.

The length of ether waves, that is to say, the distance between two ether particles that are in the same state of oscillation, is extraordinarily small. Using methods the discussion of which would lead us too far, it was discovered that ether oscillations of which the wave length is one thousandth of a millimeter, cannot be seen by us because they occur too slowly. We perceive ether oscillations as light rays when the wave length is about 760 millionth of a millimeter. But as soon as the wave length is smaller than 390 millionth of a millimeter, the oscillations are again too fast to make an impression on our eye.

Those readers who enjoy large numbers, can easily calculate how many oscillations each ether particle must do in a second in order to bring forth for our eye the phenomenon of light. We learned earlier that one oscillation requires exactly the amount of time it takes for the movement to progress by one wave length. Now light progresses in space at a speed of 42,000 miles per second or of 315,000 kilometers, that is 315 million meters or 315,000 million millimeters. But since each wave length of light is at most 760 millionth of a millimeter, the time required to progress this small distance is 315,000 million divided by 760 millionth, that is one 415th part of a trillionth of a second. Each ether particle must therefore oscillate 415 trillion times every second. But if our eye is to perceive light, the ether particles may oscillate at most 800 trillion times per second (325,000 million divided by 390 millionth).

The light that spreads by means of ether's slowest oscillations is red light; yellow light produces faster oscillations, and blue light even faster ones. The fastest oscillations that have an effect on our visual nerve produce a bluish-red, violet light. We can very easily make visible the fact that the white light of the sun contains rays of every possible wave length (of course we can have in mind here only those rays the wave length of which is within the above named limitations), so that sunlight contains rays of all wave lengths, by taking a prism, that is a piece of glass, two sides of which have been cut inclined away from one another, and by looking through it at a chink that is strongly illuminated by the sun (**Figure 36**). Then, instead of the chink, we will see a broad band in the most beautiful colors of the rainbow.

Let us imagine (**figure 37**) a ray of light reaching the prism **P** in the direction **lm**. When it enters the glass, the ray is refracted and moves through the glass in the direction **mn**. But as soon as the ray reaches **n** and again goes out into the air, it is again refracted and continues in the direction **no**. Consequently, an eye that is at **o,** will not see the ray **l** at its true place, but rather in the direction **on** in **l'**. The shining point **l** appears diverted. Under otherwise equal conditions, the size of the diversion depends of course on the strength with which the rays are refracted; the diversion is all the greater the more strongly the rays are refracted, and vice versa. But not all light rays can be refracted equally; rather, the rays of red light can be refracted the least, those of violet light the most. If in **figure**

38 we let a ray of red light **lm** pass through a prism, it will go from **m** to **n** in the prism because of the refraction and will leave the prism in the direction **no**. Our eye would see it in **r,** diverted in the direction **on**. In contrast, if the same ray **lm** comes from a violet light, when it enters the prism, it will be refracted more strongly from **m** to **q**, and in the same way when it leaves the prism from **q** to **s**, it will again be refracted more strongly than the red ray, and our eye, following the shining point in the direction **sq**, will think it sees it at **v**, so more strongly diverted than the previous ray. If we now finally unite the two points of light and continue to follow the two rays **lm** (the red one and the violet one), the red one will be refracted in such a way that we see the source of light in **r**, and the violet one in such a way that we see the source of light in **v**. So that is to say that as soon as we let the united rays go through a prism, we see the two sources of light that are united in the point **l** not only diverted, but next to each other in two different places. If the point of light **l** were to send forth yellow rays and if our eye were for example at **o**, we would see the rays progressing in the direction **lm** in such a way that we would move the source of yellow light between **r** and **v**, but closer to **r**. Under the same conditions, we would also see the source of blue light **l** between **r** and **v**, but closer to **v**. Now if the source of light **l** contains all rays that are refracted between the red and the violet light, we have to see a line from **r** to **v** instead of a point; one end of the line is turned towards the light source and appears to be red and the other end violet, while all passages between red and yellow, that is orange, then yellow, then between yellow and blue, that is green, then blue, then violet can be seen between the ends. This band of color has been called spectrum, and entirely arbitrarily and without any justification, seven colors have been distinguished in it: red, orange, yellow, green, blue, indigo, violet. However, to be precise, in such a line of color precisely as many colors are represented as there are points in the line, which is to say an infinite number, but our eye is not capable of distinguishing them all from one another.

The easiest way to produce a spectrum is to let white light enter into a darkened room through a narrow chink in the shutter of the window, or if one doesn’t have such a room available, to let sunlight or another white light enter a blackened pipe that has a narrow chink at one end. At the other end of the pipe a prism is attached in an appropriate position, so that the narrow band of light entering the chink passes through the prism, is refracted there and broken down into its colors and then exits again refracted. In order to see the rays coming out of the prism more clearly, they can be observed through a small telescope. The whole apparatus is constructed as shown schematically in **figure 39**. **L** is the source of light; **R** is the pipe with a narrow chink at the end **a**, which is turned towards the source of light; **P** is the prism, **F** the telescope, and **O** the eye of the observer.

When the source of light consists of red light that is entirely of one color (we will learn later how to produce such light of one color), the image of the chink can be seen in **r**; when the light consists of yellow light, the image is seen in **g**; when blue light, in **b**; and finally, when the light is violet, the image is seen in **v**. In **r**, a bright red line can be seen, in **g** a yellow one, etc. But if the source of light radiates white light, so light of all colors, one no longer sees one or several bright lines, but a colored band that is nothing other than an infinitely great number of bright lines lying next to one another and meshing with one another. This band is first a very dark red (on the side nearest to the source of light), then an ever brighter red, then orange, then yellow, green, blue, indigo, and finally a violet that gets ever darker and darker until it gradually disappears.

The length of the spectrum, the distance between the most extreme red and the most extreme violet, as also the diversion of the light rays as such, depends on the size of the angle **a** of the prism (**figure 40**), but in addition to the refractory strength of the substance of which the prism is made as well. For as we saw, the spectrum is produced only by refracting the various rays of light with varying strengths, and the difference in the possibility of refracting the red and the violet rays is called the **dispersion** of light or the dispersal of the light's color. Thus, we must distinguish between the diversion of light and its dispersion, so between the general ability to refract the substance and the difference in the refraction of the red and the violet rays. Now if in general the dispersion is also greater as soon as the ability to refract the substance is greater, we nevertheless find that various substances with virtually the same ability to refract have very different abilities for the dispersal of color. This difference is the greatest among various kinds of glass, because this has made it possible to construct very precise optical instruments. With the various kinds of glass, the medium possibility of refraction is virtually 3:2 or 1.6:1. However, so-called crystal glass, which differs from ordinary glass in that it contains lead compounds rather than lime compounds like the latter, has an almost equal ability to refract, whereas it has almost the double possibility of dispersion. A distinction is made between "lead glass" (flint glass), which is used for optical purposes, and "lime glass" (crown glass).

It was said above that we can only see the various colors of the spectrum as such when they are next to one another, but not when they are all at one point; then they appear as white light. We can easily prove this by placing two equally strong refracting prisms made of the same glass one behind the other so that the one causes the diversion and the dispersion of the colors in the opposite direction to the other, as in **figure 41**. The rays of white light **L** first reach the prism **P**, they are refracted and divided into the individual colors; from there they again wander refracted into the air, only to go into the second prism **A** and to be refracted in the opposite direction. Since the violet rays can be refracted more than the red, these two kinds of light will approach one another in the second prism, and when they go from the prism into the air, they will completely coincide. An eye at the point **O** then sees the light **L** a little removed from its true place as white. But if we take two equally large prisms (as is indicated in **figure 42**), one of which is made of crown glass and the other of flint glass, so in which the same diversion of rays occurs, but very different dispersion of colors, the diversion will be cancelled, that is to say, we will see the white light **L** virtually in the same place as where it in fact is; however, the dispersion of colors caused by the flint glass **P** will not be cancelled, but will rather only be diminished by half by the crown glass **Q**, so that we will see the point of light **L** virtually in its true place but divided into the individual colors. The spectrum will have half the length of that produced by the flint glass alone, and it will be of the same size as that produced by the crown glass alone. Instruments for the production of spectrums and spectroscopes "*à vision directe*" have been constructed according to this principle; they excel by the fact that they are easy to handle.

On the other hand, if we combine two prisms, one made of flint glass and the other of crown glass, with one another in the same way, but choose a flint glass prism that only diverts with half the strength of the crown glass prism, so that the dispersion of color is equally large with both of them, the various colors will coincide with one another when they leave the crown glass prism and the light **L** will appear as white. But since the crown glass prism diverts the light with twice the strength of the flint glass prism, we will observe a diversion of the rays without getting a spectrum of color, and the diversion will be exactly as great as if we had used only the flint glass prism or a crown glass prism on its own that was half the size. Such a combination of two prisms is called **achromatic prisms**. Such a pair of achromatic prisms is schematically shown in **figure 43**.

If one watches the white light of the sun more closely through the spectroscope, one can perceive an odd phenomenon. The whole colored band is infiltrated with countless black lines, as is indicated in **figure 44**. Light from a lamp or electric light does not show this phenomenon. **Fraunhofer**, who was the first to study more closely these lines that infiltrate the sun's spectrum, discovered that at all times, they appear in exactly the same places in the spectrum. He marked the lines from red to violet that stand out the most with the letters **A** to **H**. These lines are now generally called **Fraunhofer lines**. They indicate that the rays of the sun that reach us are not rays that can be refracted in any way from red to violet, but rather, that a number of rays are missing in the white light of the sun, so that no light can be perceived in their respective places on the spectrum, and therefore the image of the chink appears as a dark line in the spectroscope. We know now why these lines are present in the sun's spectrum, but we will only be able to analyze that later. Our **figure 44** shows the sun's spectrum as drawn by Fraunhofer. The spectrum's brightness is indicated by the curve above it. It is brightest between **D** and **E**.

In addition to light, the sun also sends us heat. Since we can now divide the light into its colors, we will ask ourselves whether all colors are equally warm, or does the heat change with the brightness? People have used sensitive instruments to test the individual parts of the spectrum as to the amount of heat that goes through the prism together with the rays of light with their respective refraction. Of course, glass prisms could not be used for this purpose, since the glass absorbs much too much heat and thus does not allow too large a proportion of the heat rays that go into the prism to leave it again. But it was discovered that mineral salt is an excellent material for such studies, for mineral salt allows all the heat rays to pass through without hindrance. And so the unexpected fact was discovered that the brightest part of the spectrum, yellow, is not the warmest part, but rather that, whereas hardly any traces of heat are evident in the violet and blue part, the heat increases towards the red part and is greatest at the extreme end of red; however, before the red, so where there are not yet any light rays, heat can be felt for a long stretch. So it has been discovered that heat rays in general can be refracted less than light rays, but on the other hand that, like light rays, they consist of a whole row of rays that can be refracted with varying strengths, so that we can rightly speak of a heat spectrum just as we do of a light spectrum. However, this heat spectrum begins far before the red, it reaches its greatest intensity in the red, and then continues, gradually decreasing, until about the green. So the difference between heat rays and light rays is only that on average the heat rays can be refracted somewhat less, that is to say, their wave length is somewhat longer, or, since the speed at which heat waves spread in space is equal to that of light rays, the speed of oscillation of the individual ether particles is somewhat less.

Moreover, it is easy to prove that there are rays reaching us from the sun that can be refracted even more than the extreme violet rays that are still just barely visible. For if we put a plate that has been photographically prepared behind a prism, we get a photograph of the spectrum. We will learn later what is the essence of photography; here it is enough to say that the photograph does not reproduce the visible spectrum of the sun, but rather, that the band begins very weakly at about yellow and then stands out ever more clearly until the greatest intensity is present at about violet, and from there it very slowly decreases in clarity until it finally disappears entirely behind the violet. So rays beyond the violet must have hit the photographic plate. We can recognize from this that, in addition to the visible rays, that is to say, those rays of which the length is between 760 and 390 millionth of a millimeter, the sun also sends us rays, the wave length of which is greater than 760 (millionth of a millimeter) and which we perceive as heat, and also rays, the wave length of which is smaller than 390 millionth of a millimeter, which we can show again with the help of photography. It is therefore most likely that our earth receives both rays from the sun the wave length of which is even greater than that of the most extreme heat rays and smaller than those of the rays that can still be recognized by means of photography; but so far, we are not yet capable of making these perceptible in any way.

We must still mention a most peculiar phenomenon. Our limestone, from which the lime used to make mortar is obtained by means of burning, sometimes, mainly in Iceland, can be found in the form of clear transparent crystals that are called lime spar. If one smashes a crystal with some care, the result is like rhombus-shaped cubes (**figure 45**). If we look at an object through such a piece, for example at a bright window, we see the object double. Therefore lime spar has also been called double spar. Later, it was discovered that in addition to lime spar, there are very many other transparent objects - in fact, most of the so-called crystal objects to be found in nature, that is to say, objects with flat surfaces on all sides – that produce the same phenomenon, even though not to such a noticeable extent. Glass on the other hand, as well as mineral salt, diamonds, and others do not produce such a phenomenon. After closer studies, it was discovered that this phenomenon depends on the shape, which the respective object has in its natural state. The phenomenon itself is called **double refraction**. If we imagine a number of parallel rays **L** entering the lime spar (**figure 46**), these are not only refracted, but at the same time they are split into two halves that are refracted to varying degrees. The one part, **ab**, is the less strongly refracted one, the other, **ac**, is refracted more strongly. These rays then again leave the lime spar and go into the air, where they are again refracted; **ac** is refracted to the opposite side as much more strongly as it can be refracted more strongly, so that when they exit from the lime spar, the two rays **ab** and **ac** go to **be** and **cf** parallel to one another. Now if our eye is at **ef**, we will see the point **L** in the direction **eb** and **fc**, that is to say as two points.

Only solid objects manifest double refraction; liquids do not. For insofar as solid objects are not disturbed in their growth, in by far the most cases they have a regular shape and shiny flat surfaces. The mountain crystals that are often to be found particularly in the Alps manifest this characteristic the most beautifully, so that all objects that exist with a regular shape have been called "crystals". There are only a few substances, including glass, that are not found as crystals; such substances are called **amorphous** (shapeless) objects. In addition, it was discovered that every substance has a very specific shape, so that the way the particles of mass lie next to one another occurs according to very specific laws based on the nature of the substance. Now the density of the substance in its various dimensions is not equally great in all crystallized objects; only in a part of the infinite number of different substances – though this is a considerable part – do the particles lie next to one another in the same density in all three dimensions of space. Such substances either crystallize in cubes or in shapes that can be derived from the cube; these substances are called **regularly crystallizing** substances. However, in most of the other substances, the particles lie next to one another in a way that is of unequal density in the various dimensions.

Now we learned above that light rays are refracted as soon as they pass from one transparent substance to another, and that they are refracted all the more strongly the greater the difference in density is between the two substances. Now if light rays pass from the air into a crystallized object, the density of which varies according to its various dimensions, the rays must be refracted more in one direction than in the other, and they must consequently be refracted doubly. The greater the difference in a crystal's density in its various dimensions is, the greater the crystal's double refraction must be, and as far as we know at present, lime spar is the transparent object in which the double refraction occurs most strongly. It goes without saying that regularly crystallized objects such as mineral salt, as well as amorphous objects such as glass, in which the density of the mass is equal in all dimensions, do not have the effect of double refraction.

But the double refraction of light is connected to another phenomenon, the so-called **polarization of light**. We remember from what was previously said that we assume that the spread of light occurs by means of the ether particles oscillating vertically contrary to the direction in which the light is spreading, that is to say, they oscillate contrary to the ray's direction. However, an infinite number of directions standing vertically to the one direction are possible. Thus for example, the horizontal lines (directions) must be vertical over against a plumb line. Now if a ray reaches the earth perpendicularly, in which of the infinite number of horizontal directions does the ether itself oscillate? The answer is: in normal light, in any of all the horizontal directions. But as soon as rays enter an object that refracts doubly, the ether particles are forced to oscillate in very specific directions: one of the two rays in the direction of the crystal's least density, and the other in the direction of its greatest density. Let us imagine for example a ray that is vertical to the surface of this page's paper and that reaches the paper, and the paper itself as a crystal that refracts doubly, the greatest density of which is in the direction **ab**, and the least in the direction **de** (**figure 47**); then the ray that encounters the paper at **c** would cause part of the ether particles to oscillate in the direction **ab** and another part in the direction **de**.

But since the speed at which light spreads is all the smaller the greater the density of the transparent substance, the ether particles' oscillations in the direction **ab** will communicate themselves more slowly to the neighboring particles than those oscillating in the direction **de**; that means nothing other than that the oscillations spreading the one of the two refracted rays occur vertically to those of the other, or in other words:

> The two rays into which every light ray entering an object that refracts doubly is split, are polarized vertically to one another.

We are now able to prepare the lime spar in such a way that one of the two polarized rays cannot pass through the crystal. If we do this and then look through such a piece of lime spar, we get one image of the respective object, even though it is only half as bright, because one half of the rays hastening through the lime spar cannot reach us. The lime spar is prepared as follows: in natural pieces of lime spar, the surface **bcde** (**figure 48**) forms an angle of 71° with the surface **abcf**; the former surface is polished in such a way as to form an angle of only 68° with the latter, and the surface **ahgf** is polished in the same way, so that it becomes parallel to the first. The prepared crystal is then cut in the surface **befg** so that two wedge-shaped halves are obtained, and these two halves are then glued together again with balsam. In **figure 49** we can see the mean of a piece of lime spar that has been prepared in this way. It is called **Nicol's prism**, because the physicist Nicol was the first to have taught how to make it. If light rays get into the prism, they are refracted and will move on in the two directions **mr** and **ms**. In order to get into the second half of the prism, the light rays must first go through the layer of balsam, which refracts less strongly than lime spar. Thus, they are first refracted in the layer of balsam **db**, and from there they are again refracted when they enter the second half of the prism. But of the two bundles of rays **mr** and **ms**, only one, **ms**, can pass through the layer of balsam; the other, **mr**, cannot enter into the layer of balsam because the angle at which it reaches the layer is larger than the border angle (cf. the discussion around figure 33). The bundle of rays **mr** is completely reflected in **r** and is lost to us. The eye in **o** therefore sees only one half of the rays, which continue in the direction **ms**. But these rays are completely polarized. Now let us imagine that the oscillations of the ether particles of the rays **po** in **figure 49** occur in the direction **ab** (figure 47), and let us put a second Nicol's prism in front of the first in such a way that the direction of the ether particles' oscillations is also **ab**; that way the rays can go through the second prism without hindrance. Now if we slowly turn the second prism, without otherwise removing it from its position in relation to the first, less and less light will pass through the second prism until finally, as soon as we have turned this prism by 90°, no light at all can get through anymore. For since the rays' ether particles that have gone through a Nicol's prism are forced to oscillate in one direction, and this direction depends on the position of the prism and turns with the latter, the light rays, the ether particles of which are oscillating in the direction **ab**, cannot go through a substance of which the ether particles are forced to oscillate only in a direction that is vertical to **ab**. Two Nicol's prisms that are placed next to each other in such a way that the surface of polarization of the one is vertical to that of the other, do not let any light through, "they give off a dark field of vision." The mounting of a Nicol's prism is shown in **figure 51**. These prisms are used with the so-called polarization instruments. **Figure 50** shows a simple version of such an apparatus. **M** and **N** are two Nicol's prisms enclosed in brass; between them a brass pipe that has been blackened on the inside can be inserted. One of the two Nicol's prisms (**M**) can be turned so that one can either see the light or not see it when looking at some bright object such as a light, depending on how one turns the Nicol's prism. With the help of such an apparatus for polarization, one can examine whether a crystal sliver of any substance refracts doubly or not. But it would lead us too far to discuss further this fact, which is only important for science. Another noticeable characteristic to which we shall return later, should be mentioned here. If you look through a polarization apparatus at a light that sends forth light rays of only one color (for this, it is easiest to use an alcohol flame, which will burn in pure yellow if one scatters some common salt onto the wick), and if you slowly turn the Nicol's prism just until the light can no longer be seen and then put a sugar solution between the two Nicol's prisms, the light will reappear immediately. It was discovered very soon that one must turn the one Nicol's prism towards the right by a certain number of degrees in order to again receive a dark field of vision. The amount it is necessary to turn it depends on how thick the layer of sugar solution is through which one has to look as well as on the amount of sugar that is in the solution. Now for the same apparatus, the thickness of the layer of solution always remains the same. For the solution is placed between the two Nicol's prisms by completely filling a brass pipe that can be sealed watertight at both ends by means of glass plates, and this pipe is inserted into the connecting pipe **A** (figure 51). The pipe is usually 200 millimeters long (without the glass plates), so that the thickness of the liquid surface is 200 millimeters. Since the liquid surface remains the same, it depends solely on the amount of sugar in the solution, and since a liquid containing 10% sugar requires that one of the Nicol's prisms be turned twice as much towards the right as a solution with 5% sugar, it is possible to recognize how much sugar the solution contains from the amount of turning required to reach a dark field of vision, if it is known how much the prism must be turned for every percent of sugar. Thus, instruments were in fact constructed that are based on this principle and that allow one to recognize in a very short time how much sugar is contained for example in carrot juice.

In addition to sugar, there is a large number of substances that have the same characteristic of “turning the level of polarization”, organic substances that are effective in “turning”, not in a crystallized state but as a solution, that are “optically active”, for example so-called tartaric acid, oil of turpentine, quinine, morphine, etc. In a solid crystallized state, only few substances are able “to turn the level of polarization”; of these, mountain crystal is by far the most important.

If we summarize what has been discussed so far, we thus see that the forces of nature with which we have dealt so far – the force of attraction of masses, sound, light, heat – cause a movement, and that solely the different shapes and speeds of the movement cause the various natural phenomena. But we are also able to change this shape, that is to say, we can change the forces of nature into one another, we can produce steam by warming water, and by means of the pressure this steam then exerts, it sets masses into motion; and on the other hand, we can produce warmth through friction, etc. Only in recent times was it possible to show that by transforming one force of nature into another in this way, none of the force gets lost, just as nothing is added to the force. The medical doctor from Heilbronn, J.R. Mayer (1842), then Helmholtz, Joule, Thomsen were most meritorious in proving this principle of the preservation of energy, which has contributed substantially to the true understanding of nature. But so far we have completely ignored one force of nature, a force that precisely in our day has claimed the interest of the entire civilized world to a greater extent, because it seems called to transform our living conditions as much as the discovery and implementation of the force of steam, and that is electricity. However, we have not mentioned this force until now because we cannot yet assume with the probability that borders on certainty, as with heat, light, etc., that electricity is anything other than a peculiar form of movement. Of course, it certainly looks like this is the case, if for no other reason than that we can easily transform mechanical energy into electricity and electricity again into mechanical energy, heat, light, etc., and it is precisely this transformation of mechanical energy into electricity and of this into light that are now used in producing electric light. In what follows, we shall have to discuss some of the electrical phenomena, but since we cannot yet bring these back to a fundamental principle, we do not want to discuss them at greater length here.