General Laws Governing Objects in a State of Rest

Since the most varied forces are constantly at work in nature bringing forth movement, whether it be the movement of masses or that of molecules, the masses or their molecules are put into motion and kept in motion through these forces. Thus for example, the earth attracts all the objects that are on it, and therefore all objects would have to move towards the center of attraction, the earth's center. Nevertheless, we very often see the objects in a state of rest. When does this happen? When the earth's force of attraction is cancelled by another force of equal strength that is working in the opposite direction, so by a force striving to remove the object away from the earth's center. In general, we can come to the following theorem:

> When two (or more) forces influence an object in such a way as to cancel one another, the object is in a state of rest.
> Two forces cancel one another when they are equal in strength and seeking to move the object in opposite directions.

As soon as one of these two conditions is not fulfilled, the object must be set in motion, and in this case we have to distinguish between the following three cases:

1. Two moving forces cause an object to move in the same direction. In this case, the object will move with the speed that equals the sum of the two forces. A train coming down a mountain can serve as an example. If, by its weight, the train by itself rolled down five meters per second, and if we harnessed another machine to it that would move it three meters per second on an even stretch, the train would rush down with a speed of eight meters per second.
2. Two forces work on an object in opposite directions. If they are not equal in strength, the object will move in the direction of the larger force at a speed which equals the difference between the two forces. Let us remain with the previous example but with the difference that the machine is trying to push the train up the mountain with the strength three assumed above, while the train without the machine would go down with the strength five. Then the train must roll down, and it will move down two meters every second.
3. Two moving forces work on an object in different directions. In that case, the object will move, but neither in the direction of the one force nor in that of the other, but rather in a direction that is between these two, namely in the diagonal of a parallelogram that we can construct from the two directions. In **Figure 2**, the object to be moved is **a**, and the line **ab** is the distance it would be moved by the one force in one second; line **ac** is the distance the object would be moved by the second force in the same amount of time if it alone were effective; then the line **ad** is the distance the object is really moved through the common effect of both forces. For if we

> assume that the two forces were effective one after the other, the object **a** would move from **a** to **b** in one second because of the one force. If then at point **b** the second force moved the object in the direction **ac**, that is in the direction **bd** that is parallel to this, it would cover the distance **bd**, which is just as long as **ac**, that is, after one second it would arrive at **d**. Exactly the same thing happens when both forces are effective at the same time. The object **a** has to arrive at **d** after one second. And it can easily be seen that the object **a** takes the path of **ad**, if we imagine the two forces taking turns in trying to move the object extremely tiny distances one after the other, so that the object would be following first the one force and then the other in turn, that is, that it would be moving in turn in the direction **ab** and **ac**. Let us assume for example that one force moved it for 1/20 of a second in the direction **ab**, from **a** to **m**, then the second force for 1/20 of a second in the direction **ac**, from **m** to **n**, then again the first force for 1/20 of a second in the direction **ab** from **n** to **o**, whereupon the second force for 1/20 of a second in the direction **ac**, from **o** to **p**, etc. Then the object **a** would advance along the broken line **amnopqr…** to **d**. The smaller we imagine the spaces in between, within which the object **a** would be forced to follow in turn first the one force and then the other, the smaller the individual parts of the broken line will be, and if these spaces in between finally become infinitely small, the line **ad** will become a straight line.

It follows from this first of all, that it is irrelevant to object **a**'s movement whether one single force is working on it, forcing it to go the distance **ad** in one second in the direction **ad** or whether two forces are working on it, one of which wants to move it from **a** to **b**, and the other from **a** to **c**. Of course, the object **a** will not be moved at all, so will remain still, if three forces are influencing it in such a way that one of them would move it from **a** to **b**, the second one from **a** to **c**, and a third one that would be striving to move it backwards for a distance equaling **ad**. In that case, all three forces would hold each other in balance. (**Figure 3**)

We have the simplest case of the mutual canceling of forces if we look at an object that is lying on something. Because of the earth's attraction, all objects strive to fall, and the larger the object's mass is, the greater will be the force with which it falls. If the object's fall is cancelled by means of what it is lying on, its striving to fall will be expressed by the pressure the object exerts on what it is lying on. This pressure is in proportion to the object's mass and is called its weight, its heaviness. The object can only be in a state of rest if the pressure it exerts in the downward direction is made immobile by means of an equally great counter-pressure upwards. We can easily confirm this when an object is lying on something movable, as is the case with our ordinary scales. The scale-pan on which there is some kind of a burden will have to sink, that is, will have to give in to the burden's striving to fall, until, because of the counter-weight on the other side of the scales, the force trying to lift the scale-pan is equal in strength to the force with which the burden is pressing the pan down. From this, we can derive a series of characteristics, which objects possess. The individual particles in solid bodies exert a strong attraction on one another, so that they can only be torn away from each other through the use of greater or lesser force. In any case, they are attached to one another so strongly that gravity, the earth's force of attraction, which influences every single mass particle, cannot tear them away from each other. Therefore, there must be a point in every solid body that gives sufficient support to the body's entire mass to prevent its falling. This principle can best be described as follows. Let us assume that in **Figure 4, a** and **b** are two equally heavy molecules that attract one another so strongly that earth's gravity cannot tear them away from each other; and let us imagine this mutual attraction by means of line **ab**. If we give support to the line **ab** at the point **c**, we will prevent both points from falling. Then line **ab** is a lever that molecule **a** is striving to turn around in the direction of the arrow **p**, while molecule **b** is trying to turn it around in the opposite direction, in that of the arrow **q**. Since both are trying to turn the lever with equally great strength, but in opposite directions, they will not be able to cause any turn; they will remain in a state of rest. But both are pressing on the point of support **c** with the sum of their weight. If each molecule weighed one gram, a weight of two grams pulling upwards would have to be at work in **c** in order to prevent the two molecules from falling. Consequently, the point of support **c** has to bear a pressure of two grams. Thus, we can think of the total weight of the two molecules – or, what would be the same thing, the total effect of earth's attraction of the two molecules – as being united in point **c**, and we therefore call point **c** the point of gravity of the two molecules.

We reach the same result when we imagine three molecules that attract one another, as is indicated in **Figure 5**. **a, b, d** are meant to be the three mass particles; the point of gravity of **a** and **b** is in **c**, and since the three mass particles cannot be torn away from one another by gravity, and since moreover we can think of earth's total attraction of the two molecules **a** and **b** as being united in **c**, nothing is changed in the system if we think of **c** as being a mass particle with the double weight of **d**. Thus, all we need to do is to link **c** with **d** by means of a line; then all three molecules will be prevented from falling, if we support the system at point **e**. For the line **cd** gives us a lever that can be turned at **e** and that the mass particle **d** tries to turn in the direction of the arrow **p**, whereas **c**, that unites the weight of the two molecules **a** and **b** in itself, tries to turn in the direction of the arrow **q**. Now if **e** is half as far from **c** as it is from **d**, the lever **cd** will not be turned at all; it remains in a state of rest. For it is known that a lever, that is to say a line that can be turned around a fixed point (in reality a rod such as a scale beam, a door-handle, etc.), remains in a state of rest when the two forces trying to turn it to opposite sides - such as the weights and the burden on scales, the muscular strength and the spring's tension in a door-handle, etc. - are working in the opposite direction to their targets' distance from the revolving point. So if one force attacks at a point on the lever that is three times as far from the revolving point as the other, it only needs to be one third of the size of the other.

Thus, to return to our example, only point **e** needs to be supported so as to prevent the three molecules **a**, **b**, **d** from falling. **e** is the point of gravity of the three molecules contained in a solid object. Thus, by construction we can find the point of gravity of an ever growing number of molecules. Therefore we can say:

In every solid object there is a point, the support from which is enough to prevent the object from falling; that point is its point of gravity. An object that is supported by its point of gravity is in a state of balance, in no matter what position the object might be. On the other hand, if the object's point of gravity is not itself supported, but instead that support is at some other point of the object, then the point of gravity will try to fall as far as possible. Let us think of the rod **AB** (**Figure 6**) as suspended in point **c** in such a way that it can turn around this point. In that case, its point of gravity **s** is not supported. Since the rod itself is prevented from falling, this point of gravity will fall until it has reached the deepest position possible under these circumstances, that is, until it is in a vertical position under the point of suspension.

Since the particles of solid objects exert a strong attraction upon one another, so that they can only be separated from one another by force, they will also maintain their respective positions so long as no external force such as pressure, a draft, etc. works towards a change. That means nothing other than that solid objects maintain the form they have been given; in addition to the fact that they fill a space, they have their own shape.

With liquids it is different. In them, there is still a mutual attraction between the particles, but it is so small that gravity is able to overcome it; in liquids, the particles can very easily be moved around. So if in a liquid only the molecules' forces of attraction on one another are at work, the liquid must take on the shape of a sphere, as we can easily observe if we put some oil in diluted alcohol, which has the same specific weight as oil. Because the molecules move as close together as possible so that they are all as close as possible to one another, and in a sphere, all the particles are in fact separated as little as possible from one another.

Another consequence of the fact that the particles of a liquid can easily be moved, is that every liquid takes on the shape of the vessel in which it is and that its surface must be horizontal. For if we imagine a free-standing liquid pillar in a vessel, the top layers of the pillar press on the ones beneath it. Because these can be moved easily, they will escape towards the empty sides until they bump into an obstacle that sets a limit to their escape, that is, until they come to the wall of the vessel. This goal will be reached by all liquid particles when all the top particles (the entire surface) have sunk as far down as possible and are an equal distance from the earth's middle, the central point of gravity. Then the surface forms a horizontal plane. In addition, it is clear that the liquids must exert a pressure on the bottom and on the side walls of the vessels that equals the weight of the liquid pillar above these, so that for example, in a container of water, a wall area of one square centimeter that is ten centimeters below the level, bears a pressure of ten grams (that is the weight of a pillar of water that is ten centimeters high and has a ground surface of one square centimeter). We get a confirmation of this when we insert a pipe in any place in the wall of the vessel, as in **figures 7 and 8**, thus making this part of the vessel's wall movable so to speak. The liquid can only be at rest in this place when the pressure borne by each molecule on the one (left) side is paralyzed by an equally great pressure working towards the opposite side (from the right to the left in our figure). If we imagine the same liquid in the vessel **AB** and in the pipe on the side **CD**, for example water, the liquid will be at rest when the water particles in **a**, that are being pressed to the right by the weight of the pillar of water extending from the surface **o** to **a**, are pressed to the left by an equal weight, so by a pillar of water of the same height. Consequently, the water in the pipe on the side, **CD**, must rise to the same height as in the vessel **AB**. But let us imagine on the other hand that we have mercury in the vessel **AB**, but water in the side pipe **CD**, as is shown in **figure 8**. Mercury is 13.6 times as heavy as water. Thus, if the liquid particles in **a** are to be at rest, so if the pressure from the right to the left is to be equally great as that from the left to the right, the water pillar in **CD** must also be 13.6 times higher than the pillar of mercury **oa**, since only then will the weight of the water pillar equal the weight of the pillar of mercury.

Just as it follows from the fundamental law that every object and every part of an object will be at rest when all the forces working on the object or on its respective parts cancel one another, it also follows that in liquids, every pressure spreads in all directions. For in **figure 7** above, we would only need to press down the liquid in the side pipe **CD** and the particles in **a** would be pressed into the vessel **AB**, if the molecules in **AB** itself were not pressed in the opposite direction by an equally strong counter-pressure. Let us assume that the surface of the liquid in **CD** consists of 1000 molecules and is pressed down with the strength of 1000 grams. In that case, the pressure of 1 gram would be working on each molecule. Since it is easy to move liquid particles, each molecule would evade this pressure if it were not prevented from doing so by the molecules next to it. But that is saying nothing other than that all the molecules next to the one being pressed down are receiving the same pressure. It goes without saying that these in turn are also pressing on the molecules closest to them, until finally the solid wall of the pipe **CD** absorbs the pressure. Only at **a**, where there is no wall and the liquid has a way out, it would have to give in to the pressure coming to bear at the surface **D** (aside from the pressure of the liquid pillar itself), if every molecule were not being pressed in the opposite direction – in our figure towards the right – by the weight of 1 gram. And we get this counter-pressure by putting so much pressure on the liquid in the vessel **AB** that each molecule receives the pressure of 1 gram. Now if the surface of **AB** is ten times as large as that of **CD**, there are also ten times as many molecules on the surface, and a weight of 10 kilograms is needed to establish a balance.

This shows clearly the principle of the hydraulic press, by means of which extremely strong effects of pressure can be brought about. For water is pressed together in a relatively narrow pipe, and since the narrow pipe is connected to a pipe that is normally one hundred times wider, there has to be a pressure one hundred times larger on the surface of the water in the wide pipe in order to prevent the water from flowing out.

Finally, from the theorem developed above, we can deduce the well-known fact that every object that is lowered into a liquid loses as much of its weight, that is to say of the strength with which it is attracted by the earth, as the liquid it displaces. Let us for example look at any liquid particle **m** (**figure 9**) inside a liquid. The whole liquid pillar is weighing on this particle from the surface **o** down to it, so accordingly it would have to sink if there were not an equally great pressure towards the top, causing it to remain at rest. From this follows that everywhere within the liquid there is a pressure working against gravity. This counter-pressure, which merely maintains the balance within the liquid, is the buoyancy. If we introduce a foreign body into the liquid, for example the cylinder **ABCD** (**figure 10**), because it is easy to move liquid particles, this object will strive to fall not only because of its own weight, but also because its surface is pressed downwards by a liquid pillar, which has the height of **oa** and the width of **AD**. On the other hand, because of the buoyancy in **BC**, the liquid strives to lift it. The strength with which the liquid strives to drive the cylinder to the top corresponds to the weight of a liquid pillar having the width **BC** and the height **ob**. Accordingly, the cylinder strives to fall with the strength of its weight (1’) and the weight of the liquid pillar **Adoa**, that we shall call **m**; on the other hand it strives to rise with the strength of the weight of the liquid pillar **Bcob**, that will be called **n**. Thus, it will fall with the strength **P + m – n** or, and this is the same thing, **P – (n-m)**. Now **n-m**, that is to say, the weight of the liquid pillar from the floor of the cylinder minus the weight of the pillar from the ceiling of the cylinder, is the weight of the liquid that occupies the same space as the cylinder. Thus, we can express the symbol **P – (n-m)** in words as follows: "In a liquid, every object falls with the strength that corresponds to its weight minus the weight of an equally large volume of liquid." If we assume, for example, that the cylinder weighs 12 grams and the volume of water that equals its volume 10 grams, then the cylinder will fall in the water with a weight of 2 grams. But if the cylinder also weighed 10 grams, it would not be able to fall at all, but would have to remain suspended in the water. Finally, if (with the same volume) it weighed only 8 grams, it would have to fall with the weight of minus 2 grams, that is to say, it would have to rise upwards, and it would have to do so until the volume of the water it displaced was also only 8 grams. Now that happens, when it is in the water with only 4/5 of its volume and 1/5 is sticking out. Therefore, every object that is lighter than the liquid into which it is lowered, will sink until the weight of the liquid it displaces is exactly the same as the object's own weight. This is the foundation for the simple methods for measuring the specific weight or the weight of the volume of solid and liquid objects.

It goes without saying that exactly the same laws of balance as for liquids are also valid for gasses. For the differences in the appearance of solid and liquid matter are solely due to the fact that with the latter, the easy mobility of their particles comes to bear. But as we know, this mobility is even greater in gaseous matter, and we will therefore observe the presence of all the phenomena discussed in the above, possibly with greater clarity. Thus gasses will exert pressure on the walls of the vessels in which they are, both downwards as well as to the sides and upwards, and the pressure on the floor of the vessel will only be greater than onto the ceiling by the weight of the gas pillar itself. For since the gasses do not fill any space of their own, but rather occupy every space that is offered them, they will not only assume the shape of the vessel in which they are, like the liquids, but rather, they will fill the vessel entirely, and the gas molecules will strive to escape from a vessel that is open towards the top with the same speed as from a vessel that is open at the bottom. Therefore, if gasses are supposed to remain in a vessel, the latter has to be closed on all sides, and the gasses' striving to escape will expression in the pressure they exert on the walls of the vessel.

In addition, the law of communicating vessels etc. is also true for gasses, and our barometer is nothing other than a confirmation of this law. Because the powerful layer of gas that surrounds the earth's atmosphere, has to exert pressure on the earth's surface.

We can easily measure this, if we have two vessels with a liquid, for example mercury, that are connected to one another, as in **figure 11** (a pipette barometer) or **figure 12** (a vessel barometer), but connected in such a way that the entire atmosphere can press on the surface of the liquid in the one vessel, but not onto that in the other vessel (that is a vacuum). At the point where the two vessels are connected to one another, every particle, for example **a**, has to receive an equal amount of pressure from all sides, if it is to remain at rest. This pressure consists on the one hand, of the weight of the pillar of mercury **la**, and on the other hand, of the weight of the small pillar of mercury **va** and the weight of the atmosphere that is pressing on **v**. It follows that the atmosphere's pressure itself equals **la – va = lv**. At the seashore, this pressure is as great as that of a pillar of mercury of 760 millimeters, which is about 1033 grams per square centimeter. Usually, we compare the pressure exerted by the gasses onto the walls of the vessel with the atmosphere's pressure (2, 3, 4, ½, 1/3, 1/10 atmospheres or also with the pressure of a pillar of mercury, and we say that the respective gas has a pressure of 10, 15, 20 etc. millimeters).

Moreover, gasses will reproduce the pressure on all sides; and finally, we can also perceive buoyancy in gasses. A mass of feathers falls to earth more slowly than a ball of lead, because with the feathers' far greater volume and their equal weight (measured in a vacuous space) these displace a far greater amount of air and therefore have to overcome a far greater buoyancy.

The Movement of Objects when there are constantly Working Forces

One of the most important characteristics of objects is their inertia, that is to say, their striving to remain in the state in which they are, whether this be the state of rest or of movement, until they are forced by some power to change over to a different state.

A sphere that is rolling one meter per second in any direction will cover the same distance and in the same direction in the second as well as in the third second and would continue on and on at the same speed and in the same direction, if there were not inhibiting or distracting forces such as friction, the earth's gravity, etc. that first slowed it down and then completely cancelled the sphere's progress or that steered it into another direction. So forces are necessary in order to cause an object that is moving to change over into a state of rest or in order to make it continue in a different direction. Similarly, every object that is at rest will remain at rest, if some forces do not cause it to move. Among such moving forces or forces inhibiting movement we must distinguish above all: 1) forces that are at work once, such as a shove, a throw, etc.; 2) forces that are constantly at work, such as gravity. It is easy for us to understand what constantly working forces accomplish, if we split these forces into individual ones that are at work in rapid succession to one another, so for example individual shoves. 1. If we throw a stone so that it will move 10 meters in one second, it would continue to move 10 meters in every following second, provided there are no inhibitive forces. 2. But if an object is lying on something and this is pulled away from under it, the object will begin to fall. In the beginning, its speed will be very small, but since its inertia causes it to always continue to move with the speed it has eventually reached, and since on the other hand, the earth is attracting it again and again in rapid succession, the combined effect of inertia and of the earth's gravity coming to bear again and again, will cause its speed to rise rapidly. Let us assume that after the first 1/1000 of a second the falling object had reached the speed of one centimeter, that is to say, if the earth were no longer attracting it, it would move forward one centimeter every full second; then it would of course maintain this speed in the second 1/1000 of a second. However, in addition, since in fact it is again attracted by the earth with the same strength as previously, it would reach the speed of one additional centimeter, so after the second 1/1000 of a second it would already fall at the speed of two centimeters. In the same way, just because of its inertia, in the third 1/1000 of a second it would already have the speed of 2 centimeters, plus 1 centimeter because of gravity that was again effective, so all together at the end of 3/1000 of a second it would have the speed of 3 centimeters. It goes without saying that every 1/1000 of a second would mean an increase in speed of one centimeter, and at the end of the first second, it would accordingly have reached a speed of 1000 centimeters, so of 10 meters, at the end of the 2nd second, a speed of 20 meters, at the end of t seconds t times 10, so that an object that has been falling for 20 seconds would finally have reached such a great speed that, without the earth's ongoing attraction, it would be covering a distance of 20 times 10 meters, so 200 meters. If, at any time, we call the speed of the falling object **v** (*velocitas*), the earth's power of attraction, gravity, **g** (*gravitas*), then we can express the law that was just developed by means of the equation **v = gt**.

In doing so, the falling object's approach to the center of the earth and the increase in the power of attraction caused by that, have not been taken into consideration, as they are too insignificant. In actual fact, an object falling in a vacuum attains a speed of 9.8 meters at the end of one second.

The same law is valid for an object that is thrown upwards, except that in this latter case, gravity works against the object's rising, constantly decreasing its speed until this is zero. If an object is thrown upwards at a speed of 100 meters, the speed of its movement decreases by 10 meters in one second, after two seconds it will have to be 100 – 20 meters, after five seconds 100 – 50 meters, after ten seconds 100 – 100 meters, equals zero. Accordingly, at that moment, nothing is left of the original speed, while the earth's power of attraction continues to work on it with a force that always remains the same. Accordingly, it must now begin to fall, and after one second, it will attain a downward speed of 10 meters, after two seconds one of 20 meters, etc., until after ten seconds, it reaches the ground at a speed of 100 meters.

The same law rules the oscillation of a pendulum. As is generally known, a pendulum is an object that has been fixed to a thread or a rod; this thread (or rod) has been hung up on the other end in such a way that the pendulum can revolve around the point where it has been hung, as in **figure 13**, where the sphere **K** has been hung by the thread **F** at the point **C**. The pendulum is at rest when it is hanging vertically, that is to say, when it is pointing towards the earth's center, for that is where the pendulum's point of gravity strives to fall, and it is prevented from doing so by means of the thread's strength. If the pendulum is lifted out of its vertical position towards **L** (for when it is at rest in the position **K**, the pendulum's point of gravity is at its deepest point), it begins to fall, its point of gravity strives to once again reach its deepest point, and it does so in a circular line (**LK**), which, when the oscillations are small, we can see as an inclined plane. Since the pendulum falls to its deepest point because of gravity, the speed of the pendulum's movement will increase constantly up to the moment when the pendulum has reached its point of equilibrium, when the speed will be greatest. But now inertia prevents the pendulum from remaining at rest, and at the same speed at which it enters its point of equilibrium, it must go beyond this, so rise upwards on the opposite side (to **M**). Gravity works against this rise, decreasing the speed at every moment until the latter is entirely defeated and becomes equal to zero. But at that moment, the pendulum is not at its point of equilibrium, which it strives to reach again, and so the second oscillation begins, which follows exactly the same process as the first. What interests us above all here is that the speed of the oscillating pendulum's movement at first constantly increases until it is at its height the moment the pendulum crosses its point of equilibrium, and then its speed constantly decreases until it is at its lowest point, that is to say equal to zero, the moment the pendulum has reached its highest position, its greatest deviation from its point of equilibrium.

We will, of course, encounter the same laws of oscillation whenever an object has been taken out of its point of equilibrium and some constantly working force is striving to bring it back to this point. If, for example, we fix one end of a steel rod in a vice and cause the other end to leave its position of rest a little, the rod will oscillate because of its elasticity. In this case as well, the speed will at first increase until the rod has reached its point of equilibrium and at the same time, its maximum speed of oscillation. With the latter, the rod goes beyond its point of equilibrium, continuing to oscillate at a constantly decreasing speed until it is just as far from its point of equilibrium as it had been removed from it previously to the opposite side by an external force. At that moment, its strength is also spent and it remains at rest for an immeasurably short time, when, because of its elasticity, it again attains its point of equilibrium, and so on. For example, the prongs of a tuning fork oscillate according to these laws, as do the strings of a violin and of all stringed instruments.

The same laws also rule over the movements of celestial bodies, except that these do not oscillate because of a point of equilibrium and consequently with an ever increasing speed, but rather around a point of equilibrium. So as not to make it more difficult to understand this kind of movement, let us assume that the movement of celestial bodies is circular. This assumption is not entirely correct, but it does come very close to reality. So assuming this, in addition to the constantly working force of attraction of the central point on the celestial bodies, so for example of the sun on the planets, we need only to take into consideration the so-called force of movement, that is to say, the force that would cause the celestial bodies to continue moving in a straight line towards the tangent (so what is also called tangential force) when the force of attraction from the central point, the centripental force, has ceased.

In **figure 15**, the object **C** should attract the object **a** to such an extent that the latter would move to **d** within a given particle of time, for example, a second. But on the other hand, a second force working only once causes the object **a** to move in the direction of the tangent **ab** with such speed that it would move from **a** to **b** within one second, if this force alone were influencing it. As soon as both forces work at the same time, the object **a** will be able to move neither to **d** nor to **b**, but will instead have take the diagonal line of the parallelogram **abed** from **a** to **e**. The object **a** would continue in this direction, covering the distance **ab** every following second, if it were not again drawn by the constant power of attraction of **e**, now in the direction **ec**. Thus, in this 2nd second, it would be driven from **e** to **h** solely by the attraction of **c**, from **e** to **l** solely by the force of oscillation; the combined effect of both causes it to continue on the diagonal line of the parallelogram **efgh** in the direction **eg**. In the third second, because of the force of oscillation, it would go from **g** to **i**, because of the power of attraction from **g** to **l**, so with the simultaneous action of both forces from **g** to **k**. However, in saying this, we have assumed that the force of attraction of **C** would have an effect once every second. But since this force works constantly, that is to say, since the time intervals between the individual effects are infinitely small, the broken line **aegk** must be transformed into a circular line.

It goes without saying that the same laws governing the movements of masses must also be valid for the movements of the smallest particles of mass, the molecules.

The Movement of Molecules

Since, as was mentioned above, it becomes apparent in all natural phenomena that the molecules are in constant movement, the movements in solid and liquid substances, in which the molecules attract one another, must be oscillations. These occur either by way of points of equilibrium, like the particles in an oscillating rod, when the speed is at its greatest the moment the point of equilibrium is passed, and at its smallest precisely when the molecules have reached the outer limit and a new oscillation begins in the opposite direction; or – and this is far more likely – the oscillations will occur around points of equilibrium and be either circular or elliptical. In gaseous substances, in which the molecules no longer attract one another, the molecules move in a straight line at an unchanging speed (since they do not oscillate through points of equilibrium) until they bump into other molecules or the walls of the vessel and fly back.

Let us now ask ourselves what justifies our assumption that there are such molecular oscillations in substances in all three states. The answer is that all phenomena of warmth can be explained most easily when we assume that "warmth" is nothing other than such oscillations of the molecules, and when we use the words "hot, warm, cold", we are expressing the intensity of these oscillations. It goes without saying that the molecules of our own body are also constantly oscillating. If we take a body into our hand, as for example a piece of iron of which the molecules are oscillating more intensely, in the places where this piece of iron touches our hand, the stronger impulses from the iron molecules will cause the molecules of our hand to oscillate more intensely. We say the iron is "warm", or when there is an even greater difference in the oscillations' energy, the iron is "hot". If on the other hand, the iron molecules are oscillating less intensely than the molecules of our hand, these latter will cause the iron molecules first to oscillate more strongly in the places where the iron touches our hand, and the molecules of our hand will lose precisely as much of the intensity of their oscillations as the iron molecules gain in the intensity of theirs; and we say, the iron is "cold". In ordinary life, we always compare the intensity of the molecular oscillations in the various objects, such as in the air surrounding us, etc., so its warmth, with that of our body. However, seen objectively, ice also has warmth, for there are oscillating molecules in ice as well, even though this oscillation is less intense, and in the same way, even in the coldest winter night, the atmosphere has warmth.

> According to our present-day understanding of nature, warmth is nothing other than the state of oscillation of molecules; the greater the intensity of oscillation,

that is to say, the faster and stronger these oscillations occur, the more warmth is present, and vice versa.

What follows from this is above all that warmth must be a force, for we need a certain force in order to increase the molecules' oscillation and to strengthen their movement.

But if we bring warmth to an object, we not only increase the intensity of its molecules' oscillation, but at the same time, we also increase their distance from one another; the object expands when it is warmed. It goes without saying that the part of the force that is used up for expanding the object does not show up as warmth, which only represents the intensity of oscillation. However, this is of no significance for our question, since there is a simple relation between the expansion of the objects and their warming. This circumstance is only important when we calculate precisely the strength of the force, which we communicate to an object in the form of warmth, and the amount it is actually warmed.

Accordingly, the intensity of molecular oscillation is decreased by "withdrawing warmth". Thus, it makes sense that by continually withdrawing warmth, this intensity finally becomes equal to zero, the molecular movement must cease entirely. We are not able to actually carry out such cooling, but from phenomena observed with gasses, that we will discuss right away, the temperature at which every molecular movement would cease can be calculated and has been found to lie at 273° below zero on a Celsius thermometer. At – 273°, nature's *rigor mortis* would set in.

As we know, the state of an object depends on how its molecules attract one another. This attraction in turn depends on the size of the molecules and on their distance from one another, and here again, the same laws have to be valid as in the attraction of masses to one another. The larger the mass of an object is, the larger will be its force of attraction; both have the simplest of relations to one another. An object containing three times the mass of another, so weighing three times as much, also has three times as great a force of attraction as the other. On the other hand, the mutual attraction of two objects decreases when the distance between them increases, becoming one quarter of what it was when the distance is doubled; it falls to one ninth when the distance is three times as great, but rises to four times as much when the distance between the two objects is decreased by half, and to nine times as much when the distance is reduced to one third. Both relations can be expressed succinctly in the theorem: The strength with which objects attract one another is proportional to their mass and inversely proportional to the square of their distance from one another.

We now have to assume exactly the same as regards the mutual attraction of molecules. The greater the mass of the molecules, the greater will be their mutual attraction; and the greater the distance between the molecules, the smaller will this attraction be (corresponding with the square of the distance). Since the molecules of the various substances are of varying sizes, and since their distance from one another also varies, all objects cannot naturally be in the same state at the same temperature, except when the temperature is near –273°, at which all substances must be solid. In addition, since the warming of objects not only increases the intensity of their molecular oscillation but also their distance from one another, and since accordingly their mutual attraction is weakened, it is easy to see that in warming them, objects are brought closer to the liquid and finally the gaseous state, and that, if the temperature is high enough, all objects must be gaseous, if they can bear that temperature without entirely disintegrating.

If we look a little more closely at the expansion that objects undergo when warmed, we will find it easy to understand that, when the same amount of warmth, which is to say, when the same expanding force is brought to bear, this expansion will have to be more or less great according to the different substances. The increase in the distance of the molecules from one another must be all the smaller, the stronger the molecules' force of mutual attraction is, and it must be all the greater, the smaller this attraction is. Now since the molecules' force of mutual attraction at one and the same temperature varies to such an extraordinary degree, depending on the various objects, and since it varies more in solid objects than in liquid ones, and is far greater in these latter than in gaseous ones, solid objects will expand less when warmed for example from 0° to 100° than liquids, and these will expand less than gasses. Moreover, every solid and liquid object will have its own particular ability to expand, which can only be found through experimentation with the respective object. Thus, when warmed from 0° to 100°, the increase in volume for 10,000 cubic centimeters of:

Copper	amounts to	51	cubic centimeters
Lead	” ”	89	”
Iron	” ”	37	”
Zinc	” ”	89	”
Glass	” ”	26	”
Mercury	” ”	180	”

Thus, at the same increase in temperature, the expansion of mercury is almost seven times as great as that of glass.

And another fact will become easily understandable. Since with rising temperatures, which is to say, with increased expansion, the distance of the molecules from one another is increased, and since consequently, their mutual attraction is decreased, if the same amount of temperature is added, the expansion of an object must also be greater at higher temperatures than at lower ones. In fact, with a rise in temperature, the expansion coefficient, which is to say, the increase in volume, becomes greater with every degree of warming. Thus, when 1000 cubic centimeters of mercury are warmed from 0° to 100°, the volume increases by 18 cubic centimeters, but when it is warmed from 200° to 300°, it increases by 19.2 cubic centimeters.

As has been said, the reason for the differences in expansion is not only to be found in the various substances, but also in one and the same substance at various temperatures, because the more or less great mutual attraction of the molecules has to be overcome. But how do gaseous substances behave, when there is no longer any mutual attraction of molecules? After what was said above, it is easy to answer this.

When warmed by the same number of degrees, and at all temperatures, all gasses expand an equal amount. For every degree Celsius, the expansion of all gasses amounts to 1/273 or 0.003665 of their volume.

This important law is called the Gay-Lussac Law, after the person who discovered it.

Following the discussion of the objects' change in volume due to a change in the temperature, we shall now continue by looking at the other forces that cause a change in volume. This change in volume is only an immeasurably tiny amount both in solid objects, in which the molecules' force of attraction on one another is more or less great, and with liquids, in which this attraction is very small though still present. If we therefore try to increase the distance between the molecules in solid objects by means of external force, such as pulling, bending, etc. (which is not at all possible with liquids), the boundary within which the molecular attraction effects "cohesion" is surpassed very quickly; the object tears, breaks, etc. Similarly, however, it is also extremely difficult to do the opposite and to decrease the distance of the molecules from one another in solid and liquid objects by means of external pressure; these objects strongly resist being pressed together, and even when we use great force, we succeed in pressing them together only minimally. We are therefore forced to assume that the individual molecules can be brought closer to one another only up to a certain point, which is almost reached in the solid and liquid state, that they attract one another only within very narrow limits, and that they reject one another with increasingly extreme strength when they are brought closer together. In the various solid and liquid objects, the same pressure causes varying amounts of compression, and this amount has to be determined for each object by means of experimentation.

It is different with the gasses. In them, the molecules are no longer moving around points of equilibrium, and the distance between the molecules is determined solely by the size of the vessel containing the gaseous matter. In this case, we may also expect that a change in pressure will bring about a greater change in the space occupied. But with the gasses, not only the strong interdependence between their volume and the pressure to which they are submitted has been observed; there is also a striking agreement of all gasses with one another, an agreement that made it possible to draw far-reaching consequences. For it was discovered that with an equal increase in pressure, all gasses reduce their volume in the same way, and the other way around, that the same decrease in pressure causes them to increase their volume equally. In **figure 16**, let us imagine a cylinder **A** that is filled with any gas, for example air or coal gas, etc.; the cylinder's opening is closed with a stopper **s** that is airtight and that can be moved up and down without causing friction. The stopper weighs one kilogram. That means that the stopper presses onto the gas with a weight of one kilogram, and since with gasses, the pressure reproduces itself equally to all sides, we have to assume that the gas is exerting a pressure of one kilogram everywhere within the cylinder over a surface of the same size as that of the stopper. If we then place a weight of one kilogram on top of the stopper, the latter will now exert a pressure of two kilograms onto the gas, and the stopper will immediately sink from **a** to **b**, as is shown in the cylinder in **figure 16 II**. Now the volume of the gas is exactly half of what it was at first. If we place a second weight of one kilogram on top of the stopper, so that the gas undergoes a pressure of three kilograms, the stopper will sink to **c**, as is shown in the cylinder **16 III**, and the gas now only takes up a third of the original volume. Thus, by doubling the pressure, the volume of the gas was reduced to one half, and by tripling the pressure, it was reduced to one third. It goes without saying that a decrease in the pressure by one half will cause the volume of the gas to rise to the double, and by decreasing the pressure to one third, the volume will triple. In our example, we only need to remove the weights from the stopper, and immediately the stopper would be raised by the gas from its position at **c**, first to **b** (if one kilogram is removed) and then to **a** (if both kilograms are removed). This law can be expressed as follows:

"The volume of a gas is in opposite proportion to the pressure exerted on it."

This law was first discovered by the English physicist Boyle two centuries ago (1662), long before anyone had any clear ideas about the essence of the states. But it was ignored over a longer period of time, and without knowing about Boyle's discovery, the

Frenchman Mariotte again discovered it (in 1679). Now it is usually called the Mariotte Law.

What consequences can we draw from what we have just learned about the nature of matter in a gaseous state?

In addition to the size of the mass, the space which any object occupies is determined by the size of the spaces between the individual molecules. Expansion is nothing other than an increase, and shrinking nothing other than a decrease in the distance between the molecules. A change in temperature and a change in pressure are the only conditions that cause a change in the space occupied by an object (if we do not include the increase or decrease of its mass). In both cases, we see a surprising law in gaseous objects: **all gasses react in exactly the same way to the same change in temperature or pressure**. We can explain this phenomenon the most simply by assuming that:

> With equal pressure and equal temperature, the distance between the molecules in gaseous objects is the same, and moreover, this distance is so much larger than the molecules themselves, that the size of the latter can be assumed to be minute compared to that of the former.

Most simply, it follows from this that under the same conditions, that is to say, at the same temperature and with the same pressure, the same number of molecules must be present in the same volume of gaseous objects.

Looking at it superficially, we are struck by the fact that we assume the space between the molecules in gaseous objects to be much larger than the mass of the molecules, comparable to the way we see the distances in space between the fixed stars as being infinitely greater than the size of the fixed stars themselves. But aside from the fact that already through this comparison the above reflection loses much of its surprise effect, any example, as for instance water passing from the liquid to the gaseous state as steam, shows us that the spaces between the molecules must be extremely large: if the pressure and the temperature remain the same (100° centigrade), its volume expands to more than 1600 times what it was.

So far, the above hypothesis, which was first formulated by Avogadro, has been confirmed entirely by all the new experiments that have been done since.

The mutual attraction between molecules in solid and liquid objects is decreased both by increasing the distance between the molecules and by increasing the intensity of the oscillations, which is why solid objects that are warmed first pass into the liquid and then the gaseous state. However, we can observe that when this occurs, the passage from the solid to the liquid state does not seem to be so much the consequence of increasing the distance between the molecules, but rather of increasing the intensity of the oscillations. This is why the expansion of solid objects passing over into the liquid state is only small and hardly needs to occur at all. In general, at the moment solid objects become liquid, they suddenly expand, but there are also objects that decrease their volume when they become liquid. The most important example of these latter is water. The minute the frozen water, the ice, melts, the volume is reduced by about 1/11. The other way around, when water freezes, it suddenly expands greatly (by about 1/10). Consequently, ice is only 9/10 as heavy as the same volume of water at the same temperature (0°). When the water freezes, it expands with such force that if you fill iron spheres entirely with water and then seal and cool them, they will suddenly burst. That is also why the temperature at which an object melts can only be influenced slightly by attempting to prevent the object’s expansion - that is to say, the change in the distance between the molecules - by exerting very strong pressure from the outside. On the other hand, the end of the molecules’ mutual attraction, so the passage into the gaseous state, essentially depends on the distance between the molecules, but also, of course, on the intensity of the molecular oscillations. That is why the temperature at which any matter passes into the gaseous state depends essentially on the pressure exerted on the matter. The greater this pressure is, the more the molecules are brought closer to one another by means of external force, the higher the temperature will have to be, that is to say, the more intense will the molecular oscillations have to be, so as to be able to cause the molecular attraction to disappear entirely. That is the reason for the phenomenon that has been known for a long time: the greater the pressure exerted on a liquid, the higher the temperature must be at which the object will boil. For example with water, the intensity of oscillation that we call 0° is already enough to overcome the molecular attraction, when the pressure exerted on the water per square centimeter is only 0.625 grams, or as we usually express it, when the tension of the steam maintains the balance with a mercury pillar of 0.46 millimeters. On the other hand, we have to increase the intensity of the water molecules’ oscillation to the point that we call 100°, if the pressure exerted on the water per square centimeter is 1033 grams (this corresponds to the pressure of our atmosphere), and if this pressure per square centimeter is increased tenfold, it is necessary to reach the intensity of molecular oscillation that we call 180° in order to overcome the molecular attraction. That is why we say that water boils at 100° under the pressure of our atmosphere, at 180° under the pressure of 10 atmospheres, but already at 0° under the pressure of about 1/1650 of the atmosphere. On the other hand, it will be easy to understand the generally known fact that it is possible to condense gasses to liquids by using strong pressure, as well as the fact that the higher the temperature is, the greater the pressure must be to condense gas.

However, since not only the distance between the molecules, but also the increased intensity of oscillation influences their mutual attraction, it makes just as much sense to say that there must be a state in which the intensity of oscillation alone is already able to completely stop the molecular attraction. In that case, we will perceive the phenomenon that even under the greatest possible pressure, a gaseous object cannot be condensed into a liquid, just as the phenomenon that in spite of the greatest possible pressure exerted on a liquid, it must be transformed into a gas simply through warming. Already for a long time, people have tried in vain to condense simplest gaseous matter into liquid. Thus for example, the mechanic **Natterer**, who built a very practical apparatus for condensing carbonic acid, exposed hydrogen in such an apparatus to a pressure of 3000 atmospheres at a temperature of 0°, but was not able to liquefy it. Therefore such gasses that cannot be condensed even under the greatest pressure were called **permanent** gasses; in addition to hydrogen, they include oxygen, nitrogen and a few others. When **Andrews** carefully heated liquid carbonic acid in an entirely sealed glass pipe in order to determine the expansion of the liquid, he observed that at a temperature of 31.5° the whole liquid mass was suddenly changed into a fine mist, and immediately afterwards it disappeared entirely. Thus, completely independently of the tremendous pressure being exerted on it, the liquid carbonic acid had changed into gas at a temperature of 31.5°. Very soon, Andrews discovered that other liquid gasses also manifested the same phenomenon, as for example sulfuric acid at a temperature of 83°, which under normal atmospheric pressure boils at -10°, and that even a substance that at a normal temperature is liquid, such as water, passes over to the gaseous state when the temperature is high enough, independently of the pressure being exerted on it. Water, for example, at 312°. The temperature at which objects under any pressure pass over to the gaseous state was called the **absolute boiling point** or the **critical temperature point**. With this, it became clear that the older attempts to liquefy the so-called permanent gasses had only had a negative result because the experiments' temperatures had always been above the absolute boiling point of the respective gasses. These experiments were repeated and scientists tried to compress the gasses mentioned at temperatures that were as low as possible, 100-130° below zero. Surely everyone remembers that two researchers, **Pictet** and **Cailletet**, completely independently of each other and with a very different apparatus, condensed oxygen and nitrogen at the same time, towards the end of the year 1877; thus, the appellation “permanent gasses” must disappear from science.

In view of the preceding discussions, we will have to call “absolute boiling point” the molecular state of oscillation of a substance at which the intensity of oscillation alone is enough to entirely cancel the molecular attraction. According to the larger or smaller mass of individual molecules, which is to say, according to their greater or lesser mutual attraction, the temperature of the substances’ absolute boiling point will have to be more or less great; whereas in some substances this temperature is much higher than any degree of heat that we can reach, in others it is so low that it is very difficult to attain.

Because so many people are interested in the condensation of the gasses that used to be called permanent, let us give some space here to discussing the manner in which this liquefaction is brought about. However, we shall first of all discuss the methods which enable us to create such low temperatures as from -100° to -130°.

All solid substances require a considerable amount of heat in order to pass over into the liquid state, as do all liquid objects in order to pass over into the gaseous state. For example, if you rapidly combine a kilogram of water at a temperature of 0° with a kilogram of water that is 80° hot, it goes without saying that the two quantities of water balance each other and the combination will have a temperature of 40°. However, if a kilogram of water that is 80° hot is poured onto a kilogram of ice that is just melting, so that has a temperature of 0°, the ice melts quickly, but a thermometer that is lowered into the combination will show a temperature of 0° in spite of the hot water that was added. All the heat that was necessary to heat the kilogram of water from 0° to 80° was used up in order to cause an equal quantity of ice at a temperature of 0° to pass over to the liquid state, so to water at a temperature of 0°. The other way around, the same amount of heat is again produced when liquid water becomes solid, as can be proven easily through the following experiment. If water that is sealed off from air, for example under a layer of oil, slowly cools in a quiet place, it is easy to cool it to a temperature of -10° to -12° without its becoming rigid, but every destabilization will cause it to freeze immediately. If a thermometer is lowered into water that has cooled to such a great extent, it can be observed that as soon as the vessel is shaken, along with the formation of ice, the mercury rises very rapidly to 0°. It goes without saying that the thermometer cannot rise more than that, because otherwise the ice would melt again. And with this, the entire mass of water does not become rigid, but rather only a part of it, since with the partial solidification the development of warmth is sufficient to raise the temperature of the whole mass of water from –12° to 0°.

In addition, a very large amount of heat is used up in order to cause substances to pass over from the liquid to the gaseous state, for example, liquid water to steam. For this passage, water requires about 540 units of warmth, that is to say, in order to transform one kilogram of liquid water at a temperature of 100° to steam at a temperature of 100°, we have to bring as much heat to it as is needed to heat 540 kilograms of water by one degree. Exactly the same amount of heat is again produced, is liberated according to the technical expression, when the steam is condensed to liquid water. If one kilogram of steam at a temperature of 100° is introduced into 630 kilograms of water that is 10° warm, all the steam is compressed, but at the same time the entire amount of water (631 kg after all) will now be at a temperature of 11°. Thus, the one kilogram of steam at a temperature of 100° was first liquefied and then the water produced was cooled from 100° to 10°, so by 90°. The amount of heat that became available by means of this latter cooling can of course only raise the temperature of 90 kilograms of water from 10° to 11°, so by one degree. It follows that the entire remaining mass of water (630 – 90), that is to say, the 540 kilograms is only heated by one degree, because the amount of water that is liberated into liquid water by means of the condensation of the steam is introduced into it. Both the temperature required for melting and that needed for vaporization has been determined for many substances, and the unit of heat that has been accepted is that required in order to raise the temperature of the same amount of water by one degree. The following brief table lists the most important substances:

Melting point:		Vaporization point:	
Ice	80.0	Water	535.8
Salpeter	47.4	Wood alcohol	263.9
Salpeter found in Peru	63.0	Common alcohol	208.8
Common salt	40.7	Sulfuric ether	91.1
Zinc	28.1	Vinegar ether	105.8
Silver	21.1	Oil of terpentine	68.7
Lead	5.4	Iodine	24.0
Sulfur	9.4	Sulfuric acid	94.6

Accordingly, both the melting point and the vaporization point are very different in the various substances, but they are always very high. This use of heat in melting and in vaporizing remains the same for each object, regardless of whether the required amount of heat is introduced from outside (through heating) or not. In the latter case, the required amount of heat is simply drawn from the melting object’s whole surroundings. If we leave water standing out in the open, it will evaporate. And every gram of evaporated water draws from its surroundings, that is to say from the remaining mass of water, the vessel, the closest layers of air, etc. the amount of heat required for its change into the gaseous state: the entire surroundings are cooled by the evaporating water. That is why on seacoasts the summer is cool. That is why water in alcarazzas is cool even in the warmest room, that is to say, water kept in the porous clay vessels used in Spain; these let the water seep through slowly to the outside walls and there it evaporates. But equally, if we dissolve common salt in water, whereby the salt must liquefy, the water has to cool off, since the salt is forced to draw the amount of heat it needs to liquefy almost entirely from the water.

If you combine chopped ice or snow with common salt, because of the salt's tendency to dissolve, the ice melts, and heat is used up both for the melting ice and for the dissolving salt. Therefore, while the melting is taking place, the combination must cool off, and that actually does happen to the extent to which this combination can cool at all, that is, until the temperature is reached at which a saturated salt solution becomes rigid, which is at -21°. It is generally known that in making sorbet etc., such combinations of ice and salt are used; they are called cold mixtures.

Cooling through the evaporation of substances without adding heat from the outside, is used furthermore to produce lower temperatures on a large scale in order to make ice synthetically. It is known that almost all gasses can be condensed to a liquid state through compression already at normal temperatures. In that case, the layer of gas resting on the liquid exerts strong pressure on the walls of the vessel. Of course, such liquefied gasses can only be preserved in vessels that are airtight on all sides and very resistant. Now if we open a vessel that is filled with a liquefied gas, the gas will flow out with great force, the liquid will begin to boil violently and rapidly be changed to gas again. But in so doing, since the liquid has to give all the heat that is needed in order to change into a gaseous state to the first evaporating parts, it has to cool off very much, and in fact, it rapidly cools down to the temperature at which the respective gas would liquefy without greater pressure than that of our atmosphere. Thus for example ammonia, which we know and which can be found on the market in the form of a colorless liquid dissolved in water; in its pure state it is a gas, which according to the research done by **Bunsen** liquefies at a temperature of 20° under a pressure of 8.8 atmospheres, at 0° already under an atmospheric pressure of 4.8, but under our normal atmospheric pressure at -33.7°. This gas, which can be dissolved in water extremely easily and in ever greater quantity the lower the temperature, can again be expelled completely from the water by heating the solution. Based on this, **Carré** built the ice machines that are named after him, the simplest form of which is shown in **figure 17**.

A is a vessel made of strong iron plate that is filled about ¾ with a watery ammonia solution, which is as concentrated as possible. Connected to it is an airtight wide pipe **B**, from which the narrow pipe **q** branches off and flows into the vessel **C**, which is about ¼ the size of **A**. In order to observe the temperature, a pipe that is closed at the bottom is inserted into **A**, and the thermometer **t** is lowered into that. Now when the vessel **A** is heated, the ammonia escapes from the liquid in the form of gas, going through **B** and **q** to **C**; but since the entire apparatus is sealed on all sides, the gas gradually compresses to a liquid in **C**. So as to avoid the heat produced in this process, **C** is lowered into a large vessel containing cold water. Furthermore, in order to avoid unnecessary excess pressure, the air is driven out of the apparatus by first carefully heating **A** to only 30-40° and at the same time opening the vessel **C** through a screw **s**. For by means of a narrow little pipe that can be closed with the screw **s**, this vessel is connected to a small vessel **w** that is filled with water. As long as there is air in the apparatus, it escapes through the water in bubbles, but as soon as all the air has been driven out, the ammonia, which alone is now reaching **w**, is completely absorbed by the water; no more bubbles go through the water. Now the vessel **C** is closed and while **C** is lowered into cold water, the vessel **A** is gradually heated to a temperature of 130°. In so doing, all ammonia is driven out of **A**; all that is left in **A** is water, and except for the small amount of ammonia which remains in the form of gas over the water in **A**, as well as in **B** and **q**, the ammonia is in **C** in liquefied form. Then the heat is removed from **A**, as is the vessel with water from **C**, the thin copper capsule **D** is slipped over the latter, and both (**C** with **D**) are put into a large vessel with fresh water; finally, **A** is lowered into cold water. The water in **A** begins to cool, dissolves the gaseous ammonia above it, and immediately new amounts of gas flow from **B** to **A**, and of course from **C** to **B**. The liquefied ammonia in **C** begins to boil violently, cools greatly and by passing on its low termperature, it changes the entire mass of water surrounding **C** into ice in a short time. Now **A** can again be heated, and by alternately heating and cooling **A** with the same amount of ammonia, it is possible to change any amount of water into ice as often as desired.

The lower the temperature at which a respective gas liquefies without the use of greater pressure and the faster the evaporation occurs, the greater will be the lowering of temperature through the evaporation of a gas that was liquefied by means of pressure. This can be understood easily if we take into consideration that just as hot objects cool quickly because of the air surrounding them, so very cold objects try to balance their low temperature by absorbing the heat in the air that surrounds them. So if we let a compressed gas evaporate slowly, exactly the same amount of heat will be used up, but it is supplied by the entire mass of air in a room etc., so that in a thermometer, we will only be able to observe a slight lowering of the temperature of the liquefied gas.

Carbonic acid, which is generally known, is a gas that can be compressed at a temperature of 0° under a pressure of 36 atmospheres. Under normal atmospheric pressure, it boils at -78°, but already at -65° it becomes rigid in a mass resembling a snowball. Thus, when carbonic acid has been condensed to a liquid in a vessel, and when it is poured out of the vessel, while part of it evaporates quickly, the greater part of the liquid becomes rigid in a mass like a snowball; it becomes **solid carbonic acid**.

So as we see, we are already able to cause a lowering of the temperature to at least -65° by letting liquid carbonic acid evaporate under normal atmospheric pressure. But we are capable of producing far greater cold when we let liquid carbonic acid enter a vacuum. Of course, in so doing a far larger part of the liquid evaporates much faster, so that we are forced first to condense into liquid a far greater amount of carbonic acid. The temperature reached in this case is about -100°.

If a different gas, the so-called **ethylene,** is chosen instead of carbonic acid – and it is also possible to produce large amounts of this gas - an even greater cooling can be attained. At a temperature of 0°, ethylene requires a pressure of 42 atmospheres in order to liquefy; under normal atmospheric pressure, it boils at -102°, and if it is made to evaporate in a vacuum, a temperature of -136° can be produced.

Most recently, the gasses which used to be called permanent, are liquefied in a process in which the gas inside a thick-walled narrow glass pipe is compressed by means of a hydraulic press. The pipe itself is surrounded by another vessel containing liquid ethylene. Of course, this complicated apparatus also includes instruments for measuring pressure and temperature. According to the most recent fixings, the absolute boiling point of oxygen, for example, is -113°, and it liquefies to a colorless liquid

at -131.6° under a pressure of 26.5 atmospheres
at -133.4° ” ” ” ” 24.8 ”
at -135.8° ” ” ” ” 22.5 ”

The absolute boiling point of **nitrogen** is even lower than -136°. Nevertheless, although it was only for a few moments, this latter has been condensed to a liquid by using a simple trick in order to produce an even lower temperature, which of course could not be measured.

For in **compressing** gasses, heat is produced, which can rise to blazing temperatures when the compression happens very quickly. In the same way, heat is used up through the **expansion** of gasses, of course, and the momentary cooling is all the greater, the faster the expansion occurs, because then the heat is not returned to the gas as quickly by the surroundings. That is why nitrogen was liquefied by first compressing it at -136° to the pressure of 150 atmospheres and then suddenly lessening the pressure to 50 atmospheres, thus letting it expand to three times its volume. In so doing, it can be seen condensed to a colorless liquid for a few seconds.

In these experiments, it is no longer possible to use a mercury thermometer to measure the temperature because mercury becomes rigid at -40°. Vessels that are similar to usual thermometers but that are filled with hydrogen are used as thermometers. To measure the pressure, manometers are used like those in all pressure cookers.