Chapter 11.

General Basic Rules of Natural Science.

84. If a body is either at rest or moves uniformly in a straight line, we can conclude that it is either not pushed at all from the outside, or that the forces that act on it are in equilibrium.

This rule immediately follows from the concept of persistence; for since a body will on its own either stay at rest or move uniformly along a straight line, no external force is required to maintain it in that state, but such a force would instead change its state. If a body remains in the same state, this is a certain indication that no external force is acting on it. In that case it is either not pushed at all from outside, or when forces are present that exert a pressure on it, then it is certain that these keep each other in equilibrium, and the action of each of them is eliminated by the others. But how several forces that act on a body keep each other in equilibrium, is taught by the Science of Equilibrium, which is entirely based on the consideration that when two equal forces act on a body in opposite directions, they produce no change in the state of the body, and the situation is equivalent to that where no forces are present at all. Therefore if one sees that a body remains in its state although it is being pushed from one side, one can conclude that it is pushed from the opposite side with equal strength. I see for example, that a body lying on the table remains at rest, although it would fall down if the table were penetrable, from which I conclude, that the impenetrability of the table prevents its fall, and consequently pushes the body upwards. But since, in spite of this pressure, the body remains at rest, I conclude that there must be another force that pushes the body equally strongly downwards, and that is called its weight; that means that in this case the weight and the force due to the impenetrability of the table are in equilibrium.

85. But if we see that a body at rest is set into motion, or that a moving body does not continue at the same speed, or changes its direction, we can conclude with certainty that a force is acting on it, and from the above one will be able to determine its magnitude and direction.

Since every body always remains in its state as long as it is not disturbed by an external force, it follows clearly that if the body's state changes, this change must be ascribed to an external force. For if one wanted to ascribe to the body itself a force that enabled it to change its state, then this force would be in clear contradiction to persistence, and eliminate this essential property, and it would no longer be true that every body remains in its state as long as it is not disturbed by an external cause. But since this property is shared by all bodies, it is certain that an external force must be the cause of any change in the state of a body. From the change that has occurred we can find both the magnitude and direction of this force. From the above this can be done very easily; for if a body of mass M now has a speed v, that in the time interval dt is increased by dv, then we know that during this time the body has been pushed forwards by a force = Mdv/ndt; but if its speed had been reduced by dv, then the force would have acted backwards. But if we notice that the body does not continue in a straight line, but that its path is curved, then one compares the latter with a circular arc with half diameter *r*; for this it has been shown that the body is pushed sideward towards the centre of the circular arc by a force that is *Mvv/nr*. If there are changes in both speed and direction, then we have two forces, which however can easily be combined into a single one.

86. These conclusions are however only correct, if we either consider the true movement of the body, or if the apparent movement is in reference to an observer who himself is moving uniformly in a straight line.

If we consider the true state of a body, then there is no doubt that these conclusions are correct. But since our senses never present us the true state of bodies, because we ourselves are in motion with the earth, and ascribe our own movement to the bodies, leading to the apparent movement, our judgment is most of the time concerned with the apparent state of bodies. However even this judgment would be correct if our own movement were uniform in a straight line, since it has been shown that in that case the apparent movement requires the same forces that are necessary for the true movement. But if our own movement is not uniform, and does not follow a straight line, then we are wrong if we think that the bodies are driven by the same forces that we derive by means of the given rules from the apparent movement. But we can easily correct the error, if we add to these forces those others that are able to produce in the bodies those changes that occur at our location, and do this in the same direction. For since one finds the forces required for the apparent movement, if one deducts from the actual forces those that can produce the changes at the location of the observer, one finds, working backwards, from those forces the actual ones, if one adds to them the latter. But here one assumes that the observer correctly judges directions according to parallel lines; if this is not done, then the correction also is not valid. If we therefore, in the belief that the heavenly bodies rotated about the earth in 24 hours, wanted to assign to them the forces required for such an astonishing movement, we would deceive ourselves beyond all measure, and would not be able to correct the error easily, because it arises from the fact that we do not estimate directions through parallel lines, but through lines that have the same position with respect to the earth.

87. The forces that are required to cause the changes in the state of a body must be sought in the bodies that are nearest to it and touching it ,since these forces must of necessity arise from the pressure exerted by the neighbouring bodies on it, having their origin in the impenetrability.

If nothing acted on the body from outside, then no change in its state would occur; thus if a change in its state has occurred, an external force must have acted on it. But this force cannot stem from anything other than the bodies that touch it directly; for if such bodies either did no exist, or did not exert a force on it, then there would be no cause why a change should occur in its state. The forces therefore consist of a push or pressure, through which the contacting bodies act on the one whose changed state is under discussion. However such an effect arises only because these bodies, together with the one in question, can not remain in their state without interpenetrating each other. Because therefore of necessity a change must occur in their state, the impenetrability produces those forces that can cause these changes. From this follows that all forces that are needed to produce changes in the state of any body, have their origin in the impenetrability, unless the changes are caused by a ghost. If one therefore finds that a body has been driven in a certain direction, then the force must be sought in a pressure from the opposite side, and the source of this pressure be sought in the other bodies that touch the body in question, because the pressure must always act perpendicularly to the point of contact. Either the body suffers no pressure at all from the other sides, or it is so much stronger that it exceeds the others by as much as is necessary for the change that has occurred. From the weight of a body we rightly conclude that it is pushed from above with an equal force; but it can be that this body is also pressed from all other sides, provided the pressure from above predominates.

88. A body is pushed or pressed by others when, because of its impenetrability it is in their way, so that they cannot remain in their state; and through this push or pressure the state of the body itself is altered. From these circumstances originate all forces that act on bodies.

Here we have to consider two main cases; the first is when a body is in the way of others in such a manner that they cannot maintain their speed, but that their direction is not disturbed, which causes the actual push. The second case is that where the body does not interfere with the speed of the others, but forces them to change their direction, and in that case it experiences the action that is called pressure, although in fact the push is not different from a pressure, as will be shown below. The first case occurs if the body that we have set in motion either meets in front of it another body that moves more slowly in the same direction, or when it is followed from the rear by another body at higher speed in the same direction; as long as only these two bodies interact, a push will arise, through which they press on each other at the point of contact, and in this manner change their state. But when a body has a concave shape, such as *AB* (Fig.11), and another body *C* slides along it in such a manner that it touches the concave surface in direction *EC* and begins to continue its path along the surface, then it will soon be forced to curve its path accordingly without noticeably changing its speed, and since its path can not be curved unless the body is driven towards the centre of curvature, the impenetrability of the body *AB* must take the place of the necessary force, and for this reason the body *AB* will for its part be pushed back by the body *C***.** For if we put the mass of the body $C = M$, its speed $=v$, and half the diameter of the curvature $AB = r$, then the force with which the body *C* always presses on the body *AB* at the point of contact will be Mvv/nr as was shown above. But here we regard the body *AB* as immobile; but if it were to yield to the pressure, and change its position with respect to the movement of the body *C*, then the pressure would also undergo a change. Meanwhile this example is sufficient to demonstrate how a body can, without an actual push, act on another body and exert a force, and

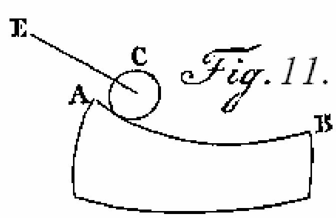

Fig. 11.

from these two cases one can easily see what would occur if two bodies collide obliquely, a case that we can here not yet examine in depth.

89. If a body is prevented by other bodies from following the forces that are acting on it, then it presses on these bodies with equal forces, which is equivalent to these bodies themselves being driven by the forces.

This likewise follows from the impenetrability in a situation where two bodies, that can not remain in their states without interpenetrating each other, are interacting; for when a body is pushed by a force, but an other body stands in its way such that the effect of the force, that would occur when the other body either were not there or were penetrable, can in fact not occur, then this body will be pushed further by the other body with equal force, and it is clear that this second continued force also arises from the impenetrability. If in addition a third body is in the way of the second, so that it can not follow the action of the force pressing on it, then this third body experiences the same pressure, which can be continued in this manner to a fourth, fifth etc. Therefore if a body that lies on a table is pushed downwards, then the table prevents the body from falling down because of this force. The table thus receives the same pressure, which is equivalent to its being driven by the same force. Further the table stands on the floor, which hinders the action of the force on the table, and thus likewise experiences the pressure of this force. Finally the floor rests on the earth, on which the same force exerts its pressure, which shows how a pressure can be propagated through many bodies over very large distances. The pressure does however only propagate that far, if it has not been able to exert its effect on any one of the intermediate bodies; for if anyone of the intermediate bodies had not encountered impediments to its changing its state according to the acting force, it would not have exerted a force on the succeeding bodies. But if the force had been able to exert its action only in part on a body, then only a part of the force would have been propagated to the succeeding bodies, namely that part which had brought about no effect. A force is thus propagated only to the extent that it has not been able to exert its full effect, as determined above.

90.When a body is pressed by a force, the cause of the latter must be sought in the immediately touching bodies, and it is always due to the fact that either these bodies do not really remain in their state, or cannot completely respond to the forces acting on them without interpenetrating the body in question.

It has already been sufficiently demonstrated that two bodies must press on each other when, without interpenetrating each other, they can not remain in their state. But a body can also be pressed by others, even when these remain at rest or persist in their motion undisturbed; this happens when these bodies are pressed by others, but when the changes in their states, that should occur due to this pressure, cannot completely take place because of the impenetrability of the first body, which body then becomes subject to that part of the pressure that could not fully exert its effect. In a similar manner can third bodies receive pressure from fourth ones, and these again from further ones, so that a pressure that arose from a first cause at some location can be transmitted to other bodies far away. But a force acting on a body achieves its full effect when it actually brings about in its state the changes that should occur according to the above rules; and if that can happen without interpenetrating an other body, the force is not transmitted to a further body. But if a force can exert its action on a body either not at all, or only incompletely without interpenetrating another body, then the body experiences in the first case the whole pressure due to this force, and in the second case only a part of that pressure. That part is just that, which could not exert its effect. Since in the state of the body a smaller change occurs that should occur due to the acting force, one can imagine a force which would have caused this smaller change; the excess of the actual force over this imagined force is the force that is transmitted to the bodies that had been in the way of the full effect being exerted. From this one sees how all bodies in the world can be exposed to a perpetual pressure from all sides, causing perpetual changes in their states, and due to no other cause than the forces of impenetrability.