THE NEW MECHANICS.[1]

IN this world, as you know, nothing is final, nothing immutable; the most powerful, the most stable empires are not eternal: this is a theme the preachers abundantly develop.

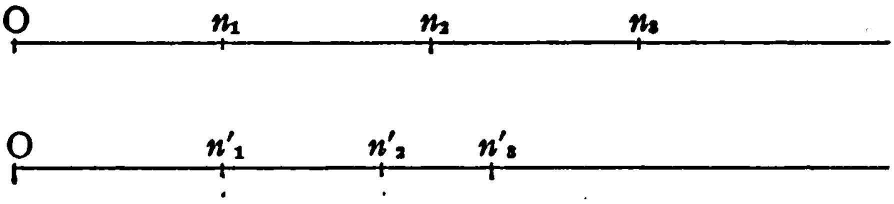
Scientific theories are like empires, they are not certain of the morrow. If any one of them seemed beyond the effects of time, it was certainly the Newtonian mechanics. It seemed undisputed, it was an imperishable monument; and behold in its turn, I shall not say the monument is thrown down, that would be premature, but anyhow it is greatly shaken. It is subjected to the attacks of powerful destroyers. There is one in Göttingen, Max Abraham, another is the Dutch physicist Lorentz. I wish to say a few words about the ruins of the ancient edifice and about the new structure by which it is sought to replace them.

First of all what is it that characterizes the old mechanics? It is this very simple fact: Consider a body at rest, impart to it an impulse, that is to say make a given force act upon it for a given time; the body moves, acquires a certain velocity; the body being impelled by this velocity, apply to it again the same force for the same time, the velocity will be doubled; if we still continue, the velocity will be tripled when we shall have given a third time the same impulse. So beginning again a sufficient number of times, the body will end by acquiring a very great velocity which can exceed all limit, an infinite velocity.

[1] Translated from the French by George Bruce Halsted.

In the new mechanics, on the contrary, we assume it to be impossible to communicate to a body starting from rest a velocity beyond that of light. What happens? Consider the same body at rest; give it a first impulse, the same as before, it will take the same velocity; repeat this impulse a second time, the velocity again augments, but it no longer will be doubled; a third impulse will produce an analogous effect, the velocity increases but less and less, the body opposing a resistance which becomes greater and greater. This resistance is inertia, it is what is commonly called mass; all this happens then in this new mechanics as if the mass was not constant, but increased with the velocity.

We can represent the phenomenon graphically: In the old mechanics the body after the first impulse takes a velocity represented by the sect On_1; after the second impulse On_1 increases by a sect n_1n_2 equal to it; at each new



impulse the velocity increases by the same quantity, the sect representing it increasing by a constant length. In the new mechanics, the velocity sect increases by sects $n'_1 n'_2$, $n'_2 n'_3$, ... which become smaller and smaller so that we cannot pass beyond a certain limit, the velocity of light.

How have we been led to such conclusions? Have we made direct experiments? The divergences only come out for bodies impelled by great velocities; only then do the indicated differences become perceptible. But what is a very great velocity? Is it that of an automobile making 100 kilometers an hour? We would go wild with excitement over such a speed in the street. But from our point of view this velocity is still very small, a snail's pace. Astronomy does better. Mercury, the fastest of the heavenly bodies, also runs over about 100 kilometers, no longer per hour but per second. However, that still does not suffice; such velocities are too slight to reveal the differences we wish to observe. I do not mention our cannon balls; they are faster than automobiles, but much slower than Mercury.

You know that we have discovered an artillery whose projectiles are much swifter; I mean radium which sends out energy projectiles in every direction. The speed of this shooting is far greater, the initial velocity being about 100,000 kilometers a second, one-third the velocity of light. The caliber of the projectiles and their weight are, it is true much slighter and we cannot count on this artillery to increase the fighting power of our armies.

Can we experiment on these projectiles? Such experiments have been actually undertaken; under the influence of an electric field, of a magnetic field, a deviation occurs which enables us to take account of the inertia and to measure it. Thus we have ascertained that the mass depends upon the velocity and we enunciate this law: The inertia of a body increases with its velocity which remains less than that of light, 300,000 kilometers a second.

I pass now to the second principle, the principle of relativity. Suppose there is an observer moving to the right; everything is as if he were at rest, with the objects about him moving to the left. There is no way of knowing whether the objects really move, whether the observer is at rest or in motion. We teach in all courses on mechanics that the passenger on a boat thinks he sees the river bank moving, while he is gently borne along by the motion of the boat. Examined more closely, this simple idea acquires capital importance; there is no way of settling the question, no experiment can disprove the principle that there is no absolute space, all displacements we can observe are relative displacements. I have often had occasion to express these considerations so familiar to philosophers. They have even given me a publicity I would gladly have avoided. All the reactionary French journals have made me prove that the sun turns around the earth. In the famous case between the Inquisition and Galileo, Galileo should be all wrong.

To return to the old mechanics. It admitted the principle of relativity; in place of being founded on experiments, its laws were deduced from this fundamental principle. These considerations sufficed for purely mechanical phenomena, but not for important parts of physics, for example optics. We considered the velocity of light as absolute with reference to the ether. This velocity could be measured. We had theoretically the means of comparing the displacement of a moving body to an absolute displacement, the means of deciding whether or not a body was in absolute motion.

Delicate experiments, apparatus exceedingly precise, which I shall not describe to you, enabled us to attempt the practical realization of such a comparison: the result was null. The principle of relativity admits of no restriction in the new mechanics; it has, if I may so speak, an absolute value.

To understand the rôle the principle of relativity plays in the new mechanics, we are led first to speak of apparent time, a very ingenious invention of the physicist Lorentz. We suppose two observers, the one A at Paris, the other B at Berlin. A and B have identical chronometers and wish to set them; but they are exceptionally scrupulous observers and require in their setting an extraordinary exactitude not only, for instance, to the second, but to the thousand-millionth of a second. How can they do it? From Paris to Berlin, A sends a telegraphic signal, by wireless, if you will, to be wholly modern. B notes the moment of reception and this will be the starting time for both chronometers. But it takes a certain time for the signal to go from Paris to Berlin; it travels only with the speed of light. B's watch would therefore be slow. B is too intelligent not to take this into account, and he proceeds to remedy it. The thing seems very simple. They cross signals, A receiving and B sending; they take the mean of the corrections thus made and so have the exact time.

But is this certain? We are assuming that it takes the signal the same time to go from A to B as from B to A. Now A and B are carried along in the motion of the earth with reference to the ether, the vehicle of the electric waves. When A has sent his signal it flies on before him, B moving away in the same way, and the time employed will be longer than if the two observers were at rest. If, on the other hand, it is B who sends, and A who receives, the time is shorter because A goes to meet the signal. It is absolutely impossible for them to know whether or not their chronometers mark the same time. Whatever the method employed, the troubles remain the same. The observation of an astronomic phenomenon and all optical methods run against the same difficulties. B can never know more than an apparent difference of time, more than a species of local hour. The principle of relativity applies completely.

In the old mechanics, however, we prove with this principle all the fundamental laws. We might be tempted to take up the classic arguments and reason as follows. Suppose again two observers, A and B, to call them what we always call two observers in mathematics. Suppose them in motion, going away from each other. Neither can surpass the velocity of light; for example let B go at the rate of 200,000 kilometers toward the right, A of 200,000 kilometers toward the left. A may think himself at rest, and the apparent velocity of B will for him be 400,000 kilometers. If A knows the new mechanics he will say: "B has a velocity he cannot attain, therefore I also am in motion." It seems he could decide about his absolute state. But he must be able to observe the motion of B himself. To make this observation A and B commence by setting their watches, then B sends telegrams to A to indicate to him his successive positions; putting them together A can reckon B's motion and trace the curve of this motion. Now the signals go with the speed of light. The watches which mark the apparent time vary at each instant and everything will happen as if B's watch went too fast. B will think himself going much less rapidly and the apparent velocity he will have relatively to A will not surpass the limit it should not attain. Nothing can reveal to A whether he is in motion or at absolute rest.

It is still necessary to make a third hypothesis, which is much more surprising, much more difficult to admit, and which greatly disturbs our present modes of thought. A body in motion of translation undergoes a deformation in the direction of its displacement; a sphere, for instance, becomes like a species of flattened ellipsoid with the short axis parallel to the translation. If we do not perceive such a transformation every day this is because it is so small as to render it almost imperceptible. The earth, borne along in its revolution through its orbit, is deformed about $^1/_{200\,000\,000}$. To observe such a phenomenon would require measuring instruments of extreme precision, but if their precision were infinite it would not avail, because they also are borne along in the motion and would undergo the same transformation. We should perceive nothing; the meter we could use would shorten like the length to be measured. We could not learn anything except by comparing the length of one of these bodies to the velocity of light.

These are delicate experiments, carried out by Michelson and I shall not expound their details; they have given results altogether remarkable. However strange it may seem to us, it is necessary to admit that the third hypothesis is perfectly verified.

Such are the bases of the new mechanics; with the help of these hypotheses we find that it is compatible with the principle of relativity.

But it is necessary to connect it then to a new conception of matter.

For the modern physicist, the atom is no longer the simple element; it has become a veritable universe in which thousands of planets gravitate around tiny suns. Suns and planets are here particles *electrified* either negatively or positively; the physicist calls them *electrons* and with them builds the world. Some represent the neutral atom as a positive central mass around which circulate a great number of negatively charged electrons, whose total electric mass equals in magnitude that of the central nucleus.

This conception of matter enables us easily to account for the augmentation of the mass of a body with its velocity, which we have made one of the characteristics of the new mechanics. Since a body is only an assemblage of electrons, it will suffice to show it to be true of them. To this end we note that an isolated electron moving through the ether engenders an electric current, that is to say an electromagnetic field. This field corresponds to a certain quantity of energy localized not in the electron but in the ether. A variation in magnitude or in direction of the electron's velocity modifies the field and expresses itself by a variation of the electromagnetic energy of the ether. While in the Newtonian mechanics the expenditure of energy is due only to the inertia of the moving body, here a part of this expenditure is due to what may be called the inertia of the ether relatively to the electromagnetic forces. The inertia of the ether increases with the velocity and its limit becomes infinite when the velocity approaches the velocity of light. The apparent mass of the electron therefore increases with the velocity; Kaufmann's experiments show that the constant real mass of the electron is negligible in relation to the apparent mass and may be considered as null.

In the new conception, matter's constant mass has disappeared. Only the ether, and no longer matter, is inert. Only the ether opposes a resistance to motion, so that we might say that there is no matter, but only gaps in the ether. For stationary or quasi-stationary motions, the new mechanics does not differ—within the range of approximation of our measurements—from the Newtonian mechanics, with the sole difference that the mass is no longer independent either of the velocity or of the angle this velocity makes with the direction of the accelerative force. If, *per contra,* the velocity has a considerable acceleration, in the case, for instance, of very rapid oscillations, Hertzian waves are produced which represent a loss of energy of the electron involving the deadening of its motion. Thus in wireless telegraphy the waves emitted are due to the vibrations of the electrons in the oscillatory discharge.

Analogous vibrations take place in a flame and likewise also in an incandescent solid. Lorentz thinks that in an incandescent body a considerable number of electrons circulate which, not being able to get out of it, fly in every direction and are reflected on its surface. We may compare them to a swarm of gnats enclosed in a jar and striking with their wings against the walls of their prison. The higher the temperature, the more rapid becomes the motion of these electrons and the more numerous the mutual impacts and the reflections on the wall. At each impact and at each reflection an electromagnetic wave is emitted and it is the perception of these waves which makes the body appear to us incandescent.

The motion of the electrons is almost tangible in a Crookes tube. There a veritable bombardment takes place of electrons issuing from the cathode. These cathode rays violently strike the anticathode and are there in part reflected, thus giving birth to an electromagnetic agitation which many physicists identify with the Röntgen rays.

In closing, it remains for us to examine the relations of the new mechanics to astronomy.

If the notion of constant mass of a body vanishes, what will become of Newton's law? It will hold good only for bodies at rest. Moreover it will be necessary to take into account the fact that attraction is not instantaneous. It may therefore well be asked whether the new mechanics will not result in complicating astronomy without obtaining an approximation superior to that given by the classic celestial mechanics. Lorentz has taken up the question. Starting from Newton's law, which he assumes to be true for two electrified bodies at rest; he calculates the electrodynamic action of the currents engendered by these bodies in motion. He thus obtains a new law of attraction containing the velocities of the two bodies as parameters.

Before examining how this law explains astronomic phenomena, we remark again that the acceleration of the heavenly bodies has as consequence an electromagnetic radiation, therefore a dissipation of energy making itself felt in return by a deadening of their velocity. Therefore, in the long run, the planets will end by falling into the sun. But this prospect can hardly frighten us, since the catastrophe can not happen for some millions of milliards of centuries.

Returning now to the law of attraction, we easily see that the difference between the two mechanics will be the greater the greater the velocity of the planets.

If there is an appreciable difference, it will therefore be greatest for Mercury, which has the greatest velocity of all the planets. Now it happens precisely that Mercury presents an anomaly not yet explained. The motion of its perihelion is more rapid than the motion calculated by the classic theory. The acceleration is 38″ too great. Leverrier attributed this anomaly to a planet not yet discovered and an amateur astronomer thought he observed its passage across the sun. Since then no one else has seen it and it is unhappily certain that this planet perceived was only a bird.

Now the new mechanics explains perfectly the sense of the error with regard to Mercury, but it still leaves a margin of 32″ between it and observation. It therefore does not suffice for bringing concord into the explanation of the velocity of Mercury. If this result is hardly decisive in favor of the new mechanics, still less is it unfavorable to its acceptance since the sense in which it corrects the deviation from the classic theory is the right one. Our explanation of the velocity of the other planets is not sensibly modified in the new theory and the results coincide, to within the approximation of the measurements, with those of the classic theory.

In conclusion, it would be premature, I believe, in spite of the great value of the arguments and of the facts set up against it, to regard the classic mechanics as finally condemned. However it may be in other respects, it will remain the mechanics of very small velocities in relation to that of light, the mechanics therefore of our practical life and of our terrestrial technic. If however, in some years, its rival triumphs, I shall venture to point out a pedagogic danger that a number of teachers, in France at least, will not escape. These teachers will find nothing more important, in teaching elementary mechanics to their scholars, than to inform them that this mechanics has had its day, that a new mechanics where the notions of mass and of time have a wholly different value replaces it; they will look down upon this lapsed mechanics that the programs force them to teach and will make their scholars feel the contempt they have for it. Yet I believe that this disdained classic mechanics will be as necessary as now and that whoever does not know it thoroughly cannot understand the new mechanics.

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