

corporate a worthy physical institute. And this institute could pilot the way in those things that pertain to the development of physical science. A reasonable number of promising students would furnish working material for the honored professors, and later they would spread the gospel.

The publication of the work of such an institute would be a matter of detail and one that would take care of itself. I believe that a suddenly created national university with the proper ideals is an almost Herculean task. However, if several institutes of the character of the proposed physical institute could be founded one by one, these could later form a loose union for cooperation without waste of energy or loss of spirit.

If my readers are inclined to admit the strength of the argument in this paper when it is considered in connection with the efforts of our state universities, but not when considered in connection with our endowed universities, they should be reminded that the latter type of institution has not succeeded in retaining such physicists as Rutherford, Jeans, Richardson and Maclaurin. Other foreign physicists have even declined to try our atmosphere. Our self-respect demands that we attempt to create one center of physical research to which eminent world physicists would be willing and happy to come. I believe that with the establishment of the physical institute we should soon have the spirit, intelligence, work and courage of the American university professor in physics raised to such an extent that men would be honored with salaries as well as with ranking titles, such that the fellowship of students would mean inspiration rather than a deadly burden, such that irregular administrative management would not be tolerated, and such that

a correct public sense of values would be established.

F. C. BROWN

THE STATE UNIVERSITY OF IOWA

THE NEW MECHANICS

IN the past decade, rumors have become current that physicists were attacking critically the ideas which have been accepted in mechanics since the time of Newton. Articles have appeared which assert that there are two mechanics, the Newtonian or classical, and the non-Newtonian or modern. And it must occur to many to ask whether this is to be a war of words, as has so often resulted from looking at the same thing from opposite sides, or whether we are living in a world perplexed by two rulers, for we have pretty generally submitted to the doctrine that we and the rest of the universe are parts of a mechanical machine. And it would be an additional perturbation, in these already troublous times, to have to decide which governor to live under. While the laws of mechanics will probably be modified, still we are now certain that the changes will not affect problems involving matter in any of its ordinary aspects. The human race, in its present state of existence, will thus continue to conform to the laws of Newtonian mechanics; but we must be prepared for an early proclamation from Sir Oliver Lodge, the apostle of the science of spiritual mechanics, that death is merely the transfer of those complexes of the ether, called man, to a massive empty space governed by the laws of non-Newtonian mechanics—where our spirits move hither and thither with the velocity of light, and think with an energy comparable to the explosion of an atom.

The real issues of this very important discussion of the laws of mechanics are now fairly determined, and when the Société Française de Physique made them the subject of a conference, no one could have been found better fitted to state the case than M. Paul Langevin, of the Collège de France. Now that his opinions have been published, it is comparatively easy to present the ideas

underlying the new mechanics as a survey of his article.¹

M. Langevin begins his discussion with the statement that the idea of mass has been the fundamental concept of mechanics since the time of Newton, and that it may be introduced in three different ways which correspond to three aspects of inertia. We may define mass as the coefficient of proportionality of force to change of velocity as derived from the formula, force equals mass times acceleration ($F=ma$); as capacity for impulse or quantity of motion, from the formula, momentum equals mass times velocity ($G=mv$); as capacity for kinetic energy, from the formula, kinetic energy equals one half mass times velocity squared ($w=\frac{1}{2}mv^2$).

Rational mechanics, to be consistent, requires that there must be perfect equality among these three definitions of mass, and that the mass of any portion of matter must remain absolutely invariable for all velocities and for all changes of the body, whether due to physical, chemical or mechanical agents.

By inertia we ordinarily mean the property which matter possesses of tending to preserve its state of rest or of uniform motion in a straight line; that is, matter resists any change of motion in such a way that an external action or force is necessary to change the quantity or the direction of a motion. Newton based mechanics on this constant proportion between force and change of motion, or acceleration; and he defined mass to be the constant of this proportion. He thus assumes that mass, determined in any other manner, will give a consistent result with his definition.

And since the time of Newton, every treatise on physics has begun with this assumption, that inertia is the fundamental property of matter, in the sense that it can not be expressed in simpler terms. Indeed, for more than two centuries, it has been held to be the essential doctrine of mechanics, that a physical phenomenon was satisfactorily explained only when it was reduced to a type of motion

governed by the laws of this rational mechanics, and particularly by the law of inertia.

But now, after a searching criticism of the postulates of mechanics, many physicists have come to the conclusion that inertia is not a fundamental property of substance, and they claim to have proved that it can be reduced to simpler terms by the laws of electromagnetism, which show evidence of being simpler and more fundamental than the laws of dynamics.

First, because it can be proved that inertia is not invariable, since the quantity of mass, as measured by the three definitions given above, ceases to be the same when the velocity of matter is not small compared to the velocity of light.

Furthermore, although for small velocities the three definitions of mass agree and assign to a given portion of matter a definite initial or "stationary" mass, m_0 , yet even this initial mass depends on the physical and chemical state of the system and also varies for each change of state which is accompanied by an interchange of energy with an outside body.

This evidently means that, if a body radiates heat, light or electro-magnetic waves to other bodies, or if a body unites with another to form a new chemical compound, then the mass of the body in each case changes. The relation between this change of mass and the change of energy is found to be a very simple one, as the change of mass equals the change of energy divided by the velocity of light squared, or

$$m - m' = \frac{V_2}{w - w'}$$

It follows because of the law of the conservation of energy that in a system of bodies whose separate parts mutually exchange energy, the masses of the separate parts vary, but the total mass of all the parts added together remains constant, if the system as a whole does not change its total quantity of energy. Thus the law of conservation of mass is merged into the more fundamental law of conservation of energy.

The inadequacy of mechanics became apparent when physicists attempted, without success, to explain electro-magnetic and optical phenomena from the accepted mechanical laws. We now see, as Professor Einstein has shown

¹ P. Langevin, "L'inertie de l'énergie et ses conséquences," *Le Journal de Physique*, July, 1913.

by the principle of relativity, that an essential error was introduced when the formulæ of dynamics and those of electromagnetism were assumed to lead to the same conceptions of space and time. According to the new mechanics, our ideas of time and space, obtained from mechanical notions, are only approximately true, while those derived from the laws of electromagnetism are correct. The result is many physicists of the new school are now seeking for an interpretation of inertia from the laws of electromagnetism rather than to continue to explain the laws of electromagnetism by mechanics. These laws of electromagnetism have the advantage of great simplicity of form which may qualify them to serve as the fundamental principle of all physical laws.

The germ of these new views of electromagnetism is to be found in the work of Faraday and Maxwell. Their true experimental foundation is Rowland's experiment, performed in 1878, when he found that an electric charge, if it be carried through space with a high velocity, acts like an electric current in that it creates about itself a magnetic field. Three years later, J. J. Thomson showed that, if an electrified body moves through space, it not only creates a magnetic field in the surrounding space, but also that this magnetic field is a form of mechanical energy; from the law of the conservation of energy, this energy must be acquired at the expense of an equal amount of energy localized in the free space about the body. Now it can be shown rigorously that this "magnetic" energy has all the characteristics of a kinetic energy, since it is proportional to the square of a velocity and contains a factor which corresponds with the mass as given in the third of our former definitions. This supplementary inertia of electromagnetic origin results solely from the fact that the body is electrified, and it is an addition to the stationary or initial mass which was denoted by m_0 .

The result is the same if we consider the second definition of mass, as a capacity for impulse or momentum. So soon as a body is electrified and moves, it develops a supplementary capacity for momentum which agrees

with the supplementary capacity for energy which has just been described. Poincaré, in order to preserve the fundamental law of the conservation of momentum, has shown that it is necessary to localize a quantity of momentum in space just as we were forced to localize a quantity of energy in space. Thus the fundamental consequence of rational mechanics, requiring the three definitions of mass to agree, is not satisfied for all cases of motion.

These ideas have affected our notions of space. Maxwell deduced as a consequence of theory that rapid and periodic variations in the electrical charge of a body should be propagated through space with the velocity of light. The existence of these electromagnetic radiations was verified experimentally by Hertz, and in the hands of his successors this new form of radiation has attained great importance under the name of wireless telegraphy. A theoretical consequence of this radiation is the now generally accepted belief that light is merely a type of electromagnetic radiation of excessively rapid vibration. To transfer the phenomena of light from a mechanical to an electromagnetic manifestation of energy was to shake profoundly the belief in the fundamental and universal nature of mechanical energy.

Another very important principle of rational mechanics was embodied in Newton's third law of motion, that to every action there is an equal and oppositely directed reaction. But we have not been able to make the forces created by an electrified body in motion conform to this law. This is especially evident when radiation also occurs. Let us suppose that an incandescent body is giving off light (*i. e.*, electromagnetic radiation) uniformly in all directions. By reason of symmetry this radiation exerts no resultant force on the source. But if the perturbation, in the form of a wave, encounters an obstacle at a distance, then we know, both from theory and from experiment, that the obstacle will be subjected to a force due to its absorbing a part of the radiant energy. This pressure of light pushes the obstacle in the direction of the propagation of the light, and the action thus exerted on the

distant body is not compensated by a reaction appearing at the source or on any other portion of matter. We thus have cases of actions without reactions, if matter alone is considered.

It must be clearly understood that the discrepancies involved in the results of the rational mechanics, which have been cited, do not become appreciable except under unusual conditions. We can still consider mass as an absolute constant and the equations of dynamics as exact, unless matter has a velocity exceeding 18,000 miles a second, or for changes of state which involve enormous quantities of energy, such as those associated with radio-active bodies or those which accompany the formation of the chemical atom. At the present day we have made no progress in attaining any of these conditions, for even in the case of radio-active bodies we should need to find a method of liberating their energy in hours rather than in hundreds of years. Thus the problem would have remained academic, if theorists had not advanced the hypothesis that electricity is atomic in nature and that the electron, as the least portion of electricity is called, ordinarily attains a velocity which does exceed a velocity of 18,000 miles a second; that radiation must be explained as a transfer of an entity, energy, through space; and that the chemical atom of the radio-active elements decomposes spontaneously and of all other elements is theoretically decomposable with the evolution of an enormous amount of energy. All of these theoretical cases would make the discrepancies between the laws of mechanics significant.

It would exceed the limits and the purpose of this article to attempt to follow M. Langevin in his exposition of the properties of electricity and of matter, of inertia, of radiant energy, and of the principle of relativity. After all, these abstruse questions are proper for the discussions of specialists as they deal with the nature of matter in a state quite outside the limits of observation. But however the hypotheses of electrons and the ether may impress the world as being matter of definition and words rather than of substance, yet

from them follow conclusions which can be tested experimentally. And the conclusions to be drawn from the new mechanics are interesting.

For example, from the assumption that the mass of a body varies when it gives out heat or light, we must conclude that if a pound of water at 32° Fahrenheit were heated to 212°, its inertia or mass would be greater. Unfortunately, when we calculate the increase of the mass for this or for any practicable heating of a body, we find that it is entirely too small to measure.

Again, let us put a known mass of hydrogen and oxygen in a closed vessel and cause them to unite to form water. Since the union of these gases liberates an immense amount of energy in the form of heat which will be radiated from the walls of the vessel, the mass of the water must be less than the combined masses of the two gases. But unfortunately again, the calculated decrease in mass is only a five-billionth part and thus entirely too small to measure.

Lastly, the radio-active bodies give off an amount of energy much greater in proportion to the mass acting than can be obtained by any chemical or other process. We might hope to measure the decrease of mass in these cases, but we can not, because these bodies give off their energy far too slowly.

Such, in the main, is M. Langevin's exposition of the new ideas in mechanics. There is not the least doubt that this rigorous searching of the classical mechanics has been a most important advance in science, and we are certain to find its laws must be revised in order to make them conform to the more rigorous exactness which is now required of mathematicians. But it is equally certain the laws of mechanics have withstood this criticism extraordinarily well, in so far as they have been unshaken when we are dealing with motions which can be attained by bodies of sensible mass.²

² That is, Newton's laws of dynamics are rigorous when bodies of tangible size, acting in measurable spaces and times, are investigated. They are approximations for exceptional cases; in much

The divergence of the new and the old mechanics occurs only for actions of separate electrons, of unattainable velocities, of energy existing in the chemical atom, and of radiant energy in empty space unassociated with matter. Now there are many men of science who think these problems are metaphysical, in that they do not deal with measurable bodies or with phenomena capable of experimental verification. And there is a great likelihood that problems of such a nature are incapable of scientific solution and are apt to drift into a discussion more of definitions and of words than of objective facts.

The warning which was given by Poincaré, shortly before he died, is one to be heeded by the over-zealous.

If, however, in some years, its rival (the new mechanics) triumphs, I shall venture to point out a pedagogic error 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 can not understand the new mechanics.

LOUIS T. MORE

UNIVERSITY OF CINCINNATI,
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GEORGE WESTINGHOUSE

My acquaintance with Mr. Westinghouse commenced in the spring of 1867 in Pittsburgh. He was at that time introducing to the railroads a patent car replacer and a double-headed railroad frog, both of his invention. These were being manufactured by Messrs. Anderson, Cook & Company, crucible steel manufacturers, I being employed by the same company. He was doing the selling—at the same time making his first acquaintance the same way as his more universal law of gravitation is accurate for ponderable bodies but fails for intangible molecular bodies.

with railroad men, so valuable to him in later years. We lived at the same hotel and later on, after we were both married for about a year, we lived in the same house on Penn Avenue, next door to where the great Westinghouse Building now stands, and, being of congenial tastes, our acquaintance ripened into a warm friendship which continued up to the time of his death.

During this time he often talked of the idea of operating the brakes of a railroad train by compressed air, one of the greatest advantages of which he thought would be the putting of the full control of all movements of the train into the hands of the engineer. He had witnessed a collision between two trains and saw the necessity of some better apparatus for controlling their speed than what was then in use. Not having the money to pay the expense of the first equipment, which only amounted to \$750, he gave a very substantial interest in the patent to one of the men who was afterward associated with him, in return for the necessary capital. This gentleman made over \$2,000,000 out of this interest in the Brake Company within the next twenty-five years.

He soon had all the details of the new invention worked out and the first train equipped. It was first tried on an accommodation train on the P. C. & St. L. Railroad, running west from Pittsburgh. It was a success from the very first, preventing a bad wreck and probably saving several lives within a week after its installation.

A company was soon formed and the manufacture of the brakes was commenced within a few months. He added from time to time improvement after improvement until in 1886 he brought out the automatic quick-action brake. The greatest rival of the air brake at that time was an electric brake. After studying this problem for some time, Mr. Westinghouse announced to his associates that he had conceived the idea of an improvement in the air brake that would make its operation quicker than the electric. No one could understand how this could be true, but when the brake was constructed and put in operation they found it was a fact.