XCI. *On the Postulates and Conclusions of the Theory of Relativity.* By LOUIS T. MORE, *Ph.D., Professor of Physics, University of Cincinnati* *.

IN spite of the wide-spread interest which has been excited by the theory of relativity, there has been a surprising lack of attention paid to the credibility of its postulates and to the effect its conclusions, if accepted, would have on our ideas of the objective world. In this theory we are not dealing with an abstract, or mathematical analysis, but with a definite conception of what we regard as a real world whose phenomena are apparent to our sense perceptions. Its conclusions must square with our experience of space and time and not with a world of the imagination. No matter what logical excellence a scientific hypothesis may have, we may judge from past experience that it will be discarded unless it satisfies the persistent and imperative need of the mind for a somewhat naive belief in the reality of the objective world, and unless it tends to establish stability and regularity in our environment.

The earliest attack on Newtonian mechanics was made by Bishop Berkeley almost contemporaneously with the appearance of the *Principia*. Newton based his mechanics on the conservation and objective reality of matter as expressed in his law of inertia and, equally important, by his principle of action and reaction he reduced the fluctuating and incomparable kinetic phenomena to a problem of statics capable of direct measurement. For these principles Berkeley substituted his famous doctrine of subjective idealism. One by one he discussed the properties by which we say we recognize matter, and showed that they are but the sense perceptions of the mind. His criticism is keen and his argument, as a logical process, is excellent. Although Berkeley intended his philosophy to be a proof, not merely of the real existence of the external world, but primarily of the real existence of God, yet his idealism has had the effect of encouraging atheism and has gone down under such illogical attacks as that of Dr. Johnson, who merely kicked a large stone as an evidence that the real existence of matter did not rest in his mind. The vortical theory of matter proposed by Lord Kelvin, which mathematically satisfied very many of the properties of matter, succumbed to the

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* Communicated by the Author.

simple criticism of Maxwell that, however interesting and erudite the theory might be, no conclusion derived from the postulate that matter was a motion of an hypothetical æther could ever satisfy the mind as a substitute for matter. The same is true of the even more subjective and idealistic hypotheses of the present time. The theory of energetics, the theory of electricity as matter, and still more, the annihilistic theory of Einstein, are all doomed to be discarded because they do not postulate matter as a substratum of reality,—as a thing independent of our varying sensations. The authors of these hypotheses unconsciously bear witness to this ; for, however they may disguise their terms, they always endue their substitutes,—energy, electricity, or æther,—with all the properties of inertia of matter. Can we expect to carry conviction and increase the reasonableness and exactness of science by a juggling of words ; by transferring reality from matter to an evidently less concrete entity ? We are merely widening the unfortunate gap between theoretical and experimental physics; the experimentalist still translates electricity and æther into the inertia of matter.

The effect which the acceptance of the theory of relativity would have can be readily shown from Einstein's own words. It is better to obtain these from his non-mathematical exposition of the theory *, as he has there spared no pains to make his philosophical ideas simple and clear.

The theory of relativity arose from the need to link up certain phenomena of light and electricity, or rather of radiation, with mechanics ; that is, to explain these phenomena of a different category, so far as our sense perceptions are concerned, on a mechanical basis. This implies, of course, that we are still to consider the explanation of all objective phenomena as, in form, a problem of mechanics ; whether these phenomena appeal to our sense of sight, of temperature, or what not, mechanical analogies will continue to be the simplest and the most satisfactory to our minds. The mechanical link which we find running through all phenomena is undoubtedly energy, either appearing directly in a mechanical form or else reducible to that form by Joule's equivalent. At first sight, it would seem that the natural procedure would be to establish the laws of pure mechanics, that is, the laws of the positions and motions of tangible bodies, and to modify the laws of light, electricity, and radiation to agree with the established laws of mechanics. Now, the laws of rational mechanics, or of classical mechanics, as they are called, have

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* 'Relativity,' by Albert Einstein. Translated by Robert W. Lawson.

been developed more slowly and more carefully than have those of any other branch of physics and, until recently, we would have agreed with Rankine that they are the nearest approach to an exact science that human reason has been able to devise.

But, with the advance in the sciences of optics and electricity a different plan has been adopted, the phenomena of electricity and radiation are now considered as fundamental; matter and energy become secondary attributes of an æther or of a substance, electricity; but, oddly enough, the explanation of this ætherial or electrical substance is still mechanical. Let me quote Einstein (p. 52): "Classical mechanics required to be modified before it could come into line with the demands of the special theory of relativity. For the main part, however, this modification affects only the laws for rapid motions, in which the velocities of matter r are not very small as compared with the velocity of light. We have experience of such rapid motions only in the case of electrons and ions: for other motions the variations from the laws of classical mechanics are too small to make themselves evident in practice."

It is quite evident that, in Einstein's opinion, the classical mechanics based on the Galileo-Newton coordinate system is adequate only for static problems. When motion is involved, the dimensions of length, mass, and time must be determined by applying the Lorentz-FitzGerald transformation. This modification is theoretically necessary for all velocities, but it becomes practically important only when matter is electrically charged and moving with a velocity comparable to light. This condition is reached only when matter is reduced in size to a sub-atomic dimension, which is itself admittedly below all our powers of sense perception, and when matter is radiating non-mechanical energy. In other words, the classical mechanics of tangible bodies must be theoretically discarded, not because its equations will not adequately define the positions, velocities, and energies of bodies of a perceptible size, but because we wish to explain the motion and energy of sub-atomic bodies and to discuss the energy of radiation *in vacuo* during the interval of time when it is emitted and afterwards absorbed by matter. In all conscience, the obvious thing to do would be to hold fast to classical mechanics as a satisfactory groundwork for our conception of the objective world and to make the subject of radiant energy a separate and distinct branch of science. Certainly, there is a fundamental difference between the reality of a body of tangible and perceptible proportions and the disembodied energy of radiation *in vacuo*. In the past, we have created many kinds of æther and many forms of radiant energy, and we tried to endue them with some likeness to ponderable matter; now, it is proposed to make matter with a remarkable likeness to a vacuum.

In our ambition to subordinate matter to light and electricity, we have forgotten that explanations of heat are likely, at some time, to be just as importunate. According to the kinetic theory of heat, temperature is the kinetic energy of small masses composing the system. As yet no one has announced that the temperature of a man rises or falls according as he runs faster or slower. According to the theory of relativity, his mass and space dimensions must be modified to account for this fluctuation in temperature. If it be argued that "this modification affects only the laws for rapid motions," we may cite the case of a moving system of bullets, in a battle, whose velocity is quite comparable to the velocities of heat molecules in a gas at ordinary temperature. Thus in our mechanical explanation of heat energy we wisely leave the laws of mechanics of bodies of a perceptible size unchanged and create a heat molecule whose kinetic energy is not mechanical but thermal. Would it not be advisable to follow the same plan for electro-kinetics and radiant energy and create a mechanical model of an electro-optical molecule whose dimensions are subject to the Lorentz-FitzGerald modification, and leave the mechanics of ponderable bodies as they are? Besides the modification in mechanical laws which, Einstein claims, must be made to explain optics and electrodynamics, he applies the concepts of relativity to the motion of stars and claims that here, too, the change is necessary. This criticism is on a different footing, for we are now dealing with pure mechanical problems. The discussion of celestial mechanics will be taken up later in the paper.

We are being misled by our desire to unite formally the different branches of physics by a single mechanical expression into the idea that radiation and heat and mechanics are one in essence because they have a mutually convertible attribute; energy. Newton, undoubtedly, bases mechanics on the law of inertia, and no amount of argument derived from phenomena of light and electricity will alter our conviction that it is a satisfactory and an adequate postulate. But the law of action and reaction is as necessary as the law of inertia. Mechanics becomes as shifting sand unless we can reduce phenomena to a balanced or static system of reactions equal to, and simultaneous with, actions. If problems of radiation require a modification of the law of inertia if they are to be explained mechanically, so also the static balance of mechanics will have to be abandoned. We find that electromagnetic radiation, when it is absorbed or reflected by matter, exerts a mechanical pressure. This pressure becomes apparent at an interval of time after the emission of energy from the radiating body. There is either no mechanical reaction on the emitting body, or, if there is, no evidence exists that it is a simultaneous one. When light is reflected from a body, is the velocity of light altered, contrary to hypothesis, in accordance with the mechanical law of equivalence of momenta, or must the laws of impact be modified? The proposed theory of relativity must therefore modify the third law of motion as well as the other two.

If one accepts the opinion of Einstein that classical mechanics is inadequate because it will not account for all phenomena, there is probably no doubt of its failure, but it can be added that no logical system can ever be devised which will accomplish that impossible task. Does Einstein suppose that the new mechanics, or rather mechanico-electrodynamics, is of that all-embracing type? Apparently he does, if the meaning of the following quotations be clear (p. 15): "As long as one was convinced that all natural phenomena were capable of representation with the help of classical mechanics, there was no need to doubt the validity of this principle of relativity [the Newtonian]. But in view of the more recent development of electrodynamics and optics, it became more and more evident that classical mechanics affords an insufficient foundation for the physical description of all natural phenomena." Then he adds (p. 16): "The principle of relativity must therefore apply with great accuracy in the domain of *mechanics*. But that a principle of such broad generality should hold with such exactness in one domain of phenomena, and yet should be invalid for another, is *a priori* not very probable." Just the contrary is true, as we always pass from one domain of phenomena to another by means of a ratio or physical coefficient whose meaning is unknown and whose measurement is expressed in units of the first domain, as when we pass from mechanics to electricity a quantity of electricity is expressed in mechanical units of mass, length, and time, and the meaning of the dielectric constant is unknown.

If classical mechanics affords us a tool by which we can account for phenomena involving the positions and motions of ponderable bodies and can reduce their force and energy to a problem of statical relations between actions and reactions, it is complete as a theory. And if further it can, by an hypothesis which does not conflict with its own deductions, link up with other phenomena in different domains, it is a general theory; and this is exactly what the classical mechanics is capable of doing.

Einstein assumes that all measurements have equal importance. That is not the case; while it is true that classical mechanics denies absolute position and motion, it tacitly assumes that a coordinate system in a static relation to the phenomenon is the ultimate system of reference. Let us suppose that several persons observe the same phenomenon. Obviously their conclusions as to positions and motions will disagree, since each person must ultimately interpret the phenomenon with reference to himself. Each observer therefore chooses a frame of reference rigidly attached to himself regarded as a point absolutely at rest. If A wishes to compare his result with that of B, he must know also the position and motion of B's frame of reference with respect to his own during the observation. Each person who measures an action may apparently refer the action to a coordinate system moving with reference to himself, but he must know the motion of the coordinate system and be able to refer it to a coordinate system attached to himself. Nor does Einstein escape this paradox. If all coordinate systems, moving relatively to each other, are of equal importance, then the world is a perfectly incomprehensible and fluctuating affair. His method of introducing stability is to assume that the velocity of light is an absolute constant of length per unit time, to which all observers of a phenomenon may refer. Thus two persons attempting to obtain concordant measurements of a kinetic phenomenon may refer to the velocity of light as a common and an invariable standard. And if either attempts to derive a length standard from this velocity coordinate, he will be forced to pin his system of coordinates to a star so distant as to be fixed to all observers or else to the absolutely stationary luminiferous æther, whatever that may mean.

This attempt to measure lengths by a velocity, even if it be such a compliant standard as the velocity of light *in vacuo* or æther, leads us into grave difficulties. In mechanics a length is the distance between two points, and we derive from this postulate that a velocity is the ratio of this distance and the time taken by a body in traversing it. Einstein does the opposite; the velocity of light is our standard measure;

a distance is the velocity of a body multiplied by the time taken during an event. If in mechanics static measurements are fundamental and kinetic problems are secondary, now the converse is true and no real advantage is gained. The velocity of light is singularly unsatisfactory as a standard of measurement, since it must be expressed in terms of an arbitrary static measure. In the next place the light considered is *in vacuo* and can be determined only by extrapolation from measurements made when moving through matter where it is not constant. Its constancy is simply the fiat of Einstein, who claims that if we agree that the velocity of light *in vacuo* shall be constant and the length of the Imperial Yard shall be variable: "There is not the least incompatibility between the principle of relativity and the law of propagation of light, and that by systematically holding fast to both these laws a logically rigid theory could be arrived at." The sacrifice to logic is too great.

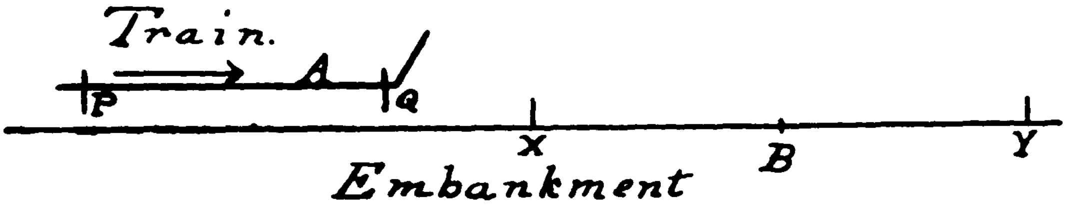
When the velocity of light is determined the distance and time are held to be mechanical. Unless we are considering abstract motion, the moving something we call light must be an entity. Is this entity of a mechanical nature or is it non-mechanical? If it is mechanical, how can it differ in its properties from all other bodies of a mechanical nature and be absolute and unchangeable in its momentum and energy? And if light is of a different nature, how can we use it as a basis for mechanical laws? Lastly, is the velocity of light in any true sense, a velocity,—a transfer of a body from position A to position B? We usually regard radiation as a periodic wave disturbance in a medium. Now even a material wave in water has no velocity in the sense of the transfer of matter from A to B. It is merely a series of particles moving, one after the other, whose individual motions may not even be in the direction AB. The velocity of a wave is purely an abstract notion which states that in the space AB a series of events occur consecutively. For example, a row of persons may pass a word along from one to the other, and I daresay it would be intelligible to speak of the velocity of speech as the distance AB divided by the time interval. How Einstein will pass from the abstract idea of the velocity of light to the motion of a ponderable body, he gives no idea.

Einstein lays great emphasis on the difficulty of measuring the length of a moving object in terms of a static standard, and it is this difficulty which causes him to accept the postulates that the length of a moving body is a function of its velocity and that time is affected by the motion of the clock.

This is due to the fact that the observer of a moving body must depend on some signal such as light in determining its length. But the following illustration seems to make it clear that concordant results can always be obtained when two observers are able to compare their standards directly or statically either before or after the measurement.

Let a long train (fig. 1) be moving in the direction of the arrow, then an observer A, on the train, would measure its length by applying a standard length. If, however, B, standing on the embankment, desires to measure the length of the moving train, Einstein states that his result must be a different one, involving the composition of the velocities of the train and of the light signal. But suppose that B marks off a distance XY along the embankment and either before or after the observation he can compare this distance with A's standard length, then he can obtain the length of the train in static measure and concordantly with B's measurement. For let him station himself half-way between X and Y. Let him record the times when Q reaches X and Y by either light or sound signals and also when P reaches the same points; although it may take time for the signals to reach him from X and from Y, yet, the distances BX and BY being equal, the differences in time will be correctly given.

Fig. 1.



Then, if t_x and t_y be the times noted when Q reaches X and Y, and if t_x' and t_y' be the times for P,

$$\frac{\mathrm{XY}}{t_y-t_x} = \text{the velocity of the train} = v,$$

and

$$v(t_x'-t_x) = \mathrm{XY}\frac{t_x'-t_x}{t_y-t_x} = l = \text{length of the train.}$$

And this length will agree with the length measured by A on the train, provided that XY is long enough to separate the signals and if XY can be measured both by A and B. It is hardly correct for Einstein to state that A and B will each consider his measurements to be of equal weight. The observer, as stated before, must compare all results to a frame of reference fixed to himself and he must, to obtain comparable or even intelligible results, be able to refer the frame of reference of any other observer to his own frame. In case this equation of transformation is lacking, then comparison or concordance is impossible.

In classical mechanics it is well known that all its equations express static relations. Time is an independent variable which can always be cancelled out. If the variable, time, is left in the equation, we gain no knowledge of the history of the event because the equation introduces the supposition that the conditions were not different in the past and will not change in the future. This is a serious limitation because past history always affects the present and the future: to obviate this difficulty Einstein makes use of Minkowski's coordinates in which time is introduced as a fourth dimension; he assumes that this method will give us a world-line or the history of an event. As it is quite evident that time has no relation to either a position or to a length but is a factor of velocity, he is introducing a kinetic system of coordinates of velocities in three real directions and an imaginary velocity for his fourth or so-called time dimension. His standard of measurement is the absolutely constant velocity of light. Thus the length of any body is different to all observers whose motions are different with respect to the body. By using the Lorentz-FitzGerald transformation the length of the body becomes the same for all these observers, but only because the standard of measure is the same for all and its frame of reference is rigidly attached either to a fixed star or to the immovable æther. Thus to have any concordant results a fixed frame of reference must again be assumed, as was the case in classical mechanics. It is merely a question whether one by temperament prefers a fixed static or a fixed kinetic frame of reference.

When we consider Einstein's definitions of time, we are forced to believe that he is labouring under the delusion that time is the same as our mechanical measurement of it by a clock or other periodically moving body. It would seem hardly necessary to point out that time is a purely subjective sequence of events by which we obtain cognisance of objective phenomena and arrange them in our minds. Time has no meaning in an inorganic world and can have no significance except to an organic being so specially developed as to have the powers of reflexion and memory. After reading his theory of relativity, one has the feeling that one's life would be shorter or longer according as clocks ran faster or slower. Can it be that the relativists seriously believe that our recording of the speed of a clock can have any bearing on our sequence of events or on our interpretation of objective phenomena?

Einstein places great emphasis on the meaning of simultaneity of events. Here again he omits the fundamental fact that for simultaneity we must start from a common point of time or event. He considers simultaneity of time as if he were dealing with a problem of objective phenomena detached from the subjective observing mind. If two flashes of lightning are impressed on the eye at the same time, they are simultaneous or else the word has no meaning. If by any means the observer can prove that one flash came from a greater distance, he can reason from experience that if it travelled with the same speed as the other, then it must have occurred before the other. And while the two flashes may not be simultaneous to another observer, they are to him. In other words, simultaneity has no meaning to two observers unless they are in the same relation of conditions or can by memory or history refer back to a common simultaneous event. Thus, NOW, to A on the earth, is what passes at the instant through his mind; NOW on the earth to B, stationed on a star 300 light years distant, is what A has learned took place in 1620. If A tries to inform B of what NOW is to him on the earth, B will not receive the intelligence until 2220, if he is still there. Einstein has done a singularly unfortunate thing in trying to establish time as an objective phenomenon. Time is not a physical quantity, as it is essentially subjective. This page is impressed on the retina of the eye as a whole; it is only when the mind attempts to interpret the objective phenomenon that time enters as a sequence of events or as if one word came after another. We may also illustrate this principle by the simple case of a horse passing from rest to motion. We say this is accomplished by the reaction of the earth; but the push of the earth and of the horse are simultaneous and motion does not occur unless the horse had previously willed to bend his leg. In objective science there is no law of cause and effect; the priority of a cause to an effect is solely the intrusion of a subjective mind which cannot interpret events except in a sequence.

If we accept Einstein's postulates, nothing is more beautifully logical than his conclusions. If it is the function of mechanics first to explain radiation and electrodynamics rather than the motion of ponderable bodies, then it may be wise to modify all those things which seem most real to us to make them harmonize with the properties of that creation of our imagination, the electron. Let us by all means create an electron subservient to the Lorentz-FitzGerald transformation and subject to all the consequences which that subserviency involves. We shall have a model which we can fashion so as to explain the Michelson-Morley experiment, the bending of light rays and many other puzzling phenomena; we can even assume Langmuir's atom which supposes matter to be nothing but electrons which are confined in cells whose stuff is hypergeometric. If the remarkable discovery of the bending of light by the sun is confirmed we are, almost certainly, going back to a corpuscular theory of light, whose particles will have a real gravitational inertia. But when we have arranged a myriad or so of these complacent electrons into a bit of uncompliant real matter, then we should go back to our classical mechanics with its invariable inertia and its other laws.

Out of the theory of relativity, there has come one problem of a purely mechanical nature. It is a distinct achievement that Einstein has found an additional term to Newton's law of gravitation which accounts for the motion of the perihelion of Mercury. It is undoubtedly a very remarkable fact that it should have resulted as a deduction from Einstein's postulates. There is, however, no reason why a second term in the law of gravitation should not be found from purely mechanical postulates, and there are many indications that we shall sooner or later find the dependence of gravitation on temperature, time, the medium, &c. The recent paper by Sir George Greenhill in this journal discusses the problem of Mercury; the additional term of Einstein is reduced to ordinary C.G.S. units, and if he is correct in his deduction: "Einstein's *m* must denote a length, in centimetres. It is mysterious then that Einstein is quoted as calling *m* the mass of the Sun, as if a mass could be measured in centimetres, by a metre rule, and not in grammes; some mysterious unexplained astronomical units must have been employed, and writers should enlighten us on this point of the theory." This is really not more mysterious than many other things in physics. If we explain a quantity of electricity as a complex unit of mass, length, and time without objection, should we complain if mass turns out to be a length when we announce that matter is a system of electrons whose mass becomes infinite if it moves with the velocity of light?

To the man of simple mind, the situation in science to-day is marvellously like that during the struggle between Galileo and the mediæval schoolmen. Galileo won because he held fast to the belief that men of science must deal with a sensible world and not with a phantasmic system of intricate logic. If the age of Galileo seems outworn as an example, there is also the conviction of Faraday that science has always had the task of "repressing and dissolving the phantoms of the imagination." The cost of thrusting us into a continuum of four dimensions where time is confused with space and the velocity of light *in vacuo* is our foot-rule in order that we may solve logically a few comparatively insignificant phenomena is too great.

Cincinnati, 8 March, 1921.

XCII. *Comparison of Processes of Ionization which give rise to Currents in Gases. By* E. W. B. GILL, *M.A., B.Sc., Fellow of Merton College, Oxford* *.

1. THE experimental verification of the theory of ionization by collision given by Professor Townsend depends principally on the comparison of the currents obtained between parallel plates with the formula for the currents calculated on the hypothesis that all the new ions are generated in the gas by the collisions of electrons or positive ions with molecules of the gas.

With a view of finding to what extent the quantum theory of radiation may be applied to effects produced by collisions with molecules, a large number of experiments have recently been made to determine the minimum potential required to ionize a molecule of gas by collision, and the minimum potential required to excite radiation by impacts between electrons and molecules; which radiation has the effect of setting free electrons from a metal electrode. The latter potential has been found to be the smaller of the two, so that in many cases in which the additional currents have

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* Communicated by Prof. J. S. Townsend, F.R.S.