The Principle of Relativity*

A Revolution in the Fundamental Concepts of Physics

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Revolutionary changes in our general ideas of natural phenomena may take place in two distinct ways. A new phenomenon, hitherto unobserved, may suddenly be discovered, and may force us to abandon some principle hitherto regarded as unassailable. Of this we have examples in the discoveries of the Röntgen rays and of radio-activity, the former of which entirely remodeled our ideas of transparency, while the latter broke down the "indestructible" atom.

Another type of change is less obvious. It does not get into the daily press; but it may be as profound and far-reaching as the revolutions produced by the more sensational discoveries. It is usually the outcome of some slight outstanding anomaly, some unsolved riddle, some deviation from numbers indicated by mathematical theory. In astronomy we have instances of such anomalies in the motion of the perihelion of Mercury, and even in the moon's motion. When these riddles are solved, it is an event of the first importance in the science concerned, and it makes an immense impression upon its leaders, though its lesser devotees may fail to see any cause for excitement or enthusiasm. But the next generation is taught to look back upon that period as one of paramount importance.

Such a period seems to be upon us in the sciences of physics and mechanics. The outstanding puzzle in this case is the result of a celebrated experiment performed by Prof. Michelson, of Chicago, who, by means of an arrangement of mirrors and the use of interference fringes, proved that the earth's motion through the "ether" does not affect the velocity of propagation of light.

This experiment, repeated with the most elaborate precautions in 1887, and confirmed by other proofs of the absence of "ether drift," due to Morley and Miller, Trouton and Noble, Rayleigh and Brace, and Sir Oliver Lodge, has ever since rankled in the minds of physicists, and produced a large number of more or less fantastic attempts at explanation.

THE COMING OF EINSTEIN.

And then, in 1905, came a fundamental and (as the future historian will probably say) an epoch-making contribution to the controversy in the shape of an unassuming and dry-looking dissertation, "Concerning the Electro-dynamics of Moving Bodies," by A. Einstein, a Swiss professor of physics. It appeared in the *Annalen der Physik*, the German counterpart of our *Philosophical Magazine*. It created no sensation at the time. It was hardly noticed, and if it was noticed, it was adversely criticised. Yet, at the present time, you cannot open a journal devoted to physics without finding some fresh contribution to the ever-increasing literature of the subject—some criticism, perhaps, of the more daring and startling consequences of Einstein's work; a criticism which, so far, has invariably resulted in the discomfiture of the critic, and the triumph of Einstein's Principle of Relativity.

NEWTON AND EINSTEIN.

In the system of mechanics founded by Galileo and formulated by Newton, it is assumed (with good reasons) that the behavior of mechanical systems obeys the same laws, whether they are "at rest" or endowed with a uniform velocity in a straight line. This assumption is the Newtonian principle of relativity. Its application depends upon what we mean by "rest." Most of our machines and mechanical systems are independent of the earth's rotation. All of them are independent of the earth's revolution. We cannot prove the earth's motion through space by any mechanical device, although Foucault's pendulum and other devices enable us to place the earth's rotation in evidence. The latter, however, does not contradict Newtonian relativity, since this only refers to rectilinear motion.

Einstein's new Principle extends the Newtonian Principle from mechanical phenomena to optical and electrical phenomena. It declares "that the laws of mechanical, optical, and electromagnetic phenomena remain the same, no matter to which of two systems of co-ordinates in uniform relative motion they may be referred." In other words, we cannot prove rectilinear motion through space by any physical device, whether mechanical, optical, magnetic, or electrical. All we can prove is relative motion.

THE ETHER QUESTION.

It is obvious that this new Principle is in full accord with Michelson's experiment. It is, in fact, based upon this experiment. It embodies our despair of ever being able to prove motion through the "ether," of our ever discovering any evidence of "ether-drift." The numerous and varied attempts to discover absolute motion were foredoomed to failure. We could only hope to do so by the help of a stationary ether. The ether has signally failed to help our quest, and many physicists are disposed to show their chagrin by denying its existence. "It is unscientific," they assert, "to postulate the existence of a body whose properties can by no means be ascertained and demonstrated." The evidence in favor of an interstellar ether dwindles down to the finite rate of propagation of light and of electro-magnetic pulses. Then why not accept that finite speed as a fundamental world-fact, and cease looking for any "explanation" which introduces more difficulties than it removes?

It must be remembered, however, that negative evidence is always precarious. A single positive demonstration of ether-drift would suffice to invalidate all previous failures. Yet we base what is perhaps the root principle of physical science, that of the Conservation of Energy, upon a vast array of negative evidence, and practically upon the observed impossibility of perpetual motion. And it may be that Einstein's Principle will attain an equally commanding position by the sheer accumulation of negative evidence in its favor.

THE VELOCITY OF LIGHT.

The most far-reaching consequence of Einstein's Principle is that the velocity of light always appears to be the same, whether measured in a system "at rest," or in a moving system. It is Einstein's merit to have drawn attention to the very foundations of our conceptions of time and space, and of the methods of measuring them. In fact, his original essay deals mostly with the problem of synchronizing clocks and measuring lengths—matters which appear simple enough in ordinary practice, but which bristle with difficulties and pitfalls as soon as the velocities dealt with approach that of light. It then becomes necessary to define what we mean by two "simultaneous" events. If two events happen in London and New York, respectively, at 12 noon as shown by the chief public clocks, everyone is aware that they are not "simultaneous." The New York event is five hours behind the London event. They can be made simultaneous by adopting, say, Greenwich time in both cities. But then the difference of longitude must be known, or two clocks must be synchronized, one for each city. Both devices require a signal, preferably a telegraphic one. But the utmost speed of a telegraphic signal is the speed of light, which is 186,330 miles per second. That speed suffices for ordinary purposes, and as it is 10,000 times the orbital velocity of the earth, the signal is, for most terrestrial purposes, practically instantaneous.

NEW SPEED RECORDS.

But quite a different situation arises when the velocities dealt with begin to be comparable with that of light. And such velocities have been observed again and again in vacuum discharges. "Canal rays," consisting of positively charged atoms, have been known to attain a speed equalling one-tenth the speed of light, and the swifter electrons which constitute cathode rays reach 95 per cent of the speed of light. Even this prodigious velocity is, according to recent Norwegian investigations, exceeded by the speed of some electrons, which produce the aurora borealis.

Kaufmann proved that the "mass" of electrons increases considerably when they are projected with these prodigious velocities. A similar increase of apparent mass has not been observed in the case of canal-ray particles, chiefly because their speed is not high enough. But Einstein's principle goes to show that all matter must increase in "mass" (i. e., inertia) when its speed approaches that of light, so that the difference between "material" mass and "electro-magnetic" mass becomes meaningless. The Principle of Relativity appears on the scene as a kind of universal solvent. It establishes a Roman Peace between the mechanical and electro-magnetic world-theories, by subjecting both claimants to its own superior sway.

SYNCHRONIZED CLOCKS.

The relativity of time is one of the most revolutionary conceptions introduced by the new Principle. Events which are simultaneous in two systems at rest are no longer simultaneous when the two systems are in relative motion. Identical chronometers, originally showing identical time, no longer indicate identical time when in relative motion, and do not even have identical rates! The epoch of an event is, therefore, purely relative, and so is its duration. There is no such thing as absolute time. Time holds only for a given system of co-ordinates, and its duration is affected by its motion; or rather, its comparative duration, as compared with another system, depends upon the relative motion of the two systems.

Some idea of the reasons for this may be arrived at as follows: Let us substitute the velocity of sound for the velocity of light, and sound-signals for light-signals, so as to get more into touch with ordinary experience. Let there be a canal with a number of clocks along it, within hail of each other. Let there be a fog on the canal, which stops all light-signals. How will the clock-keepers keep their clocks in agreement?

The timekeeper at clock *A* will, say, give a shout, or other audible signal at noon. The timekeeper at clock *B*, 1,100 feet away, will shout back the time shown by his clock as soon as he hears *A*'s signal. It will be 12 hours 0 minute 1 second, *A* will hear the answer shout at 12 hours 0 minute 2 seconds. Without necessarily knowing the distance *A B*, he will conclude that the clocks are synchronous, since *B*'s time is midway between his own first signal and the time of hearing *B's* signal.

This method holds good in a calm. If the master clock is at *A*, *B* will be safe in regulating his clock so that his time bisects the time between the departure of the signal from *A* and its return to *A*.

But in a wind this method breaks down. For the total time of the sound covering the distances *A B* and *B A* is increased, and if *B* adjusts his clock to bisection as before, he actually puts it back if the wind blows from *B* to *A*, and forward if it blows from *A* to *B*. Thus an independent observer would find all the windward clocks increasingly slow as he proceeded to windward along the canal, and fast as he proceeded to leeward.

It might be urged that the wind velocity could be allowed for, and thus the error eliminated. So it could in the case of sound-signals: but in the case of light-signals the wind would become an ether-drift, and that is the very thing which all experiments have hitherto utterly failed to measure or discover.

EINSTEIN'S TRANSFORMATION.

Einstein showed not only that the clocks are fast or slow to the extent of $L\frac{v}{V^2}$ seconds (when L is the distance, positive or negative, from the master clock, V the velocity of light, and v the speed of the moving system), but that there is a retardation of the time-rate in the proportion of $\sqrt{V^2 - v^2}$ to V. Not only this, but all lengths in the direction of the velocity are apparently diminished in the moving system, as seen from the system (assumed to be) at rest, in the same proportion.

This shrinkage was postulated by Fitzgerald and Lorentz to account for the negative result of Michelson's experiment. It now turns out to be an apparent shrinkage due to our limitations in measuring time, which limitations are imposed by the finite velocity of light. The change in the time- and space-scales thus rendered necessary is called the Lorentz-Einstein transformation. It reduces all optical and electrical problems involving moving bodies to the same problems applied to bodies at rest.

This, in itself, is a great service rendered by the new Principle. It prepares us for some conclusions which we should otherwise feel much hesitation in accepting—such as that all mass is really energy bottled up; that all energy possesses inertia, and even exerts gravitational attraction; that gravitational force is propagated with the velocity of light; and that the velocity of light is the limit of physically possible speed, and is practically identical with an infinite velocity.

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Automatic Regulator for Electric Lamps.—It is well known that incandescent electric lamps must be burned at the proper tension. If this voltage is exceeded, a brighter light is obtained, but the life of the lamp is shortened. A German engineer has devised a lamp which regulates its own voltage. The current passing through the lamp is forced to pass through an iron wire. When the voltage rises more current flows. This current heats up the iron wire, and since the resistance of the iron increases as its temperature rises, the flow of destructive current through the lamp filament is prevented.—*Popular Electricity.*