MATHEMATICS-PHYSICS

The Special Theory of Relativity

"A Classic of Science"

Einstein's First Epoch-Making Paper Shows That Changes In the Speed of an Observer Can Stretch or Contract Time

ZUR ELEKTRODYNAMIK BEWEGTER KOERPER; von A. Einstein, In Annalen der Physik, vol. 17, 1905. Translated for the SCIENCE NEWS LETTER.

IT IS well known that Maxwell's electrodynamics—as it tends to be interpreted at present—in its application to moving bodies, leads to inconsistencies which do not seem to be inherent in the phenomena. They appear, for example, in the reciprocal electrodynamic action between a magnet and a conductor. The observable phenomenon here depends only upon the relative motion of conductor and magnet, but, according to the usual idea, two cases, with the one or the other of these bodies as the moving one, are sharply differentiated from each other. When the magnet moves, for example, and the conductor is at rest, there arises in the neighborhood of the magnet an electric field of known strength which produces a current in the place where part of the conductor is. But when the magnet is at rest and the conductor moves, there arises in the neighborhood of the magnet no electric field, but instead, in the conductor, an electromotive force which does not, in itself, correspond to energy, but which—presupposing equality of the relative motion in the two cases considered—gives rise to an electric current of the same strength and the same direction as the electric field in the first case.

Examples of similar kind, as well as the futile attempts to establish motion of the earth relative to the "medium of light," lead to the supposition that, not only in mechanics but also in electrodynamics, no essentials of the phenomena correspond to the surmise of absolute rest; rather, on the other hand, for all systems of co-ordinates for which mechanical equations hold good, the same electrodynamic and optical laws apply as already proved for quantities of the first order. We will take this surmise (whose substance will hereafter be called the "Principle of Relativity") as a postulate, and also add to it the only apparently contradictory hypothesis that light is always transmitted in empty space with a definite velocity V independent of the state of motion of the emitting body. These two postulates together suffice to base a simple, consistent electrodynamics of moving bodies, making use of Maxwell's theory of bodies at rest. The introduction of a "light ether" will prove unnecessary according to the viewpoint which we develop insofar as there is introduced neither absolute space at rest and endowed with particular properties nor a velocity vector associated with a point of empty space in which electromagnetic processes take place.

The theory which will be developed is limited—like all other electrodynamics—to the kinematics of rigid bodies, since the statements of every theory have to do with the relation between rigid bodies (co-ordinate systems), clocks and electromagnetic processes. The fact that people have not had sufficient regard for these circumstances is at the root of the difficulties with which the electrodynamics of moving systems at present has to contend.

Simultaneity

Let us assume a co-ordinate system in which the equations of Newtonian mechanics are valid. We shall call this co-ordinate system, for the sake of distinguishing it in our speech from later co-ordinate systems, and for precision of definition, the resting system. If a material point is at rest relative to this co-ordinate system, its position relative to it according to a definite scale of measurement can be determined by using the methods of Euclidean geometry, and can be expressed in Cartesian co-ordinates.

If we wish to describe the *motion* of a material point, we will give the values of its co-ordinates as functions of time. We must keep it very carefully in mind that a physical meaning can be ascribed to such a mathematical description only if one has clearly comprehended beforehand what is here understood by the word "time." We must bear in mind that all our judgments in which time plays a part are always judgments about *simultaneous occurrences.* If I, for example, say: "The train arrives at 7 o'clock," it means just about this: "The short hand of my watch pointing to 7 and the arrival of the train are simultaneous events."[1]

It might seem that all the difficulties which cling to the definition of "time" could be overcome by putting in place of time, "the position of the short hand of my clock." Such a definition actually is sufficient, if it is a question of time defined exclusively for the place at which the clock stands; the definition however no longer suffices when we link together in a temporal relation a series of events occurring in different places, or—which comes to the same thing—to give temporal values to occurrences at places which are distant from the clock.

We could of course content ourselves with giving temporal evaluation to events if an observer with a clock who found himself at the origin of co-ordinates should ascribe to each event the position of the clock hand when the light ray, coming to him through

[1] The inaccuracy which is inherent in the conception of simultaneity of two events in (approximately) the same place, and must at the same time be bridged over by an abstraction, will not be discussed here.

empty space, bearing witness of the event reaches him. Such an ascription, however, brings with it the difficulty that it is not independent of the standpoint of the observer who has the clock, as we know by experience. We arrive at a much more practical point of view through the following consideration.

If a clock is placed at point A in space, an observer stationed at A can evaluate temporally the events in the immediate vicinity of A by finding the positions of the clock hands simultaneous with these events. If a clock is also situated at point B in space—we will add, "a clock of precisely the same properties as that at A"—the evaluation of events in the vicinity of B by an observer who is at B is also possible. It is not, however, possible without further explanation to compare as to time an event at A with an event at B; we have so far only an "A-time" and a "B-time," but no common "time" defined for A and B. This latter time can now be defined, if we will settle *by definition* that the "time" which light takes to travel from A to B is equal to the "time" which it takes to travel from B to A. That is, a ray of light starting out from A toward B at "A-time" t_A is reflected at "B-time" t_B from B to A, and comes back to A at "A-time" t'_A. The two clocks run synchronously, according to definition, if

$$t_B - t_A = t'_A - t_B.$$

We assume that this definition of synchronism may be stated in a manner free from contradictions, and in fact that for as many points as you wish the general relations are:

1. If the clock in B runs synchronously with the clock in A, the clock in A runs synchronously with the clock in B.

2. If the clock in A runs exactly as the clock in B and also as the clock in C, then the clocks in B and C run synchronously relative to each other.

We have thus by the use of hypothetical physical experiments defined what is to be understood by clocks at rest running synchronously at different places, and by it have won an evident definition of "simultaneous" and of "time." The "time" of an event is the simultaneous indication of a clock at rest, at the place of the event, which runs synchronously with a given clock at rest, and indeed for all determinations of time with the same clock.

We assume in accordance with experience that the quantity

$$\frac{2AB}{t'_A - t_A} = V$$

(the velocity of light in empty space) is a universal constant.

It is evident that we have defined time of clocks at rest within a resting system; we will call time so defined, because it belongs to a resting system, "the time of a system at rest."

Relativity of Lengths and Time

The following considerations are based on the principle of relativity and on the principle of constancy of the velocity of light, which two principles we define as follows:

1. If the conditions of physical systems are expressed with reference to two different co-ordinate systems moving relative to each other with uniform velocity of translation, the laws according to which the system changes condition will be the same for either.

2. Every ray of light moves in a resting co-ordinate system with the definite velocity V, regardless of whether the ray of light is emitted by a resting or a moving body. Hence

$$\text{Velocity} = \frac{\text{path of light}}{\text{duration of time}}$$

in which "duration of time" is to be understood in the sense of the definition in Article 1.

Let there be a rigid rod at rest; let it be measured with a likewise resting measure of length l. Let us now imagine the axis of the rod as placed on the X-axis of a resting co-ordinate system, and then given a uniform motion of parallel translation (with uniform velocity v) along the X-axis in the direction of increasing x. We shall inquire as to the length of the *moving* rod, which we shall think of as determined by the following two operations:

a) The observer himself moves, together with the previously mentioned measuring rod, with the rod to be measured, and determines the length of the staff directly by laying the measuring rod along it, just as he did when the rod to be measured, the observer and the measuring rod were at rest.

b) By means of synchronous clocks

set up in the resting system, according to Article 1, the observer determines at what points the beginning and the end of the rod to be measured are at a given instant t. The distance between these two points, measured with the same measuring rod used before, but in this case at rest, is also a length, which may be considered as the "length of the staff."

According to the principle of relativity the length found by operation a), which we will call "the length of the rod in the moving system," must be the same as the length l of the rod at rest.

The length which we find by operation b), which we will call "the length of the (moving) rod in the resting system," we will determine, making use of our two principles, and we will find that it is different from l.

The generally accepted kinematics tacitly assumes that the lengths determined by the two operations described will be exactly equal to each other, or, in other words, that a moving rigid body at the instant t could be replaced in all its geometric relations by the *same body* when it *rests* in a given position.

We consider further the two clocks (A and B) located at the ends of the rod, which are synchronous with the clocks of the resting system, that is, their reading corresponds to "the time of the resting system" at the places where they happen to be at that time; these clocks are therefore "synchronous with the resting system."

We assume further that with each clock there is an observer who moves with it, and that these observers apply to both clocks the criterion for the synchronous running of two clocks which we set up in Article 1. Let a ray of light leave A at the time t_A,[2] let it be reflected at B at the time t_B, and return to A at the time t'_A. Taking account of the principle of constancy of the velocity of light we find:

$$t_A - t_B = \frac{r_{AB}}{V - v}.$$

and

$$t'_A - t_B = \frac{r_{AB}}{V + v}$$

where r_{AB} denotes the length of the moving rod measured in the resting system. The observers moving with the moving rod would therefore find that the two clocks were not running synchronously, but the observers in the resting system would declare that the clocks were running in synchronism.

We see therefore that we are not able to ascribe to the concept of simultaneity any *absolute* meaning, but that two events which, viewed from one co-ordinate system, are simultaneous, viewed from another co-ordinate system in motion relative to the first can no longer be considered simultaneous events.

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[2] Time here means "time of the resting system" and at the same time "position of the hand of the moving clock which is at the same place that we are discussing."

PSYCHOLOGY

The Psychology Of Adolescence

THOSE whose interest in last week's classic causes them to desire to read more of G. Stanley Hall's discussion of adolescence will find that "Adolescence" is published by D. Appleton & Company, New York, and that this book has gone through many editions since its original publication in 1904.

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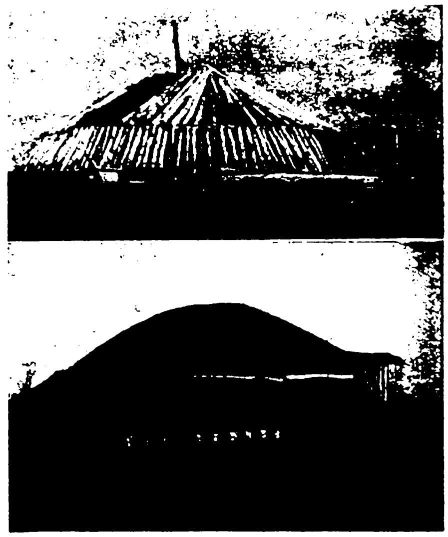
Science News Letter, February 14, 1931

There are a number of kinds of so-called cow trees which yield milk, a Field Museum technologist states.



THE MAKING OF A MONUMENT

A unique monument to the memory of three Indian tribes has been erected on the grounds of the State Capitol at Bismark, N. D. The monument is a faithful reproduction of the earth lodges in which the Arikara, Mandan, and Hidatsu tribes lived before the coming of white men. The suggestion that the Indian house would be an appropriate historic state monument was made by Dr. Melvin R. Gilmore, formerly in charge of the State Historical Society. The project was started by the society last September, under the direction of Russell Reid, acting superintendent. The earth lodge is circular.

MEDICINE

Men Brave Death to Help Solve Monkey Disease Mystery

THREE brave men have again offered their lives to help science fight disease. Fortunately they escaped death, modern methods of treatment having cured the disease which they voluntarily contracted for the sake of their fellow men.

They made their heroic contribution to the advancement of science at the Panama laboratory of the Gorgas Memorial Institute. The disease they acquired was relapsing fever, in itself no trifling ailment. But when the three men submitted to the experiment, they had no certain knowledge that the disease they were risking was one known to science and for which science had found fairly effective methods of treatment.

The problem which the three volunteers helped to solve was one of those scientific mysteries the account of which, even in the technical report of the Institute, reads like a good detective story.

The wild monkeys of Panama have been the subject of study at the laboratory for some time. In the blood of one of these animals, a juvenile squirrel monkey commonly known as a marmoset, a new disease germ was found. This germ belonged to the spirochete family. Members of this family cause various forms of relapsing fever, syphilis, and other diseases.

"This particular animal had spent three nights on its way into the laboratory in native villages that are endemic centers for relapsing fever, a spirochetal disease," the scientist detectives found. "We first concluded that