First three pages of "Zur elektrodynamic bewegter Korper" by Albert Einstein *Annalen der Physik* Vol 17, 1905, pages 891-921. Translation by Arthur I. Miller

ON THE ELECTRODYNAMICS OF MOVING BODIES

By A. Einstein

That Maxwell's electrodynamics – the way in which it is usually understood – when applied to moving bodies, leads to asymmetries which do not appear to be inherent in the phenomena is well known. Consider, for example, the reciprocal electrodynamic interaction of a magnet and a conductor. The observable phenomenon here depends only on the relative motion of the conductor and the magnet, whereas the customary conception draws a sharp distinction between the two cases in which either the one or the other of these bodies is in motion. For if the magnet is in motion and the conductor at rest, there arises in the neighborhood of the magnet an electric field with a certain definite energy, producing a current at the places where parts of the conductor are situated. But if the magnet is at rest and the conductor in motion, no electric field arises in the neighborhood of the magnet. In the conductor, however, we find an electromotive force, to which in itself there is no corresponding energy, but which gives rise – assuming equality of relative motion in the two cases discussed – to electric currents of the same path and intensity as those produced by the electric forces in the former case.

Examples of this sort, together with the unsuccessful attempts to discover any motion of the earth relatively to the "light medium," lead to the conjecture that to the concept of absolute rest there correspond no properties of the phenomena, neither in mechanics, nor in electrodynamics, but rather that as has already been shown to quantities of the first order, for every reference system in which the laws of mechanics are valid*, the laws of electrodynamics and optics are also valid.

We will raise this conjecture (whose intent will from now on be referred to as the "Principle of Relativity") to a postulate, and moreover introduce another postulate, which is only apparently irreconcilable with the former: light is always propagated in empty space with a definite velocity c which is independent of the state of motion of the emitting body. These two postulates suffice in order to obtain a simple and consistent theory of the electrodynamics of moving bodies taking as a basis Maxwell's theory for bodies at rest. The introduction of a "luminiferous ether" will prove to be superfluous because the view here to be developed will introduce neither an "absolutely resting space" provided with special properties, nor associate a velocity-vector with a point of empty space in which electromagnetic processes occur.

The theory to be developed is based – like all electrodynamics – on the kinematics of the rigid body, since the assertions of any such theory concern

---

[* The preceeding memoir by Lorentz was not at this time known to the author. (A.S.)]

the relationships between rigid bodies (coordinate systems), clocks, and electromagnetic processes. Insufficient consideration of this circumstance is the root of the difficulties with which the electrodynamics of moving bodies presently has to contend.

I. KINEMATICAL PART

§1. *Definition of Simultaneity*

Let us consider a coordinate system in which the equations of Newtonian mechanics hold.* For precision of demonstration and to distinguish this coordinate system verbally from others which will be introduced later, we call it the "resting system."

If a material point is at rest relatively to this coordinate system, its position can be defined relative to it by rigid measuring rods employing the methods of Euclidean geometry, and can be expressed in Cartesian coordinates.

If we wish to describe the *motion* of a material point, we give the values of its coordinates as functions of the time. Now we must bear carefully in mind that a mathematical description of this kind has no physical meaning unless we are quite clear as to what we will understand by "time". We have to take into account that all our judgments in which time plays a role are always judgments of *simultaneous events*. If, for instance, I say, "That train arrives here at 7 o'clock," I mean something like this: "The pointing of the small hand of my watch to 7 and the arrival of the train are simultaneous events."**

It might appear possible that all the difficulties concerning the definition of "time" can be overcome by substituting "the position of the small hand of my watch" for "time." In fact such a definition is satisfactory when we are concerned with defining a time exclusively for the place where the watch is located; but it is no longer satisfactory when we have to connect in time series of events occurring at different places, or – what comes to the same thing – to evaluate the times of events occurring at places remote from the watch. We could in principle content ourselves to time events by using an observer located at the origin of the coordinate system, and equipped with a clock, who coordinates the arrival of the light signal originating from the event to be timed and traveling to his position through empty space, to be timed with the hands of his clock. Yet as we know from experience, this coordination has the disadvantage that it is not independent of the standpoint of the observer with the clock. We arrive at a much more practical arrangement by means of the following considerations.

[* i.e., to the first approximation. (A.S.)]

** We shall not here discuss the inexactitude which lurks in the concept of simultaneity of two events at (approximately) the same place, which must be removed through introducing an abstract concept.

If at the point A of space there is a clock, an observer at A can time the events in the immediate vicinity of A by coordinating the positions of the hands which are simultaneous with these events. If there is at the space point B another clock – and we wish to add, "a clock being of exactly the same characteristics as the one at A" – then it is possible for an observer at B to time the events in the immediate neighborhood of B. But, without further definitions it is not possible to compare, in respect with time, an event at A with an event at B. Thus far we have defined only an "A time" and a "B time", but no common "time" for A and B. The latter time can now be defined by requiring that by definition the "time" necessary for light to travel from A to B be identical to the "time" necessary to travel from B to A. Let a ray of light start at the "A time" t_A from A toward B, let it at the "B time" t_B be reflected at B in the direction of A, and arrive again at A at the "A time" t'_A. The two clocks run in synchronization by definition if

$$t_B - t_A = t'_A - t_B. \qquad [\S 1.1]$$

We assume this definition of synchronization to be free of any possible contradictions, applicable to arbitrarily many points, and that the following relations are universally valid: –

1. If the clock at B synchronizes with the clock at A, the clock at A synchronizes with the clock at B.
2. If the clock at A synchronizes with the clock at B and also with the clock at C, the clocks at B and C also synchronize with each other.

Thus with the help of certain (imaginary) physical experiments we have defined what is to be understood by synchronous stationary clocks located at different places, and have clearly obtained a definition of "simultaneous," or "synchronous," and of "time." The "time" of an event is the reading simultaneous with the event of a clock at rest and located at the position of the event, this clock being synchronous, and indeed synchronous for all time determinations, with a specified clock at rest.

In addition, in agreement with experience we further require that the quantity

$$\frac{2AB}{t'_A - t_A} = c, \qquad [\S 1.2]$$

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

It is essential to have time defined by means of clocks at rest in a resting system, and the time now defined being appropriate to the resting system we call "the time of the resting system."

§2. *On the Relativity of Lengths and Times*

The following considerations are based on the principle of relativity and on the principle of the constancy of the velocity of light. We define these two principles thus –