

Chapter 1

HISTORY OF THE DEVELOPMENT OF RELATIVITY THEORY

The history of development of special relativity theory is both interesting and instructive. We restrict ourselves to a brief review of the three crucial contributions of Hendrik Anton Lorentz (1853-1928), Henry Poincaré (1854-1912) and Albert Einstein (1879-1955); the breakthrough was achieved by these scientists in 1904-1905.¹ Even though the formal content of the quoted papers is rather similar, their motivations and the viewpoints that underly them are considerably different.

The concept of an absolute ether at rest became suspect when Michelson and Morley could not succeed in determining the motion of the Earth relative to the ether at rest, despite the fact that the

¹ H.A. Lorentz, Proc.Acad.Sc. Amsterdam 6,809(1904);
H. Poincaré, Comp.Rend. 140, 1504 (1905) and Rendiconti Circolo
Mat. Palermo 21, 129 (1906);
A. Einstein, Ann. Physik 17, 891 (1905).

The papers of Lorentz and Einstein are reprinted in the volume entitled "H.A. Lorentz, A. Einstein, H. Minkowski, and H. Weyl: The Principle of Relativity - a Collection of Original Memoirs", trans. W. Perrett and G.B. Jeffery (Methuen & Co., London, 1923; paperback reprint, Dover Publications, 1958). An English translation (with commentary) of essential parts of the Rendiconti work of Poincaré may be found in the articles of H.M. Schwarz, Am. J. Phys. 39, 1287 (1971), 40, 862, and 1282 (1972).

sensitivity of their experiment sufficed to observe the effects predicted by the then current theory. In order to save the ether concept, G.F. Fitzgerald and, independently, Lorentz suggested the hypothesis that material bodies contract in the direction of their motion by a factor $\sqrt{1-v^2/c^2}$. (This is called the Lorentz-Fitzgerald contraction.) This assumption allowed for an interpretation of the null-result of the Michelson-Morley experiment.¹ But now Lorentz and also Poincaré had to face the problem: how could one explain the contraction in terms of a model of matter. We should note that contraction of distances occurs also in Einsteins framework. However, this does not require explanation via some model, since, according to the relativity principle, it arises already as a consequence of the observer's point of reference. In contrast, Lorentz provided an explanation for the contraction by an electromagnetic model of matter. This electron-theory of matter was expounded in the research contribution of 1904. This paper contains the Lorentz transformation, and presents also the transformation rules for the electromagnetic field strengths \vec{E} and \vec{B} . Lorentz introduced along with absolute time a so-called "local time", but he looked at this merely as a mathematical trick. He did not try to give local time some experimental meaning. The physical content of the transformation formulae was obscure. Lorentz insisted on an ether at rest even in 1910, and eventually gave up the notion of absolute simultaneity of events only with reluctance.

In his talk delivered at the International Congress of Arts and Sciences (St. Louis, 1904) H. Poincaré presented a clear formulation of the relativity principle. "According to the principle of relativity the laws of physical phenomena must be the same for a stationary observer as for an observer carried along in a uniform motion of translation; so that we have not and can not have any means of

¹ However, the Lorentz contraction hypothesis contradicts the principle of relativity. Lorentz and Fitzgerald believed in an absolute state of rest which pertains to all moving bodies. The shortening of moving meter sticks is here not a reciprocal effect as in the theory of relativity; and, in principle, it could serve to determine an absolute reference frame at rest. But this concept contradicts all experience.

discerning whether or not we are carried along in such a motion."¹ However, Poincaré's argumentation is different from Einsteins. He was familiar with Lorentz's work of 1904, and in his view the principle of relativity should be "explained", somehow as Lorentz attempted to give a dynamical explanation of the Lorentz contraction. On the other hand, Poincaré also pointed out the large number of arbitrary hypotheses in Lorentz theory. In addition he suggested that a "new mechanics" ought to be developed in place of Newtonian mechanics. However, he did not formulate the new mechanics; it was for him only a program. With his discovery that the Lorentz transformations form a group, Poincaré made a lasting contribution to the theory of relativity. In his work of 1905 he established the terms "Lorentz transformation" and "Lorentz group" and demonstrated the invariance against Lorentz transformations of the vacuum Maxwell equations. He succeeded in deriving the Maxwell equations from an invariant action principle. Poincaré also managed to find an interpretation of the Lorentz transformations in terms of rotations in a four-dimensional Euclidean space with coordinates x, y, z, ict .

But the crucial contribution came from Einstein² in his famous paper "Zur Elektrodynamik bewegter Körper" (Electrodynamics of moving bodies), *Ann. Physik* 17, 891-921 (1905). As we know today, one may assume that Einstein was not familiar with Lorentz's 1904 work nor with Poincaré's 1905 paper.³ Einstein finds that it is not necessary to assume the existence of an ether at rest. His starting point is

¹ English translation in H. Poincaré, *The Value of Science* (Dover Publications, New York 1958).

² An important contribution to the scientific, philosophical, and historical analyses of what Einstein did or did not accomplish or assert in 1905 has been given by A. I. Miller, *Albert Einstein's Special Theory of Relativity, Emergence (1905) and Early Interpretation (1905-1911)* (Addison-Wesley, Reading 1981). For a scientific biography of Albert Einstein we refer the reader to the excellent book by A. Pais, "Subtle is the Lord..." *The Science and the Life of Albert Einstein* (Oxford University Press, Oxford 1982).

³ G. Holton, *Am. J. Phys.* 28, 627 (1960).

that all experiments aimed at observing a motion relative to the ether failed.¹ This then justifies one to demand that the equivalence of reference frames in uniform motion (a valid statement in Newtonian mechanics) should have general validity. (This statement is the "Einstein principle of relativity".) We must emphasize that in Einstein's work the principle of relativity has a fundamental axiomatic role in the theory. Consequences derived from it should be confronted with experiments.

The second assumption of Einstein is that the light velocity in vacuum has the same value in all frames of reference that are in uniform relative motion. The light velocity is a universal constant, i.e. it is independent of the velocity of the light source which is in uniform motion relative to an observer. The assumption of reference frames in uniform relative motion is important, because if one allows for accelerated systems, the light velocity loses its absolute character. Einstein does not provide a detailed justification of his two postulates, and restricts himself to ascertain that these assumptions are universally verified by facts. These two statements are only in apparent contradiction to each other because of the traditional and unfounded assumption that simultaneity of two events has an absolute meaning. In Newtonian physics one could (in a Gedankenexperiment) overtake a ray of light. Because of the simple additivity of velocities, the light velocity would be essentially different for observers in frames of reference that are in relative motion. This can be avoided if one gives up the notion of absolute time. In this manner also the apparent contradiction between the two postulates disappears; and thus, these postulates permit the construction of a non-contradictory theory of the electrodynamics of moving bodies.

Einstein analyses the definition of simultaneity in terms of measurement procedures. If one gauges the clocks applied for the measurement of time with the use of light signals, one finds that events which are simultaneous in a reference frame K , are no longer simulta-

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The Michelson-Morley experiment is not mentioned by Einstein.

neous in a system K' which is in uniform motion relative to K . One must give up the relation $t'=t$, which would hold in Newtonian physics. The postulates noted above are used to derive from them the Lorentz transformation; and the lengthwise contraction of measuring rods, as well as the time dilatation of clocks, is discussed. In Einstein's theory, notably, length contraction is not connected to some particular model of forces holding matter together; rather, it arises directly from the definition of length. Likewise, time dilatation arises from the definition of time. Einstein, then derives the new velocity addition law; this does not permit the overtaking of a light ray. The transformation laws for the electromagnetic field are demonstrated; the Doppler effect and the aberration of light is explained; the dynamics of an electron is described; the motion of an electron in a constant electric and magnetic field is analysed. But the famous equation $E_0 = mc^2$ is not yet explicitly stated; it appears first in later researches, cf. the paper entitled "Ist die Trägheit eines Körpers von seinem Energieinhalt abhängig?" (Does the inertia of a body depend on its energy content?), Ann. Physik 18, 639-641 (1905).

In summary, one may say that the theory of special relativity was initiated by H.A. Lorentz, its physical foundations and its physical content was shown by A. Einstein, and its mathematical structure was made clearest by H. Poincaré.

Looking at it from a contemporary viewpoint, one would think that the new ideas of Einstein must have had the general effect of a revelation, as the slashing of the Gordian Knot. In actual facts, their effect on thinking came only in isolated steps and with delay. To start with, Einstein's ideas surely did not lead to a significant number of other publications in the topical area. This happened only about four years later. Max Planck (1858-1947) was apparently the first to recognize immediately the importance of Einstein's researches. Already in 1906, Planck presented the Lagrangian of relativistic mechanics in the form as used today.

Poincaré himself later came to doubt the principle of relativity. Influenced by the earlier experimental findings of W. Kaufmann

on the specific charge of fast-moving electrons, Poincaré wrote this in 1906: "The principle of relativity may well not have the rigorous value which has been attributed to it".¹ Up to his death in 1912 he often discussed the principle of relativity in his writings, without, however, acknowledging the contributions of Einstein. On the other hand, H.A. Lorentz gradually came to accept relativity theory.

The next significant contribution to the theory of relativity came from Hermann Minkowski (1864-1909) who gave it a covariant formulation. He used a four-dimensional space-time continuum and showed that Einstein's theory may be expressed especially simply in the language of the pseudo-Euclidean geometry (Minkowski space). At the Meeting of the German Scientists and Medical Doctors (Cologne, 1908) Minkowski gave a popular talk on "Space and Time" which was very well received and which led to wider acceptance of relativity theory.² In his memories Max Born (1882-1970) says the following regarding his teacher in those days H. Minkowski: "He told me later that it came to him as a great shock when Einstein published his paper in which the equivalence of the different local times of observers moving relative to each other was pronounced; for he had reached the same conclusions independently but did not publish them because he wished first to work out the mathematical structure in all its splendour. He never made a priority claim and always gave Einstein his full share in the great discovery."³

The great experimentalist, Albert Michelson (1852-1931) could not come to terms with the theory of relativity. According to Einstein's recollection, at their only personal meeting in 1931, Michelson expressed toward him a certain regret that his own work started this "monster".⁴

¹ Quotation from S. Goldberg, *Am.J.Phys.* 35, 934 (1967).

² H. Minkowski, *Phys.Z.* 10, 104 (1909); also reprinted in the collection "The Principle of Relativity" (trans. W. Perrett and G.B. Jeffery), l.c.

³ M. Born, *My Life* (Scribner, New York 1978), p. 131.

⁴ G. Holton, *Am.J.Phys.* 37, 968 (1969).

Now we come to the question whether the Michelson-Morley experiment was indeed the foundation and take-off point of Einstein's theory of relativity, as it is claimed in many textbooks. Certainly, in Einstein's 1905 work neither is the experiment mentioned nor is there a reference to other sources of literature. In a letter from 1954, Einstein, who definitely appreciated the importance of the Michelson experiment, makes the following statement: "In my own development Michelson's result has not had a considerable influence. I even do not remember if I knew of it at all when I wrote my first paper on the subject (1905). The explanation is that I was, for general reasons, firmly convinced that there does not exist absolute motion and my problem was only how this could be reconciled with our knowledge of electro-dynamics. One can therefore understand why in my personal struggle Michelson's experiment played no role or at least no decisive role."¹

But Einstein's contemporaries were much amazed by the outcome of the Michelson experiment. It was a blow to the ether-hypothesis. However, nowadays it is an unnecessary roundabout to follow the historical path with all mistakes, in course of which one first introduces the unrealistic concept of an ether, only to eliminate it in the end. Besides, to do so, it would be necessary to take into account other experiments as well. For this reason, too, and not only from a historical point of view, one cannot take the Michelson experiment alone as the crucial experiment. One cannot deduce the theory of relativity from the Michelson experiment.

In his lecture delivered in honour of Max Planck's sixtieth birthday (1918)² Einstein makes a more general comment regarding this

¹ The full text of the letter to Davenport may be found in the quoted paper of G. Holton (1969). For more details see also the Chapter "Einstein, Michelson, and the 'Crucial' Experiment" in the historical studies by G. Holton, *Thematic Origins of Scientific Thought; Kepler to Einstein* (Harvard University Press, Cambridge, Mass. 1973).

² This lecture is reprinted with the title "Principles of Research" in A. Einstein, *Essays in Science* (Philosophical Library, New York, 1934).

problem. He says: "The supreme task of the physicist is, then, to search for those most general elementary laws from which one can gain the world-picture ("Weltbild") by pure deduction. No logical path leads to these elementary laws; but only intuition, supported by insight into experience, can lead to them."

Accordingly, we shall employ only Einstein's principle of relativity to derive therefrom the theory of special relativity.

