Poincaré and the Special Theory of Relativity

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The special theory of relativity is one of the cornerstones of physics. When we learn this theory in our college years we focus on the subject in its finished form, rather than on the history of its evolution. It is often not appreciated that it took many great minds to finally attain the point of view that is now called 'the special theory of relativity'. In this article we focus on the contribution of the French mathematician Henri Poincaré in the development of this theory. While it is true that Einstein's unique and radical point of view established the universal validity of the principle of relativity, many great physicists and mathematicians, Poincaré in particular, came very close to anticipating this.

In the mid to late 1800s, several experiments were conducted to detect the motion of the Earth through the ether. (In fact there were ingenious schemes proposed for converting this motion into useful work!) In 1887 the American scientists A A Michelson and E W Morley tried to detect this motion with an interferometer. They were, however, unable to detect any relative motion between the Earth and the ether. In order to explain the null result of this experiment, the Dutch physicist H A Lorentz and independently the Irish physicist G F Fitzgerald proposed that the arm of the interferometer in the direction of the motion contracts and exactly compensates the effect of the Earth's motion. Lorentz and others came up with separate hypotheses to account for the null result in each such experiment.

In 1895, Poincaré expressed his dissatisfaction with such ad hoc hypotheses and emphasized the need for a more general point of view. He stated : "Experiment has revealed a multitude of facts which can be summed up in the following statement: it is impossible to detect the absolute motion of matter, or rather the relative motion of ponderable matter with respect to the ether; all that one can exhibit is the motion of ponderable matter with respect to ponderable matter." In 1904 his ideas crystallized further and he stated his "Principle of Relative Motion" as one of the six general principles of physics: "The principle of relativity, according to which the laws of physical phenomena should be the same, whether for an observer fixed, or for an observer carried along in a uniform movement of translation; so that we have not and could not have any means of discerning whether or not we are carried along in such a motion". Poincaré again stated his unease with the ad hoc hypotheses proposed by Lorentz to explain the null result of the experiments probing the motion of the earth relative to the ether. He was, however, very appreciative of one of these hypotheses: the notion of a local time. Lorentz had introduced this notion in order to simplify the theoretical study of electromagnetic processes in a frame moving with a velocity v relative to the ether. The difference between the 'local time' and the 'true time' was vx'/c^2 for each point on the x' axis of the moving system, with c the speed of light in vacuum. Poincaré recognized the importance of this notion in the context of the principle of relativity. He showed that the concept of a local time introduced by Lorentz could be given a simple physical interpretation in the following manner. He considered an operation by which observers at various points along the axis x' of the moving system synchronize their respective clocks by exchanging light signals with an observer at the origin. Assuming that the velocity of light is independent of the motion of its source, the difference between the local and the true times would give a measure of the extent to which each clock has been thrown out of 'true synchrony'. He went on to stress that although the time in a moving frame would differ from the true time in a fixed system, such a difference would not be inconsistent with the principle of relativity. The observer in the moving frame would not be able to detect the absolute motion of the frame since he would be unaware of the fact that the clocks in his frame were out of synchrony with those in the fixed frame. Thus we see that a crucial ingredient in Einstein's theory of relativity, namely the notion of relativity of simultaneity, was already anticipated by Poincaré. It is remarkable that

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Poincaré, the mathematician, realized the importance of attaching an operational and physical meaning to the concept of a local time whereas Lorentz, the physicist, considered local time to be a mere mathematical trick to simplify the electrodynamic equations!

Poincaré was the first one to take the bold step of advocating the importance of formulating a general principle embracing all physical laws. He repeatedly questioned the value of ad hoc hypotheses. In this respect his philosophy was close to that of Einstein's. However, a closer analysis shows that he could not formulate a proper theory of relativity because of some views which, in retrospect, appear conservative. While he adhered to the principle of relativity, he believed that this principle might be deducible from a suitably revised version of electrodynamics. Consequently, he was not ready to take the important step of eliminating the ether. This concept was in conflict with the spirit of the principle of relativity which is supposed to treat all frames on an equal footing. Poincaré was also troubled by the fact that gravitational phenomena seemed to be inconsistent with the principle of relativity. In this respect Poincaré was, in fact, handicapped by having too large a canvas. He would perhaps have been able to go further with special relativity if he had restricted his attention to electrodynamic phenomena. The time was not right for including gravity. It would be many years and many efforts later that gravity was finally encompassed in the framework of relativity.

Poincaré's principle of relativity can be viewed as a transitional stage between traditional electrodynamics and the fully relativistic theory formulated by Einstein. Einstein's radical and unique perspective helped in building an inherently relativistic theory. Unlike Poincaré, Einstein did not try to account for this principle in terms of other physical phenomena like electrodynamics. He transformed Lorentz's notion of 'local time' (retaining the physical interpretation given by Poincaré) into a standard definition of time valid for all of physics without any reference to any preferred frame. Einstein's main contribution

Suggested Reading

[1] Charles Scribner, *American Journal of Physics*, 32, 672, 1964.

[2] Sir Edmund Whittaker, *A History of the Theories of Aether and Electricity: The Modern Theories* 1900–1926 (Philosophical Library, New York, 1954), p 40.

[3] Sir Edmund Whittaker, *From Euclid To Eddington* (Cambridge At The University Press, 1949).

[4] Jeremy J Gray, *Mathematical Intelligencer*, Vol.17, No.1, p.65, 1995.

Box 1. The Postulates of Special Relativity.

1. The laws of physics are the same in all inertial frames. No preferred inertial frame exists. (The Principle of Relativity.)
2. The speed of light in free space has the same value c in all inertial frames. (The Principle of the Constancy of the Speed of Light.)

Box 2. Lorentz Transformation.

It is interesting to note that, unknown to Einstein, Lorentz had come up with the transformation equations (connecting two inertial reference frames) *almost* in identical form a year before Einstein's paper appeared. In 1895, motivated by Poincaré's belief in the need for a principle of relativity valid for all physical laws and his rejection of ad hoc assumptions for explaining the results of experiments probing motion relative to the ether, Lorentz demonstrated the invariance of Maxwell's equations in two inertial frames, using a set of transformation equations, which were correct to order v/c. Later on he tried to write down the *exact* transformation equations. However, he was unable to shed the burden of the ether and he continued to refer to motion relative to the ether. Furthermore, he continued to make a difference between the effect of contraction of moving bodies along the direction of relative motion and the idea of relativity of simultaneity which follows from the notion of a local time. He attached physical meaning to the first effect while dismissing the second one as a mere mathematical artifice. While he was able to write down the transformation equations for the spatial coordinates, he failed to write down the right transformation equations for the time coordinate. Thus he was unable to establish perfect symmetry between two inertial frames moving relative to each other.

to the principle of relativity was to recognize that there is no essential difference between a 'stationary' and a 'moving' frame of reference. In other words he was the first one to give up the idea of singling out a reference frame at rest relative to the ether. This helped him in constructing a simple logical structure based on the two postulates (see *Box* 1). Consequently, he was the first one to arrive at the exact transformation equations relating two inertial frames of reference (See *Box* 2).

The British writer Edmund Whittaker takes the point of view that Einstein's role in formulating the special theory of relativity was limited to elaborating on the theoretical insights of others like Poincaré and Lorentz. He believed that Einstein had little to contribute in terms of original ideas in this field. This is clearly an extreme point of view and it is in sharp contrast to the viewpoint that we are exposed to in our college years that the special theory of relativity is the product of Einstein's fresh and unique perspective on space and time. The truth perhaps lies somewhere between these two extreme points of view. Although Poincaré was the first one to put forward a general principle embracing all physical laws one cannot ignore the fact that it was Einstein who finally constructed a fully relativistic theory by giving up the 'ether'.

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