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Einstein's Investigations of Galilean Covariant Electrodynamics Prior to 1905

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Abstract

Einstein learned from the magnet and conductor thought experiment how to use field transformation laws to extend the covariance of Maxwell's electrodynamics. If he persisted in his use of this device, he would have found that the theory cleaves into two Galilean covariant parts, each with different field transformation laws. The tension between the two parts reflects a failure not mentioned by Einstein: that the relativity of motion manifested by observables in the magnet and conductor thought experiment does not extend to all observables in electrodynamics. An examination of Ritz's work shows that Einstein's early view could not have coincided with Ritz's on an emission theory of light, but only with that of a conveniently reconstructed Ritz. One Ritz-like emission theory, attributed by Pauli to Ritz, proves to be a natural extension of the Galilean covariant part of Maxwell's theory that happens also to accommodate the magnet and conductor thought experiment. Einstein's famous chasing a light beam thought experiment fails as an objection to an ether-based, electrodynamical theory of light. However it would allow Einstein to formulate his general objections to all emission theories of light in a very sharp form. Einstein found two well known experimental results of 18th and19th century optics compelling (Fizeau's experiment, stellar aberration), while the accomplished Michelson-Morley experiment played no memorable role. I suggest they owe their importance to their providing a direct experimental grounding for Lorentz' local time, the precursor of Einstein's relativity of simultaneity, and doing it essentially independently of electrodynamical theory. I attribute Einstein's success to his determination to implement a principle of relativity in electrodynamics, but I urge that we not invest this stubbornness with any mystical prescience.

1. Introduction

Although we have virtually no primary sources, the historical scholarship of the last few decades has painstakingly assembled clues from many places to give us a pretty good sketch of Einstein's route to special relativity. He had a youthful interest in electrodynamics and light with no apparent skepticism about the ether. As a sixteen

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year old in the summer of 1895, he wrote an essay proposing experimental investigation into the state of the ether associated with an electromagnetic field.[2] The skepticism emerged later along with a growth of his knowledge of electrodynamics. By the end of 1901, he was writing confidently of work on a "capital paper" on the electrodynamics of moving bodies that expressed ideas on relative motion.[3] Later recollections stress the guiding influence of his recognition that the electric field induced by a moving magnet has only a relative existence. His pursuit of the relativity of inertial motion led him to reject Maxwell's theory and its attendant constancy of the velocity of light with respect to the ether in favor of investigation of an emission theory, somehow akin to Ritz' later approach, in which the speed of light was a constant with respect to the emitter. These investigations proved unsatisfactory and Einstein was brought to a crisis in the apparent irreconcilability of the relativity of inertial motion and the constancy of the velocity of light demanded by Maxwell's electrodynamics. The solution suddenly came to Einstein with the recognition of the relativity of simultaneity and a mere five to six weeks was all that was needed to complete writing the paper, which was received by *Annalen der Physik* on June 30, 1905.

My understanding of this episode is framed essentially by the historical researches of John Stachel, individually and in collaboration with the editors of Volume 2 of the *Collected Papers of Albert Einstein*; and by Robert Rynasiewicz and his collaborators. See Stachel (1987, 1989), Stachel *et al.* (1989a), Rynasiewicz (2000) and Earman *et al.* (1983) and the citations therein for their debts to other scholarship. In addition to the arduous scholarship of discovering and developing our present framework, they have supplied particular insights of importance. For example, Rynasiewicz and his collaborators have pointed out that Einstein must have known of field transformations akin to the Lorentz transformation for fields years before he adopted the novel kinematics of the Lorentz transformation for space and time, so that the historical narrative must somehow account for a development from field transformation to the space and time transformations they necessitate. In addition to his work as editor of the Einstein papers in finding source material, Stachel assembled the many small clues that reveal Einstein's serious consideration of an emission theory of light; and he gave us the crucial insight that Einstein regarded the Michelson-Morley experiment as evidence for the principle of relativity, whereas later writers almost universally use it as support for the light postulate of special relativity.[4]

My goal in this paper is not to present a seamless account of Einstein's path to special relativity. That is an ambitious project, hampered by lack of sources and requiring a synthesis with Einstein's other research interests at the time.[5] Rather I seek to extend our understanding of several aspects of Einstein's path to special relativity:

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[2] *Papers*, Vol. 1, Doc. 5.

[3] *Papers*, Vol. 1, Doc. 128.

[4] Even today, this point needs emphasis. The Michelson-Morley experiment is fully compatible with an emission theory of light that contradicts the light postulate.

[5] How could we ignore the possibility of a connection between Einstein's reflections on an emission theory of light and his 1905 postulation of the light quantum hypothesis? But what might that connection be? See Rynasiewicz, (2000), Sections 6 and 7.