Einstein and ether drift experiments

Recently discovered letters, written at the turn of the century to his fiancée, shed new light on the origin of the special theory of relativity.

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Volume 1 of *The Collected Papers of Albert Einstein*,[1] to be published on 22 May, contains a number of previously unpublished lecture notes, examination papers and letters by Einstein. Among the most notable new items are 42 letters written between 1898 and 1902 to his fiancée Mileva Marić, whom he met while they were fellow students of physics at the Swiss Polytechnical School in Zurich, which both entered in 1896.

These letters confirm Einstein's later recollection that he had begun to work on the electrodynamics of moving bodies many years before submitting his epochal 1905 paper on special relativity to *Annalen der Physik*.[2] They also record Einstein's continued interest, in the years between 1899 and 1901, in designing an optical experiment to test the putative motion of the Earth through the ether—which should have been detectable according to the then prevalent interpretation of Maxwell's theory.

While there is no mention of Albert A. Michelson in any of the letters in volume 1, which covers the period from Einstein's birth until he got an appointment as patent clerk at the Swiss Patent Office, there is strong indirect evidence[3] that he must have known of the Michelson–Morley experiment by 1899. Here I will review briefly the new evidence of Einstein's early theoretical and experimental work on the electrodynamics of moving bodies.

Einstein's first comments on the subject, which appear in a remarkable letter that has been dated to August 1899, were inspired by a rereading of Heinrich Hertz's basic papers on Maxwell's electrodynamics.

> I am more and more convinced that the electrodynamics of moving bodies, as currently presented, is not correct, and that it should be possible to present it in a simpler way. The introduction of the term "ether" into theories of electricity leads to the notion of a medium of whose motion one can speak without, I believe, being able to associate any physical meaning with such a statement.

Einstein is clearly skeptical about the concept of a movable ether, a concept that was basic to Hertz's theory of the electrodynamics of moving bodies. Whether this skepticism already extended to the concept of the ether itself, as was certainly the case by 1905, is more doubtful. On the whole, Einstein's views in this letter seem similar in many ways to those of Hendrik A. Lorentz, who postulated a universal but immobile ether. But there is no mention of Lorentz in any surviving letter of Einstein's until December 1901, when he states that he intends to study what Lorentz and Paul Drude have written on the subject. So it is entirely possible that Einstein arrived at his views in 1899 independently of Lorentz.

Einstein refers in this letter to the need for "radiation experiments" to decide between various views of electrodynamics. In September of 1899, he writes:

> A good way of investigating how a body's relative motion with respect to the luminiferous ether affects the velocity of propagation of light in transparent bodies occurred to me in Aarau [a Swiss town Einstein had recently visited]. I have also thought of a theory on this subject that seems to me to be very plausible. But enough of this!

Einstein goes on to commiserate with Marić, who was preparing to take the intermediate examinations at the Polytechnical School, a set of examinations that Einstein had already passed. There is no further evidence in the letters about the nature of Einstein's experiment or of his theoretical ideas.

A couple of weeks later, he informs Marić that

> I also wrote to Professor [Wilhelm] Wien in Aachen about the work on the relative motion of the luminiferous ether with respect to ponderable matter, which "the boss" [Heinrich Friedrich Weber, Einstein's physics professor at the Polytechnical School] treated in such a stepmotherly fashion.

This remark partially confirms the narrative that Rudolf Kayser, Einstein's son-in-law, gives in his 1930 biography of Einstein[4] (written with Einstein's cooperation and approval):

> He encountered at once, in his second year of college [1897–98], the problem of light, ether and the Earth's movement. This problem never left him. He wanted to construct an apparatus which would accurately measure the Earth's movement against the ether. That his intention was that of other important theorists, Einstein did not yet know. He was at

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that time unacquainted with the positive contributions, of some years back, of the great Dutch physicist Hendrik Lorentz, and with the subsequently famous attempt of Michelson. [Michelson first performed his experiment in 1881, and repeated it in 1887, partly in response to a criticism by Lorentz, before Lorentz's first major work on the electrodynamics of moving bodies in 1892.] He wanted to proceed quite empirically, to suit his scientific feeling of the time, and believed that an apparatus such as he sought would lead him to the solution of a problem, whose far-reaching perspectives he already sensed.

But there was no chance to build this apparatus. The skepticism of his teachers was too great, the spirit of enterprise too small.

Kayser's account still does not offer any clues to what Einstein's experimental design could have been. The only evidence known to me on this question is the record of Einstein's 1922 lecture at Kyoto University, "How I created the theory of relativity," kept by the physicist Jun Ishiwara.[5] He was the first Japanese to publish on the theory of relativity, had visited Einstein on a trip to the West, was instrumental in getting Einstein to come to Japan and acted as translator of his lectures. Ishiwara's record, in Japanese, of Einstein's lecture includes Einstein's description of an experiment that occurred to him while he was a student:

> So I wanted to demonstrate by some means this motion of the Earth relative to the ether. . . . At the time when I posed this problem to myself I never doubted the existence of the ether and the motion of the Earth. Thus, I predicted that if light from a source is reflected by a mirror, it should have different energies depending on whether it is propagated parallel or antiparallel to the direction of motion of the Earth; and I proposed verifying this with two thermocouples, by measuring the difference in the heat produced in each.

This may well be a description of the idea that Einstein had in Aarau, although his reference to "the velocity of propagation of light in transparent bodies" suggests that he may have had in mind some variant of Armand Fizeau's well-known experiment on this subject. Indeed, it is curious to note that in 1854 Fizeau had proposed an experiment on the difference in energy between light rays moving in opposite directions, which was actually performed in 1902 by Nordmeyer.[6]

In the "Aarau" letter of September 1899, Einstein explains why he turned to Wien for support of his ideas: "I read a very interesting paper from the year 1898 by this man [Wien] on the same topic." The paper[7] was the text of Wien's report to the Society of German Scientists and Physicians, "On questions relating to the translatory motion of the luminiferous ether." Here Wien discusses both Hertz's concept of a moving ether and Lorentz's concept of an immobile ether, and he briefly considers 13 experiments bearing on the question. The last one he mentions is the Michelson–Morley experiment. It is reasonable to conjecture that Einstein read this account in 1899, and that it thus represents the minimum information he had about that experiment by then. Here is Wien's account:

> *The Michelson–Morley experiment.* If the ether is at rest, then the time a light ray needs to travel back and forth between two glass plates must change if the plates are moving. The change depends on the quantity v^2A^2 [v is the velocity of the plates; A is the reciprocal of the speed of light], but should be observable by the application of interferometry.
>
> The negative result is incompatible with the assumption of an ether at rest. This assumption can only be maintained by means of the hypothesis that the linear dimensions of rigid bodies are altered by motion through the resting ether in the same ratio, so as to compensate for the lengthening of the path of the light ray.

Wien does not make it clear that interference between two perpendicular rays is the basis of the Michelson–Morley experiment. It is possible that Einstein did not see a more detailed account of the experiment until he read Lorentz's 1895 monograph[8] or Drude's book on optics, which contains a summary[9] of Lorentz's theory; both books include detailed discussions of the Michelson–Morley experiment. Just when Einstein read Lorentz and Drude is not clear, although as noted above, in a letter from December 1901 he states his intention to study their work.

Einstein's next comment on relative motion occurs in a letter to Marić written in March 1901: "How happy and proud I will be when the two of us together will have brought our work on relative motion to a successful conclusion." This comment raises the intriguing question of the nature of Marić's role in their collaboration. Her letters to Einstein (only ten from the period of the first volume have been found) contain no substantial references at all to physics. His letters to her contain references to joint study of books, requests for her to look up data, and one or two other mentions of joint work; but these letters give no indication of any ideas she contributed to their work.

Writing to his friend and former fellow-student Marcel Grossman in September 1901, Einstein returns to the subject of ether drift experiments:

> On the investigation of the relative motion of matter with respect to the luminiferous ether, a considerably simpler method has occurred to me, which is based on customary interference experiments. If only relentless fate would give me the necessary time and peace! When we see each other, I will tell you about it.

The reference to "customary" [*gewöhnlich*] interference experiments in this letter is intriguing but puzzling. Any suggestion that Einstein had in mind nothing more than a repeat of the Michelson–Morley experiment seems to be ruled out by Einstein's report, in a subsequent letter, that Alfred Kleiner of the University of Zurich was enthusiastic about his experimental proposal. Kleiner was a well-informed experimenter, who later wrote a number of surveys of the then current state of physics. It is hard to believe that he would not have known enough about the Michelson–Morley experiment to recognize a description of it.

Einstein was also developing his theoretical ideas on electrodynamics during this period. During the same month, he wrote Marić:

I am now working very eagerly on

Einstein's 1899 letter on the ether

The following is part of a letter Albert Einstein wrote to Mileva Marić, in August 1899. It is reprinted from The Collected Papers of Albert Einstein *with the permission of Princeton University Press (© 1987 by the Hebrew University of Jerusalem).*

Ich hab den Band Helmholtz zurückgetragen & studiere gegenwärtig noch einmal aufs Genaueste Hertz' Ausbreitung der elektrischen Kraft. Der Anlaß dazu war, daß Helmholtz' Abhandlung über das Prinzip der kleinsten Wirkung in der Elektrodynamik nicht verstand. Es wird mir immer mehr zur Überzeugung, daß die Elektrodynamik bewegter Körper, wie sie sich gegenwärtig darstellt, nicht der Wirklichkeit entspricht, sondern sich einfacher wird darstellen lassen. Die Einführung des Namens, "Äther" in die elektrischen Theorien hat zur Vorstellung eines Mediums geführt, von dessen Bewegung man sprechen könne, ohne daß man wie ich glaube, mit dieser Aussage einen physikalischen Sinn verbinden kann. Ich glaube, daß elektrische Kräfte nur für den leeren Raum direkt definierbar seien, von Herz auch betont. Ferner werden elektrische Ströme nicht als "Verschwinden elektrischer Polarisation in der Zeit" sondern als Bewegung wahrer elektrischer Massen aufzufassen sein, deren physikalische Realität die elektrochemischen Äquivalente zu beweisen scheinen. Mathematisch sind sie dann immer in der Form $\partial X/\partial x + \cdot + \cdot$ aufzufassen. Die Elektrodynamik wäre dann die Lehre von den Bewegungen bewegter Elektrizitäten & Magnetismen sein [*sic*] im leeren Raum: Welche von beiden Anschauungen gewählt werden muß, werden ja die Strahlungsversuche ergeben müssen. —Bis jetzt hab ich übrigens von Rektor Wüst keine Nachricht. Ich werde ihm nächstens schreiben.

Hier im Paradies ist es fortgesetzt sehr schön, zumal wir wunderbares Wetter haben. Doch haben wir immer unangenehme Besuche von Mamas Bekannten, deren stumpfsinnigem Geschwätze ich durch die Flucht zu entrinnen pflege wenn nicht grade gegessen wird.

an electrodynamics of moving bodies, which promises to become a capital paper. I wrote you that I doubted the correctness of the ideas about relative motion [that letter has not been found]. But my doubts were based solely on a simple mathematical error. Now I believe in it more than ever!

This passage suggests that Einstein had already adopted some version of the relativity principle—which is not to say that he had yet disentangled his ideas on relative motion from their electrodynamical background, let alone given them the kinematical foundation that proved essential to the formulation of the special theory of relativity. But the passage does suggest that he may have fully expected the outcome of his experiment to be negative.

In December, as mentioned above, Einstein wrote that he had

> spent the whole afternoon with Kleiner in Zurich and explained my ideas on the electrodynamics of moving bodies to him.... He advised me to publish my ideas about the electromagnetic theory of light for moving bodies together with the experimental method. He found the experimental method proposed by me to be the simplest and most appropriate one conceivable.... I shall most certainly write the paper in the coming weeks.

A few days later in December, he wrote Marić:

> I now want to buckle down to work and study what Lorentz and Drude have written on the electrodynamics of moving bodies. [Jakob] Ehrat [a friend and former fellow Polytechnical School student, who was now an Assistant there] must get the literature for me.

Whatever reading and writing he may have done at this time, Einstein published nothing on the subject for $3\frac{1}{2}$ years. Surviving correspondence sheds very little light on what happened. Perhaps a reading of Lorentz's work temporarily shook his faith in the relativity principle; perhaps he saw that the problems involved in upholding it were greater than he had anticipated. I have speculated elsewhere[10] on the question of what happened between 1902 and 1905, but there are unfortunately no relevant new letters from this period.

In summary, the newly discovered correspondence with Marić proves that Einstein was concerned with the theoretical and experimental aspects of the electrodynamics of moving bodies from at least 1899 on. He was very much interested in ether drift experiments, and appears to have designed at least two, which he hoped to carry out himself. While he was almost certainly aware in a general way of the existence of the Michelson–Morley experiment from late 1899 on, it is not mentioned at all in his surviving letters from that period. The new evidence thus serves to confirm, at least for the period 1899–1902, Gerald Holton's conclusion that the experiment did not play a significant role in Einstein's work.[3] But ideas about ether drift experiments did form an important strand in his thinking about the complex of problems that ultimately led him to develop the special theory of relativity.

References

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2. A. Einstein, Ann. Phys. (Leipzig) **17**, 891 (1905).
3. For studies of the relationship of the Michelson–Morley experiment to Einstein's work, see the fundamental article by G. Holton, reprinted in G. Holton, *Thematic Origins of Scientific Thought*, Harvard U. P., Cambridge, Mass. (1973), p. 261. See also J. Stachel, Astron. Nachr. **303**, 47 (1982).
4. R. Kayser [under the pseudonym A. Reiser], *Albert Einstein: A Biographical Portrait*, Boni, New York (1930), p. 52.
5. J. Ishiwara, *Einstein Kyôzyu-Kôen-roku* [The Record of Professor Einstein's Lectures], Kabushika Kaisha, Tokyo (1971), p. 79. Widely differing English translations of the relevant passages on the origins of special relativity have appeared. [See, for example, PHYSICS TODAY, August 1982, p. 45, and the letter by Arthur Miller on page 9 of this issue.] Fortunately, they all agree more or less closely on the passage cited. (I have also consulted a German translation prepared by H. J. Haubold and E. Yasui, whom I thank for making it available to me.) For the translation used here, see J. Stachel, Astron. Nachr. **303**, 47 (1982).
6. See J. Stachel, Astron. Nachr. **303**, 47 (1982) for references and details.
7. W. Wien, Ann. Phys. (Leipzig) **65**(3), Beilage (1898), p. i.
8. H. A. Lorentz, *Versuch einer Theorie der elektrischen und optischen Erscheinungen in bewegten Körpern*, Brill, Leiden (1895). Einstein later recalled that this was the only work by Lorentz he read before writing his paper on special relativity.
9. P. Drude, *Lehrbuch der Optik*, Hirzel, Leipzig (1900). Chapter VIII of section 2 of the part on physical optics is entitled "Bewegte Körper."
10. See J. Stachel, Astron. Nachr. **303**, 47 (1982); and my article to appear in *Atti del Convegno Internazionale: L'Opera di Einstein.* □