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Author(s): Olivier Darrigol
Reviewed work(s):
Source: *Isis*, Vol. 95, No. 4 (December 2004), pp. 614-626
Published by: The University of Chicago Press on behalf of The History of Science Society
Stable URL: http://www.jstor.org/stable/10.1086/430652
Accessed: 13/03/2013 12:08

The Mystery of the Einstein–Poincaré Connection

By Olivier Darrigol*

ABSTRACT

This essay discusses attempts that have been made to explain the striking similarities between two theories propounded in 1905 by Albert Einstein and Henri Poincaré without any mutual reference.

DESPITE THE SCARCITY OF RELEVANT DOCUMENTS, the last twenty years have brought significant progress in our understanding of Albert Einstein's and Henri Poincaré's contributions to relativity theory. A number of circumstances have made this possible: the authoritative edition of Einstein's collected papers for the years 1879–1909, the discovery of the correspondence between Einstein and Mileva Marić, better knowledge of the earlier history of electrodynamics, closer analysis of Poincaré's criticism of electrodynamics at the turn of the century, and attention to his and Einstein's involvement in technologies of time measurement. One benefit of this progress is that we now have a more precise idea of the similarities and differences between the two thinkers' contributions to relativity theory. Yet the historical connection between these contributions remains highly mysterious.[1]

Curiosity about this connection seems legitimate, not to agitate pointless priority debates, but because our understanding of the origins of modern physics strongly depends on comparisons between Einstein's and other theorists' approaches to the major problems of early twentieth-century physics. The inclination to deem Einstein's contributions *a priori* singular and superior to any others has long obscured the endeavors of his contemporaries as well as the nature of his own reflections. This is especially true for relativity theory and

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* CNRS: Rehseis, 83 rue Broca, 75013 Paris, France.

[1] John Stachel, David Cassidy, Jürgen Renn, and Robert Schulmann, eds., *The Collected Papers of Albert Einstein,* Vols. 1 and 2 (Princeton, N.J.: Princeton Univ. Press, 1987, 1989). Edmund Whittaker, Marie-Antoinette Tonnelat, Gerald Holton, Russell McCormmach, Tetu Hirosige, Lewis Pyenson, Stanley Goldberg, Camillo Cuvaj, Arthur Miller, and Abraham Pais gave the most influential of the older accounts. We owe the most innovative of the newer ones to John Stachel, Michel Paty, Jürgen Renn, Albrecht Fölsing, Michel Janssen, and Peter Galison. References to these contributions are given below or in the bibliography of Olivier Darrigol, *Electrodynamics from Ampère to Einstein* (Oxford: Oxford Univ. Press, 2000).

Isis, 2004, 95:614–626

0021-1753/2004/9504-0004$10.00

its primary context, the electrodynamics of moving bodies. Once this sort of prejudice has been eliminated, the interesting question no longer is whether a contemporary of Einstein got it right or wrong—using Einstein as a gauge—but how the similarities and dissimilarities between his and Einstein's approaches can be explained.

In this essay I discuss existing suggestions about the connection between Einstein and Poincaré and try to relate them to historians' diverse outlooks. I first elaborate the extent of the overlap between Poincaré's and Einstein's contributions to relativity theory. After touching briefly on the dangers of focusing on the priority issue, I discuss two ways of accounting for this overlap: that the two actors had similar interests and resources or that one borrowed from the other. Last, I speculate on the reasons that may lead historians to opt for one or the other of these explanations. For the convenience of readers who are not familiar with the prehistory of relativity, a few important events are listed in the Appendix.

SIMILARITIES AND DIFFERENCES

Einstein's and Poincaré's theories of relativity are incommensurable: some of the basic concepts and deductions of one theory have no counterpart in the other. Some commentators, ignoring this incommensurability, have misinterpreted the relations between the two theories and have concluded that Poincaré's approach was basically inconsistent. Others have instead exaggerated the incommensurability and have consequently underestimated the similarities between the two theories. The difficulty is that in order to compare incommensurable theories, one must identify a conceptual stratum that they implicitly share. In what follows I assume that this has already been done, and I do not explore the related epistemological questions.

By 1905 Poincaré's and Einstein's reflections on the electrodynamics of moving bodies led them to postulate the universal validity of the relativity principle, according to which the outcome of any conceivable experiment is independent of the inertial frame of reference in which it is performed.[2] In particular, they both assumed that the velocity of light measured in different inertial frames was the same. They further argued that the space and time measured by observers belonging to different inertial systems were related to each other through the Lorentz transformations. They both recognized that the Maxwell-Lorentz equations of electrodynamics were left invariant by these transformations. They both required that every law of physics should be invariant under these transformations. They both gave the relativistic laws of motion. They both recognized that the relativity principle and the energy principle led to paradoxes when conjointly applied to radiation processes.[3]

On several points—namely, the relativity principle, the physical interpretation of Lorentz's transformations (to first order), and the radiation paradoxes—Poincaré's relevant publications antedated Einstein's relativity paper of 1905 by at least five years, and his suggestions were radically new when they first appeared. On the remaining points, publication was nearly simultaneous.

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[2] This statement of the relativity principle differs both from Poincaré's (who rather phrased it in terms of the undetectability of the ether wind) and from Einstein's (who further required the invariance of the expression of the laws of physics). I have deliberately chosen a statement that both of them would have approved.

[3] For the evidence and for relevant literature see Olivier Darrigol, "Henri Poincaré's Criticism of *Fin-de-Siècle* Electrodynamics," *Studies in History and Philosophy of Modern Physics,* 1995, *26:*1–44.

I turn now to basic conceptual differences. Einstein completely eliminated the ether, required that the expression of the laws of physics should be the same in any inertial frame, and introduced a "new kinematics" in which the space and time measured in different inertial systems were all on exactly the same footing. In contrast, Poincaré maintained the ether as a privileged frame of reference in which "true" space and time were defined, while he regarded the space and time measured in other frames as only "apparent." He treated the Lorentz contraction as a hypothesis regarding the effect of the edgewise motion of a rod through the ether, whereas for Einstein it was a kinematic consequence of the difference between the space and time defined by observers in relative motion. Einstein gave the operational meaning of time dilation, whereas Poincaré never discussed it. Einstein derived the expression of the Lorentz transformation from his two postulates (the relativity principle and the constancy of the velocity of light in a given inertial system), whereas Poincaré obtained these transformations as those that leave the Maxwell-Lorentz equations invariant. Whereas Einstein, having eliminated the ether, needed a second postulate, in Poincaré's view the constancy of the velocity of light (in the ether frame) derived from the assumption of a stationary ether. Einstein obtained the dynamics of any rapidly moving particle by the direct use of Lorentz covariance, whereas Poincaré reasoned according to a specific model of the electron built up in conformity with Lorentz covariance. Einstein saw that Poincaré's radiation paradoxes could be solved only by assuming the inertia of energy, whereas Poincaré never returned to this question. Lastly, Poincaré immediately proposed a relativistic modification of Newton's law of gravitation and saw the advantages of a four-vector formalism in this context, whereas Einstein waited a couple of years to address this problem complex.[4]

These differences between the two theories are sometimes regarded as implying different observable predictions even within the domain of electromagnetism and optics. In reality, there is no such disagreement, for Poincaré's ether is by assumption perfectly undetectable, and every deduction made in Einstein's theory can be translated into a deduction in Poincaré's theory by (artificially) deciding that one given frame of reference is the ether frame and by distinguishing between the "true" space and time of this frame and the "apparent" space and time of the others. As Lorentz himself once commented, the difference between the two theories is merely epistemological: it concerns the amount of conventional, arbitrary elements that we are willing to introduce in the definition of basic physical concepts.[5] Einstein's approach is more economical, for it avoids physical distinctions that have no empirical counterpart (such as the distinction between induction by moving magnet and induction by moving wire); Poincaré's approach is more intuitive, inasmuch as it maintains concepts and ways of reasoning that have long been known to be perfectly adapted to the physics of everyday phenomena.

It has often been argued that Einstein's approach has greater logical simplicity, for it distinguishes clearly between three sorts of physical properties: kinematic, dynamic, and model dependent. Einstein's relativity theory of 1905 is deliberately a theory of principles that eludes "constructive," model-dependent features, whereas Poincaré's theory is a "dy-

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[4] See, e.g., Arthur I. Miller, *Albert Einstein's Special Theory of Relativity: Emergence (1905) and Early Interpretation (1905–1911)* (Reading, Mass.: Addison-Wesley, 1981); and Michel Paty, *Einstein philosophe: La physique comme pratique philosophique* (Paris: Presses Univ. France, 1993). On the inertia of energy see Darrigol, "Henri Poincaré's Criticism of *Fin-de-Siècle* Electrodynamics," pp. 41–44; and Olivier Darrigol, "Poincaré, Einstein, et l'inertie de l'énergie," *Comptes Rendus de l'Académie des Sciences,* 2000, *4*(1)*:*143–153.

[5] H. A. Lorentz, *Das Relativitätsprinzip* (Leipzig, 1920), p. 23.

namics of the electron," as the titles of his publications of 1905 and 1906 assert. Yet the difference is not as great as it at first appears. In 1900, Poincaré already understood that Lorentz's local time could be derived (to first order) from an appropriate time-measurement convention for moving observers. In his Sorbonne lectures of 1906 and in later publications he showed that the exact Lorentz transformations were compatible with the same convention, together with the assumption of the Lorentz contraction. Although this was not purely kinematic reasoning in Einstein's sense, Poincaré could thus justify the Lorentz transformations without appealing to the Maxwell-Lorentz equations. In the same lectures, he obtained the relativistic dynamics of a particle by seeking a covariant generalization of Newtonian dynamics, independently of any specific model. Hence, by 1906 some of the structural differences between Einstein's and Poincaré's derivations of basic relativistic formulas had disappeared, despite a persistent contrast in the conceptual basis.[6]

Several historians have insisted on the different heuristics that accompany Einstein's and Poincaré's versions of relativity theory. Whereas Poincaré's approach still depended on the electromagnetic worldview of previous electron theorists, in 1905 Einstein believed in a limited validity of the Maxwell-Lorentz electrodynamics and even argued for a quantum structure of radiation. This programmatic difference had a number of consequences. First, Poincaré spent much time discussing a mostly electromagnetic model of the electron, whereas in 1905 Einstein judged any attempt at a theory of the electron premature. Second, Poincaré made the general validity of Lorentz covariance depend on a hypothetical similarity between any force (internal cohesion of the electron, gravitational force, etc.) and electromagnetic forces, whereas Einstein's own covariance requirement depended on electromagnetism only through the postulated constancy of the velocity of light. Third, whereas Einstein firmly believed in the truth and expediency of his postulates, Poincaré complained about the Ptolemaic character of his own theory and hoped that a new Copernicus would come along to simplify everything.[7] Beyond electromagnetism, Einstein's kinematico-geometric interpretation of the Lorentz transformations may have eased the transition to general relativity.

This ends my short comparison of the contents of Einstein's and Poincaré's theories of relativity. The discussion of the contextual or causal links that have been drawn between them that follows is confined to histories that essentially agree with this comparison. On other kinds of histories, I have only a few critical words to say.

Blinded by the radiance of Einstein's thought, some historians have failed to see that important components of his theory were present in Poincaré's as well. For example, it has sometimes been held that the relativity principle belonged to Einstein alone because Poincaré maintained a physical distinction between different inertial frames of reference. Although the latter assertion is true, the former follows only if the principle of relativity is defined as implying complete equivalence between different inertial frames; according to Poincaré's statement of the principle, however, only phenomenal equivalence, not representational equivalence, is required. Historically, the important point is that this more limited principle was a major novelty when Poincaré introduced it. Another example of a

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[6] Poincaré's lectures of 1906–1907 are discussed in Darrigol, "Henri Poincaré's Criticism of *Fin-de-Siècle* Electrodynamics" (cit. n. 3). One could speculate that Einstein's relativity paper caused the evolution of Poincaré's views. This does not seem likely, both because the internal logic of Poincaré's approach required this evolution and because strong differences in the formal developments remain.

[7] Henri Poincaré, "Sur la dynamique de l'électron," *Rendiconti del Circolo Matematico di Palermo,* 1906; rpt. in *Oeuvres,* 11 vols. (Paris, 1950–1965), Vol. 9, pp. 494–550, on p. 498.

pro-Einstein bias is the ignorance or downplaying of Poincaré's interpretation of Lorentz's local time. Until very recently, most historians of relativity overlooked the fact that Poincaré offered this interpretation in 1900, in a widely read memoir. Even if they acknowledged its occurrence in Poincaré's St. Louis lecture of 1904, they failed to see the structural similarity with Einstein's derivation of the Lorentz transformations.[8]

Other historians have had the opposite bias. Exclusive focus on the formal and empirical content of relativity theory (the Lorentz group and covariance properties) has led some of them to ignore the difference between Poincaré's and Einstein's concepts of space and time, while nationalism, anti-Semitism, or *esprit d'Ecole* induced others to read much more into Poincaré's text than is really there. For instance, it has been claimed that Poincaré had the second principle of relativity theory on the basis of his having written in 1898 that

> the astronomer [who dates stellar events in light-years] has begun by *supposing* that light has a constant velocity and, in particular, that its velocity is the same in all directions. That is a postulate without which no measurement of this velocity could be attempted. . . . The postulate conforms to the principle of sufficient reason and has been accepted by everybody; what I wish to emphasize is that it furnishes us with a new rule for the investigation of simultaneity.

It is clear from the context that Poincaré meant here to apply the postulate only in an ether-bound frame, in which case he could indeed state that it had been "accepted by everybody." In 1900 and in later writings he defined the apparent time of a moving observer in such a way that the velocity of light measured by this observer would be the same as if he were at rest (with respect to the ether). This does not mean, however, that he meant the postulate to apply in any inertial frame. From his point of view, the true velocity of light in a moving frame was not a constant but was given by the Galilean law of addition of velocities. Moreover, Poincaré never derived the exact form of the Lorentz transformations by directly combining the relativity postulate and the light postulate. He instead assumed the Lorentz contraction (justified by the negative result of the Michelson-Morley experiment or by the transitivity of apparent time measurements) and modified his earlier interpretation of Lorentz's local time accordingly.[9]

As these examples show, in order to compare Poincaré's and Einstein's theories properly one must read every one of their statements in context, taking into account both the inner logic of their investigations and the contemporary problematics to which they were responding. Insofar as historians of relativity follow this precept, they should agree on most of the comparisons between Poincaré's and Einstein's theories that I have outlined.

To sum up, Einstein's and Poincaré's versions of relativity theory differed in their basic concepts and in the accompanying heuristics. These differences should not hide the following facts: the two theories had the same observable consequences in the domain of classical electromagnetism; they both postulated the relativity principle; they both required the Lorentz-group symmetry of the laws of physics; and they both provided a physical interpretation of the Lorentz transformations in terms of measured space and time in moving frames. Despite this strong overlap, many commentators have anointed Einstein the true discoverer of relativity theory and others have bestowed this honor on Poincaré. For

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[8] The first recent exception to this oversight is found in the editorial notes to Stachel *et al.,* eds., *Collected Papers of Albert Einstein* (cit. n. 1), Vol. 2, p. 308n.

[9] Henri Poincaré, "La mesure du temps," *Revue de Métaphysique et de Morale,* 1898, *6*:371–384; trans. in *The Foundations of Science* (New York, 1913), pp. 223–234, on pp. 232–233.

historians, such concern with single authorship and priority is both misplaced and misleading. It seems wiser to acknowledge that Lorentz, Poincaré, and Einstein all contributed to the emergence of the theory of relativity, that Poincaré and Einstein offered two different versions of this theory, and that Einstein provided the form that is *now* judged better. This attitude avoids biases in the assessment of respective contributions, and it is better adapted to historical studies of the reception and later evolution of relativity theory.[10]

Having dismissed the single-author myth, we are left with the intriguing similarity of two theories whose authors ignored each other's contributions. We seem to be facing a typical case of simultaneous discovery, with the usual caveat that the thing discovered is not quite the same in the two instances. A first explanation of this coincidence could be that physics, at some stage of its evolution, had to include the basic relations of relativity theory, because these relations belong to nature, not to the mind that first uncovered them. If this is the case, it is no wonder that two different thinkers should have come to recognize these relations independently. Some will find this argument exceedingly teleological; others will regard it as plain common sense. At any rate, it fails to explain the approximate simultaneity of the two discoveries. As Thomas Kuhn did long ago in looking at the case of the energy principle, we may imagine two sorts of explanations for this simultaneity: that the same "factors," resources, and interests were at play in Poincaré's and Einstein's endeavors; and that Einstein found inspiration while reading Poincaré.[11] These two explanations are not mutually incompatible. Both are found in the recent historiography of relativity. I begin with the common-circumstances approach.

COMMON CIRCUMSTANCES

Poincaré and Einstein were addressing the same basic problem: the electrodynamics and optics of moving bodies. This was a large, growing field of inquiry, opened by the failure of the Maxwell-Hertz theory to account for the optical properties of moving bodies and much widened by Lorentz's theory and its criticism by various competitors. Emil Cohn reproached Lorentz with introducing atomistic considerations into purely large-scale phenomena and proposed his own etherless, macroscopic theory, obtained by modifying Maxwell's equations. Alfred Bucherer agreed with Cohn that the ether should be eliminated from physics, but he preferred to return to a retarded-potential theory in which the relativity principle would exactly hold. Other physicists, such as Wilhelm Wien and Max Abraham, imagined a purely electromagnetic electron theory that in principle involved (hard to detect) effects of the ether wind. Ether-drift experiments—especially Fizeau's experiment of 1851 and the Michelson-Morley experiment of 1887—played an important role in all of these discussions and suggestions. In most of them, the rise of a new, electron-based microphysics was also influential.[12]

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[10] The following reception studies are exemplary in this respect: Andrew Warwick, "Cambridge Mathematics and Cavendish Physics: Cunningham, Campbell, and Einstein's Relativity, 1905–1911," Pt. 1: "The Uses of Theory," Pt. 2: "Comparing Traditions in Cambridge Physics," *Studies in History and Philosophy of Science,* 1992, *23:*625–656, 1993, *24:*1–25; Richard Staley, "On the Histories of Relativity: The Propagation and Elaboration of Relativity Theory in Participant Histories in Germany, 1905–1911," *Isis,* 1998, *89*:263–299; and Scott Walter, "Minkowski, Mathematicians, and the Mathematical Theory of Relativity," in *The Expanding Worlds of General Relativity,* ed. Hubert Goenner, Jürgen Renn, Jim Ritter, and Tilman Sauer (Einstein Studies, 7) (Boston: Birkhäuser, 1999), pp. 45–86.

[11] See T. S. Kuhn, "Energy Conservation as an Example of Simultaneous Discovery" (1959), in *The Essential Tension: Selected Studies in Scientific Tradition and Change* (Chicago: Univ. Chicago Press, 1977), pp. 66–104.

[12] See Olivier Darrigol, "The Electrodynamic Origins of Relativity Theory," *Historical Studies in the Physical and Biological Sciences,* 1996, *26:*241–312.

There is much evidence that Poincaré and Einstein were aware of these debates around Lorentz's theory. They both knew the Fizeau experiment and the negative result of many ether-wind experiments, including that of Michelson and Morley. Poincaré found the nearly exact form of the Lorentz transformations in Lorentz's memoir of 1904. Although Einstein had no direct access to this memoir, he may have read summaries of the main results in the journals he regularly checked. Certainly he was familiar with Lorentz's *Versuch* of 1895, which contained bits and pieces of the transformations.

Poincaré and Einstein both witnessed dizzyingly fast changes in contemporary physics. At the turn of the century, this turmoil prompted many reflections on the foundations of physics, on concept formation, and on the unity or conflict between various domains. This critical turn was especially strong in Germany, for reasons including the influence of Ernst Mach's writings, the traumatic replacement of the old German theories of electrodynamics by Maxwell's theory, and the emergence of an experimental microphysics that threatened the phenomenological tradition. As Einstein's friend Maurice Solovine later remembered, "the end of the nineteenth and beginning of the twentieth century was the heroic age of research on the foundations and principles of the sciences, and this is what was also our constant preoccupation."[13]

Peter Galison has recently pointed out that Poincaré and Einstein were also familiar with advances in contemporary technology, including those regarding the distribution of time. The electric or telegraphic synchronization of clocks was being intensely developed, for the purpose of longitude measurements (in which Poincaré was involved) and for the Swiss distribution of time (about which Einstein examined relevant patents). For both thinkers, Galison argues, the definition of simultaneity was a critical problem that lay at the intersection of their interests in new technologies, in the foundations of physics, and in the philosophy of knowledge. At this triple juncture they both realized that Lorentz's local time had a physical meaning as the time measured by optically synchronized clocks in motion. They both borrowed their synchronization procedures from the telegraphic context.[14]

Finally, shared psycho-cognitive circumstances may be invoked. Both Poincaré and Einstein belonged to the fringes of the physics community. One was a foremost mathematician with a special interest in physics, the other a young patent clerk trained at the Zurich Polytechnikum. They both lacked some of the prejudices of established physicists; they both took the stance of an impartial judge; they both preferred to reformulate existing theories in their own way rather than digging out the original motivations of their authors. Jürgen Renn has emphasized the cognitive benefit of this situation: by ignoring Lorentz's intricate, two-step, semiformal, semiphysical interpretation of his own coordinate and field transformations, Einstein and Poincaré were free to imagine a simpler, radically innovative interpretation.[15]

We may now return to the main similarities between Poincaré's and Einstein's theories of relativity and examine the extent to which they might have resulted from common

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[13] Maurice Solovine, ed., *Albert Einstein: Lettres à Maurice Solovine* (Paris: Gauthier-Villars, 1956), p. viii (here and throughout the essay, translations are my own unless otherwise indicated).

[14] Peter Galison, *Einstein's Clocks, Poincaré's Maps: Empires of Time* (New York: Norton, 2003). According to Galison, immersion in time technology may also explain, together with epistemological concerns, why optical synchronization played a central role in Einstein's theory.

[15] Jürgen Renn, "Einstein as a Disciple of Galileo: A Comparative Study of Concept Development in Physics," *Science in Context,* 1993, *6:*311–341.

circumstances. That both Poincaré and Einstein postulated the relativity principle could be explained by the accumulation of negative ether-drift experiments and by the contemporary emergence of a critical attitude toward the ether. That they both obtained the exact form of the Lorentz transformations and the invariance of the Maxwell-Lorentz equation under them could be explained by their awareness of approximate forms of these transformations.[16] Einstein may also have reached these transformations directly, through the redefinition of simultaneity (as he does in his publication), in which case common circumstances should rather be sought for his and Poincaré's criticisms of simultaneity. This is where Galison's study is particularly suggestive: the similarities between Einstein's and Poincaré's optical synchronization procedures could well have resulted from their equal familiarity with aspects of contemporary time technology.

DIRECT BORROWING

I now examine the possibility that Einstein directly borrowed some essential elements of relativity theory from Poincaré. With his friends of the informal "Akademie Olympia," Einstein read Poincaré's *La science et l'hypothèse* sometime between 1902 and 1905. Another member of that reading group, Solovine, describes this book as one that "profoundly impressed us and kept us breathless for many weeks." In 1921, Einstein praised the "profound and acute Poincaré" for the discussion of non-Euclidean geometries given in *La science et l'hypothèse.* In his "reply to criticisms" of 1949, he interrupted a fictitious dialogue between Hans Reichenbach and Poincaré on the same topic, arguing that "the conversation cannot be continued in this fashion because the respect of the writer for Poincaré's superiority as thinker and author does not permit it."[17]

Poincaré's critical depth, his unraveling of implicit conventions, his attention to organizing principles, his ability to penetrate and compare a great variety of theories, and his promptness to detect crises and paradoxes were but a few of the qualities that could have inspired the young Einstein. *La science et l'hypothèse* also contained elements that directly foreshadowed aspects of relativity theory. On the ether, Poincaré expressed a prophetic skepticism:

> It matters little whether the ether really exists; that is the affair of the metaphysicians. The essential thing for us is that everything happens as if it existed, and that this hypothesis is convenient for the explanation of phenomena. After all, have we any other reason to believe in the existence of material objects? That, too, is only a convenient hypothesis; only this will never cease to be so, whereas, no doubt, someday the ether will be thrown away as useless.

Poincaré also argued for the relativity principle: "I consider it very probable that optical phenomena depend only on the relative motion of the material bodies present—light sources or optical apparatus—*and this not only to first or second order . . . but exactly.* . . . All attempts to measure the velocity of the earth in relation to the ether have led to

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[16] On the possibility that Einstein arrived at the (exact) Lorentz transformations before he hit upon the new kinematics see Robert Rynasiewicz, "The Construction of the Special Theory: Some Queries and Considerations," in *Einstein: The Formative Years, 1879–1909,* ed. Don Howard and John Stachel (Boston: Birkhäuser, 2000).

[17] Henri Poincaré, *La science et l'hypothèse* (Paris, 1902); Solovine, ed., *Albert Einstein: Lettres à Maurice Solovine* (cit. n. 13), p. 8; Albert Einstein, "Geometrie und Erfahrung," *Preussische Akademie der Wissenschaften, Mathematisch-Physikalische Klasse, Sitzungsberichte,* 1921, rpt. in *Mein Weltbild* (Zurich, 1953), pp. 119–127, on p. 122; and Einstein, "Remarks to the Essays Appearing in This Collective Volume," in *Albert Einstein: Philosopher-Scientist,* ed. Paul Arthur Schilpp (La Salle, Ill.: Open Court, 1949), pp. 665–688, on p. 677.

negative results. In this case experimental physics has been more faithful to the principle than mathematical physics." Poincaré further expressed the view that Lorentz's theory should be modified in order to comply perfectly with this principle. He generally pleaded for a "physics of principles" that organized theories around stable principles, rather than attempting the sort of arbitrary, molecular constructions found in the older, Laplacian physics. He also had something to say on time measurement: "Not only do we not have a direct intuition of the equality of two time intervals, but we do not even have that of the simultaneity of two events that are produced at different localities; I have explained this in an article entitled 'The Measurement of Time.'" The German version of *La science et l'hypothèse,* published in 1904 and perhaps read by Einstein, had a long quotation from Poincaré's article of 1898, including: "The simultaneity of two events or the order of their occurrence, and the equality of two time intervals, must be defined so that the expression of the laws of physics should be the simplest possible; in other words, all those rules and definitions [conventions for time measurement] are only the fruits of an unconscious opportunism." The German editor further mentioned the possibility that a new time coordinate might be a function of the older time *and space* coordinates.[18]

We know that Einstein read Poincaré's contribution to the Lorentz *Festschrift* of 1900, for he referred to it in a publication of 1906. It is likely, but not certain, that he read it before 1905, given the frequent references made to it in the literature on electron theory. This brilliant paper contains a formal introduction of the electromagnetic momentum, the above-mentioned radiation paradoxes, and an interpretation of Lorentz's transformed field-states in terms of measurements performed by moving observers. This interpretation implied a physical "definition" of Lorentz's local time:

> I suppose that observers placed in different points set their watches by means of optical signals, that they try to correct these signals by the transmission time, but that, ignoring their motion of translation and thus believing that the signals travel at the same speed in both directions, they satisfy themselves with crossing the observations, by sending one signal from A to B, then another from B to A. The local time t' is the time indicated by watches set in this manner.

The similarity with Einstein's later definition of simultaneity is obvious. Moreover, Einstein explicitly based one of his derivations of the mass–energy relation on one of Poincaré's radiation paradoxes. His earliest derivation, which does not refer to Poincaré, may be seen as a response to another of Poincaré's paradoxes.[19]

In sum, then, Einstein could have borrowed the relativity principle, the definition of simultaneity, the physical interpretation of the Lorentz transformations, and the radiation paradoxes from Poincaré. How plausible is all of that?

Let us begin with the radiation paradoxes. In this case the evidence is direct, since Einstein himself refers to Poincaré as a source. However, the first derivation of the inertia of energy may have been independent of Poincaré's reflections, for Einstein certainly did not lack the ability to conceive problematic thought experiments.

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[18] Poincaré, *La science et l'hypothèse,* p. 215; Henri Poincaré, *Electricité et optique* (Paris, 1901), p. 536 (see also *La science et l'hypothèse,* pp. 201–202); Poincaré, *La science et l'hypothèse,* p. 111; and Poincaré, *Wissenschaft und Hypothese* (Leipzig, 1904), pp. 286–289.

[19] Henri Poincaré, "La théorie de Lorentz et le principe de la réaction," in *Recueil des travaux offerts par les auteurs à H. A. Lorentz à l'occasion du 25ème anniversaire de son doctorat le 11 décembre 1900* (The Hague, 1900), pp. 252–278, on p. 272. On Einstein's early derivations of the mass–energy relation see Darrigol, "Henri Poincaré's Criticism of *Fin-de-Siècle* Electrodynamics" (cit. n. 3).

That Einstein borrowed the relativity principle from Poincaré is suggested by the fact that Poincaré was, apart from the much less well known Bucherer, the only electron theorist who assumed a strict validity of this principle. All other experts, including Lorentz and Joseph Larmor, believed in the existence of ether-wind effects that were too small to be observed with existing techniques. Nevertheless, it is more likely that Einstein arrived at the relativity principle before reading Poincaré, through his own concern with ether-drift experiments, his sympathy for the critical philosophies of David Hume and Ernst Mach, and his awareness of Paul Drude's dream of an ether-free electrodynamics. Einstein's understanding of relativity seems, from the very beginning, to have been correlated with his rejection of the ether, whereas Poincaré separated the two issues. As can be judged from Einstein's introduction to the relativity paper of 1905, his belief in the relativity principle resulted in part from his Hertzian and Machian desire to eliminate from physical theory any asymmetry that had no empirical counterpart. As the assumption of a stationary ether implied such asymmetries in the basic case of electromagnetic induction, the ether had to go; and strict relativity then naturally held. No such reasoning can be found in Poincaré, who instead maintained the psychological necessity of the ether.[20]

The case of time measurement looks different. The profound originality of Poincaré's idea seems to make it unlikely that it would have germinated independently in another mind, no matter how powerful. In a recent biography of Einstein, Albrecht Fölsing speculates that during the decisive conversation that Einstein later remembered having had with Michele Besso in early 1905, the two friends discussed Poincaré's remark on Lorentz's local time and Einstein suddenly saw in it the basis of a redefinition of space and time in harmony with the Lorentz transformations. The main problem with this speculation is that Poincaré's name does not appear in Einstein's relativity paper and that Einstein never admitted any such influence in this regard.[21]

One can imagine many reasons for his silence. First, and least plausible, is the possibility that the ambitious Einstein deliberately occulted Poincaré's role in order to get full credit for the new theory. This hardly fits what we know of Einstein's personality. Second, it may have been that although Einstein was aware of Poincaré's remark, he did not believe that it truly originated with Poincaré. Two other authors related Lorentz's local time to optical synchronization—Emil Cohn in 1904 and Max Abraham in early 1905—and neither of them referred to Poincaré. In fact, the great mathematician himself introduced his interpretation of the local time in a brief and casual manner—and ascribed it to Lorentz! Perhaps this interpretation sounded *retrospectively* obvious for thinkers immersed in the culture of electric synchronization described by Galison, to the point that no need was felt to identify its true inventor. A third possibility is that Einstein ascribed this interpretation to Poincaré but did not think that it was an important component of his new theory. In his view, the elimination of the ether, the requirement of a complete symmetry between different inertial systems, the foundation of the theory on two principles, and the introduction of new concepts of space and time were far more important. A fourth explanation is that Einstein worried little about the precise identification of his sources, as is suggested by

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[20] Albert Einstein, "Zur Elektrodynamik bewegter Körper," *Annalen der Physik,* 1905, *17:*891–921, on p. 891.

[21] Albrecht Fölsing, *Albert Einstein: Biographie* (1993; Frankfurt am Main: Suhrkamp, 1999), pp. 201–202. Galison, *Einstein's Clocks, Poincaré's Maps* (cit. n. 14), pp. 257–261, mentions the possibility that Einstein came across Poincaré's remark but regards this as one among many germs that could have precipitated the relativistic train of thought in a mind saturated with time coordination problems and philosophico-critical questioning.

the almost complete lack of footnotes in his 1905 paper and by the unusual apology found in a paper of 1907: “It seems to me to be in the nature of the subject that what is to follow might already have been partially clarified by other authors. However, in view of the fact that the questions under consideration are treated here from a new point of view, I believed I could dispense with a literature search that would be very troublesome for me.”[22] A fifth possibility is that Einstein had read Poincaré’s interpretation of the local time in the Lorentz *Festschrift* well before 1905 and did not then pay attention to it (nor did Lorentz and other electron theorists). In 1905 he suddenly realized the importance of this interpretation, but by then he had forgotten where it originated and could even fancy that it was his own. This is a plausible account, for it is based on a common psychological phenomenon. Altogether, Einstein’s silence does not exclude the possibility that his reading of Poincaré’s memoir of 1900 played a determining role in his discovery of relativity theory.

What is perhaps more intriguing is the long persistence of Einstein’s ignorance of Poincaré’s contributions to relativity theory. In 1906, when he referred to Poincaré’s paper of 1900 in the context of a new derivation of the mass–energy relation, Einstein had an opportunity to indicate that Poincaré had proposed a physical interpretation of Lorentz’s local time. He did not do so then, nor even in the review article written in 1907 for the *Jahrbuch der Radioaktivität.* This review also missed Poincaré’s major memoir of 1906, published—improbably—in the *Rendiconti* of the Circolo Matematico di Palermo and therefore still unknown to most authorities in the field. More surprisingly, Einstein continued to ignore Poincaré’s contribution in all his later writings on special relativity and in his autobiographical notes. In the early 1950s he told Abraham Pais that he had never read the Palermo memoir. Only during the two last years of his life did he acknowledge the importance of Poincaré’s work in this field, perhaps after having read the copy of the memoir that Pais lent (and lost) to him. Two months before his death, he wrote to his biographer Carl Seelig: “Lorentz had already recognized that the transformations named after him are essential for the analysis of Maxwell’s equations, and Poincaré deepened this insight still further.”[23]

Not much can be inferred from Einstein’s long silence. One might speculate that his reluctance to express an opinion on the Palermo memoir, together with his fulsome praise of Poincaré in other circumstances, betrays some guilt that he failed to acknowledge the decisive inspiration he found in the *Festschrift* paper of 1900.[24] More sympathetically, one might speculate that his silence reflected the sincere conviction that he did not owe anything to Poincaré for the discovery of relativity theory. Most reasonably, one might invoke Einstein’s haughty self-confidence and lack of interest in parallel developments. That he had a hidden debt to Poincaré is a possibility, but clear evidence is still missing.

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[22] Albert Einstein, “Über die vom Relativitätsprinzip geforderte Trägheit der Energie,” *Ann. Phys.,* 1907, *23:*414–427, on p. 416; quoted in Abraham Pais, *“Subtle Is the Lord . . .”: The Science and the Life of Albert Einstein* (Oxford: Oxford Univ. Press, 1982), p. 165.

[23] Albert Einstein to Carl Seelig, 19 Feb. 1955, in Seelig, *Albert Einstein: Eine dokumentarische Biographie* (Zurich: Europa, 1960), p. 114. See also Pais, *“Subtle Is the Lord . . .,”* pp. 169–172. Both Pais (*ibid.,* p. 170) and Fölsing (*Albert Einstein* [cit. n. 21], p. 242) assume that Einstein had a frustrating exchange on relativity theory with Poincaré at the Solvay Congress of 1911, based on the following misquotation of a letter to Heinrich Zangger dated 15 Nov. 1911: “Poincaré war (gegen die Relativitätstheorie) einfach allgemein ablehnend, zeigte aber bei allem Scharfsinn wenig Verständnis für die Situation.” Einstein spelled the name “Poinkaré” and did not write the words in parentheses: Martin J. Klein, A. J. Kox, and Robert Schulmann, eds., *Collected Papers of Albert Einstein,* Vol. 5 (Princeton, N.J.: Princeton Univ. Press, 1993), p. 349. Most likely, he was alluding to Poincaré’s attitude toward the quantum problem.

[24] This is the view Fölsing expresses in *Albert Einstein,* p. 242.

THE HISTORIAN'S PREJUDICES

To sum up, the similarities between Poincaré's and Einstein's theories of relativity can be explained in two different ways: by common circumstances or by direct borrowing. Further evidence may someday emerge to support one of these explanations, but it will not completely eliminate the other, since they are mutually compatible. In the present state of evidence, the two options seem to require a comparable degree of speculation. Therefore, a historian's preference for one or the other necessarily depends on his or her broader interests and methodology.

Most trivially, a historian biased in favor of Poincaré's precedence over Einstein will tend to favor the direct-borrowing thesis and a historian with the opposite bias will favor the common-circumstances thesis. I will confine my analysis to historians who are fair and unconcerned with priority issues. This does not exclude more respectable prejudices, a few of which I will sketch.

Some historians tend to maximize the mutual connections between the ideas expressed among the actors working in a given field at a given time. They do so in order to minimize the differences between one idea and the next and thus to make the sequence of innovations seem more natural. This may be called the gradualist tendency. Other historians seek a maximal role for external conditions or events. In their view, major innovative steps often occur at the border between distinct fields of activity. The conjuncture is even more favorable when three fields are involved, as Galison cleverly suggests in the case of the redefinition of time. This may be called the transculturalist tendency. Still other historians believe that the moves of an actor are mostly determined by the socio-intellectual network in which he is evolving. This may be called the constructivist tendency. A last group of historians emphasize the discoverer's ability to perform cognitive leaps or gestalt switches when confronted with a confused state of affairs. This may be called the cognitivist tendency.[25]

The gradualist historian will favor the direct-borrowing thesis, because it makes Poincaré's interpretation of the local time an intermediate step between Lorentz's and Einstein's theories. All others will prefer the common-circumstances approach. The transculturalist will like the idea that contemporary time technology inspired both Poincaré and Einstein. The constructivist will welcome reference to the intensity of contemporary debates on the electrodynamics of moving bodies and to the contemporary trend to scrutinize foundations. The cognitivist will readily assume that Poincaré and Einstein were able to step away from Lorentz's original intentions because both of them largely ignored those intentions and reasoned from a different perspective. Most historians cannot be labeled so decisively. They may combine several of these attitudes, and they may adjust their approach to a topic over time. In my own studies of the history of relativity, I have combined the constructivist and the gradualist approaches. But even a touch of gradualism is enough to incline one toward the direct-borrowing explanation.

The wisest attitude might be to leave the coincidence of Poincaré's and Einstein's breakthroughs unexplained, though it is hard—perhaps impossible—to do history without succumbing to one (or several) of the tendencies I have distinguished. One should, in any case, at least avoid the sort of speculation that can later be refuted—as has happened with

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[25] I have chosen these labels for the lack of better words, without regard for the more precise meanings they have sometimes been given.

the rational reconstructions of Einstein's endeavors that portray him as unconcerned with the Michelson-Morley experiment or as a born skeptic with regard to the ether. One should also worry about the consequences of an excessive attention to the mysteries of Einstein's and Poincaré's breakthroughs: we could thus forget that 1905 marked only the beginning of the history of relativity and that relativity theory as we know it was collectively shaped in the years that followed.

APPENDIX

A FEW MAJOR EVENTS IN THE HISTORY OF THE ELECTRODYNAMICS OF MOVING BODIES

1888: Hertz's experiments confirm Maxwell's theory of electromagnetism.

1890: Hertz proposes an extension of Maxwell's theory to moving bodies in which the ether is fully dragged by moving bodies, but he recognizes that this theory does not account for some well-known results of the optics of moving bodies (stellar aberration and the Fizeau experiment of 1851, according to which the ether should be partially dragged by transparent bodies).

1895: Lorentz publishes his *Versuch,* a microphysical theory of electrodynamics in which the atoms, molecules, and ions that make up matter move freely through a perfectly stationary ether. This theory accounts for Fizeau's result and for numerous failures to detect first-order effects of the ether wind caused by the earth's motion. Thanks to the assumption of the Lorentz contraction, it also accounts for the negative result of the second-order ether-wind experiment of Michelson and Morley (1887). Lorentz's derivations involve compound transformations of coordinates and fields under which the Maxwell-Lorentz equations (for the fields and their coupling with the motion of charged particles) are approximately invariant. In his view the transformed quantities are mere mathematical aids.

1899: Poincaré asserts the principle of relativity, understood as the general and strict impossibility of detecting the ether wind.

1900: Poincaré interprets Lorentz's transformed fields and coordinates (to first order) as those measured by moving observers. In particular, he interprets the transformed time (Lorentz's "local time") as the time measured by optically synchronized clocks bound to the moving earth. He also shows that the combined application of the relativity principle and the energy principle leads to paradoxes for the emission of radiation.

1904: Lorentz generalizes his transformations to obtain a nearly complete invariance of his equations at any order.

1905–1906: Poincaré perfects Lorentz's transformations to obtain exact invariance of the Maxwell-Lorentz equations. He regards this invariance as the mathematical expression of the relativity principle. He designs a relativistic invariant model of the electron and attempts a relativistic modification of Newton's law of gravitation.

1905: Einstein publishes his own electrodynamics of moving bodies, based on the principle of relativity—understood as the requirement that the laws of physics should be the same in any inertial frame—and on the principle of the constancy of the velocity of light in a given inertial frame. He redefines space and time to comply with these two principles, thus obtains the Lorentz transformations, the contraction of lengths, and the dilation of times, then proves the invariance of the Maxwell-Lorentz equations under them and derives the relativistic dynamics of a corpuscle through the requirement of Lorentz invariance. In a separate paper, he concludes that the inertia of a body should depend on its energy content.