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To Bob,
with best wishes —
Arthur

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Arthur I. Miller

Why did Poincaré not formulate Special Relativity in 1905?

What Albert Einstein and Henri Poincaré accomplished in 1905 continues to fascinate historians and philosophers of science. Everyone agrees that Einstein and Poincaré confronted the same empirical data for which they formulated identical mathematical formalisms. Most scholars agree that whereas Einstein interpreted the mathematics as a theory of relativity, Poincaré considered it as an improved version of H. A. Lorentz's theory of the electron. Others contend that both men arrived at the special theory of relativity and, consequently, Poincaré ought to share the accolades with Einstein.

This essay brings together extant archival and primary sources to explore the codiscovery issue, which turns out to be insupportable. The errors are rooted in poor history coupled with hidden biases (e. g., Edmund Whittaker[1]) or attempting to fold history into philosophical views never held by Poincaré (e. g., Jerzy Giedymin,[2] and Elie Zahar[3]). But this is not merely a debate about priority. Key issues are involved in and emerge from the analysis to follow. Among them are the affect of Poincaré's writings on Einstein's thoughts toward the special theory of relativity; when do scientists elevate hypotheses to the lofty heights of being untestable by experiment and unquestionable by theory; the notions of underdetermination and conventionalism; differing opinions on the weight of empirical data; and the problem of scientific creativity. Although it turns out that the affect of Poincaré on Einstein might have been substantial, the honors for special relativity go to Einstein, alone.

I will proceed as follows. After setting aspects of Poincaré's philosophy of science germane to this essay, I turn to his views of time in mechanics and electromagnetic theory, and then to his opus's of 1905 and 1906, "Sur la dynamique de l'électron."[4] At this juncture it is apro-

1 Whittaker (1953), particularly Chapter II, "The Relativity Theory of Poincaré and Lorentz." For commentary see Miller (1987)

2 Giedymin (1977); (1982), esp. Chapter 5; (1991), 15.

3 Zahar (1989).

4 Poincaré (1905c), (1906).

pos to compare and contrast the opinions of Poincaré and Einstein on physics in 1905. Next I address the vexatious point of why Poincaré and Lorentz insisted on the complete equivalence of Lorentz's electron theory with special relativity, even though this is not the case. Then I comment specifically on Giedymin, Whittaker and Zahar.

The following results emerge. In 1905 Poincaré did not create a theory of motion based on the relativity of time and simultaneity. Are these two points not the essential content of Einstein's special theory of relativity? Poincaré neither elevated the principle of relativity in electron theory to a convention, nor did he ever dismiss the ether. So, is it not reasonable that he never attributed a relativistic interpretation to the Lorentz transformations? Poincaré's *La Science et l'Hypothèse*,[5] which Einstein read in 1904,[6] and Poincaré's 1900 essay "La Théorie de la Réaction et la Théorie de Lorentz",[7] which Einstein cited in 1906,[8] could have influenced Einstein's thoughts on simultaneity and the characteristics of light pulses.

Poincaré's philosophy of science

Poincaré's theory of knowledge is neo-Kantian based on two synthetic a priori organizing principles for the purpose of constructing knowledge from the potpourri of sense perceptions assimilated through interactions with the environment: the principle of mathematical induction and continuous groups of transformation (Lie groups).[9] Assimilation of perceptions leads us to realize that the "sole objective reality consists in the relations of things."[10]

Consequently, grist for the mill of the two synthetic a priori intuitions are the displacements of solid bodies, which are relations between perceptions. Processing these data with the two synthetic a priori intuitions leads to the axiomatic Euclidean geometry. Poincaré summed up his geometrical conventionalism thus: "we choose this geometry rather than that geometry, not because it is more *true*, but because it is more *convenient*" (emphasis in original).[11]

For Poincaré the testability of axiomatic Euclidean geometry was out of the question because it does not refer to objects of the laboratory. Consequently, the axioms of Euclidean geometry are in that lofty level of hypotheses he referred to as conventions. But what about the

[5] Poincaré (1905a). Throughout I refer only to the French editions of Poincaré's reprint volumes in order, from time to time, to render more accurate translations. Hereafter *La Science et l'Hypothèse* will be referred to as *SH*.

[6] For discussion of the philosophical and scientific literature that Einstein was aware of in mid-1905 ("definitely," "very probably," and "maybe") see Miller (1981), Chapter 1.

[7] Poincaré (1900).

[8] Einstein (1906).

[9] See Miller (1986b), esp. Chapter 1.

[10] Poincaré (1905b), 184. Hereafter this book is referred to as *VS*.

[11] Poincaré (1898b), 42. The synthetic a priori intuition of Lie groups permitted Poincaré to resolve the dilemma of why it is that an infinite number of geometries are possible whereas only three-dimensional Euclidean geometry is useful for the world in which we live. He came upon this resolution as a result of the purely mathematical discovery that any geometry can be generated by a Lie group, see Poincaré (1887).

rough geometry which pertains to the world of sense perceptions? Poincaré adroitly pointed out that in this case empirical tests entail geometry and mechanics. In turn, this realization led him to conclude that *any* physical theory is the conjunction of physics and geometry. It makes no sense at all, therefore, to talk about the testability of rough Euclidean geometry because any set of data can be brought into agreement with a scientific theory by altering the physics, while leaving Euclidean geometry fixed.[12] This is Poincaré's conventionalistic thesis in science. As it refers to geometry, he tersely writes: "To sum up, whichever way we look at it, it is impossible to discover in geometric empiricism a rational meaning."[13]

Just as Poincaré's theory of knowledge is based on sense perceptions, his scientific epistemology, or philosophy of science, is rooted in empiricism, "Experiment is the sole source of truth."[14] All hypothesizing begins with empirical data, whose selection is not necessarily straightforward.[15] From any set of data there are an infinite number of paths of generalization, which is Poincaré's statement of the underdetermination thesis: "The choice can only be guided by considerations of simplicity."[16] Each generalization is a hypothesis. Higher level hypotheses account for a wider class of phenomena than lower level ones and have, as well, wider powers of prediction. Examples of hypotheses at this highest level are Newton's principles restricted to approximately isolated systems.

The highest level hypotheses are conventions obtained "in searching for what there was in common in the enunciation of numerous physical laws; thus, they represent the quintessence of innumerable observations."[17] At this highest level Newton's laws are boldly generalized to the entire universe, and so they are no longer experimentally falsifiable. But Poincaré was too good a scientist to lock himself into a particular set of hypotheses. Consequently, although Newton's principles as conventions cannot be disconfirmed by experiment, they can be demoted if no longer "fruitful for theorizing."[18] This is what happened in 1904 when Poincaré demoted Newton's third law (action and reaction) from a convention in Lorentz's electromagnetic theory where actions are not compensated simultaneously by reactions.[19]

Since any geometry convenient for use anywhere in the universe is realized through studying displacements, then of key importance for generating prescientific knowledge is the relative position of bodies. When discussing the origins and testability of geometry, Poincaré referred to this result as the "relativity of space,"[20] and the "law of relativity."[21] In mechanics he referred to these statements collectively as the "principle of relative motion":[22]

[12] See, *SH*, 94–95.

[13] *Ibid.*, 101.

[14] *SH*, 157.

[15] Poincaré (1958a).

[16] *SH*, 160, and see also 145. The choice of proper path is part of the problem of scientific creativity, a topic in which Poincaré was intensely interested, see Miller (1992).

[17] *Ibid.*, 177.

[18] *Ibid.*, 178.

[19] *VS*, 100–102.

[20] *SH*, 98.

"The movement of any system whatever ought to obey the same laws whether it is referred to fixed axes or to movable axes which are implied in uniform motion in a straight line."

Like the axioms of Euclidean geometry, the principle of relative motion can never be discarded because in addition to the successes of Newtonian mechanics, its contradiction "is singularly repugnant to the mind,"[23] owing to its basis in the origins of geometry.

What about space? Poincaré carefully distinguished between "representative" and "geometrical," or mathematical, spaces.[24] Representative space is that of the world in which we live, and so is neither isotropic nor homogeneous. In contrast geometrical, or mathematical space, is the space of axiomatic geometry and so is isotropic and homogeneous. In view of the conventionality of geometry, wrote Poincaré in 1912, "In reality, space is therefore amorphous, a flaccid form, without rigidy, which is adaptable to everything; it has no properties of its own."[25] Consequently, space is three-dimensional owing to the convenience of three-dimensional Euclidean geometry.

In summary, since physical theories reflect the world about us, then it is proper, or convenient, for them to be formulated in 3-dimensional Euclidean geometry and, as far as possible, be based on contiguous actions.

The notion of time in mechanics

In a remarkable paper of 1898 entitled "Measurement of Time,"[26] Poincaré cleanly separated the problems of defining simultaneity and time in a manner more exact than anyone previously.[27] It is in "Measurement of Time," rather than Poincaré's papers of 1905 and 1906, "Sur la dynamique de l'électron," where he came closest to Einstein's relativity theory whose central theme is the relativity of time and simultaneity. Although Poincaré's methods and results closely resemble those in Einstein's 1905 relativity paper, they differ in emphasis on sense perceptions. To paraphrase a lovely French song, Poincaré came so close and yet was so far.

Poincaré's analysis includes distinguishing between local and distant simultaneity. In addition he set about to locate vicious circles involved in defining cause and effect in terms of time order of events, as well as in attempting to define time in terms of velocity. Of interest here is his analysis of simultaneity and time in mechanics and electromagnetic theory.

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[21] *Ibid.*, 99.

[22] *Ibid.*, 129

[23] *Ibid.*, 129.

[24] *Ibid.*, Chapter IV.

[25] Poincaré (1913), 97–109, 100. Hereafter this book is referred to as *DP*.

[26] Poincaré (1898a).

[27] With the exception of the little known French philosopher A. Calinon, who Poincaré cited in "Measurement of Time", *VS*, 45–46. See Miller, (1986b), note 9, 26–27.

Poincaré writes in "Measurement of Time," "let us watch [scientists] at work and look for the rules by which they investigate simultaneity."[28] He offers two examples – measurement of the velocity of light and determination of longitude.

In order to make astronomical measurements, astronomers have to agree on a value for the one-way light velocity which entails postulating 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."[29]

This postulate satisfies the "principle of sufficient reason,"[30] because it includes symmetry properties expected of space. Although such a postulate can never be experimentally verified, Poincaré considers it fortunate that no contradictions have occurred. In Poincaré's terminology, astronomers work in geometrical space which, by definition, is homogeneous and isotropic.

As a concrete example Poincaré takes Olaf Roemer's 1676 measurement of the one-way light velocity which involved two events ordered in time and space: Light leaves one of Jupiter's moons and then arrives on earth. The observed facts can be explained with slightly different values for the velocity of light. But this would entail replacing Newton's laws with more complicated ones based on *definitions* of time other than the one from the transformations used in Newton's mechanics, namely,

$$x_r = x - vt, \qquad (1)$$

$$y_r = y, \qquad (2)$$

$$z_r = z \qquad (3)$$

$$t_r = t \qquad (4)$$

which relate two inertial reference systems with space and time coordinates (x_r, y_r, z_r, t_r) and (x, y, z, t), in relative motion with the velocity v. Eq.(4) states the equality of times for every inertial observer regardless of their relative velocities. While, the absoluteness of time in Eq.(4) agrees with our sense perceptions, Poincaré does not assume that simultaneity is absolute.

Poincaré turns next to the measurement of longitude, which requires ascertaining the time in Paris from wherever you happen to be. If the time check is done by telegraph, then one neglects the transmission interval because it is "much less than the errors of observation."[31] So, in contrast with Roemer's measurement, in this case Poincaré assumes simultaneity to be absolute.

In summary, writes Poincaré, we could "amuse" ourselves with different rules for simultaneity, but these would greatly complicate Newton's laws: "Time should be so defined that the

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[28] *VS*, 52.

[29] *Loc. cit.*

[30] *Ibid.*, 54.

[31] *Loc. cit.*

equations of mechanics may be as simple as possible."[32] As in the case of geometry, Poincaré concludes: "We choose these rules, not because they are true, but because they are the most convenient."[33] The descriptive simplicity of Newton's laws is of paramount importance. Poincaré meant these two examples to illustrate that the "qualitative problem of simultaneity is reduced to the quantitative problem of the measurement of time."[34] In 1905, Einstein took both problems to be quantitative.

The notion of time in electromagnetic theory

When Poincaré put on his hat as electrodynamicist, he filled Newton's cosmic receptacle with the ether, Thus, the space of inertial reference systems should be representative space, which is neither homogeneous nor isotropic. Yet the failure of the ether-drift experiments made the representative space of inertial reference frames seem like geometrical space. Why? This was the key problem H. A. Lorentz tackled in his 1892 opus.[35]

Let us remind ourselves of the situation in Lorentz's electromagnetic theory with its mix of wave optics and Newtonian mechanics. Ever since James Clerk Maxwell, the fundamental method of the electrodynamics of moving bodies was as follows: write down the equations of electromagnetism relative to an ether-fixed reference system. By axiom, in ether-fixed reference systems the velocity of light is a special quantity because it is a definite constant independent of any relative motion between emitter and observer. Changing the problem situation to the electrodynamics of moving bodies requires the space and time transformations in Eqs.(1)–(4). These transformations lead to the Newtonian addition law for velocities

$$V = v + c, \tag{5}$$

where v is the earth's velocity relative to the ether and c is the velocity of light measured relative to an ether-fixed reference system. The velocity *v* in Eq.(5) is a statement of the expected anisotropy of the representative space of inertial reference systems for the velocity of light. Consequently, Lorentz's electromagnetic theory predicted violations of the principle of relative motion because it offered a means to measure the motion of an inertial reference system – measure the velocity of light in that system. But, circa 1900, experiment gave

$$V = c \tag{6}$$

to second order accuracy in (v/c). Eq.(6) contradicts Eq.(5). As Poincaré put it in 1904: "Experiment has been more faithful to the principle [of relative motion] than mathematical physics."[36]

Physicists removed conflict between theory and experiment, that is, between Eqs.(5) and (6), by hand: they proposed hypotheses specifically for the purpose of canceling effects predicted by theory but not observed experimentally. For example, Lorentz's hypothesis of contraction

[32] *Ibid.*, 46–47.

[33] *Loc. cit.*

[34] *Loc. cit.*

[35] Lorentz (1892a).

[36] *VS*, 133.

offers counter-terms to cancel effects expected owing to a body's movement through the ether, thereby explaining the failure of the 1887 Michelson-Morley experiment. Physicists interpreted the quantity v in Eq. (5) as a *causal* agent *causing* such *effects* as the contraction of moving bodies.[37] Such hypotheses as Lorentz's were interpreted as dynamical explanations because the *cause* of their postulated *effects* was assumed to be the interaction between electron's constituting matter with the ether. The goal of an ether-based electrodynamics of moving bodies was to *construct* a principle of relativity for electromagnetic phenomena occurring in inertial reference systems.

Starting in 1892, Lorentz devised variations on the transformations from Newtonian mechanics which he systematized in an 1895 treatise.[38] In the *Versuch* he proposed a new set of space and time transformations specifically for the optics of moving bodies:

$$x_r = x - vt, \tag{7}$$

$$y_r = y, \tag{8}$$

$$z_r = z, \tag{9}$$

$$t_L = t - vx/c^2 \tag{10}$$

where (x, y, z, t) refer to an ether-fixed reference system and (x_r, y_r, z_r, t_L) refer to an inertial reference system, t_L is Lorentz's mathematical hypothesis of the "local time" accurate to order (v/c), and v can be the relative velocity between inertial reference systems or the velocity of an inertial reference system relative to the ether.[39] The real physical time remains $t_r = t$. For the case of radiation propagating in the free ether, the transformation Eqs.(7)–(10), in conjunction with transformations for the electric and magnetic fields, rendered the form of Lorentz's electromagnetic field equations the same as if these equations were expressed in an ether-fixed reference system. The same laws, therefore, for radiation in the free ether held for both systems to order (v/c). So, assuming that a laboratory on the earth is an inertial reference system, then Lorentz's theory agreed with experimental data that, to order (v/c), the velocity of light is always c and independent of any relative velocity between source and observer. Consequently, to this order of accuracy a principle of relative motion can be constructed systematically in Lorentz's theory.[40] In 1895 Lorentz referred to this result as the "theorem of corresponding states,"[41] which rests on the local time. While an undergraduate at the Zurich Polytechnic Institute (ETH) during 1896–1900, Einstein had carefully studied Lorentz's *Versuch*.

In 1899, Poincaré insisted that any differences between t_L and t can be neglected because they are beyond sense perceptions: "In what concerns the difference of local time, that dif-

[37] For details, as well as other examples, see Miller (1981), note 6, Chapter 1.

[38] Lorentz (1895). For details see Miller (1981), note 6, Chapter 1.

[39] *Ibid.*, 82.

[40] Until Lorentz's 1904 electron theory, Lorentz's contraction hypothesis was deemed to be ad hoc. See Miller (1981), note 6, Chapter 1.

[41] Lorentz (1895), op. cit., note 38, 85.

ference is too weak to be appreciated."[42] But after Lorentz's 1904 paper with its version of the local time ostensibly complete to all orders in (v/c),[43] Poincaré took a very different and, at first sight, relativistic position with regard to synchronizing clocks by exchanging light signals. He considers synchronizing two clocks at relative rest in the ether. Observers at these clocks exchange light signals and simply correct for the time differences with terms obtained by dividing the distance between the clocks by the velocity of light.

But the situation is different if the two clocks are in motion relative to the ether. In this case two steps are necessary in order to synchronize the clocks in such a way that they maintain their synchrony despite their motion relative to the ether, while they remain at relative rest with respect to each other.[44] The first step is to replace the distance between the two clocks with

$$l\sqrt{1-\frac{v^2}{c^2}},$$

where l is the "true distance" measured by observers in an ether-fixed reference system and v is the clocks velocity relative to the ether.[45] The true distance l, however, is unknown to the inertial observer all of whose measuring instruments Lorentz contract.[46] The next step is to invoke Lorentz's "ingenious idea" of the local time. In this way the to-and-fro times for the velocity of light is L/c, where

$$L\ (= l\sqrt{1-\frac{v^2}{c^2}},)$$

is the measured Lorentz contracted distance between the two clocks as measured in their inertial reference system. As we have seen above, this is the method used by Lorentz and Poincaré for providing compensating terms for the purpose of explaining the failed ether-drift experiments. There is nothing relativistic about it. This conclusion is further supported by Lorentz's and Poincaré's continued separation of the local time from the true time. As Poincaré writes:

> "The watches adjusted in that way will not mark, therefore, the *true time*; they will mark what we can call the *local time*, so that one of them will gain on the other" (emphasis added).[47]

This is not the synchronicity in Einstein's special relativity.

[42] Poincaré (1901), 532.

[43] Lorentz (1904).

[44] I am juxtaposing here Poincaré's argument in *VS* (p. 133) with details in Lorentz (1909), 224–226, and Poincaré (1912), 43–47.

[45] Lorentz (1909), cit., 224.

[46] Lorentz emphasized this point in Lorentz (1892b), 74. For details see Miller (1981), note 6, Chapter 1. See also Brown (1993).

[47] *VS*, 133.

So, to complete the task of constructing a principle of relativity Lorentz was forced into "accumulating hypotheses",[48] such as the local time and the contraction of moving bodies. In Einstein's special relativity, on the other hand, all of Lorentz's accumulated hypotheses are consequences of an axiomatic principle of relativity.

In 1905 Einstein realized the necessity to go beyond sense perceptions in order to formulate a consistent electrodynamics of moving bodies in which Newton's equations maintain their form with a concept of time other than the one in Eq.(4). But this requires assuming axiomatically the covariance of Newton's second law. Poincaré could never make this assumption because since 1904 he was involved in the grandiose research program known as the electromagnetic world-picture in which Lorentz's electromagnetic theory is the fundamental theory for all matter in motion.[49] Consequently, mechanics would be *deduced* from Lorentz's electromagnetic theory, and subsequently the rest of physics.

The origins of principles, conventions in peril, the unity of science and the ether

An immediate prediction of the electromagnetic world-picture is the velocity dependence of the electron's mass. Although the problem of why experiments failed to detect the ether remained important, any complete explanation of them became secondary to Walter Kaufmann's exciting new data verifying this prediction in 1901.[50] Physicists extended Lorentz's electromagnetic theory to Kaufmann's data. In early 1904 Lorentz offered his own theory of the electron that agreed adequately with Kaufmann's data while also explaining the failure of all known ether-drift experiments, and *hopefully* future ones too.

Poincaré applauded Lorentz's new theory and immediately set about improving it. In September 1904 he called Lorentz's new theorem of corresponding states extended to all orders in (v/c) the "principle of relativity,"[51] which he worded similarly to the principle of relative motion in mechanics. But the status of the principle of relativity was of great concern to him because, after all, might new ether-drift experiments reveal effects of the earth's motion on electromagnetic phenomena? And what about new results from Kaufmann? Poincaré acknowledged that if Kaufmann's data are confirmed there "would arise an entirely new mechanics, which would be, above all, characterized by this fact, that no velocity could surpass that of light..."[52] But despite such radical changes in physics who can doubt that the great principles, such as the principle of relativity, "will not come forth from out of the fray, victorious and intact"?[53]

[48] *Loc. cit.*

[49] See Miller (1981), note 6, Chapter 1 for details and bibliography.

[50] Kaufmann (1901).

[51] *VS*, 132.

[52] *Ibid.*, 132–133.

[53] *Ibid.*, 147.

According to Poincaré the great principles of the physical sciences have their roots in arithmetical reasoning. The very way in which he arranged *La Science et l'Hypothèse* emphasizes his intention of not "tracing artificial frontiers between the sciences."[54] The "unity of nature" was a guiding theme in Poincaré's scientific research.[55] After discussing arithmetic and the importance to it of the principle of mathematical induction, Poincaré passes to geometry whose exact version requires another synthetic a priori intuition: continuous groups of transformations. Considerations of testing geometry bring into play concepts of mechanics. Then there is physics, to which Poincaré referred in 1902 as the "physical sciences," in which the scientist is on less sure ground compared to mechanics.[56]

Are there not unsolved problems in the physical sciences? Conventions are threatened: Carnot's principle (the second law of thermodynamics) is threatened by "Brownian movement"[57]; the principle of relativity can be undermined by future ether-drift experiments; and then there is the unknown nature of "new phenomena" such as

"cathode rays, x–rays, uranium and radium rays."[58] Poincaré conjectured a connection between these new rays and the production of an "electric spark under the action of ultra-violet light," the ultra-violet effect.[59]

In 1905 Einstein solved these three problems in his monumental trio of papers in Volume 17 of the *Annalen der Physik*; the Ariadne's thread running through them is the nature and constitution of light.[60] Although Einstein's approach to these problems differed from Poincaré's, we must take seriously the effect on Einstein that an authority such as Poincaré had when emphasizing their importance.[61]

Much as Poincaré stressed the importance of maintaining the principle of relative motion in mechanics (its contradiction is "repugnant to the mind"), in 1904 he wrote that the "principle of relativity...is irresistibly imposed upon our good sense."[62] Then, as he had done for the principle of relative motion („experiment is the sole source of truth"), Poincaré went on to support the principle of relativity with a reason based on his scientific epistemology:[63] "it is not merely a principle which it is a question of saving, it is the indubitable results of the experiments of Michelson." The empirical component of Poincaré's philosophy of science cannot be overstated. Nor can we neglect its reference to his theory of knowledge in which the

[54] *SH*, 152. See, too, *VS*, 126.

[55] *SH*, 161.

[56] *Ibid.*, 26. See, too, *Ibid.*, Chapter X, "The Theories of Modern Physics."

[57] *Ibid.*, 187.

[58] *Ibid.*, 188.

[59] *Loc. cit.*

[60] See Miller (1981), note 6, Chapter 2, esp. 135–137. See, too, Holton (1973a) and Klein (1967).

[61] In 1904, Einstein had read the 1904 German translation of *SH*. See Einstein (1956), viii.

[62] *VS*, 98.

[63] *Ibid.*, 138.

"sole objective reality consists in the relations of things."[64] Since for Poincaré science is a more refined way of understanding nature than common sense intuition, the "aim of science is not things themselves but the relations between things; beyond these relations there is no reality knowable."[65] But had not every ether-drift experiment failed? So, does not the ether contradict Poincaré's notion of physical reality as well as the principle of relative motion?

No. In fact, the ether fit quite nicely into Poincaré's view of physical reality: the ether is real because it is the connector of electromagnetic phenomena; electromagnetic theories based on an ether reflect closely how prescientific knowledge is constructed, namely, contiguously; and the ether serves to transmit disturbances such as light and electromagnetic forces.[66]

Poincaré elaborated on this point with terminology couched in his theory of knowledge:[67]

> "It may be said, for instance, that the ether is no less real than any external body; to say this body exists is to say there is between the color of this body, its taste, its smell, an intimate bond, solid and persistent; to say the ether exists is to say there is a natural kinship between all optical phenomena, and neither of the two propositions has less value than the other."

Maintaining an ether required Poincaré to soften his aversion for metaphysical quantities which he regarded as quantities incapable of being defined even by in-principle measurement operations.[68] Because although the ether-drift experiments had failed, their failure was explicable by counter-terms whose origin is in the interaction between electrons constituting matter and the ether. These terms serve the purpose of rescuing the principle of relativity in electromagnetic theory. Poincaré permitted scientific advances to alter his philosophical stance.[69] Relativism was essential to Poincaré's theory of knowledge, philosophy of science, and actual scientific practice, too.

The dynamics of electrons

From the end of 1904 into early 1905 Poincaré brought to bear his immense arsenal of mathematics on Lorentz's theory of the electron. As had been the case with Lorentz's previous work on electromagnetic theory there were mathematical errors to clean up, but now

[64] *Ibid.*, 184.

[65] *SH*, 24.

[66] *Ibid.*, 180.

[67] *VS*, 183. The unwary reader can be misled by a rhetorical set of comments Poincaré made on the ether in 1889, and reprinted in Chapter XII of *SH* (pp. 215–216): "Whether the ether exists or not matters little -- let us leave that to the metaphysicians...some day, no doubt, the ether will be thrown aside as useless." However, one ought not jump to a hasty conclusion, because he continues: "But at the present moment the laws of optics, and the equations which translate them into the language of analysis, hold good...It will therefore be always useful to study a theory which brings these equations into connection."

[68] *SH*, esp. 118, where Poincaré writes that in order for any definition of force to be of use "it must inform us how to *measure* force" (emphasis in original).

[69] Similarly, between 1902 and 1904, Poincaré became a realist regarding atoms.

there were deeper matters as well. The key problem was that according to the manner in which Lorentz formulated his theory in 1904, his deformable electron ought to explode under the enormous repulsive forces between its constuent parts. We can glimpse Poincaré's progress on this problem from three letters he wrote to Lorentz during this period. These letters are in the Poincaré Archives which, in the summer of 1976, I had the good fortune to discover in the possession of Henri Poincaré's grandson, M. François Poincaré. I have discussed their content in some detail elsewhere.[70]

The contents of the second letter are particularly revealing for the theme of this essay (see Figure 1). Poincaré writes the Lorentz transformations in their now familiar form and goes on to prove that they form a group if the multiplicative factor l is unity (see Figure 1, at the end of the text).[71]

But lest we conclude from their special relativistic aura that these space and time transformations have anything at all to do with simultaneity, let us stop and inquire into what the space and time coordinates refer to. The primed system of coordinates is a fictitious mathematical inertial reference system in which the equations of electromagnetism (along with certain other transformations for velocity, fields and convection currents) take the same form as if the primed system were an ether-fixed system. The unprimed coordinates refer to an ether-fixed reference system which, according to the failure of ether-drift experiments, cannot be communicated with. So what have we here? We have a reference system with which we cannot communicate related to a fictitious reference system. One cannot do physics in this manner. So, in practice, physicists took the unprimed system to be at rest in the laboratory and the primed system to be an inertial reference system. Of course, the *real physical time* remains $t_r = t$. Their underlying assumption is that the ratio of all velocities relative to the ether with the velocity of light is small.

That Poincaré never changed this interpretation of the Lorentz transformations is clear from a lecture he gave in July 1912 at l'École Supérieure des Postes et des Télégraphes:[72] "In summary, the Lorentz transformation relates a real phenomenon which occurs at x,y,z at the instant t, and an ideal phenomenon which is the image of it and which occurs at x', y', z' at the instant t'." This distinction parallels the one everyone made between real and ideal electrons in the various electron theories under consideration.[73]

A by-product of Poincaré's group-theoretical investigation is a new velocity addition law. But Poincaré never investigated its ramifications in print until 1912, when he proved that two subluminal velocities cannot be compounded to produce a resultant velocity greater than that of light in the free ether, c.[74]

[70] See, Miller (1981), note 6, and Miller (1980).

[71] See Miller (1981), note 6, Chapter 1 for discussion of the various reference systems and transformations used circa 1900.

[72] Poincaré (1912), note 44, 50. These lecture notes were published posthumously.

[73] For details see Miller (1981), note 6, Section 1.14.

[74] *Ibid.*, 61–62.

The very core of Einstein's relativity theory – simultaneity – is never mentioned by Poincaré, neither in these letters nor in "Sur la dynamique de l'électron." But this was not Poincaré's goal which was, as wrote in 1906, a theory in which "everything in the universe is of electromagnetic origin."[75]

Poincaré developed the results mentioned in these three letters in his papers of 1905 and 1906 "Sur la dynamique de l'électron."[76] Einstein's relativity paper was received at the *Annalen der Physik* on 26 June 1905 and published 26 September 1905. There is no historical evidence that Einstein read the 1905 version of "Sur la dynamique de l'électron" before submitting his 1905 relativity paper for publication. Einstein, himself, denied ever having read it at all.[77]

Did Poincaré ever elevate the principle of relativity to a convention?

If one wishes to claim that Poincaré ought to share the accolades with Einstein for special relativity, then it is essential to establish that Poincaré regarded the principle of relativity as a convention. Elie Zahar contends that in *La Science et l'hypothèse* Poincaré[78]

> "had *generalized* this principle by asserting that uniform motion gives rise to no detectable effects whatsoever. He elevated relativity to the rank of a postulate which applies not only to mechanics but also to electromagnetism" (emphasis in original).

After expounding his own version of linguistic conventionalism circa 1977, Jerzy Giedymin concludes:[79]

> "From this point of view one can show – against Poincaré's critics – that it was perfectly possible for him to regard the Principle of Relativity as a conventional statement, which is not falsifiable by any experimental result, and yet to consider giving it up in view of the result of Kaufmann's experiment."

But Poincaré's own writings reveal otherwise.

On attempts to discover any effects on optical phenomena of the earth's motion through the ether, writes Poincaré, "Will anything come of this? I expect not...[80] [Poincaré did not believe that] more precise observations will ever make evident anything other than the relative motion of material bodies."[81] But what if they did? Then, "it would be necessary that there is

[75] Poincaré (1905c), note 4, 131.

[76] See Miller (1981), note 6, esp. Chapter 1, and Miller (1973).

[77] Private communication from Professor Abraham Pais.

[78] Zahar (1989), note 3, 172.

[79] Giedymin (1977), note 2, 299.

[80] *SH*, 181.

[81] *Ibid.*, 182.

an ether in order that these so-called absolute movements should not be their displacements with respect to empty space but with respect to something concrete."[82]

Poincaré's explicit and careful discussions of experimental possibilities for violating the principle of relativity in Lorentz's electromagnetic theory can only mean that in 1902 he did not yet raise this principle to be a convention in electromagnetic theory.

After describing how the "principle of relativity has been valiantly defended,"[83] in 1904 Poincaré concludes that "as yet nothing proves that the principles will not come forth from out the fray, victorious and intact."[84] Are these the words of someone who has raised the principle of relativity to a convention, which is a statement that can no longer be experimentally tested?

Lest I have not yet convinced everyone that the principle of relativity was not a convention for Poincaré, surely quotes from Poincaré's "Sur la dynamique de l'électron" will suffice. At the paper's beginning the tone is one of guarded optimism regarding the principle of relativity in Lorentz's theory of the electron:[85]

> "The impossibility of experimentally demonstrating the absolute motion of the earth *appears* to be a general law of nature; it is reasonable to *assume* the existence of this law, which we shall call the postulate of relativity and to *assume* that it is universally valid" (emphasis added).

I have emphasized the words "appear" and "assume" because Poincaré goes on to write:[86]

> "Whether this postulate, which so far is in agreement with experiment, be later confirmed or disproved by more accurate experiments, it is, in any case, interesting to see what consequences follow from it."

Poincaré goes on to explore what the consequences would be if the principle of relativity were a "general law of nature."[87] That Poincaré does not presently consider this to be the case, he makes abundantly clear:[88]

> "I have, therefore, not hesitated to publish these incomplete results, even though at this moment the entire theory seems to be threatened by the discovery of magnetocathode rays."

Reference is made here, in an admittedly curious way ("magnetocathode rays"), to Kaufmann's most recent data of early 1906 which he claimed disproved the "Lorentz-Einstein

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[82] *Ibid.*, 181. See, too, *Ibid.*, 242.

[83] *VS*, 134.

[84] *Ibid.*, 147.

[85] Poincaré (1905c), note 4, 129.

[86] *Loc. cit.*

[87] *Loc. cit.*

[88] *Ibid.*, 132.

theory" of the electron.[89] If these data are correct, then the principle of relativity in Lorentz's theory is in danger.

It turned out that Kaufmann's data were flawed.[90] But even after Alfred Bucherer vindicated the "Lorentz-Einstein theory" (so-called by everyone but Poincaré) in 1908,[91] Poincaré could still not raise the principle of relativity to a convention owing to the discrepancy of his gravitational theory with the observed advance of Mercury's perihelion. In 1908 Poincaré writes that "this cannot be regarded as an argument in favor of the new Dynamics...but still less can it be regarded as an argument against it."[92] He is an optimist. In 1912 Poincaré maintained the same attitude toward his gravitational theory, and so, too, the principle of relativity.[93]

In summary, the historical evidence is undeniable and crystal clear: Poincaré never elevated the principle of relativity in Lorentz's theory to a convention, as Zahar and Giedymin contend, nor did Poincaré consider giving up the principle of relativity in the face of Kaufmann's data.[94]

Throughout "Sur la dynamique de l'électron," Poincaré emphasized the constructive manner in which covariance is obtained and maintained. As was de rigueur, Poincaré made exactly this point in a letter to Lorentz written in early 1905 where he described how in Lorentz's theory there is "perfect compensation (which prevents experimental determination of absolute motion)."[95] Scientists on the sharp end of scientific research believed that exact, that is, axiomatic covariance, eventually would be constructed as a result of proposing additional compensating terms to explain the failure of future ever-more precise ether-drift experiments.[96]

A Patent Clerk Third Class in Berne, Switzerland, had other ideas.

Einstein and theories of principle versus constructive theories

By 1905 Einstein's results on the nature of radiation had convinced him that the time was not ripe to attempt a grand unified theory based on electromagnetism. Calculations on fluctuation phenomena in a radiation cavity convinced him that light is composed of wave and particle

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[89] Kaufmann (1906).

[90] See Miller (1981),note 6, Chapter 12.

[91] Bucherer (1908).

[92] Poincaré (1908b), 263. Hereafter this book will be referred to as *SM*.

[93] Poincaré (1912), note 44, 64.

[94] See *SM*, 248, where Poincaré suggests a wait-and-see attitude toward Kaufmann's 1906 data. Lorentz, on the other hand, considered Kaufmann's data as having disconfirmed his theory. See Lorentz's letter of 8 March 1906 to Poincaré in Miller (1981), note 6, 336–337.

[95] Cited from the third letter that Poincaré sent to Lorentz during the period late 1904 to early 1905 and produced in its entirety in Miller (1980), 81–82.

[96] For example, see, Wien (1900), esp. 107 and *SH*, 182.

modes. But Lorentz's theory could deal only with wave properties.[97] Consequently, Lorentz's theory could not be the foundation of physics. Einstein "despaired of discovering the true laws by means of constructive efforts based on known facts."[98] By "constructive efforts" he meant "constructive theories," and by "known facts" the failed ether-drift experiments and Kaufmann's data.[99] Constructive theories, such as Lorentz's, explain why phenomena occur by means of assumptions based on the constitution of matter.

Einstein opted for "theories of principle" because they make no assumptions on the constitution of matter.[100] They are based on overarching principles accepted as axioms, which indicate the form that physical laws must assume in order to forbid certain phenomena. An example is the Newtonian principle of relative motion which insists without explanation that theories of mechanics be so formulated that the laws of mechanics remain the same in every inertial reference system.

Einstein's terminology enables us to see clearly that although the principles of relativity of Poincaré and Einstein are worded similarly,[101] their content and intent differ sharply: Poincaré's principle of relativity was the cornerstone of a constructive theory, was never a convention, and refers specifically to an electromagnetic theory of the electron. Einstein's is the cornerstone of a theory of principle and so it is accepted without proof experimental or theoretical, while embracing mechanics and electromagnetism on an equal footing. Consequently, Poincaré's and Einstein's ultimate goals for a principle of relativity differed: Poincaré's was the Lorentz covariance of electromagnetism through constructive methods, while Einstein elevated Lorentz covariance to a mathematical statement of his *axiomatic* principle of relativity. Einstein found that in a theory of principle the counter terms set by hand into Lorentz's theory *emerge* as "secondary consequences," as he wrote in 1907.[102] Whereas in Lorentz's electron theory the ether is essential, in Einstein's special theory of relativity it is "superfluous."[103]

Guided by a theory of principle Einstein moved boldly counter to the prevailing currents of theoretical physics by resolving problems in a Gordian manner. He proposed a view of physics in which certain problems do not occur. For example, he replaced insoluble problems

[97] See, for example, Holton (1973a), note 40, 165–183; Klein (1980) and Miller (1981), note 6, Chapters 2 and 11.

[98] Einstein (1949), 53.

[99] The nomenclature "constructive theory" and "theory of principle" is taken from A. Einstein, "What is the Theory of Relativity?", written for the London Times 28 November 1919. Version in Einstein (1967), 227–232. For discussion of Einstein's formulation of special relativity see Miller (1981), note 6, esp. Chapters 2 and 3.

[100] *Loc. cit.*

[101] Einstein (1905), translated in Miller (1981), note 6, 392–415, 395: "The laws by which the states of physical systems undergo changes are independent of whether these changes of state are referred to one or the other of two coordinate systems moving relatively to each other in uniform translational motion."

[102] Einstein (1907), 413.

[103] Einstein (1905), note 101, 392.

in the *dynamics* of electrons with soluble *kinematical* problems. A good example is how Einstein resolved the inconsistency between Eqs.(5) and (6), or "paradox" as he referred to it some years later.[104] Raising the principle of relativity to an axiom means that Eq.(5) is incorrect and Eq.(6) is exactly correct both theoretically *and* experimentally. This step requires extending our intuition beyond the "known facts" as interpreted within the concepts of space and time in Newton's physics. Poincaré was unwilling to do this.

An important ingredient in Einstein's resolution of this paradox was a thought experiment framed in highly visual terms that he conceived of in 1895, and meditated on for ten years until he realized it contained the "germ of the special relativity theory."[105] Einstein's emphasis on visual imagery was among the factors decisive in formulating special relativity. Poincaré's mode of creative thought was nonvisual.[106]

In summary, working with a theory of principle in which the ether is "superfluous," meant that Einstein essentially announced the failure of all ether-drift experiments past and future as a foregone conclusion, contrary to Poincaré's empirical bias. Special relativity is set in Poincaré's geometrical space and yet makes assertions about phenomena in the world of sense perceptions. A formulation of this sort was unacceptable to Poincaré who advocated a cut between geometrical and representative space. On this point, in 1921, Einstein wrote that Poincaré is correct *sub specie aeternitatus*.[107] But this was beside the point, which was to focus on the practical or rough geometry.

Time and simultaneity in special relativity

Toward Einstein's realizing the relativity of simultaneity, might he have found useful a particularly pregnant comment by Poincaré in *La Science et l'Hypothèse* to the effect that:[108]

> "Not only have we no direct intuition of the equality of two durations, but we have not even direct intuition of the simultaneity of two events occurring in two different places. This is what I have explained in an article entitled 'Measurement of Time'."

We have no proof that Einstein read "Measurement of Time" before mid–1905. As far as I know, it had not yet been translated into German before 1905 and Einstein's French was not exactly *facile* for the purpose of reading philosophical texts. But before inquiring into what Einstein could have learned from this passage, it is important to establish the impact on him of Poincaré's *La Science et l'Hypothèse*.

A close friend of Einstein's from his days in Berne, Maurice Solovine, recalled that in 1904 Poincaré's *La Science et l'Hypothèse* "profoundly impressed us and kept us breathless for

[104] Einstein (1949), note 98, 53.

[105] *Loc. cit.*

[106] On this point, see Miller (1992), note 16.

[107] A. Einstein, "Geometry and Experience," in Einstein (1967), note 99, 232–246, esp. 236.

[108] *SH*, 112.

weeks on end!"[109] Thus, Poincaré's conclusion that we have not "direct intuition of the simultaneity of two events occurring in two distant places" – distant simultaneity – may well have struck a responsive chord in Einstein because of its relation to his other readings in philosophy. From Poincaré, Einstein learned the importance in scientific analysis of moving beyond science *per se* into the realm of sense perceptions, a lesson underscored by his readings in Ernst Mach.[110] But from David Hume, Einstein realized the dangers of this route[111] and so the necessity to realize that the absoluteness of "simultaneity unrecognizedly was anchored in the unconscious."[112] Einstein realized the need to go beyond sense perceptions to an analysis of thought itself, thereby transcending the notion of "direct intuition." In so doing he had to take seriously the consequences for simultaneity of the finite velocity of light.[113] As Einstein recalled in 1907, only by going beyond sense perceptions was he able to conclude that Lorentz's local time is the "physical time."[114] Amongst Einstein's reasons for coming to this conclusion were: the key role played by the local time in systematically explaining the failure of ether-drift experiments accurate to order (v/c) and its use in deducing a new velocity law which agreed with the intuition of the thought experimenter from Einstein's 1895 thought experiment on the measurements made by an observer attempting to catch up with a point on a light wave.[115]

The concept of an "event" is central to Einstein's analysis of time and simultaneity in 1905. In its larger sense, Einstein's event is similar to Poincaré's, namely, a phenomenon occurring at a point in space and time measured relative to a reference system. Might Poincaré's passage quoted above from *La Science et l'Hypothèse* be the source for Einstein's use of the term "event," and for his focusing on the distant simultaneity of two events? The similarity between Poincaré's and Einstein's conclusions on how to distinguish between local and distant simultaneity is astonishing.[116]

Concerning simultaneity and time, in 1905 Einstein took a route entirely different from Poincaré's. Einstein shifted the problem of defining the distant simultaneity of two events to seeking a procedure for synchronizing two distant clocks. Why did he take this route? As far as I know, before 1905 Poincaré was the only one who explored connections between clock synchronization, simultaneity and measurement of the velocity of light. Assuming that Einstein had not read Poincaré's "Measurement of Time" before 1905, or, for that matter, Poincaré's *Électricité et Optique*, then the only other place where Einstein could have seen Poin-

[109] Einstein (1956), note 61, viii.

[110] See, Miller (1981), note 6, Chapter 4 as well as G. Holton, "Mach, Einstein, and the Search for Reality," in Holton (1973b), note 60, 219–259.

[111] See, Miller (1981), note 6, Chapter 4.

[112] Einstein (1949), note 98, 53.

[113] See Miller (1981), note 6, esp. 170, 189, 190.

[114] Einstein (1907), note 102, 413.

[115] This scenario is presented in detail in Miller (1981), note 6, Chapter 3.

[116] Compare *VS*, 49, with Einstein's (1905), note 101, 393.

caré further discuss time is in the paragraph before the one quoted above from *La Science et l'Hypothèse*, where Poincaré writes:[117]

> "There is no absolute time. To say that two durations are equal is an assertion which in and of itself has no meaning, and can acquire one only by convention."

We can assume that the conjunction of this passage, with the previous one concerning simultaneity, in combination with Einstein's realization that Lorentz's local time is the physical time, was what led Einstein to explore clock synchronization using light signals and to *define* the one-way light velocity. We may further conjecture that Einstein explored and rejected alternative experiments with clocks and light signals available to everyone, including Poincaré.

Chief among such alternatives are the following ones.

In "Measurement of Time," Poincaré pointed out the vicious circle in defining time in terms of velocity.[118] Consider a two-clock measurement of the one-way light velocity $c_{\rightarrow}$ in Figure 2, where

$$c_{\rightarrow} = \frac{\overline{AB}}{(t_B - t_A)}, \qquad (11)$$

and $\overline{AB}$ is the distance between two clocks that were synchronized using the velocity of light. Eq.(11) is one equation for three unknowns: $c_{\rightarrow}$, t_B, and t_A.

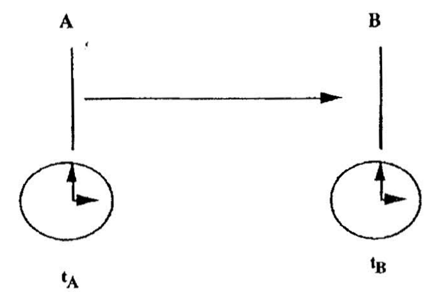

Fig. 2

Figure 2. A one-way, two-clock measurement of the velocity of light. At time t_A, a light ray leaves the source at A, arriving at time t_B. The clocks are separated by a distance $\overline{AB}$.

[117] *SH*, 111.

[118] *Loc. cit.*

equivalent, they are *not* physically equivalent. So the two theories do not cover the same data and no one's notion of conventionalism or underdetermination applies.

One example suffices. Special relativity predicts a transverse Doppler effect and results for stellar aberration which are not possible in Lorentz's theory. The reason is that in special relativity the velocity of light is postulated to be a definite constant independent of any relative motion between source and observer. Contrary to Lorentz's theory, in special relativity this axiom holds in every inertial reference system, thereby eliminating the cumbersome and ambiguous distinction between relative and absolute rays, in addition to avoiding the appearance of unknown velocities relative to the ether.[131]

On the claim by Giedymin, Whittaker and Zahar that Poincaré should share the accolades with Einstein for the special theory of relativity

Having developed what Poincaré accomplished during 1895–1912, in addition to salient points of Einstein's special theory of relativity, we can now comment further on claims that Poincaré is codiscoverer of special relativity.

Giedymin writes that "Poincaré embraced independently a conception of physical theory equivalent to Hertz's."[132] Drawing on his own version of Hertz, Giedymin concludes:[133]

> "A physical theory is a family of observationally equivalent theories which share the same mathematical structure (or: whose mathematical structures are equivalent) and which differ with respect to experimentally indistinguishable ontologies. This conception of physical theory... *explains why [Poincaré] regarded Einstein's (special) relativity theory to be virtually the same as Lorentz's 'new mechanics'*" (emphasis added).

Can Giedymin's claim of an equivalence between the philosophies of Hertz and Poincaré be maintained past 1902? No, for at least two reasons: (1) After 1902 Poincaré became a realist regarding electrons and atoms. This is most unHertzian. (2) While Poincaré's conventionalism recognizes the underdetermination thesis raised by Hertz, Lorentz's "new mechanics" and Einstein's special theory of relativity are not observationally equivalent.

Elsewhere I have explored Whittaker's claim for Poincaré's priority in the controversial Chapter II of his Volume II of *A History of the Theories of Aether and Electricity*, entitled "The Relativity Theory of Poincaré and Lorentz."[134] It is riddled with factual errors. Suffice it to say the reason why Whittaker wrote this chapter has yet to be ascertained.

[131] For details see Miller (1981), note 6, Chapters 1 and 10.

[132] Giedymin (1991), note 2, 15.

[133] *Loc. cit.*

[134] Miller (1987), note 1.

Zahar argues his case in great detail with philosophical and physical acumen in his book *Einstein's Revolution: A Study in Heuristic*, where he writes:[135]

> "In what follows I propose to defend a thesis as brutally simple as Whittaker's, namely that Poincaré did discover special relativity..."

But he fails to convince due, amongst other oversights, to adherence to his mentor Imre Lakatos's, Methodology of Scientific Research Programmes (MSRP).[136] Zahar writes:[137]

> "In connection with Poincaré, we shall find it useful to *reinterpret* his philosophy by adopting a unified standpoint which will give us a synoptic view of his whole position. In other words, we shall carry out a *rational reconstruction* which is not strictly compatible with the detail of all the theses advanced by Poincaré (the conjunction of all these theses is inconsistent) but which affords, in return, a better insight into his conception of the foundation of geometry and of relativity" (emphasis added).

Immediately the historically minded philosopher of science senses problems. Is the "conjunction of [Poincaré's] theses...inconsistent" because they do not square with the "rational reconstruction" required by the MSRP? Zahar contends that a "rational reconstruction" makes it easier to see that "in 1905, Poincaré had gone far beyond the results obtained by Einstein; that, in 1900, he had already given an operational definition of clock synchronization which is usually, but incorrectly, attributed to Einstein."[138] Zahar hopes that his analysis will "redress [the] injustice" of considering "Einstein as the sole founder of [special] relativity..."[139] Let us see why Zahar does not succeed.

Zahar claims that "[i]n a chapter of his [Poincaré's] *Électricité et Optique* (1901), then again in his paper 'Lorentz's Theory and the Principle of Reaction' (1900) [Poincaré] was led to give an operational definition of [the local time] by means of convention, which was later attributed to Einstein."[140] But I find nothing of the case. Instead, in *Électricité et Optique* (1901) Poincaré neglects any differences between the real and local time. I discussed this point in Section 3.

In "Lorentz's Theory and the Principle of Reaction" there is a brief discussion of how two moving observers set their clocks by exchanging light signals. They use the local time "to correct the times of transmissions of these signals."[141] The local time provides corrections in

[135] Zahar (1989), note 3, 150.

[136] Elsewhere I have critiqued Zahar's use of the MSRP for historical and philosophical analysis of relativity in Miller (1974).

[137] Zahar (1989), note 3, 150.

[138] *Ibid.*, 170.

[139] *Ibid.*, 150–151.

[140] *Ibid.*, 171.

[141] Poincaré (1900), note 7, 483.

order that the "signals are transmitted with equal velocity in both directions." This is hardly relativistic.

What we do find in Poincaré's 1900 paper are desperate attempts to save Newton's third law (action and reaction) in Lorentz's electromagnetic theory. Basically the problem is that in Lorentz's theory the ether acts on bodies but not vice versa. Lorentz pointed this out in the 1895 *Versuch*.[142] For Poincaré the situation is exacerbated by the fact that since actions are transmitted with the velocity of light through the ether, then actions are not compensated for simultaneously by reactions.

Any violation of Newton's third law was catastrophic for Poincaré because of its intimate connection with the principles of relative motion and conservation of energy, which Poincaré explicitly demonstrates for any conservative system.[143] Poincaré's first step in dealing with this situation was to widen the law of conservation of momentum to include the electromagnetic field. This enabled him to argue that compensatory forces of unknown origin arise in the ether to cancel the time rate of change of the electromagnetic momentum. These forces preserve Newton's third law *separately* for emitter and detector. Poincaré even proposed experiments to detect the compensatory forces,[144] declaring that now "we believe that we can touch the ether with our fingers."[145] This became another of his reasons for assuming an ether, else we would have to "change all of mechanics."[146]

But further hypotheses were necessary for the more general case of relative motion between an emitter of unidirectional radiation and a detector. As always the local time must be applied to ensure covariance of Lorentz's equations to order (v/c). However, a surprise was in store for Poincaré. Upon calculating the Poynting vector and the energy density of a bounded plane wave (light pulse), he obtained different results for the "apparent" and "real" values of these quantities. "Apparent" quantities refer to inertial reference systems and "real" quantities to reference systems fixed in the ether.[147] As Poincaré put it: "phenomena in relative motion are not exactly the same as in absolute motion."[148]

And indeed they are not, because Poincaré found that apparent and real quantities differ by terms of first order in (v/c). In order to render the real and apparent energies equal, Poincaré postulated yet another "apparent complementary force" for the purpose of canceling the extra terms proportional to (v/c). Now he believed that he could ensure energy conservation in both reference systems. The postulated forces serve as well to preserve action and reaction separately for emitter and detector, as in the case when they are at relative rest in the laboratory.[149] We recall that this procedure is the accepted one of proposing hypotheses for the

[142] Lorentz (1895), note 38, 28.

[143] Poincaré (1900), note 7, 481–482.

[144] *Ibid.*, 488.

[145] *SH*, cit., 181.

[146] *Loc. cit.*

[147] *Ibid.*, esp. 483–485.

[148] *Ibid.*, esp. 484.

[149] *Ibid.*, 486.

purpose of removing unobserved effects predicted by an ether-based electrodynamics of moving bodies.

The thrust of Poincaré's methods in the 1900 paper is of deepest importance when critiquing scholars like Zahar who claim that even in 1900 Poincaré was close to relativity. The reason is that what we see in Poincaré's "La Théorie de Lorentz et le Principe de la Réaction," is confusion over invariant quantities, conserved quantities and transformed quantities. For example, since electric charge is an invariant quantity, it is exactly the same in every reference system. But although energy is a conserved quantity, its value is not necessarily the same in every inertial reference system: energy is not Lorentz invariant.

It turns out that the extra terms containing (v/c) in Poincaré's calculations with the local time should be present because he was the first to deduce the Lorentz transformation equations for the energy of a light pulse and the Poynting vector to this order of accuracy. The full relativistic results were first presented in Sections 7 and 8 of Einstein's 1905 relativity paper. For the purpose of calculating the electron's mass, in "Sur la dynamique de l'électron" Poincaré finally succeeded in deducing the correct Lorentz transformation equations for the energy density of the electromagnetic field.[150] But he attempted neither to explore these results further, nor did he return to his results of 1900 regarding unidirectional pulses of radiation.

Zahar goes on to allude to the importance of Poincaré's discussions of simultaneity in the 1900 paper.[151] But I cannot find any mention of this point. In fact, did not Poincaré propose the "apparent complementary force" in order to avoid the lack of simultaneity of action and reaction?

Now I turn to the more intriguing problem of whether Einstein read Poincaré's 1900 paper before mid–1905? I raise this point because in a paper received at the Annalen on 17 May 1906 entitled, "Das Prinzip von der Erhaltung der Schwerpunksbewegung und die Trägheit der Energie,"[152] Einstein referred to Poincaré's 1900 paper and writes that some of his 1906 results are "in principle"[153] already in it. Despite Einstein's mediocre French, the essence of Poincaré's 1900 paper is in the equations with rather easy to translate intervening text. The link with Poincaré's 1900 paper is Einstein's derivation of the equivalence of mass and energy, $E = mc^2$ using the example of unidirectional emission of radiation by one body and its absorption by another. This case is the one already contained "in principle" in Poincaré's 1900 paper. Einstein's meaning of "in principle" is that Poincaré never attributed an actual decrease in mass to the emitter. Nor did Poincaré deal with actual radiation but a "*fluide fictif*".[154]

[150] Poincaré (1906), note 4, 152–153. For further details see Miller (1973), note 76., esp. Section 6.7.

[151] Zahar (1989), note 3, 171.

[152] Einstein (1906), note 8.

[153] *Ibid.*, 627.

[154] See Poincaré (1900), note 7, 468. Whittaker erroneously claims this to be paper where Poincaré discovered the mass-energy principle before Einstein, see Whittaker (1953), Vol. II, note 1, 51. For commentary see Miller (1987), note 1, 97–98.

Nevertheless, the affect of Poincaré's calculations using Lorentz's local time for the radiation from moving emitters could well have been one more piece of evidence for Einstein that the local time is the "physical time," in addition to suggesting to Einstein another problem to which he could apply his *own* special theory of relativity.

Concluding comments

The verdict of archival and primary historical evidence is that Einstein, and not Poincaré, is the discoverer of the special theory of relativity. The codiscovery, or priority, issue turns out to be (no pun intended) relativistic – relative to philosophical reconstructions or frameworks which do not square with extant historical documents. When I discovered the Poincaré archival material in the summer of 1976, I thought to myself wouldn't it be amazing if there were a letter from Einstein to Poincaré expressing gratitude for what he learned before mid–1905 from "Measurement of Time," among others of Poincaré's essays. Apparently no such communication exists.

At no time during 1905–1912 did Poincaré and Einstein ever engage in priority disputes, nor did Einstein ever respond to claims that Poincaré was the codiscoverer of special relativity. For example, Einstein was nonplussed regarding Max Born's concern over the impending publication of Whittaker's Volume II.[155]

We have found that Poincaré's accomplishments and conclusions in 1905 are:

1. Poincaré almost discovered the relativity of simultaneity. But he did not succeed owing to reliance on sense perceptions in addition to his conventionalism which embraced a desire for descriptive simplicity of Newton's laws under what turned out to be inappropriate space and time transformations, Eqs.(1)–(4).

2. During 1904–1912 Poincaré was not interested in a theory of space and time, but sought a grand unified theory of the then known forces based on Lorentz's theory of the electron.

3. Although worded similarly, the principles of relativity of Poincaré and Einstein differed in content and intent.

4. Poincaré never elevated the principle of relativity in the physical sciences to a convention, nor did he ever disavow the ether.

5. Emphasis on conventionalism, or the underdetermination thesis, while ignoring the ramifications of Einstein's special relativity for the optics of moving bodies, led Poincaré and Lorentz to continue to believe in the mathematical *and* observational equivalence of special relativity and Lorentz's electron theory. This is incorrect.

This summary list is the reply to the question posed in the title of this paper. Giving up the ether was a possibility that Poincaré and most others of his generation would never have entertained. It formed the basis of the most successful theory of their lifetime, the Maxwell-Lorentz theory of electromagnetism with its weighty dependence on abstracting from phenomena we have actually witnessed in the world of sense perceptions. If light is a wave phenomenon then something in space and time must undulate. After all, how can we contemplate water waves with no water? That this sort of reasoning must be discarded is one of special relativity's lessons.

[155] See Miller (1987), note 1, 94.

Attempting to conflate the research of Poincaré and Einstein confuses issues, obscures Poincaré's achievements in 1905, and ignores the important topic of what Einstein might have learned from Poincaré's papers, particularly concerning the notion of events, distant simultaneity, the importance of attributing a physical interpretation to the local time, the structure of science, frontier issues in physics, and the physics of light pulses emitted from moving sources. This information may well have been significant to Einstein's formulation of the special theory of relativity.

Poincaré's death at age fifty eight was truly premature. Like French wine he improved with age. Imagine if he had lived to see Einstein's generalized theory of relativity in 1915. Being the great physicist and philosopher he was, I believe that Poincaré would have altered his conventionalistic stance on geometry and physics. And who knows what contributions he might have made to general relativity?

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