On Writing the History of Special Relativity[1]

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Einstein himself had a few words to say about the writing of the history of science. From the first of his famous conversations with Einstein, Robert Shankland relates: "Then he gave me his ideas on historical writing of science. 'Nearly all historians of science are philologists and do not comprehend what physicists were aiming at, how they thought and wrestled with their problems... .' The struggle with their problems, their trying everything to find a solution which came at last often by very indirect means, is the correct picture." (Shankland 1963, p. 50).

Why should we take these words seriously? After all, Einstein was not an historian, and, unless we are to pose him as an authority on every topic, these comments represent but a personal opinion. This, however, is precisely why they should be taken seriously, if we are interested in the history of Einstein's own accomplishments. For as a generalization, they are based principally on a single case, viz. that of the master himself. It remains for us to decide what sort of account of the genesis of the special theory of relativity would faithfully exemplify these remarks.

PSA 1982, Volume 2, pp. 403-416

In contrast to the development of general relativity, which is well documented in a series of increasingly technical papers over roughly a ten year period and by an extant and voluminous contemporary correspondence, the foremost difficulty in reconstructing Einstein's path to the special theory is the near vacuum of corresponding documents. No ancestral manuscripts are available, and only a handful of letters from 1905 or before either have survived or were even written. Most of what counts as external evidence is in the form of later reminiscences addressed to questions of genesis or of occasional comments embedded in lectures or subsequent articulations of the theory.

With respect to the first of these two categories of evidence, Einstein himself reminds us in his "Autobiographical Notes", written at the age of sixty-seven, "Every reminiscence is colored by today's being what it is, and therefore by a deceptive point of view." (1949, p.3). In addition to the significance conferred on the past by intervening developments, there is, no doubt, a psychological aversion, after having painfully struggled to achieve a new point of view, to attempt to recreate the preceding stages of confusion and partial understanding.

With respect to the second category of evidence, there is the additional problem of discerning what is intended as personal history and what is the result of convenience of exposition. For example, in his first review essay on special relativity Einstein remarks, "Surprisingly, however, it proved only necessary to grasp the concept of time sharply enough... . All that was needed was the recognition that an auxiliary quantity introduced by H. A. Lorentz, which he called 'local time', can simply be defined as 'time'." (1907, p. 413). The importance of the analysis of simultaneity for Einstein is too well documented to doubt that there is *some* autobiography behind this passage. But can we take seriously the claim that this was "all that was needed", or is this merely an indication of how facile in retrospect the transition to special relativity appears? Can we infer that Lorentz's 'local time' played the genetic role that a *de dicto* reading of its context suggests, or rather is its context *de re*, indicating only that Einstein realized that a quantity equivalent to Lorentz's 'local time' could be defined as 'time'? If in May of 1905 Einstein was unaware of (Lorentz 1904), then only the *de re* reading is licensed, since the expression for 'local time' in the *Versuch* (Lorentz 1895) cannot "simply be defined as 'time'" in special relativity.

The problematic character of later testimony is rendered more acute by the fact that on several important points it is not self-consistent. This is why Grünbaum (1961, 1963, 1973) on the one hand and Polanyi (1958, 1961) and Holton (1969) on the other could continue to debate the significance of the Michelson-Morley experiment, each side citing testimony that would have been considered almost conclusive in the absence of contravening testimony. Clearly the evidence of later commentary and reminiscence must be evaluated on the basis of criteria of coherence. The only foundations are the few documents from 1905 and before, and thus the 1905 paper itself must bear the greatest weight. It is surprising then, given its overriding evidential importance, that this text has not received more attention. For its structure and contents raise a series of crucial questions. What are the relations between its various sections? Why are Maxwell's equations with and without sources treated separately? Why does the introduction motivate only the principle of relativity and not the principle of the source-independence of the velocity of light? What governs the choice of the optical applications found in sections seven and eight? Why is the powerful velocity addition rule used but once in the entire paper? Why does the final section on the dynamics of the electron appear, in the words of Miller "almost as an after thought" (1981, p. 332)? Why is the professed theme of the paper the asymmetries of electromagnetic induction and the problem of the action of the field on moving charges, instead of the nature of simultaneity and relativistic kinematics? In other words, why is the paper titled "On the Electrodynamics of Moving Bodies" and not, say, "A New Kinematics Based on the Conventional Character of Simultaneity, With Applications to Electrodynamics and Optics"? Unless these types of questions are seriously addressed, little if any real progress can be made in deciphering the genesis of special relativity at the hands of Einstein.

The type of impasse which currently exists is well illustrated by the higher level disagreement between Grunbaum and Holton. Grünbaum insists that unless Einstein's creation of the theory admits a reconstruction scrutable from a methodological perspective, then "the theoretical guesses of an Einstein [cannot] be regarded to have been genuinely more *educated*, as opposed to just more *lucky*, than the abortive fantasies of those quixotic scientific thinkers whose names have sunk into oblivion." (1963, pp. 377-8). Holton, taking to heart Einstein's *dicta* on the writing of the history of science, warns that "the empiricist fallacy of imposing a logical sequence must be resisted." (1969, p. 329). Why these two writers should be at odds, as they consciously are, is not clear. Why can't we have a methodologically scrutable account which also exemplifies Einstein's "struggle with [his] problems, [his] trying everything to find a solution which came at last...by indirect means"? The answer lies in a shared presupposition.

In contrast to Einstein's first publication of 1905, which does not present a *theory,* but instead gives a sustained argument for a "heuristic point of view", viz., light quanta, the 1905 relativity paper *does* lay out a theory in the sense of an articulated, axiomatically based system of propositions constituting a new and complete kinematics, which, when conjoined with electrodynamics and mechanics, bears many new consequences for these.[2] Although everything issues ultimately from the fountainhead of the two postulates and the definition of simultaneity, the main lemma, as it were, explicitly used in every subsequent application, is the set of Lorentz transformations. These, it would seem, presuppose the recognition of the relativity of simultaneity in accord with the epistemological analysis given in the published paper. It is difficult to imagine a sequence of discovery which does not reflect this logical heirarchy. A number of independent sources establish that the discovery of the relativity of simultaneity preceded the completion of the relativity paper by some five or six weeks. In 1952 Einstein wrote to Seelig, "Between the conception of the idea of this special relativity theory and the completion of the corresponding publication, there elapsed five or six weeks. But it would be hardly correct to consider this as a birthdate because earlier arguments and building blocks were being prepared over a period of years, although without bringing about the fundamental decision." (Holton 1967-8, p. 197).

The presupposition shared not only by Holton and Grünbaum, but also by most others, is that these "earlier arguments and building blocks" do not represent enduring theoretical results which eventually found their place in the body of the 1905 publication, since all *these* -- the Lorentz transformations, the field transformations, the optical applications, the dynamics of the electron, etc. -- ensued from the discovery of the relativity of simultaneity by and large in the manner suggested by the text. Thus, the principal historical project, apart from elucidating the background of Einstein's predecessors and contemporaries, is perceived to be that of reconstructing what these consequently obscure arguments and building blocks, which precipitated the discovery of the relativity of simultaneity, could have been.

Returning to the Grünbaum-Holton debate, any methodologically scrutable scenario, since it can now incorporate the "struggle", the "trying everything", the "solutions which came...by very indirect means" in only a wholly arbitrary, adventitious way, must portray Einstein thinking almost syllogistically toward the desired conclusion. But, as Wertheimer reports Einstein to have remarked, "No really productive man thinks in such a paper fashion." (Wertheimer 1945, p. 229). Consequently Holton deems that we must find a new way to reconstruct such episodes, in which "evanescent, partly unconscious, unobserved, unverbalized activity--is by definition going to yield a report with apparently vague and contradictory elements." (1969, p.328). We must consider "the problem of genius, of reasons for thematic and aesthetic choices, of interaction between private and public science, not to speak of the problem of induction." (1969, p.328) Miller, articulating Holton's vision, affirms "that a truly interdisciplinary approach is required, one taking account of such apparently disparate fields of scholarship as physics, mathematics, psychology, philosophy, and sociology." (1975, p. 95). The broadly holistic tone suggests that the "experimenticist fallacy" is not so much that of imposing a *logical* sequence, but that of imposing any sequence at all! But no tapestry of suggested sources and influences, of thematic unities, of aesthetic motifs, or of vaguely articulated affinities, no matter how artfully woven, adds up to an historical account. Theories are created by individuals who ratiocinate over time. And although an individual can, and usually does, entertain several, often interacting lines of thought simultaneously, nonetheless these ratiocinations are sequential. To say how a theory emerged just *is* to posit a sequentially ordered causal net of such ratiocinations coincident with the life of the theory's creator.

Thus, the common presupposition would impale us on one or the other horn of the resulting dilemma--either we give a scrutable but straw man reconstruction, or else an inscrutable non-account. The dilemma, however, is only apparent. Einstein's comments to Seelig do not deny that these "earlier arguments and building blocks" in fact became substantive elements of the final theory. It is entirely consistent to suppose that, prior to the discovery of the relativity of simultaneity, Einstein might have had in his possession the Lorentz and field transformations and that he had even applied these to areas of especial contemporary interest, e.g., the dynamics of the electron, or the behavior of light "complexes". No one can doubt the pivotal importance of the discovery of the relativity of simultaneity, but nowhere is there evidence which establishes it as the point of inauguration of all positive theoretical articulation, as opposed to, say, the critical transition point at which correct, but fragmented and foundationally insecure bits of theory suddenly gelled into place in light of his analysis of simultaneity. Einstein's locution, "the conception of the idea of this special relativity theory", refers then to this solidification into a foundationally secure theory of universal validity.

Our suggestion to interpret this remark to Seelig in this fashion is not a caprice. There are at least four major considerations which demand it and which in turn present insurmountable difficulties for the customary point of view.

1) *Considerations of Timing.* In the spring of 1905 Einstein had strong conflicting demands on his time. His first child was then a year old. Einstein's son-in-law reports that as a matter of routine "he could be seen carefully wheeling a baby carriage through the streets of Bern." (Reiser 1930, p. 67). His job at the patent office consumed forty-eight hours a week, and as Martin Klein has noted "contrary to what is sometimes suggested, this job kept him busy--'eight hours of exacting work every day'--as he described it to Stark." (1967, p. 513). Moreover, there is no indication that the intensity of his social life waned from the pace set by the 'Olympia Academy'. In all probability, by the spring of 1905 Einstein preferred to channel his conversations into discussion of his current research, using individuals such as Michele Besso and Joseph Sauter sometimes as therapists for his occasional fits of theoretical neurosis (as it appears Besso functioned in the discovery of the relativity of simultaneity), and also as surrogate adversaries against which to gauge the strategy necessary to get his point across. Sauter recalled that in the spring of 1905 "I pestered him for a whole month with every possible objection." (Seelig 1954, p. 73). Einstein had a set of notes to give to Sauter at the beginning of this period, and in a letter to

Conrad Habicht he refers to the relativity work as "im Konzept", i.e., in first draft or note form, thus suggesting a more protracted evolution of the manuscript than the standard account would like to imagine.

Proponents of the standard account will no doubt point to the rapid rate at which Einstein turned out articles in the spring of 1905 as evidence that he could have produced the special theory of relativity in its entirety in five weeks. But this requires misrepresenting these other publications as entirely independent investigations worked out seriatim. Einstein was a genius, but it makes no more sense to postulate a miracle of a genius than of a non-genius.

2) *Psychology and Epistemology*. The standard account, because it grants chronological priority to the discovery of the relativity of simultaneity, and thus to purely kinematical considerations, forces us to imagine that Einstein navigated unwaiveringly past the shoals of apparent paradoxes and absurdities that continue to set aground intelligent minds, prior to any definite assurance of the appropriateness of this kinematics for the solution of problems in optics and electrodynamics. On the other hand, the discovery of the relativity of simultaneity is understandable, because it is naturally motivated, if dynamical considerations mandated a definite nonclassical group of coordinate transformations which then incited a reexamination of fundamental kinematical concepts. Epistemological analysis alone reveals only the conventional character of simultaneity (a feature already appreciated by Poincare). Without a mathematically consistent rival to classical kinematics, the further *factual* question as to which different conventional criteria of synchronicity can be expected to agree or disagree receives no answer other than the customary classical judgment. Some ground must be present to perceive the exchange of light signals as *physically* adequate and clock transport as *physically* inadequate.

3) *The Asymmetries of Electromagnetic Induction*. The problem of the nature of the force acting on a charge in motion through a magnetic field is the single most important factor in the genesis of special relativity cited by Einstein. This is unequivocally attested to by three independent sources widely separated in time: (i) the 1905 paper itself, (ii) an unpublished essay written in 1919, and (iii) a letter to Shankland dated from 1952. In contrast to the situation with respect to the role of the Michelson-Morley experiment, there is no contravening testimony to compromise these sources. The account in (ii) establishes that the conception of the relativity of the electromagnetic field preceded the discovery of the relativity of simultaneity by at least a year. Why the electromagnetic asymmetries should have persisted as the preponderant consideration, instead of optical null results, for example, is mysterious unless they were responsible for the gaining of definite ground. That this should have been the case is apparent from the fact that, unlike the optical null results, whose interpretation with respect to the principle of relativity is unproblematic (what they make problematic is the consistency of the principle of relativity with the light postulate), the electromagnetic

asymmetries pose a direct challenge to the principle of relativity itself. For to coherently entertain the thesis that the electric and the magnetic fields by themselves have only a relative existence, an assurance is needed that there exist field transformation equations consistent with the principle of relativity. But this is not a problem which vexed Einstein in May of 1905, for by then he was quite settled on the legitimacy of the postulate. Hence, unless we deem Einstein's conception of the relativity of the electromagnetic field quixotic, this initial problem must have been addressed and settled prior to the spring of 1905. And, if the asymmetries of induction are appreciated with respect to "magnetomotive" as well as "electromotive" forces, then the only resolution is the discovery of the relativistic field transformations.

4) *Internal Evidence*. If sufficient attention is paid to the structuring and stylistic vagaries of the text of the 1905 paper, it becomes manifest that it does not represent a single piece of sustained composition, as would have been the case if the entire positive theory emerged in only a five week period. The final §10 on the dynamics of the electron is oddly connected with what precedes it. Most saliently, it directly contradicts the definition of 'electron' provided in §9 immediately before it. This suggests that §9 and §10 were drafted at markedly separate times and later juxtaposed. §10, however, cannot be the final addition, since the introduction and §6 (resolving the electromagnetic asymmetries and demonstrating the covariance of Maxwell's equations for free space) anticipate every detail of § 10. This degree of foreshadowing is uncharacteristic of the remainder of the text. In fact, if the introduction, §6 and §10, with appropriate modifications, are lifted from the text and set together, there emerges a remarkable unity, as though these three sections originally stood together as a separate essay on the purely electrodynamical aspects of the theory of relativity, now with the fully appropriate title "On the Electrodynamics of Moving Bodies." Only one significant alteration need be supposed: that it included a derivation of the Lorentz transformations from the field transformation equations.

The hypothesis of such a proto-manuscript drafted before the discovery of the relativity of simultaneity is not outlandish. Side by side comparison of the 1907 review essay and the original 1905 paper establishes that the procedure of editing in verbatim, or nearly verbatim, previously drafted material was characteristic of Einstein. Furthermore, if such a proto-manuscript existed, a number of otherwise perplexing peculiarities of the 1905 paper became explicable.

(a) Of the theory's two postulates, only the principle of relativity receives discussion. The statement of light postulate appears almost parenthetically inserted in the introduction. The light postulate, however, was not a separate supposition in the proto-manuscript, since the Lorentz transformations were not derived independently of Maxwell's equations. The light postulate actually *is* a later insertion in the introduction.

(b) There is no logical reason to devote separate sections to Maxwell's equations for free space (§ 6) and Maxwell's equations with sources (§ 9), and the natural procedure would have been to treat just the general case, as Einstein did in his 1907 review essay. But if §6 had been written before Einstein knew how to treat Maxwell's equations with convection currents, it would have been far simpler, and logically innocuous, to add a treatment of the general case as a separate section.

(c) The velocity addition rule, despite the fact that it is commonly heralded as central to Einstein's resolution of the apparent incompatibility between the principle of relativity and the light postulate, plays a decidedly minor role in the paper. The apparent incompatibility of the two postulates is dispelled even before the derivation of the Lorentz transformations is completed, and the addition rule is used but once--in the treatment of Maxwell's equations with convection currents (§9)--although we might have expected its direct application to problems that admittedly concerned Einstein, viz., aberration and Fizeau's result. This is understandable, however, if the order of discovery is on the whole that of dynamics before kinematics in contrast to the standard account. The velocity addition rule represents then, as it were, the penultimate result, followed only by its application to Maxwell's equations with sources.

For the considerations adduced above to be fully appreciated, further documentation and amplication on key points are required. In particular, it is incumbent on us to propose a detailed reconstruction of the hypothetical proto-manuscript and to show precisely how one can simply and naturally derive the exact relativistic field transformations from the facts of induction and the principle of relativity alone. These we can provide, but, for reasons of space have reserved for other publications. Our principle task here is to call into question the received view. Even if one does not accept some of our substantive proposals, e.g., the existence of the proto-manuscript, the view that the "earlier arguments and building blocks" referred to by Einstein consist of major elements of the final theory cannot be regarded as just an interesting speculation. Unless complete agnosticism is to be embraced, a choice must be made. The received view is no less speculative, and, we have urged, far more problematic than the one we are advocating. We hope that it will at least be realized that its basic tenets cannot be assumed, but must be argued for.

Naturally, our view will be much more palatable if we can provide a definite scenario that details every stage of the genesis of special relativity. Unfortunately, if this can ever be accomplished, we do not possess at this time a complete model which answers every question that can be asked. Nonetheless, we believe there are enough fixed points to sketch an outline that answers the most salient ones.

Our account should not diverge significantly from an adequate one given on the basis of the customary view for the years prior to 1903, since it is in that year that Einstein began achieving partial solutions to the problems that motivated special relativity. Questions concerning aether and matter, and in particular, motion through the aether, had concerned him for a number of years. But in January of 1903 he wrote to Besso expressing an intent to undertake a thorough study of the electron theory. The most important area of research for the newly emerging 'electromagnetic world view' was the dynamics of high speed electrons. Impressed as he was by Lorentz's *Versuch* and the subsequent successes of the electron theory, Einstein nonetheless found certain features of it fundamentally objectionable. One of these was its inability to naturally account for the stability of a finite electron without the introduction of non-linear field equations. A second was its failure to conform with the principle of relativity, which Einstein had already become inclined to accept. Inspired by Abraham's (1902, 1903) investigations on the dynamics of the electron, Einstein asked whether it might be possible to satisfactorily treat this problem in conformity with the principle of relativity, treating the electron as a point charge, and using only linear field equations, viz., the Maxwell-Hertz equations. Had the asymmetries of electromagnetic induction previously vexed him, he now had additional reason to be suspicious. Abraham's entire approach was determined by the fact that the Lorentz force does no work, as Abraham himself explicitly emphasized (1902, p. 21). This is Einstein's specific complaint in the opening of the 1905 paper against the current understanding of electrodynamics--that there exist electromotive forces "to which in [themselves] there exists no corresponding energy." Einstein's response, of course, was the insight that the fields could be regarded as having only a relative existence. The necessary transformation equations followed uniquely by requiring that empirically adequate first order approximations conform with the principle of relativity. These then determined the Lorentz transformations as the set of coordinate transformations under which the Maxwell-Hertz equations would covary. Deferring questions as to the interpretation of these non-standard coordinate transformations, Einstein forged ahead to see what sort of dynamics of the electron would result.

All this was accomplished by late 1903 or early 1904, and was written up, constituting what we have referred to as the proto-manuscript. At first blush, this seems too much to grant Einstein at such an early date. But he really had no idea of what he had accomplished. He certainly thought little enough of this work not to submit it for publication. The extant data did not support his approach over Abraham's, and there was nothing else to recommend it apart from his conviction in the relativity of the field. The necessity for these non-standard coordinate transformations in fact appeared to be, more than anything, an indictment of the Maxwell-Hertz equations. Moreover, by March of 1904 Einstein had obtained, on independent thermodynamical grounds, evidence for the fundamental invalidity of these field equations. Thus, during 1904, he sought a constructive replacement to Maxwell's theory.

This period of "constructive efforts" included an examination of emission theories, which did not satisfy the light postulate. Presumedly, Einstein also demanded that candidates be adequate to the peculiarities of the thermodynamics of radiation which he had unearthed. Having no success, he nevertheless had developed sufficient arguments to propose his "heuristic viewpoint" concerning quantization of the field. By the spring of 1905 Einstein also had ruled out in principle the possibility of an emission theory. Thus, the Maxwell-Hertz equations ought at least to adequately describe the time-average behavior of the field. And if the principle of relativity is valid, this entails that the number of light quanta per unit volume must be an invariant. Applying the transformation equations derived in the proto-manuscript to light "complexes", Einstein found, remarkably, that the energy and frequency transform according to the same formula. (these calculations form the basis of §§ 7 and 8 of the 1905 paper.) Thus, Einstein sensed he was in possession of something of great power, if only it could be understood whether, and on what basis, the non-standard kinematics required could justifiably supplant the seemingly *a priori* given kinematics of classical mechanics. The task was not easy, for the dilemma which had originally forced him to investigate emmission theories remained: how can the velocity of light be independent of the motion of its source if the principle of relativity is valid? As Einstein is recorded as explaining this in the 1922 Kyoto address, "...this constancy of the velocity of light is inconsistent with the law of addition of velocities already known from mechanics." (Stachel 1981, p. 11). The solution did *not* lie in the derivation of a new velocity addition rule, for the problem was not one of *mathematical* consistency. The existence of the Lorentz transformations sufficiently allayed any suspicion of a *formal* inconsistency between the principle of relativity and the light postulate. The issue was one of *interpretation*. These postulates appeared to be *physically* inconsistent, since there seemed to be no way of understanding a law of velocity addition *other* than the Galilean.[3]

The record of the Kyoto address continues:

> But a friend of mine living in Bern (Switzerland) helped me by chance. One beautiful day, I visited him and said to him: "I presently have a problem that I have been totally unable to solve. Today I have brought this 'struggle' with me." We then had extensive discussions, and suddenly I realized the solution. The very next day, I visited him again and immediately said to him: "Thanks to you, I have completely solved my problem."
>
> My solution actually concerned the concept of time. Namely, time cannot be absolutely defined by itself, and there is an unbreakable connection between time and signal velocity. Using this idea, I could now resolve the great difficulty that I previously felt.

After I had this inspiration, it took only five weeks to complete what is now known as the special theory of relativity. (Stachel 1981, pp. 11-12).

The completion then consisted in (i) working out the 'Kinematical Part' (§§ 1-5), (ii) changing the derivation in § 6 so that the field transformations followed from the Lorentz transformations, rather than *vice versa* as in the proto-manuscript, and (iii) showing in § 9 that "the electromagnetic basis of the Lorentzian electrodynamics and optics of moving modies" remains consistent with the principle of relativity when suitably reinterpreted, carrying over Lorentz's definition of electrons as "electric charges invariably coupled to small rigid bodies". The original introduction to the proto-manuscript was deemed still appropriate, with minor additions, as an introduction to this greatly expanded work. And, if Einstein was aware of or worried by the conflict between the definitions of 'electron' in § 9 and in his dynamics of the electron, he thought it innocuous enough to retain his original treatment of the dynamics of the electron as a suitable culmination.

Does this sound like the way a physicist would think and wrestle with his problems, try everything to find a solution which came at last by very indirect means? We think so, more than any other outline that has been offered of the genesis of special relativity. No doubt other accounts are possible along the lines we are suggesting. But, we contend, it is no longer possible to rest content with the received view or to take refuge in ineffability. Let us try our best to "comprehend what physicists were aiming at."

Notes

[1]Robert Rynasiewicz would like to acknowledge the support of the Andrew Mellon Foundation for postdoctoral fellowships held with the Department of History and Philosophy of Science, University of Pittsburgh and with the Sage School of Philosophy, Cornell University.

[2]Holton contends that "the style of the...papers is essentially the same," (1960, p. 168; 1980, pp. 54-55), where by "style" he clearly means to include argument structure. Indeed, there are salient affinities in the style of thought, particularly with regard to the opening statements of asymmetries, but Holton's statement is true only if we blur important differences.

[3]The problem can be put as follows. If at t=0 a spherical light pulse is emitted from the origin of a "stationary" frame, the two postulates (entailing the denial of the Galilean addition rule) require that the shape of the light pulse be a sphere about a point at rest in a "moving" frame of reference which coincided with the origin of the "stationary" frame at t=0. But how can two distinct points both be the geometric centers of one and the same sphere? That a sphere has

a unique geometric center appears to demand the Galilean rule. The fact that in § 3 of the 1905 paper Einstein uses this example to dispell the "apparent irreconcilability" of the two postulates suggests that he thought of the dilemma specifically in these terms.

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