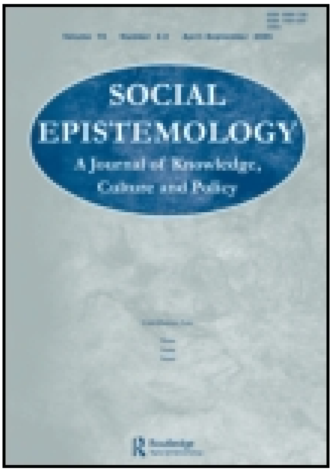

Social Epistemology: A Journal of Knowledge, Culture and Policy
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/tsep20

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Published online: 24 Mar 2009.

To cite this article: Peter Hayes (2009) The Ideology of Relativity: The Case of the Clock Paradox, Social Epistemology: A Journal of Knowledge, Culture and Policy, 23:1, 57-78, DOI: 10.1080/02691720902741399

To link to this article: http://dx.doi.org/10.1080/02691720902741399

Social Epistemology
Vol. 23, No. 1, January–March 2009, pp. 57–78

The Ideology of Relativity: The Case of the Clock Paradox

Peter Hayes

In the interwar period there was a significant school of thought that repudiated Einstein's theory of relativity on the grounds that it contained elementary inconsistencies. Some of these critics held extreme right-wing and anti-Semitic views, and this has tended to discredit their technical objections to relativity as being scientifically shallow. This paper investigates an alternative possibility: that the critics were right and that the success of Einstein's theory in overcoming them was due to its strengths as an ideology rather than as a science. The clock paradox illustrates how relativity theory does indeed contain inconsistencies that make it scientifically problematic. These same inconsistencies, however, make the theory ideologically powerful. The implications of this argument are examined with respect to Thomas Kuhn and Karl Popper's accounts of the philosophy of science.

Keywords: *Einstein; Twin Paradox; Antirelativism*

In 1919 Arthur Eddington led a scientific expedition to make light-deflection measurements during an eclipse to test Albert Einstein's theory of relativity. The accuracy of the scientists' work is now seen as problematic; they made errors "as great as the effect they were trying to measure", and the outcome was either "sheer luck, or a case of knowing the result they wanted to get" (Hawking 1988, 36–37; see also Brown 1977; Marmet 1997, 189–196). At the time, however, the results were presented as a decisive confirmation of relativity theory and Einstein achieved worldwide fame. One of his admirers, a youthful Karl Popper, was inspired to develop his own idea that scientific advance depended on the willingness of scientists to honestly test falsifiable theories, a fundamental insight on which he built his distinction between the open and the closed society (Popper 1963, 34–37). Not everyone, however, was so impressed. In a public meeting in 1920, the theory of relativity was challenged, Eddington's results called into question, and the clock paradox used to illustrate how the theory ended in absurdity.

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ISSN 0269–1728 (print)/ISSN 1464–5297 (online) © 2009 Taylor & Francis
DOI: 10.1080/02691720902741399

This meeting was only the beginning of a series of attacks on Einstein's theory as, throughout the interwar period, a substantial number of academic critics maintained that relativity theory was an ideological imposition masquerading as science.[1]

Einstein attended the 1920 meeting in which his theories were rubbished. Afterwards he responded that such criticism of his work was politically motivated. He argued that almost all theoretical physicists of any note recognised that the theory of relativity was both logical and experimentally supported, but because he was "a Jew of liberal international views" he was being attacked by German nationalists and Nazi sympathisers. He admitted that his critics included the physics Nobel Prize winner Philipp Lenard, but said that Lenard's objections to the theory were superficial. As for the clock paradox, the claim that any attempt to make it consistent with relativity lead to nonsensical results had been refuted by "the best experts of the theory" (Einstein 2001). These comments by Einstein have helped to define the widely accepted account of how the controversy that greeted his theory of relativity assumed ideological dimensions. Supporters of the theory were seen as having natural political affinities: they were scientists, liberals, progressives. The opponents were also seen as having overlapping political affiliations as conservatives, anti-Semites and Nazis. It was claimed that these antirelativists had only a shallow understanding of a complex theory in which they were eager to find errors as part of their broader ideological agenda. The usual argument concludes that the antirelativists have now been discredited. The science of the open society has triumphed over the ideology of the closed society.

Here we explore an alternative view of these events. The meeting of 1920 certainly indicates that relativism was quickly becoming embroiled in political and social arguments but these were debates in which *both* sides placed personal and political loyalties high. The result, for supporters of relativism, was that the theory became seen as part of a package, so that the logical problems in the theory were overridden by the social impetus to take sides. This raises the question of how certain we can be that the antirelativists were the ideologues and the relativists the scientists. It is at least conceivable that things were the other way around, and that the triumph of relativity theory was due to its success in the ideological power struggle rather than its scientific value. Einstein's opponents had strong logical arguments against relativity theory, with the inconsistencies revealed by the clock paradox providing a good example. It is true that many of the antirelativist objections were obvious, but that did not necessarily make them superficial. In fact, the case made by the critics, politically abhorrent as some of them were, was so simple and so powerful that it is at least plausible to conclude that it was they, not Einstein, who were correct. If relativity theory does contain palpable flaws and explains far less than it purports to, then this has a number of intriguing implications for social epistemology.

Conflicting Principles

What divides the critics from the supporters of relativity theory? We can begin to answer this question in a general way by identifying the extraordinary claim Einstein made at the outset of his 1905 paper "On the Electrodynamics of Moving Bodies"

(Einstein 1923). Einstein introduced the special theory of relativity by asserting that it was possible to reconcile two principles that appeared to be contradictory. According to Einstein: (1) the "principle of relativity" extended to electrodynamics and optics the mechanical relativity described by Galileo. Provided that reference frames were in uniform motion with respect to each other, Einstein asserted that electromagnetic and optical laws, like the laws of mechanics, were identical from one reference frame to the next. In these circumstances there was no preferred reference frame and "no properties corresponding to the idea of absolute rest" (Einstein 1923, 37–38). (2) The second principle was the constancy of the velocity of light, or "that light is always propagated in empty space with a definite velocity *c* which is independent of the state of motion of the emitting body" (Einstein 1923, 38). These principles were carefully phrased so that they were not unambiguously contradictory. The second principle, for example, could be read merely as a restatement of the first, as the principle of relativity suggested not that light was *dependent* on the state of motion of the emitting body but that this body was no more in motion than the empty space surrounding it. To guard against any confusion, therefore, it is helpful to provide an example that makes the conflict between the two principles unmistakable.

Consider a spaceship moving evenly through empty space toward a star. As the spaceship moves, someone on board flicks a light switch on and off so that light, emitted from a single source, radiates out in all directions. After the spaceship has travelled a certain distance, the relative positions of the light and spaceship are moot. If the principle of relativity holds good, then the light will have travelled an equal distance from the final position of the spaceship and an unequal distance from its initial position. In other words, the point reached by the spaceship will be at the centre of the radiated light. If the propagation of light is independent of the state of motion of the emitting body, then the light will have travelled an equal distance from the initial position of the spaceship and an unequal distance from its final position. In other words, the point where the spaceship had been when the light switch was flicked on and off will be at the centre of the radiated light.

Einstein set himself the task of explaining that these contradictory assumptions were reconcilable. The nub of the dispute between his supporters and his critics is that where his supporters believed he succeeded in his explanation, his critics think that he failed. From a critic's perspective, however artfully Einstein slips between the two principles, the argument he makes can always be shown to be inconsistent with one or other or them. Criticism of the theory that draws on the clock paradox, like many of the other technical criticisms of Einstein, originates in this observation.

The Clock Paradox

The clock paradox is one of the most famous of Einstein's predictions, familiar to the lay public as one of the wonders of relativity theory. The paradox refers to Einstein's hypothesis that under certain circumstances identical clocks will move at different rates. In the eyes of relativity's supporters, this hypothesis is not strictly speaking a paradox at all but is rather a surprising implication of relativity. Einstein claims that if one clock travels in a space rocket while the other clock stays on earth, then when the space rocket returns its clock will show less elapsed time than the clock that has remained on the earth. This hypothesis is now better known as the twin paradox, after Paul Langevin made the Hobbesian assumption that the human organism was just another form of clock in 1911 (Miller 1981, 259). However, introducing twins has provocative implications for advocates of free will so, to avoid digressing, we will stick with the original clocks.

From the perspective of a critic, Einstein's hypothesis calls into question one of the two principles on which the theory of relativity is supposedly based—the principle of relativity. It is not the prediction that one clock will record less elapsed time than another that most opponents object to, but rather the claim that this prediction is compatible with relativity theory. By contrast, supporters contend that apparent inconsistencies between the clock paradox and the theory of relativity have been resolved. Thus in 1938, when Herbert Ives and G. R. Stilwell, empirically corroborated the prediction that a moving clock would keep time at a slower rate, Einstein and his supporters took this experiment as a confirmation of special relativity, despite Ives's repeated protestations that it showed nothing of the kind.[2] Ives, one of Einstein's more distinguished critics, had already argued that the principle of relativity was contradicted in logic by the clock paradox (Ives 1937). The experimental result demonstrated the same problem in practice.

The Clock Paradox and Special Relativity

In 1895 Hendrik Lorentz had argued that a moving object contracted along an axis aligned in the direction of travel (Lorentz 1895). In 1904 Lorentz extended his theory to argue that a moving system slowed the speed of electrons within it to create what he termed "local time" (Lorentz 1904, esp. 13–26). This theory was consistent with absolute time and space as local time could be rephrased as a systemic change in speed within absolute time. In 1905 Einstein, who was apparently unaware of the 1904 article, adapted Lorentz's 1895 equation in his special theory of relativity, the theory that that would replace absolute time and space with the time space–time continuum. Einstein contended that, as a "peculiar consequence" of his special theory of relativity, the greater the velocity of a reference frame, the slower the speed of a clock within it:

> If at points A and B of [stationary system] K there are stationary clocks which, viewed in the stationary system, are synchronous; and if the clock at A is moved with the velocity v along the line AB to B, then on its arrival at B the two clocks no longer synchronize, but the clock which moved from A to B lags behind the other which has remained at B by $\frac{1}{2}tv^2/c^2$ …, t being the time occupied in the journey from A to B.
>
> It is at once apparent that this result still holds good if the clock moves from A to B in any polygonal line, and also when the points A and B coincide.
>
> If we assume that the result proved for a polygonal line is also valid for a continuously curved line, we arrive at this result: If one of two synchronous clocks at A is moved in a closed curve with constant velocity until it returns to A, the journey lasting t seconds, then by the clock which has remained at rest the travelled clock on its arrival at A will be

> $\frac{1}{2}tv^2/c^2$ second slow. Thence we conclude that a balance clock at the equator must go more slowly, by a very small amount, than a precisely similar clock situated at one of the poles. (Einstein 1923, 49–50)

This first appearance of what has become known as time dilation in Einstein's work requires careful attention. In particular, anyone who assumes that the special theory deals only with uniform movement in a straight line and is thus a precisely delineated subset of the later general theory, will wish to explore why Einstein extends his conclusions to polygonal and circular movements. It is by no means "at once apparent" that what is true for a straight line is true for a polygon, nor that what has been "proved" for a polygon applies to a circle. The principle of relativity introduced at the outset of the 1905 paper implicitly limited the special theory to reference frames moving at a constant speed in a straight line with respect to one another. In later work, Einstein explicitly stated that the special theory applied only to a reference frame "in a state of *uniform rectilinear and non rotary motion*" in respect of a second reference frame, in contrast to the general theory that dealt with reference frames regardless of their state of motion (Einstein 1920, 61). Acceleration, therefore, would appear to be the province of the general theory. A polygon, however, would seem to necessarily involve acceleration whenever there is a abrupt alteration in the direction of travel. Even more confusingly, a circular path, far from allowing movement at a "constant velocity", has a velocity that continually changes.

Einstein, it is argued, wished to *minimise* the significance of acceleration—as he did not mention acceleration at all in the passage, he could hardly be said to do otherwise (Essen 1971, 13). With respect to the transition from the straight line to the polygon, this assumption is corroborated by comments Einstein made in 1911 when he said that the larger the polygon the less significant the impact of a sudden change of direction would be.

> The [travelling] clock runs slower if it is in uniform motion, but if it undergoes a change of direction as a result of a jolt, then the theory of relativity does not tell us what happens. The sudden change of direction might produce a sudden change in the position of the hands of the clock. However, the longer the clock is moving rectilinearly and uniformly with a given speed in a forward motion, i.e., the larger the dimensions of the polygon, the smaller must be the effect of such a hypothetical sudden change. (Einstein et al. 1993, 354)

Einstein's concern to minimise the impact of sudden changes of direction may also help to explain his reasoning in shifting from a polygon to a curved path. The 1905 reference to travelling at a "constant velocity" in a closed curve is a translation of "*konstanter Geschwindigkeit*" (Einstein 1905, 904). However, *Geschwindigkeit* does not necessarily refer to velocity, which is directional; it might equally refer to speed, which is not. The ambiguity of the term eases the shift from a straight line to a circle. The assumption that Einstein wished to minimise the impact of acceleration, if correct, explains why rather than choosing to illustrate the clock paradox with the now familiar out-and-back journey when the direction is abruptly reversed, Einstein preferred to illustrate the effect of time dilation through movement where there is a continual gradual change of direction at a constant speed.

Einstein had predicted a real difference between the times shown by the reunited clocks and reinforced this claim by stating unequivocally that a clock at the equator moved more slowly than one at the pole. At an empirical level, this asymmetric outcome provided a testable proposition. At the level of logic, however, the hypothesis was problematic as it was inconsistent with the principle of relativity. For the principle to hold good, the effect on each clock should be identical; for if one clock showed an earlier time when two clocks were reunited, then it suggested this was because the clock had travelled in a reference frame that had *really* moved at a greater speed than the reference frame of the second clock. The reference frame of the two clocks, therefore, could not be equally said to be either stationary or moving depending on the frame of reference of the observer.

Einstein responded to this criticism of the special theory by referring to the general theory, but before examining his argument let us pause to suggest how Einstein's reasoning in 1905 led him into the clock paradox. (1) Einstein had, like Lorentz before him, developed the idea that the faster a system moves, the slower things move within that system. In arriving at this idea Einstein had—again like Lorentz—assumed either that there was absolute space or at least that there was a preferred reference frame against which this movement could be measured. The idea of time dilation was not, therefore, derived with the help of the principle of relativity, as one of its underlying assumptions contradicted the principle of relativity. (2) In a separate theoretical endeavour, Einstein used the restrictive assumption of uniform rectilinear velocity to allow consideration of systems that moved in accordance with the principle of relativity. This restrictive assumption was not required to explain time dilation; hence it was possible to write of polygons and circles. (3) Einstein then amalgamated the idea that moving systems slowed down with the principle of relativity, presenting them in one apparently continuous train of argument in which he asserted that time dilation was consistent with the principle of relativity. This claim created the clock paradox.

The Clock Paradox and General Relativity

The argument that the prediction of time difference between a moving and a stationary clock violates the principle of relativity is well known. Certainly, it must have become known to Einstein, for in 1918 he created a dialogue in which "Kritikus" voiced exactly this objection (Einstein 1918). In response to this criticism, Einstein underwent a *volte-face*, reversing his reasoning in 1905 and 1911. The sudden change in direction of the moving clock, far from having unknown effects that needed to be minimised, was now said to provide the *entire explanation* for the change. Instead of imagining a moving clock travelling in a huge polygon or circle to make sudden changes in direction as insignificant as possible or the journey as smooth as possible, Einstein imagined an out and back journey. He then explained that the slow-down in the moving clock occurred during the sudden jolt when it went into reverse.

Einstein compared two clocks, identified as U1 and U2 (the equivalent of the stationary and moving clocks in the 1905 article). The separation and return of these two clocks was described as a five-part process, which differed according to whether the perspective of the first or second clock was adopted. From the perspective of the clock U1 (the stationary clock), this process was as follows. (1) The clock U2 (the moving clock), was accelerated until it reached a set velocity. (2) The clock U2 moved with constant velocity. (3) A force of acceleration in the opposite direction caused the clock U2 to reverse direction. (4) It moved back at a constant velocity. (5) It was brought to rest. Einstein gave a symmetrical description of the second and fourth parts of this process from the perspective of clock U2. He confirmed that during these two stages, from the perspective of both clocks, the other clock would appear to be moving more slowly. However, in parts one, three and five of the process, Einstein gave an asymmetric account of the forces of acceleration at work from each clock's perspective. He then suggested that the transitional third stage was critical. During this stage, Einstein claimed that clock U1 ticked more quickly than clock U2. He added that, according to his calculations—*which he did not supply*—clock U1 would advance by an amount that was double the sum of the amount of retardation observed on clock U1, from the perspective of clock U2, during stages two and four (Einstein 1918, 698–699). Einstein concluded that when the clocks were reunited clock U2 would be found to have gone more slowly, just as he had predicted in 1905.

Given Einstein's argument in 1918, it seems inescapable that his 1905 prediction of time dilation was not, in fact, a "peculiar consequence" of his forgoing account of special relativity (Einstein 1923, 49). When it is also remembered that in 1904 Lorentz deduced the existence of "local time", it is reasonable to conclude that the prediction that the clocks would end up showing different times can be reached without entering into Einstein's reasoning on the special theory at all. The supporters of Einstein, however, generally maintain that one needs to move *beyond* the special theory to the general theory to understand why the times shown by the clocks would be different. However, as Einstein's prediction preceded the general theory, this argument is problematic (Lovejoy 1931, 159; Essen 1971, 14). It has been seen that: (a) in 1911 Einstein explicitly rules out the ability of the special theory of relativity to say what happened if the moving clock suddenly changed direction, and (b) in 1918 Einstein tacitly admitted that his explanation of the clock paradox in 1905 was incorrect by transforming the polygonal or circular journey of the moving clock into an out and back journey. If the general theory is necessary to explain the clock paradox, then Einstein must have (a) predicted the effects of acceleration in 1905 even though he did not incorporate them into his theory for another decade, and (b) hidden his intuition by describing a journey that discounted their significance.

A Critical Error

Einstein's belated explanation of the clock paradox as a manifestation of general relativity raises several more problems (Dingle 1972, 191–201; Essen 1971, 14; Lovejoy 1931, 159–165). One of these objections is simple and in the eyes of critics insurmountable. Once a rocket with clock U2 on board has accelerated into space, it can continue at a constant velocity indefinitely. Einstein could not, therefore, reasonably claim that the amount of change in clock times in the third part of the process bore a fixed relationship with an indeterminate amount of change observed in clock times in parts two and four. It has been seen how in 1911 Einstein pointed out that "the longer the clock is moving rectilinearly and uniformly with a given speed in a forward motion … the smaller must be the effect of … a … sudden change" (Einstein et al. 1993, 354) in direction. Nothing in Einstein's 1918 explanation invalidated this observation. The out and back journey of the clocks in stages two and four might be any distance. During these symmetrical parts of the process, each clock was said to slow from the perspective of the other clock. The greater the distance covered during these stages, the greater the time needed to cover it; and the greater the time of the journey, the greater the sum of the observed retardation. However, the forces needed to reverse the direction in part three were not altered by the length of the journey of the clock in parts two and four. They were the same for a long journey as for a short one. This elementary criticism of the revised clock paradox was first pointed out by Max von Laue in a 1913 response to Langevin—who had not only turned the clocks into people but had also prefigured Einstein's "asymmetric" explanation (Kracklauer and Kracklauer 2000; Miller 1981, 262). The following year Laue won the Nobel Prize in Physics, but it is not necessary to be an advanced physicist to notice the problem. It is one of the theory's more obvious anomalies.

A limited number of more recent physicists and philosophers who, like Laue, are sympathetic to relativity theory, have identified this problem with Einstein's 1918 account of the clock paradox. Roger Angel, for example describes the "serious difficulty" as follows:

> The discrepancy between the two clocks is a function of the total distance or total elapsed time. Hence, by choosing a sufficiently great distance one could render the putative effect of acceleration negligibly small. That is to say, that a trip to the sun and back at a given velocity would involve roughly the same acceleration as a trip involving that same velocity to a distant star and back, yet the theoretical prediction is that the discrepancy in aging would be very much greater in the latter case than in the former. (Angel 1980, 80)

Angel, and other sympathisers including E. G. Cullwick, A. F. Kracklauer and P. T. Kracklauer, and J. R. Lucas and P. E. Hodgson, go on to proffer their own explanations for how to clear up a problem that has lain unresolved for a century (Angel 1980, 80–81; Cullwick 1957, 72–73; Kracklauer and Kracklauer 2000; Lucas and Hodgson 1990, 72–76). It would be doing these authors an injustice to dismiss their arguments without considering them. However, it can be pointed out that while they have lighted on the same problem, their resolutions are different. Culwick concludes that the reunited clocks would show the same time after all. Although the others agree that the theory of relativity can somehow be squared with the clocks showing different times, there is no consensus about how this can be so.

The Problem Ignored

In the mainstream scientific community and also amongst mainstream philosophers there *is* a well-established consensus on how to treat the problems arising from

Einstein's revised explanation of the clock paradox: while the prediction in the paradox is celebrated, its problematic relationship to the principle of relativity is ignored. No note is taken of the honest attempts to come up with a resolution to the obvious problems of the clock paradox, because there is no acknowledgement that these problems exist in the first place. Monographs on relativity theory and university textbooks alike simply claim that the argument Einstein made in 1918, or something like it, completely resolves the paradox (see, for example, Adams 1997, 206–207; Terletski 1968, 38–41). If there is recognition that a problem exists, it is said that it is easy to solve by asserting that the accelerative phase has a continuing effect after the clock has re-established a uniform velocity (Marder 1971, 114–115). It has been seen, however, that this effect is ruled out by Einstein in 1911 and is not the argument made in 1918. If Einstein *had* made such an argument, say by contending that the acceleration in part three of the process had a continuing effect on a clock in stage four, then this would violate the principle of relativity, and he would be back to square one in his argument with "Kritikus". The only noticeable development in the mainstream explanations of time dilation is that they may now incorporate a discussion of a "Doppler effect". For example, it is suggested (contrary to Einstein in 1918) that the clocks appear slower in stage two but faster in stage four (Benson 1991, 805; Davies 1977, 39–45). But whatever the line that is taken, once it has been asserted that the clock journeys are asymmetric, the problem is said to be essentially solved, with the rest of the argument relegated to a mere matter of detail, albeit a rather complicated one, which the reader is asked to take on trust: "A detailed calculation confirms the above discussion" (Benson 1991, 805). "Careful analysis shows that [the earthbound twin] is correct" (Sears, Zemansky, and Young 1991, 930). The omission of these calculations also follows Einstein's "explanation" of 1918.

There is, nonetheless, some divergence about how to resolve the clock paradox amongst mainstream scientists and philosophers who address the issue. The majority suggest that (a) the general theory is required to resolve the paradox because like "Kritikus" they have deduced—quite correctly—that it cannot be explained by the special theory. However, a minority believe that (b) the paradox *can* be explained by the special theory because they have deduced—again quite correctly—that it is incredible to suppose that only the general theory can explain a prediction ostensibly arising from the prior special theory.[3] Each deduction, considered in isolation, is allowable within the mainstream; what is not permitted is to bring the two of them together to conclude that (c) neither the special nor the general theory explains time dilation.

The Counter-argument of Complexity

The prediction that clocks will move at different rates is particularly well known, and the problem of explaining how this can be so without violating the principle of relativity is particularly obvious. The clock paradox, however, is only one of a number of simple objections that have been raised to different aspects of Einstein's theory of relativity. (Much of this criticism is quite apart from and often predates the apparent contradiction between relativity theory and quantum mechanics.) It is rare to find any attempt at a detailed rebuttal of these criticisms by professional physicists. However, physicists do sometimes give a general response to criticisms that relativity theory is syncretic by asserting that Einstein is logically consistent, but that to explain why is so difficult that critics lack the capacity to understand the argument. In this way, the handy claim that there are unspecified, highly complex resolutions of simple apparent inconsistencies in the theory can be linked to the charge that antirelativists have only a shallow understanding of the matter, probably gleaned from misleading popular accounts of the theory.[4]

The claim that the theory of relativity is logically consistent for reasons that are too complex for non-professionals to grasp is not only convenient, but is rhetorically unassailable—as whenever a critic disproves one argument, the professional physicist can allude to another more abstruse one. Einstein's transformation of the clock paradox from a purported expression of the special theory to a purported expression of the much more complicated general theory is one example of such a defence. A more recent example is found in Alan Sokal and Jean Bricmont's scornful account of Henri Bergson's attempt to investigate the clock/twin paradox. Like "Kritikus", Bergson (1968, 76–80) argued that the asymmetric outcome of the paradox was incompatible with the principle of relativity. Like Einstein, Sokal and Bricmont explain that Bergson has failed to recognise the asymmetric forces of acceleration at work. They go on to claim that the special theory tells us what happens under these circumstances and that the general theory only laboriously leads to the same conclusion (Sokal and Bricmont 1997, 177). The suggestion that to vindicate this claim would be laborious functions in the same way as Einstein's elusive "calculations"; that is, it is not an explanation but an explanation-stopper. Sokal and Bricmont do not demonstrate how either the special theory or the general theory explain time dilation. Nor do they explain how their claim can be reconciled with Einstein explicitly limiting the special theory to objects travelling at a uniform velocity, nor account for why the circular journey of 1905 became the out and back journey of 1918.

Although a claim based on reasons that are said to be too complicated for non-specialists to understand can never be finally disproved, there are grounds to be suspicious. The argument for complexity reverses the scientific preference for simplicity. Faced with obvious inconsistencies, the simple response is to conclude that Einstein's claims for the explanatory scope of the special and general theory are overstated. To conclude instead that that relativity theory is right for reasons that are highly complex is to replace Occam's razor with a potato masher. Furthermore, most of Einstein's critics who make use of a popular account of the theory refer to the one written by Einstein himself. As Melbourne Evans (1962) has shown, this work is not an over-simplification of special relativity, but rather accurately reflects Einstein's earlier more technical presentation.

The defence of complexity implies that the novice wishing to enter the profession of theoretical physics must accept relativity on faith. It implicitly concedes that, without an understanding of relativity theory's higher complexities, it appears illogical, which means that popular "explanations" of relativity are necessarily misleading. But given Einstein's fame, physicists do not approach the theory for the first time once they have developed their expertise. Rather, they are exposed to and probably examined on popular explanations of relativity in their early training. How are youngsters new to the discipline meant to respond to these accounts? Are they misled by false explanations and only later inculcated with true ones? What happens to those who are *not* misled? Are they supposed to accept relativity merely on the grounds of authority? The argument of complexity suggests that to pass the first steps necessary to join the physics profession, students must either be willing to suspend disbelief and go along with a theory that appears illogical; or fail to notice the apparent inconsistencies in the theory; or notice the inconsistencies and maintain a guilty silence in the belief that this merely shows that they are unable to understand the theory.

The gatekeepers of professional physics in the universities and research institutes are disinclined to support or employ anyone who raises problems over the elementary inconsistencies of relativity. A winnowing out process has made it very difficult for critics of Einstein to achieve or maintain professional status. Relativists are then able to use the argument of authority to discredit these critics. Were relativists to admit that Einstein may have made a series of elementary logical errors, they would be faced with the embarrassing question of why this had not been noticed earlier. Under these circumstances the marginalisation of antirelativists, unjustified on scientific grounds, is eminently justifiable on grounds of realpolitik. Supporters of relativity theory have protected both the theory and their own reputations by shutting their opponents out of professional discourse.

Disgruntled physics graduates who claim that their career hopes have been blighted after they called Einstein's work into question attest to these observations.[5] Even well established members of the scientific community can ill afford to point to elementary (as opposed to recondite) problems with the theory. When, in the 1950s and 1960s, Professor Herbert Dingle ventured to argue that relativity theory left obvious inconsistencies unresolved, he found that his status as a respected exponent of the special theory changed rapidly into that of a near pariah.[6] When Professor Paul Marmet, a former President of the Canadian Association of Physicists, ventured to make criticisms and call for a return to Newtonian principles, first his funding was cut off and then, in 1999, he was subject to constructive dismissal from his academic post and his experimental apparatus destroyed.[7] From a career perspective, the only safe course for a sceptic within the physics profession is to adopt a prudent silence and to busy himself or herself with other fields of work.

Relativity as an Ideology

Einstein's theory of relativity fails to reconcile the contradictory principles on which it is based. Rather than combining incompatible assumptions into an integrated whole, the theory allows the adept to step between incompatible assumptions in a way that hides these inconsistencies. The clock paradox is symptomatic of Einstein's failure, and its purported resolution is illustrative of the techniques that can be used to mask this failure. To uncover to the logical contradictions in the theory of relativity presents no very difficult task. However, the theory is impervious to such attacks as it is shielded by a professional constituency of supporters whose interests and authority are bound up in maintaining its inflated claims. Relativity theory, in short, is an ideology.

To describe relativity theory as an ideology rather than a science is not synonymous with saying that the theory is worthless. To give a familiar parallel, one can argue that Marxism is an ideology and still acknowledge that Marx gives insights into the workings of capitalism. Once relativity theory is understood for what it is, one is better able to make a realistic assessment of what Einstein can and cannot explain, of where he has advanced knowledge and where he has impeded this advance.

"Ideology" is an essentially contested term; it is often used as a kind of innocuous catch-all for any set of beliefs or values, and it is sometimes assumed to refer to ideas that are logically related. It may, therefore, be helpful to indicate the intellectual provenance of ideology as the term is used here. There are various theories that, for all their differences, share an understanding of ideology as a term of opprobrium in contrast to a more positive alternative (e.g. theories that pit religion against reason; bourgeois ideology against scientific socialism; the closed versus the open society; totalising versus erudite knowledge; ideology versus pragmatism). Borrowing freely from such theories, ideology is taken to mean a collection of ideas that are used to advance or maintain the authority and power of their exponents in a way that prevents critical analysis of whether these ideas are true or false, consistent or inconsistent. Ideology can be contrasted with a collection of ideas that are subject to critical assessment by their exponents. Here, of course, we are contrasting ideology with science.

If relativity theory is an ideology, then its illusory explanatory power enhances the real power and authority of theoretical physicists. Precisely because Einstein's theory is inconsistent, its exponents can draw on contradictory principles in a way that greatly extends the apparent explanatory scope of the theory. Inconsistency may be a disadvantage in a scientific theory but it can be a decisive advantage in an ideology. The inconsistency of relativity theory—to borrow the language of the early Marx—gives relativity its apparent universal content. This seeming power of explanation functions to enhance the status of the group, giving them power over others through the enhanced control over resources, and a greater power to direct research and to exclude and marginalise dissent.

Relativity Theory and the Philosophy of Science

One of the difficulties facing anti-relativist physicists is that it is very difficult to go beyond negative criticism of Einstein's claims to proffer alternative explanations. However, when the argument that relativity theory is an ideology is considered in the context of social epistemology, the case is quite different. For everything that is lost by realising that the theory is not, in fact, a science, there is a corresponding gain in the realising that the theory is, in fact, an ideology. To demonstrate the positive value of this realisation, we can consider its implications for the work of two leading philosophers of science, Thomas Kuhn and Karl Popper, both of whom derived their "main inspiration from Einstein's overthrow of Newtonian physics" (Lakatos 1972, 92). What does it mean for Kuhn and Popper's theories if Einstein's overthrow of Newtonian physics represents an ideological rather than a scientific success? For Kuhn's sociology of science, the notion that relativity is an ideology provides quite a good fit, but only because his concept of science is loosely drawn. By contrast, an ideological theory of relativity cannot be contained within Popper's concept of science: it is wholly and explicitly at odds with it. When it comes to their explicit treatment of Einstein, Kuhn and Popper could hardly be expected to agree with the depiction of relativity theory as an evidently syncretic mixture of ideas that only apparently superseded Newton. Nonetheless, for Popper and to a lesser extent Kuhn, the identification of relativity as an ideology helps to explain gnawing doubts over whether Einstein's theory could really be said to have instituted a scientific revolution.

Kuhn

Science is generally taken to be an analytic term that must be defined, at least in part, by reference to what it is not. Kuhn, however, has taken a more inclusive approach and has not drawn a clear demarcation between science and ideology, or even between science and almost any other field of endeavour (Feyerabend 1974). The difficulties in accepting Kuhn's claim to be concerned with distinctly scientific change include his argument that, while logic is important, it does not provide a final arbiter between competing theories that are to some extent incommensurable (Kuhn 1970, 150, 158–159). They include Kuhn's attempt to defend himself against the charge of relativism without acceding to the idea that scientific progress is made when new theories provide a closer approximation of the truth (Kuhn 1970, 205–207). They also include his reluctance more generally to discuss the relationship between science and truth beyond a comparison with natural selection, a comparison that can be criticised for its vagueness (Fuller 2000, 174).

In this context, Kuhn's failure to separate ideology from science refers to the pejorative meaning of ideology, as distinct from at least two other meanings of the term that arise in discussion of his work. (1) Kuhn himself uses the term "ideology" in the innocuous and inclusive sense of belief system or values, including the values of scientists, without associating the term with power relationships or dogmatism (Kuhn 1974a, 248). (2) Ideology is sometimes used to mean a plurality of competing theories on a subject—an account of ideology that assumes not one belief system but the interplay of several. In this meaning of the term, a Kuhnian paradigm arises out of the separation of science from ideology, as it develops when exponents of one theory start to communicate only with each other, and ignore the dissenting advocates of alternative ideas (Fuller 2000, 259). If we revert to the pejorative concept of ideology, however, it can be seen that Kuhn's account of the creation of a new paradigm provides a fair description of the behaviour of advocates of any number of new ideas; it might well refer to supporters of relativity theory, but it could also refer to members of a cult. As Kuhn fails to give a definitive logical or evidential rationale for accepting a paradigm to the extent of excluding or disregarding opposing voices, the adherents of the paradigm may not be scientists but rather be ideologues, in the pejorative sense of the term.

Kuhn's overly inclusive view of science helps to explain the criticism he has attracted from other philosophers of science, including Popper, but it also helps to explain his fame. Rather as Einstein had done in developing the special theory, Kuhn draws on conflicting principles to explain the aims of those involved in a field termed "scientific". He switches between inconsistent characterisations of scientists as critical thinkers in the Popperian sense, and as ideologues. By blurring this inconsistency in his all encompassing account of "science", Kuhn makes it appear that his theory can explain more than it actually does. Kuhn said that reading some of the criticisms that had been made of his *Structure of Scientific Revolutions* alongside the work itself left him thinking that there were two Thomas Kuhns, one of which was a serious misreading (Kuhn 1974a, 231). The idea of two Thomas Kuhns is actually a helpful pointer to the mixing of science and ideology in his work; the Kuhn of the critics is the Kuhn that allows ideologues to be styled as scientists. Within a scientific profession there are both practicing scientists and practicing ideologues. Kuhn conflates their activities, and calls the result science. In doing so he appears to bring together a sociological analysis of how scientists actually operate with a philosophical concept of scientific advance. This impression, however, is unfounded, for members of a scientific profession that take an ideological position do not encourage scientific advance; they impede it.

Kuhn does, however, introduce an innovative and helpful distinction between revolutionary science and normal science. If this distinction is combined with the distinction between science and ideology that Kuhn *should* have made, but did not, then we have the basis for a better understanding of the revolution in physics that Einstein began in 1905. When he talks of normal science, Kuhn sometimes means a scientific approach that can be insightful and imaginative within the confines of a paradigm, as he implies when he identifies Lorentz's theorising as puzzle-solving within normal science (Kuhn 1974b, 6). However, because Kuhn fails to distinguish science and ideology, his critics have been able to construct a picture of "normal science" that might be better expressed as "normal ideology". Popper, for example, characterises the normal scientist as a:

> not-too-critical professional … who accepts the ruling dogma of the day; who does not wish to challenge it; and who accepts a new revolutionary theory only when everybody else is ready to accept it—if it becomes fashionable by a kind of bandwagon effect. (Popper 1974, 52)

The same distinction between science and ideology that can be used to analyse normal puzzle-solving activities can also be made with respect to revolutionary change. Sometimes a revolution is genuinely scientific, as in the case of Newton, but Kuhn's concept of "science" also leaves open the possibility of an ideological revolution.

It is suggested that Einstein's special theory of relativity inaugurated an *ideological revolution*. Members of the physics profession and philosophers, who pursue ever more abstruse consequences of the paradigm of relativity theory while ignoring or lightly skimming over its elementary contradictions, have consolidated this ideological revolution by pursuing *normal ideology*. We are thus provided with the categorisation presented in Table 1.

Table 1 Normal Activity and Revolutionary Change

	Normal	Revolutionary
Science	Lorentz	Newton
Ideology	Relativity physicists and philosophers	Einstein

In contrast to this categorisation, Kuhn equates Einstein with the greatest of revolutionary scientists, including Newton. However, Kuhn has also suggested that the general theory of relativity is so complicated that it is "largely fruitless", which is somewhat hard to square with a revolutionary scientific advance (Kuhn 1977, 189). Kuhn ties his identification of the unfruitful nature of general relativity with the prediction that over time the general theory will fade from view to leave only the special theory (Kuhn 1977, 188–189). This prediction may not do justice to the ideological advantages of complexity, as the prohibitively complicated general theory can provide an unanswerable defence against the charges of elementary inconsistencies that can be levelled against the special theory. By recategorising relativity theory as a whole as a revolutionary ideology, Kuhn's observation on the near sterility of general relativity can be explained, rather neatly, as the outcome of a theory that has only apparent explanatory power.

Popper

In a passage in his intellectual autobiography, Popper explained that he had first seen the distinction between science and ideology when he compared Einstein's theory of relativity with Marxism and with the psychiatric theories of Sigmund Freud and Alfred Adler. According to Popper, the way that ideological theories have been constructed and used gives them the appearance of great explanatory power. However, when one examines these explanations, one finds that they are always fitted to events and are never truly tested against them, as the advocates of the theories form a self-serving group determined to show the rightness of their approach regardless of the truth. Popper went on to say that relativity was the exact opposite to such pseudo-science, as it was a theory yielding testable propositions pursued by open-minded scientists. Einstein's approach "was the true scientific attitude … utterly different from the dogmatic attitude which constantly claimed to find 'verifications' for its favourite theories" (Popper 1992, 38).

Popper, it is agreed, drew a clear and compelling distinction between science and ideology in this passage. His mistake was to put Einstein in the wrong category, as his pejorative description of ideology provides a fair description of relativity theory and its supporters. The same miscategorisation is made by most philosophers of science, and in most cases there is there is not much more to be said; the well-worn story of Einstein's genius is related uncritically; the palpable logical difficulties in relativity theory are either unnoticed or unmentioned; the theory gains one more shield from a member the philosophical profession. What makes Popper's case far more interesting is that, over the course of a long career, the seeds of doubt began to grow, so that, as he published new books and revised old ones with footnotes and addendums, there is a fascinating interplay between his almost adulatory attitude to Einstein and an intellectual honesty that is pushing him, hesitantly and reluctantly, to the realisation that relativity theory is not in fact the revolutionary scientific advance he had once believed it to be.

Einstein's Eureka moment, the one that inspired his 1905 *Electrodynamics* article, occurred when he conceived of an operational definition of simultaneity that replaced absolute simultaneity with a "more malleable form". [8] Critics of relativism have rightly criticised this version of simultaneity as illogical (Essen 1971; Evans 1962; Lovejoy 1931). However, in Popper's first work, *The Logic of Scientific Discovery*, there is only admiration for Einstein's reasoning. Popper described how Einstein's modification of the concept if simultaneity had produced "a decisive advance" (1972, 76n). To press the point home, Popper drew a disparaging contrast between Lorentz, whose theory was no more than an "unsatisfactory auxiliary hypothesis" to rescue Newton, and Einstein, whose theory "predicted new consequences" (Popper 1972, 83). These included, for example, the mass-energy equivalence (Popper 1963, 334). There is no doubt as to who is Holmes and who is Watson.

Over the years Popper gradually qualified this thesis. He recognised that some of Einstein's predictions, including mass-energy equivalence, not did not require relativity theory for their derivation (Popper 1972, 447). His view of Lorentz became more generous, his view of Einstein's operational definition of simultaneity more critical.[9] With respect to the special theory, he went furthest in *Quantum Theory and the Schism in Physics* (Popper 1982), written after a series of test results in quantum mechanics had indicated action at a distance, and hence absolute simultaneity. The response to these results within the physics profession has been to say that a unifying theory is necessary. To his credit, Popper did not accede to this blandishment. Instead, he concluded that if the experiments were corroborated (as they have been), then "we have to give up Einstein's interpretation of special relativity and return to Lorentz's interpretation and with it to Newton's absolute space and time" (Popper 1982, 29). This is fully in accord with the argument presented here. Lorentz was developing a scientific theory of "local time". Einstein adapted it into an ideology that, through inconsistency, apparently extended its scope. Shorn of the ideological trappings, we are indeed back with Lorentz.

Popper obscures but does not altogether hide the extraordinary implications of his tentative suggestion that Lorentz and Newton may not have been superseded after all. We see a kind of internal duel in which Popper the falsificationist scientist wrestles with Popper the ideological defender of Einstein. The result is a messy draw in which, through what can only be called a series of unsatisfactory auxiliary hypotheses, Popper attempts to retain the idea that Einstein's relativity theory represents some form of scientific advance even in if absolute space and time remain intact. Thus, Einstein's other achievements are emphasised and the difference between Einstein and Lorentz is minimised (Popper 1982, 29, 35, 48, 158). Finally, the very concept of scientific advance is adapted to fit the new circumstances:

> The decisive thing about Einstein's theory, from my point of view, is that it has shown that Newton's theory—which has been more successful than any other theory ever proposed—*can* be replaced by an alternative theory which is of wider scope, and which is so related to Newton's theory that every success of Newtonian theory is also a success for that theory, and which in fact makes slight adjustments to some results of Newtonian theory. So for me, this logical situation is more important than the question which of the two theories is in fact the better approximation to the truth (Popper 1982, 29–30).

To consider the implications of Popper's argument that a situation in which one theory *can* replace another counts for more than the question of which theory is closer to the truth, it is helpful to begin with two points of clarification:

(1) The unresolved question of which theory is a better approximation of the truth refers to Newton's concept of absolute space and time against Einstein's time–space continuum. Popper appears to be uncertain whether the general theory can come to the rescue of space–time in the special theory, or whether space–time in the general theory is also undermined by the experiments in quantum mechanics.
(2) The "slight adjustments" are Einstein's explanation for the perihelion of Mercury, the light deflection tested by Eddington, and the red shift of light from distant stars. According to Einstein, these explanations and predictions arise from the general theory (Einstein 1920, 103–104). In Popper's earlier triumphalist version of Einstein's revolution, they are the "crucial experiments" that overthrow Newton (Popper 1966, 266, 364n).

It now becomes clear that once significant uncertainty over whether Newton or Einstein are closer to the truth is admitted, then the significance of the "slight adjustments" are also called into doubt. Alongside Popper's earlier assumption that these adjustments, once corroborated, also corroborate Einstein's relativity theory more generally, two further possibilities have to be admitted: (a) Einstein's adjustments are incorrect; or (b) the adjustments are correct, but the reasoning that explains them is consistent with Newton's absolute space and time rather than Einstein's time–space continuum. If one or other of these possibilities is correct (anti-relativists differ amongst each other and argue for both points of view), then the time–space continuum in all its forms should be discarded as the outcome of the ideological attempt to explain too much through inconsistent assumptions Popper's alternative view—in defiance of his earlier analysis of scientific advance—is that the truth content of a theory is somehow less important than its purported explanatory scope. But to adopt this standard is to assess the relative worth of rival theories by comparing how much each *appears* to explain, rather than by what they actually explain. The appearance of having great explanatory power has been precisely the advantage that the syncretic ideology of Einstein's theory of relativity has held over Newton's logically consistent alternative.

One of the difficulties that Popper had in stepping away from his characterisation of Einstein as a revolutionary scientist was the physicist's role as a living symbol of western opposition to Nazism. It might seem that Einstein's politics would be irrelevant to his approach to physics, but this is not the way that Popper understood the matter. Popper allied the open society closely with science and separated it from ideology, which he associated with the closed society. True to his ideal of scientific theorising, Popper couched his argument as a bold generalisation, categorising the supporters of the open and closed society in a way that allowed little room for ambiguity or overlap. Despite his scathing attack on Hegel there is a faintly Hegelian ring to these antithetical portrayals; and, to compound the irony, Popper tended to follow Plato (who he also attacked) in equating the form taken by a society with the psychology of the individual. The open-minded approach to life, including doubt, the willingness to identify mistakes, questioning of accepted assumptions in the search for truth was said to be systematised in the research of scientists like Einstein (Popper 1966, Vol. II, 13 and 289, n35, 20, 220–221). The certainty and dogmatism of a totalising, unfalsifiable ideology was likewise seen as the systematisation of a close-minded approach to life. Popper's argument, therefore, can be reduced to a simple table in which advocates of the open society hold a scientific attitude as against the ideological advocates of a closed society (Table 2).

Table 2 Popper's Association between Societal Form and Epistemology

	Open society	Closed society
Science	X	
Ideology		X

The association Popper drew between the open society and science and the closed society and ideology is overly schematic, at least when it comes to categorising an individual. Posing the question of whether someone holds an ideological or scientific attitude towards a specific theory is rather different than making summary judgements about people as ideologues, or as scientists. If one considers a person's attitudes on a theory-by-theory basis, then it is possible for them simultaneously to be a scientist in one respect, an ideologue in another. Although some of Einstein's critics were ideologues of the worst kind in their political views, when their views were considered specifically in respect of relativity theory, then at least some of them could be deemed scientific. Conversely, physicists who support relativity for ideological reasons can still be defined as scientists in other aspects of their work. Given the antipathy between Einstein and the Nazis, when the political as well as the more narrowly professional views of physicists and other scientists are taken into consideration, it may be that political commitment to the open society resulted, ironically, in an insufficiently critical attitude toward the theory of relativity.

Conclusion

I have tried to draw together (1) anti-relativist criticisms of Einstein and (2) pejorative definitions of ideology as distinct from science, to suggest that relativity theory is an ideology. The clock paradox has been used as an illustration of this theory. To make the case, it has been see how in 1918 Einstein tacitly admitted that the clock paradox in its original 1905 form was inconsistent with the principle of relativity. In response, he radically revised his description and explanation of the paradox by incorporating an account of acceleration. This revised explanation was supposedly consistent with the general theory of relativity, but is in fact highly problematic. The problems include an obvious unresolved difficulty: the asymmetric forces of acceleration that supposedly determine the time difference are unrelated to the symmetric periods of uniform rectilinear movement that determine the extent of this difference. Most mainstream physicists have ignored this and other problems. Viewing relativity as an ideology, with at least some of the opponents of relativity as attempting to uphold scientific standards, helps to explain this state of affairs.

Once relativity theory is viewed as an ideology, aspects of the theory that are scientifically problematic can be redefined as ideologically advantageous. (1) The foundation of the theory upon two conflicting principles allows advocates to create the impression that these principles can be reconciled. By then appealing to either one of them, the apparent explanatory power of the theory is vastly increased. (2) Tests that call a theory into question are said to confirm it as a way of fitting the facts to the theory, as seen with Ives and Stillwell's test of the clock paradox. (3) Einstein's shift from the special theory to the general theory to maintain the principle of relativity against the clock paradox provides an instance of ideological repositioning to defend a theory in all circumstances. (4) The assertion that an apparently inconsistent theory is correct for reasons that are too detailed to explain, or too complicated to understand, is an ideal ideological argument because it is irrefutable.

The argument that Einstein fomented an ideological rather than a scientific revolution helps to explain of one of the features of this revolution that puzzled Kuhn: despite the apparent scope of the general theory, very little has come out of it. Viewing relativity theory as an ideology also helps to account for Popper's doubts over whether special theory can be retained, given experimental results in quantum mechanics and Einstein's questionable approach to defining simultaneity. Both Kuhn and Popper have looked to the other branch of the theory—Popper to the general and Kuhn to the special—to try and retain their view of Einstein as a revolutionary scientist. According to the view proposed here, this only indicates how special and general theories function together as an ideology, as when one side of the theory is called into question, the other can be called upon to rescue it. The triumph of relativity theory represents the triumph of ideology not only in the profession of physics bur also in the philosophy of science. These conclusions are of considerable interest to both theoretical physics and to social epistemology. It would, however, be naïve to think that theoretical physicists will take the slightest notice of them.

Acknowledgement

The author thanks Sam Valentine for his valuable criticisms and suggestions.

Notes

[1] See Israel, Ruckhaber, and Weinmann (1931). A bibliography of German antirelativists, many whose works date from the interwar period, can be found online (http://www.datadiwan.de/

netzwerk/index.htm?/moch/). For contemporary antirelativists, see the Natural Philosophy Alliance (http://www.worldnpa.org/main/index.php?&MMN_position=1:1) and its associated journal, pointedly called *Galilean Electrodynamics* (http://mywebpages.comcast.net/adring/).

[2] Herbert E. Ives and G. R. Stilwell (1938) "An experimental study of the rate of a moving atomic clock", *Journal of the Optical Society of America* 28: 215–26, reprinted in Ives (1979). For the significance of the Ives–Stilwell experiment, see Miller (1981, 265–266).

[3] For the minority view, see Builder (1957), V. Allen White's "Ray on the Twin Paradox" (http://www.uwmanitowoc.uwc.edu/staff/awhite/ray.htm), Miller (1981, 262–264) and Pesic (2003).

[4] Discussion with Chris Van Den Broeck of the Institute for Theoretical Physics, Leuven University, Belgium (*Journal of Theroetics* 1 (June 1999) [cited 6 March 2005]. Available at http://www.journaloftheoretics.com/Comments/1-2/c1-2.htm; INTERNET.

[5] See "What ideas does the NPA [National Philosophy Alliance] stand for?" (http://mywebpages.comcast.net/Deneb/Steps.htm).

[6] In a long scientific career Dingle became a well-known exponent of Einstein's "profound and far-reaching achievement" in developing special relativity. However, after being slighted by Einstein, Dingle decided that he had been misled about the merits of special relativity and published a letter and then an article in *Nature*, contending that the clock paradox showed that the theory was, in fact, plainly wrong. When Dingle tried to follow this up with further journal articles and in letters to leading physicists, mathematicians and philosophers of science, he found that he was ignored or stonewalled—although in one or two instances his respondents rather engagingly confessed that they had never actually understood the theory. See Dingle (1949, 554; 1972, 41–42, 99, 228–239) and Einstein (1949, 687).

[7] "About the Author" (2005), appended to Paul Marmet, "Big Bang Cosmology Meets an Astronomical Death", excerpt, at http://www.newtonphysics.on.ca/BIGBANG/Bigbang.html; INTERNET.

[8] Friedrich Herneck's *Einstein privat* (Berlin, 1984, 349) in Brian (1996, 61).

[9] In later editions of *The Logic of Scientific Discovery*, Popper said he was wrong to call Lorentz's theory untestable. Popper also claimed that Einstein accepted in conversation that his operational definition of simultaneity was mistaken. See Popper (1992, 96–97). This recantation does not appear in Einstein's works, but is borne out by the recollections of Werner Heisenberg (1971, 63).

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