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Popper's response to Dingle on special relativity and the problem of the observer

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ABSTRACT

Dingle contended that Einstein's special theory of relativity was physically impossible for the simple reason that it required clocks to be simultaneously faster and slower than each other. McCrea refuted Dingle using an operationalist argument. An operational response did not satisfy Popper, who wrote an unpublished essay to counter Dingle's claim. Popper developed an analysis that avoided operationalism by using a system of coinciding clocks, contending that this system showed that special relativity withstood Dingle's criticism that it was not a symmetrical and consistent physical theory. However, Popper mistakenly included an asymmetric calculation in his analysis. Once this is corrected, the amended result supports Dingle's position. Popper went on to argue that to avoid determinism, special relativity had to be reconciled with absolute time; this too supports Dingle. Popper's failure to refute Dingle calls into question his claim that 'the observer' is superfluous to special relativity.

1. Introduction

For more than thirty years Herbert Dingle, a physicist and philosopher of science based in London, doggedly promoted a straightforward disproof of Albert Einstein's special theory of relativity (STR). It is perhaps not surprising that Karl Popper disagreed with Dingle's analysis as his falsificationist philosophy of science was inspired by Einstein's overthrow of Newtonian physics. To accede to the claim that Einstein had made an elementary mistake in a vital aspect of STR would, at the very least, have required a fundamental re-examination either of relativity theory or of Popper's own presuppositions. However, when Popper attempted a thorough refutation of Dingle's criticism of STR, it transpired that the views of the two men were not as far apart as might be supposed.

Dingle and Popper knew each other fairly well. They had first crossed swords in 1940 in the pages of *Nature*, when Dingle had sharply criticised Popper's concept of a 'clock'—an issue that was to become one of Dingle's bugbears in his campaign against relativity (Popper, 1940; Dingle, 1940a). Despite this slightly unpropitious beginning, when Popper moved to England to take up a position at the London School of Economics after the Second World War, he became friends with Dingle through the Philosophy of Science Group that Dingle had founded (Popper, Letter to McCausland). In the mid 1950s, Dingle ignited the controversy that would swirl around him for the rest of his life. Popper followed the debate with a mixture of interest and frustration; he wrote a paper that answered Dingle's objections 'to satisfy my conscience'—and then lost it (Popper, Imperial a). Eventually Dingle approached Popper directly to seek his support in getting physicists to respond to his argument, and this prompted Popper to draw up another reply to Dingle's criticism.

Popper's answer to Dingle is now among The Popper Papers at the Hoover Institution Archive, in Stanford, CA. The unpublished paper represents the most extensive statement of Popper's view on STR and forms the principal focus of the analysis presented here. The paper went through three main drafts: A handwritten draft, a typed draft dated 26 September 1973, and a further typed draft dated 4 October 1973. This third draft is 14 pages long with four additional unnumbered pages of diagrammatic figures. It is annotated with handwritten additions and corrections. In a second paper in the Hoover Archive, dated May 1979, Popper set out to undertake a step-by-step reconstruction of STR. There is a first draft of 40 handwritten pages, and a typed draft of 15 pages plus two pages of handwritten notes and diagrams. This unfinished paper is also briefly considered. The correspondence between Dingle and Popper has been consulted at London University, Imperial College Archives, where the Dingle Papers are held. In addition to the letters of 1973 that are discussed here, this correspondence includes unpublished papers exchanged in 1940 and friendly letters exchanged in 1960 and 1972. I have also had access to the 1980 correspondence

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between Popper and Ian McCausland, summarised in McCausland's *The Relativity Question* (1988, pp. 26–27).

Popper's papers on STR are unpublished, but this does not mean that they are ephemeral. Popper may have set out merely to answer Dingle, but in the course of his first essay this objective became transformed into the question of how Einstein's theorising in STR could be reconciled with Popper's philosophy of science. A response to this question is of central importance to Popper's account of the revolution in twentieth century physics initiated by Einstein, but his limited discussion of STR in his published work provides little in the way of an answer. When Popper explained his decision not to submit the 1973 paper for publication to Dingle he gave no indication that he found it unsatisfactory; on the contrary, he described the paper as full, clear, and cogent (Popper, Imperial a). If the 1973 paper did indeed provide a clear account of how STR was consistent with Popper's philosophy of science, this would provide grounds enough to consider it now. But what really makes the paper fascinating is that Popper found it far harder to bring the theory and his philosophy together than he was willing to admit. Although Popper claimed to have refuted Dingle, his opposition to determinism and to operationalism gave his reasoning an underlying logic that drew him ever closer to Dingle's conclusions. Einstein's use of 'the observer' appeared to have both determinist and operationalist implications, and the more Popper attempted to demonstrate that the observer was not in fact required by STR, the more it appeared that the observer *was* required. Using Popper's terminology, this made STR more like an ideology than a science. The tension between what Popper wanted to argue and where his argument was actually heading may help to explain why the 1973 paper remained unpublished and the 1979 paper unfinished. It is this same tension that makes the two essays of particular interest. Before entering into an analysis of Popper's papers, however, it is necessary to specify Dingle's principal objection to STR. In fact, Dingle had numerous objections to the theory, but by the time Popper entered the debate these had been narrowed down to one simple question.

2. The question

Dingle began his campaign against STR by attacking the clock paradox. According to Dingle, Einstein had made an error in the 1905 article that first presented STR by stating that a travelling clock would show less elapsed time than a stationary clock (Dingle, 1956, p. 784). Dingle argued that according to the principle of relativity, if two clocks were in uniform relative motion then 'motion is a relation between them and not something belonging to one or the other, so that all its effects, if any, must apply equally to both' (Dingle, 1956, p. 783). At this stage in his career, Dingle commanded great respect as a physicist with expertise in special relativity and as a philosopher of science, so that his claim drew considerable attention (Chang, 1993, pp. 742–743). McCrea (1956) immediately penned a refutation, but this was only the first of more than three dozen published responses in the period 1956–58 (Chang, 1993, p. 741). The respondents did not always agree with each other, but where they did agree, it was that Dingle was wrong (Cullwick, 1967). Reflecting on these responses, Dingle shifted the focus of his attack. The clock paradox required clocks to be separated and then reunited, which appeared to require acceleration. In his 1956 article Dingle argued that acceleration could not explain asymmetric clock readings, because any impact that acceleration had on a clock could be rendered negligible by an extended journey in uniform relative motion (Dingle, 1956, pp. 782–783). This argument had been widely contested by Dingle's opponents (Chang, 1993, p. 765, 774, 777). Although he continued to maintain that acceleration could not resolve the clock paradox, Dingle sought to avoid becoming embroiled in any further discussion of it by refining his objection so that it referred *only* to uniform relative motion (Dingle, 1962, 1964).

In 1967, Dingle published an article in *Nature* in which he put this revised objection in its simplest terms. He contended that if there were two identical clocks in uniform relative motion, STR required each clock 'to work steadily and continuously both faster and slower than the other' (1967, p. 119). This was physically impossible and the theory was therefore invalid. McCrea (1967) responded with an operationalist explanation of clock rates. To say that a clock was at once fast and slow was to combine discontinuous observations in separate reference frames. This, McCrea said, was meaningless: 'About the first thing that relativity theory does is to deny any operational meaning to the notion of simultaneity at two different places' (1967, p. 123). The editors of *Nature* sided with McCrea in a leader (1967), and there the matter might have rested. It did not. Dingle wrote another article rejecting McCrea's explanation (1968). Then, in an attempt to put his opponents on the spot, he rephrased his objection to STR as 'The Question', and challenged defenders of the theory to answer it. According to Dingle, given two clocks in relative motion, STR demands that 'one clock must work steadily at a slower rate than the other. The theory, however, provides no indication of which clock that is, and the question inevitably arises: How is the slower working clock distinguished?' (1972, p. 45). Armed with this question Dingle made a determined though unsuccessful effort to keep the controversy alive in *Nature*; he appealed to members of The Royal Society; he wrote a book (1972), and he wrote repeatedly to numerous physicists, mathematicians and philosophers of science. When Dingle had exhausted all other avenues he turned to public figures to intercede on his behalf, including the Archbishop of Canterbury, to whom he wrote three times (McCausland, 1988, pp. 55–62).

After *Nature* tried to put a stop to the argument in its columns, Dingle decamped to *The Listener*. It is here that Karl Popper's only direct published comment on the debate Dingle fomented is found. Popper wrote a letter that described Einstein as perhaps the greatest thinker of the age (1971). However, Popper also conceded that there had once been an 'Einstein fashion in physics' (fashion was a term Popper associated closely with ideology), and that he had some sympathy with the critics of relativity. These comments whet one's appetite to learn more, and here we must turn to the archives.

On 7 September 1973, Dingle wrote to Popper (Dingle, Imperial a). Would Popper, Dingle asked, write a letter to *Nature* saying that The Question should be answered by a specialist in relativity theory? Dingle pointed out that coming from Popper such a letter would carry great weight, while no one now took any notice of what he had to say: 'I . . . am written off as an ignoramus, who is naïve, lacks imagination, and makes himself a general nuisance by writing nonsense about what he cannot understand'.

Ten days later Popper replied that he had answered The Question himself:

> Although I am desperately occupied with very pressing and very different work . . . I have spent the last six days (and nights) exclusively with writing and rewriting a lengthy paper (provisionally entitled "The Symmetry and Consistency of Special Relativity") as a reply to your letter (Popper, Imperial a).

Popper went on to agree that the answers which had been given to Dingle's question were 'often contradictory and often bad, and often merely formal'. However, his own paper, he believed, fully answered it. He did not, however, want to send the paper to *Nature*, because he did not have the time to field the large number of replies that it would generate, and because the paper was longer than the brief response Dingle had asked for. He 'fervently'

hoped that Dingle would not insist on being given a copy of it either, as the paper was 20 pages long with ten diagrams and he was too busy to get it typed and to add references.

Dingle replied on 25 September that he did not want to cause Popper trouble and would not dream of asking him to type up his paper (Dingle, Imperial b). He added:

> I don't for one moment doubt the symmetry or consistency of s.r., and am only surprised that you should have needed to write so much to establish it. But my question is, what is the characteristic of *clocks* that distinguishes the faster from the slower working one?

Dingle continued that he was willing to grant that Einstein's relations between time in different reference frames followed logically from his postulates and definitions, but because of the impossibility of explaining how a clock could work both faster and slower than another, he denied that STR was a 'physical theory'. Implicit in Dingle's reply was that STR could either be deemed a physical theory, or it could be deemed symmetrical and consistent, but it could not be both.

On 28 September Popper wrote back (Imperial b). Making the implicit assumption that two clocks in inertial reference frames were in uniform rectilinear motion with respect to each other, Popper pointed out that these clocks could only meet once. However, Popper wrote, 'a *system* of clocks . . . can work, in a very clear sense " faster and slower" than another such system'. While this might sound impossible, Popper asserted that his paper showed that it was not. Popper had this second letter initialled on his behalf; as far as he was concerned the correspondence was at an end. Dingle wrote back on 3 October (Imperial c, 1973), agreeing that the clocks could only meet once and making some guesses about the argument in Popper's paper, but he received no further reply.

Although Popper never sent his paper to Dingle, he did go on to prepare a typewritten draft, to which he added further handwritten annotations (Popper, Hoover a). This paper contains much of interest on Popper's views on both the special and the general theory. Here, however, we limit ourselves to two questions. First, *did* Popper answer Dingle's question? In other words, did he explain how a system of clocks could be both faster and slower in a way that showed that STR was (a) a physical theory, (b) a symmetrical theory in accordance with the principle of relativity and, insofar as it was symmetrical, and (c) a consistent theory? Second, did Popper deal with his own doubts about STR? Dingle had indeed destroyed his professional reputation by breaking with Einstein, while Popper had reached ever-greater heights of fame. Yet Popper too had problems with Einstein's theory, including Einstein's apparent operationalism in STR and his more general determinism. Einstein's determinism was problematic because it was linked to his concept of time (Popper, 1982a, pp. 89–92). Einstein's seeming operationalism was perhaps even more difficult to reconcile with Popper's philosophy, as he argued that this doctrine had led to 'stagnation in theoretical physics' (Popper, 1963, p. 114).

3. Operationalism and determinism

In Einstein's account of STR there are various instances, including the simultaneity of distant events, length contraction and clock rates, when he invites the reader to consider how the observations and measurements of someone situated in one reference frame differ from observations and measurements made in another. Einstein can then appear to argue that these measurements and observations cannot be reduced to one true state of affairs; each perspective is equally true and contradictions between them provide a starting point on which to build a theory rather than a problem that needs to be reconciled with the theory (Einstein, 1923, ch. 1, 2, 4, 1920, ch. 9, 10, 12). By contrast, Popper claimed to comprehend STR in a way that ignored observers and criticised Einstein for creating the impression that to understand STR it was necessary to follow 'the observer and his doings' (Popper, 1992 p. 96). Popper contended that operationalism or instrumentalism denied the scientific attempt to arrive at a consistent account of the truth across different frameworks (1963, p. 108; 1994, pp. 173–4). Popper associated this form of operationalism with the principle of complementarity in physics, the argument that if contradictions arose in a theory, in cases where 'these conflicting applications were physically incapable of ever being combined in one experiment' there was no need to contain them within a single interpretation (1963, p. 100). Without yielding to essentialism, Popper's realist view was that perspectives may differ but there is only one truth. Therefore, if there are different and apparently contradictory perspectives of similar events, then these seeming contradictions cannot be explained away as meaningless, but must be resolved.

Popper did not explain how one could interpret STR in way that rendered the observer superfluous. On the contrary, in one of his more extensive published comments on STR Popper had himself given an operationalist account of the theory. In *The Open Universe* (written in the 1950s), Popper considered the problem that STR appeared determinist as the past from one perspective was the future from another. He argued that the theory was in fact indeterminate because an observer within a reference frame had their own past and future and could not receive a signal from a future event until it had become the past, (Popper, 1982a, pp. 57–61). Thus Popper explained that in STR 'there exists for every observer—or, as I prefer to say, for every local inertial system—an absolute past and an absolute future' (1982a, p. 57). In trying to move Einstein's theory away from determinism Popper had relied upon the observer—call it what you will—having a time that was valid only in their own frame of reference.

Dingle's position on operationalism had evolved with his criticism of relativity. Before he broke with the theory, Dingle presented operationalism as its main innovation, arguing that STR was concerned only with measurements in different reference frames and could not be considered a physical theory (1940b, pp. 39–40). Once relativity theory was accepted, operationalism became inescapable (Dingle, 1950, p. 5). Dingle's view that STR and operationalism were inextricably intertwined explains why his break with relativity coincided with an equally decisive break with operationalism in favour of what was, in Popper's terms, a realist position (Dingle, 1954, p. 14). Therefore, while Dingle's attack on STR moved him away from Popper's understanding of Einstein's revolutionary scientific advance, he moved closer to Popper's philosophical position. From the mid 1950s onwards, the principal difference between Dingle and Popper concerned the place of operationalism in STR. Popper argued that relativity theory could be divorced from operationalism, Dingle argued that—with respect to the special theory at least—the two were inseparable. Behind Dingle's question, therefore, was the assumption that Einstein did not merely appear to be an operationalist; he was one. It was in accordance with this operationalist view that a clock could be said to run fast or slow according to the reference frame of the observer. Dingle set himself against this as a realist: A clock could be either fast or slow but not both at once. Popper attempted to square the circle. Eschewing McCrea's operationalist claim that Dingle's formulation of the problem was meaningless, Popper argued that a system of clocks could be shown to run fast and slow without referring to the perspectives of different observers, and could therefore be reconciled with a single consistent theory.

In making this case, the problem of the operational definition of simultaneity was particularly acute because, as Popper well

knew, Einstein had insisted that it was central to an understanding of relativity (Popper, 1992, p. 97; Einstein, 1920, p. 22). In *Unended Quest* (first published in 1974), Popper responded to this problem by arguing that while Einstein said he was doing one thing, he was in fact doing another. Einstein's relativity theory did not require an operational definition of simultaneity; the issue was, 'simply', as follows:

> In any inertial system, if the event *a* is simultaneous with *b*, and *b* with the event *c*, then *a* is simultaneous with *c*. *But* this transitivity law *does not hold in general for the timings of three distant events unless the system in which a and b are simultaneous is the same as the system in which b and c are simultaneous* (1992, p. 97).

From this starting point Popper set out to show that Dingle was wrong without recourse to operationalism, and also set out to reconsider whether STR could be separated from determinism.

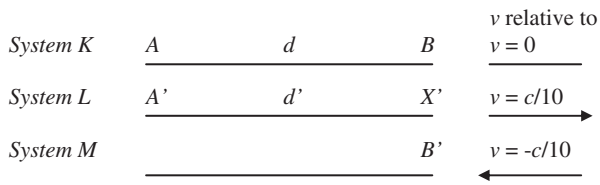
4. Coinciding clocks

Popper began 'A Note on the Symmetry and Consistency of Special Relativity' with an elaboration of his discussion of transitivity in *Unended Quest*. He explained that to avoid an operational definition of simultaneity, he would use coincident clock readings. Coincidences between the clocks were of vital significance to the realist because it was only here that events existed 'absolutely' or independently of any inertial system' (Hoover a, p. 2). Popper then quoted directly from the passage in Einstein's 1905 paper, which introduced the claim that clocks move at different rates in different reference frames:

> If at the points *A* and *B* of *K* there are stationary clocks which, viewed from the stationary system *K* 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 moved from *A* to *B* lags behind the other which has remained at *B* by $1/2\ tv^2/c^2 \ldots$, *t* being the time occupied in the journey from *A* to *B* (Popper, Hoover a, p. 4; Einstein, 1923, p. 49).

This passage, said Popper, had occasioned much comment, although he had always found it 'perfectly clear' (p. 1). This was slightly disingenuous as Popper had truncated his quotation at the very point at which Einstein extends his argument to say that a time lag will also result when a clock prescribes a polygonal or circular route, that is, a clock that returns to its starting point 'where points *A* and *B* coincide' (1923, p. 49). The omission of this latter part of the passage appeared to justify Popper's decision to limit his discussion to clocks that only met once and allowed him to sidestep a number of difficulties raised by Dingle's allies, such as reconciling STR with circular motion (Burniston Brown, 1967; Essen, 1968, 1971). A single meeting of clocks also met the terms of the question set out by Dingle, as if two clocks met twice this required one of them to change direction, something that could 'be misused *ad lib*, to meet any need' (Dingle, 1972, p. 11). However, the difficulty in answering Dingle's question using clocks that could only meet once was that it required Popper to keep track of an ever increasing number of clocks in three mutually intransitive reference frames. Even with the aid of the 'extremely simple' (p. 1) diagrams (replaced by a single aide memoire in Fig. 1), this layer upon layer of complexity made it difficult for Popper to guard against errors creeping in.

Using Einstein's 1905 passage as a starting point, Popper made his first minor modification. Instead of assuming two clocks, Popper had three. The first two clocks were situated in the inertial system *K* at points *A* and *B*. According to the law of the transitivity



System *K*: clocks *A* and *B* (*K* moves at $v = -c/10$ relative to *L*)
System *L*: clocks *A'* and *X'* (*L* moves at $v = c/10$ relative to *K*)
System *M*: clock *B'* (*M* moves a at $v = -c/10$ relative to *K*)

Fig. 1. Three reference frames and five clocks.

of simultaneity within an inertial system, events at these two clocks could be said to be simultaneous. Popper then introduced a third clock, A', in a second inertial system *L*. This third clock A' moved from *A* to *B* along the *x* axis, where all Popper's clocks were to be situated. For illustrative purposes, Popper assumed that clock A' moved at one tenth of the speed of light relative to *K*, that both clocks *A* and A' were set at zero when they coincided, and that when A' arrived at *B* it showed 398 s had passed, while 400 s had passed at *B*. Popper then restated Dingle's objection that a clock cannot be at once faster and slower in the following terms:

> Now one of the reasons why Einstein's statement strikes one at first as absurd is this. It seems to violate the symmetry between *K* and *L*. If (in our reformulation) the system *L* with A' in it moves from *A* to *B* with velocity v, we can just as well say that the system *K* with *B* in it moves towards A' with velocity v: Especially in a theory which is based on the idea that movement is always relative, these two situations must be indistinguishable, and so must be their result. But the result is that A' and *B* coincide when A' shows an earlier time (398 seconds, say) than *B*. Yet when *K* with *B* moves towards A', for symmetry reasons *B* ought to show the earlier time upon coincidence (Hoover a, p. 5).

Popper then introduced a fourth clock, B', into a third inertial frame *M* moving in the opposite direction to frame *L*. Clock B', therefore, moved from *B* to *A*. At this stage in his argument, Popper did not specify the times at *B* and B' when they coincided, merely stating that when B' reached *A* it showed 398 s while *A* showed 400 s. Popper continued: 'The symmetry . . . is obvious; and it removes, I think, our first misgivings' (Popper, Hoover a, p. 7). It is not clear, however, what misgivings have been removed, as it is precisely this symmetry of outcome that is problematic. The symmetry appears necessary to maintain the principle of relativity, but also seems to suggest that a clock must be both faster and slower. In other words, clock B' appears to be identical to the situation, described above as absurd, in which clock *B* moves towards A' and shows an earlier time when the two clocks coincide.

Popper immediately acknowledged this difficulty

> But I am very ready to agree that it does not solve the problem. We must show that *we still obtain symmetry* if we assume that *L* is stationary and with it A', and that *K* moves in such a way that *B* reaches A', as before, when *B* shows 400 and A' shows 398 (Hoover a, p. 7).

To try and explain how clock *B* showing a later time in a *moving* system was symmetrical with it showing a later time in a *stationary* system, Popper introduced a fifth clock X', which he placed in system *L*. When clock X' coincided with clock *B*, clock X' read 0 s as did clock A'. Clock *B*, however, read just under 4 s. Clock *B* then moved from X' to A'. At this point, clock A' read 398 s and clock *B* read 400 s.

Popper arrived at these figures by introducing length contraction, so that the distance between *A* and *B* could not be assumed to be identical to the distance between A' and X'

> the distance d between A and B measured in K (or when K is at rest) is greater than the distance d' between A and B (when measured in L (in L this is the distance d' between A' and X'); Hoover a, p. 9).

Given length contraction, Popper calculated that when B coincided with A' it would not have taken 398 s but just over 396 s. As B, when it coincided with X', read just under 4 s, the total reading was 400 s. With respect to the reading of clock A', Popper explained

> Clearly, d' is the distance measured in L between A' and X', according to Special Relativity; and as the velocity of K relative to L is $-c/10$, we find that the time, measured in L, which elapses between the coincidences of B with X' and of B with A' is exactly 398 seconds, as it should be (Hoover a, p. 9).

Had Popper's analysis been right, then he would have succeeded in showing that an asymmetric result can be obtained from symmetrical calculations, that is (1) when A' moves from A to B, one gets a reading of 398 s on clock A' and 400 s on clock B, and (2) when A' is stationary and B moves to A', one gets an identical reading of 398 s on clock A' and 400 s on clock B. But Popper had made a mistake. Let us go back to the two statements, quoted above, that Popper made after he had introduced length contraction into his calculations. In accordance with the principle of relativity, the same statements must apply if the systems involved are reversed. To preserve the symmetry of the calculations, therefore, it follows that: *The distance d' between A and B measured in L (or when L is at rest) is greater than the distance d between A and B (when measured in K).* Given this, we can calculate that when A' reaches B it will have taken not 398 s but just over 396 s, and as it also must have started from just under 4 s, the total is 400 s. It also follows that: *d is the distance measured in K between A and B; and as the velocity of L relative to K is c/10, we find that the time, measured in K, which elapses between the coincidences of A' with A and A' with B is exactly 398* s. In other words when A' and B coincide, A' reads 400 s and B reads 398 s.

Popper went on to introduce a sixth clock, Y, and to reveal that on the coincidence of B and B', clock B' shows zero seconds and B two seconds. However, there is no need to further examine his reasoning as Popper did not acknowledge that with clock X' he had introduced asymmetric calculations into his analysis. Once this is corrected and symmetry re-established we are back to the initial absurdity that if A' is at rest it shows a later time than B and if B is at rest it shows a later time than A'.

5. True time

In the final part of his 1973 paper, Popper changed tack. He claimed to have vindicated STR against Dingle: 'The *prima facie* objections against Einstein's theory of the relations between clocks in two inertial systems appear to be invalid' (Hoover a, p. 10). This, however, had 'very little to do with the question whether Special Relativity is true, even locally' (Hoover a, p. 13). Popper then made four brief numbered observations. (1) Hendrik Lorentz did not accept that STR was true, maintaining that 'its success was compatible with the existence of a preferred (or "absolute") inertial system'. (2) 'Einstein's General Theory led to a preferred "cosmic time".' (3) Deductions regarding blue shift observations when a solar system moved toward distant nebulae and red-shift observations when it moved away from them meant that 'the system of nebulae would provide a preferred framework'. (4) The cosmic background radiation 'seems to provide a kind of independent check on this preferred system' (Hoover a, p. 13). These points converged on Popper's conclusion that there is absolute time or at least a preferred time.

Popper quoted the principle of relativity from the outset of Einstein's 1905 paper: 'the same laws of electrodynamics and optics are valid for all frames of references for which the equations of mechanics hold good' (Hoover a, p. 13; Einstein, 1923, p 37). In spite of the arguments for absolute time, this principle, Popper maintained, remained valid. But Popper went on:

> Nevertheless, it seems that Einstein's very ingenious relativistic interpretation of his and Lorentz's mathematical theory (the Lorentz transformations) is invalid, and that Lorentz's own position is preferable (Hoover a, p. 13).

In his final annotated draft, Popper thought better of this sentence and crossed it out. In its place he added a marginal note to the second point on cosmic time.

> But if there is a preferred time (such as "cosmic time"), which is locally applicable, then of the various local inertial systems only one can incorporate this preferred time. Thus in Einstein's General Theory, "cosmic" time gives rise to preferred (local) inertial systems. Thus on the basis of Einstein's cosmology, the apparent conflict between Einstein's and Lorentz's views disappears (Hoover a, p. 13).

Whether Einstein had successfully transcended STR with the general theory of relativity (GTR), or whether STR was ingenious but invalid, there was an evident problem with the principle of relativity. Popper had asserted that it was valid, but had also appeared to contradict this by endorsing the principle of a preferred time.

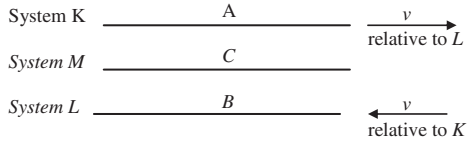
Although Popper never explicitly rejected the principle of relativity, its problematic status when applied to time was reinforced in his final argument, which was concerned with the rejection of determinism in STR. With the aid of a diagram, summarised in Fig. 2, Popper stated that STR could be shown to be a deterministic theory by comparing the sequence of distant events in intransitive reference frames.

Popper identified reference frames K and L as moving in opposite directions from the perspective of a third frame M. He placed an event in each reference frame and, using an operational definition of simultaneity, considered the sequence of events from each perspective

> for any inertial system K and any two events A and B, such that A and B occur at different times relative to K (for example, A is in the future of B), there will be an event C simultaneous with B relative to K, and an inertial system L such that A and C are simultaneous relative to L, and therefore also an inertial system M such that A is in the past of C, relative to M (Hoover a, p. 14).

According to STR, therefore, events which are yet to occur in one reference frame have already taken place in another. Popper immediately concluded

> It is easily seen that this means that for any future event there exists an inertial system which makes that event belong to the past, and therefore determined (Hoover a, p. 14).



System K: event A (an arrow indicates K moves left to right with respect to L)
System M: event C (M is stationary on the page)
System L: event B (an arrow indicates L moves right to left with respect to K)

Fig. 2. The determinism of special relativity.

Popper rejected this built-in *prima facie* determinism of STR. He explained that 'the minimum deviation from Special Relativity compatible with indeterminism is seen in the postulate that there is a preferred "true time" ' (Hoover a, p. 14).

Popper did not point out that if the timings of events occur in accordance with clocks at these events, then his argument could be rephrased so that a future event is indicated by a clock that runs more quickly and a past event by a clock that runs more slowly. This means that relative to *K*, the (stationary) clock at *A* runs more quickly than the (moving) clock at *B*, but relative to *M*, the (moving) clock at *A* runs more slowly than the (stationary) clock *C*. Therefore, for any clock running fast there exists an inertial system, which makes the same clock run slow. In rejecting this implication of STR, Popper had implicitly endorsed Dingle's view that it was impossible for a clock to be at once faster and slower.

6. Two Einsteins

In the same year that Popper was trying to show that STR was consistent, he was elaborating his view that there were two incompatible Einsteins for the 1973 Herbert Spencer Lectures. The first Einstein instituted a 'scientific revolution', beginning with STR that 'overthrows Newton's kinematics' (Popper, 1994, p. 20). The second Einstein was the father of an 'ideological revolution' founded, in part, on the mistaken belief that a logically untenable form of operationalism had been essential to the development of relativity theory (Popper, 1994, pp. 16–17, 20). In other words, the Einstein who said he was doing one thing was the ideologist, and the Einstein actually doing another was the scientist. To keep the two Einsteins apart, Popper had to separate the wheat from the chaff in his reading of STR. The principle of relativity, left in limbo in Popper's reply to Dingle, presented an immediate challenge to this endeavour. The principle could hardly be discarded, but neither could Einstein's innovative extension of the principle be interpreted in an operational manner that allowed the perspective of one observer to be as true as another without attempting to reconcile them.

In 1979 Popper started to confront this challenge in his unfinished paper entitled 'Special Relativity and Moving Clocks' (Hoover b). In an ambitious undertaking he set out to separate the scientific Einstein from the ideological Einstein; to show that Einstein's extension of the principle of relativity was not based on operationalism, and to show that Einstein was no relativist as however many observers there might be, there was only a single truth. In his opening sentences Popper launched into these tasks immediately by indicating that he would criticise tangential aspects of STR while upholding its core, and identifying 'the observer' as one of the main red herrings of the theory

> This paper is nowhere critical of Einstein's special theory of relativity, although it is here and there a little critical of some of what may be described as Einstein's asides. Among these asides I count Einstein's introduction of "the observer" (Hoover b, p. 1).

Popper then touched on the influence of the observer on quantum mechanics and mentioned that his realist philosophy had led him to criticise essentialist 'definitions in general, and Einstein's so-called definition of simultaneity in particular' in *The Open Society* (Hoover b, p. 1; Popper, 1966, p. 20). However, Popper rightly admitted that his criticism of Einstein (such as it was) had been 'a bit timid; and it could have been put more clearly' (Hoover b, p. 1). In Section 2 he provided an overview of Einstein, Newton, and Maxwell. In Section 3, entitled 'Two Principles or One?', he entered into a detailed discussion of how the principle of relativity was developed in STR.

Popper argued that confusion arose from the very outset of Einstein's 1905 paper, as the constancy of the velocity of light, which should have been presented as a consequence of the principle of relativity, was mistakenly said to be a second independent principle that seemed to conflict with the first (Hoover b, pp. 4–5). According to Popper, Einstein quickly realised his mistake but, inexplicably, never subsequently realised that this changed his problem focus. Under the heading 'Definition of Simultaneity' Einstein had asked how to reconcile the two principles, when what he should have done was to ask whether or not the principle of relativity was consistent, 'for since the second postulate follows from the first, any doubt about their irreconcilability has to be replaced by a doubt about the internal self-consistency of the first, the Principle of Relativity' (Hoover b, p. 5). The result of this confusion, in both the 1905 article and in *Relativity: The Special and the General Theory*, was 'a considerable muddle—not in Einstein's theory, but in his description of the problem situation' (Hoover b, p. 8). After highlighting 'a particularly bad sentence' in Chapter 7 of *Relativity*, Popper concluded this section with the comment that there were so many contradictions in this part of Einstein's presentation as to make it incomprehensible:

> Although none of this affects Einstein's theory, Einstein's argument here is certainly impossible to follow, since it contains several involved inconsistencies; and this may perhaps be one explanation (a rational one) for the persistent opposition to the theory (Hoover b, p. 8).

The ideological Einstein had been taken to task and the objections of Dingle and others like him accounted for; the critics of STR had assumed that the muddle which Einstein had created in explaining his theory was the theory itself. It was now Popper's intention to show how a revised account of STR, differing 'radically from Einstein's presentation' would reveal the scientific Einstein (Hoover b, p. 12).

The scientific Einstein, however, remained elusive. In Section 4, Popper concluded that to demonstrate the consistency of the principle of relativity 'is a difficult problem even if freed from the muddle described in my Section 3' (Hoover b, p. 11). After discussing the transitivity of simultaneity within an inertial system in Section 5 and drafting notes and diagrams in preparation for a renewed discussion of intransitive reference frames, Popper set the paper aside. We never do learn how, once the inconsistencies are removed, the scientific theory emerges and the observer disappears.

7. The observer

In 1965 Popper began an unfinished monograph called 'Exorcising the observer from modern physics', which was to have included chapters on STR and GTR (Miller, 2006, p. 30). Drawing on this work, he published an essay in which he argued against the role of the observer in the Copenhagen interpretation of quantum mechanics (1967), and repeated this argument in *Quantum Theory and the Schism in Physics* (1982b). Popper contended that the scientific role of an observer was as an experimentalist who tested a theory against reality, but the Copenhagen interpretation used the observer in a way that rejected the concept of objective reality (1967, p. 7). The observer in quantum mechanics, therefore, allowed a theory to appear consistent when it was inconsistent with realism. If the same charge was not to be laid against the observer in STR, Popper needed to uncover a scientific thread of argument beneath an ideological overlay of operationalism.

By his own admission, Popper had been somewhat timid in his published criticisms of STR (Hoover b, p. 1), and had said little on

how these criticisms were to be resolved. The assertion in *Unended Quest* that STR could be read without the observer was not followed through, and the more extended defence of STR in *The Open Universe* was problematic because it hinged on the observer that Popper sought to eliminate. The unpublished papers are the only place where we can see a sustained attempt to reconcile STR with his philosophy of science. Yet in his effort to excise the observer from STR, Popper only succeeded in showing how vital the observer was to the theory. It was the observer who provided the 'so-called definition of simultaneity'; the observer who undermined realism; the observer who appeared to be in the vanguard of Einstein's extension of the principle of relativity; the observer who denied true time.

Popper's (1973) paper showed his difficulty in bridging the gap between the assertion that one can construct STR without the observer and an account of how this is actually done. The paper demonstrates that despite Popper's rhetorical protestations that one 'simply' needs to recognise that there are intransitive reference frames, reading STR as a symmetrical, consistent physical theory without the observer is no easy matter. Popper's very failure to provide such a reading makes the 1973 paper of forensic interest. It allows us to trace how the logic of Popper's argument develops in exactly the opposite direction to that which he intended to take, and reveals the difficulty in marrying his philosophy of science to Einstein's theorising. The fact that the follow up paper of 1979 makes highly critical comments on Einstein's presentation of STR, and then stops without providing an alternative reading, suggests that reconciling STR with Popper's philosophy of science is not just difficult, but may be impossible. If so, this means either (a) Popper was mistaken in his criticism of operationalism and determinism, or (b) he was mistaken in his characterisation of STR as a revolutionary scientific advance.

8. Questions of consistency

In the period that Popper was considering STR, experimenters continued to research time dilation by making comparisons between moving and stationary clocks, whether atomic clocks or muons. The results showed asymmetric clock rates (Hafele & Keating, 1972a, 1972b; Bailey et al., 1977). In *Nature* these findings were seen as corroborating STR and were used to close the Dingle debate (Nature, 1972; Wilkie, 1977). In fact, Dingle's argument did not rest on there being no effect of movement on a clock. Rather, Dingle contended that STR could only be read as a consistent theory if Einstein's prediction that there was an asymmetric effect on clock rates was regarded as an error. If this effect was found, and was seen as confirming Einstein's prediction, then from Dingle's perspective the internal consistency of the theory was cast into doubt. Chang has suggested that Dingle's long campaign did not produce an agreed answer to this criticism amongst physicists, but did define 'what questions *not* to ask' of STR in standard science journals such as *Nature* (Chang, 1993, pp. 786–787). By deciding not to publish his answer to Dingle, Popper helped to place questioning the consistency of STR within this no-go area. Given Popper's standing it is possible that if 'A Note on the Symmetry and Consistency of Special Relativity' had been published, the question of the internal consistency of STR may have gained more legitimacy as a contested issue within mainstream physics. Publication of the paper may also have encouraged more debate over whether experimental evidence confirmed STR or Lorentz's interpretation of relativity. In this respect, Popper's (1973) contention that Lorentz's position was either preferable to or reconcilable with the views of Einstein would have added weight to his later published remarks that although Lorentz's 'adherence to an ether at rest and Newtonian absolute space and time was a bit shocking', there was some evidence that argued for a return to such an interpretation (Popper, 1982b, pp. 29–30, p. 30n).

In 'Don't Bring Back the Ether', the 1967 editorial that endorsed McCrea's rejoinder to Dingle, the editors of *Nature* wrote: 'now that most people are disciples of Popper, an inconsistency is more likely to be welcomed than ignored' (p. 114). One can only speculate what kind of welcome 'A Note on the Symmetry and Consistency of Special Relativity' would have received if Popper had changed his mind and submitted it to *Nature*. However, one person at least would have been delighted if Popper's paper had been accepted and published: Herbert Dingle. Popper had claimed that his paper refuted Dingle, but the reasoning it contained told a different story. (1) Popper had rejected an operationalist explanation of clock rates of the type offered by McCrea. (2) In attempting a non-operationalist analysis he had mistakenly introduced asymmetric calculations, which when corrected to restore symmetry led to results that supported Dingle. (3) He had concluded that STR needed to be to be made consistent with absolute time.

It is suggested here that Popper had set himself an impossible task. Operationalism is not an 'aside', it is integral to STR. Only by accepting the vital role of operationalism in STR can it be made symmetrical and consistent. However, in terms of Popper's philosophy this means that STR is incompatible with realism, or to use Dingle's terms it is not a physical theory. Popper therefore, failed to demonstrate that the ideological Einstein who said he was doing one thing was different from the scientific Einstein who was actually doing another. If anything, it was Popper who had said one thing and done another. He had said that STR was a scientific theory and that Dingle was wrong, but within his own terms of reference, which rejected operationalism and determinism, he had actually shown that STR is an ideological theory and that Dingle was right.

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