philosophy students to bring some of these all important strands together.

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Physical Relativity—Space-time Structure from a Dynamical Perspective
By Harvey Brown
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§1 It is not uncommon to read that Einstein's Special theory of relativity (STR) represents one of the great revolutions in scientific thought. Einstein himself assessed his achievement quite differently. The STR was not a 'revolutionary act', he declared. Rather it was the crowning of classical physics, in particular of the work of Faraday and Maxwell. There are good reasons not to regard the STR as a scientific revolution. There are equally good reasons to think that the STR had nevertheless profound impacts on philosophy and our view of the natural world. First, the STR challenged traditional assumptions about time. It showed mathematically that clock times depend on the motion of inertial systems as judged from inertial systems at rest. It demonstrated the same relativity for the behaviour of measuring rods. Second, the STR showed that events will not be judged as simultaneous events by all observers, irrespective of their motion. What are simultaneous events for stationary observers turn out to be non-simultaneous events for observers moving inertially at great speed with respect to the stationary observers. Relative simultaneity has seduced many physicists into thinking that time is a human illusion. Kant's idealistic notion of time seemed to be vindicated by a profound scientific theory. Third, the STR showed that the inertial mass of an object is not an invariant property but, again, depends on the motion of the object. Further, mass and energy are related. Fourth, the STR made the speed of light, c, a limiting speed for all mass-objects in the sense that according to the equations of the STR no material object can reach the speed of light. The STR also showed that the speed of light is independent of the motion of the source, from which it is emitted and independent of the direction of its propagation. Thus, the speed of light is both finite and invariant for all inertially moving observers.

§2 Physicists and philosophers alike have discussed these numerous philosophical consequences of the STR for our general philosophical

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view of nature from the moment of the inception of the theory. In his book, *Physical Relativity*, Harvey Brown is not preoccupied with these broader philosophical consequences. In fact, his aims seem to be twofold. The general aim of the book concerns 'the nature of special relativistic kinematics, its relation to space and time, and how it is supposed to fit in to general relativity (viii).' A more specific aim is to rebut the idea that space-time is explanatory, e.g. that space-time can be treated as an entity in its own right, which explains the behaviour of inertial systems (24). Although the book is not a textbook on relativity, it is a contribution to the philosophy of physics. In particular it supports a dynamical interpretation of special relativity. This interpretation is not new. In fact Brown devotes two chapters (4, 7) to a discussion of the 'trailblazers' of this interpretation. It is customary for physics textbooks on relativity to adopt the Minkowski presentation. According to this geometric presentation, space-time is a four-dimensional geometric structure, which incorporates the postulates of the special theory of relativity. Following the thoughts of physicists like Fitzgerald, Lorentz, Poincaré and J. S. Bell, Brown argues that a purely geometric understanding of the theory of relativity is insufficient. It needs to be augmented by a dynamic understanding. According to Brown there is a much tighter connection between kinematics and dynamics in Einstein's 1905 paper than has hitherto been fully recognized. In Brown's view a proper understanding of two of the most striking consequences of Einstein's 1905 paper—length contraction and time dilation—cannot be properly understood without taking into consideration the micro-structure of rods and clocks. It is not the geometry of space-time, which makes the rods shrink and the clocks dilate; rather length contraction and time dilation need to be understood from the atomistic point of view (132ff). For rods and clocks are basically atomistic systems, although for the purpose of presentation abstraction is made from this micro-structure. Thus Brown argues from the kinematics of inertial systems to their dynamic underpinning, as he denies that there is a strict separation between kinematics and dynamics.

§2 Before I go any further I should say that this book is not written for beginners or even for readers with an intermediate knowledge of the philosophy of space-time. There is simply too much technical terminology, which the author presupposes, without ever explicitly explaining it. The list is too long but typical examples include 'foliation', 'Langevin clock', 'gauge transformation', 'Aharonov-Bohm effect' 'tangent space geometry' and so on. Sometimes a technical term is introduced ('strong equivalence principle') and

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explained much later in the book. In some cases such terms are only mentioned once or twice and disappear without trace. The expert reader will not necessarily be interested in all parts of the book. For instance, such a reader may not want to see another derivation of the Lorentz transformations or a detailed account of inertial systems or an appendix on the entanglement of quantum systems. I find these chapters very interesting but regret that, due to Brown's style, they are not more accessible to a less informed reader. I expect that the expert reader will also find different parts of the book more interesting than others. The historian of science may be more interested in the detailed discussion of the Fitzgerald-Lorentz deformation hypothesis. The philosopher of physics will pay more attention to the central claim of the book, e.g. that the geometric presentation of space-time is not explanatory of relativistic behaviour of the measuring rods and synchronized clocks, which define an inertial system in Einstein's exposition. In order to account for this behaviour a dynamic explanation is required. Brown calls the existence of inertial coordinate systems in the STR a 'miracle' (rather than an idealization), adding that 'anyone who is not amazed by this conspiracy has not understood it' (15). In this sense there are of course many 'miracles' in physics: the postulation of circular orbits in the Copernican heliocentric system was a miracle prior to Kepler's laws and Kepler's laws are a miracle prior to Newton's inverse square law. To treat these idealizations as 'miracles' is to gloss over the techniques of abstraction, idealization and factualization in the history of science.

There is of course interesting material for the philosopher of physics even in the historical details. For instance, we learn that the textbook representation of the Fitzgerald-Lorentz contraction hypothesis is mistaken. Fitzgerald proposes a deformation hypothesis, like Lorentz, but he does not seem to have thought of longitudinal contraction. Brown also stresses that Fitzgerald's reasoning makes no essential reference to the ether. Another important feature of the historical section is Brown's emphasis on early speculations on an atomistic explanation of length contraction and time dilation. Brown spends half of the book on preparing the reader for a defence of the insight that dynamic considerations are required to account for relativistic behaviour. In preparation Brown devotes a whole chapter to the discussion of 20th opinion on these matters. There is much interesting (not necessarily new) material and a number of textbook misconceptions are highlighted. Brown uses an analogy with Darwin to drive home his point. Darwin knew nothing of the mechanism of inheritance. His theory

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of natural selection was successfully formulated in ignorance of the laws of genetics. But when molecular biology had made its strides evolutionary theory and genetics could finally be combined to form the 'new synthesis'. The analogy serves to prepare the reader for the result of the first half of the book. What meets the reader, however, can only be described as bathos. Tucked away in a footnote (148, Fn. 55) Brown writes:

> To provide a quantum theoretical analogue of Bell's constructive pedagogical model, involving inter-atomistic forces, would be an ambitious undertaking, outlandishly so if the starting point is the most fundamental theory we have: quantum field theory. I am unaware of a systematic derivation of the stable structure of even the hydrogen atom within relativistic quantum field theory. And even today, relativistic treatments of the cohesion of matter based on quantum mechanical models of interaction are not thick on the ground.

One wonders then what the point of the argument has been up to this point. Brown tells us that it is 'part of the full picture'. This presumably does not mean a full physical picture, which by Brown's own admission is not yet available. Perhaps then there is something in it for the philosopher. However, the bathos continues for Brown states that there

> is no way that appreciation of the role quantum theory plays in the most fundamental account of the relativistic behaviour of rods and clocks can lead to as profound a change in the philosophy of relativity theory [as molecular biology has in evolutionary theory].

In the following chapters Brown goes on to discuss the compatibility of the dynamic view with the General theory of relativity (GTR). The discussion turns to the explanatory nature of space-time but the reader is greeted at the very end (177) with a similar bathos:

> There is, after all, a crucial tension between the dynamical interpretation of SR and the structure of GR. It arises from the fact that Einstein's field equations refer to classical fields. In particular, the matter fields appearing in the definition of the stress-energy tensor are classical. To follow the history of attempts to circumvent this problem would take us too far afield.

Whilst there are many interesting technical details in this book the general outcome is therefore quite disappointing. Besides this, the book suffers from some serious defects, which I should point out.

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§3 The most serious defect is Brown cavalier attitude towards technical terminology, as mentioned above. One of the most frequently used terms in this book is 'Lorentz covariance'—nowhere is it explicitly introduced.[1] Furthermore it seems to be used in four different senses: **a)** in Einstein's sense as an extension of the relativity principle (74–5, 186); **b)** in Einstein's sense of form invariance (5, 120, 179); **c)** in the sense of symmetry invariance of the Maxwell equations (146, passim) and **d)** in the sense of general covariance (143, Appendix). This will be annoying even for the expert reader, since much scholarly work has been done on these distinctions (Earman, Friedman, Norton, Stachel, Scheibe) in an attempt to clarify their precise meaning in Einstein's work and the role the notion of covariance has played in the development of the GTR. Despite all this scholarly work there are still open questions: What *is* form invariance? Is covariance empirically vacuous (Kretschmann, Weinberg) or not (Einstein, Norton)? In this reviewer's opinion a reader may have expected that Brown, who has an admirable grasp of physics, shed some light on these technical issues. But the reader is let down; even an appendix, which bears the title 'Einstein on General Covariance' fails to discuss how it is related to Lorentz covariance, how it is related (if at all) to the principle of relativity and what implication form invariance has for questions of empirical objectivity and reference.

Secondly, a certain ambiguity seems to run through the whole argument. Brown tells us that space-time structure has to be viewed from a dynamical perspective (the subtitle of the book). But dynamic structure sometimes just refers to space-time relationism and sometimes to quantum micro-structure (133). In the former case, it is substantivalism which is under attack. In the literature, space-time relationism is typically discussed without reference to atomistic systems but with reference to STR and GTR. Brown informs us that GTR finally solved the mystery of inertial motion (it does not assume that ruts and grooves run through space-time guiding the inertial systems). The reference to GTR is not a reference to microstructure because General relativity and quantum mechanics cannot easily be unified. GTR operates on classical fields. Brown seems to be sympathetic to space-time relationism but does not take his book to be a defence of this approach. Given

[1] I regard the footnote explanation that by Lorentz covariance is meant 'covariance with respect to the 10-dimensional inhomogeneous Lorentz group, or the "Poincaré" group' (...) as unilluminating (129).

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the paucity of the result about the atomistic approach, I think this neglect of relationism was a mistake. The expert reader may have expected a more systematic and possibly more fruitful discussion of space-time relationism.

At the beginning Brown claims that his book, like Darwin's *Origin of Species* is 'one long argument' (viii). In one sense it is, since it argues from the kinematics of inertial systems to the need for a dynamic consideration. But in another sense it is not. It reads like a compilation of Brown's research papers, with no attempt to adapt the style to a book-length argument. The footnotes at the beginning of each chapter reveal indeed that much of this material has been published elsewhere. Often the material draws heavily either on Brown's own work or that of others. I think that Brown's central idea—a philosophical defence of a dynamic reading of space-time—could have been explained in a research paper in the *British Journal for the Philosophy of Science*. I admire Brown's knowledge of theoretical and experimental physics and have learned many interesting points from the discussions in this book. But the overall argument fails to live up to its Darwinian analogy.

Friedel Weinert

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