From Physics to Philosophy, edited by Jeremy Butterfield and Constantine Pagonis. Cambridge: Cambridge University Press, 1999. Pp. xv + 235. H/b £37.50

Most of the essays in this book were presented as papers at a conference held to mark the retirement of Michael Redhead from his post at Cambridge. Almost all of the essays begin with at least a nod to Redhead, and the entire volume is conceived in his honour. The title of the volume alludes to the title of Redhead's Tarner Lectures—*From Physics to Metaphysics,* Cambridge University Press, 1995—and the volume concludes with a comprehensive bibliography of Redhead's writings.

Apart from a brief introduction by the editors, the remaining content of the book is as follows:

1. "Locality and the Hardy theorem", by Arthur Fine
2. "Beables in Algebraic Quantum Theory", by Rob Clifton
3. "Aspects of Objectivity in Quantum Mechanics", by Harvey Brown
4. "The 'Beables' of Relativistic Pilot-Wave Theory", by Simon Saunders
5. "Bohmian Mechanics and Chaos", by James Cushing and Gary Bowman
6. "Strange Positions", by Gordon Fleming and Jeremy Butterfield
7. "From Metaphysics to Physics", by Gordon Belot and John Earman
8. "Models and Mathematics in Physics: The Role of Group Theory", by Steven French
9. "Can the Fundamental Laws of Nature be the Results of Evolution?", by Abner Shimony

Not surprisingly—given the important place in the literature which is occupied by Redhead's classic <u>Incompleteness, Nonlocality and Realism: A Prolegomenon to the Philosophy of Quantum Mechanics</u>, Oxford University Press, 1987—many of the essays in the volume are concerned with issues in the foundations of quantum theory. Equally unsurprisingly, most of the essays are liberally sprinkled with mathematical formulae and equations, and the questions upon which they focus are not readily accessible to those not already versed in the intricacies of current discussions of the foundations of quantum mechanics.

Shimony's essay is the one piece which will be accessible to a wide readership, so let me begin with it. The topic of the piece is the ontological status of fundamental natural laws, and, in particular, the suggestion that fundamental natural laws might be given an evolutionary explanation. As Shimony points out, it is hard to see how it could be that *all* fundamental laws have an evolutionary explanation: evolution requires an "arena" in which to occur, and that "arena" will itself be governed by fundamental laws. However, Shimony also allows that it might be that we can give an evolutionary explanation of at least some of the fundamental laws of particle and spacetime physics. Shimony cites the recent work of Lee Smolin as an example here: the fundamental dimensionless parameters of elementary particle physics might be given an evolutionary explanation in multi-universe cosmogonies. (Quentin Smith's earlier and independent development of the theory which Shimony attributes to Smolin should be noted here: see his "A Natural Explanation of the Existence of the Laws of our Universe" *Australasian Journal of Philosophy* **68**, March 1990, pp.22-43.) Of course, the Smith/Smolin view is highly controversial: but it remains an open question just how far the project of giving evolutionary explanations for fundamental laws can be extended. (Note that, by ‘fundamental law’, Shimony means something like ‘base level law for a given domain of inquiry’: on this way of viewing things, there may be fundamental laws of social psychology, vertebrate anatomy, inorganic chemistry, particle physics, and so forth. Note, too, that Shimony denies that there is a fundamental law of natural selection—so *that* line of objection to the project of giving an evolutionary explanation of *all* fundamental laws is foreclosed.)

French discusses model–theoretic accounts of scientific theories. In particular, he is interested in the representation of the relationship which holds between mathematics and science in these theories. He suggests that in many cases one finds a hierarchy of models related by “partial isomorphisms”; moreover, he claims that this account in terms of “partial models” is better able to represent the actual relations which held between, say, group theory and quantum mechanics at the time that Weyl and Wigner recast quantum mechanics in group–theoretic terms. Finally, French suggests that his preferred account of scientific theories might underwrite a kind of “structural realism”, i.e. a view which holds that “objectivity” should be understood “structurally”, in terms of the “invariants” of those theories.

Belot and Earman argue that recent philosophical objections to Einstein’s “hole” argument—and, in particular, the variant of this argument used by Earman and Norton in arguing for the conclusion that substantivalist interpretations of general relativistic spacetimes must be indeterministic—fail to take account of the serious regard which is paid to the argument by substantial numbers of contemporary physicists. According to Belot and Earman, what the “hole” argument shows is that general relativity is indeterministic under a literal interpretation, but deterministic under a gauge invariant interpretation. Other things being equal, this gives us a reason to prefer the gauge invariant interpretation. But—and this is the point which worries the previously mentioned physicists—gauge invariant interpretations of general relativity seem to imply that reality has no temporal or changing aspect. Moreover, this same problem straightforwardly carries over to canonical approaches to quantum gravity: in canonical approaches to quantum gravity it seems that there is neither time nor change. Belot and Earman conclude by sketching four recent responses to this “problem of time”: two “Parmenidean” approaches (Barbour, Rovelli) which accept that the world is not temporal; and two “Heraclitean” approaches (Kuchař) which seek for ways to find time in canonical theories of quantum gravity. Perhaps the right moral to draw is that a more radical approach to quantum gravity is required; but whether or not that is so, Belot and Earman make a good case for not dismissing the “hole” argument too lightly.

Fleming and Butterfield discuss some of the difficulties which confront the use of localised position operators in Lorentz–invariant quantum theory. In particular, they are interested in defending the approach developed by Newton and Wigner, despite the fact that this approach apparently entails both (i) superluminal propagation for localised states; and (ii) complete delocalisation by operations which represent passive transformations to relatively moving frames of reference. In previous work, Fleming has recommended a hyperplane dependent parameterisation for position operators: it is the dependence of localised states on hyperplane parameters which gives rise to the consequences (i) and (ii) mentioned above. The line which Fleming and Butterfield take is to deny that the association of an operator with a spacetime region entails that one can measure that operator by performing operations which are confined to the given spacetime region. This enables them to claim—against critics such as Malament and Saunders—that the approach developed by Newton and Wigner has not been *shown* to give rise to causal anomalies.

Cushing and Bowman are interested in reasons for preferring Bohm/de Broglie "pilot wave" interpretations of quantum mechanics to "standard" (Copenhagen) interpretations of quantum mechanics. In particular, they suggest that Bohm's programme may help to provide insight into quantum chaos and the general notion of "the classical limit". Since there are no trajectories in Copenhagen interpretations of quantum mechanics, these interpretations cannot accommodate "highly irregular behaviour of trajectories"—but this is just how chaos is described in classical systems. So the thought is that Bohmian mechanics might be able to naturally incorporate this classical conception of chaos—and the difficulties which have beset attempts to find some other conception of quantum chaos will thereby be avoided. However, one apparently awkward consideration is that, under this interpretation, there might well be classical systems which cannot be reached as the limit of quantum mechanical systems—and that would cast doubt on the idea that quantum mechanics is a fundamental theory. Perhaps this is a good reason for supposing that there must be some other acceptable characterisation of quantum chaos—but, as things stand, there is clearly plenty of work for physicists to do in this area.

Saunders provides an argument against Bohm/deBroglie "pilot wave" interpretations of quantum mechanics. The chief advantage of "pilot wave" interpretations of non-relativistic quantum mechanics is that they provide an immediate solution to the measurement problem. However, Saunders argues, when we move to relativistic quantum mechanics, it is not so clear that there is any advantage on offer. On the one hand, if we take the beables in the relativistic case to be field configurations, then the measurement problem arises over again for the localisation of these field configurations—and it is not at all clear how "pilot wave" interpretations could hope to solve this "new" measurement problem. On the other hand, if we take the beables in the relativistic case to be particles, then plausibly we shall be required to believe in the existence of an infinity of point–particles with negative energy and negative charge in every non–zero volume of space—and that seems to be a rather high price to pay to solve the measurement problem. As Saunders admits, his argument is hardly rigorous: who knows what clever alternatives might be dreamt up by proponents of "pilot wave" interpretations? However, it does seem plausible to think that proponents of "pilot wave" interpretations have serious work to do in extending their interpretation to the relativistic case.

Brown begins by discussing some problems raised by the covariance of the Schroedinger equation under local gauge transformations and Galilean coordinate transformations, and by the discovery of geometric phase in Berry's study of systems undergoing cyclic adiabatic evolution. Brown defends the view that the non–invariance of current formulations of geometric phase is not obviously worrying; and he suggests that the true significance of geometric phase may turn out to be similar to the significance of Minkowski's geometric formulation of special relativity, viz. that it has heuristic power for the future reformulation of quantum principles. Brown then goes on to note that the possession of "sharp values" is not gauge–independent in quantum mechanics; and from this, he draws the conclusion that there is even more reason in quantum mechanics to regard "sharp values" of properties as relational—

and not intrinsic—features of systems. Finally, Brown discusses the theory of "quantum reference frames" (or "quantum frame bodies") developed by Aharanov and Kauffher, and suggests that this theory lends further support to the previously mentioned conclusions about the relational status of "sharp values".

Clifton aims to provide an algebraic characterisation of beables—i.e. of observables for which it is true that the probability of the quantity being a particular value is the probability of observing that value. (Familiar no–go theorems—such as the Kochen–Specker theorem—are defused if we allow that not all self-adjoint operators correspond to beables: this is the fundamental idea which guides modal interpretations of quantum mechanics.) Clifton works in the framework of C*–algebras, and calls the appropriately characterised collections of beables "Segalgebras".

Fine criticises some recent work—by Hardy, Goldstein, and others—which seeks to "go beyond Bell's theorem" by "dispensing with inequalities". Fine points out that these new proofs—like the earlier "no go theorems" upon which they are modelled—make assumptions which go well beyond the commitments of locality (and so can hardly be taken to establish that quantum mechanics is non–local). Moreover, as Fine notes parenthetically at the end of his piece, even if these proofs did establish that quantum mechanics is non–local, that would hardly establish that nature is: we are a long way from having established that standard quantum mechanics is a true fundamental theory.

The standard of the essays in this collection is very high. All of the essays are interesting; and everyone who works in the field will want to read them. The volume makes a fine tribute to Michael Redhead; and the editors are to be commended for their work, and for the helpful introduction.

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