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BOOK REVIEW

Bohmian Mechanics and Quantum Theory

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James Cushing, Arthur Fine and Sheldon Goldstein (eds), *Bohmian Mechanics and Quantum Theory: An Appraisal* (Dordrecht: Kluwer), viii + 403 pp., ISBN 0792340280.

This collection *Bohmian Mechanics and Quantum Theory* gives us the broadest perspective yet on this important realist alternative to standard quantum theory. The book treats the history, philosophical ramifications and consistency of theories arising from Bohm's original model and their relations to other alternative theories. Significantly, it also contains applications of these theories to practical situations, such as scattering theory—a sign of the subject's increasing maturity.

Most importantly among its contributions to physics and the philosophy of physics, Bohmian mechanics provides an existence proof in support of the hidden-variable approach to explaining quantum phenomena: it is a causal mechanics observationally equivalent to standard non-relativistic quantum theory. As with the study of the foundations of quantum theory generally, Bohmian mechanics is undergoing a renaissance. During those long years of neglect between the appearance of the EPR argument in 1935 and the emergence of various theories of microphysics, Bohmian mechanics and Everett's relative state theory emerged as little-regarded testimonies that alternatives to standard quantum theory were indeed conceivable. In these later times, we have this exciting volume of contemporary work on Bohmian mechanics. Though the editors have included among the contributors several contemporary advocates of the approach, sufficient sceptical analysis is also provided to put optimistic claims in proper perspective.

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The simplest way to view the introduction in 1952 of Bohm's theory is as a direct response to the acausality that Bohr and Pauli, amongst others, saw as essential to quantum phenomena. After all, these workers saw acausality unmistakably manifest in the apparent impossibility of understanding quantum phenomena with theories attributing definite trajectories in space-time. Bohm's move was to take as fundamental the contrary, that physical systems, beginning with single particles, have definite positions at all times and that their initial positions at a given time determine their future behaviour, in accordance with Newton's equation of motion. This required mainly the addition of a 'quantum potential' to those potentials ordinarily present. The result was a complete theory of motion for microscopic systems whose statistics accord with the predictions of standard quantum mechanics. In a broader sense, Bohm's theory can be seen as a materialist response to the mystic character of the standard theory, most clearly exhibited in its dependence on the special status of the observer of quantum phenomena.

The paper by Millard Baublitz and Abner Shimony gives order to the conceptual tug-of-war now surrounding Bohmian mechanics, distinguishing two components within Bohm's initial theory: the 'causal view' and the 'guidance view'. These contributors show how the presence of the two views within Bohmian mechanics engenders an inner tension that has haunted the subject since its inception. The former, causal view involves a Newtonian interpretation of Bohm's equation of motion, which includes the auxiliary 'quantum potential'.

The guidance view instead makes the 'guidance condition'—Bohm's special assumption that a corpuscle's velocity can be written as the derivative of its Hamilton–Jacobi function divided by its mass—fundamental and exact, while dispensing with the quantum potential. Support for the stripped-down guidance view is now strong, having numbered amongst its advocates John S. Bell. By contrast, there are not many advocates of the causal view as a stand-alone framework. Rather, the causal view is a component of the specific hidden variables theories proposed by David Bohm and B. J. Hiley and others.

Under the causal view, Bohmian mechanics is subsumed under classical mechanics—provided the additional 'quantum potential' is included—thereby inheriting the realist metaphysics of classical theory. The price paid is the loss of necessary agreement with the Born rule and of explanations for the behaviour of entangled systems. This, in turn, means the loss of explanations for measurement results. Such a loss is reason enough to abandon the formalism of the causal view as sufficient for a stand-alone theory. The guidance view, on the other hand, reproduces the quantum mechanical predictions for entangled systems. The price paid is the loss of the intuitive clarity of a classical theory. These two views complement one another; abandoning either involves a significant loss, one physical and the other intuitive. It is, therefore, understandable that Bohm was compelled to incorporate both views into his theory to the extent allowed, though this threatens the theory's consistency. This tension occupied Bohm, and has occupied others ever since the theory's introduction.

Not surprisingly, this situation has also not been resolved within the current volume. However, the book does bring us closer to the heart of the matter through its careful analyses of existing theory and presentations of exploratory variants. Beyond these questions, others of more explicitly historical and philosophical natures are also addressed in this collection. Recall that another concern of EPR's critique of standard quantum theory, beyond the issue of completeness, was the nature of 'physical reality'. Mara Beller's essay, 'Bohm and the "Inevitability" of Acausality' takes up this question. Beller carefully delves into Bohm's position, which sees a positivistic eschewing of unobservables as the source of physicists' reluctance to go beyond the trappings of the standard theory since its formulation. (Notably, critic Robin Collins takes a similar position against Bohmian realism in his 'Epistemological Critique ... '.) Importantly, Beller points out a long antagonism between Bohm and Bohr regarding the relation between classical and quantum concepts: Bohm had resisted from the beginning of his career the conclusion that the quantum world is fundamentally acausal. It was only later that Bohm's theory demonstrated the deniability of the acausality advocated by Bohr.

As Arthur Fine notes in his essay, Bohm developed an independent ideological framework based on 'radical holism'. Fine also points out that the realism of Bohm is of an unusual sort; the properties found in measurement are not simply disclosed by the act of measuring but may change during measurement. This was recognised by Einstein already in 1953, when he saw that in the case of a corpuscle travelling between two walls the pre-measurement speed would be zero, with a non-zero velocity being acquired during measurement. Such compromised realism turned Einstein away from support of the Bohm model.

The question of how the properties of a Bohmian mechanical system are to be attributed is taken up by Harvey Brown, Andrew Elby and Robert Weingard. Ontologically, two components are generally associated with a Bohmian system: the Ψ-function and the corpuscle. The former has been viewed by Peter Holland as acting on the latter in a causal manner. Holland assumes the non-localisability hypothesis: that the dynamical state-independent parameters of mass, charge and magnetic moment cannot be attributed to (i.e. localised within) the coupuscle alone. This hypothesis is motivated in part by Ψ's (non-local) dependence on these parameters. One who accepts the non-localisability hypothesis faces the options of parsimony or generosity with regard to Ψ's bearing these attributes. On the former option all these properties are associated with Ψ, whereas on the latter they are attributed to the conjunction of Ψ and the corpuscle. Brown *et al.* suggest a choice in favour of generosity, as parsimony would give rise to paradoxical situations such as a pair of quantum mechanical particles being associated with a single Bohmian corpuscle should the pair have coincident trajectories.

For his part, Holland argues elsewhere that quantum mechanics and Bohmian mechanics cannot be universal physical theories since the formal structure of quantum theory prevents the recovery of the full range of possible classical mechanical motions. In essence, Holland is denying the reducibility of classical to quantum theory. In a related contribution, Detlef Duerr, Sheldon Goldstein and Nino Zanghi argue that Bohmian mechanics, being a hidden-variables theory, should be viewed as the 'foundation of quantum mechanics' in that one may arrive at a version of Bohmian mechanics by adding to quantum mechanics particle positions as hidden variables. This raises the question as to whether Bohmian mechanics and quantum mechanics or Bohmian mechanics and classical mechanics are to be seen as closer pairings.

Variant versions of Bohmian mechanics are also presented, along with factors motivating them. Trevor Samols points out that, though Bohmian mechanics can be viewed as a realist version of quantum mechanics, there is great difficulty in extending the theory in a relativistic form, however well the phenomenology (in the physicists' sense) may work out: Bohmian mechanics bears the burden of a preferred frame of reference due to its use of the guidance condition. Samols offers an alternative field theory in the spirit of Bohmian mechanics that does not depend on such a frame. Similarly, Antony Valentini offers his own 'pilot-wave theory' of fields, gravitation and cosmology. P. N. Kaloyerou, and Chris Dewdney and George Horton also discuss the treatment of bosonic fields within the Bohmian tradition.

In addition to the above contributions, this collection contains a number of carefully worked out applications of Bohmian mechanics to interferometry, position measurements, scattering theory, tunnelling phenomena and other practical situations to which any mature physical theory must be applicable. Though this book does not answer all the questions one is compelled to ask of Bohmian mechanics, it does demonstrate that Bohm's theory and its successors form a vibrant part of contemporary physical theory and a locus of stimulating philosophical inquiry.