THE PHYSICS OF DAVID BOHM AND ITS RELEVANCE TO PHILOSOPHY AND THEOLOGY

by Robert John Russell

Abstract. The purpose of this paper is to analyze David Bohm's work in terms of physics, philosophy, and theology. First, I discuss the development of Bohm's thought since 1951. Then, using the methodology of Imre Lakatos, I evaluate the scientific status of his research program. Next, I explore the philosophical dimensions of Bohm's views in which realist and idealist, monist and dualist, contingent and determinist outlooks occur in creative tension. Finally, I suggest ways in which Bohm's ideas are relevant to theology through concepts of God and cosmos, beauty and purpose, grace and free will, church, self and evil.

> The entire universe is basically a single, indivisible . . . but flexible and ever changing, unit (Bohm 1951, 140).

This paper is based on several books and technical papers by David Bohm; its purpose is to analyze Bohm's work in terms of physics, philosophy, and theology. Bohm's physics and the philosophical interpretations it supports have evolved remarkably during the past three decades. In 1951, Bohm published a new formulation of quantum physics based on "hidden variables" and a realist philosophy of nature. This theory drew on the thought of Albert Einstein and Werner Heisenberg and provided an alternative to the widely held positivist approach to quantum physics. It has triggered a continuing series of often controversial papers. More recently, Bohm's research has produced a new metaphysical system, the "implicate order," based on a sweeping reformulation of the foundations of physics. Bohm's work yields compelling insights into physical cosmology, philosophy,

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language, and mind which are ripe for philosophic and religious reflection.

My overall reaction to Bohm's work is respect for what has been accomplished to date and expectation for the future, though laced with some critical questions from several perspectives. I am grateful for the pioneering spirit of Bohm. It is all too rare, in my opinion, that someone from within the scientific community dares to challenge the leading paradigm and to accept the isolation which it inevitably involves. Most physicists accept the Copenhagen interpretation of Niels Bohr as final and treat as unanswerable or unimportant the philosophical problems it raises. Accordingly, nature at the microscopic level is no more than an inference from the dials, counters, valves, and keyboards of the experimentalist and the chalk and logic of theorists; concepts about nature are merely terms in a convenient language game for linking sequences of data to exotic mathematical formalism.

Bohm runs counter to all that. His life's passion is to understand nature as real, objective, infinitely sublime. To paraphrase Isaac Newton, Bohm strains to encounter that hidden ocean of global movement underlying sensation and data, rather than to be satisfied with the streaming, but momentary, froth it has mothered by its stirrings. He dares to ask the "metaphysical" question in the midst of the empirical community. Lifting the veil, he hopes to peer at nature directly, sharing with us a mystical vision of her as a resplendent, shining whole.

How then is one to understand the work of Bohm: As metaphysics but not as physics, a blind alley better abandoned—as many of his critics stress—or, as his proponents believe, a serious alternative to the leading paradigm, perhaps heralding a sweeping change in our view of physics? If so, what new insights into human nature can Bohm's vision bring to our theological enterprise? And should our theological appropriation of Bohm's mystical vision depend on the acceptance of his research by the scientific community? In this short paper I can only approach selected aspects of these broader questions. Hopefully this will lead to a further, more detailed exploration of the physics, the philosophy, and the theology of David Bohm.

From Hidden Variables to the Implicate Order: The Physics of David Bohm

The context of Bohm's research grows out of the early discussions about the meaning of quantum theory. During the first three decades of this century, alternative formulations of quantum theory were developed by Bohr, Arnold Sommerfeld, Erwin Schroedinger, Heisenberg, and P. A. M. Dirac. Although these eventually were shown to be equivalent in terms of their physical content, a consensus on the *mean-*

ing of the formalism was never obtained, and this question remains open today.

The dominant view was initiated in 1927, when Bohr introduced the idea of complementarity in what was to be called the Copenhagen interpretation of quantum physics. According to Bohr, we are to regard "space-time coordination" and the "claim of causality" as *complementary but exclusive* features of physical theory, reflecting the incongruency between the various experimental procedures on which such theory is based and hence the conceptual and linguistic limitations of physical theory. Bohr's view invokes both wave-like and particle-like models for a complete description of the results of quantum experiment, even though such models are logically incompatible. Bohr argued that since quantum processes cannot be treated independently from the observation process, it is scientifically meaningless to assign physical existence to the elementary physical phenomena themselves. Thus dismissing a realist philosophy as incompatible with quantum theory, Bohr adopted an instrumentalist approach in which statements about the properties or causal features of nature are mere shorthand for descriptions of the experimental procedures. Finally, the Copenhagen interpretation was regarded by Bohr then, and by most physicists today, as a permanent paradigm for any future physics.

Other interpretations, however, have been proposed. Heisenberg held that indeterminacy is an objective feature of nature and that many of the properties of microscopic entities are only potentially real; they become actual by the measurement process itself. Einstein, Louis de Broglie, and Max Planck, on the other hand, believed that natural processes are objective and deterministic in character. They viewed the indeterminacy principle as an indication of the incompleteness of quantum theory (see Barbour [1966] 1971, ch. 10).

The ideas of Bohr, Heisenberg, Einstein, and de Broglie form the seeds of Bohm's vision. In an early book entitled *Quantum Theory* (1951), Bohm repeatedly states his agreement with Bohr's insistence on the *physical* interdependence of phenomena and apparatus. Yet he regards quantum indeterminacy as arising from the very nature of quantum systems since quantum properties are imprecisely defined prior to the measurement process. Moreover, Bohm's *analysis* treats microprocesses separately from observational apparatus: the theoretical formalism refers to independently existing microscopic phenomena. The realism of his attitude is evidenced by the purpose of his book: to develop "qualitative and imaginative concepts" with the explicit intention of picturing quantum phenomena. Thus to the extent that these properties are incomplete *potentialities* Bohm reflected Heisenberg's interpretation. Since the measurement process realizes the potential quantum processes, his thinking carried one of Bohr's themes. Yet, since these processes are treated as real and objective, Bohm's interpretation was partially like Einstein's. Bohm thus adopted a qualified realism drawn from several of the founders of quantum physics, a realism which limited the degree to which specific properties can be viewed as having autonomous objective existence in quantum systems.

Although this early exposition was intriguing, it did not involve a new theoretical formalism. This was to come shortly. Beginning in 1952, Bohm broke new ground in the history of quantum physics by producing a new formulation of quantum physics in terms of hidden variables (Bohm 1952a; 1952b). He described this approach as providing a "broader conceptual framework" than the Copenhagen interpretation, demonstrating that "it is not necessary for us to give up a precise, rational, and objective description of individual systems at a quantum level of accuracy" (Bohm 1952a, 166). This new interpretation is based on the proposal that certain physical variables are normally hidden since their values are averaged in standard experiments; Bohm argues that this may explain the indeterminacy which characterizes the data of quantum experiments. These variables represent additional causal activity by a new physical field called "the quantum potential Q": a global, sourceless field acting upon the entire quantum system but not directly determined by any single part of the system. In this interpretation, particles follow precise, continuous trajectories in space and time, subject to both the usual fields of force (electromagnetic, gravitational, etc.) and the new quantum potential.[1]

In a crucial move, Bohm argues that in a modified version of hidden variables such as his, in which such variables depend "both on the state of the measuring apparatus and the observed system," John von Neumann's earlier proof against hidden variables theories will *not* hold (Bohm 1952b, 187-188).[2] Hence, contrary to Bohr, at *very* small distances the uncertainty principle need no longer apply, though at the level of current (1952) experiments, the actual particle variables are in effect hidden by the quantum potential resulting in the statistical scatter in experimental data.

Based on this reformulation of quantum physics, Bohm wrote *Causality and Chance in Modern Physics* (1957), interpreting his ideas to a general audience. Now we see a fully developed realist philosophy of nature in which the infinite complexity of the physical world makes a complete analysis unattainable, leaving every theory partial and abstractive. The concepts of physical theory reflect objective structures in nature, arranged in an infinite series of levels. Some levels are predominantly causal in character, while others are more contingent, yet both are present in a complementary fashion in all physical processes. Causal and contingent modes of analysis are therefore appropriate in an alternating rhythm from level to level *ad infinitum*. Causality at the macroscopic level (as are Newton's laws of planetary motion) is consistent with contingency on the microscopic level (such as the Heisenberg uncertainty principle), just as microscopic contingency need not preclude the occurrences of causal, though as yet hidden, regularities at the nuclear particle level. In this sense the mode of regularity at a higher level is a limiting case of the mode at a lower level, as classical thermodynamics was explained via statistical thermodynamics, and as Brownian motion, with its statistical features, was explained by causal processes at the molecular level.

Thus, at a level deeper than current experimental physics there could lie new causal features (hidden variables) which determine nature's higher level quantum character. Although the Heisenberg uncertainty principle and the Schroedinger equation hold at the quantum level, they are not *necessary* components of *all* future physical theory since, according to Bohm, at a deeper level of nature, new laws and features could exist to which these limitations need not apply. Accordingly the simple concepts of particles and waves will eventually need refining and enriching. New concepts and theories, when formed, will then "lead to new kinds of experiments and thus to the discovery of new facts." This process of development of our conceptuality "will eventually point the way to revolutionary changes in the whole conceptual structure" (Bohm 1957, 97-99).

During the following decades Bohm and others explored a variety of hidden variables-type theories but the experimental results were unsatisfactory.[3] Perhaps the broader underlying assumptions, rather than the specific scientific theory, warranted a reassessment: What indeed should be our basic assumptions about the real, the knowable, the intuited, and the unformalizable? Bohm now shifted his attack to these types of metaphysical questions which underlay both his earlier work and those of his competitors, and in 1981 he published *Wholeness and the Implicate Order*. With this book Bohm proposed a new world view which incorporated his earlier emphasis on wholism but embedded it in a new conception of order.

Here he critiques special relativity, general relativity, and quantum physics and quantum field theory. Bohm first stresses the change in conceptuality from separate material particles and rigid bodies interacting by signals to world tubes representing processes in space and time. We now understand "objects" to be "abstractions" of a "relatively invariant form" or "pattern of movement" emerging out of the undivided wholeness of the universe. In the theory of (general) relativity Bohm detects increasing signs of the newly emerging order, since analysis of the world into "distinct but interacting components" is rendered impossible by the nonlinearity of the equations. Such nonlinearity forces one out of normal analytic procedures where superposition holds; hence the traditional method of analysis and synthesis breaks down.

Yet underlying these problems with relativity is Bohm's analysis of the problem of motion. Bohm argues that motion at the quantum level is characterized by radical discontinuity. The classical picture of smooth, continuous motion is completely untenable and must be abandoned. The "indivisibility of the quantum of action" induces discontinuous transformations of physical systems from one quantum state to another, so that quantum systems reveal first wave, then particulate properties depending on the experimental context. Bohm takes these dual properties of quantum systems to be more like incompatible potentialities than actual qualities.

Along with the idea of continuous motion, Bohm urges that we abandon one aspect of the principle of locality: that all interactions involve point contacts between elementary particles and their fields. Clearly in the new paradigm since physical phenomena are never fully separable in the first place, referring to point particles and point contacts is meaningless. However, Bohm insists that the nonlocal correlations in his theory do *not* entail a violation of the limit on the speed of transmission of information and matter which, according to special relativity, is equal to the speed of light. Thus his formulation of quantum physics *is* consistent with special relativity, although it is usually referred to as a nonlocal theory.

Thus in Bohm's view, the ideas of efficient causality, locomotion, and locality are overturned by the implications of quantum physics. Since relativity depends on locality, continuous motion, and causality, it is in conflict with quantum physics and must ultimately be viewed as an abstraction. To the extent that quantum theory is interpreted as treating the apparatus separately from the phenomena, it too must be replaced by a new interpretation. Although the invariance of physical laws may remain a feature of the new order, the incompatibility of relativity, with its strict classical causality, and the inappropriate treatment of phenomena and apparatus as separable in quantum theory, must *both* give way to a new conception of connectedness, or as Bohm puts it, of order.

Ultimately then, every vestige of continuity in space-time must be replaced by a new kind of connectedness. This new vision will come from what relativity and quantum theory do have in common: wholeness as a new form of ordering. The governing characteristics of such a wholistic order will be noncontinuity, noncausality, and nonlocality. We are to regard empirical phenomena as "explicate," the fragmentary traces of an ever-present yet hidden implicate order endowed with entirely new ontological structures. Consequently we must rethink our entire conceptual structure and construct a new starting point for our deepest presuppositions about nature. Our starting point is to be a new wholistic conception of order and a new scientific procedure in which analysis is replaced with synthesis and linearity in the underlying equations is replaced by nonlinearity. With this "implicate order," Bohm envisions an undivided, inexhaustible, infinite whole each portion of which contains all the rest.

He develops several analogies for the implicate order. In a model based on the hologram, the complex order in which information is carried on a hologram is analogous to the intricate unfolding and enfolding of the whole into itself characteristic of the implicate order. In the ink-drop model, consecutive foldings and unfoldings of implicate structures produce a sequence of momentary drops whose locus gives the appearance of a continuous trajectory in the explicate order. Through this movement of the implicate order, the structures in the explicate order—particle and environment—are internally related through the complex implicate relationship of whole to subwhole. In another model, the juxtaposition of two-dimensional pictures of a moving three-dimensional object produces an illusion of noncausal, nonlocal correlations in the motion. Objects in space-time are thus projections of a higher-dimensional reality. What is actual is unified, whole; what is measured is a projection, an appearance. The implicate order is a "process of enfoldment and unfoldment in a higher-dimensional space" (Bohm 1981, 189).

In *Wholeness and the Implicate Order*, Bohm extends his critique of fragmentation to the nature of language and thought. For example, he views the processes of cognition as similar to the discontinuity of quantum processes. Thought, too, is to be understood as part of this infinite-dimensional implicate order. Similarly, in order to manifest the interconnectedness of human experience, language must be transformed along with our assumptions about nature. In more recent papers, Bohm has begun to explore more complex striations within the implicate order and the ways in which mind and matter are nested within it. Although these areas of Bohm's work are fascinating, the focus of this present paper will remain on those portions of Bohm's writings discussed above or published prior to the Berkeley conference.

The Scientific Status of Bohm's Program

Though provocative and original, Bohm's work has often been criticized for its lack of a decisive test. Without an unequivocal prediction which would distinguish it clearly from standard quantum physics, many have asked whether Bohm's ideas should be regarded as a genuine part of research physics. If one presupposes a philosophy of strict falsificationism, Bohm's work is, at best, modest in its scientific value. But the history of science suggests that much more is involved in the evaluation of a theory than predictive power; shifts in the paradigms of science are based in part on a variety of aesthetic, philosophical, and personal criteria.

This fact is reflected in the disagreement between leading philosophers of science including Karl Popper, Thomas Kuhn, Imre Lakatos, and Paul Feyerabend over what constitutes scientific rationality. Kuhn, for example, argued for the incommensurability between different scientific paradigms and the irrationality inherent in the process of consensus formation in the scientific community. Though agreeing with Popper about the central importance of stipulating in advance potential falsifiers, Lakatos underscored the tenacity of leading paradigms to direct falsification by a specific anomaly. I suggest that Lakatos's methodology of scientific research programs can provide a useful assessment of Bohm's research program (Lakatos 1980).

According to Lakatos, each research program consists of a core theory surrounded by an auxiliary belt of protective hypotheses. The program generates an increasingly complex sequence of models which articulate the general conception of the core hypothesis; the auxiliary belt of hypotheses account for anomalies in the data and attack the observational theories of competing programs. The generation of expendable models plus the introduction of auxiliary hypotheses constitute a strategy for protecting the core theory against direct falsification.

Lakatos claims that a "progressive" research program is characterized both by a *continual* increase in the content of its theory (evidenced by increased predictive power), and by *intermittent* empirical corroboration. Thus a successful theory need be tested only occasionally, and some anomalies may be temporarily ignored, while the theory is still being developed. In this way Lakatos can account for the historical fact that some anomalies are usually tolerated while the need for a crucial test is nevertheless acknowledged. Hence with Kuhn, Lakatos stresses the tenacity of rival theories and the difficulty of obtaining direct falsification. Yet with Popper, he can specify in advance rational criteria for choosing between competitive theories, and thus he can differentiate between a successful and a failing or "degenerating" research program. In the latter case, auxiliary hypotheses are created purely ad hoc, which Lakatos defines as meaning that, first, they predict no new facts but only account for known facts, second, their predictions consistently fail to be corroborated, or, third, even if they predict new facts which are corroborated, the theory they defend is a makeshift composite of semiempirical formulae lacking any solid formal basis. Such auxiliary hypotheses are then mere "face-saving devices" constructed to save the core theory.

Nevertheless, Lakatos admitted that a failing research program can be revitalized by a "clever auxiliary hypothesis" through which counterevidence is found or in which data previously considered irrelevant are reinterpreted as corroborative. Because of this possibility, Feyerabend stressed that the decision between staying with a program or abandoning it is ultimately irrational. Still, Lakatos believed he had given convincing grounds for the rationality of the scientific method. Like Popper, the basis of the decision as to what constitutes "science" is to be made, not strictly on *content*, but more on *method*.

Using the methodology of scientific research programs advocated by Lakatos, we return to our question: Should we consider Bohm's work a viable research program? In my opinion, if we adopt Lakatos's criteria the conclusion would be undecideable at present; hence active involvement in such a program is a reasonable though delicate option. This conclusion seems warranted on the grounds of the mixed assessments one would have to make of different aspects of Bohm's physics.

Arguing against Bohm would be the observation that, although each step in Bohm's program has shown theoretical content increase, empirical corroboration has been mainly after the fact through the claim that Bohm's theory accounts for the same data as does standard quantum theory. There have been few detailed prescriptions for crucial experiments yet to be performed by which his theory could be distinguished from quantum theory, and those that have been stated have not been corroborated.

In the 1950s, for example, Bohm suggested that evidence for hidden variables could begin to turn up when high energy particle physics began probing matter at subnuclear scales. Yet to date there has been no such evidence, and one could certainly argue that these features should have shown up by now, for in the past three decades the sensitivity of particle experiments has been increased by a factor of at least a thousand.

In *Wholeness and the Implicate Order*, Bohm returned to the issue of a crucial test. He first reiterates that *the mere construction* of a plausible hidden-variables theory was important, since no such theory was previously considered possible. Next he argues that his approach will be to go beyond both quantum mechanics and special relativity, eventually producing testable empirical content and containing standard quantum mechanics and relativity as limiting cases. Such tests would involve "entirely new methods" for detecting subquantum mechanical processes dependent upon correlations between the classical apparatus and hidden variables. Bohm then suggests that at "high energies" and with "extremely high precision," one might detect small fluctuations in an isolated light beam. Unfortunately this suggestion seems pseudo-empirical since Bohm does not specify even the order of magnitude of these fluctuations. Finally he argues that in Einstein-Rosen-Podolsky-type experiments the measuring apparatus could be reoriented during the experiment in order to test standard quantum predictions. When completed, such experiments will shed light on the prognosis of Bohm's thesis.

Of course one could argue that present experiments are still not sufficiently sensitive to detect hidden variables. In a recent interview with Renee Weber (Weber 1982, 55-56), Bohm suggested that we must look to phenomena lying at the Planck length, 10^{-33} centimeters—almost a million million million times smaller than the scale of present experiments. In this extraordinary realm, where even space-time would break down, Bohm hopes we may finally discover evidence of a new, wholistic, implicate order. The problem with this argument is its lack of originality, its vagueness, and its untestability. Many other physicists have already predicted that physics as we know it will break down at this scale. Since Bohm has not said precisely what we should expect to find there, we would not know whether data from this realm would argue for or against his views. Worst of all, since it is so far beyond the reach of any experiments in the foreseeable future, his appeal to the Planck length effectively constitutes yet another ad hoc auxiliary hypothesis which postpones the untestability of the core theory for a very long time. In my opinion, it does not enhance the credibility on one's case to propose an unperformable "crucial experiment." In sum, it appears that Bohm's hypotheses should be regarded as ad hoc in all three senses which Lakatos delineates. Whether one should continue with such a program is certainly questionable.

Bohm's paradigm must also be judged against its competitors, both in terms of other formulations of basic quantum physics and the current comprehensive field theories. First of all, there are several alternatives to Bohm's interpretation of quantum physics, such as the "many worlds" hypothesis of Hugh Everett, the coupling of consciousness to quantum processes in the theory of E. P. Wigner, Henry Stapp's pragmatic interpretation, and new formalisms of "quantum logic" using multivalued or nondistributive logic. Recent work by Bohm in collaboration with B. Hiley (unpublished) has produced a response to some of these alternative formulations of quantum theory. Returning to the quantum potential formulation, they extend the analysis to relativistic quantum mechanics, and they reply to the arguments of both Wigner and Everett. By interpreting the wave function as carrying "active information" about the quantum system and its environment they emphasize the physical meaning of the wholistic quality of the quantum state, while the irreversibility of the measurement process provides a framework for understanding why the macroscopic world lacks such explicit wholism. They cite some recent experimental results as lending some support for their approach.

Second, Bohm's program must compete with the leading paradigm in particle physics, quantum field theory, which arose out of the merger of quantum mechanics with special relativity. Through successive applications to atomic, nuclear, and particle domains, quantum field theory has become a stunningly successful paradigm, spawning current research in quantum chromodynamics (quark theory), supersymmetry, supergravity, and grand unified theories (GUTS). Bohm's critique of field theory involves its treatments of infinities in the formalism and its acceptance of a positivistic philosophy. He sees the idea of a second quantum potential and a super-implicate order as legitimate alternatives to the field theory approach which will eventually lead to testable predictions and carry the additional philosophical advantage of allowing a realist interpretation of nature.

To suggest what he means by "the implicate order" Bohm has constructed various analogies or models. One such analogy compares the implicate order to a sequence of ink droplets folded into a viscous medium in a moving container. As the medium is stirred, the foldings and unfoldings of successive ink drops gives the appearance of a single moving particle like the illusion of continuous motion in a motion picture. Although this model has heuristic value, it raises substantive questions if taken at all seriously. The folding process, for example, would have to be strictly *laminar* since if turbulence occurred, vortices would spread and mix the drops throughout the medium, and no amount of unwinding would return them to their initial shape. Even with laminar flow, diffusion processes would eventually spread the drops out irreversibly. Finally, to produce the illusion of a single moving particle, the sequenced foldings and unfoldings of countless drops would require extraordinarily ordered initial conditions. The amount of global order necessary to produce an explicate order containing such regular spatial structures as it does (cars, people, cells, protons) is staggering! One way to estimate the order involved would be to compare the size of an elementary particle (roughly 10^{-15} meters) to the universe (based on the Hubble constant, roughly 10^{+28} centimeters). Assuming that the implicate and explicate orders are comparable in size, the drop, when unfolded, is over one hundred thousand billion billion billion billion times larger than it is when folded! Moreover, if each physical elementary particle is composed of an infinity of such unfolded drops, then for all such tracks in all such experiments to be consistent with the same laws of physics would require an unthinkably unlikely set of initial conditions! What if the implicate order had been any other way?

In Bohm's more recent work, however, he has addressed this criticism by extending his model to include a super-quantum potential or super-implicate order. (Indeed he suggests that this extension could be continued indefinitely to higher levels of order.) One motivation for such an "auxiliary hypothesis"—to use Lakatos's phrase—is that the nonlinearity and nonlocality of the super-quantum potential would together account for the production of an apparently autonomous, ordered explicate world (Bohm 1985, 119). If this response is sustained, we might even regard the earlier linear, laminar model as a falsifiable theoretical model in Lakatos's framework! In this way the inadequacies of earlier models and their replacement are a positive sign of the vitality of the core hypothesis.

In this same spirit, other very general questions arise out of Bohm's approach. For example, why should the dimensionality of the explicate order be four (instead of five or three or ten thousand, or perhaps even a fractal number)? What is the basis for time and time's arrow, an explicitly *asymmetric* feature of the explicate order, if the dominating ontology is the *highly symmetric* implicate order? Surely such asymmetries as time, history, evolution, entropy, and so on, are more than mere distortions of an underlying massive symmetry.

Of course, this might be pushing Bohm's analogies too far. They often seem more like heuristic devices which Bohm uses instinctively in exploring his intuition about nature. Yet Bohm himself uses such geometrical analogies to stress what can only be for him realistic features of the implicate order, features which, like unbroken symmetry, are radically different from those of the actual, physical world. Perhaps then another new underlying principle, like the super-implicate order, will have to be found if one is to adequately account for the solidification, the dimensionality, the structures, and the broken symmetries such as the direction of time characterizing the explicate order.

Instead of stressing the difference between Bohm's approach with its competitors, however, one might also look for elements in common. For example, we might identify theoretical elements in quantum chromodynamics with Bohm's hidden variables. Since quarks have not been isolated experimentally, theorists have explicitly built quark confinement into their theory. Such a move turns the impossibility of directly detecting individual quarks into a theoretical prediction. Could quarks, or perhaps a quark property like color (which is also explicitly constructed to be undetectable), be considered as analogous to some of Bohm's ideas?

A more promising approach, in my opinion, would be to compare Bohm's work with that of Geoffrey Chew. After pioneering work in S-matrix theory, Chew developed the bootstrap theory of elementary particles along quite different lines than quantum field theory. Rather than starting with elementary particles or other fundamental entities, Chew's approach treats nature as a tapestry of interconnected events, the qualities of each being determined by all the characteristics of the others. Its recent further elaboration as topological bootstrap theory (TBT) has produced increasingly successful results in both strong and electro-weak interactions and presents a viable competitor to quantum field theory. TBT starts with the principle of self-consistency and uses a generalization of the Feynman diagram to construct a topological explanation of particle mass spectra and interaction strengths without the prior assumption of continuous, microscopic space-time. TBT thus includes features in its formalism which have no direct experimental correspondence, making the comparison with Bohm's work intriguing (see Chew 1985; Capra 1982, 113-16). One might argue that the underlying themes in the work of Bohm and Chew, that of wholeness and of self-consistency, might themselves be closely related.

Yet prior to all of these considerations, we should ask whether one ought to start with models of continuity and extension or instead with models emphasizing discontinuity and discreteness. As an infinite-dimensional, continuous manifold, the implicate order draws on the mathematics of geometry and topology. (In a sense, what Bohm has done is attribute realistic status to the mathematical scaffolding of standard quantum theory: he has ontologized Hilbert space.) John Wheeler, however, has repeatedly stressed that we should start with the discrete and through large numbers obtain the continuous, rather than start with the smoothly extended and then try to derive the localized and particulate. If Wheeler is right, Bohm's direction should be reconsidered in its entirety. This could constitute a serious challenge to the core hypothesis in Bohm's program.

Wheeler's position results from his work in gravitational physics and cosmology, an area to which Bohm has given relatively little attention. Here, Einstein's general theory of relativity has been successful in its applications to the solar system, stellar formation and evolution, and galactic evolution; and its cosmological model, the Big Bang, can account for the age and expansion of the universe, the cosmological microwave background, the cosmological abundances of hydrogen and helium, and the correlations between predictions in particle physics and data concerning the very early evolutionary universe. Many find the most staggering discovery of this century to be the expansion and evolution of the universe itself. This cosmic "fact" seems radically at odds with Bohm's cosmology in which even the dimensionality, not to mention the evolution of the universe and the direction of time, is arbitrary. Perhaps Fred Hoyle's steady-state cosmology, specifically constructed to eternalize matter, would have been more in keeping with the timelessness of the implicate order and the explicate universe it houses.

Recently Wheeler has argued that we abandon all geometrical models of the universe. He stresses the crises occurring at both the global scale, where geometry cannot handle the problem of cosmogenesis, and the micro scale, where at the Planck length (10^{-33} cm.) geometry cannot represent the foamlike, multiple-connected character of nature. "The concept of 'ideal mathematical geometry' as applied in physics is too finalistic to be final and must give way to a deeper concept of structure. Towards the finding of this 'pregeometry' no guiding principle would seem more powerful than the requirement that it should provide the Universe with a way to come into being" (Wheeler and Patton 1977, 35).

What then is the prognosis for Bohm's program? Apparently this question remains open, a mixture of promise and warning. Alternative programs such as Bohm's are pursued by only a small portion of the scientific community; yet it is healthy, according to philosophers such as Feyerabend, for a discipline to contain competing programs, and none should be dismissed out of hand. As Lakatos admits, a clever new hypothesis could come at any time, and the tide could be reversed. One wonders if such a move might not be close at hand; perhaps we are on the verge of a new paradigm in modern physics. How Bohm develops his work on quantum wholeness in response to temporal irreversibility and other broken symmetries, cosmogony and other singularities, order and disorder, continuity and discreteness, phenomena and formalism, and other general problems in physics, will determine the future of Bohm's program.

Philosophical Dimensions of Bohm's Thought

In my opinion, Bohm's thought holds in creative tension realist and idealist, monist and dualist, contingent and determinist points of view.[4] As a critical realist, Bohm stresses the incompleteness of theory and the objectivity of nature. Theories are only partial representations of an objectively existing nature whose existence is independent of the consciousness of the experimenter. "As an alternative to the positivist procedure of assigning reality only to that which we now know how to observe . . . we assume that the world as a whole is objectively real, and that, as far as we know, it has a precisely describable and analysable structure of unlimited complexity" (Bohm 1957, 100).

Bohm's emphasis on the inexhaustibility of nature speaks in opposition to the philosophy of reductionism dominating modern science. Bohm repeatedly warns us against assuming that any theory could be final or complete; nature's complexity and the infinitude of her levels makes final analysis impossible.

Recently the realist approach has been severely challenged, at least within physics, by Bell's theorem (Bell 1964), which implies that realism is inconsistent with quantum physics. In particular, a specific class of predictions based on local realism (which assumes inference, special relativity, and objectivity as typified by the assumptions of local hidden variables-type theories) can be shown to contradict similar predictions based on standard quantum theory. Several experiments have been performed to test these predictions; the results so far strongly favor quantum theory and seem to rule out local realist theories.

Bohm's quantum formulation, however, is a *nonlocal* theory. On the one hand it is consistent with the relativistic limitation on signals; hence information and matter cannot propagate at greater than light speeds, so that events outside each other's light cone can be thought of as separable. Yet it also includes the wholistic, global element: the quantum potential which qualifies the sense in which such events are separable. For those particles which are describable as parts of a single wave function, although the individual events be statistical, the quantum potential can produce surprising correlations between them.

Bohm was the first person to construct this kind of nonlocal hidden variables theory; as noted above, other variations have been suggested since Bohm's original work. As of 1983, no inconsistencies seem to have arisen between the predictions of such nonlocal hidden variables theories and quantum mechanics (Rohrlich 1983). Such theories are apparently neither ruled out by experiment nor do they predict novel results compared to quantum mechanics.[5] Hence I would argue that his critical realist interpretation of physics based on nonlocal hidden variables theories such as Bohm's is viable in spite of the more general challenge to realism by Bell's theorem.

Interestingly, Bohm's more recent work reflects more of an idealist philosophy of nature. His thought reminds one of Benedictus de Spinoza, Arthur Eddington, James Jeans, E. A. Milne, and others who stress the status of mind or the priority of mathematics. Yet Bohm attributes to thought a structure isomorphic to physical processes and an independent, irreducible reality. Given such a dualism of mind and matter, how then does one account for their interaction? This perennial problem in idealist philosophies receives from Bohm an intriguing and novel solution: recently he has suggested that this dualism may be overcome through a process in which mind and matter are both more deeply enfolded into the prior whole of the super-implicate order. This approach, with its overtones of mysticism, could lead to some interesting developments in the future of Bohm's work.

Bohm's thinking moves between monist and pluralist modes as well. Throughout Bohm's works, reality is pictured as multiform, an infinite sequence of levels or an infinite succession of implicate and super-implicate orders. Evidence of the multiplicity of nature is the interplay of causality and contingency, whose predominance shifts from level to level in nature. In Bohm's view, these alternating levels of contingency and causality display both the transforming activity and the constant harmony of nature, prefiguring the theme of nature's overall unity which is intensified in Bohm's more recent work. "The entire universe is basically a single, indivisible . . . but flexible and ever changing unit" (Bohm 1951, 140).

In *Wholeness and the Implicate Order* the predominant version of the unity theme in Bohm's work becomes that of wholeness, reflected in Bohm's concept of the quantum potential. Here the wholistic potential governs the trajectory of the wave function, although statistical spread in the ensemble of particles arises from fluctuations from hidden variables. The potential is a real, objective feature of the quantum system, even as the particles are real entities in nature. Since the quantum potential is not coupled to matter as classical electromagnetic fields, for example, are coupled to charge, it does not decrease with distance, and it can thus directly influence the whole system. This real, nonlocal structuring of the system gives the whole an ontological status which cannot be reduced to a classical sum of parts.

Bohm frequently uses the word potential in an Aristotelian sense, referring to complementary variables as "interwoven potentialities" of ". . . opposing properties that can be comparatively well defined under different conditions" (Bohm 1951, 159). Hence the whole determines the properties of the subwholes, reflecting the environment of the quantum system through the quantum potential. Measurement events realize potential properties of matter. Still Bohm views nature as objective, not dependent on the consciousness per se of the observer (as Wigner and others argue) and hence never radically subjectivized. This is a delicate balance to maintain, for in arguing against the direct inclusion of consciousness in the physical process Bohm might be seen as tacitly accepting a Cartesian dualism between mind and matter; yet in requiring the objective properties of matter to depend on measurement to actualize one of several potential properties, Bohm must treat the whole as objectively greater than the sum of its parts, arguing against reductionism. In fact, Bohm finds a striking parallel between the processes of physical nature and the thought process.

Bohm's stress on wholeness leads to his critique of traditional epistemology involving its assumptions of neutral observation and linear analysis. I am not convinced that analysis is impossible due to nonlinearities in the phenomena. Yet his insistence that the coupling between observation and system is independent of the consciousness of the observer seems cogent to me. In my opinion, Bohm tends to identify too closely the epistemological process with the ontology of the phenomena. If it were in fact inadequate to quantum phenomena, why has the analytic process worked as well as it has?

Bohm urges us to overcome the fragmentation of specialized knowledge and compartmentalized ontology, yet he advocates an infinite sequence of theories, none of which would be final or complete (or unified?), reflecting the inexhaustible complexity of nature. "This process cannot be studied in its totality which is inexhaustible" (Bohm 1957, 29). How are we to interpret the overcoming of fragmentation if nature's own levels keep the fields which study one from being reduced to those of another? Moreover wholeness itself may only be a theme on some levels and not a global feature of nature since according to Bohm no theory, including Bohm's which contains the vision of wholeness overcoming fragmentation, should be regarded as exhaustive.

If fragmentation is then only epistemological, what is its source? Is it based on our mind's operation? Why have specialized forms of knowledge arisen in the explicate order? Why are they so resistant to unification? In physics, for example, the task of unifying all of physics is staggering. If physicists labor to bring together the fragments, must not Bohm in turn work harder at explaining both their differences and their tenacity as difference? Bohm seems to be caught in a vicious circle between reductionism and fragmentation.

Theological Implications of Bohm's Thought

The theological relevance of critical realism. Most Christian theology currently works from a critical realist interpretation of God, world, history, and human nature, although idealism and nominalism continue to be present in some streams of thought. The realism implicit in Bohm's approach parallels that of such theologians as Ian Barbour, Philip Hefner, Sallie McFague, Jürgen Moltmann, John Cobb, Jr., Wolfhart Pannenberg, A. R. Peacocke, Paul Tillich, Harold Schilling, Pierre Teilhard de Chardin, and Thomas Torrance. Barbour, for example, stresses the realist intent of theological language as it uses models of God, Christ, and the world in various ways throughout the history of the Christian tradition. Peacocke draws on Ernst Nagel to argue that different disciplines, such as the natural sciences, the human sciences, philosophy, and theology, form an epistemological hierarchy.

Still the empirical content of these fields gives them a common realist outlook. McFague underscores both the creative tension and the realist intent of metaphorical language as it occurs in science and theology.

Yet realism—at least in some of its forms—is under attack in the field of quantum mechanics. There, as we have seen, the demise of local realism seems inevitable since the advent of Bell's theorem and its tests. It is especially germane to the theological enterprise which takes science and a modern view of nature seriously that Bohm's quantum potential approach, representing a nonlocal realist physical theory, offers an alternative to local realism in precisely the area where it is most under attack. Although the viability of realist theology ought not be solely dependent on its status in another field (such as quantum physics), the continuing option of a homogeneous philosophic position between physics and theology strengthens the fruitfulness of any conceptual exchange between them.

Concepts of cosmos and God in Bohm's thought. Every generation yearns for a valid sense of cosmos; it is a perennial part of human religion rooted in our pilgrimage to home and peace. Yet for a theological cosmology to be credible in our scientific culture, it must use terms such as cosmos or creation in an empirically meaningful fashion.

In a recent article, Stanley Jaki argued that, after Immanuel Kant, "cosmology" was scientifically unacceptable until Einstein provided the resolution of Kant's antinomy of space by his theory of general relativity (Jaki 1982).[6] In a different way but with no less potential merit, Bohm's thought responds to our need for cosmos as the "totality of consistently interacting things," to use Jaki's apt phrase.

First of all, Bohm treats the universe as an objective, self-contained, interconnected whole, a unit of infinite complexity. Nothing can arise out of nothing; everything has an antecedent, forming an endless string of generations. In this sense Bohm's cosmology resonates particularly with the Judeo-Christian creation tradition in which nothing that is can come to be independently of God's creative activity, and in which all that is depends on God's sustaining power for its continual existence. That nonbeing by itself cannot produce being resonates with Bohm's conception of the unending string of antecedents in nature. Second, the statistical patterns of quantum processes are correlated in a holistic sense through the quantum potential, while the fragmentation of nature at the explicit level is harmonized with a greater implicit unity in which each part of nature contains the rest. Both the nonlocal structure of the quantum potential and the interconnectedness of the implicate order which comes prior to space and time lay grounds for the theological meaning of the world as a single, whole and yet ongoing creation of God.

In Bohm's writings the concept of cosmos is suggestive of the divine. For example, the implicate order undergirding nature is similar to Spinoza's formulation of an impersonal God as nature, *deus sive natura*. Similarly, Bohm's notions of mind and matter often seem like the irreducible substances of Spinoza's metaphysics. In addition, one gets a sense of divine transcendence in an unusual way in Bohm's writing about the inexhaustible (probably nondenumerable) infinity of levels in nature. In Anselm's theology, for example, God is that the greater of which cannot be conceived. If our concept of nature is to be so infinitely foliated, how much more so our concept of God.

The implicate order is a geometric metaphor for both unity and structure in nature. Geometry has also been a rich tool for conceiving of the relationship between God and nature. In Thomistic cosmology, the world is infused with an organic unity expressed through a homocentric geometry. From the highest sphere, the divine animated the movement of this world. The absolute space and time of the Newtonian/Cartesian metaphysics provided the deists with a divine *sensorium* by which they pictured God's relation the world. Karl Heim, and more recently Torrance, have attempted to describe the God-world relationship explicitly using spatial metaphors. It will be interesting to see if Bohm develops his own ideas about the divine using similar metaphors drawn from the geometry of the implicate order (see Peters 1985).

Of course Bohm's view of nature does not necessarily imply the further premise that God is personal. Moreover, Bohm is very cautious about extrapolating from nature to a personal God, a hesitancy which would be endorsed by many theologians. One can even argue that Bohm's ideas are closer to a pantheistic interpretation of the divine. Still I think that his ideas as they have developed over the past three decades point to transcendent, even self-transcending, features of nature which could correspond to divine presence. Hence on balance Bohm is probably closest to a panentheistic and impersonal conception of God (see Bohm 1985, 123-24).

Does order lead to beauty, design, purpose? Starting with modern physics, Bohm gives one of the most structured systems for the cosmos that I know of: explicate order, implicate order, super-implicate order, and so on indefinitely through orders of mind and matter. Can one not find beauty in this order? Does such an order suggest the explicit intentionality of design and purpose?

Clearly these questions lead to traditional theological issues involving the rationality versus contingency of nature and the model of God as designer. Often the statistical character of modern science, whether it be of Darwinian or quantum origin, seems to cancel all efforts to move from creation to Creator. Bohm is tentative about such theological implications of his cosmology. Yet as his cosmology is explored further, its theme of cosmic order could provide renewed grounds for the intelligibility of faith in the creative presence of God in nature and a new mode of divine purpose in the world.

Grace, free will, and quantum indeterminacy. Free will is fundamental to human experience. Although the psychological and religious dimensions of free will ought not be reduced to a purely physical explanation, can one find a basis in natural law which at least allows for human volition? Eddington (1928) and Arthur Compton (1935), for example, have suggested that quantum indeterminacy provides a physical basis for our experience of self-determination, given that physical indeterminacy is interpreted ontologically. Ian Barbour ([1966] 1971) criticizes this view on several accounts: that freedom is more than randomness and has little in common with it, that the act of choice involves the total person and an awareness of future goals, and that an epistemology of levels is preferable to either reductionism or Cartesian dualism.

Bohm's cosmology provides an interesting twist to the discussion since quantum indeterminacy is interpreted as real in nature, but not as final. His view thus brings a new framework for the discussion of free will, both in terms of his earlier metaphysics of levels and his more recent conception of the implicate order. For example, if Bohm is correct, the predominance of chance versus order oscillates from level to level in nature through a sequence of levels that never terminates, or alternatively from implicate to super-implicate order *ad infinitum*. If there is no "bottom level" or final order, then the argument over the proposed physical basis for free will becomes empty since without a final level neither chance nor order could determine the predominant character of nature. In addition, if Bohm's theory of levels extends to levels within the human self one can understand afresh the occurrence of psychological states as different as spontaneity and compulsion, ambiguity and certainty, even hatred and compassion.

Extended to theology, Bohm's approach addresses the arguments over the divine grace versus human free will which have for so long continued within the church. William Pollard, for example, has argued that the activity of God need not violate physical law if such acts occur within the uncertainties of quantum processes to actualize certain results over others (Pollard 1958). However, if Bohm's conception of an infinity of levels is correct, God's activity could be thought of as occurring at the infinitely many-ordered levels laced between the infinitely many levels of chance, rather than as working within the bottom rung of nature. Alternatively God's activity could be taken as enfolded within nature, there to be unfolded by the decisions of self.

Wholeness as a theological model for the church. Many perceive the church as both the visible body of believers and the invisible body of Christ, reflecting a community whole which cannot be simply equated with those assembled in one place or time. We are called to be members of one body through the mystery of the uniting Spirit, though without losing our individuality and uniqueness. The wholeness of this body supports the wholeness of each part of the body, a theme found in Tillich's dialectic of individualization and participation, in Friedrich Schleiermacher's view that "sin is in each the work of all, and in all the work of each," in Paul's theology of the church as Christ's Body, and in the cosmic scope of Teilhard's vision. In many ways we affirm the reality of the whole body as complementary to each individual person. This forms a striking analogy with the quantum potential in quantum formalism as stressed by Bohm, and in the factorization of the whole into relatively autonomous subwholes in the explicate order as Bohm has more recently emphasized.

Fragmentation, evil, and the self. A dominant theme in Bohm's cosmology is that of fragmentation: the explicit order is broken in a way which extends from the realm of matter to society where we struggle destructively with each other and to our processes of analysis which rend the wholistic knowledge into bits and pieces. A major contributor to fragmentation is self, as it acts for its own sake through ignorance of its unity with nature.

The theme of fragmentation is ripe for theological discussion. A major focus of Western religion has been on the paradox of evil: How can a God of compassion allow human suffering? In response to this question, theologians have pointed to free will as an irreducible component of the human self. Sin is then the abuse of finite freedom in which we destroy what is whole and good. Although we seek to grow spiritually our paths are hindered by hate and greed, arrogance and betrayal (Hick 1966). Normally, however, the human person is also seen as a source of God's self-disclosure, a recipient of healing forgiveness , and a visionary of a future filled with genuine community. Still the primary, even exclusive, meaning of evil in traditional theology is given in moral terms; the pain and devastation of nature at the physical level is at most a backdrop reflecting social and personal corruption.

The theological importance of fragmentation in Bohm's cosmology is that it provides a way to move beyond the moral interpretation of evil and address its physical dimensions. Here even nature (as explicate order) seems broken and disparate, in need of a deeper unity which may lie at the hidden, implicate level. Not only are there hurricanes, disease, starvation, predators, and earthquakes, but even the very form of nature is a fragmentation of a deeper hidden unity. This suggests that we might gain new insight towards the overcoming of fragmentation at the societal and psychological levels if we can learn how physical reality is internally connected.

Yet even though Bohm's vision of a whole of wholes echoes at times with persuasive religious power, in other places Bohm seems to reduce evil to a state of mind or to a faulty epistemology and to view the dissolution of the self as a cure for the wrongs of society. To this I would argue for the irreducible reality of the self by drawing on the aspect of Bohm's cosmology in which the parts of wholes are real wholes in themselves. Moreover, I believe that fragmentation or sin, while real, is not ultimate; that brokenness can be mended through forgiveness; that the sicknesses of society, self, and world can be healed through compassion; and that a new creation lies in that particular future to which God persuades us and which God creates in and through us.

Conclusion

Bohm's cosmology is based on several root metaphors: nature as whole and one yet infinitely leveled and inexhaustibly subtle; as dynamic and changing, yet as transforming into itself; as contingent, yet as causally regular; as knowable, yet ultimately beyond analysis. Such a cosmology rings with many of the central beliefs of the Judeo-Christian traditions, in which nature is the blessed and free creation of a loving and redeeming God. Bohm's discovery of a nonlocal realist interpretation of quantum processes gives support to the realist philosophies underlying general theological inquiry. Bohm's work holds idealist and realist, monist and pluralist, theistic and naturalistic poles in creative tension, resonant with broad areas of theological and philosophical opinion. Bohm's physics offers a remarkable alternative to current physics at the frontiers of research. Where differences are clear between the fields in dialog here, each partner can learn from the concerns and critiques of the other.

Although he has come a great distance since his early work, Bohm considers even his recent ideas more as a "proposal" than as a "conclusion," a proposal beyond which "there could in principle be an infinity of further development . . ." (Bohm 1981, 213). On a similar note, C. W. Kilmister concludes his review of *Wholeness and the Implicate Order*: "It is important that these fundamental new ideas should be put forward even if in incomplete form and it is to be hoped that this publication will bring more workers into the field" (Kilmister 1981). With the continuing promise and challenge of the thought of David Bohm, there is indeed a remarkable opportunity for creative interchange between theologians, philosophers, and scientists both now and in the future.

NOTES

1. In this paper, Bohm showed that the Schroedinger equation can be written in a form similar to a modified Hamilton-Jacobi equation such that each particle of an ensemble can carry a well-defined (though hidden) position and momentum given appropriate initial conditions. Unlike electric fields, which are tied to individual charges, the quantum mechanical force in Bohm's formulation is sourceless, suggestive of the configuration of the whole system. For an extended discussion of this and other hidden variables theories, see Belinfante (1973) and Jammer (1974).

2. Here Bohm is responding to a long-standing problem for a hidden variables version of quantum theory. During the 1920s, John von Neumann began to focus his work at the University of Berlin on the mathematical basis in quantum mechanics for the statistical character of the results of measurement. Von Neumann's famous "impossibility proof" argued that any approach which introduces hidden variables as deterministic elements that affect the dynamics of the quantum system and thereby produce the statistical scatter in observations would be inconsistent with quantum formalism. Von Neumann's results were widely discussed and broadly accepted in the physics community, until Bohm's 1952 papers reopened the question. Bohm argued that von Neumann's results, though correct for hidden variables affecting only the observed system, would not apply in the case where the results of observation involve both the observed and the observing system. Although in other ways Bohm is at odds with Bohr's interpretation, here in 1952 he agreed with the "feature of wholeness" so typical of Bohr's philosophy. "In this point we are in agreement with Bohr, who repeatedly stresses the fundamental role of the measuring apparatus as an inseparable part of the observed system" (Bohm 1952b, 187-88). Interestingly, five years later he will describe the resolution of his disagreement with von Neumann differently: Bohm then stresses instead the inapplicability of quantum formalism as such to hidden variables of a subquantum mechanical level. If hidden variables need not obey quantum rules, von Neumann's theorem would simply not apply. No reference is made in this passage to either Bohr or the "feature of wholeness" (Bohm 1957, 95). For a further discussion of von Neumann's proof and its reformulations by other researchers, see Jammer (1974, ch. 7).

3. See, for example, Bohm and Bub (1966). Regarding the ERP problem see Bohm and Aharonov (1957). For early results which tend to confirm quantum mechanics versus local hidden variables theories, see Freedman and Clauser (1972); more recent experiments are discussed in Clauser and Shimony (1978). A detailed discussion, including a review of several arguments raised against hidden-variables theories, is given in Jammer (1974, ch. 7).

4. There are important ties between Bohm's philosophy and that of Alfred North Whitehead. See Griffin (1985).

5. For an introduction to the problems posed to a philosophy of realism by quantum mechanics, see d'Espagnat (1979), Clauser and Shimony (1978), and Rohrlich (1983).

6. I find this a plausible argument, although I would question other points in Jaki's article.

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