Chapter 4
Growing Recognition of Bohm's Causal Interpretation

In terms of Bohm's contribution to physics—at least in the narrow sense of his original 1952 papers and of the extension of that work to include spin and special relativity—the last 60 years have seen a slow but significant change. Let us first remind ourselves that although standard quantum mechanics was developed in Copenhagen in the late 1920s, many of its pioneers moved to the United States to flee Nazi Europe in the 1930s, and theoretical quantum physics was at a world high point in America when Bohm was recruited by Oppenheimer. But despite the very visible application in the atomic bomb and the horrific bombings of Hiroshima and Nagasaki in 1945, the applications of quantum physics were only beginning in the 1950s. The first transistor was made in 1947, and transistor radios first went on sale in the US in 1954. The first transistor computer was built at Manchester in the UK in 1953, and integrated circuits were developed at Texas Instruments and Fairchild Semiconductors in the US in 1958, but it took until the 1980s before the PC we all know went into mass production. The first laser did not appear until 1960 and the CD in 1982. But nowadays, according to a recent interesting book by Brian Clegg,[1] about 35 per cent of GDP in the "advanced" countries comes from technology using quantum physics.

David Bohm's causal interpretation now provides an increasingly recognised area in the vast research output of theoretical physics that underpins this "Quantum Age". It could be said that the pragmatic criticisms of Bohm's work in the 1950s by other physicists, namely that he had failed to produce "results", are beginning to be answered. Citations of Bohm's two 1952 papers never reached more than 20 per year as late as 1975, yet by 2000 they never fell below a hundred.[2]

Of great importance here is a relatively new type of research—the application of Bohm's approach to different problems in physics, using the particle trajectories that can be computed by the Bohmian methodology.[3] In their introduction to this

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[1] Clegg (2014).

[2] Oriols and Mompart (2012), p. 8.

[3] Oriols and Mompart (2012), Sanz and Miret-Artés (2012) & Sanz and Miret-Artés (2014).

C. Talbot (ed.), *David Bohm: Causality and Chance, Letters to Three Women*,
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area, Oriols and Mompart stress that it "is not at all devoted to the foundations of quantum mechanics, but only to discuss about the practical application of the ideas of de Broglie and Bohm to understand the quantum world." They give "examples of such practical applications written by leading experts in different fields, with an extensive updated bibliography", addressing "students in physics, chemistry, electrical engineering, applied mathematics, nanotechnology, as well as both theoretical and experimental researchers who seek new computational and interpretative tools for their everyday research activity." The authors cite Steven Weinberg as giving the typical objection of physicists to Bohm:

> In any case, the basic reason for not paying attention to the Bohm approach is not some sort of ideological rigidity, but much simpler—it is just that we are all too busy with our own work to spend time on something that doesnt seem likely to help us make progress with our real problems.

But to this they can reply by pointing out that "in contrast to the Copenhagen formulation, the Bohmian formulation allows for an easy visualization of quantum phenomena in terms of trajectories that has important demystifying or clarifying consequences" and that "[i]n some systems, Bohmian equations might provide better computational tools than the ones obtained from the orthodox machinery."[4]

Another interesting new area of research, which is not, strictly speaking, quantum physics, and perhaps not as widely known as Bohmian trajectories, is in the study of experiments involving oil droplets bouncing on a vibrating tray of oil, or computer simulations of such experiments. Oil droplets behave like particles interacting with the wave on the surface of the oil they create (in effect this is a "pilot wave"). The phenomenon resembles very closely the Bohmian approach to quantum mechanics.[5]

Such new developments in computing, physics, chemistry, engineering, etc. relating to the Bohmian view of quantum mechanics, taking this in a broad sense, are relatively recent. Since they mainly relate to computer techniques, it is perhaps not surprising that a useful introduction to Bohm's approach has been given in a Cambridge (UK) course by Mike Towler.[6] Towler participates in the Cambridge Monte Carlo Quantum Computing group and hosts conferences at the Towler Institute, his sixteenth century monastery in Tuscany, Italy.

There is now also a possibility that the Bohm-de Broglie version of quantum mechanics will actually receive support from astronomical observations. In a series of papers over the last two decades, Anthony Valentini has attempted to show that the de Broglie theory[7]—there is a small technical difference between the original de Broglie theory and Bohm's later version, and Valentini has co-authored a book on the history of this[8]—gives slightly different results to standard quantum mechanics when applied to the early evolution of our universe. But information from that early

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[4] Oriols and Mompart (2012), Introduction.

[5] Wolchover (2014).

[6] Towler (2009).

[7] Everyhope-Roser (2013).

[8] Bacciagaluppi and Valentini (2009).

stage is available to us in the microwave radiation that was emitted at that time, the so-called background radiation. This radiation contains small anomalies or fluctuations, corresponding to "lumpiness" formed under gravitational attraction that would eventually give rise to the galaxies that we see today. Valentini is hoping that the latest measurements of the background radiation by the Planck satellite will be accurate enough to test the de Broglie theory against the standard interpretation.

The rather optimistic picture I am painting of current attitudes of physicists towards the Bohm (or de Broglie, according to Valentini) version of quantum theory should probably be tempered by stressing that virtually all of the physics literature involved is overwhelmingly technical, using a lot of mathematics and computation, possibly looking at related experiments, but in general, this research would not dream of referring either to the philosophical ideas that motivated Bohm in the 1950s or to his later philosophy of the "Implicate Order". In today's academic climate, and even in the 1950s (as we see Bohm complaining in his letters), such "metaphysical" considerations are excluded from physics by the research funding process, by peer-reviewed journals, and generally, by the desire to preserve one's career.

There is, however, an area of physics known as "Foundations" which developed in the 1970s, together with small specialised areas in the philosophy and history of science, where it is possible to discuss alternatives to the standard "Copenhagen" interpretation quantum mechanics, or to discuss and develop the many other interpretations which have been put forward since Bohm's 1952 papers. It has now been well established in the historical study of Mara Beller, amongst others,[9] that there was really no consistent viewpoint to quantum mechanics developed by Bohr, Heisenberg, Schrodinger and others in the 1920s, but a rather botched together compromise. But although this philosophy, history and foundational physics is regarded as academically respectable, unlike Bohm's philosophical work of the 1950s or his later "ontological" developments, it seems to have had little impact on academic physics, although a number of introductory quantum mechanics texts do now refer favorably to Bohm's "causal" interpretation.[10]

One contribution to the Foundations area should perhaps be particularly noted. The recognition that Bohm's version of quantum mechanics was as valid as the standard interpretation and would appear to give the same results in every application was at the center of James T. Cushing's book in 1994,[11] which remains a good technical introduction to Bohmian quantum physics. Cushing, both a physicist and a philosopher of science in the analytic tradition, was highlighting what philosophers of science call the "underdetermination" of scientific theories by experiments—meaning that both the standard and Bohm's version of quantum mechanics describe the same experimental results, and so far, no experimental test has been devised to verify one of them and refute the other.

It is fitting here to mention the "Bohmian Mechanics" group, which developed in the 1990s and is by far the largest and best known of the researchers in the field of

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[9] Beller (1999).

[10] For example Baggott (1992); Ghirardi (2005).

[11] Cushing (1994).

physics relating to Bohm. On their website,[12] they list 13 full Professors from the United States, France, Germany and Italy who, together with their research students, make up this group (Its most well-known members are Sheldon Goldstein, Detlef Dürr and Nino Zanghi, and it also includes Jean Bricmont, of "Science Wars" fame). It is impossible to summarize here all the research carried out by this group. They list dozens of papers and several books published under the Bohmian Mechanics imprimatur on a wide range of subjects in theoretical physics, and clearly pride themselves on mathematical rigor and a "no-nonsense" approach to philosophical issues, striving to convince the majority of physicists of the validity of Bohm's causal interpretation. It is still an uphill struggle.

A readable introduction is given by the philosopher of the group, Tim Maudlin.[13] Perhaps the most notable feature in Maudlin's account is the rejection of the conceptual importance of the "quantum potential". Bohm and Hiley stressed that the quantum potential explains "a number of strikingly new features which do not cohere with what is generally accepted as the essential structure of classical physics".[14] In contrast, Maudlin states that "the deeper defense against criticisms of the quantum potential is that it is superfluous".[15] Thus, the defense against physicists' accusations concerning unnecessary metaphysical baggage is to drop many of the conceptual ideas from Bohm's work, including the quantum potential, while preserving what is seen as the core of Bohmian physics. To return to Detlef Dürr's review of *Science, Order and Creativity*[16]:

> Bohmian mechanics is a robust theory which leaves no place for quantum romanticism or quantum mystery, and in the present cultural period I feel the need to state that as clearly and absolutely as possible. Such a statement does of course go against the spirit of Bohm's philosophy which, for all it may be humbly presented, is at the same time very ambitious in that it tries to grasp eternal truth, in the midst of which Bohmian mechanics is nothing but a tiny event. . . . .when it comes to physics urgent matters have to be dealt with, and Bohm's theory, Bohmian mechanics, is the best possible way to make, if not a better world, better physics. To some, like this reviewer, that is enough for a life's work.

In contrast to this "anti-metaphysics" tendency, Basil Hiley, now an octagenarian, continues to provide us with a prodigious output that staunchly defends what he sees as Bohm's contribution to physics.[17] Hiley is applying the mathematics of algebras, especially Clifford Algebras, to the *Implicate Order* conception which he and Bohm developed out of the original causal approach to quantum mechanics in the 1970s. Clifford, also known as Geometric Algebras, are an increasingly popular way of doing mathematical physics. First put forward by mathematicians Sir William Hamilton, Hermann Grassmann and William Kingdon Clifford in the 19th century, it was pushed aside by physicists such as Willard Gibbs at the beginning of the 20th

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[12] http://www.bohmian-mechanics.net/.

[13] Maudlin (Maudlin (2011)).

[14] Bohm and Hiley (1993), p. 31.

[15] Maudlin (2011), p. 110.

[16] Düerr (2012).

[17] Hiley (2001).

century, who employed the now familiar vector approach to physics and engineering.[18] Popularized by American physicist David Hestenes in the 1960s, it was taken up by Bohm and Hiley as a way of doing fundamental physics which would move away from traditional conceptions of space and time. It was also studied in the 1950s by Mario Schönberg (or Shenberg), the Brazilian physicist referred to above, whom we shall meet again in Bohm's letters (in one of his papers, Hiley acknowledges the influence of Schönberg on him and Bohm on this topic[19]).

In a collection of essays dedicated to Paavo Pylkknen,[20] Hiley explains the evolution of his own and Bohm's thinking, and gives a muscular opposition to the Bohmian Mechanics approach, with its rejection of the quantum potential ("not the approach that Bohm originally proposed, nor is it the theory that our group at Birkbeck worked on with Bohm for three decades"). Hiley clearly hopes that, by his creative development of mathematics—which is certainly impressive, if difficult to follow, even for someone who has had some mathematical training—he can better establish Bohm's approach as central to theoretical physics. He insists that the "holist" conception of the *Implicate Order* as well as Whitehead's "Process Philosophy" can help provide a way forward in understanding the quantum domain.

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[18] Fletcher (2014).

[19] Frescura and Hiley (1984).

[20] Hiley (2010).

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