Chris Talbot
Editor

David Bohm

Causality and Chance, Letters to Three Women

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Chapter 1
Introduction

David Bohm (1917–1992) was a physicist, but his influence has gone far beyond the world of physics. He has become one of the most widely discussed intellectual figures of the twentieth century. While his work is still relevant to physicists and plays a part in contemporary areas of cutting edge research, Bohm's ideas have taken on a much wider cultural significance, reflecting his own wide-ranging genius. Growing up in the coal mining town of Wilkes-Barre, Pennsylvania, his outstanding talent eventually led him to be recruited into Robert Oppenheimer's theoretical physics group at Berkeley, where he joined the world's leading physics researchers at the beginning of World War II. He carried out brilliant investigations in a number of areas of front-line research, especially plasma physics, and was recognized as an equal to Richard Feynman in original thinking. At Berkeley he mixed with politically radical students in Oppenheimer's group, such as Joseph Weinberg and Rossi Lomanitz, and became a convinced supporter of Marxism and of the Soviet Union, joining the Communist Party for a brief period. Because of his political views, he was refused security clearance to work under Oppenheimer on the development of the atomic bomb at Los Alamos. However, his doctoral dissertation was regarded as so important that it was classified and used in the Manhattan Project.

At the beginning of 1947, Bohm was appointed to an Assistant Professorship at Princeton, where he delivered undergraduate lectures on quantum mechanics. He supervised research into plasma physics and other areas, and was able to hold discussions with Einstein on issues of fundamental physics. With the McCarthyite witch-hunt at its height during the Cold War, Bohm was summoned to appear before the House Un-American Activities Committee (HUAC) in 1949. He pleaded the Fifth Amendment and refused to testify. In response, in December 1950 he was indicted for contempt of Congress and arrested. He was driven to Trenton, the local capital, by a marshal, with whom he later recalled that, in his characteristic fashion, he had discussed Einstein's theories. He was eventually granted bail and released, but he was suspended from his post at Princeton. In May 1951 he appeared in court and was acquitted on all counts. His students had campaigned in his support and the physics

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department had praised his teaching and research, recommending that his contract be continued. However, in the anti-communist atmosphere of the time, Bohm was sacked by Princeton president Harold W. Dodds in June 1951. Unable to find work in the US and worried he could be imprisoned by a government he saw as increasingly fascistic, he took a job as Professor of Physics at the University of São Paulo, Brazil.[1] Most of the letters collected in this book were written during Bohm's stay in Brazil.

When he had spent a year at Princeton,[2] Bohm began lecturing on advanced quantum mechanics to graduate students. The notes from this course, based originally on courses given by Oppenheimer at Berkeley, became the basis for Bohm's highly regarded text-book *Quantum Theory*,[3] which was published in 1951, before Bohm left for Brazil. In the physics of quantum mechanics, there were, and still are, particularly difficult philosophical problems. It was the standard or "Copenhagen" approach to quantum mechanics that was being taught in universities in Bohm's day—and still is today, with very few exceptions.[4] Bohm's distinctive approach in his book was to develop the student's conceptual understanding, attempting to clarify the strange features of the theory rather than stressing the formal mathematical side, which most textbooks had done and still do. He brought out the intrinsic randomness of individual processes at the atomic level, and the so-called wave-particle duality. He investigated the measurement process which, some claimed, showed that the consciousness of the observer would determine the outcome of experiments, etc., etc. It is also evident, and this will become clearer when we look at the letters, that, without any explicit references, Bohm was attempting to develop a Marxist dialectical materialist approach to standard quantum mechanics.[5]

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[1]For this earlier period see Peat (1996), Chaps. 1–7, Freire (2015), Chap. 2, and Mullet (2008).

[2]Peat (1996), p. 74.

[3]Bohm (1989).

[4]See Chap. 6 for a brief outline.

[5]See Chap. 6.

Chapter 2
The Causal Interpretation and Causality and Chance

In spite of the book's acclaim, as the letters show, Bohm was not satisfied that he had dealt adequately with the philosophical issues from the standpoint of Marxism. In a relatively short period at Princeton, in the year before leaving for Brazil, he developed his alternative "hidden variable", or "causal", as it was later called, approach to quantum mechanics. It is also known as the Bohm-de Broglie approach, since Bohm unwittingly repeated Louis de Broglie's so-called "pilot wave" theory of the 1920s. After criticism from other physicists, particularly Wolfgang Pauli, de Broglie had dropped this approach in 1927. Bohm had a thorough grasp of the standard theory and its weaknesses after writing his book and was therefore able to deal in detail with Pauli's criticisms.[1] He eventually published the two papers setting out the "causal" interpretation at the beginning of 1952, after he had arrived in Brazil.[2] Pauli, who was now the reviewer of Bohm's papers, had to admit they gave a consistent approach to quantum mechanics, despite his intense hostility to Bohm's philosophy. To this day, Bohm's version of quantum mechanics is just as valid as the standard theory. No experimental test that gives a result confirming the standard theory has yet been devised that does not also confirm Bohm's theory.

As we shall see from these letters, in Brazil, notwithstanding illness and depression, Bohm intensively developed scientific, philosophical and political views from his distinctive Marxist standpoint. In science, he not only worked on developing the "causal" approach so as to include spin and relativity, he also carried out concentrated work on probability theory and statistical mechanics. He had hoped to interest other physicists in the "causal" interpretation but as the letters show, he became increasingly discouraged at the possibility of achieving this. Physicists, even Communist Party members, wanted to see "results". Unless new physical phenomena, explicable only by Bohm's interpretation, were discovered, or developments were

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[1] See Freire Jr. (2015), pp. 31–32 for more on this.

[2] Bohm (1952a,b).

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made by Bohm in new areas, such as particle physics, the physics community remained sceptical.[3]

It must be stressed that Bohm's ideas in this early period formed a closely integrated whole, with philosophy and politics being given as much, if not more, attention than science in the letters.[4] The politics was definitely Stalinist but was not intended for public discussion, and in any case, went through a drastic shake-up after Bohm's moving to Israel, with all the revelations about the USSR that became available. However, from 1952 onwards, Bohm clearly intended to put together a book on science and philosophy from a Marxist standpoint.[5] This was eventually published as *Causality and Chance in Modern Physics* in 1957.[6] As with *Quantum Theory*, there are no explicit references to Marxism in the book, but the letters help to shed much light on how the dialectical materialist ideas that went into it were developed, making it one of the few serious attempts to bring together the Marxist philosophical tradition and physics in the 20th century.[7]

It is worth recalling here how the "causal interpretation" is referred to in *Causality and Chance*. The new interpretation of quantum mechanics was not to be regarded as a finished or final theory. That would go entirely against the dialectical materialist conception, namely that scientific theories are not free from error but rather an "unending process in which the degree of truth in our knowledge is continually increasing".[8] In *Causality and Chance* Bohm explains that he had intended to show that "alternative interpretations of the quantum theory were in fact possible".[9] He even argued that his theory had "many aspects which seemed quite artificial and

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[3]It was probably mainly this pragmatism and inherent conservatism that prevented Bohm from making a greater impact, though widespread anti-communism certainly also played a part. See Freire (2005) for a discussion on this issue.

[4]References to letters throughout this introduction are given in the form (X,**Y**, p. Z) where X is the chapter in Part 2, **Y** the letter number, and Z the page number.

[5]There are several references in the letters to Miriam Yevick in 1952 to the difficulties in writing a proposed book on philosophy. Then, in February 1953 (26, **96**, p. 317), he tells Miriam he is experimenting with a number of ideas, which he may publish first as articles. A little later, he writes to Melba Phillips about a book gradually taking shape (18, **42**, p. 163) and thanks her for efforts in trying to get a "paper" on causality published (18, **45**, p. 169). In April 1954, he tells Miriam that his book has been accepted by Routledge and Kegan Paul (30, **116**, p. 395), and in August (31, **120**, p. 414), he has a six-page summary of his ideas on probability (not found in the archives). Finally, in October 1955 (19, **52**, p. 180), he writes to Melba that the publishers have asked him to shorten the book, cutting out some technical material, and he also decides to cut out material on positivism. The revised version, with five chapters remaining, is probably the book in its present form.

[6]Bohm (1957).

[7]This is not to dismiss the work of Soviet physicists such as V.A. Fock (see Graham (1971), especially Chap. III), but they were working under even more disadvantageous circumstances than Bohm, as we will attempt to show in Chap. 12 on Soviet Physics and Philosophy.

[8]Bohm (1957), Chap. 5, especially Sect. 12.

[9]Bohm (1957), Chap. 4, Sect. 3.

unsatisfactory", and listed the criticisms of his new approach.[10] In particular, he made the remarkable point that:

> . . . our model in which wave and particle are regarded as basically different entities, which interact in a way that is not essential to their modes of being, does not seem very plausible. The fact that wave and particle are never found separately suggests instead that they are both different aspects of some fundamentally new kind of entity which is likely to be different from a simple wave or a simple particle, but which leads to these two limiting manifestations as approximations that are valid under appropriate conditions.[11]

This was written long before the seminal work of John Stewart Bell appeared, and the recognition of the phenomenon of quantum "entanglement", including the fact that at the quantum level, in either the standard or Bohm's interpretation, matter cannot be isolated in a localised, particle-like form. Bell would later use the term "beable". Bohm himself seems already to have intuited the existence of some such entity.

Whatever the limitations of Bohm's theory, it was and still remains a challenge to standard quantum mechanics. Even if one accepts that the standard interpretation does not necessarily imply that the observer's consciousness affects the outcome of quantum processes,[12] the idea that there is an ultimate purely random level in nature is at odds both with Bohm's version of quantum mechanics and the philosophy he put forward in *Causality and Chance*.

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[10] As Bohm wrote in his second 1952 paper: "We should never expect to obtain a complete theory of this structure [the objectively real world of unlimited complexity]" (Bohm 1952b), and in 1953: "It is true that this model is somewhat crude, and that a deeper synthesis should be sought" (18, **43**, p. 165).

[11] Bohm (1957), Chap. 4, Sect. 5.

[12] Though many writers appear to think it does. See Rosenblum and Kuttner (2011) for a recent example.

Chapter 3
Bohm After Brazil

After Bohm moved to Israel in 1955, the few letters in the archives (all to Melba Phillips) show a distinctive change. In philosophy, he continued and deepened the study of Hegel he had begun in Brazil, especially under the influence of the Brazilian physicist and Communist Mario Schönberg. Whatever his misgivings about Marxism, however,[1] he went ahead with the publication of *Causality and Chance*.

More and more revelations about what was happening in the Soviet Union became available, which, while in Brazil, Bohm had insisted were only temporary problems, due to the backward conditions, to hostility from the west, and so on. But in Israel, as well as through Kruschev's revelations, he learnt directly about Russia and Eastern Europe from exiles, some of whom were long-standing Communists. The letters show he abandoned his support for Stalinist Communist Party politics, though continuing at that time to hold socialist ideals. Although he met and then married Saral, which put him on a more stable emotional footing, he appears to have gone through a considerable intellectual crisis.

Bohm appears to have spent much of the late 1950s and the 1960s pursuing "holistic" philosophy, studying the philosophy of Hegel[2] and A.N. Whitehead, conducting dialogues with the Indian speaker and writer Jiddu Krishnamurti and with a

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[1]In (19, **54**, p. 182), in 1956 he wrote the following to Melba: "I have been studying Hegel (along with some other people here in Israel). It is true that Marx and Engels stood Hegel's ideas on their feet, by making them materialistic. Nevertheless, there was a tremendous wealth of ideas that they did not use, because the science of the time did not require them. But now, with the further development of science, these ideas applied to space, time and matter are surprisingly fruitful, as well as beautiful".

[2]An interesting summary of Bohm's views on Hegel in the 1960s is given by Paul Feyerabend, who discussed with Bohm when they were both at Bristol University (Radner and Winokur 1970), pp. 31–36 and 113–116). Feyerabend is well aware of the connections between Marxism and Hegel and teases the philosopher of science Imre Lakatos for pretending to be a Wittgensteinian and hiding his dialectical training in Hungary (by Georg Lukacs among others).

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research student, Donald Schumacher, on language, exchanging letters with Charles Biederman on art,[3] and so on.[4]

In terms of his work on physics in the 1960s period, he is mostly remembered for work with Yakir Aharonov, his research student in Israel and at Bristol, which led to the proposal of the Bohm-Aharonov effect.[5] But on the causal interpretation, we know from Basil Hiley that "in the first ten years I worked with David Bohm his '52 paper was not discussed at all", the main reason being that "first of all David Bohm was not that interested in it and secondly I didn't believe it."[6] Only when a student insisted that Hiley studied it did he become interested.[7] With the involvement of a number of students—Christopher Philippidis, Christopher Dewdney, Peter Holland, Fabio Frescura and others—Bohm and Hiley renewed work on the causal interpretation.[8] From the early 1970s on, Bohm developed his philosophy of wholeness, which was also featured in a key paper he wrote with Hiley in 1975.[9] In this paper Bohm and Hiley returned to the causal interpretation, highlighting the non-locality or "entanglement" issue referred to above, which had been brought out by John Bell: "the most fundamentally different new feature [of quantum mechanics] of all; i.e., the intimate inter-connection of different systems that are not in spatial contact."[10] This point was made while experiments were still continuing on the issue of Bell's theorem and entanglement, a long struggle documented by Freire[11] and culminating in the experiments of Alain Aspect in 1981–82.[12] Thus, Bohm reinterpreted the 1952 papers in terms of his distinctive ontology of the *Implicate Order*,[13] and worked with Hiley on their ontological interpretation of quantum mechanics in order to eventually produce the ground-breaking textbook *The Undivided Universe*.[14]

The development of Bohm's ideas after the period covered by the letters collected in this book is, of course, a vast subject which I can only touch on here. Bohm seems to have engaged with many different people in areas that seem so disparate that it makes it hard to take in his multi-faceted thinking about the world. For example, with

[3] Pylkkänen (1999).

[4] See Peat (1996), Chaps. 11–13.

[5] See, for example, Peat (1996), pp. 190–2.

[6] See http://www.bbk.ac.uk/lib/bohm/bibliography-publications-by-david-bohm, which verifies this point. From 1961, after David Bohm met Hiley, there is only one paper in the 1960s on the causal approach, and this is published jointly with de Broglie and de Broglie's former research student and Communist Party activist Jean-Pierre Vigier, who retained their commitment to the 1952 approach.

[7] https://www.youtube.com/watch?v=q_jHmoxuxsY.

[8] Hiley expanded on this to Olival Freire in an interview (Freire Jr. 2015), p. 61 and made the same points to me in an interview, January 25th, 2015.

[9] Bohm and Hiley (1975).

[10] I am indebted to Olival Freire for pointing this out.

[11] Freire Jr. (2015), Chap. 7.

[12] See also Whitaker (2011).

[13] Bohm (1980).

[14] Bohm and Hiley (1993).

David Peat he wrote *Science, Order and Creativity*,[15] which is in line with the view of the infinite possibilities/resources of humankind that he refers to in his letters. It is interesting to read the review of it by Detlef Dürr, one of the "Bohmian Mechanics" group of physicists we shall touch on later[16]:

> Only a few writers would be able to cover such a broad landscape of ideas and themes without condemning themselves to shallowness. Bohm, who was one of the greatest thinkers and physicists of the last century, shows in this discourse with Peat a tremendous depth of understanding which makes the book a helpful resource for all those who have the urge to inquire into human understanding of our physical world, our behavior, and the development of society.

For those interested in the scientific problem of "consciousness", an area which seems to be of growing interest to many physicists, the attempt of Paavo Pylkkänen to understand the implication of Bohm's later views for the philosophy of mind is well worth studying.[17] For "hard" physicists, repelled by Bohm's involvement in "spiritualistic" or "metaphysical" areas, I would recommend a look at the philosophical, psychological and political outpourings of the founding fathers of quantum mechanics, as discussed by historian of science Mara Beller in response to the smugness of many scientists in the so-called "Science Wars" in the 1990s,[18] when Alan Sokal and Jean Bricmont, after getting a "spoof" article published in a social science journal, lambasted the postmodern trends in the humanities.[19]

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[15] Bohm and Peat (2010).

[16] Düerr (2012).

[17] Pylkkänen (2007).

[18] Beller (1998).

[19] Sokal and Bricmont (1998).

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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

[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).

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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

[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

[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

[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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Chapter 5
Introduction to the Letters

Turning to the archival material included in the second part of this book, there are, firstly, copies of 23 brief letters from David Bohm to his former girlfriend, Hanna Loewy, 12 of which were written in 1950 before Bohm went to Brazil. One (also brief) letter from Hanna to Bohm survives, not included here, dated June 7, 1950, telling Bohm that although she loves him she does not want to marry him. A letter from Bohm specifically replying to this June 7 letter explains that he has completed his book, Quantum Theory (Bohm 1989). Loewy was the daughter of Lilly, who had married Erich Kahler, a Jewish intellectual and writer on social philosophy who had fled Nazi Europe. Bohm had lived as a lodger in Kahler's house while he was in Princeton, which was then renowned as a centre of intellectual life, attracting visitors that included Albert Einstein, Thomas Mann and Jacob Bronowski.[1] The folder numbers in the Birkbeck archives are C37-40 and C97. Here, they are letters 1–12 (1950) in Chap. 14, and letters 13–23 (1951–53) in Chap. 15. Also, two letters from David Bohm to Lilly Kahler from December 1953 are included as letters 24 and 25 in Chap. 15 (folder number C96 in the Birkbeck archives). It seems that the C37-40 material was obtained by Bohm himself, probably when he needed evidence to back his application for an American passport, whereas C96 and C97 were obtained by David Peat.

Next, there are copies of 30 letters to Bohm's friend and fellow physicist Melba Phillips (two of which are incomplete). Phillips, like Bohm, had been a student of Oppenheimer, and also refused to testify under the McCarthy witch-hunt. In her case, it was the McCarran internal security commission, whereas with Bohm it was the

[1] Peat (1996), pp. 84–5.

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House Un-American Activities Committee, HUAC. She was sacked from Brooklyn College in 1952 and, although a talented physicist who co-authored a textbook that is still in use, remained unemployed for five years. Melba died in 2004, so I spoke to Melba's niece, Ellen Vinson (Wolfe 2015), but unfortunately she has no knowledge of any material relating to David Bohm, including the originals of these letters. The folder numbers in the Birkbeck archives are C46-49, and they are included here as letters 26–55 in Chaps. 16–19.

Finally, there are photocopies of 68 letters (10 of which are incomplete, plus five loose pages from missing letters) from Bohm to Miriam Yevick, a mathematician who was married to physicist George Yevick but had a personal relationship with Bohm. Yevick had fled from Nazi Europe with her family at the age of 15, which she has detailed in her book (Yevick 2012). She obtained a PhD in Mathematics at MIT in 1947, the first woman to obtain this qualification.

These photocopies were obtained by David Peat from originals held by Yevick. Peat explains how his wife persuaded Miriam to stuff letters and documents into plastic bags and accompany her to a photocopying shop. After a while, Miriam said "That's enough", and took the bags back (Peat 2005). Consequently, only a part of this valuable material is available, sometimes with poor quality copies.[2] Repeated emails from me, attempting to obtain access to Miriam Yevick's letters, have met with no reply. Only one letter from Miriam Yevick to Bohm is in the archives, and it is not included here. It is from late 1951, mainly of a personal character, but also explaining a mathematical point (on a "strong law" in probability theory). Additionally, there is one letter to George Yevick, probably from early 1952, on Bohm's ideas about the "ether" or "substratum". The folder numbers in the Birkbeck archives for the Yevick letters are C115-126, and they are included here as Letters 56–124 in Chaps. 20–33.

It is hard to make sense of the development of Bohm's ideas just from reading through all the letters. Scientific and philosophical issues such as quantum theory, statistical mechanics, causality and determinism are juxtaposed with personal concerns about the possibility of sexual relationships in Brazil and problems of repeated diarrhoea and sickness. Mixed up with philosophical discussions of the qualitative infinity of levels, one finds endless political analysis from a pro-Soviet viewpoint, not to mention the agonies of suffering from severe depression. In order to give some assistance to the reader (hopefully!), I have outlined some themes, giving appropriate references to the letters in each case. The themes are Philosophy, Mathematics, Development of the Causal Approach to Quantum Mechanics, Probability and Statistical Mechanics, Feminism, Politics, Soviet Physics and Philosophy and Psychological Issues.

[2]See Figs. 9.1–9.3 in Chap. 9 for an example.

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Chapter 6
Bohm's Philosophy as Revealed by the Letters

The letters demonstrate that Bohm was exceptional for a physicist in that he took his philosophy very seriously.[1] More than that, he is even prepared to develop his own original philosophical ideas. One can attempt to divorce his scientific achievements from his philosophical approach, as do the Bohmian Mechanics group, but only if one ignores the actual development of his ideas as revealed in these letters.

Bohm based his philosophy on Marx and Engels, but their ideas had been interpreted by their followers, especially by Russian Marxists, such as Lenin. Thus Lenin's ideas were clearly an influence on Bohm, as we shall see. Additionally, there was a further important development of serious philosophical study and debate in the USSR in the 1920s, after the 1917 revolution. After 1930, Stalin took a personal interest in philosophy, suppressed all debate and banished all material from the 1920s so that he could present himself as the direct heir to Lenin in philosophical leadership (see Tucker 1990, Chap. 7). As a result, a debased form of philosophy was imposed under Stalin and exported to the Communist Parties of the world. This background is important in understanding Bohm, and we will return to it in Chap. 12 on Soviet Physics and Philosophy.[2] In discussing Marxism with his physicist friends in the 1940s, although his politics remained at a crude Stalinist level, as we shall see below, Bohm's philosophy linked up with the ideas of Marx and Engels while providing a framework to his attempt to deal with quantum mechanics. He would probably have

[1] See his letter admonishing Melba for ignoring philosophical questions (18, **45**, pp. 167–169). He argues that "[a]lmost no great physicist worked entirely without a philosophy", whereas today all physicists "want are "results" that "pay off" immediately in higher jobs, recognition, job security, navy contracts, etc.". Note also his comment to Miriam: "But I am afraid that my first love is the philosophical problem and not the detailed dry scientific problems. Yet it is the latter which supply the means by which the philosophical point of view comes close to reality and demonstrates its fruitfulness." (27, **104**, p. 344).

[2] In a 1953 letter, Bohm clearly shows some awareness of the "mechanical" approach of the Soviets, see (26, **97**, p. 320).

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read some of Engels' pamphlets, and we know he read the notes written by Engels on philosophy and science in *Dialectics of Nature*[3] in Portuguese,[4] so presumably he was familiar enough with the English version. In his interview with Wilkins[5] he noted that with his friend Weinberg in the 1940s "we were discussing on a rather superficial level, but even that level was enough to give overtones that were enough to arouse my energy."

We can assume that the "overtones" related, at least to some extent, to the distinctive ontology, or theory about the "stuff of the world" developed by Marx and Engels. This is a difficult subject, and its exposition is based on scattered parts of Marx and Engels' fifty-volume collection of writings, most of which are about their chief concerns with economics and politics. Also, much of their work, especially from the earlier formative period, was not available in English at the time of these letters. Here I would recommend the books of Allen Wood[6] and Scott Meikle[7] for far more complete expositions than the sketch I can give here. The first author is not a Marxist, but offers the sympathetic account of an expert on classical German philosophy; the second author is a Marxist, and unfortunately writes in the disputative style of left-wing groups, but has the distinct advantage of being an expert on Aristotle. Both authors would agree that Marx supports an ontology that is materialist. Wood takes the basic tenet of Marx's materialism to be *Naturalism*, which "says that the sole reality is the natural world, and this world is made up solely of matter." Naturalists, "deny that the world was created by anything outside it, and that natural motion requires God (or any other supernatural agency) as its cause". Naturalism thus defined implies realism, namely the "thesis that material things are not dependent for their existence or nature on any mind or minds."[8] Bohm is not usually very precise, but we may assume he was a materialist of this type in the period covered by the letters.

Marx's ontology, and Bohm seems to have agreed with this, in some sense, for most of his life, is also "organicist" or "essentialist". The world is made up of things or entities that have "qualities", that are not unchanging but have self-movement and internal tendencies, and that display novelty, coming into being and passing away. Both Wood and Meikle regard the entities of this philosophy as "goal directed" or "teleogical". They insist that the latter term need not mean, as critics suggest, directed by a "higher" power, or that the future can somehow cause the past. Aristotle used the term "final cause", distinguishing the tendencies in organic entities from "efficient causes", i.e. the usual causes in the natural sciences. Both authors see no fundamental conflict between efficient and final cause explanations, they may in

[3] Marx and Engels (1988).

[4] (20, **57**, p. 201).

[5] Wilkins (1986), Vol III.

[6] Wood (2004).

[7] Meikle (1985).

[8] See Wood (2004), Chaps. 7, 8, 11 and 12, for a fuller explanation, as well as a refutation of the post-war academic trend wishing to deny Marx's materialism.

fact be deemed to be complementary,[9] but see below for the problem of "mechanistic" ontologies. Both authors wish to treat Aristotle seriously, despite the tendency, since the 17th century Enlightenment, to denigrate him by identifying his philosophy with Scholastic interpretations of his work developed in the Middle Ages.

Such a "teleological" approach as referred to above has been widespread in evolutionary biology, though not without controversy.[10] Marx and Engels themselves used such an organicist approach in their analysis of society, which later became known as "historical materialism". The same approach was also deployed by Marx for economics in his *Capital*. Working within the German philosophical tradition, especially that of Hegel, Marx and Engels considered that social and economic entities developed in a "dialectical" manner. In simple terms,[11] this means such entities contained opposing forces, also known as "contradictions", which could lead to their transformation into something new. Unlike some of their followers, they only used this approach with subject matter in which they were very knowledgeable—Marx spent 25 years studying economic theories and data. As they point out several times in their polemics, nothing is easier than using dialectics as sophistry, something we will find Bohm guilty of in Chap. 11 on politics.

There is, generally, a problem of emphasis in interpreting Marx and Engels on the question of "mechanism"[12] or a "mechanistic philosophy": the approach which says the world can be reduced to basic entities or "simples" which are fixed, or changing only quantitatively, normally using causality in the "efficient" sense of causal determinism only, although Bohm is not restricted to this. Especially in the *Dialectics of Nature*, Engels introduces the idea of levels, or what he calls "forms of motion". Wood examines the various references and reconstructs a list beginning with mechanical motion and going from the branches of physics, chemistry and biology through to the levels of life and consciousness, the latter including a tentative materialist theory of mind. Engels is especially opposed to attempts at mechanical reductionism, which "blots out the specific character" and "qualitative difference" of non-mechanistic forms of motion.[13] Wood regards this aspect of Marx and Engels's

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[9] See Wood (2004), pp. 107–8 and footnote 8, and Meikle (1985), p. 171.

[10] A similar distinction to Aristotle's was made by the great biologist Ernst Mayr, who used the term "ultimate cause" in relation to Darwinian natural selection and that of "proximate cause" for immediate, physiological and mechanical causes. For a recent critical discussion of Mayr's approach with references see Laland et al. (2013).

[11] See Wood (2004), Chaps. 13 and 14 on the complex issue of dialectics in Hegel and Marx and the differences between them.

[12] This is Bohm's terminology. Wood uses the term "mechanistic reductionism" and Meikle uses the term "atomism".

[13] Marx and Engels (1988), pp. 527–532.

philosophy as a "characteristic wrinkle",[14] based on Hegel and Schelling, and does not seem to take it as a significant trait of their work. Meikle, however, goes in for a strong denunciation of mechanical reductionism, or what he terms "atomism", though he bases himself largely on Aristotle.[15] The issue played a crucial role in the debate over "reductionism" between Deborinites and Mechanists in the 1920s, as we will see in Chap. 12 on philosophy and science in the USSR. Despite having no direct knowledge of the 1920s dispute, Bohm clearly saw "mechanism" as a major problem and apparently has some familiarity with the *Dialectics of Nature* arguments.

Besides mechanism, the other major philosophical issues which Bohm raises are "positivism" and the related question of "idealism." He took up ideas from Lenin's work *Materialism and Empiriocriticism*,[16] or most probably a Soviet publication based on Lenin.[17] Lenin's earlier philosophical work is often contrasted unfavourably to his later study of Hegel in the *Philosophical Notebooks*, and has had many criticisms from its first appearance,[18] but the important points for our purposes are: (1) it was directed against the positivist philosophy which was beginning to gain influence at the beginning of the 20th century, due especially to Ernst Mach, and which, to Lenin's horror, was supported in his own Bolshevik Party[19]; (2) it advocated that, philosophically speaking, all the new discoveries in science at the time – electromagnetic radiation, electrons, radioactivity, etc. – were all different forms of matter and the "levels" of matter were infinite. For the dialectical materialist, "matter" should not be limited to the corpuscular matter of 19th century science.

Relating to (1), by "positivism"[20] we mean the philosophical approach that merely correlates sensory perceptions, or experimental results, opposing the claim that such correlations reflect actual relationships among real things, which exist independently of observation.[21] Lenin thought that Mach's positivism led to "idealism", in the subjective sense, i.e. not in the "absolute" sense of Hegel or Schelling. Lenin's idealist is a "methodological solipsist", like the 18th century philosopher Bishop Berkeley, who thinks we can begin only with our experience and that we can never attain knowledge from a world beyond experience.[22] We assume Bohm is using the

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[14] Wood (2004), pp. 169–170.

[15] Meikle (1985), especially Chap. 7.

[16] Lenin (1962).

[17] Wilkins (1986), Vol VI.

[18] See Bakhurst (1991), Chap. 4, for a more sympathetic treatment.

[19] For a good introduction to Mach and positivism see Holton (1993), Chap. 1. It is well known that Mach influenced Einstein in his earlier period, see Holton (1993), Chap. 2.

[20] In the sense of Lenin and Bohm. It is now often called anti-realism. David Joravsky uses the term differently to mean limiting "knowledge to the methods and results of the empirical sciences". Joravsky (2009), p. xi.

[21] See the definition Bohm gives in his 1952 paper Bohm (1952b) and the definition in Bohm (1957), Chap. III, Sect. 8.

[22] See Bakhurst (1991), Chap. 4, for more detail. Bakhurst draws the "modest conclusion that there are reasonable, though perhaps not conclusive, grounds to associate Empiriocriticism [i.e. positivism in Bohm's sense] with the doctrines of Lenin's idealist" (ibid. p. 102).

term "idealist" in the same sense as Lenin, and that he sees it as the opposite of "materialism". On point (2), we note that the idea of "levels" does not explicitly appear in Lenin. Although Lenin always bases himself on Engels, giving extensive quotes, *Dialectics of Nature* was not available at that time. Lenin writes only that "[t]he electron is as inexhaustible as the atom, nature is infinite, but it infinitely exists."[23] As we shall see, Bohm expands this idea into the "qualitative infinity of levels."

To understand how Bohm developed his distinctive philosophical approach, one must start from the issues arising from standard "Copenhagen" quantum mechanics and his attempt to expound it in the book "Quantum Theory".[24] Let us review some key features of standard or "Copenhagen" quantum mechanics, developed by Niels Bohr, Werner Heisenberg, Wolfgang Pauli and others in the second half of the 1920s.[25] "Copenhagen" quantum mechanics assumes that quantum systems do not have definite properties until measurements are carried out, and that the theory can only predict the probabilities of the results obtained by these measurements. Previous physical theories using probability had assumed an underlying reality whose details, such as the positions and velocities of very large numbers of atoms in the theory of "ideal" gases developed by Maxwell and Boltzmann, were knowable in principle, if not in practice. However, in standard quantum mechanics, there is assumed to be no such underlying reality at the quantum level until measurements have been carried out.

Certain pairs of properties of quantum systems are called "complementary", such as a particle (which is associated with position) and a wave (which is associated with corresponding momentum or velocity). Unlike the properties of "classical", 19th century physics, according to Heisenberg's uncertainty relation, the more accurately position is measured, the less accurately the momentum can be measured and vice versa, and similarly with other complementary physical variables.[26]

The probabilities in quantum mechanics are given by the Schrodinger wave function that uniquely describes the state of the system.[27] Since there is no other information about the system, the theory is *essentially* random, or to paraphrase Einstein, "God *does* play dice." After measurement, the wave function somehow "collapses" to correspond to the value measured. There is ambiguity in forming the division (or "cut") between the non-classical quantum system and the classical measuring apparatus. Since the observer can be regarded as part of the measuring apparatus, it

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[23] Lenin (1962), p. 262.

[24] Bohm (1989).

[25] For a more detailed historical but non-mathematical treatment see Bohm (1957), Chap. III. For a good, more mathematical treatment see Baggott (1992). It should be said, however, that the outline given here must be qualified by the recognition that there was a lack of clarity and agreement among the founding fathers (Beller 1999).

[26] Other examples of such properties are energy and duration, as well as the "spin" of a quantum particle along different axes.

[27] Usually denoted by the Greek letter "psi", ψ, which is assumed to be a solution of Schrodinger's wave equation.

is possible for the measurement process to be interpreted as involving a conscious observer (and hence to support an idealist philosophy).

In practice, the emphasis in the standard approach was, and still is, on mathematical calculations and applications to experiments, in which outstanding successes could be reported, from the late 1920s onward.

In *Quantum Theory* Bohm attempted to develop a rational approach to this strange quantum world. Using the Schrodinger wave function, or usually a kind of concentrated piece of it, a "wave packet", he takes the student through a range of experiments and develops enough mathematics to analyse what is happening. As he writes in a letter to Miriam, "a qualitative "plausibility" argument is more valuable at an early stage in the text than a precise argument full of a forest of symbols."[28] He was basing himself on notes from Oppenheimer's lectures and was influenced by the approach, as he understood it at that time, of Niels Bohr.[29] The book was widely acclaimed for its conceptual treatment rather than the usual formal, mathematical exposition, and even the greatest critic of quantum mechanics, Einstein, thought that "It is the best that could be done with the usual interpretation."[30]

Bohm thus wanted to reveal what was happening in the "collapse of the wave function". He opposed positivistically inclined physicists who "say that after all, only the results of measurements need to be treated, and what happens to the apparatus when nobody looks at it is a "meaningless" question."[31] Opposing this "basically idealist" position, Bohm developed the theory of the measurement process.[32] It is obvious, then, that combating positivism and idealism were central to Bohm's approach.

One would have thought that this was a great achievement and that Bohm could now settle down to a career in teaching and researching theoretical physics. It did not work out to his satisfaction, however. Bohm had argued that there did indeed exist a quantum mechanical reality, whether measurements were being carried out on it or not. He suggested that causal determinism (or "complete" determinism as he called it) should be replaced by "statistical laws". To understand the "complementary" properties of this reality, he had used the idea of "potentialities"[33] But these did not allow him to confidently claim that here was a genuinely "dialectical" feature,

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[28](21, **65**, pp. 225–229). $\Delta x \Delta k \geq 1$ is mathematical shorthand for the Heisenberg relation. Further discussion on *Quantum Theory* is undertaken at (21, **66**, pp. 234–236) and (22, **67**, pp. 238–240). We will leave Bohm's very critical views on mathematics and the role of mathematicians in holding back theoretical physics to the next chapter.

[29]Later he considered it was Heisenberg's approach rather than Bohr's. Bohm and Hiley (1993), p. 18.

[30](21, **65**, p. 226).

[31](22, **67**, p. 239).

[32]Bohm (1989), Chap. 6, Sect. 2 and Chap. 22. In this latter chapter, he analyses the apparatus as well as the quantum system under investigation and concludes that "this problem can be solved without carrying the analysis as far as the stage in which the apparatus interacts with a human observer" (Bohm 1989, p. 606).

[33]See Bohm (1989), Chap. 8 and the reference in his letter to Hanna in early 1950 (14, **1**, pp. 99–100).

something that a Marxist could point to, as a verification of his or her philosophy in nature. As he explained it to Miriam, Bohr's approach had seemed incredibly vague, but it had offered something more, "(i)t seemed progressive because it broke the old mechanist materialist determinism, which left no room for growth and development of something new."[34]. But after all his years of toil, Bohm was unable to reveal genuine dialectics: "dialectically opposing concepts are made just vague enough so that the contradictions between them are avoided."[35] Instead of the synthesis of opposites that a Marxist view requires, "contradictions leading to something new at another level" were thereby lost.

With this disappointing outcome to the completion of his book in the summer of 1950,[36] Bohm spends the next year, or at least part of it, working on the causal interpretation, or the hidden variable interpretation, as he called it then.[37] He submits his papers based on this work to the Physical Review in July 1951.[38] Bohm had clearly decided by then that he could take the complementarity approach no further, and that only a causal determinist approach could place quantum mechanics on materialist foundations. What influenced him to make this turn? Olival Freire notes that Bohm later refers to at least two influences in his sudden shift to the causal interpretation: discussions with Einstein and the "reading of a paper by a Soviet physicist criticizing the complementarity view for its idealistic and subjectivist inclinations."[39]

The influence of Einstein is very clear. For example, in a letter in 1953, Bohm wrote: "In fact, you may remember that after writing a whole book on the usual interpretation of the quantum theory, I abandoned it when presented with arguments which convinced me."[40] As Freire points out, there is no evidence in the letters of a paper written by a Soviet physicist. We review the situation in Soviet physics and philosophy as well as Bohm's responses to it below in Chap. 12. However, since the attack on the idealist interpretation in standard quantum mechanics came from the highest levels in the USSR, which Loren Graham describes as "the most intense ideological campaign in the history of Soviet scholarship,",[41] to the extent that even the term "complementarity" was banned from 1948 to 1960,[42] it would be naive to believe that, given his politics, Bohm was not influenced by this in some way,

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[34](21, **66**, p. 235).

[35](21, **66**, p. 235).

[36]See the letter to Hanna (14, **10**, p. 110). Note that Bohm is hoping to work with Niels Bohr on a philosophy book!

[37]In (14, **11**, p. 112), he is "getting interested in the problem of the electron again", which may well relate to this.

[38]Bohm 1952a, b.

[39]Freire (2015), p. 27.

[40]Letter to Einstein, Feb 27, 1953 in Folder C12 in the Birkbeck archives.

[41]Graham (1971), p. 74.

[42]ibid, p. 80.

probably through Communist Party publications, whether he read material from a Soviet physicist or not.[43]

What Bohm views as the essential characteristics of his causal interpretation is explained in a letter to Melba, responding to Phil Morrison, a leading physicist and Communist Party member, who thought Bohm's philosophy was correct, but the standard theory was "simpler".[44] The probabilistic aspect of his theory, Bohm explains, is "a result of chaotic collisions with atoms, molecules, etc., undergoing random thermal motion", and so the "probabilities have the same origin as those of classical statistical mechanics", i.e. the result of an extremely large number of causally determined processes and not some unexplained, essentially random, process.[45] In Bohm's theory, quantum systems have both a wave function and a particle or particles. Therefore two atoms, for example, can have the same wave function but may not be identical, and there exist also particles which, though unobserved, can be at different positions. To emphasize his point, Bohm notes that in the apparently "simpler" standard theory, a uranium atom exploding tomorrow and another one exploding in two billion years have exactly the same wave function and so are indistinguishable. In contrast, in his causal interpretation, "the two uranium atoms are not "physically identical" because each of them has a particle in it in a position that will determine when it will disintegrate." So whilst admitting that this is not "simpler", in that it makes for an additional hypothesis, "namely that there exists an as yet unobserved particle", Bohm can clarify "things that were previously arbitrary".[46]

Bohm's new causal interpretation certainly seemed to deal with the positivism and idealism of the standard theory. But hadn't he also re-opened the door to that very "old mechanist materialist determinism" which he had once thought Niels Bohr had

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[43]See (26, **94**, p. 311): here Bohm states that a "vigorous criticism of the foundations of quantum mechanics is going on in the "East"". Loren Graham refers to a 1951 paper by the Russian physicist D.I. Blokhintsev, which was critical of the standard interpretation. It advocated his own, distinctive statistical ensemble approach, which is not at all similar to Bohm's. However, according to Graham, Blokhintsev dismisses the usual objections to "hidden variable" theories and acknowledges that such a "theory of quantum mechanics might at some future date permit a numerical description of the individual microparticle, although at the present time he considered such a description to be impossible." Graham (1966). It may be that an earlier version of Blokhintsev's work had reached the US and an English translation was obtained by Bohm.

[44](17, **37**, pp. 151–153).

[45]He clarifies this in a paper following up the original 1952 papers (Bohm (1953)), referred to in mathematical notation by $P \to |\psi|^2$ and discussed in a number of letters (23, **74**, p. 257), (23, **78**, pp. 264–265), (24, **83**, p. 277), (25, **88**, p. 293), (26, **93**, p. 308), (26, **94**, p. 312), (17, **37**, p. 151) and (17, **38**, pp. 154–155). Another version, with input from Vigier, was published in Bohm and Vigier (1954).

[46]Note that in explaining his theory to Morrison, Bohm only uses the wave function and not the "quantum potential" concept derived from it, which features in the 1952 papers. He only discusses the "quantum potential" aspect of his theory in the letters once, in (25, **90**, p. 298), explaining how hypotheses are put forward. In Bohm (1957), Chap. 4, Sect. 4 he considers a general "quantum force" rather than a quantum potential, the nature of which, it is presumably hoped, will be clarified in the relativistic generalizations of the theory. See also Hiley and Peat (1987), p. 37, where Bohm explains that the instantaneous "entanglement" of distant particles was seen to contradict relativity and was regarded as a "serious difficulty to be resolved with the aid of further new orders.".

successfully dealt with, in other words, was this not a reiteration of the problem of a mechanist ontology referred to above? Had his introduction of causal laws brought in the "nightmare of a mechanically determined universe that follows an inevitable course"[47]? It is to counter this threat that Bohm developed his own distinctive philosophy of an infinite number of levels.[48] With such qualitatively distinct levels "we can have complete causality at every level, in the sense that we can use this causality to change the world in a predictable way, with the error in the predictions dependent only on our level of knowledge;" but with the addition that "we can in no sense conceive of the world as completely determined".[49] In the early 1952 period we find a number of letters to Miriam setting out Bohm's infinite levels philosophy in relation to physics[50]; note also the letter to Hanna on this issue.[51] The reader may also find Hans Freistadt's 1956 paper of use here.[52] Freistadt was a Marxist physicist who lost his job in the McCarthy witch-hunt. He was supportive of Bohm's views, and was apparently in contact with Bohm via Melba Phillips.[53] Note that Freistadt has a reference to the 1951 paper, in Russian, by the Soviet physicist Blokhintsev, already referred to above.

In these letters, Bohm wants to explain the concept of matter and some aspects of dialectics, from his infinity of levels standpoint. He proposes that "in some aspects at least, matter is indestructible and uncreatable" and "matter as a whole in its infinity of properties and potentialities is eternal". This would seem to make change and transiency impossible. But with the levels approach:

> The things at each level, are made up of smaller elements at a more fundamental level, and it is the motion of these more fundamental elements (not usually directly visible to us, except with the aid of elaborate scientific research) which causes the appearance and disappearance of the things existing at a higher level.[54]

By considering his work on plasma physics, Bohm points to examples where the behaviour of an "individual" at one level is "collectively conditioned" by a higher level. Thus:

> The universe cannot be analyzed into a series of components, each of which are the constituents of the next higher level, and each of which determine the higher levels in a purely analytic way. For the higher levels will also always help determine the character of things that may exist at the lower levels. Thus, every level is in a sense, just as real as every other, since the "whole picture" cannot be deduced by starting at the "lowest level" and working upward.[55]

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[47](22, **73**, p. 254).

[48]In a November 1951 letter to Miriam, (20, **58**, p. 205), it is clear that Bohm expects Miriam to know about his infinity of levels approach, so presumably he first developed the idea at Princeton.

[49](22, **73**, p. 255).

[50](21, **65**, pp. 227–229), (22, **68**, pp. 245–246) and (22, **73**, pp. 254–255).

[51](15, **20**, pp. 123–124).

[52]Freistadt (1956).

[53]See the distribution list in (19, **52**, p. 180).

[54](21, **65**, p. 227).

[55](22, **68**, p. 246).

in Microscopic Physics".[70] That did not happen, and Bohm admits in 1957 that his approach had also often been criticised as too mechanical. But it still, he argues, "may be a good starting-point from which qualitatively new developments are likely to arise."[71]

Bohm also gives a brief indication of how to go beyond mechanism in a philosophical sense, and this is the subject of his last chapter in *Causality and Chance*. It is partly, of course, by means of the "qualitative infinity of levels". But he also wants to extend the type of change that matter can undergo, moving beyond the more limited "efficient" causality of mechanism:

> But more general types of change are possible. Thus, we may have qualitative change, as in evolution or in embryology. The appropriate causal laws then govern the qualitative changes, and tell which things will change into what and under which conditions.[72]

This broader usage is developed in *Causality and Chance* and is an essential part of Bohm's attempt to move beyond mechanism in physics. Of course, it is always permissible to extend a definition. But in order to avoid confusion, it is important to note that "causality", used in this broader sense by Bohm, refers not to "efficient" cause but to the "teleogical" change in the "organicist" ontology of classical Marxism, as referred to above.[73]

There is clearly a problem facing Bohm that refers to the key area of natural science, biology, to which, as we pointed out at the beginning of this chapter, such an organicist ontology is highly relevant. Although criticizing Lysenko's methods, as late as March 1955 Bohm thinks he was basically correct against geneticists.[74] Bohm's reference to evolution and embryology in these letters to Melba is, therefore, only a passing one. Perhaps because of his isolation in Brazil, he was unable to grasp Lysenkoism's fraudulent character, or to make any reassessment of Darwinian evolution from a Marxist standpoint at this stage, although, by the early 1950s, many Communist Party members and supporters were becoming aware of the complete disaster in Soviet genetics.[75] By the time he writes *Causality and Chance*, Bohm appears to have given Darwinian evolution more thought.[76]

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[70]The title of Bohm (1957), Chap. 4, Sect. 7. Lenin (1962), Chap. 5, Sect. 1, is entitled the "Crisis in Modern Physics", following the lead of Henri Poincaré.

[71]Bohm (1957), Chap. 4, Sect. 9.

[72](18, **46**, p. 171).

[73]In *Causality and Chance*, Bohm refers to causal laws related to the "mode of being" of things, in Chaps. 1 and 6, and the "Process of Becoming" in Chaps. 5 and 8.

[74]In (19, **50**, pp. 178–179) he writes of "the extremes to which Lysenko went in criticizing backward trends in biology". Previously, in March 1953 (26, **97**, p. 320), he wrote of "Lysenko's excessively dogmatic presentation of his basically correct point of view".

[75]See Brown (2012) for details of and on the response of the famous Communist physicist J.D. Bernal. Although Bernal wrote an appalling eulogy to Stalin after his death in 1953, he did recognize the importance of the discovery of DNA in the same year.

[76]See the references to the theory of evolution and "natural selection" in Chaps. 1 and 6, and the "well-known evolution of the species" in Chaps. 5 and 8, where Bohm also considers evolutionary processes in geology, astronomy and cosmology.

This chapter has concentrated on the relatively small number of letters relating to the philosophy of physics and to the development of the ideas in *Causality and Chance*. An examination of Bohm's numerous letters concerning probability and the relation between causal and statistical laws is left to Chap. 9. However, we should also note that the philosophical concepts that Bohm uses in his physics, and that can be explained fairly precisely as we attempted above, are employed by Bohm in a much looser sense and quite extensively throughout these letters, when referring to social and political issues, issues relating to science and society, and so on.

A few examples will illustrate Bohm's type of socio-political analysis. Firstly, an example on positivism, where Bohm is concerned, not with the application of philosophy to quantum mechanics, but with what he sees as a problem with physicists:

> The flexibility of positivism is amazing, for among [experimental] physicists in [the] U.S., there is a belief that physics flows solely from empirically observed data, or "operations", which is also combined with a belief that theorists take these numbers, and with the aid of a few geniuses like Dirac, produce equations that fit these numbers.[77]

For Bohm, positivism is not just confined to scientists, but is a philosophical problem of society in general, with a related view of "relativism":

> Thus, a characteristic attitude of people toward life is a cynical one, "relativistic", in the sense that morals and responsibilities are said to be determined only by the prevailing society. If one happens to be in a Nazi society, then one naturally adopts Nazi morals, etc. In America, one adopts the prevailing "American Way of Life".[78] This is the counter-part of positivism, for it says that there is no objective material basis for morals, but that all is determined by a commonly agreed upon convention, which introduces "order" into the system of behaviour.[79]

Secondly, Bohm sees mechanism or mechanical materialism as dominating current social thought:

> It was in dealing with nature that man was forced to produce his first objective and clearly thought out concepts, and in this way developed a form of thinking that we hope can now be applied to human beings and to society. But the experience gained in this pursuit up to now has largely been seen in terms of the distorted idea that "things are what they are, and nothing more". Mechanical materialism is a form of this idea.[80]

Such scattered and quite numerous philosophical remarks relating to society are usually made in a pejorative sense. The "infinity of levels" idea, however, is used by Bohm in a more optimistic sense:

> But in this regard, human nature is no different from Nature in general; for according to the ∞ of levels, all properties can be altered with sufficient changes in conditions. Thus, the ∞ of levels is an integral part of a better view of Nature in general, and of human nature in particular.[81]

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[77](17, **35**, p. 148).

[78]Bohm has a profound hatred of the "American Way of Life", to which he repeatedly refers.

[79](20, **59**, pp. 206–207).

[80](21, **66**, p. 233) See also (32, **123**, pp. 430–431).

[81](27, **101**, pp. 332–333).

One could argue that these social or political aspects of Bohm's philosophical thought, as shown in these few examples – there are many more – are not separate from his thoughts on physics, and also can be seen to provide a motivation for his scientific work. I have taken the view that there are, in fact, differences between social criticism and philosophy of physics, and that Bohm's profound knowledge of physics does give more validity to his scientific philosophy. It can also be placed firmly in the Marxist tradition that was largely suppressed by Stalin. I have, therefore, only briefly considered his far less well-defined social philosophy in Chap. 11, in the context of looking at his politics as a whole.

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of mathematics to physical theory. Following Engels,[4] Bohm considers all concepts and scientific laws to be "abstract". In the Marxist tradition, to say that something is abstract means that it is taken out of context, in other words, that it has been abstracted.[5] Concepts and laws are abstract because they can only give an approximation to the truth, as there are always processes and levels in reality that are not taken into account. Bohm wants to employ abstractions in order to give a theory that is sufficiently close to reality and likely to represent what is essential in the problem under consideration.

The problem with mathematicians, in Bohm's opinion, is that they tend to utilise abstractions that are too far removed from physical reality. This is because their propensity will always be to choose that mathematics which offers a tractable solution. Thus, in a letter to Miriam on mathematics he writes: "Of course, there are certain advantages in abstracting the problem in the way you mathematicians do, but in this case [statistical mechanics] I have hopes that the treatment of something approaching a real physical problem may suggest new ideas that will even be useful in the more abstract problems thus far treated in mathematics."[6]

Bohm expects the inter-connections in the world to be rationally understandable, but clearly also recognizes that this can lead to difficult problems. Skill is always involved in choosing between moving closer to reality, in order to bring out the more complex interconnections in the world, and taking a more abstract approach that is simpler to deal with.[7] Too much abstraction, however, can obscure the real problem. Mathematicians tend to have lost this skill and to be lazy, opting for those abstractions that can be given a simple solution, rather than "breaking their heads on real problems that might lead to new concepts and new modes of inter-connection of these concepts".[8]

The point about choosing the abstractions in order to give solutions is further expanded upon in Bohm's critique of von Neumann's work in relation to quantum mechanics. It is quite dangerous to use a number of abstract postulates in physics, and then to deduce "a great many things in an impressively ironclad way, including for example, that no causal interpretation of quantum theory can possibly lead to all of the results given by the usual probability interpretation".[9] It is not possible to check that the postulates are correct, and, even worse, nobody is clear (even von Neumann himself) "just what is being assumed." Bohm is clearly angry at the way mathematical virtuosity, towards which he admits feeling some jealousy, has held back conceptual clarification of the subject matter, perhaps by as much as 20 years. Hard, clear mathematical thinking is needed, but the postulates must be "clearly defined and well established". In relation to physics, it is possible that "with the aid

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[4] Part I of Anti Dühring, Marx and Engels (1988).

[5] See Bohm (1957), p. 2.

[6] (21, **64**, p. 223).

[7] In Chap. 9, we will see Bohm attempting to follow this approach in developing a model for "chaos".

[8] (21, **64**, p. 223).

[9] (22, **67**, pp. 237–239).