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**Dialectical Materialism and the Construction  
of a New Quantum Theory: David Joseph Bohm,  
1917–1992**

# Dialectical Materialism and the Construction of a New Quantum Theory: David Joseph Bohm, 1917-1992

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In 1951, David Bohm created a realistic interpretation of quantum theory. His theory stood in contradiction to the hegemonic standard interpretation of quantum mechanics, in which the quantum mechanical wave function describes a purely mathematical probability amplitude. Bohm's worldview, based on dialectical materialism, contributed substantially to the construction of new physical entities in his theory and led him to work intensively on the philosophy of science. His example shows that the ideology and political attitude of a physicist can play a major role in the construction of scientific theories and entities, with the important reservation that a change in social context was the necessary impulse for Bohm's work.

## Introduction

This paper wants to touch on some general questions of theory construction in physics, by presenting a biographical case study of David Bohm through the perspective of Fleckian thought-collectives and their thought-style.<sup>2</sup> In the 1920s a small elite of physicists established the Copenhagen Interpretation of quantum mechanics as a new thought-style in the thought-collective of the physicists. In the following decade the Copenhagen Interpretation was transferred from Europe to the USA, from one thought-collective into another, and was integrated into a specific American thought-style. David Bohm was initiated in this mode of thought during his undergraduate studies at the Pennsylvania State College and his graduate studies at Caltech and the University of California at Berkeley.

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<sup>2</sup> Ludwik Fleck, *Genesis and Development of a Scientific Fact* (Chicago: Chicago University Press, 1979, translation from the first edition of 1935). Fleck showed by the example of the Wassermann reaction in medicine that knowledge belongs to social groups, which he called thought-collectives. Each thought-collective has its specific thought-style and constrains the thought of its members. A scientist, for example, can be a member of several thought-collectives: a scientific, a political or even a religious one. Each collective has its own thought-style. Knowledge is transferred from personal knowledge (presented in journal papers) by an individual author into impersonal Handbuch-science which is conform with the collective's thought-style. An easy transfer from personal knowledge to Handbuch-science is possible only as long as the personal knowledge does not depart too far from the thought-style of the collective. Otherwise it is ignored by the collective.

Within the framework of the Manhattan Project, he contributed to war research at the Berkeley Radiation Laboratory. A concocted spy case in the Radiation Laboratory during the Manhattan Project was reopened in the McCarthy era. At this time Bohm was already a professor in Princeton and well established in his collective. In the aftermath of a hearing before the Committee on Un-American Activities, Bohm was dismissed from Princeton University. After the loss of his professorship and several discussions with Einstein, Bohm started to work on his interpretation of quantum mechanics and finally diverged from the thought-style of the collective which had repudiated him. During his exile in Brazil, Bohm justified his new quantum theory from the perspective of dialectical materialism. In the isolation from the US-community, a philosophical thought-style took hold of him. This style differed essentially from that of his former collective.<sup>3</sup>

Bohm denied the standard interpretation, in particular the reduction of the wave function in the measuring process, as befitting an idealistic theory. During the measurement, the quantum-mechanical wave function  $\psi$  reduces to an eigen-function of the system. Before the observation only a probability statement about the system can be made. A particle only has an impulse when the impulse is actually measured. The same applies to other quantities, like energy and position of the particle. In Bohm's view, the observer's consciousness is the determining and decisive factor in the standard interpretation, not the properties of matter. In this way Bohm understood it as idealistic. In Bohm's interpretation, however, the particle possesses at all times a well-defined position and momentum regardless of observation or associating ideas. So, in Bohm's view, matter came before mind in his theory. Thus he called his interpretation a materialistic one.<sup>4</sup> With this materialist interpretation, Bohm wanted to expel mysticism from physics. He also believed that scientific theories change in the long run people's thinking about society.<sup>5</sup>

## Education, Career and Un-American Activities

David Bohm studied physics at the Pennsylvania State College, at Caltech and at the University California in Berkeley. At the latter J. Robert Oppenheimer had established a distinguished school of theoretical physics. The excellent reputation of physics at Berkeley

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<sup>3</sup> For a biography see F. David Peat, *Infinite Potential: The Life and Times of David Bohm* (Reading, MA: Addison-Wesley, 1997); Russel Olwell, 'Physical Isolation and Marginalization in Physics. David Bohm's Cold War Exile', *ISIS* 90(1999):738-758 focuses on Bohm and Cold War, Alexei Kojevnikov, 'David Bohm and Collective Movement', *Historical Studies in the Physical and Biological Sciences*, 33 (2002): 161-192 analyses the connection between Bohm's world view and his research on plasma physics.

<sup>4</sup> Letter from David Bohm to Miriam Yevick, 28 Januar 1952, David Bohm Papers, uncatalogued.

<sup>5</sup> Letter from David Bohm to Miriam Yevick, 20 November [1951], David Bohm Papers, uncatalogued.

was also based on the close collaboration of the theorists with the Radiation Laboratory of Ernest O. Lawrence.<sup>6</sup>

Not only in physics did Berkeley play a prominent role. In the 1930s and 40s, it developed into a center of leftwing politics. There were talks of representatives of the Socialist Party and the Communist Party and numerous activities of the regional trade unions that worked closely together with the student organizations. The actions and discussions were dominated by the Spanish civil war and its aftermath. Money was collected on numerous rallies for the benefit of the refugees who had to leave Spain after Franco's victory. Another central topic was the spread of fascism in Europe and the German aggressions. These discussions, rallies and political actions formed a local leftwing political culture.<sup>7</sup> Bohm's political attitudes fit in this local hegemony of the left. His anti-fascist position was central, as he felt that the Nazis were a total threat to civilization. The Spanish civil war, the Appeasement policy and the Munich agreement encouraged Bohm in the belief that the Soviet Union was, in the end, the only force willing to counter the Nazis. Bohm's philosophical and political views were rather vague during his earlier years, but they were rendered more precise on the basis of dialectical materialism in Berkeley. He joined a discussion group with a number of other students. These discussions led him to a systematic examination of the philosophical basis of Marxism, but he was completely disinterested in political actions on the campus.<sup>8</sup>

In autumn, 1941 Bohm took up his research project in Berkeley. Oppenheimer suggested to him the investigation of scattering problems of protons and deuterium. In 1943 Oppenheimer certified that Bohm had done the necessary research and Bohm received his PhD.<sup>9</sup> During the Second World War he worked in a sub-project of the Manhattan Project in Berkeley. In the Radiation Laboratory he investigated the electromagnetic separation of uranium plasma.<sup>10</sup> At the same time he had been involved in a leftwing trade union, the Federation of Architects, Engineers, Chemists and Technicians and for a short time in the

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<sup>6</sup> Peter Goodchild, *J. Robert Oppenheimer. Shatterer of Worlds*. (New York: Fromm, 1985). John L. Heilbron and Robert W. Seidel, *Lawrence and his Laboratory: A History of the Lawrence Berkeley Laboratory* (Berkeley: University of California Press, 1989).

<sup>7</sup> Interview with Giovanni R. Lomanitz, conducted by Shawn Mullet, 26/27 July 2001, American Institute of Physics, Center for History of Physics, College Park, MD, USA, 16-7, 24. Ellen W. Schrecker, *No Ivory Tower: McCartyism and the Universities* (New York, Oxford: Oxford University Press, 1986), 24-62, Gregg Herken, *Brotherhood of the Bomb: The Tangled Lives and Loyalties of Robert Oppenheimer, Ernest Lawrence, and Edward Teller* (New York: Owl Books, 2003), 28-32.

<sup>8</sup> Interview with David Bohm conducted by Martin Sherwin, 15 June 1979, David Bohm Papers, Birkbeck College, London, UK, Folder A.116; Interview with David Bohm, conducted by Maurice Wilkins, 1986, American Institute of Physics, Center for History of Physics, College Park, MD, USA, 198-226.

<sup>9</sup> Interview Bohm-Wilkins, 257-8.

<sup>10</sup> A. Guthrie and R.K. Wakerling (eds.), *The Characteristics of Electrical Discharges in Magnetic Fields* (New York: McGraw-Hill, 1949).

Communist Party. Bohm asked several times for a transfer to Los Alamos, but his requests were denied, as he seemed to be a security risk in the eyes of the military because of his political engagement.<sup>11</sup>

In the post-war period Bohm remained two additional years at Berkeley, until he received a job as Assistant Professor at Princeton University in February 1947. After the first evaluation, his contract was renewed up to the 30th June 1951. By this time Bohm was well integrated into the thought collective of US physicists. He was one of the about 30 participants of the Shelter Island conference in 1947. The Shelter Island conference was of central importance for the development of post-war physics in the USA. During that conference the main future research directions were fixed: Quantum electrodynamics and particle physics.<sup>12</sup> Bohm published on QED and on superconductivity.<sup>13</sup> However, his research focused mainly on electron theory in metals on the basis of the plasma-theoretical work, which goes back to his war research in the Berkeley Radiation Laboratory.<sup>14</sup> Everything seemed to go well for Bohm, until he was charged before the Committee on Un-American Activities in May and June 1949. The object of the hearing was a supposed spy case in the Berkeley Radiation Laboratory during the war. There were no new proofs of spying; rather the old files of the Military Intelligence Division of the Manhattan Project were dragged in again. In the end, a former colleague of Bohm was identified as the putative spy. Bohm refused to testify at both sessions of the hearing before the Committee and appealed to the Fifth Amendment concerning self-incrimination.<sup>15</sup> On the 4th December 1950, 1 1/2 years after the hearing, Bohm was indicted for contempt of congress because of his refusal to testify. After that Princeton University suspended Bohm from all duties and forbade him to enter the university campus. When Bohm was later acquitted on the 3rd June 1951, the suspension was revoked three days afterwards. There was no need for the official dismissal of Bohm: His contract ended three weeks later and the university simply did not renew it. Officially, professional reasons were cited. However, from the correspondence of the president of the Princeton University, the impression arises that it was clearly a political decision. From that point on Bohm was blacklisted and it was impossible for him to get a job in the academic sector of the US. With the help of a former

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<sup>11</sup> United States Atomic Energy Commission, *In the Matter J. Robert Oppenheimer. Transcript of the Hearing before Personnel Security Board and Text of Principal Documents and Letters*, Washington D.C. April 12, 1954, through June 29, 1954 (Reprint Cambridge: M.I.T. Press, 1971), 149-50.

<sup>12</sup> Silvan S. Schweber, *QED and the Man who Made it: Dyson, Feynman, Schwinger, and Tomonaga* (Princeton: Princeton University Press, 1994), 156-205.

<sup>13</sup> David Bohm, 'Note on a Theorem of Bloch Concerning Possible Causes of Superconductivity', *Physical Review* 75 (1949): 502-4; David Bohm and M. Weinstein, 'The Self-Oscillations of a Charged Particle', *Physical Review* 74 (1948): 1789-98.

<sup>14</sup> Alexei Kojevnikov, 'David Bohm and the Collective Movement', *Historical Studies in the Physical and Biological Sciences* 33(2002), S. 161-192.

<sup>15</sup> Hearings Regarding Communist Infiltration of Radiation Laboratory and Atomic Bomb Project at the University of California, Berkeley, Calif.—Vol. I. Hearings before the Committee on Un-American Activities, House of Representatives, Eighty-First Congress (Washington 1949), 319-27, 347-53.

student, and on the recommendation of Einstein and Oppenheimer, he received a professorship at the University of São Paulo in Brazil. After his arrival in Brazil Bohm's passport was retained by the American consulate. For this reason it was impossible for Bohm to travel, e.g. for taking part in international conferences, and he got more and more isolated from the community in the US. <sup>16</sup>

## An Un-American Textbook

Bohm described the time during his suspension as a period in which he could freely follow his research interests without any social constraints:

‘Now, what happened was that, not being able to go to the university, I had to work at home. I felt in some way it liberated me. I was able to think more easily and more freely, you know, without having to talk in the language of other people.’<sup>17</sup>

Feeling free from that pressure Bohm started to work on his interpretation of quantum theory with hidden variables. But before he took up his investigations on the interpretation of quantum mechanics, he completed his textbook *Quantum Theory*<sup>18</sup>, which appeared in 1951. The book originated from the quantum theory lectures, which Bohm had held in Princeton in the years 1947 and 1948. According to Bohm it seems that the central equation of quantum mechanics, the Schrödinger equation, appears from nowhere and it needs a great genius to invent it. To avoid such an impression, Bohm expounded in the first 150 pages of his book the experiments, which made the transition from the classical theory to the quantum theory necessary. In this way, he led the reader to the Schrödinger-equation. This is really atypical for an American textbook of that time, as is Bohm's detailed discussion of the wave-particle-dualism. There is no other American textbook, which discusses this topic at such length. Either quantum mechanics was founded axiomatically<sup>19</sup> or operationalistically, often with reference to Percy Brigrman's *The Logic of Modern Physics*.<sup>20</sup> Therefore Bohm's textbook is no typical ‘American’ textbook at all.

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<sup>16</sup> Russel Olwell, ‘Physical Isolation and Marginalization in Physics. David Bohm's Cold War Exile’, *ISIS* 90(1999): 742-51.

<sup>17</sup> Interview with David Bohm conducted by Lilian Hoddeson, 8 May 1981, American Institute of Physics. Center for History of Physics. Niels Bohr Library. One Physics Ellipse, College Park, MD 20740, USA, 11.

<sup>18</sup> David Bohm, *Quantum Theory* (New York: Prentice Hall, 1951).

<sup>19</sup> Pauling, Linus and E. Bright Wilson, *Introduction to Quantum Mechanics: With Applications to Chemistry* (New York: McGraw-Hill, 1935).

<sup>20</sup> E.g. Arthur E. Ruark und Harold C. Urey, *Atoms, Molecules and Quanta* (New York: McGraw-Hill, 1930); Edwin C. Kemble, *The Fundamental Principles of Quantum Mechanics with Elementary Applications* (New York: McGraw-Hill, 1937).

With his textbook he had already moved slightly away from the operationalistic thought-style of the American physicists.<sup>21</sup> At the same time Bohm wanted to put quantum mechanics on a firm material basis. It was not the mind of a genius, which made quantum mechanics necessary, but, as Bohm saw it, the properties of matter at an atomic level.<sup>22</sup>

Bohm also interpreted the indeterminism of quantum mechanics as a fundamental property of matter. In contrast to the representatives of the Copenhagen interpretation, who saw indeterminism as consequence of a restriction of our knowledge of the incompatible properties of systems, Bohm construed it independent from observation as a fundamental property of matter.<sup>23</sup>

Bohm believed he was presenting Bohr's point of view in his book. Some resemblances can be seen. Like Bohr, Bohm spoke of the unpredictable transfer of single quanta and the indivisibility of the quantum processes.<sup>24</sup> Nevertheless there are some deviations.

According to Bohr, the need to use classical concepts or, more exactly, a classical language to describe the quantum phenomena is the cause of complementarity. Unlike Bohr, Bohm did not insist on the impossibility of a new quantum language and called for the creation of new concepts.<sup>25</sup>

Bohm saw in the wave-particle-dualism the dialectic unity of opposing properties inspired by Friedrich Engel's philosophical writings on dialectical materialism. Which of the opposing properties of an electron is realized, depends on the interaction with the environment:

'The most important new concept to which we are led is that any given piece of matter (for instance, an electron) is not completely identical with either a particle or a wave, but that, instead, it is something potentially capable of developing either one of these aspects of its behaviour at the expense of the other. Which of the electron's opposing potentialities will actually be realized in a given case depends as much on the nature of the systems with which the electron interacts as on the electron itself. Because the electron interacts continually with many different kinds of systems, each of which develops different potentialities, the electron will undergo continual transformations between its different possible forms of behaviour (i.e., wave or particle).' <sup>26</sup>

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<sup>21</sup> Silvan S. Schweber, Silvan S., 'The Empiricist Temper Regnant. Theoretical Physics in the United States 1920–1950', *Historical Studies in the Physical and Biological Sciences* 17 (1986), S. 55–98.

<sup>22</sup> Letter from David Bohm to Miriam Yevick, 7 January 1952, David Bohm Papers, uncatalogued.

<sup>23</sup> David Bohm, *Quantum Theory*, (New York: Prentice Hall, 1951), 100.

<sup>24</sup> *Ibid.*, 114.

<sup>25</sup> *Ibid.*, 165; Mara Beller, *Quantum Dialogue: The Making of a Revolution* (Chicago: Chicago University Press, 1999), 208.

<sup>26</sup> David Bohm, *Quantum Theory*, (New York: Prentice Hall, 1951), 138-40.

Bohm's book *Quantum Theory* remained within the scope of the standard interpretation, including a denial of hidden variable theories. However, in the text passages where the physical interpretations became central, Bohm started to turn away from the standard quantum mechanics and formulated own positions. Bohm's worldview, based on dialectical materialism, became apparent only in few text passages; it was not dominant at all.

## A New Interpretation of Quantum Mechanics

After Bohm had finished his book, he started to work on his new interpretation of quantum theory. In 1952 he proposed in the *Physical Review* a realistic interpretation of quantum mechanics.<sup>27</sup> This happened 25 years after the successful establishment of the Copenhagen interpretation of quantum mechanics developed by Niels Bohr, Werner Heisenberg and Max Born. In their theory the quantum-mechanical wave function  $\psi$  is a purely mathematical quantity: It describes a probability amplitude, which only allows predicting the probability of a measurement outcome. In David Bohm's interpretation, the wave function gets a real physical meaning. It becomes a kind of pilot wave, which guides the particle on a trajectory that is fixed deterministically with given initial conditions. That is: if one knows the position and momentum of a particle at a certain time, one can predict the particle movement for all future times. Statistical statements are necessary only because of the observer's lack of knowledge and are no fundamental part of the theory.

What motivated Bohm to his new interpretation, which differs fundamentally from the standard interpretation? The simplest explanation would be the rediscovery of a historical precursor. However, this fails. Bohm knew neither the work of Erwin Madelung or Louis de Broglie from the 1920s nor from Nathan Rosen from 1945. It was Wolfgang Pauli who drew Bohm's attention to them after he received a preprint of Bohm's paper. From Bohm's correspondence it is also evident that the work of the Soviet physicists Yakov Terletsky and Dmitri Blokhinzhev were unknown to him at that time.<sup>28</sup>

At the end of the article, Bohm thanked Einstein for numerous discussions and put himself in the line with one of the most famous critics of the Copenhagen Interpretation. Einstein got in contact with Bohm in Princeton, after Bohm had sent to him his book *Quantum Theory*. From then on, the two remained in regular correspondence until Einstein's death. We do not know much about the discussions between the two. All we know derives from

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<sup>27</sup> David Bohm, 'A suggested interpretation of quantum theory in terms of 'hidden variables'. Part I and II', *Physical Review* 85 (1952): 166-179, 180-193.

<sup>28</sup> Letter from David Bohm to Miriam Yevick, 7 January 1952, David Bohm Papers, uncatalogued. David Bohm, 'A suggested interpretation of quantum theory in terms of 'hidden variables'. Part I', *Physical Review* 85 (1952): 167.

later interviews with Bohm. The correspondence of Bohm with Einstein is preserved only from 1951 onwards after the paper was submitted for publication and barely admits inference on the preceding discussions. In later interviews Bohm reported that it was Einstein who aroused his doubts on the completeness of quantum mechanics.<sup>29</sup>

The recollections of Murray Gell-Mann support the thesis of Einstein as a seminal influence for the new theory. In his book *The Quark and the Jaguar* he reports about David Bohm, whom he had got to know in Princeton. In numerous walks they discussed quantum mechanics and its interpretation. Gell-Mann remembers, that Bohm had attempted to bring the theory in harmony with his worldview and for this reasons had written his book on quantum theory. Only after the discussions with Einstein, he said to Gell-Mann: ‘He [Einstein] talked me out of it. I’m back where I was before I wrote the book.’<sup>30</sup>

Thus we can interpret the discussions between Bohm and Einstein as crucial flash point for Bohm’s way towards his new interpretation. However, Bohm had to dissociate himself first from the thought-style of the collective, otherwise discussions with Einstein might not have been decisive. The process of moving away from his thought-collective can be seen in his book *Quantum Theory* and intensified rapidly with Bohm’s suspension from Princeton.

In Bohm’s hidden variables paper we can see that he had not separated completely from his thought-collective. The frequent use of the *pluralis modestiae* in his article makes clear that he still appeals to the collective for recognition. Another linguistic sign for the incomplete separation is the use of the words like ‘unpredictable’ and ‘uncontrollable’ in his analysis of the measuring process, which belong to standard quantum mechanics. The 1952 paper shows many other tokens of Fleck’s journal science. The preliminary character of the paper is obvious in the title, ‘a suggested interpretation’, and becomes clear in the numerous quotation marks when Bohm introduced new concepts as well as in Bohm’s hope for a violation of standard quantum mechanics in experiments at the level of particle physics.<sup>31</sup>

After Bohm had submitted the article to the Physical Review he started to reconsider his theory on the basis of the dialectical materialism. Bohm considered philosophy as a guideline for his physical research. To him, philosophy served the better as a heuristic for science the better it represented reality. To him dialectical materialism accomplished this best of all.<sup>32</sup>

This strong linkage of physics, worldview and society becomes clear in Bohm’s concept of causality. This concept contained two aspects. On the one hand, a prediction of the effects

<sup>29</sup> Interview Bohm-Wilkins, 348-51, Interview Bohm-Hoddeson, 13-4.

<sup>30</sup> Murray Gell-Mann, *The Quark and the Jaguar. Adventures in the Simple and the Complex* (London: Abacus, 1995), 170.

<sup>31</sup> David Bohm, ‘A suggested interpretation of quantum theory in terms of ‘hidden variables’. Part I and II’, *Physical Review* 85 (1952): 166-179, 180-193.

<sup>32</sup> Letter from David Bohm to Melba Philips, undated [spring/summer 1954], David Bohm Papers, Folder C.47.

is possible if one knows the causes. On the other hand, a change of the causes leads to a predictable change of the effects. If the people were able recognize the causes for social mismanagement, then they could also change society. In Bohm's view, the possibility of change was essentially different from a simple determinism, which allows just only predictions but no change.<sup>33</sup>

## Dialectical Materialism and Physics in Brazil

In Brazil, Bohm continued working on his concept of causality. This work resulted in his book *Causality and Chance in Modern Physics*.<sup>34</sup> In this book we can recognize numerous partly literal correspondences to Friedrich Engel's *Dialectics of Nature*, which Bohm had read during his graduate studies and which he used for learning Portuguese in Brazil.<sup>35</sup>

The central topic in Bohm's book is the relationship of causality and chance in the physical laws. If we observe nature, we ascertain constant relations, we consider these constant relations as necessary and in the next step we denote these necessary relations as causal laws. This definition of causal laws is completely analogous to that of Engel's *Dialectics of Nature*. Bohm regarded causal laws as the dialectic contradiction to chance. For example, a falling sheet of paper can be raised again by a sudden gust of wind. Necessity and chance are two categories, which exclude each other, but, indeed, both are necessary to get to an adequate description of the object.<sup>36</sup>

According to Bohm, the causal laws lead to different levels of approximation to reality. Each of these levels is determined by different causal factors and possesses a relative autonomy of qualities, entities and relations, which are characteristic for each level. The transitions between these levels occur in the form of a dialectic jumps. Gradual quantitative changes lead to qualitative jumps. These jumps contradicted in Bohm's and Engel's view pure mechanism, that admits only quantitative changes. Bohm set against the rigid basic qualities and purely quantitative laws of mechanism an infinite number of properties, qualities, systems and levels. Each single level is determined causally. By the acceptance of qualitative jumps between these levels and the central concept of the infinity of nature Bohm was able to avoid a simple deterministic conception. We can find the notion of the infinity of nature also in numerous passages in the so-called classics of

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<sup>33</sup> Letter from David Bohm to Miriam Yevick, received 31 March [1952], David Bohm Papers, uncatalogued.

<sup>34</sup> David Bohm, *Causality and Chance in Modern Physics* (London: Routledge, 1984 [1957])

<sup>35</sup> Telephone interview of Joseph Weinberg conducted by F. David Peat, see F. David Peat, *Infinite Potential: The Life and Times of David Bohm* (Reading, MA: Addison-Wesley, 1997), 59; Letter from David Bohm to Miriam Yevick, 20 November [1951], David Bohm Papers, uncatalogued.

<sup>36</sup> Bohm, *Causality and Chance*, 1-3; Friedrich Engels, 'Dialektik der Natur', in *Marx Engels Werke*, Vol. 20 (Berlin: Dietz Verlag, 1965), 497, 486-7.

Marxism-Leninism. Thus Lenin spoke of the infinity of the electron, Mao Tse-Tung of the infinite variety of the matters of nature. Also in Engel's writings similar passages can be found.<sup>37</sup>

Bohm introduced these philosophical reflections in form of a sub-quantum-level into physics. He used an argument by analogy and considered the wave function  $\psi$  as a real field, which satisfies the Schrödinger equation. This field carries out a quantum-mechanical force on a particle and drags it in areas where  $|\psi|^2$  is large. The field leads the particle. In addition to that a contradicting tendency should exist, an accidental movement, analogously to the Brownian movement. The cause of this chaotic movement was not clear to Bohm. He thought it might be possible that it results from fluctuations of the  $\psi$ -field. Important to him was only the basic acceptance of the existence of a sub-quantum-level and the investigation of effects that might result from this level. He understood the present quantum mechanics as an approximation to this sub-quantum-level, like thermodynamics to the kinetic gas theory. At the same time he hoped for the discovery of new theories to explain the quantum effects.<sup>38</sup>

These considerations led to a series of articles between 1952 and 1957, which appeared mainly in the *Physical Review* and *Nuovo Cimento*. In some of these articles and in his correspondence Bohm described the  $\psi$ -field also as a kind of continuous fluidum in which the particle moved. This fluidum reminds one of the old idea of ether filling the space. In fact Bohm used the term "ether", however, only in his personal correspondence, it appears in none of the publications. These highly speculative ideas were motivated by his research on plasma. Similar to plasma the chaotic movement of the individual parts of the "ether" led to the "organized"  $\psi$ -field, which determined the motion of the individual particle. In this case chaotic movement led to causality.<sup>39</sup> Since causality and chance form a dialectical unit, the other way, causality leading to chaos, should also be possible. Thus Bohm started to work on a theory of probability, where a very small perturbation of the individual particle leads to an uncontrollable effect of motion. These ideas seem to be closely linked to modern chaos theory.<sup>40</sup>

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<sup>37</sup> Bohm, *Causality and Chance*, 34-57; Engels, 'Dialektik der Natur' 325, 349-50, 516-20. Wladimir I. Lenin, 'Materialismus und Empirio-kritizismus', in: *Lenin Werke*, Band 14 (Berlin: Dietz Verlag, 1962), 262, see also 282; Mao Tse-Tung, 'Über den Widerspruch', in *Ausgewählte Werke*, Band 1 (Peking: Verlag für Fremdsprachige Literatur, 1968), 375.

<sup>38</sup> David Bohm, *Causality and Chance*, Chapter III and IV, 68-129.

<sup>39</sup> David Bohm und Jean-Pierre Vigièr, 'Model of the Causal Interpretation of Quantum Theory in Terms of a Fluid with Irregular Fluctuations', *Physical Review* 96 (1954): 208-216. Letter from David Bohm to Miriam Yevick, 7 Januar 1952, David Bohm Papers, uncatalogued; Letter from David Bohm to George Yevick, not dated [January/February 1952], David Bohm Papers, uncatalogued.

<sup>40</sup> David Bohm und Walter Schützer, 'The General Statistical Problem in Physics and the Theory of Probability', *Supplemento al Nuovo Cimento* 2 (1955): 1004-47.

## Conclusion

The Copenhagen Interpretation of quantum mechanics was created by a small group of physicists centered at Copenhagen, Göttingen and Munich. This elite group displayed a high level of scientific exchange and thought transfer. The new theory was transferred step by step into a specific American thought-style. In the first phase of the reception, we can still recognize some reminiscences of the European discussions. With the move from journal to Handbuch and to textbook science, these reminiscences became less and less frequent. The Copenhagen Interpretation was integrated in a thought-style that distinguished itself from the European discussions by the pragmatic and operational attitude towards physics. David Bohm was inaugurated in this thought-style during his studies at Pennsylvania State College, Caltech and Berkeley. In Berkeley he got in touch with another thought-collective, the political left, and dialectical materialism forming the thought-style of this collective. Bohm's philosophical views were not effective in the construction of physical theories until he was completely dissociated from the American physical community. Bohm had to separate first from the thought-style of the collective; otherwise discussions with Einstein might not have been decisive. The process of moving away from his thought-collective and its style can be recognized in his book *Quantum Theory* and the process got rapidly intensified with Bohm's suspension in Princeton. However, in his hidden variables paper we find many appeals to the collective for recognition. Not until his complete isolation from the collective did Bohm start to reconsider his theory in the light of dialectical materialism and used it as a guideline for the construction of new physical theories and entities.

The creation of Bohm's quantum theory and its further development shows how philosophical thought-styles may act as guideline for the construction of physical theories. However, thought-styles belong to their collectives and, as we can see in Bohm's case, these collectives forbid a diverging way of thinking: Bohm started to work on his new theory only after he dissociated from his scientific thought-collective, and his philosophical thought-style became effective in the moment when it was impossible for his former collective to exert a constraint on thought.