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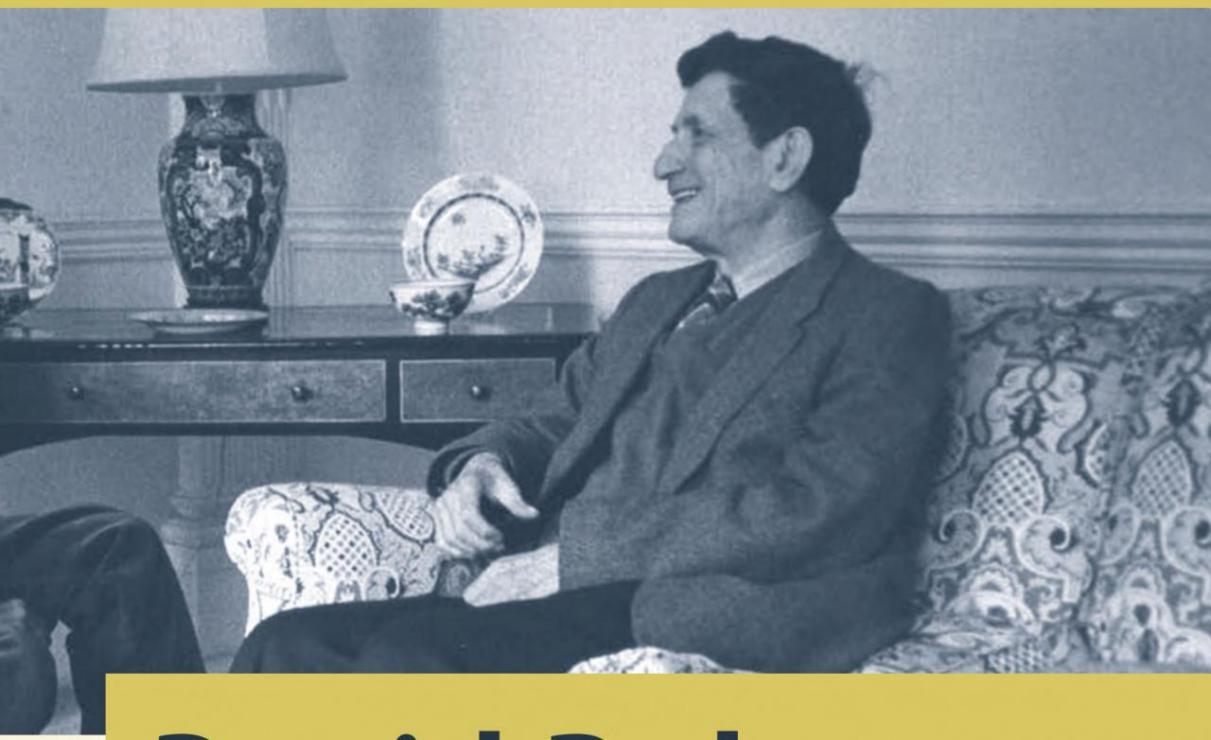

David Bohm

A Life Dedicated to Understanding the Quantum World

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Chapter 1
Introduction: Living Through Cold War Storms, Attempting to Understand the Quantum

> When I went to work with J. Robert Oppenheimer, I found a more congenial spirit in his group. For example, I was introduced to the work of Niels Bohr and this stimulated my interest, especially in the whole question of the oneness of the observer and the observed. […] I can still recall the many discussions I had on matters like this which had the effect of setting me on the course I'm still following today.
> David Bohm, in Bohm and Peat, *Science, Order and Creativity*, 1987

Biographies are usually of interest because we may learn from them about the life of a person, their singularities in the plethora of humankind, as well as about the times in which the person lived. This is the case of David Joseph Bohm, a physicist who was born in the US, in 1917, educated there, lived in Brazil, Israel and the UK where he passed away in 1992. He was an outstanding theoretical physicist with achievements in standard science and breakthroughs in the way we obtain predictions and interpret the most successful physical theory, the quantum theory. His life was entangled with two major intellectual trends which prevailed in the twentieth century, Communism and Eastern traditions. In fact, he was first associated with the US Communist Party, thus Soviet-inspired Communism, and later with the Indian thinker Jiddu Krishnamurti. However, he faced obstacles both in the scientific community and in the political arena. Indeed, his proposals to an alternative interpretation of quantum mechanics were initially poorly received among his fellow physicists, which only changed when the overall physics community changed its appreciation towards the research on the foundations of quantum mechanics, from the 1970s on. Commitment to Communism and works close to the American atomic project at Berkeley, during WWII, cost Bohm his professional stability and permanence in the US at the apex of McCarthyism. He left the US and lived as an expatriate in Brazil, then Israel, and later in the UK. In the meantime, reflecting the Cold War times, the US government withdrew his American citizenship, which he only recovered in the mid-1980s. Proximity to mystical thinkers and Krishnamurti came as a follow-up of his break with Communism, after the 1956 Soviet invasion of Hungary. In addition, his philosophical and scientific views were never fully independent of the contexts

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where he lived. Through Bohm's biography we may thus learn about twentieth century history, physics, and the history of physics. We shall also meet the person and his ongoing anxieties, both with the understanding of the quantum and the attempt to frame it in wider cultural frameworks. Biographies are like windows, or points of perspective, through which a life and its times can be seen.

In this introductory chapter to David Bohm's biography we are going to see first an overview of his ideas and life and then methodological considerations and sources which were helpful during the writing of this book. They concern biographies as a genre in history, approaches in history such as the history of ideas and cultural history, and the sources for studies on David Bohm. From Chaps. 2–7, the biography itself is presented in chronological order, the seventh chapter being an epilogue about how Bohm's ideas have been appropriated and developed since his death. The final chapter, the eighth, is an attempt to use a quantitative criterion to assess the influence of Bohm's works among physicists. This is done through a scientometric essay about the number of papers citing Bohm's own papers.

1.1 An Overview of Bohm's Life and Works

Bohm worked almost entirely dedicated to the foundations of quantum mechanics, particularly on the interpretation of this theory, for more than 40 years. His most original and heterodox contribution to quantum physics may have been the elaboration of the causal interpretation of quantum physics, published in 1952, which departed significantly from the standard theory in its conceptual and philosophical assumptions but still arrived at the same predictions, at least in the non-relativistic domain. Departure from the standard theory came as Bohm assumed a realist point of view about the meaning of quantum mechanics and recovered the determinism for quantum phenomena, which had been discarded by the standard interpretation of this theory. The standard interpretation was also known as the complementarity point of view and it was the Danish physicist Niels Bohr who developed it, but there were important different views among the physicists who supported it. With his interpretation Bohm opened the way for alternative interpretations of quantum mechanics and showed that quantum mechanics could be supplemented by additional variables. This way he disproved by this counter example the proof against the possibility of additional variables in quantum mechanics which had been proposed by the mathematician John von Neumann in the early 1930s. Furthermore, and more importantly, Bohm's interpretation inspired John Bell to develop, a decade later, what is now called Bell's theorem. This theorem, and the series of its experiments, which are being performed even nowadays, have led the physicists to accept entanglement, that is, the quantum correlation among systems which are far away one from the other, as a physical effect, that is predicted from the theory and confirmed by experiments. Entanglement has become the physical effect on the basis of quantum information,

a field which has blossomed since the early 1990s and promises the use of quantum mechanics to obtain more powerful computers and cryptography in years to come.[1]

However, Bohm's proposal was poorly received at the time. Research in foundations without new predictions was then considered more philosophy than physics. Treating foundations as just philosophical issues enhanced professional bias in the physics community against the subject, which was thus considered the realm of philosophical research and not research in physics. Furthermore, the common view among physicists in the 1950s was that foundational issues in quantum mechanics had already been solved by the creators of this physical theory. Thus there were no unsolved questions that deserved the energy of physicists, particularly young talents. In fact, the subject was considered, in the best case, a marginal topic on the physics research agenda. I have used the term quantum dissidents to designate the physicists who through their work pushed this subject from the margins to the mainstream of physics. Paramount among these quantum dissidents was David Bohm, the subject of our biography. In addition, Bohm hoped to obtain a relativistic generalization of his causal interpretation, however, he failed to do so, at least in the first years after the publication of his alternative interpretation. All this together may have alienated him from the kind of physics being developed in the 1950s, and led him to a certain isolation among his fellow physicists.[2]

Despite this isolation, Bohm was able to make another contribution to our understanding of quantum mechanics, which was later recognized as a major breakthrough. Indeed, in the late 1950s, he and his doctoral student Yakir Aharonov published their seminal paper on the understanding of the role of phases and electromagnetic potentials in the quantum description of the world. They suggested the so far unknown Aharonov-Bohm effect, meaning that quantum mechanics may lead a magnetic field to act on a charge even in regions where this field is null. The suggestion of this effect stirred up a number of theoretical and experimental works and it is now well grounded on the physicists' toolkit of quantum phenomena. Much of the recognition of Aharonov as a first-ranking physicist came from the wide acceptance of this work.[3]

Later on, in the early 1960s, Bohm abandoned the causal interpretation and moved to the program he named wholeness and order, which was fleshed out, through his collaboration with Basil Hiley, Bohm's collaborator at Birkbeck in London, as a highly mathematical approach. Working with Hiley, he looked for the most basic algebraic structures from where space, time, and quantum theory might emerge. In the early 1980s Bohm saw his initial interpretation revived by some of his students who were able to produce computer-created graphs of trajectories and potentials obtained from the causal interpretation of quantum physics. He spent his last years trying to reconcile these different approaches to the quantum.[4]

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[1] Bohm (1952).

[2] Freire Junior (2015a).

[3] Aharonov and Bohm (1959).

[4] Philippidis, Dewdney et al. (1979); Bohm and Hiley (1993).

Bohm lived his life attempting to understand the puzzles of quantum mechanics. Since the late 1940s, when he began to systematize his views to write the textbook *Quantum Theory* (Bohm 1951) till his last days with Basil Hiley in the writing of the book *The Undivided Universe* (Bohm and Hiley 1993), there were more than 40 years dedicated to this intellectual challenge. In the history of twentieth century physics, the time and energy he spent on this may be compared to that of Einstein, Bohr, and Schrödinger, among other great physicists. As a younger physicist, he was less prepared to face the isolation derived from the manner most physicists received his alternative interpretation for quantum mechanics. Bohm's endurance, however, was formidable. To think about the meaning of the quantum and its implications for science was his bread and butter for decades. This endurance may illustrate the double motivation I had to adopt the term quantum dissidents. The first motivation considered that physicists such as Bohm, Bell, and others, were critical of what they perceived as the complementarity interpretation, or the usual interpretation of quantum mechanics. However, they did not share a unique alternative interpretation of quantum mechanics. They shared the professional and intellectual attitude that issues in foundations of quantum mechanics were worthy of pursuit as part of a professional career in physics, and that denying this was a dogmatic attitude. The second motivation, however, came from the analogy with major political dissidents in the twentieth century. When I first thought of this term I had in mind the examples of Nelson Mandela, Luís Inácio Lula da Silva, and Martin Luther King. They, or the cause they embraced won, at least in the medium term. This was possible, among other factors, thanks to the moral endurance of the dissidents.[5] In the case of quantum mechanics, the moral value of the resilience is similar. The foundations of quantum mechanics eventually became a respectable field of research and it has contributed to a better understanding of the quantum. This was possible, among other reasons, owing to the moral, intellectual, and professional endurance of the quantum dissidents. David Bohm was a paramount character among these dissidents sharing their common features, including their perseverance.

Bohm's contributions to physics were not limited to foundations of quantum mechanics. He was a doctoral student of Julius Robert Oppenheimer at Berkeley in the early 1940s, and worked on subjects which were of interest to the Manhattan Project, the American atomic project. He emerged from the war effort considered a highly promising American theoretical physicist and was then hired by Princeton University being recommended by the American physicist John Archibald Wheeler. While working on subjects which were part of the war effort, he dealt with the problem of electrical currents passing through a gas in magnetic fields, which led him to the study of plasmas. When the war ended, Bohm and his graduate students Eugene Gross and David Pines worked on plasmas, developing the approach called "collective variables" and applied it to the study of current in metals, elaborating a quantum approach to the phenomenon using the same collective variable resource he had successfully applied in the classical treatment of plasmas. Later, this approach

[5] I coined the term quantum dissidents in 2009 (Freire Junior 2009). Ten years later, regressive trends in many parts of the world and market pressures on researchers suggest taking the "medium term" with a grain of salt as progressive accomplishments are never assured forever.

was used in superconductivity by Pines, and in nuclear physics by Aage Bohr and Ben Mottelson. The jointly-authored papers of Bohm, Pine, and Gross became landmarks in the field also known as many-body physics.

Bohm's achievements in science ranked him as a very influential physicist in the twentieth century. He was elected Fellow of the Royal Society, had a *Festchrift* with papers signed by four Nobel prize winners, and had his work on the reinterpretation of quantum mechanics featured in the *Physical Review* centennial anniversary volume. Using the metrics of the number of citations, the extent of his influence can also be traced. At the end of 2018, ten of his papers had obtained more than 300 citations, one of them, on the Aharonov-Bohm effect had over 4300 citations, and another, on the causal interpretation, had almost 3000 citations. These are impressive numbers, by any standard, for twentieth century physics papers. He also wrote a number of well received books, among them a textbook on quantum mechanics still considered today a good textbook on the matter. However, his reputation fluctuated. From being considered a promising young physicist, his reputation was damaged by the adverse reception of his work on the foundations of quantum mechanics; exemplifying the bias against research on foundations in the 1950s. After the experiments related to Bell's theorem, interest in his early work was slowly resumed. Ultimately, this theorem and its experiments set entanglement as a strictly quantum feature and shed light on the equivalence between standard quantum mechanics and Bohm's interpretation. Both of them feature quantum entanglement as one of their features while they provide different explanations for it. Thus, due recognition for his outstanding contributions came later, as noted by his old friend the physicist Melba Phillips, in the early 1990s: "It is too bad, very sad indeed, that he did not live to see how his reputation has shot up recently. His interpretation of quantum mechanics is becoming respected not only by philosophers of science but also by 'straight' physicists".[6]

In hindsight how can we assess Bohm's legacy to quantum physics? In addition to his specific and lasting contributions, I think he should be acknowledged for his attitude which highlighted the relevance of the research on the foundations of this theory. John Bell's recollections about how he was driven to these issues encapsulate this feeling: "In 1952 I saw the impossible done," and "Bohm's 1952 papers on quantum mechanics were for me a revelation," referring to the appearance of the causal interpretation which was considered by current wisdom an impossible feat.[7]

Bohm developed his own scientific style from his first years of graduate studies at Caltech and Berkeley. To follow the terms used by historian Suman Seth (2010, p. 2), between a "physics of problems," illustrated by Arnold Sommerfeld, and a "physics of principles," whose paragons in the early twentieth century were Albert Einstein and Max Planck, Bohm tailored his own and distinctive style. He was more inclined towards a scientific style based on concepts and philosophical views as points of departure, freely using pictures as supports for his physical thinking, and only then going to the mathematical machinery. He was well trained in

[6]The Festschrift is (Bohm et al. 1987) and the textbook is Bohm (1951). Phillips letter is quoted in (Freire Junior 2015a, p. 63).

[7]Bell (1982 and 1987).

mathematics, thus mathematics coming at the end was rather a scientific and epistemological choice than a handicap. His scientific style was closer to Einstein's than to Sommerfeld's. Furthermore, in the early 1950s, his quest for a new interpretation for quantum mechanics was associated to a disdain for the machinery of mathematics—renormalization techniques—built by Richard Feynman and others to deal with the infinities plaguing quantum field theories. Later, in the 1960s, in discussions with Jeffrey Bub, one of his former graduate students, it became explicit that Bohm did not keep in high esteem axiomatic approaches such as those adopted by von Neumann.

From when he was a teenager, David Bohm developed a keen social consciousness. He grew up in Wilkes-Barre, a coal mining town in Pennsylvania that was devastated in the decade of 1930 in the wake of changes in the use of coal and the Great Depression. Unemployment, social unrest, and labor organizations were part of the ambiance where Bohm came of age. Later, under the influence of threats of the rising Nazi power and the US entrance into the war, at Berkeley Bohm joined the Communist Party. After the Second World War, in the inception of the Cold War, he was caught up in American anxieties with Communism and the suspicion of leaks of atomic secrets. He was called to testify before the House Un-American Activities Committee (HUAC) and exercised his constitutional right to remain silent in order to prevent self-incrimination and name names of colleagues. His attitude was in stark contrast with the HUAC's expectations. He was condemned of contempt to the Congress, jailed, released on bail and later acquitted. Despite being acquitted, Princeton University did not renew his contract. In 1951, he left the US for a job in Brazil and later went to Israel and eventually the United Kingdom in 1957. Reflecting US policies in the Cold War times, his passport was apprehended by American officials in Brazil. In order to get a passport to travel abroad, he applied and got Brazilian citizenship but the US then cancelled his American citizenship. He only recovered it 30 years later, in the twilight of the Cold War and through a legal procedure. He lived for almost 3 decades as one of the most notable American expatriate scientists. In the late 1950s, following Khrushchev's report on Stalin's crimes and the Soviet invasion of Hungary, he broke his ideological ties with Marxism. Following this rupture, he moved towards a rapprochement with mystical thinkers such as George Gurdjieff, born in Armenia, then part of Russian empire, and the Russian Peter Ouspensky. Furthermore, Bohm was strongly drawn to the writings of Jiddu Krishnamurti. This philosopher was born in India and educated by the esoteric movement Theosophy to be its new world religious leader. Later Krishnamurti rejected this connection and went his own way of expressing his teachings. From that time on Bohm moved away from his political interests and focused on self-improvement, particularly following Krishnamurti's lessons and dialoguing with him. He then became an iconic figure in the New Age culture of the 1970s. His life illustrates thus much of the political and cultural turmoil of the times as it reflected the circumstances and vicissitudes of the twentieth century, in politics and culture at large. In addition, these commitments as well as their changes exemplify his anxieties with values and wider intellectual frameworks.

Bohm's life circumstances and work in physics were intertwined enough to lead commentators to highlight the strong influences of the former on the latter.

Alex Kojevnikov suggested his approach to plasma and electrons in metals in terms of collective variables reflected his early Marxist commitments. Christian Forstner saw his move towards the causal interpretation as conditioned both by his Marxist views and his isolation from the Princeton community during his persecution under McCarthyism. I suggested his moving away from the causal interpretation, in the late 1950s, was constrained by his break with the ideological ties of Communism. The connections between his wholeness and implicate order approach, which he adopted from the 1970s on, and the thoughts of Krishnamurti are conspicuous. Bohm himself saw it this way and wrote on it, for instance in his 1980 book *Wholeness and Implicate Order*. The complexities of these connections will be discussed at greater length in Chaps. 5 and 6. In an analogous manner, his return to the causal interpretation was strongly influenced by John Bell, either through his theorem and its implications or by Bell's support for Bohm's hidden variables interpretation, as well as by Hiley's students, who produced computer-based pictures based on the causal interpretation. Not all of the connections are equally grounded on evidence and some lack either documentary evidence or plausibility or both. This was the case of the suggestion that the poor reception of the causal interpretation was influenced by his persecution during McCarthyism; a suggestion I found unfounded.[8] Thus, on the one hand, the study of Bohm's scientific work requires tracing the contexts in which he lived as the former was constrained by the latter and the latter was also shaped by the impact of the former. On the other hand, Bohm was above all a physicist, thus, the study of the contexts without due attention to his scientific work would dilute what he saw as his main contributions.

1.2 Biographies, History, and History of Science: Methodological Notes

A biography of a great scientist is a professional endeavor which brings together different areas of history. Biography, history, history of science, history of ideas, and cultural history were the fields I had to walk through during the research for and the writing of this book. Let me make a few short comments about these subjects.

While biographies have been bestsellers for decades, they are latecomers to historiographical scholarship. The reason for this has been professional distrust towards a kind of historical work usually related to the description of heroes and saints. Interestingly, it is from here that the term hagiography comes, the deadliest of sins committed by professional historians. The history of science is no different, many biographies of scientists have been published but the genre has been suspect for history of science scholarship. Replacing heroes and saints with individual geniuses, most biographies in science were idealized descriptions of these outstanding scientists. As noted by the historian of science Thomas Söderqvist, influences from philosophy and later from sociology in history of science did not value biography as a genre. The same may be

[8] Kojevnikov (2002), Forstner (2008), Freire Junior (2015a).

said of the post-structuralist trends with its deconstruction of the subject. Evidence of this distrust is that, who was writing a biography of a scientist, could ask, twenty years ago: "What is the legitimate place of biography in history of science? Is it simply a sort of sophisticated entertainment, the scientist's bedside companion after the daily torments in the laboratory or at the desk, and thus better handed over to novelists, or is biography a possible and valuable scholarly pursuit in itself?"[9]

It was more recently that the genre was fully recovered through the approach the French historian François Dosse called the hermeneutical stage in the historiographical fortune of biographies. The historian has no ambition to represent the individual as a coherent character in his times, instead, fractures, contradictions, and conflicts should be highlighted. In scholarship, however, new trends cannot be only rhetorical, they require good examples. During the research for this book I had in mind two biographies which dealt with the current standards of the history as a discipline particularly well. The first was *Never at Rest*, Newton's biography by Richard Westfall. While most of Newton's biographies portray the genius, Westfall's book illustrates how off scale individual and contributions can be accommodated in a biographical portrait full of other human features. The second was Jacques Le Goff's portrait of Saint Louis, King of France and later a Catholic saint. I had Le Goff's work in mind not so much because of its content, a thirteenth century king and saint is a too distant comparison for a twentieth century physicist, but because the late dean of French historians presented a number of methodological concerns which may be useful for any biography as a genre in history. Initially Le Goff discussed the ongoing debate among professional historians about the return of the narrative in the historiographical scholarship, many of them condemning this return. According him, "all history is narrative because, placing itself in time by definition, in succession, it is necessarily associated with narration. But that is not all. First, contrary to what many—even many historians—believe, there is nothing immediate about the narrative. It is the result of an entire series of intellectual and scientific operations that one has every reason to expose, in other words, to justify". On the risks of the biographical genre, Le Goff was well aware of them, stating, "[The biographical narrative] also induces an interpretation and represents a serious danger. Jean-Claude Passeron has pointed out the risk of the 'excess of meaning and coherence inherent in any biographical approach". Furthermore, still following Le Goff, "what he [Passeron] calls the 'biographical utopia' not only consists in the risk of believing that 'nothing is meaningless' in biographical narrative without selection and criticism, but perhaps even more in the illusion that it authentically reconstitutes someone's destiny". As Le Goff's readers were familiar with Pierre Bourdieu's critique of what he called biographical illusion, Le Goff acknowledged the threat and explained how he dealt with it: "I have tried several times to escape the constraining logic of this 'biographical illusion' denounced by Pierre Bourdieu. Saint Louis did not ineluctably proceed toward his destiny as a saintly king in the conditions of the thirteenth century and in following the dominant models of his time. He formed himself and formed his era as much as he was formed by it. This construction was made up of chance and hesitation

[9]On biographies in the history of Science, see Kragh (1987). Söderqvist (1996, 46).

over different choices". The readers of my David Bohm biography will note that I did not ignore his hesitations, his anxieties, his frustrations with physics and politics at large, and his toing and froing about how to interpret quantum mechanics. This approach may not please some members of the circle of Bohm's admirers, however, I think otherwise. As in other fields of human experience, it is better to deal with the "real" portraits than with idealized representations.[10]

Still following Le Goff's reflections, he made two considerations I took into account: "Finally, as [Jorge Luis] Borges stated, a man is never really dead until the last man who knew him is dead in turn, […]. The biography I have written therefore continues up to Saint Louis' definitive death, and no further". Still, "I have dedicated the second part of this work to the critical study of the production of the memory of the saintly king by his contemporaries". Unable to strictly follow the recommendation for a personage who lived mostly in the second half of the twentieth century, I attenuated the problem dealing with Bohm's disciples in Chap. 7, the Epilogue. This was also the reason I used, when possible, oral histories as sources of my research. Finally, in Chap. 8, I tried to see how Bohm was seen by his contemporaries through the use of the lens of scientometry, drawing from the number of citations of Bohm's papers by his contemporaries.[11]

These considerations led me to the first type of questions I had to deal with. How did contextual constraints affect Bohm's personal and intellectual choices? Furthermore, what kind of choice did he have at each crucial moment he faced and how did he act in response? These questions will haunt us throughout this book. A biography of a scientist who worked at the cutting edge of his discipline requires an account of the content of the science produced by this scientist and the changes he was able to instigate. Except for his early works, on plasmas and the approach of collective variables, almost all of Bohm's scientific productions were dedicated to understanding the foundations and the possibly different interpretations of this physical theory. As we know, the interpretation of this theory, focused as it was on the understanding of light, microscopic matter, and their interactions, occupied most of Niels Bohr and Albert Einstein lives, while they adopted opposite stances on many of these issues. Figure 1.1, a sculpture of Bohr and Einstein in a park in Moscow, may thus illustrate the backdrop of Bohm's work. It may give us an idea of the scale of the problems Bohm himself chose to tackle in his professional career.

As Bohm chose this subject, the foundations of quantum theory, for his research, I had to take into account the way in which this subject dramatically changed in content and prestige from the 1950s to the 1990s. My task was made easier as this was the subject of my previous book entitled *The Quantum Dissidents—Rebuilding the Foundations of Quantum Mechanics 1950–1990* and I had Paul Forman's and Max Jammer's seminal works on the long controversy over the interpretation of quantum mechanics and the vast literature on the history of quantum mechanics as useful resources. In the *Quantum Dissidents* I valued the manner in which the

[10] Dosse (2010). Westfall (1980). Le Goff's citations are in the introduction of Le Goff (2009).

[11] All citations of Le Goff are in the introduction of his Saint Louis' biography (Le Goff, 2009), particularly on pages xxv, xxxi–xxxii.

Fig. 1.1 Bohr and Einstein's debate, the major motivation for Bohm's work, portrayed in the artistic imagination—Sculpture in Park Muzeon, Moscow. *Credits* Photo by Climério P. da Silva Neto

individuals (who were the protagonists of these changes) indeed acted. The changes and their contexts, described in the book, were also influential in Bohm's case, and for this reason a full chapter of the book was dedicated to Bohm.[12] As the changes in the appreciation of foundations of quantum mechanics among physicists constrained what happened with Bohm's varying scientific reputation, in this biography I had to exploit the singularities of his case. Thus I had to deal with the internal consistency, but also the changes, including the ruptures, and the ambiguities in the way Bohm interpreted the quantum.

In addition to Bohm's science, particularly foundations of quantum mechanics, I had to deal with the historical contexts in which he lived, in particular the contexts which strongly shaped his own life. Thus it was a deep dive into twentieth century history, namely the years 1930s, Word War II, Cold War and McCarthyism, the rise, crisis, and decline of the influence of Communism throughout the world, and the appeal of eastern thinkers such as Krishnamurti in western societies.[13] I also mobilized resources from what historians Suman Seth and Massimiliano Badino have called the New Intellectual History, strongly influenced by cultural history. The last resource I have used throughout my research was the transnational approach to the history of science.[14] This was necessary due to the very difficulty of labeling David Bohm: was he an American physicist? Yes and no. He was trained and blossomed as a physicist in the US but he lived most of his active scientific life in exile or as an expatriate, in Brazil, Israel, and the UK. Thus following Bohm while he crossed national borders, and paying attention to the obstacles he had to overcome to cross borders it made sense to me to use this historical approach. All these contexts in science, this long lasting quantum controversy, and in society at large coalesced in a single life, that of David Bohm, with his ambitions, expectations, hesitations, changes, achievements and frustrations. Thus, if I had to single out my major expectation while writing this biography, I would say it is similar to that of Söderqvist. He appealed to the philosopher Richard Rorty, to say what he expected from biographies in the history of science: namely they should "help scientists and non-scientists alike to strengthen their abilities to live fuller and more authentic intellectual lives". Thus, I finish this section citing Söderqvist (1996, 47–75) in extenso:

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[12] Freire Junior (2015a). A short presentation of the book's argument is Freire Junior (2015b). Forman (1971) and Jammer (1974).

[13] It would be beyond the scope of this chapter to comprehensively identify the literature I looked to for support to understand those contexts. A summary list includes: on the Cold War and twentieth century history, Gaddis (2005), Westad (2017), Hobsbawm (1995 and 2002), and Judt (2005); on McCarthyism, Schrecker (1986 and 2002) and Wang (1999); on Marxism, (Hobsbawm 1991 and 2011), Ory and Sirinelli (2004), and Caute (1967); on Krishnamurti and Bohm, (Moody 2017).

[14] On the intellectual history and the history of physics, see Seth (2011) and Badino (2016). See also Staley (2013) and the editorial, written by Peter Galison and Andrew Warwick, to the special issue of *Studies in History and Philosophy of Modern Ph*ysics [29(3), 1998], titled "Cultures of Theory". On the transnational approach to the history of science, see John Krige (2019). In this last book our contribution (Freire Junior and Silva 2019) exploits the case of David Bohm concerning his move from the US to Brazil.

> The aim of biography is not primarily to be an aid for the history of science, nor to be a generator of case studies. Instead of adding to the 'hermeneutics of suspicion' that governs so much of today's history and sociology of science, the main purpose of science biography is, I suggest, as a genre that can provide a variety of exemplars of existential projects of individual scientists—narratives through which we can identify ourselves with others who have been confronted with existential choices and struggled with the existential conditions for living in and with science. Such life stories not only provide us with opportunities to understand ourselves, intellectually as well as emotionally, but may also change and create ourselves. Hence biographies of scientists are 'edifying'—they can help us reorient our familiar ways of thinking about our lives in unfamiliar terms, and 'take us out of our old selves by the power of strangeness, to aid us in becoming new beings.'

1.2.1 Sources for the Study of Bohm's Life and Works

The writing of this biography was eased by the vast amount of studies and resources on Bohm's life and works made available in the last four decades. They include his papers, which are catalogued and deposited at Birkbeck College, London; several interviews, most of them transcribed and deposited at the American Institute of Physics, College Park, MD, in the US; a handful scholarly and popular works, beginning in 1977; the full opus of Bohm's published articles and books; and some websites, mostly related to his relationship with Jiddu Krishnamurti. I initially address Bohm's first biography, and then move to comment on the other works and sources.

As there already is a biography of Bohm, written by F. David Peat, the first question to be raised is what is the point of writing a second biography? A trivial answer would be that many great physicists have more than one biography written on them and Bohm was a great scientist. A more substantive answer requires considering the strong and weak aspects of this biography. While well written, and extensively based on letters and interviews in addition to personal acquaintance with Bohm, this biography is more a biography of Bohm's life than of Bohm's ideas. To be more precise, in key points in the development of Bohm's quest to understand quantum theory and its philosophical implications, Peat's book is too shallow and sometimes mistaken. Let me illustrate this with a conspicuous case. Bell's theorem and its impact on physics received a mere 2-page text in the full book. Peat did not acknowledge the distinction among the two papers by Bell, which were published in the inverse order of their production, one dealing with von Neumann's proof and Bohm's causal interpretation, and the second suggesting what we call now Bell's theorem. Therefore the conundrum involved in that proof and Bohm's and Bell's works is simply ignored. In addition, the book did not discuss how Bohm reacted to Bell's theorem at all. Bohm evolved from an initial misunderstanding of Bell's theorem to a full comprehension of its implication. Furthermore, Bohm grasped these implications at a moment when there were still conflicting experimental results, those from Clauser and Freedman at Berkeley, confirming quantum mechanics and those from Holt and Pipkin at Harvard, confirming local theories. Only after Clauser's replication of Holt's experiment and mainly after Fry and Thompson experiment in 1976, did the balance incline towards

quantum mechanics and its non-locality. Instead of analyzing this rich moment, Peat simply and briefly stated the following: "Soon after Bell's theorem was published, a number of experimental tests, each one more refined and each one designed to overcome possible objections, confirmed the essential nonlocality of the quantum world".[15] Thus, Peat's book ignored both the scientific content and the human drama of the ten years between the appearance of Bell's theorem and the full vindication of quantum mechanics nonlocality, which later was dubbed entanglement. In fact, characters such as John Clauser, Abner Shimony, Ed Fry, Alain Aspect, and Bernard d'Espagnat are meaningfully absent in this biography. Thus a new biography of Bohm is in order, one integrating the history of his ideas and the history of his life, all articulated in their relevant contexts.

Similar comments on the strengths and weakness of Peat's book were made by the contemporary reviewers of the book. Thus, the physicist Sheldon Goldstein praised how Peat presented the manner in which Bohm's ideas were treated by fellow physicists but remarked that "Peat's treatment of the relevant physics is not always entirely accurate," and then illustrated his point. The historian Alexei Kojevnikov, after positively commenting on how Peat inserted Bohm in the contexts of the times, concluded stating "As for Bohm's science, that awaits another, more thorough analysis". Finally, the philosopher James Cushing went along the same lines, stating, "Peat does not always represent well Bohm's scientific work itself (such as his 1952 papers on quantum theory) or its subsequent impact," and "in summary, this book does make a *prima facie* case for Bohm as a 'fascinating and important scientist' and is certainly well worth reading. But it probably has not 'given David Bohm his due.'" During the research for this book, I also realized that Peat's biography underestimated certain aspects of Bohm's personal life, for instance, the role of the high school in his coming of age and the roots of his early social consciousness.[16]

Studies in history, sociology, and philosophy of science on Bohm's life and works began to pop up while Bohm was still alive. The new sociology of science was the first to approach the subject. Trevor Pinch used the theoretical framework proposed by Pierre Bourdieu to analyze Bohm's challenge to von Neumann's proof against the existence of hidden variables in quantum mechanics. The philosopher James Cushing analyzed the position of Bohm's causal interpretation in the physics community as constrained by historical contingency. Cushing appealed both to Paul Forman's study on the inception of the acausal quantum mechanics in Weimar's Germany and the Duhem-Quine thesis on the underdetermination of scientific theories by the empirical data. He argued that Bohm's proposal became the minority interpretation only because it appeared later, in the early 1950s. The acausal standard quantum mechanics, had appeared and been accepted earlier, in the mid-1920s. Bohm's troubles with the American McCarthyism was studied by Russ Olwell and Shawn Mullet. Bohm's political commitments shaping and constraining Bohm's studies on plasma

[15] Peat (1997, pp. 168–170). Bell (1964 and 1966). Bohm and Hiley (1975). Peat (1997, p. 170). For a detailed discussion of the appearance of Bell's theorem and its early experiments, see (Freire Junior, 2015a), in particular Chap. 7.

[16] Goldstein (1997). Kojevnikov (1998). Cushing (1997).

and many-body systems was investigated by Alexei Kojevnikov. My own studies have been dedicated to Bohm's stay in Brazil, the early reception of his causal interpretation, and his later change of mind regarding the interpretation of quantum mechanics. Connections between Marxism and Bohm's causal interpretation was considered by Andrew Cross while Christian Forstner studied contextual influences in the inception of the causal interpretation. The philosopher Paavo Pylkkänen has investigated Bohm's philosophical approach concerning the idea of order and exploited its implications for the philosophy of mind and has edited part of Bohm's correspondence with the artist Charles Biederman. More recently, Boris Kožnjak revised Bohm's participation at the 1957 Bristol conference and Chris Talbot brought a magnificent resource to Bohm's studies, the transcription and critical edition, plus an introductory analysis, of Bohm's correspondence, in the 1950s, with Melba Phillips, Hanna Loewy, and Miriam Yevick. This list is more exhaustive in the English language but it is far from comprehensive in a wider language spectrum. For instance, in Portuguese, Rodrigo Carvalho dedicated his doctoral dissertation to Bohm's philosophical views and Rodolfo Petrônio wrote an essay on and translated *Causality and Chance*. I was lucky enough to undertake this biography at a moment when I could count on these scholar works; they were both useful for the writing of this book and sources of pleasure during their readings.[17]

The David Bohm Papers, deposited at Birkbeck College, London, was a rich resource for my research. I was able to consult them a number of times always counting on the tireless support of librarians Sue Godsell and Emma Illingworth. Bohm, however, was a poor preserver of his own correspondence. Thus I had to supplement the research at Birkbeck with a search for documents from and to Bohm in other archives. Particularly useful in this sense was the Léon Rosenfeld Papers, deposited at the Niels Bohr Archive, in Copenhagen. Throughout the book the reader will note that from time to time I cite Bohm's correspondence deposited elsewhere as I also found relevant correspondence and documents on Bohm at these other archives, for instance the Guido Beck Papers at the Centro Brasileiro de Pesquisas Físicas, Rio de Janeiro; the Costas Papaliolos Papers, at Harvard Archives; the Norbert Wiener Papers, at the MIT Archives; and the John Wheeler Papers, at the American Philosophical Society, in Philadelphia. I also could use documents concerning Bohm at Technion, in Israel, at the Universidade de São Paulo, in Brazil, at the Krishnamurti Foundation, in Ojai, CA. in the USA; and at the GAR Memorial Junior and High School, in Wilkes-Barre, PA, in the USA.

Bohm intended to write an autobiography, which never materialized. In order to do this, he was extensively interviewed by Maurice Wilkins. The results were impressive: twelve sessions of recording, 612 pages of transcripts, between 6 June 1986 and 16 April 1987, covering Bohm's entire life. That Maurice Wilkins, the "third man" in the Nobel Prize for the discovery of the DNA structure, had spent so much time interviewing Bohm is a sign of the high esteem he had for Bohm. They

[17] Pinch (1977). Cushing (1994). Olwell (1999). Mullet (2008a and b). Kojevnikov (2002). Freire Junior (1999, 2005 and 2011). Cross (1991). Forstner (2008). Pylkkänen (2007) and Bohm et al. (1999). Kožnjak (2018). Talbot (2017). Carvalho (2015), Petrônio (2013).

met each other at Berkeley, during World War II, when they began a solid and lasting friendship. According to Wilkins, Bohm "became a long-standing friend in England. We three [Wilkins, Bohm, and Eric Burhop] enjoyed a holiday together […] on Lake Tahoe, and Dave and I went on to Lake Pyramid to climb the famous pyramid-shaped rock there. Eric and Dave combined their enthusiasm for scientific progress with a sensitivity and concern for the problems of human life more generally". It is noticeable that in Wilkins Papers, 23 folders are dedicated to publications concerning David Bohm.[18] Bohm interviewed by Wilkins is a mandatory source for studies on Bohm's views. This interview and a certain number of other interviews with Bohm are available for consultation at the American Institute of Physics (AIP), College Park, MD.

The collection of interviews with physicists available at the AIP is impressive and I used a number of them to collect relevant information for Bohm's biography. Furthermore, I was able to interview people, who were kind enough to save time for these interviews, and deposit them at the AIP. They were Basil Hiley, Chris Dewdney, Franco Selleri, Alain Aspect, Anton Zeilinger, Nicolas Gisin, Yanhua Shih, and Sheldon Goldstein. I first met Hiley in 1998, in São Paulo, when he suggested I write a second biography of David Bohm. I balked at the suggestion but it stayed at the back of my mind. In 2015, when Angela Lahee, editor at Springer, suggested I write a biography of one of the quantum dissidents, Hiley's suggestion came back to the forefront and this time I did not hesitate. During all these years Hiley has read and commented on the papers I have written and spared time every time I have visited Birkbeck to talk with me; I have no words to express my gratitude for his kindness. While I did not record an interview, I also met Jeffrey Bub for several conversations about his experience as a student, first, and then a colleague of David Bohm's. I also had useful unrecorded conversations with Marco C. B. Fernandes and Jayme Tiomno. I am also indebted to other people whose remarks on Bohm or on my previous work on Bohm were for me intellectually challenging. They are Paul Forman and Michel Paty, and, in memoriam, Sam Schweber, Joan Bromberg, Alberto da Rocha Barros, and Amelia Hamburger.

Acknowledgements I have been working on Bohm's ideas since my Ph.D., obtained in 1995 at the University of São Paulo under the supervision of Michel Paty and Shozo Motoyama. My doctoral dissertation was dedicated to the analysis of Bohm's interpretation of quantum theory and its reception in the 1950s. Most of my time since then I have worked on the research which led to the book, *The Quantum Dissidents*, where Bohm was a major player. Thus, it is hard to list all the people and institutions I am grateful to for their support which resulted in this biography. While risking omissions, I would like to mention a few, in addition to those in the previous paragraphs. For the last sprint in the work on this biography, I obtained a leave of absence from my university, the Universidade Federal da Bahia, in Brazil. I am particularly grateful to João Carlos Salles, the president of the university, for understanding my need for leave of absence from my duties so as to finish this book. I spent this time at the American Institute of Physics, in its Center for History

[18]Wilkins (2003, 82). For the catalogue of Maurice Wilkins Papers, deposited at King's College, London, see: http://www.kingscollections.org/catalogues/kclca/collection/w/wilkins-maurice/. See, in particular, the following references: "K/PP178/12/26/1-23 Papers, 1965–1999, relating to the writings of quantum physicist and philosopher David Joseph Bohm (1917–1992)"

of Physics and Niels Bohr Library and Archives, in College Park, MD, in Washington, DC, area. I am thankful to its staff and particularly to Gregory Good, its director, and Stephanie Jankowski. During this time this study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior—Brasil (CAPES)—Finance Code 001 and the research was supported by the CNPQ [Grant 443335/2015-0]. I am grateful to Alex Wellerstein, for reading and commenting on Chaps. 2 and 3; Chris Talbot, for a careful reading of the full manuscript; Adam Becker, for sharing with me information about Bohm's FBI files, which he obtained through a FOIA request; Gustavo Rocha and Mirella Vieira, for discussions on Krishnamurti; my colleagues and students at the Laboratory Science as Culture [LACIC, Portuguese acronym], for discussion on biographies in the history of science; Cory Fischer, from the Krishnamurti Foundation; Amit Hagar, Amiram Ron, Gil Lainer, Yvette Gershon, Elaine Fletcher, Michael Liss and Nel Ben Ami, for obtaining documents and testimonies from Bohm's times at Technion and translation from the Hebrew; the Physics Institute at the Universidade de São Paulo and Ivã Gurgel, for the invitation to present a preliminary result of this book; Denise Sara Key, for her enduring support in the English revision; Angela Lahee for the suggestion and careful revision of the book proposal, as well as for her tolerance with my delays; Victoria Florio, for our conversation about science fiction magazines; Ricardo Zorzetto, for questions concerning the book; Italo Carvalho, for helping me with the graphs concerning scientometry; Thiago Hartz and Christian Joas, for their comments on a talk at the 25th International Congress of History of Science, held in Rio de Janeiro, 2017, which was an earlier version of Chap. 8; Monique Grimord, for discussions about the Pennsylvania mining towns; Chris Talbot, for several discussions on Bohm's work; Inés Cortazzo and Sonia Cabeda, for informal discussions about this project. My journey to Wilkes-Barre was easier thanks to the support of Peter Grimord, who also took some of the pictures over there; Agnes Soares, who explained the role of the Yearbook as source of information concerning American high schools, and Colleen Robatin and Patrick Peter, principals at the GAR Memorial Junior Senior High School. While I am thankful for all comments from these colleagues, undoubtedly however, faults in the final version of the manuscript are my entire responsibility.
I am also indebted to my sisters, Fatima, Inês and Silvana, and my son, Vitor, for their moral support; and Agnes Soares for her lovely and kind support and interest in this work.

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If the family environment was grim, Bohm had more fun at school. He attended the G. A. R. Memorial Junior/Senior High School, located at 250 South Grant Street. There he blossomed both as a promising science student and as a teenager with good social skills. Bohm's persona among his fellow high school colleagues was recorded in the 1935 Yearbook, on the occasion of his graduation. His calling and talent for science and mathematics is evidenced in his nickname, "Einstein," as well as in the manner colleagues and teachers portrayed his personality: "Deep sighted in intelligences, Ideas, atoms, influences". From this publication Bohm's other social skills can be inferred. He was part of the "Commencement Announcement Committee," which testifies his popularity among colleagues, and attended the German Club, the Math Club, two Dance committees, and Swimming Club. From later recollections, we also know how impressed Bohm was by learning geometry guided by his Mathematics teacher, Meyer Tope.[4]

The memory of Bohm is alive at the current G. A. R. High School. In 2004, the school created the "David Bohm Science Award," for excellence in science and mathematics. In the plate with the list of the students who have been awarded, it is written: "David Bohm was a 1935 graduate of G. A. R. Memorial High School. He was one of the most brilliant minds of the Twentieth Century. A world renowned physicist explorer of consciousness and colleague of Albert Einstein". If we consider the formative experiences Bohm had at home and at school, we may note, incidentally, that David Peat's focus on Bohm's family troubles led him to underestimate the positive role played by school in Bohm's education and personality (Figs. 2.1, 2.2, 2.3, 2.4, 2.5 and 2.6).

2.1.1 The Inception of Concerns with the Big Social Picture

Bohm's concerns with politics and societal issues were awakened still as a teenager stimulated by the social environment in Wilkes-Barre. This Pennsylvania coal mining town is part of the larger Appalachian anthracite coal region where the extensive and intensive coal mining began in the mid 19th century. Working conditions were oppressive, with the widespread use of child labor and unfair subcontracting systems, and labor unions and battles were part of the daily life of the region. However, Wilkes-Barre was a flourishing town with the coal and garment industries and a population of over eighty thousand people. In the 1920s and 1930s, this economic growth stalled, first due to the changes in the use of fuel with the decline of anthracite for home

[4]The GARCHIVE 1935, published by the Senior Class of G.A.R. Memorial High School, Wilkes-Barre, Pennsylvania. Recollections about the mathematics teacher, Meyer Tope, are in Interview of David Bohm by Maurice Wilkins on 1986 June 12, Niels Bohr Library and Archives, American Institute of Physics, College Park, MD USA, www.aip.org/history-programs/niels-bohr-library/oral-histories/32977-2. In the transcription of this interview his name is spelled as Mario Tope. The transcription was not revised by Bohm himself and the school records indicate the right name is Meyer Tope. I am thankful to Colleen Robatin for facilitating my consultation of the school records and to Agnes Soares for discussing the meaning of some of these records.

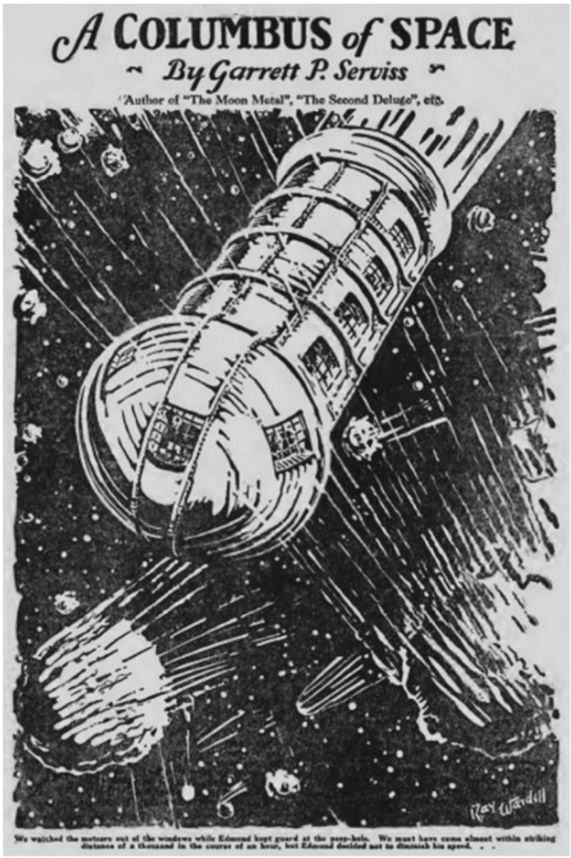


Fig. 2.1 A Columbus of Space, by G. P. Serviss, the science-fiction story which fascinated Bohm in his childhood, published in Amazing Stories, 1926

heating purposes, and then from the vicissitudes of the Great Depression. The crisis brought huge social unrest and unemployment to the region. Indeed, the decline on the US mining towns in that region would become a lasting drama, with ups and downs, which included few periods of recovery succeeded by new declines. Nowadays the signs of decline are omnipresent in Wilkes-Barre with a population around forty thousand people. The most recent chapter in this drama took the shape of a clash in the US 2016 presidential elections between the two major candidates presenting different proposals for the future of the region.[5]

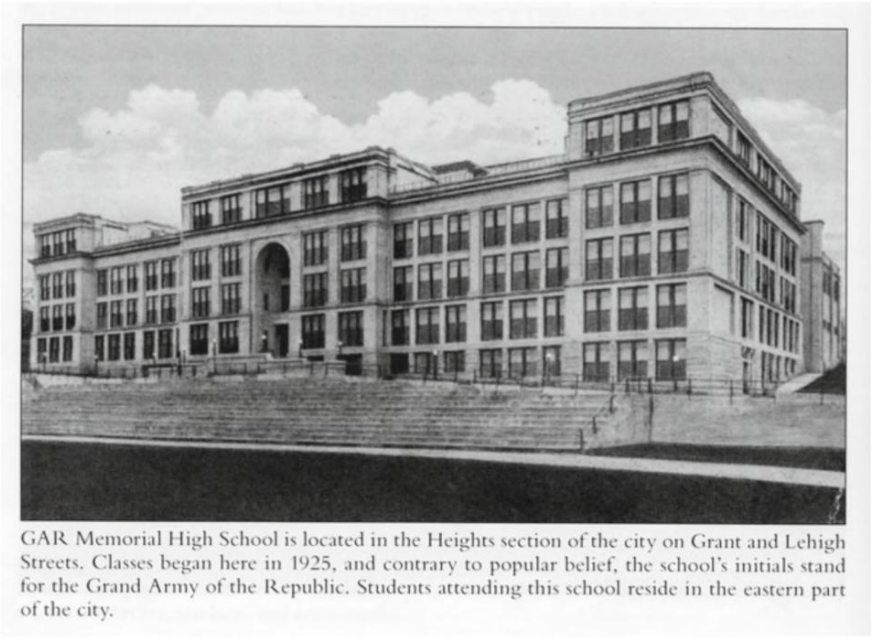
Back to the 1930s, we have a vivid testimony from somebody who lived most of the 1930s in Wilkes-Barre trying to organize the unemployed in the fight for their rights. "Behind the very real beauty of the region lay a bitter poverty. The depression had started there here in the twenties, and by the time it reached other areas, the eastern

[5]On the history of labor contracts and battles in the anthracite region, see Wolensky and Hastie Sr. (2013). On the clash in the presidential elections concerning the drama of the mining towns, see the NPR podcasts "In The Coal Counties Of Central Appalachia, Will Trump's Promises Come True?" 09 May 2018, available at https://www.npr.org/2018/05/09/607273500/in-the-coal-counties-of-central-appalachia-will-trump-s-promises-come-true, accessed on 23 Jan 2019. I am thankful to Monique Grimord for discussion on this subject.

Fig. 2.2 410 Hazle Street, Wilkes-Barre, PA, where Bohm's father ran his second-hand furniture store and lived on the first floor. As an evidence for the economic decline of the town, the current store went out of business. *Credits* Picture by Peter Grimord

Pennsylvania mining towns were already devasted". The impact of the depression on the working classes at the towns may be illustrated by the following figure: "the number of miners in the industry fell from 140,000 in 1928 to less than 80,000 in 1930". At that time there was no unemployment benefits. This dramatic social crisis created social unrest and the workers began to organize themselves to protest. They were helped by field organizers from unions and left groups such as the Communists. These grassroot organizations were not accepted by the owners of the coal companies. Still according to this testimony, in Wilkes-Barre, "the political repression was as bad as anywhere in Illinois, and the economic situation was much worse," and "there was virtually a rule of terror by the coal companies, who controlled the police and local officials in most towns". However, the leaders of the social movement also found some support in the Wilkes-Barre's local elites, which included some teachers, ministers, lawyers, and even the mayor. The picture in Fig. 2.10 taken from a 1933 manifestation in Wilkes-Barre, is a clear evidence of the strength of this movement. Still according to this testimony, the movement of the unemployed in this region contributed to change the way the unemployment was treated in the US. According to him, "in the summer of 1935, Congress passed the Social Security Act. This bill incorporated our main goal of unemployment compensation as well as a pension system".[6]

[6]Nelson et al. (1981, 94–161).



GAR Memorial High School is located in the Heights section of the city on Grant and Lehigh Streets. Classes began here in 1925, and contrary to popular belief, the school's initials stand for the Grand Army of the Republic. Students attending this school reside in the eastern part of the city.

Fig. 2.3 G.A.R. Memorial Junior Senior Highschool, Wilkes-Barre, PA. Façade in the 1930s, when Bohm studied there. *Credits* Elena Castrignano, Wilkes-Barre, Postcard History Series, Arcadia Publishing, 2008

Fig. 2.4 G.A.R. Memorial Junior Senior Highschool, Wilkes-Barre, PA. Current façade. *Credits* Picture by Peter Grimord

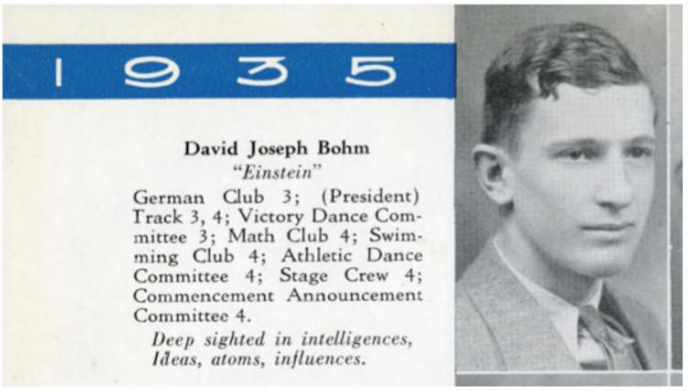


Fig. 2.5 Bohm portrayed in the Yearbook 1935 from the G.A.R. Memorial Junior Senior High-school, Wilkes-Barre, PA. Interestingly Bohm was nicknamed by his colleagues, Einstein, and portrayed as "deep sighted in intelligences, ideas, atoms, influences". *Credits* The GARCHIVE (1935), courtesy of Colleen Robatin

The authorship of this testimony has some overlapping with Bohm's life history. These recollections came from the autobiography of Steve Nelson, who was a member of the Communist Party and spent most of the thirties organizing coal workers in the region of Wilkes-Barre. He only left the town to voluntarily fight in the Spanish Civil War, coming back to the town for a while after this.[7] Bohm's and Nelson's life would become entangled during the war, at Berkeley, in an episode which would be later used against Bohm during McCarthyism. We will come back to this later in the book. As far as we were able to track down, neither Nelson nor Bohm recalled having met each other while Bohm was a teenager living in Wilkes-Barre. In fact, a later research conducted in 1943, when Bohm was already at Berkeley, led the FBI to conclude that "no derogatory information relative to either the subject [Bohm] or his family was developed at Wilkes-Barre concerning Communistic or other radical tendencies".[8]

"My main interest was really physics you see. Although I had a vivid interest in politics and the general state of civilization;" these were Bohm's recollections, more than forty years later, from his high school and college times. While we should take any later recollections with a pinch of salt, as they are also shaped by current experiences, it is appealing to follow Bohm's recollections of his political and cultural views as they evolved throughout his life. As a teenager Bohm strongly believed in the American dream as consequence of individual achievements. As the Great Depression hit Wilkes-Barre, individualism ceded room for more socially and collectively inspired views. Towards the end of his high school years the news from

[7] Nelson et al. (1981).

[8] David Bohm's FBI File, (1358423-0-100-HQ-207045, p. 7). I am grateful to Adam Becker for sharing with me these documents which were obtained through a FOIA [Freedom of Information Act] request.

Fig. 2.8 Child labor was still common in the coal mines at the time Bohm was born. Title of this picture: Breaker boys in #9 Breaker, Hughestown Borough, Pa. Coal Co. The smallest boy is Angelo Ross, Location: Pittston, Pennsylvania. In 2018 these pictures were part of an exhibition of Anthracite Photographers: Photographers of Anthracite, Anthracite Heritage Museum, Scranton, PA, curated by Black et al. (2018). *Credits* Picture by Lewis Hine. Library of Congress, Prints and Photographs Division, National Child Labor Committee Collection, LC-DIG-nclc-01139

2.2 The Shaping of a Scientific Style

During high school in Wilkes-Barre, Bohm nurtured a combination of highly imaginative ideas either in science-fiction or in science itself with the acquisition of mathematical skills. From this time Bohm had recollections of being impressed by tornados, trying to see how objects and shapes could emerge from sole movements. He had a vivid recollection of a hurricane and its consequences hitting his father's store. And yet, as we have seen, his first contact with geometry left an indelible mark.[11]

High school over, his father supported him to go to Pennsylvania State College, near Wilkes-Barre (120 miles away), despite mistrusting science as a potential professional career. Penn State, now a university with 100,000 students and 24 campus, had been set up in the mid 19th century, and was then a college with a stronghold position in agricultural sciences but with a small number of students doing undergraduate degrees in physics. Indeed, as Bohm recalled later, it had about five physics students when he was there.

[11] Interview of David Bohm by Maurice Wilkins on 1986 June 12, AIP, College Park, MD USA, www.aip.org/history-programs/niels-bohr-library/oral-histories/32977-2.

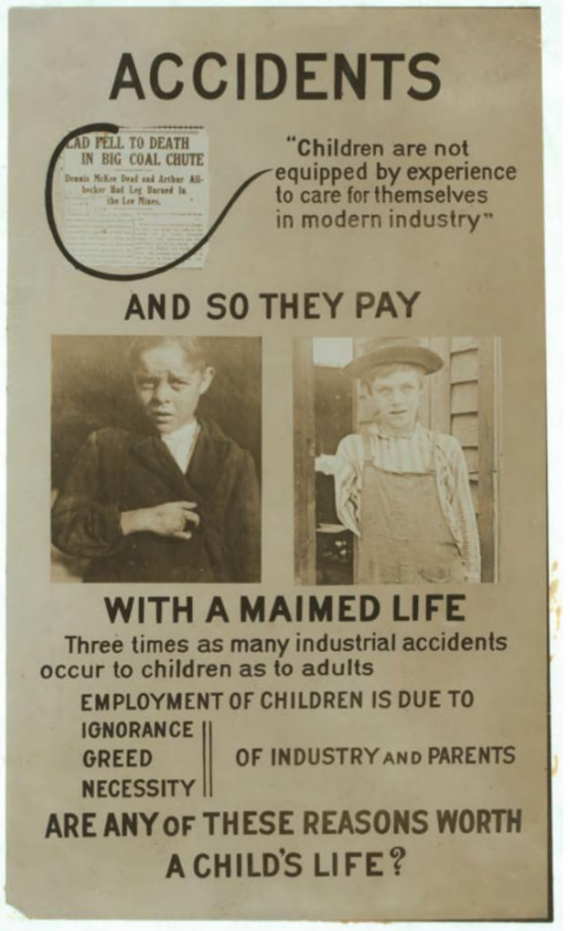


Fig. 2.9 Campaign against the child labor in the coal region at the end of the 1910s. Title: Exhibit Panel, c. 1913 or 1914. In 2018 these pictures were part of the exhibition of Anthracite Photographers: Photographers of Anthracite, Anthracite Heritage Museum, Scranton, PA, curated by Black et al. (2018). *Credits* Picture by Lewis Hine. Library of Congress, Prints and Photographs Division, National Child Labor Committee Collection, LC-DIG-nclc-04924

Penn was not an enticing intellectual environment for a would-be physicist. Quantum mechanics teaching, for instance, was limited to Bohr's atom. In spite of these constraints, the four years Bohm spent at Penn were very positive for his training in physics. He attended a good mathematics course, dealing with topics such as analytic functions, series, and transcendental functions and solving problems from *A course of modern analysis*, a standard university textbook written by E. T. Whittaker and G. N. Watson, whose first edition was in 1902. Later on, at Caltech, he realized how appropriate the mathematics and physics skills he had acquired at college were for physics research. In addition, he had time to constantly walk around the town, a college town, and talk to colleagues about science and social issues. This lifestyle, walking and talking, would become his favorite way of thinking about scientific issues.[12]

[12] Whittaker and Watson (1943).

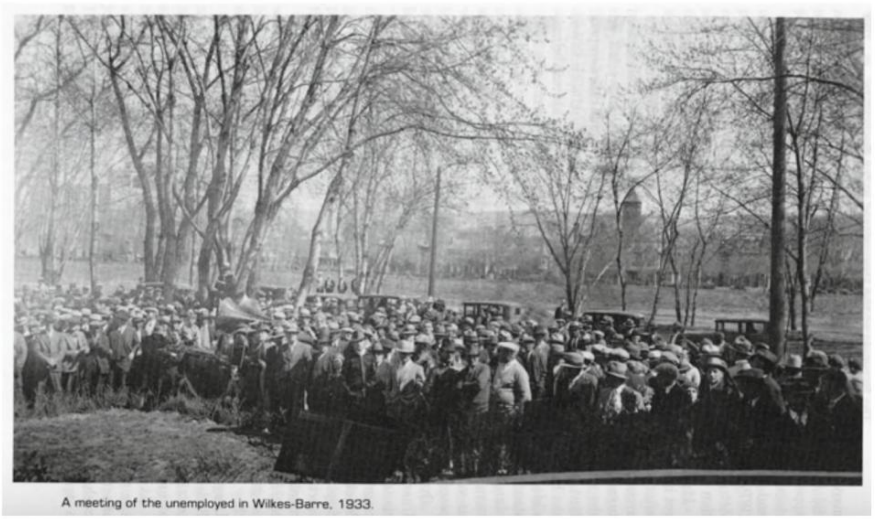


Fig. 2.10 Meeting of unemployed miners, in Wilkes-Barre, 1933. *Credits* Nelson et al. (1981)

Fig. 2.11 Osterhout Free Library, Wilkes-Barre, PA, where Bohm used to read the magazines The Nation and New Republic and developed his social awareness. *Credits* Picture by Agnes Soares