
Robert Temple

# David Bohm

**A shy professor, his questioning of quantum theory seems largely to have been misunderstood by fellow physicists; yet for this and often profound views on the nature of scientific thought he deserves wider recognition. Robert Temple has talked to him and gained some insight into this very private physicist**

DAVID JOSEPH BOHM is probably best-known as an iconoclast; his subject, quantum physics. But he did not come to this position by choice. He really did try to accept the orthodox viewpoint; in fact, he wrote what many consider the standard textbook about it. But he could not accept the apparent contradictions and confusions of the orthodox view championed most notably by the Danish physicist Neils Bohr in the 1920s. David Bohm's story is one of an odyssey into dissent, and general lack of comprehension of his alternative views.

Born in 1917, Bohm was the son of a Jewish furniture dealer in a mining town in upstate Pennsylvania. There had been no scientists in Bohm's family. Indeed, his father did not encourage this inclination in his son, and thought he should go into the family business instead, and think about something practical, like making money. But Bohm went to the nearby Pennslyvania State College, obtained a science degree, and from then on his career as a scientist seemed inevitable. He did his PhD at the University of California under Robert Oppenheimer, and stayed to become a research physicist there. In 1947 he received an appointment as assistant professor at Princeton University, in New Jersey, an indication of the high opinion in which he had rapidly come to be held. Considerably before he arrived at Princeton, Bohm had already begun work on his classic book, *Quantum Theory* (Prentice Hall), which he was to complete in 1951.

"I wrote my book *Quantum Theory* in an attempt to understand quantum theory from Bohr's point of view. After I'd written it I wasn't satisfied that I really understood it, and I began to look again. I sent copies to [Albert] Einstein, to [Neils] Bohr, and to [Wolfgang] Pauli. I got no answer from Bohr, an enthusiastic answer from Pauli, and Einstein answered saying he'd like to discuss it with me since I was at Princeton. He felt the book was about as good as you could do about Bohr's point of view, but he still wouldn't agree. We discussed it, and the basic criticism of quantum mechanics was not its lack of determinism but its lack of any way of conceiving the structure of the world in any way at all. That is, essentially, Bohr says it is inherently ambiguous or meaningless to give a more detailed description of the nature of reality than is determined by [Werner Heisenberg's] uncertainty principle; not merely that it is unknown, but that it has no meaning.

"Now, I perceived that point of view, but I didn't feel entirely satisfied with it. I had accepted it for several years. Then, after finishing the book I still felt that something was not terribly clear. In particular, there was no real way of representing or understanding what is meant by movement or process in the quantum mechanics. One could only discuss an observation, and then another one, and then another one, with the wave function collapsing from one to the other, and it seemed to make the whole of existence depend on the physicist being around to observe it. And while Bohr didn't really say that, nevertheless it essentially meant that we were restricted to describing the phenomena, and even that up to some limited degree of accuracy given by Heisenberg's uncertainty principle. I was primarily disturbed by the inability to conceive of motion at all."

**Birth of an alternative view**

Bohm's discussions with Einstein were a turning point for him. But even before they took place he had begun work on an alternative view of quantum phenomena: "Something that was rather close to what the 'implicate order' turned out to be later [referring to his current theory], which was to say that if a wave spreads out from some source, then another wave must converge onto the place where it's observed, and somehow one wave gives rise to the other . . . the new wave would unfold into a point where the electron would be observed."

However, Einstein's invitation to discuss the basic issues of physics deeply affected the development of Bohm's ideas. "After the discussion with Einstein, I began to think on other lines, and I began to think that this Schrödinger equation [the wave equation of quantum theory] resembled a Hamilton-Jacobi equation, and you could think of a particle being *effected* by a wave. That was the model which I proposed in papers in 1952."

Bohm elucidates the historical background by discussing the idea of the theory of mechanics put forward by the two 19th-century mathematicians, Sir William Rowan Hamilton (1805-65) and Carl Gustav Jacobi (1804-51). "In the 19th century there were various people, including Hamilton, who showed that classical mechanics could be understood as a theory of waves, and particles moving normal to those waves. From this you could have anticipated a large part of quantum mechanics, but in fact people didn't do it because they said it was only mathematics. When quantum mechanics was developed, it was seen to be very similar to classical Hamilton-Jacobi theory. What I did was to see that the difference was what I called the 'quantum potential'. I modified the Hamilton-Jacobi equation by the introduction of the quantum potential, which explained the difference between classical and quantum mechanics. I later found that [Louis] de Broglie had proposed a similar idea many years before, but that he had abandoned it because of criticisms by Pauli, showing that it did not properly handle a system consisting of many particles. However, I then went on to answer these criticisms, by extending the notion of quantum potential to the many-particle system."

When asked what the quantum potential *is*, Bohm replies: "You cannot state what any potential *is*. Potentials are things which, when assumed, explain the connections of other things. You see, why do we assume an electric field? What *is* an electric field? We don't know. If we knew, we would understand why field and charge are connected in the particular way in which they are.

"Shall we begin by explaining what we mean by a phrase, 'classical potential'? People are using the phrase quite freely, but do they know what it is? If you say there's a gravitational potential, you merely mean that if you put a particle at a certain place, it will liberate energy when it falls. You do not have any picture of where it gets the energy from, of what the force is, or anything. It's the same as when I was a child, people would say 'Electricity is very mysterious'. Now we say it's not so mysterious, but still nobody knows what electric force *is*. We're used to it, that's all, by giving it a name and getting used to handling it. If you assume these potentials, you will explain a wide range of phenomena, and calculate them, and so on. Now in 1952, I was merely proposing the quantum potential as an explanation in that spirit. In the same spirit as the classical explanation, but to understand the difference between classical and quantum mechanics at that level. In order to understand what the quantum potential *is*, you would have to go deeper and go so deep as to explain what all these potentials are. What is a gravitational potential, what is an electrical potential, what is a quantum potential? You see, you would have to explain all the forces and explain why they act on particles. Now, nobody has done that."

Just as Bohm reached this crucial stage in his theoretical insights, his life in the US was totally disrupted by the McCarthy era. As a former colleague of Robert Oppenheimer, Bohm was caught up in the investigations and, apparently unwilling to testify against friends, he left the US and took refuge at the University of Sao Paulo in Brazil for four years. From there, he went to Israel for two further years. During all this time he confesses he was somewhat disheartened and lacked feedback from physicists and colleagues to such an extent that his real theoretical work was considerably impeded.

During this low point of his life, Bohm was fortunate enough to meet Sarah Woolfson, whom he married in Israel in 1956. Since that time, Bohm has had the invaluable support and companionship of a totally devoted partner. Sarah Bohm takes an interest in everything her husband does and says. She describes her first impression of her husband: "When I first met Dave, it struck me that here was a tremendous courage in looking at things honestly, whatever the consequences. He was ready to look at something whatever the results would be, whether it would go along with what he might be proposing or not. And this really did strike me very forcibly."

When questioned about whether he had from his earliest days been so determined to break free of conventional and comfortable notions, Bohm replies with what could be taken as a general credo of his life: "In the long run it is far more dangerous to adhere to illusion than to face what the actual fact is. And secondly, you can say, what is the point of life if you live in an invented world; if there's no relationship either to the world or to the people or to anything? It *isn't* a relationship if you're related to something which isn't there, or which is just there to make yourself feel comfortable. I think we all have this tendency, and it's the problem of mankind. I could put it in terms of three words: illusion, delusion, and collusion. They are all based on the word *ludere*, meaning 'to play'. You can see illusion as 'playing false with perception', delusion as 'playing false with thought', and collusion as people playing false together to support their illusions and delusions. This is the thing that has always made mankind's life miserable, and which is threatening our survival. We can't face the implications of what we're doing, and it will lead us over the edge, into the abyss.

"The essential point is that we must admit that when thought is playing false, it's playing, but even when it's not playing false, it's also playing. Einstein emphasised that, that thought is free creation; thought is play. And you have to play with thought and discover to what extent it has any significance, rather than to say you're grasping truth. Now, the attempt of thought to say it's grasping final truth starts it playing false. That's why people who think they have the final truth are unwilling to change their ideas. And the fundamental mistake which has gone wrong in the thought process is that people fail to see that thought is play. Now, I think that I've always seen that."

The year after his marriage, Bohm brought out his second book, *Causality and Chance in Modern Physics* (Routledge, 1957), more or less continuously in print for 25 years and being reprinted again now. This is the book familiar to most of Bohm's admirers in the field of philosophy of science, and which made his name as an original thinker. In it he articulates his sense of the inexhaustibility of Nature and the transience scientific theories.

In the same year, 1957, Bohm came to England as a research fellow at the University of Bristol. Finally, in the autumn of 1961, he took up an academic post commensurate with his standing, and became professor of theoretical physics at Birkbeck College, University of London, a post that he still holds.

In 1965, Bohm published *The Special Theory of Relativity*, in the first paragraph of which he stresses that the subject is "significant as the first stage of a radical change in our basic concepts . . . For as is well known, the modern trend is away from the notion of sure 'absolute' truth." And the final sentence of the book insists again that "no absolute knowledge is to be encountered".

Between the appearance of these two books, Bohm began to be interested in the Indian philosopher Krishnamurti. He says: "I first became interested in him in 1959. I came across a book of his in the public library in Bristol, *First and Last Freedom* [Gollancz, 1954], which interested me because he referred to the observer and the observed, which is of course the thing in quantum theory. He said there is no distinction between the observer and the observed, which quantum theory is always saying, which really I felt was one of the essential new features of quantum theory. He was referring of course to the psyche, but I felt a great similarity. I met him in 1961. He came to London and we had discussion, and after that I began to see him when he came to London and later I saw him more frequently, and got to know him quite well."

Friendship with the Indian philosopher seems to have encouraged Bohm to be unashamed of discussing "wholeness" in Nature, and to express his thoughts on matters which were not purely to do with physics. In 1968, Bohm published two remarkable non-scientific essays. The first, "On creativity", appeared in volume 1 of the journal *Leonardo*. It was based on a talk delivered before the Architectural Association in London early in 1967. Bohm pointed out the similarities between artistic creativity and the scientist's impulse "to learn something different from what can be inferred from previous knowledge". He notes that the vast majority of human beings are not fully creative and appear to be in a "state of sleep". He attributes "the tendency to 'fall asleep'" to "an enormous number of habitually applied preconceptions and prejudices, most of which are absorbed at a very early age", and believes the example of scientific enquiry can help to free people from such constraints, and lead the mind back to "a more nearly normal order of operation". His second essay was "On the relationships of science and art", for an anthology edited by Anthony Hill, *Data: Directions in Art, Theory and Aesthetics*, in company with a large number of artists, architects, designers, and planners.

In this extraordinarily profound essay, Bohm remarked

## The problem with quantum mechanics

Quantum mechanics, which allows physicists to calculate the behaviour of matter at the subatomic level, was born in the first decades of the 20th century, and is particularly associated with names of Neils Bohr and Werner Heisenberg, both Nobel laureates. Bohr it was who fathered the quantum theory of the atom, in which electrons orbit a nucleus with only certain specific, or "quantised", energies; Heisenberg is best known for his "uncertainty principle", which lies at the heart of quantum mechanics.

The root of the philosophical disquiet with quantum mechanics rests with its inherent lack of determinism, which Heisenberg's uncertainty principle embodies. Heisenberg showed that there is a limit to the precision with which certain pairs of properties of an electron, for instance, may be known simultaneously; it is possible to know very precisely, for example, the momentum of a particle, but not at the same time its position. Furthermore, quantum mechanics gives only the probability that a particle will be in a certain state at a certain time. This probability is given by the so-called "wave function", according to the "wave equation", laid down in the 1920s by another Nobel laureate, Erwin Schrödinger.

Another, more subtle "problem" with quantum mechanics is that of "nonlocality". The basic concept here is enshrined in the paradox due to Albert


Werner Heisenberg


Neils Bohr


Albert Einstein

Einstein, who was never happy that quantum mechanics told the whole story, and his colleagues Boris Podolsky and Nathan Rosen. They envisaged a thought-experiment in which two parts of an atomic system fly apart, as when a molecule splits into two atoms. They argued that a measurement made on one part would, according to quantum mechanics, influence the other; but how could this be without some sort of action at a distance, that is, some non-local effect; or, perhaps, the propagation of a signal faster than the speed of light?

Such intrinsic difficulties with quantum mechanics have led some people to postulate "hidden variables": properties that exist at some deeper level than we can currently measure, and which would give results consistent with quantum theory, while at the same time restoring determinism and locality to physics. Einstein himself figures among those who have espoused such views. However, experimental tests that put the thought-experiment into practice continue to suggest that quantum mechanics gives the correct answers without the necessity for hidden variables, as Bohm's colleague Basil Hiley has discussed in *New Scientist* (vol 85, p 746) and recent results have shown (Monitor, 19 August, p 485). *CS*

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*Sarah Woolfson married Bohm in 1956. "It struck me that here was a tremendous courage in looking at things honestly, whatever the consequences," she recalls*

*The Philosophy of Quantum Mechanics: The Interpretations of Quantum Mechanics in Historical Perspective* (Wiley, 1975), failed in some ways to understand Bohm. When confronted with this point, Bohm readily agrees but tries to apologise for Jammer, saying that their conversations were in Israel in the 1950s when "my mind was not really on my work", and so forth. But the fact remains, that the large section on Bohm's theory of hidden variables in Jammer's book is the main source of information about Bohm to many physicists, and that information is not really adequate.

Jammer portrays hidden-variables theory as an attempt to impose determinism on an otherwise indeterministic quantum theory, and makes out that Bohm is

that art had its origins in the artist's necessity "to observe nature with a certain kind of objectivity that could be called the germ of a 'scientific' attitude". He believes that science can be of service to art and culture through strengthening this tendency and says: "The most significant implication of science is . . . that it teaches us to look at facts in an unbiased way, *whether we like it or not*, and that it is meaningless to do otherwise . . . such a *scientific spirit* is necessary, not only in what is commonly called 'scientific research', but also in art and every phase of life . . ."

In these essays, Bohm made his public debut as a thinker concerned with all the larger questions of human nature and culture. And as usual, he is at his full force as the true iconoclast, a destroyer of icons. His reforming zeal is intensely felt, but it is very hard to appreciate from his personal manner. For he is extraordinarily shy, modest, self-effacing, and quiet-spoken. He is the epitome of the ancient Confucian gentleman's motto, "Live unnoticed". From his modest house in the quiet London suburb of Edgware, if he were to venture out shopping (and before his open-heart surgery recently he was a great walker), no neighbour would guess that the softly-spoken, almost apologetic manner of the 65 year-old man with the American accent masked the tenacity and courage of a Bengal tiger, living unnoticed in their midst. Bohm's complete lack of ego or any air of importance completely disguise the enormity of his intellect. With an almost painful reluctance does Bohm allow his wife to coax him to reveal that he has written this or that article, or force him to admit that he has actually published one more book than one had thought. His shyness is so complete, that one soon realises why Bohm is known to few scientific colleagues, and understood by even fewer. He has no disciples, but for many years he has had the invaluable support and collaboration of his junior colleague, Basil Hiley at Birkbeck College, and they have written several important scientific papers together.

To date, Bohm's position in quantum physics has been subject to so many drastic misunderstandings and misinterpretations, that it is to be doubted whether more than a handful of physicists alive today really appreciate his position. Max Jammer, who is usually reliable in his book

a determinist. But Bohm is probably as far from being a determinist as any physicist in the world today, and even in the 1940s he tolerated determinism only as a mere possibility: "At one stage, I saw that the advantages of determinism were a certain clarity of what you were talking about, but I didn't like determinism in many ways because it seemed too rigid. It rigidly limited possibilities in an arbitrary way. So I was always somewhat repelled by determinism, but at the same time, at a certain stage I was ready to accept it as a possible way of trying to get a clear statement of the laws of Nature. But even my theory of 1952 was *not* deterministic . . . The theory I proposed does not, as Jammer said, get around Heisenberg, it simply gives a rational basis to Heisenberg. In fact, Heisenberg gave up his explanation and adopted Bohr's point of view. So we must distinguish two Heisenbergs: the early Heisenberg, which is the one people usually talk about, and the later one who denies the earlier one, but people don't know that. So in a way you could say that the theory I proposed supports the early Heisenberg. It enables you to make sense out of what the early Heisenberg proposed. So rather than being pro-deterministic, it actually gives a rationale behind the indeterminism of Heisenberg."

Jammer had been misled by Bohm's attempt to conceive of Heisenberg's uncertainty principle as a manifestation of processes at deeper levels, or activities of so-called "hidden variables", as being an attempt to impose determinism on the ineffable. What Bohm merely wished to do was to probe deeper and postulate levels of reality that could be intuitively understood and which would "make more sense", and of whose operations the mysterious uncertainty principle could be seen in context as a sensible manifestation rather than as an inexplicable "final truth" acting as a permanent philosophical cul-de-sac. What it came down to was this: most quantum physicists were quite content to acept thingsas they were, seizing up on Bohr's futilism as a ready excuse to avoid the trouble of further deep thought. They could simply get on with calculating and solving equations and refer enquirers to Bohr if anyone dared to approach them and ask: "What are you actually *doing?*"

Bohm, on the other hand, was most definitely, determinedly *not* satisfied. His was the voice from the crowd that shouted: "The Emperor has no clothes!" And a certain amount of closing of ranks in the crowd may be presumed to have taken place, to muffle this comment. For example, although in his exciting and original papers "On the notion of order", Bohm has made giant strides towards redefining some of the basic concepts and terminology of order, structure, and measurement, which deserve to be considered some of the finest philosophical writings of recent decades, not one philosopher has apparently ever commented upon them. Bohm plaintively and modestly says: "These things take time."

Bohm's latest book, and certainly his most interesting, is *Wholeness and the Implicate Order* (Routledge, 1980). In this book may be found a mature presentation of Bohm's basic philosophical position, along with many details of his revolutionary proposals for altering our basic ideas of physics. The central idea in this book is the "enfolded order", an idea that struck Bohm in the 1960s as he was watching a television programme. A specially-designed jar at the Royal Institution has a rotating cylinder inside; between the cylinder and the glass jar itself is a narrow space filled with glycerine. The cylinder is turned by a handle at the top, and some ink is dropped into the glycerine from above. As Bohm watched the handle turning the cylinder, he saw the dark ink become "enfolded" into the light-coloured viscous glycerine and smear away almost to nothing. Then, the handle was turned back the other way and as if by a miracle, the original drop of ink reappeared; it was "unfolded" from the glycerine, and reconstituted itself and regained its original coherence. Bohm exclaimed: "Well, that's what I want!" And it became the central visual image in his explanations of his theory of the "enfolded and unfolded orders," also called the "implicate and explicate orders".

Bohm now believes that forms "explicate" themselves similarly from the Universe as a whole, and then "fold back in again", only to re-emerge again, in ceaseless succession. The ink in the glycerine is the image to demonstrate how order can appear to be absent but nevertheless be implied and ready to recur under the right conditions. He views the position and the momentum of the electron in the way he views two drops of ink dropped into the glycerine at different stages of turning; if the position is clearly observed, the momentum is still "smeared", whereas by the time the turning has progressed far enough for the momentum to become clear, the position has become "smeared". There is no doubt at all that Bohm regards himself and every one of us as also being momentarily explicated or precipitated forms which have emerged from the Universe and will return into it, like drops of ink. The implication of this "implication" is that our "disappearance" need not be the end of us.

Bohm's challenge to physics is multifarious, detailed, highly mathematical, and revolutionary. Although physicists of his own age are unlikely to want to look into the challenges he poses, as they have now shown such reluctance to do so for more than 30 years, younger scientists have been showing increased interest in his ideas. As Terry Clark of the Physics Department of the University of Sussex told me, with genuine affection in his voice, after admitting that he didn't know Bohm and had only met him once: "Bohm has been an inspiration to us kids in trying to break out of these closed philosophical views the Bohr school set up in the 1920s and 1930s. I'm just grateful to Bohm for his trying to kick the chair away from what has been set up for the last 40 years."

Perhaps the great glycerine jar of the Universe will turn and smear the *r* slowly into an *m*, and what was the "Age of Bohr" may become in future the "Age of Bohm". The implicate order seems to have a sense of irony, and stranger things have happened in the history of science. □