Werner Heisenberg and Albert Einstein

Albert Einstein was the early model and inspiration for Heisenberg, but scientific conflicts and political stresses marred their relationship.

Gerald Holton

Werner Heisenberg is suddenly in the news again, this time thanks to the award-winning new play *Copenhagen* by Michael Frayn.[1] The play centers on the ambiguous reasons for Heisenberg's visit in 1941 to his early mentor, Niels Bohr, in German-occupied Copenhagen. It speculates on what might have transpired during the evening walk they took at that time, which Bohr ended abruptly, disturbed by something Heisenberg had said. (See David Cassidy's article on page 28.)

The play brings together the three quite different worlds of science, history, and theater, and there is a danger that some might confuse the play—a work of fiction—with a documentary. One must never forget, as Samuel Taylor Coleridge put it in his *Biographia Literaria* of 1817, that the task of the poet and dramatist is to create the "willing suspension of disbelief"; and, as John Keats commented at about the same time, one of the "negative capabilities" of great authors is that of "remaining content with half knowledge."

Scientists and historians also must often be content with only half knowledge, at least for a time. One poignant example is that private conversation between Heisenberg and Bohr during their walk in 1941. Heisenberg gave his most familiar version of what transpired in a letter to the journalist Robert Jungk, who published it in his book *Brighter than a Thousand Suns: A Personal History of the Atomic Scientists* (Harcourt, Brace, & Co., New York, 1958). The main thrust of Heisenberg's account was that the researchers in his "Uranverein" in 1941 "knew that one could produce atom bombs but overestimated the necessary technical expenditure at the time." Still, the physicists engaged in such work could have "decisive influence on further developments, since they could argue with the government that atom bombs would probably not be available during the course of the war." The discussion during the evening walk "probably started with my question whether or not it was right for physicists to devote themselves in wartime to the uranium problem." Heisenberg said that Bohr was shocked by this train of thought, assuming "that I had intended to convey to him that Germany had made great progress in the direction of manufacturing atomic weapons." Heisenberg was unable to "correct this false impression."

Although Heisenberg had begun the letter by cautioning, "I may be wrong after such a long time," and even though Jungk later called the notion of passive resistance owing to moral compunction by wartime German scientists working on exploitation of nuclear energy "a myth," many have taken the above to be the definitive description of the Bohr–Heisenberg meeting, and have considered Heisenberg's letter and similar statements by him and others to be an accurate reflection of the goals of Heisenberg and his fellow researchers.

However, in 1985, when I was in Copenhagen to speak at a meeting in honor of Niels Bohr's memory, I was approached by Bohr's son, Erik Bohr. He showed me a letter written by his father and found after his death, folded in his copy of the book by Jungk. That letter, addressed to Heisenberg, took serious issue with Heisenberg's published version of the meeting, in quite firm language—so much so that Niels Bohr had apparently decided not to mail it.

When asked what should be done with the letter, I advised that it be kept in the archives. Today the letter is part of the Bohr political correspondence file, which the family has decided not to release to the public until 2012, fifty years after Niels Bohr's death. It would therefore be inappropriate for me to say more about it now. Thus, on the question of what happened during that walk, the world will remain with half knowledge for perhaps another dozen years. In the meantime, Jeremy Bernstein's book, *Hitler's Uranium Club* (American Institute of Physics, New York, 1996) is an excellent source for understanding the ambitions of Heisenberg's "Uranverein," and the reasons for its ultimate failures.[2]

Captured by Einstein

The larger theme of Heisenberg's long-term relationship with Bohr, starting with their first meeting in 1922, has been well covered in the biographies by David Cassidy and Abraham Pais.[3] But to better understand Heisenberg's enormous talent and his responses to the challenges of history, it is useful to take a complementary point of view, and to examine another deeply significant relationship with a major scientist.

At the center of this case are Heisenberg and Albert Einstein. My interest in their interaction was aroused at a December 1965 UNESCO conference on Einstein's work, where I had a first, accidental encounter with Heisenberg himself. I had been invited to lecture on Einstein's epistemology, focusing on his pilgrimage from an early positivism, strongly influenced by Ernst Mach, to a rational realism close to that of Max Planck.[4] On finishing my lecture, I left the podium, the next speaker came forward, and we met midway. It was Heisenberg. He seemed pleased, and in passing whispered to me, "We must talk afterwards." I shall return to this encounter later.

Among the main sources for what follows are Heisenberg's eloquent books and autobiographical articles, the unpublished transcripts of the twelve interviews he gave to the History of Quantum Mechanics Project, his unpublished letters to Einstein, and some thoroughly researched biographies. From these it emerges first of all that, in the history of modern physics, no one but young Werner was so destined by the fates to be captured by Einstein's relativity theory. In his *Gymnasium* days, he read

Gerald Holton *is Mallinckrodt Professor of Physics and professor of history of science at Harvard University.*

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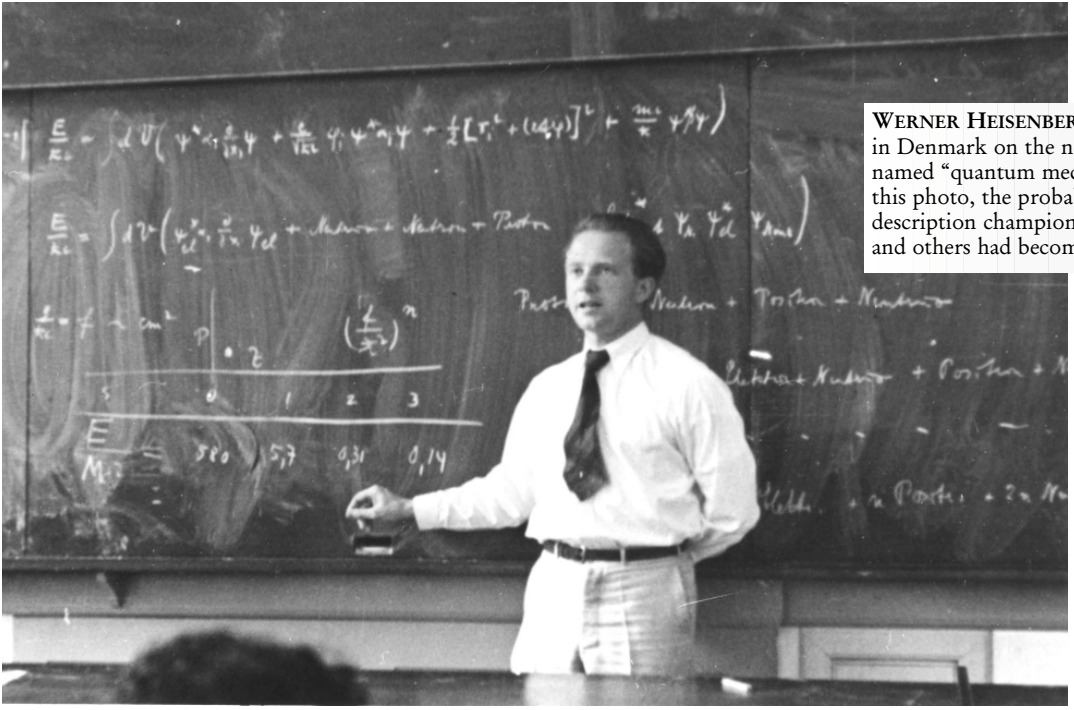


WERNER HEISENBERG LECTURING IN 1936 in Denmark on the new physics that he had named "quantum mechanics." By the time of this photo, the probabalistic "Copenhagen" description championed by Heisenberg, Bohr, and others had become well established.

and loved Einstein's newly-published popular book on special and general relativity. He would have been not quite eighteen when he heard of the sensational November 1919 eclipse expedition results. At the University of Munich, where he studied under the guidance of Arnold Sommerfeld, he attended Sommerfeld's lectures on relativity. Heisenberg was also captivated by Herman Weyl's book, *Raum-Zeit-Materie*. To top it off, one of his closest friends in Munich was Wolfgang Pauli, who, while still a fellow student, was writing his *Handbuch* monograph on relativity theory. When Heisenberg moved to the University at Göttingen, he got more relativity theory from Max Born. In short, it came to him from all sides. Although Pauli wisely warned him to devote his future research to quantum physics instead of relativity, there was no way that Heisenberg could escape being fascinated by Einstein's work.

Early in his years at Munich, Heisenberg went with some friends on a bicycle tour around Lake Walchensee. The talk turned to Sommerfeld's relativity course, and Heisenberg was especially struck by a remark from his friend Otto Laporte, recalling it later as follows:[5]

> We ought only to use such words and concepts as can be directly related to sense perception. . . . Such concepts can be understood without extensive explanation. It is precisely this return to what is observable that is Einstein's great merit. In his relativity theory, he quite rightly started with the commonplace statement that time is what you read on a clock. If you would keep to such commonplace meaning of words, you will have no difficulties with relativity theory. As soon as a theory allows us to predict correctly the result of observations, it gives us all the understanding we need.

This "instrumentalist" or "operational" view of Einstein's method was quite common at that time, and for decades afterwards. As we shall see below, Laporte's long-remembered praise of it laid the groundwork for one of Heisenberg's key insights many years later.

In the summer of 1922, Sommerfeld arranged for Heisenberg to go to Leipzig, where Einstein was to give a lecture. It was to be Heisenberg's first encounter with Einstein, but instead it turned into a surrealistic glimpse of things to come. When Heisenberg entered the crowded lecture hall, a handbill was forced on him, signed by the Nobel physicist Philipp Lenard and eighteen other German scientists. It contained a vicious attack on Einstein, whose theory, as Heisenberg recalled, "was said to be nothing but wild speculations, alien to the German spirit, and blown up by the Jewish press."[5]

Heisenberg was shaken by this political attack on scientific truth—so much that he didn't even notice that the speaker on the distant platform was not Einstein but rather Einstein's courageous friend and colleague, Max von Laue. Einstein had decided not to come, knowing he was in mortal danger from Nazi rowdies who had recently assassinated his close friend, Foreign Minister Walther Rathenau, and who had published a list of future Jewish victims, including Einstein himself. This threat was a major reason for Einstein's leaving Germany for his around-the-world trip in 1922–23.

Only the theory decides what one can observe

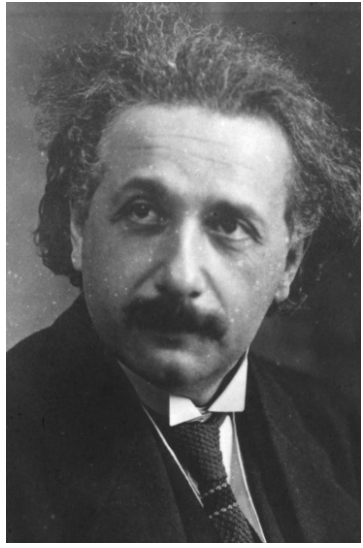
The first real meeting between our two protagonists occurred in 1924, when Einstein—at age forty-five about twice as old as Heisenberg—came briefly to Göttingen. The recent work of Bohr, Kramers, and Slater—the BKS theory—was hot news. But because it relaxed the requirements of strict causality and of energy and momentum conservation, Einstein wrote to Max Born that if this kind of science would persevere, "I would rather be a shoemaker or employee in a gambling casino than a physicist."

Against that background, Einstein and Heisenberg had a private talk in 1924, during a walk through the neighborhood. (By the way, what has happened to the life of scientists? Where have all those walks gone?) But, as Heisenberg, a proponent of Bohr's point of view, immediately wrote to his parents, "Einstein had a hundred objections" to the BKS theory. Coming from the scientist whose work Heisenberg had been admiring since early youth, this rejection of the new way of doing physics must have been difficult. But he consoled himself, as he said in one of his later interviews, that his generation, having "grown up into a complete mess" in quantum physics, was in the happy position of being able to give up old schemes if necessary.

On 25 September 1925, Heisenberg published in *Zeitschrift für Physik* his brilliant breakthrough to quantum mechanics, "On the Quantum Theoretical Reinterpretation of Kinematic and Mechanical Relations." From the beginning, the abstract of the paper announced Heisenberg's fundamental guiding principle: "This work is

an attempt to find foundations for a quantum-theoretical mechanics which is based exclusively on relations between quantities that are in principle measurable." The paper restricted itself to the observable properties of a spectrum, eschewing models built on unobservables such as the position and periods of electrons in the atom.

Heisenberg later observed that his crucial insight was an echo from the days when he had been struggling with relativity theory at the University in Munich. In his work leading up to that 1925 paper, he remembered "the philosophy presented as Einstein's viewpoint by our friend Otto during our bicycle tour, to regard only the observable magnitudes as the indication of atomic phenomena."[5]



Albert Einstein could never accept the indeterminacy inherent in Heisenberg's quantum mechanics. Here, Einstein is shown at about the time of Heisenberg's 1926 lecture on matrix mechanics at Max von Laue's colloquium in Berlin. After the lecture, Einstein invited Heisenberg on a walk where he astonished Heisenberg by vigorously disputing the assumption that a theory should include only directly observable quantities. Einstein's assertion, "Only the theory decides what one can observe," was a key element in Heisenberg's formulation the following year of the uncertainty principle.

But if Heisenberg had any illusion that his article would be approved by Einstein, he was wrong. One of Heisenberg's five surviving letters in the Einstein archive, dated November 30, 1925, is evidently a reply to a note from Einstein (now lost) that had contained many objections. In his response, Heisenberg tried to hold out the hope of an eventual peaceful bridging between Einstein's theory of light quanta and what he called "our quantum mechanics." Heisenberg also drew prominent attention to his having used only "observable magnitudes" in his theory. All to no avail.

The following year, 1926, is one of high drama in this growing but troubled relationship. In April, Heisenberg gave a two-hour lecture on his matrix mechanics in von Laue's famous physics colloquium at the University of Berlin. In the audience, with a whole group of potentates, was Einstein. It was their second meeting. Einstein, interested and no doubt disturbed by the lecture, asked Heisenberg to walk home with him (there is that walk again) and thus ensued a remarkable discussion, which Heisenberg first reported in print in 1969.

In the discussion with Einstein, Heisenberg once more tried to draw attention to his having dealt not with unobservable electron orbits inside atoms, but rather with observable radiation. He said to Einstein: "Since it is acceptable to allow into a theory only directly observable magnitudes, I thought it more natural to restrict myself to these, bringing them in, as it were, as representatives of electron orbits." Einstein responded, "But you don't seriously believe that only observable magnitudes must go into a physical theory?" Heisenberg goes on, "In astonishment, I said, 'I thought that it was exactly you who had made this thought the foundation of your relativity theory. . . .' Einstein replied, 'Perhaps I used this sort of philosophy; but it is nevertheless nonsense.' " And then came Einstein's famous sentence: "Only the theory decides what one can observe."[5]

All this must have come to Heisenberg as a scathing attack on what he regarded as his fundamental orientation, derived from reading Einstein's early works, and being guided by them from the start, right through his most recent triumph. Einstein, whose development away from positivistic instrumentalism to a rational realism had escaped Heisenberg's notice, went on to explain at length how complicated any observation is in general, how it involves assumptions about phenomena that in turn are based on theories. For example, one almost unconsciously uses Maxwell's theory when interpreting experimental readings involving a beam of light.

Perhaps this discussion helped Heisenberg eventually to embark on his own epistemological pilgrimage, which ultimately ended with a kind of neo-Platonism in the description of nature through the contemplation of symmetries. But in 1927, just before starting on his next breakthrough—later called the uncertainty principle paper—Heisenberg suddenly remembered Einstein's provocative statement, "Only the theory decides what one can observe." It was a key to Heisenberg's advance. As he later put it, "I just tried to turn the question around according to the example of Einstein."

At this point I should pause briefly to return to the unfinished story of my own encounter with Heisenberg in 1965. After giving his lecture, Heisenberg came over to tell me in detail about that 1926 meeting with Einstein, and what it had meant for him. Indeed, as if to make sure I had it straight, Heisenberg followed up by sending me a letter in January 1966, in which he repeated the story, and added a rather striking conclusion: While the theory determines what can be observed, the uncertainty principle showed him that a theory also determines what cannot be observed. Ironically, Einstein, through his 1926 conversation, had provided Heisenberg with some genetic material for the creation of the uncertainty principle article of 1927.

Descending along two tracks

We can now follow the effect of Einstein on Heisenberg along two diverging tracks. Both start at a high level, but descend eventually into terrifying terrain below. One track is the scientific one. Despite all his misgivings, Einstein of course realized the brilliance of Heisenberg's work. He nominated Heisenberg for a Nobel Prize for three years before Heisenberg was so recognized, even though Einstein to the end believed that Heisenberg's way of doing physics would ultimately turn out not to be true to the thoughts of the "Old One," the Creator.

The third meeting of the two men took place in October 1927, at the six-day Solvay Congress in Brussels. That conference was the scene of famous debates, mainly between Einstein and Schrödinger on one side and Bohr, Heisenberg, and their "Copenhagen" colleagues on the other.[6] It soon became clear that the Copenhagen spirit had triumphed. Day after day, Einstein presented ingenious arguments, which Bohr then answered before nightfall, until Paul Ehrenfest finally said, according to Heisenberg, "Einstein, I am ashamed for you."

Heisenberg in a later interview added a shrewd point: "I would say that a change had taken place, which I can only express in terms of lawsuits. That is, the burden of

THE SOLVAY CONFERENCE OF 1927 is one of the few occasions when Heisenberg (back row, third from right) and Einstein (front row, center) were photographed together. This conference was the scene of vigorous debates about quantum theory, mainly between Einstein and Schrödinger on one side and Bohr, Heisenberg and their "Copenhagen" colleagues on the other.

proof was reversed. . . . That made a complete change of view among the younger generation." Ironically, the same kind of reversal of fortunes had happened long before, in the triumph of Einstein's relativity over its opponents. Heisenberg's last surviving letter to Einstein, written a few months before the Brussels meeting, already showed the cocky self-confidence of the victors in that new struggle. Heisenberg writes that while in the new quantum mechanics Einstein's beloved causality principle is baseless, "We can console ourselves that the dear Lord God would know the position of the particles, and thus He could let the causality principle continue to have validity."

Heisenberg once more sought out Einstein in 1954, a year before Einstein's death, and the final meeting between the two men took place in Princeton. Heisenberg found that Einstein's view had not changed since the 1927 Solvay Congress. Despite all Heisenberg's persuasive skills, Einstein just said, "No, that's nothing. That's not the thing I am after. I don't like your kind of physics. I think you are all right with the experiments . . . but I don't like it."

The second track that follows the later relation between the two men concerns the full emergence in 1933 of what in Germany had been foaming from the mouth of the Beast since the early 1920s. For a time, Heisenberg continued to mention Einstein in his lectures and publications. But the scene was now dominated by demons, including the raving articles published by Johannes Stark, branding Heisenberg in 1935 the "spirit of Einstein's spirit." The published attacks on Heisenberg, and on theoretical physics as such, culminated on 15 July 1937 with an article in the official journal of the SS, *Das Schwarze Korps*. That article, endorsed by Stark, called Heisenberg a "white Jew," and dismissed relativity and quantum theory as non-German, Jewish thinking.

There followed a one-year attempt by Heisenberg to obtain exoneration from Heinrich Himmler, head of the SS, who was a family acquaintance. That effort finally succeeded, but Heisenberg was ordered to, in the future, "clearly separate for your audiences, in the acknowledgment of scientific research results, the personal and political characteristic of the researcher." Privately, Himmler had his eye on Heisenberg as a possible researcher on Himmler's own crazy "World Ice Theory," of which I will spare you the details here.[7] But any future playwright dealing with a version of the Heisenberg–Einstein relation will not be able, as *Copenhagen* does, to avoid including the cries, offstage and ever more distant, of the unmentioned millions who had also loved their homeland but had no way to make a deal with Himmler, or to bribe an SS man bent on murder.

Despite Nazi condemnations of relativity theory, the use of the equation $E = mc^2$ continued to be quite permissable for German scientists. Indeed, putting that equation to use remained their Holy Grail from the very beginning of the Uranium Club, and they had been called into action by the German government well before the Allies got going in an organized way on their research. Although several crucial mistakes ruled out producing a

Das Schwarze Korps

ZEITUNG DER SCHUTZSTAFFELN DER NSDAP

Organ der Reichsführung SS

Berlin, 15. Juli 1937

„Das Schwarze Korps"

„Weiße Juden" in der Wissenschaft

Die Taktik wechselt

"WHITE JEWS IN SCIENCE" reads the July 15, 1937 headline in the *Schwarze Korps*, the official journal of the SS. This article, endorsed by Johannes Stark, condemned Heisenberg for his support of the "Jewish" theory of relativity. By appealing directly to SS head Heinrich Himmler, a family acquaintance, Heisenberg was able to achieve a conditional rehabilitation.

bomb (see Hans Bethe's article on page 34), the German scientists continued to hope, under Heisenberg's leadership, to exploit nuclear energy for powering the war machine by building a reactor.

Recasting the portrait of Einstein

At this point in the narrative, we are at last in peacetime, and Heisenberg is securely installed as the leader of a new generation of German physicists—as he had hoped to be all along. But now, in two of Heisenberg's lectures, we find passages that signal the depth to which his relationship with Einstein has fallen—as had earlier, on a parallel path, his relationship with Niels Bohr.

Shortly after Einstein died in 1955, Heisenberg published a popular article entitled, "The Scientific Work of Einstein."[8] The article began with a generous assessment of Einstein's contributions, but then found a serious fault with him, namely "that Einstein, to whom war was hateful, should have been moved by the infamous practices under Nazism to write a letter to President Roosevelt in 1939, urging that the United States vigorously set about the making of atomic bombs . . ." which eventually "killed many thousands of women and children."

That bitter statement was at the very least a major exaggeration. The famous letter of August 1939 that Einstein signed had been written just as the German war machine was poised to start its Blitzkrieg—and, as we now know, four months after Paul Harteck and Wilhelm Groth had asked the German War Office to investigate nuclear explosives. Far from urging that the United States vigorously set about the making of atomic bombs, the letter was, in its own words, "a call for watchfulness and, if necessary, quick action," not least because "Germany has actually stopped the sale of uranium from the Czechoslovakian mines which she has taken over." The letter asked only to establish a liaison between the US government and physicists and for help to raise funds for experimental work in university laboratories, if necessary, from private donors and industrial laboratories. The direct result was that all of $6,000 was made available to Enrico Fermi at Columbia University. Einstein declined the invitation to be a member of a group to coordinate further research.

Einstein signed a second letter to Roosevelt in March 1940 reporting that he had heard that research on the use of uranium was indeed going on in Germany; this letter, too, produced little action. In fact, the US government did not gear up seriously until October 1941, when it received the so-called Maud Committee report with the conclusions of a British-sponsored study on how to produce an atomic bomb. Leo Szilard persuaded Einstein to write a third letter in early 1945, simply a letter of introduction to Roosevelt, without telling Einstein the need for it. Szilard had hoped to use this letter to convey to Roosevelt his doubts of "the wisdom of testing and using bombs," but Roosevelt died before this plea reached him.

Einstein himself was carefully shielded from direct knowledge of the Allied nuclear project. This secrecy even resulted in a moment of comedy. In late December 1941, Vannevar Bush tried to get advice from Einstein on building diffusion plants, but because Einstein was given only vague details, his reply was useless. Asked if Einstein could be given more information, Bush cried no, don't tell him one more thing, or he will guess the rest of the project, and might blab. The voluminous files the FBI kept on Einstein show that FBI director J. Edgar Hoover was deeply suspicious of Einstein. While on one side of the Atlantic, Heisenberg was called a "white Jew," Einstein on the other side was considered by some a red one.

Heisenberg's 1955 remarks about Einstein were not to be an isolated exaggeration. Heisenberg gave a second attack on Einstein in June 1974, when he spoke, of all places, in the so-called Einstein house in Ulm, Germany. (Part of the *Volkshochschule* in Einstein's birthplace, this building was dedicated in 1968 as a living memorial to Einstein.) As in 1955, he began with a generous survey of Einstein's work on relativity; he then repeated some of the points made in earlier publications, including an account of Einstein's rejections of the theories of Heisenberg. Heisenberg then said that he would have to add something, "in order not to leave the portrait of Einstein all too incomplete." Einstein, he said, "wrote three letters to President Roosevelt, and thereby contributed decisively to setting in motion the atom bomb project in the United States. And he also collaborated actively, on occasion, in the work on this project."[9]

If there is to be someday a play based on the relation between these two men, the playwright will perhaps note that these astonishing exaggerations, uttered in Einstein's birth town, were part of a Heisenberg lecture with the title "Encounters and Conversations with Albert Einstein." In that last talk, Heisenberg, two years before his death, had his final encounter with the person whom he had once called his *Vorbild*, his model; the person who for good and ill had unknowingly been the cause both of deep insights and of fierce insults throughout Heisenberg's scientific and personal life; and whose acceptance Heisenberg had sought again and again, always in vain. Niels Bohr, to his death in 1962, was also deeply saddened by Einstein's constant refusal to accept his interpretation and program. And as to Einstein himself, he often cursed the quantum he himself had set loose, only to have it haunt him in the form of a physics that he could not accept, initiated largely by Bohr and Heisenberg.

It all had started so well. But in that future play, as the curtain falls on these three extraordinary men, even the evil spirit that has been watching them from the wings of the stage, and that had haunted that whole terrible century, will, in the end, shed a tear for humanity.

This article is based on a paper presented at the Symposium, "Creating 'Copenhagen,' " held on 27 March 2000 at the Graduate Center of the City University of New York.

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