Niels
Bohr, 1922

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Bohr, and Atomic

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Heisenberg the Bomb

The relationship between Niels Bohr and Werner Heisenberg was irrevocably changed by the Second World War. While we may never know what transpired during their famous meeting in Copenhagen, their story highlights the ethical complexities—and heavy burdens—that sometimes come with being a scientist.

Werner Heisenberg, 1933

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Bohr (right) and Heisenberg at the 1934 Bohr Institute Conference in Copenhagen.

Paul Ehrenfest Jr./Courtesy of AIP Emilio Segrè Visual Archives/Weisskopf Collection

Niels Bohr and Werner Heisenberg—perhaps in another time, theirs would have been one of the great scientific partnerships. Both brilliant minds, they were scientific contemporaries, fast friends, and, eventually, reluctant adversaries. When World War II broke out in Europe, the two found themselves on opposite sides of the conflict—and the race to build one of the most destructive weapons known to humankind.

Bohr was born 16 years earlier than Heisenberg, on the 7th of October 1885 in Copenhagen. He expressed his interest in natural science early in primary school and devoured books on scientific topics. When he enrolled in the University of Copenhagen, he decided to devote his life to physics.

He is most famous for the Bohr model of the atom, which improved upon an earlier theory proposed by a New Zealand researcher Ernest Rutherford; it described an atom using quantum theories, which gave rise to a new approach to physics.

On 5 December 1901, Werner Heisenberg entered the world—in Wurzburg, Germany, to be exact. Like Bohr, he admired nature even as a child and expanded his interests early in lower secondary school by reading, among other things, Kronecker's paper on numbers. While at the University of Munich, he explored the secrets of natural science under the watchful eyes of Arnold Sommerfield and Wilhelm Wien.

Heisenberg was made a professor at only 26 years of age after he had proved his mettle by formulating matrix quantum mechanics. Having been granted the Rockefeller scholarship in 1924, he travelled to Denmark, where he met Bohr.

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After spending a year in Copenhagen, Heisenberg returned to Munich. The two kept in touch through letters or when they met at occasional international conferences. In 1939, Europe became divided, and unfortunately so too did Bohr and Heisenberg—the former on the Allies' side and the latter on Hitler's.

Heisenberg and the German bomb effort

The German Ministry of Armaments took notice of Heisenberg's skills and knowledge and invited him to take part in the project related to the fission of uranium only a few days after the war had started. The facilitators of the first meeting were Kurt Diebner and Erich Bagge, both of whom were members of the Nazi party. Ten days later, Diebner called another conference and suggested the formation of three research centers dedicated to the development of an atomic bomb.

Under Heisenberg's supervision, a reactor was built in the first center in Lipsk. In Berlin, Carl Friedrich von Weizsäcker was in charge of constructing the bomb itself. The third center, a military one, was also located in the capital of Germany. But despite diligent work, the Germans did not produce the bomb.

Many years later, it became apparent that Heisenberg had gotten a key variable very wrong—the critical mass of uranium required to perform a nuclear explosion. Heisenberg had calculated a mass on the order of tons, while the correct value is only about 50 kg!

Some historians suggest that Heisenberg purposefully hindered the completion of the German atomic bomb project. In his memoir *The Part and the Whole,* Heisenberg suggests that he and other physicists of the Third Reich were unsure of how to proceed when it came to bomb production.

Heisenberg's famous 1941 visit to Niels Bohr in occupied Copenhagen is, to this day, shrouded in mystery; it is the subject of Michael Frayn's award-winning play *Copenhagen*. While Heisenberg apparently did not want to give the bomb to Hitler, he was not sure whether the physicists who had immigrated to the United States were developing a bomb to drop on Berlin. In his own words:

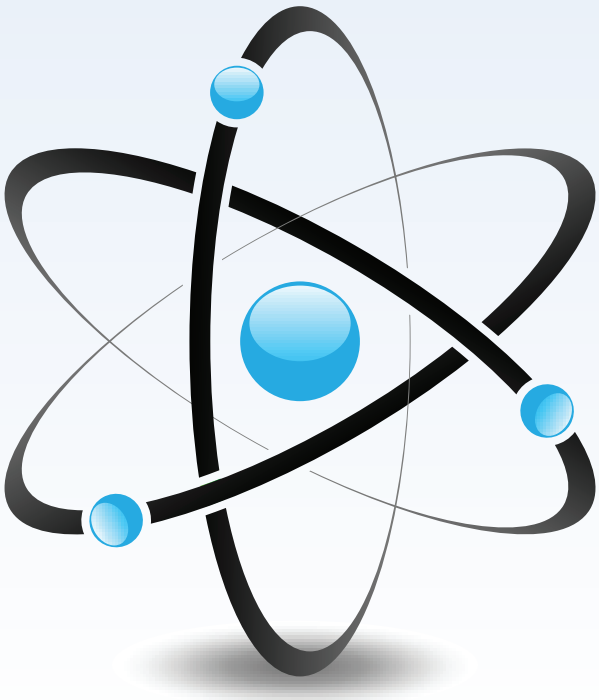
> *"Being aware that Bohr was under the surveillance of the German political authorities and that his assertions about me would probably be reported to Germany, I tried to conduct this talk in such a way as to preclude putting my life into immediate*

The Bohr Atom Turns 100

In July 1913, Niels Bohr transformed our understanding of light and matter. Though his simple idea seems obvious to us now, it was revolutionary then: take the quantization rule that Planck and Einstein used to describe the energy of light and apply it to the mechanical motion of particles in atoms. Since Planck's constant h has the dimensional units of angular momentum, Bohr suggested that it provide the basis of angular momentum quantization: $L = nh / 2\pi$, for $n = 1, 2, 3, \ldots$ without end.

Bohr found that when this method was applied to the circular orbits of hydrogen-like systems, it reproduced, within experimental uncertainties, the wavelengths of all 33 spectral lines of atomic hydrogen that were known at the time. He also showed that a number of other lines that were then ascribed to hydrogen were actually due to He+. His method predicted additional lines in the extreme ultraviolet, which were discovered in 1914 by Theodore Lyman, and in the infrared, found in subsequent years by Brackett, Pfund and Humphries. Harold Urey used Bohr's theory to find deuterium, the heavy stable isotope of hydrogen—a discovery of great importance in nuclear physics. (See "The Optical Discovery of Deuterium," *Optics & Photonics News*, May 2012.)

Bohr-like transitions have been observed in the interstellar medium for values of $n > 1{,}000$, so the model gives an accurate description of atomic spectral lines across nearly nine decades of frequency in the electromagnetic spectrum. Although his specific atomic model was superseded by quantum mechanics, Bohr's basic concept endures and is often a useful guide to understanding new aspects of atomic, molecular and optical physics. —*Charles W. Clark*



Bohr (front, left) and Heisenberg (front, middle) at the 1933 Bohr Institute Conference.

Nordisk Pressefoto/ Courtesy of AIP Emilio Segrè Visual Archives/ Magrethe Bohr Collection

danger. This talk probably started with my question as to whether or not it was right for physicists to devote themselves in wartime to the uranium problem—as there was the possibility that progress in this sphere could lead to grave consequences in the technique of the war."

Heisenberg went on to write that Bohr had been shocked by his words and assumed that he was there to tell him that Germany had made progress in manufacturing atomic weapons. Heisenberg stated that he had tried to correct this "false impression" but that he may not have succeeded given how vague and cautious he was being with his speech.

For his part, Bohr walked away from the Copenhagen meeting convinced that Heisenberg wanted the bomb. He was aware of the enormous destructive power of the weapon and hence terrified after his friend's visit. He also perceived that Werner was strongly convinced that the Germans would declare victory in the near future.

According to a letter Bohr wrote to Heisenberg in 1957:

"You and Weizsäcker expressed your definite conviction that Germany would win and that it was therefore quite foolish for us to maintain the hope of a different outcome of the war … I also remember quite clearly our conversation in my room at the Institute, where in vague terms you spoke in a manner that could only give me the firm impression that, under your leadership, everything was being done in Germany to develop atomic weapons."

Even if that was Bohr's view, his impression was indeed wrong, as around half a year after the meeting Heisenberg told the German Minister of Armaments that there was not the slightest chance that an atomic bomb would be developed in Germany at that time.

Journalist Thomas Powers, author of the book *Heisenberg's War*, attempted to prove that Heisenberg had sabotaged the German project.

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According to him, the German scientist arrived in Copenhagen and met his old friend Bohr in order to give an ultimatum: The Germans won't build the bomb if the Allies don't. Powers also contends that Heisenberg assured Bohr that the German scientists diverted their work toward obtaining nuclear energy so that their results could not be misused to aid in the production of an atomic bomb.

Varying interpretations

From one point of view, that could suggest that the huge discrepancy between the critical mass of uranium calculated by Heisenberg and the actual critical mass to produce the bomb was intentional, and that Werner Heisenberg did not want to give the bomb to Hitler. Carl Friedrich von Weizsäcker, the last living member of the German nuclear energy project (he died in 2007), maintained that the German physicists had deliberately chosen not to build the bomb because they did not want such a powerful weapon to fall into the hands of Nazis.

Others claim that von Weizsäcker only purported that he and his team had moral qualms after the fact—and that the true reason they never succeeded was that they simply lacked the technical know-how. In *The Manhattan Project: Making of the Atomic Bomb*, David Rhodes suggests that the Copenhagen meeting of the two friends was arranged merely so that Heisenberg could conduct some espionage.

The truth may never be clear. What is known, however, is that Heisenberg was neither Nazi nor anti-Nazi. He believed that democracy was obsolete and that Europe would endure under either German or Soviet rule; he regarded a German dictatorship as the lesser evil. Even among the individuals most interested in his biography, there are contradictory interpretations of his motives.

What actually governed Heisenberg when he arrived to meet with his old friend in Copenhagen? Did he intend to elicit from Niels Bohr the knowledge that would enable him to produce an atomic weapon and gain advantage for Germany in the World War II? Or was he misunderstood by his friend? Perhaps his

(Clockwise from far left) Fermi, Debye, Stern, Marconi, Bohr and Heisenberg at the 1935 Rome Conference.

AIP Emilio Segrè Visual Archives

Dismantling the German experimental nuclear pile at Haigerloch, 1945.

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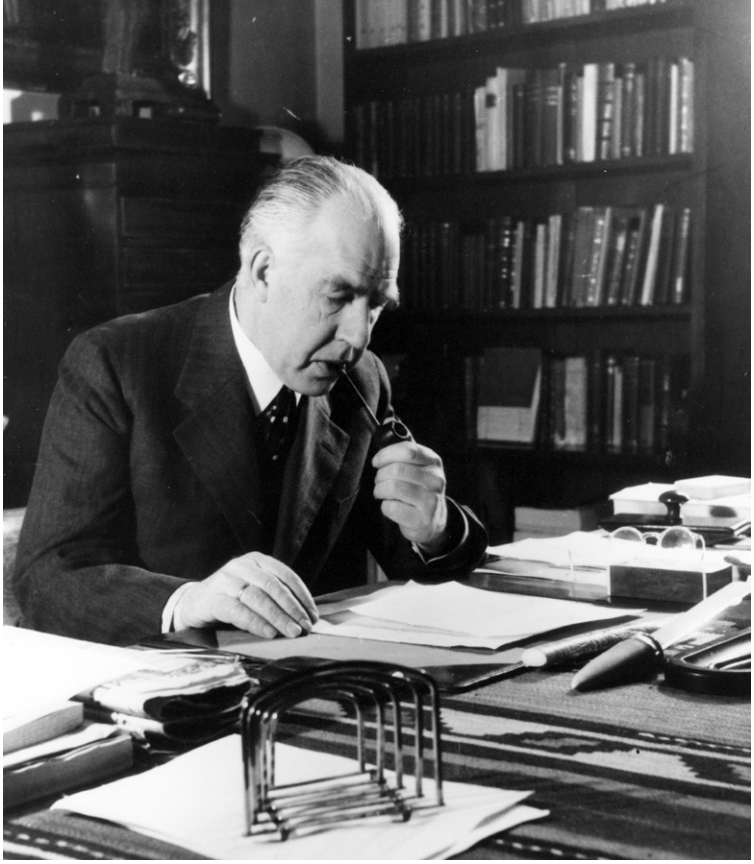

Bohr working in his study.

Niels Bohr Archive/ Courtesy of AIP Emilio Segrè Visual Archives

purpose was to make a pact to cease work on the atomic bomb on both sides of the conflict.

Niels Bohr denied that any such offer was put forth during their conversation. Around the end of 1943, he fled to Denmark and arrived in the United States, where he took part in the Manhattan Project, which had the objective of building the bomb that would later be dropped on Nagasaki in 1944.

Fractured friendship, enduring mystery

After the war, Bohr and Heisenberg returned to their research centers, but they never managed to rekindle the friendship they had before. Their communications were characterized by a degree of restraint and formality.

In one of the warmer letters, Bohr sent Heisenberg good wishes on the occasion of his 60th birthday—a time "when you can look back on such a rich life's work in the service of the physical sciences." Bohr also writes that he often thinks about the great achievements of his old friend and how important it was to be his colleague. Yet he also makes clear: "That does not mean that I have forgotten everything that has happened since, in which you have played such a leading role."

For the most part, the two were not able to speak about the war or their parts in it. The political situation entangled the two intellectuals and, in effect, overwhelmed both.

The Copenhagen meeting is one of the most compelling scientific mysteries of the 20th century. It is conceivable that we might owe to that meeting the fact that Hitler did not obtain an atomic bomb and wreak havoc in Europe and the rest of the world.

For scientists, the experiences of Bohr and Heisenberg raise troubling ethical dilemmas: Should inventors work on problems that might bring death and destruction if they get into the wrong hands? Is it necessary to define the notion of scientific morals? Can political affairs alter our internal morality, making us insensitive to others' circumstances? Can one's actions be justified, as Werner Heisenberg suggested, by treating politics like a game of chess, "where feelings and human desires are subject to the present course of political events, just as the chess pieces to the rules of the game?" OPN

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References and Resources

- R. Jungk. *Brighter Than a Thousand Suns—A Personal History of the Atomic Scientists*, Harcourt (1956).
- W. Heisenberg. *Physics and Beyond: Encounters and Conversations* (titled *The Part and the Whole* in the German version of the book), Harper and Row (1972).
- T. Powers. *Heisenberg's War: The Secret History of the German Bomb*, Knopf (1993).
- D. Rhodes. *The Manhattan Project: Making of the Atomic Bomb*, Simon & Schuster (1995).
- Niels Bohr archive: www.nba.nbi.dk

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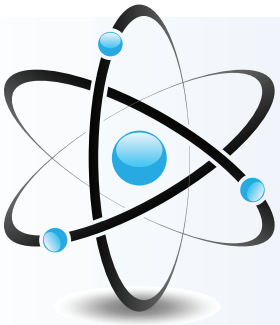


A 21st Century Meeting of the Minds

On Sunday 6 October, a panel of distinguished scientists will take part in the symposium on the 100th Anniversary of the Bohr Atom at Frontiers in Optics, the OSA annual meeting. The meeting will take place at the Hilton Bonnet Creek in Orlando, Fla., U.S.A.; here are some highlights from the speakers. For more information, visit www.frontiersinoptics.com.

Niels Bohr's Nutcracker

Charles W. Clark ▸ National Institute of Standards and Technology, U.S.A.

▸ In 1913, Niels Bohr solved all the outstanding problems of the spectroscopy of hydrogen and predicted many new lines. His quantization of angular momentum remains a central organizing principle of quantum theory today.

The Quantum World of a Rydberg Electron in Atoms and Exotic Molecules

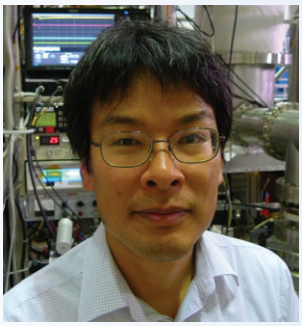
Chris Greene ▸ JILA, Univ. of Colorado at Boulder, U.S.A.

▸ Our understanding of Rydberg electron physics has enabled spectra of remarkable complexity and richness to be quantitatively understood and qualitatively interpreted.

Quantum Interference of Clusters and Large Molecules

Nadine Dörre ▸ Univ. of Vienna, Austria

▸ Recent advances in matter-wave experiments exploit the quantum delocalization of nanoparticles. De Broglie wave interferometers allow tests of the quantum superposition principle for mesoscopic objects and new avenues to molecule metrology.



Determination of the Antiproton-to-Electron Mass Ratio by Two-Photon Laser Spectroscopy of Antiprotonic Helium Atoms

Masaki Hori ▸ Max-Planck Inst. for Quantum Optics, Germany

▸ Researchers have used two-photon laser spectroscopy to study an exotic helium atom containing an antiproton. The antiproton mass relative to the electron mass was determined as 1836.1526736(23) from this result—which agrees with the corresponding proton value.