Werner Heisenberg

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| **Werner Heisenberg** | |
| Heisenberg in 1933, as professor at Leipzig University | |
| **Born** | Werner Karl Heisenberg 5 December 1901 Würzburg, Kingdom of Bavaria, German Empire |
| **Died** | 1 February 1976 (aged 74) Munich, Bavaria, West Germany |
| **Resting place** | Munich Waldfriedhof |
| **Nationality** | German |
| **Alma mater** | University of Munich |
| **Known for** |  |
| **Spouse(s)** | Elisabeth Schumacher (1937–1976) |
| **Children** | Maria Wolfgang Barbara Christine Jochen Martin Verena |
| **Awards** | * Matteucci Medal (1929) * Barnard Medal for Meritorious Service to Science (1930) * Nobel Prize in Physics (1932) * Max Planck Medal (1933) * ForMemRS (1955) |
| **Scientific career** | |
| **Fields** | Theoretical physics |
| **Institutions** | University of Göttingen University of Copenhagen University of Leipzig University of Berlin University of Munich |
| **Thesis** | *On stability and turbulence of liquid flows* (1923) |
| **Doctoral advisor** | Arnold Sommerfeld |
| **Other academic advisors** | Niels Bohr Max Born |
| **Doctoral students** | Felix Bloch Edward Teller Rudolf E. Peierls Reinhard Oehme Friedwardt Winterberg Peter Mittelstaedt Șerban Țițeica Ivan Supek Erich Bagge Hermann Arthur Jahn Heimo Dolch Hans Heinrich Euler Edwin Gora Bernhard Kockel Arnold Siegert Wang Foh-san Karl Ott Bary F. Malik |
| **Other notable students** | William Vermillion Houston Guido Beck Ugo Fano Ettore Majorana Herbert Wagner |
| **Influenced** | Robert Döpel Carl Friedrich von Weizsäcker |
| **Signature** | |
|  | |
| **Notes** | |
| He was the father of the neurobiologist Martin Heisenberg and the son of August Heisenberg | |

**Werner Karl Heisenberg** (/ˈhaɪzənˌbɜːrɡ/; German: [ˈhaɪzənbɛɐ̯k]; 5 December 1901 – 1 February 1976) was a German theoretical physicist and one of the key pioneers of quantum mechanics. He published his work in 1925 in a breakthrough paper. In the subsequent series of papers with Max Born and Pascual Jordan, during the same year, this matrix formulation of quantum mechanics was substantially elaborated. He is known for the Heisenberg uncertainty principle, which he published in 1927. Heisenberg was awarded the Nobel Prize in Physics for 1932 "for the creation of quantum mechanics".

He also made important contributions to the theories of the hydrodynamics of turbulent flows, the atomic nucleus, ferromagnetism, cosmic rays, and subatomic particles, and he was instrumental in planning the first West German nuclear reactor at Karlsruhe, together with a research reactor in Munich, in 1957. He was a principal scientist in the Nazi German nuclear weapon project during World War II. He travelled to occupied Copenhagen where he met and discussed the German project with Niels Bohr.

Following World War II, he was appointed director of the Kaiser Wilhelm Institute for Physics, which soon thereafter was renamed the Max Planck Institute for Physics. He was director of the institute until it was moved to Munich in 1958, when it was expanded and renamed the Max Planck Institute for Physics and Astrophysics.

Heisenberg was also president of the German Research Council, chairman of the Commission for Atomic Physics, chairman of the Nuclear Physics Working Group, and president of the Alexander von Humboldt Foundation.

Life and career

**Early years**

Werner Karl Heisenberg was born in Würzburg, Germany, to Kaspar Ernst August Heisenberg (de), a secondary school teacher of classical languages who became Germany's only *ordentlicher Professor* (ordinarius professor) of medieval and modern Greek studies in the university system, and his wife, Annie Wecklein.



Heisenberg, Habilitation 1924

He studied physics and mathematics from 1920 to 1923 at the *Ludwig-Maximilians-Universität München* and the *Georg-August-Universität Göttingen*. At Munich, he studied under Arnold Sommerfeld and Wilhelm Wien. At Göttingen, he studied physics with Max Born and James Franck, and he studied mathematics with David Hilbert. He received his doctorate in 1923, at Munich under Sommerfeld. He completed his Habilitation in 1924, at Göttingen under Born.

Because Sommerfeld had a sincere interest in his students and knew of Heisenberg's interest in Niels Bohr's theories on atomic physics, Sommerfeld took Heisenberg to Göttingen to the *Bohr-Festspiele* (Bohr Festival) in June 1922. At the event, Bohr was a guest lecturer and gave a series of comprehensive lectures on quantum atomic physics. There, Heisenberg met Bohr for the first time, and it had a significant and continuing effect on him.

Heisenberg's doctoral thesis, the topic of which was suggested by Sommerfeld, was on turbulence;  the thesis discussed both the stability of laminar flow and the nature of turbulent flow. The problem of stability was investigated by the use of the Orr–Sommerfeld equation, a fourth order linear differential equation for small disturbances from laminar flow. He briefly returned to this topic after World War II.

Heisenberg's paper on the anomalous Zeeman effect was accepted as his *Habilitationsschrift* (Habilitation thesis) under Max Born at Göttingen.

In his youth he was a member and Scout leader of the *Neupfadfinder*, a German Scout association and part of the German Youth Movement. In August 1923 Robert Honsell and Heisenberg organized a trip (*Großfahrt*) to Finland with a Scout group of this association from Munich. Heisenberg arrived at Munich in 1919 as a member of Freikorps to fight the Bavarian Soviet Republic established a year earlier. Five decades later he recalled those days as youthful fun, like "playing cops and robbers and so on; it was nothing serious at all."

**Career**

**Göttingen, Copenhagen, and Leipzig**

From 1924 to 1927, Heisenberg was a Privatdozent at Göttingen. From 17 September 1924 to 1 May 1925, under an International Education Board Rockefeller Foundation fellowship, Heisenberg went to do research with Niels Bohr, director of the Institute of Theoretical Physics at the University of Copenhagen. His seminal paper, *Über quantentheoretischer Umdeutung* was published in September 1925. He returned to Göttingen and with Max Born and Pascual Jordan, over a period of about six months, developed the matrix mechanics formulation of quantum mechanics. On 1 May 1926, Heisenberg began his appointment as a university lecturer and assistant to Bohr in Copenhagen. It was in Copenhagen, in 1927, that Heisenberg developed his uncertainty principle, while working on the mathematical foundations of quantum mechanics. On 23 February, Heisenberg wrote a letter to fellow physicist Wolfgang Pauli, in which he first described his new principle. In his paper on the uncertainty principle, Heisenberg used the word "*Ungenauigkeit*" (imprecision).

In 1927, Heisenberg was appointed *ordentlicher Professor* (ordinarius professor) of theoretical physics and head of the department of physics at the Universität Leipzig; he gave his inaugural lecture on 1 February 1928. In his first paper published from Leipzig, Heisenberg used the Pauli exclusion principle to solve the mystery of ferromagnetism.

In Heisenberg's tenure at Leipzig, the quality of doctoral students, post-graduate and research associates who studied and worked with Heisenberg there is attested to by the acclaim later earned by these people; at various times. They included Erich Bagge, Felix Bloch, Ugo Fano, Siegfried Flügge, William Vermillion Houston, Friedrich Hund, Robert S. Mulliken, Rudolf Peierls, George Placzek, Isidor Isaac Rabi, Fritz Sauter, John C. Slater, Edward Teller, John Hasbrouck van Vleck, Victor Frederick Weisskopf, Carl Friedrich von Weizsäcker, Gregor Wentzel and Clarence Zener.

In early 1929, Heisenberg and Pauli submitted the first of two papers laying the foundation for relativistic quantum field theory. Also in 1929, Heisenberg went on a lecture tour in China, Japan, India, and the United States.

Shortly after the discovery of the neutron by James Chadwick in 1932, Heisenberg submitted the first of three papers on his neutron-proton model of the nucleus. He was awarded the 1932 Nobel Prize in Physics.

In 1928, the British mathematical physicist P. A. M. Dirac had derived the relativistic wave equation of quantum mechanics, which implied the existence of positive electrons, later to be named positrons. In 1932, from a cloud chamber photograph of cosmic rays, the American physicist Carl David Anderson identified a track as having been made by a positron. In mid-1933, Heisenberg presented his theory of the positron. His thinking on Dirac's theory and further development of the theory were set forth in two papers. The first, *Bemerkungen zur Diracschen Theorie des Positrons (Remarks on Dirac's theory of the positron)* was published in 1934, and the second, *Folgerungen aus der Diracschen Theorie des Positrons (Consequences of Dirac's Theory of the Positron)*, was published in 1936. In these papers Heisenberg was the first to reinterpret the Dirac equation as a "classical" field equation for any point particle of spin ħ/2, itself subject to quantization conditions involving anti-commutators. Thus reinterpreting it as a (quantum) field equation accurately describing electrons, Heisenberg put matter on the same footing as electromagnetism: as being described by relativistic quantum field equations which allowed the possibility of particle creation and destruction. (Hermann Weyl had already described this in a 1929 letter to Einstein.)

In the early 1930s in Germany, the *Deutsche Physik* movement was anti-Semitic and anti-theoretical physics, especially including quantum mechanics and the theory of relativity. As applied in the university environment, political factors took priority over the historically applied concept of scholarly ability, even though its two most prominent supporters were the Nobel Laureates in Physics Philipp Lenard and Johannes Stark.

After Adolf Hitler came to power in 1933, Heisenberg was attacked in the press as a "White Jew" by elements of the *Deutsche Physik* (German Physics) movement for his insistence on teaching about the roles of Jewish scientists. As a result, he came under investigation by the SS. This was over an attempt to appoint Heisenberg as successor to Arnold Sommerfeld at the University of Munich. The issue was resolved in 1938 by Heinrich Himmler, head of the SS. While Heisenberg was not chosen as Sommerfeld's successor, he was rehabilitated to the physics community during the Third Reich. Nevertheless, supporters of *Deutsche Physik* launched vicious attacks against leading theoretical physicists, including Arnold Sommerfeld and Heisenberg. On 29 June 1936, a Nazi Party newspaper published a column attacking Heisenberg. On 15 July 1937, he was attacked in a journal of the SS. This was the beginning of what is called the Heisenberg Affair.

In mid-1936, Heisenberg presented his theory of cosmic-ray showers in two papers. Four more papers appeared in the next two years.

In June 1939, Heisenberg bought a summer home for his family in Urfeld am Walchensee, in southern Germany. He also travelled to the United States in June and July, visiting Samuel Abraham Goudsmit, at the University of Michigan in Ann Arbor. However, Heisenberg refused an invitation to emigrate to the United States. He did not see Goudsmit again until six years later, when Goudsmit was the chief scientific advisor to the American Operation Alsos at the close of World War II. Ironically, Heisenberg was arrested under Operation Alsos and detained in England under Operation Epsilon.

**Matrix mechanics and the Nobel Prize**



Niels Bohr, Werner Heisenberg, and Wolfgang Pauli, ca. 1935

Heisenberg’s paper establishing quantum mechanics has puzzled physicists and historians. His methods assume that the reader is familiar with Kramers-Heisenberg transition probability calculations. The main new idea, non-commuting matrices, is justified only by a rejection of unobservable quantities. It introduces the non-commutative multiplication of matrices by physical reasoning, based on the correspondence principle, despite the fact that Heisenberg was not then familiar with the mathematical theory of matrices. The path leading to these results has been reconstructed in MacKinnon, 1977, and the detailed calculations are worked out in Aitchison et al.

In Copenhagen, Heisenberg and Hans Kramers collaborated on a paper on dispersion, or the scattering from atoms of radiation whose wavelength is larger than the atoms. They showed that the successful formula Kramers had developed earlier could not be based on Bohr orbits, because the transition frequencies are based on level spacings which are not constant. The frequencies which occur in the Fourier transform of sharp classical orbits, by contrast, are equally spaced. But these results could be explained by a semi-classical Virtual State model: the incoming radiation excites the valence, or outer, electron to a virtual state from which it decays. In a subsequent paper Heisenberg showed that this virtual oscillator model could also explain the polarization of fluorescent radiation.

These two successes, and the continuing failure of the Bohr-Sommerfeld model to explain the outstanding problem of the anomalous Zeeman effect, led Heisenberg to use the virtual oscillator model to try to calculate spectral frequencies. The method proved too difficult to immediately apply to realistic problems, so Heisenberg turned to a simpler example, the anharmonic oscillator.

The dipole oscillator consists of a simple harmonic oscillator, which is thought of as a charged particle on a spring, perturbed by an external force, like an external charge. The motion of the oscillating charge can be expressed as a Fourier series in the frequency of the oscillator. Heisenberg solved for the quantum behavior by two different methods. First, he treated the system with the virtual oscillator method, calculating the transitions between the levels that would be produced by the external source.

He then solved the same problem by treating the anharmonic potential term as a perturbation to the harmonic oscillator and using the perturbation methods that he and Born had developed. Both methods led to the same results for the first and the very complicated second order correction terms. This suggested that behind the very complicated calculations lay a consistent scheme.

So Heisenberg set out to formulate these results without any explicit dependence on the virtual oscillator model. To do this, he replaced the Fourier expansions for the spatial coordinates by matrices, matrices which corresponded to the transition coefficients in the virtual oscillator method. He justified this replacement by an appeal to Bohr’s correspondence principle and the Pauli doctrine that quantum mechanics must be limited to observables.

On 9 July, Heisenberg gave Born this paper to review and submit for publication. When Born read the paper, he recognized the formulation as one which could be transcribed and extended to the systematic language of matrices, which he had learned from his study under Jakob Rosanes at Breslau University. Born, with the help of his assistant and former student Pascual Jordan, began immediately to make the transcription and extension, and they submitted their results for publication; the paper was received for publication just 60 days after Heisenberg's paper. A follow-on paper was submitted for publication before the end of the year by all three authors.

Up until this time, matrices were seldom used by physicists; they were considered to belong to the realm of pure mathematics. Gustav Mie had used them in a paper on electrodynamics in 1912 and Born had used them in his work on the lattice theory of crystals in 1921. While matrices were used in these cases, the algebra of matrices with their multiplication did not enter the picture as they did in the matrix formulation of quantum mechanics.

In 1928, Albert Einstein nominated Heisenberg, Born, and Jordan for the Nobel Prize in Physics, but it was not to be. The announcement of the Nobel Prize in Physics for 1932 was delayed until November 1933. It was at that time that it was announced Heisenberg had won the Prize for 1932 "for the creation of quantum mechanics, the application of which has, inter alia, led to the discovery of the allotropic forms of hydrogen".

**The *Deutsche Physik* movement**

On 1 April 1935, the eminent theoretical physicist Arnold Sommerfeld, Heisenberg's doctoral advisor at the University of Munich, achieved emeritus status. However, Sommerfeld stayed in his chair during the selection process for his successor, which took until 1 December 1939. The process was lengthy due to academic and political differences between the Munich Faculty's selection and that of the Reichserziehungsministerium(REM, Reich Education Ministry) and the supporters of *Deutsche Physik*, which was anti-Semitic and had a bias against theoretical physics, especially quantum mechanics and the theory of relativity.

In 1935, the Munich Faculty drew up a list of candidates to replace Sommerfeld as ordinarius professor of theoretical physics and head of the Institute for Theoretical Physics at the University of Munich. There were three names on the list: Werner Heisenberg, who received the Nobel Prize in Physics for 1932, Peter Debye, who received the Nobel Prize in Chemistry in 1936, and Richard Becker – all former students of Sommerfeld. The Munich Faculty was firmly behind these candidates, with Heisenberg as their first choice. However, supporters of *Deutsche Physik* and elements in the REM had their own list of candidates, and the battle dragged on for over four years. During this time, Heisenberg came under vicious attack by the *Deutsche Physik* supporters. One attack was published in *Das Schwarze Korps*, the newspaper of the Schutzstaffel(SS), headed by Heinrich Himmler. In this, Heisenberg was called a "White Jew" (i.e. an Aryan who acts like a Jew) who should be made to "disappear". These attacks were taken seriously, as Jews were violently attacked and incarcerated. Heisenberg fought back with an editorial and a letter to Himmler, in an attempt to resolve this matter and regain his honor.

At one point, Heisenberg's mother visited Himmler's mother. The two women knew each other, as Heisenberg's maternal grandfather and Himmler's father were rectors and members of a Bavarian hiking club. Eventually, Himmler settled the Heisenberg affair by sending two letters, one to SS Gruppenführer Reinhard Heydrich and one to Heisenberg, both on 21 July 1938. In the letter to Heydrich, Himmler said Germany could not afford to lose or silence Heisenberg, as he would be useful for teaching a generation of scientists. To Heisenberg, Himmler said the letter came on recommendation of his family and he cautioned Heisenberg to make a distinction between professional physics research results and the personal and political attitudes of the involved scientists. The letter to Heisenberg was signed under the closing "Mit freundlichem Gruß und, Heil Hitler!" (With friendly greetings, Heil Hitler!") Overall, the Heisenberg affair was a victory for academic standards and professionalism. However, the appointment of Wilhelm Müller to replace Sommerfeld was a political victory over academic standards. Müller was not a theoretical physicist, had not published in a physics journal, and was not a member of the Deutsche Physikalische Gesellschaft; his appointment was considered a travesty and detrimental to educating theoretical physicists.

During the SS investigation of Heisenberg, the three investigators had training in physics. Heisenberg had participated in the doctoral examination of one of them at the *Universität Leipzig*. The most influential of the three was Johannes Juilfs. During their investigation, they had become supporters of Heisenberg as well as his position against the ideological policies of the *Deutsche Physik* movement in theoretical physics and academia.

**World War II**

In 1939, shortly after the discovery of nuclear fission, the German nuclear weapon project, also known as the *Uranverein* (Uranium Club), had begun. Heisenberg was one of the principal scientists leading research and development in the project.

From 15 to 22 September 1941, Heisenberg travelled to German-occupied Copenhagen to lecture and discuss nuclear research and theoretical physics with Niels Bohr.

On 26 February 1942, Heisenberg presented a lecture to Reich officials on energy acquisition from nuclear fission, after the army withdrew most of its funding. The Uranium Club was transferred to the Reich Research Council (RFR) in July 1942. On 4 June 1942, Heisenberg was summoned to report to Albert Speer, Germany's Minister of Armaments, on the prospects for converting the Uranium Club's research toward developing nuclear weapons. During the meeting, Heisenberg told Speer that a bomb could not be built before 1945, and would require significant monetary and manpower resources. Five days later, on 9 June 1942, Adolf Hitler issued a decree for the reorganization of the RFR as a separate legal entity under the Reich Ministry for Armament and Ammunition; the decree appointed Reich Marshall Hermann Göring as the president.

In September 1942, Heisenberg submitted his first paper of a three-part series on the scattering matrix, or S-matrix, in elementary particle physics. The first two papers were published in 1943 and the third in 1944. The S-matrix described only the states of incident particles in a collision process, the states of those emerging from the collision, and stable bound states; there would be no reference to the intervening states. This was the same precedent as he followed in 1925 in what turned out to be the foundation of the matrix formulation of quantum mechanics through only the use of observables.

In February 1943, Heisenberg was appointed to the Chair for Theoretical Physics at the *Friedrich-Wilhelms-Universität* (today, the Humboldt-Universität zu Berlin). In April, his election to the *Preußische Akademie der Wissenschaften* (Prussian Academy of Sciences) was approved. That same month, he moved his family to their retreat in Urfeld as Allied bombing increased in Berlin. In the summer, he dispatched the first of his staff at the *Kaiser-Wilhelm Institut für Physik* to Hechingen and its neighboring town of Haigerloch, on the edge of the Black Forest, for the same reasons. From 18–26 October, he travelled to German-occupied Netherlands. In December 1943, Heisenberg visited German-occupied Poland.

From 24 January to 4 February 1944, Heisenberg travelled to occupied Copenhagen, after the German army confiscated Bohr's Institute of Theoretical Physics. He made a short return trip in April. In December, Heisenberg lectured in neutral Switzerland. The United States Office of Strategic Services sent former major league baseball catcher and OSS agent Moe Berg to attend the lecture carrying a pistol, with orders to shoot Heisenberg if his lecture indicated that Germany was close to completing an atomic bomb. Heisenberg did not give such an indication, so Berg decided not to shoot him, a decision Berg later described as his own "uncertainty principle".

In January 1945, Heisenberg, with most of the rest of his staff, moved from the *Kaiser-Wilhelm Institut für Physik* to the facilities in the Black Forest.

**Uranium Club**

In December 1938, the German chemists Otto Hahn and Fritz Strassmann sent a manuscript to *Naturwissenschaften* reporting they had detected the element barium after bombarding uranium with neutrons and Otto Hahn concluded a *bursting* of the uranium nucleus; simultaneously, Hahn communicated these results to his friend Lise Meitner, who had in July of that year fled to the Netherlands and then went to Sweden.

Meitner, and her nephew Otto Robert Frisch, correctly interpreted Hahn's and Strassmann's results as being nuclear fission. Frisch confirmed this experimentally on 13 January 1939. Frisch along with Rudolf Peierls, by then both in Britain, subsequently wrote the Frisch–Peierls memorandum and joined the British Tube Alloys project.

Paul Harteck was director of the physical chemistry department at the University of Hamburg and an advisor to the *Heereswaffenamt* (HWA, Army Ordnance Office). On 24 April 1939, along with his teaching assistant Wilhelm Groth, Harteck made contact with the *Reichskriegsministerium* (RKM, Reich Ministry of War) to alert them to the potential of military applications of nuclear chain reactions. Two days earlier, on 22 April 1939, after hearing a colloquium paper by Wilhelm Hanle on the use of uranium fission in a *Uranmaschine* (uranium machine, i.e., nuclear reactor), Georg Joos, along with Hanle, notified Wilhelm Dames, at the *Reichserziehungsministerium* (REM, Reich of Education), of potential military applications of nuclear energy. The communication was given to Abraham Esau, head of the physics section of the*Reichsforschungsrat* (RFR, Reich Research Council) at the REM. On 29 April, a group, organized by Esau, met at the REM to discuss the potential of a sustained nuclear chain reaction.

The group included the physicists Walther Bothe, Robert Döpel, Hans Geiger, Wolfgang Gentner (probably sent by Walther Bothe), Wilhelm Hanle, Gerhard Hoffmann and Georg Joos; Peter Debye was invited, but he did not attend. After this, informal work began at the Georg-August University of Göttingen by Joos, Hanle and their colleague Reinhold Mannfopff; the group of physicists was known informally as the first *Uranverein*(Uranium Club) and formally as *Arbeitsgemeinschaft für Kernphysik*. The group's work was discontinued in August 1939, when the three were called to military training.

The second *Uranverein* began after the *Heereswaffenamt* (HWA, Army Ordnance Office) squeezed the *Reichsforschungsrat* (RFR, Reich Research Council) out of the *Reichserziehungsministerium* (REM, Reich Ministry of Education) and started the formal German nuclear energy project under military auspices. The second *Uranverein* was formed on 1 September 1939, the day World War II began, and it had its first meeting on 16 September 1939. The meeting was organized by Kurt Diebner, advisor to the HWA, and held in Berlin. The invitees included Walther Bothe, Siegfried Flügge, Hans Geiger, Otto Hahn, Paul Harteck, Gerhard Hoffmann, Josef Mattauch and Georg Stetter. A second meeting was held soon thereafter and included Klaus Clusius, Robert Döpel, Werner Heisenberg and Carl Friedrich von Weizsäcker. Also at this time, the *Kaiser-Wilhelm Institut für Physik* (KWIP, Kaiser Wilhelm Institute for Physics, after World War II the Max Planck Institute for Physics), in Berlin-Dahlem, was placed under HWA authority, with Diebner as the administrative director, and the military control of the nuclear research commenced.

When it was apparent that the nuclear energy project would not make a decisive contribution to ending the war effort in the near term, control of the KWIP was returned in January 1942 to its umbrella organization, the *Kaiser-Wilhelm Gesellschaft* (KWG, Kaiser Wilhelm Society, after World War II the Max-Planck Gesellschaft), and HWA control of the project was relinquished to the RFR in July 1942. The nuclear energy project thereafter maintained its *kriegswichtig* (important for the war) designation and funding continued from the military. However, the German nuclear power project was then broken down into the following main areas: uranium and heavy water production, uranium isotope separation and the *Uranmaschine* (uranium machine, i.e., nuclear reactor). Also, the project was then essentially split up between a number of institutes, where the directors dominated the research and set their own research agendas. The dominant personnel and facilities were the following:

* *Institut für Physik* (Walther Bothe) of the *Kaiser-Wilhelm Institut für medizinische Forschung* (KWImF, Kaiser Wilhelm Institute for Medical Research),
* Institute for Physical Chemistry (Klaus Clusius) at the Ludwig Maximilian University of Munich,
* HWA *Versuchsstelle* (testing station) in Gottow (Kurt Diebner),
* *Kaiser-Wilhelm-Institut für Chemie* (Otto Hahn),
* Physical Chemistry Department (Paul Harteck) of the University of Hamburg,
* *Kaiser-Wilhelm-Institut für Physik* (Werner Heisenberg),
* Second Experimental Physics Institute (Hans Kopfermann) at the Georg-August University of Göttingen,
* Auergesellschaft (Nikolaus Riehl), and
* *II. Physikalisches Institut* (Georg Stetter) at the University of Vienna.

Heisenberg was appointed director-in-residence of the KWIP on 1 July 1942, as Peter Debye was still officially the director and on leave in the United States; Debye had gone on leave as he was a citizen of The Netherlands and had refused to become a German citizen when the HWA took administrative control of the KWIP. Heisenberg still also had his department of physics at the University of Leipzig where work was done for the *Uranverein* by Robert Döpel and his wife Klara Döpel. During the period Kurt Diebner administered the KWIP under the HWA program, considerable personal and professional animosity developed between Diebner and the Heisenberg inner circle – Heisenberg, Karl Wirtz, and Carl Friedrich von Weizsäcker.

The point in 1942, when the army relinquished its control of the German nuclear energy project, was the zenith of the project relative to the number of personnel devoting time to the effort. There were only about 70 scientists working on the project, with about 40 devoting more than half their time to nuclear fission research. After this, the number of scientists working on applied nuclear fission diminished dramatically. Many of the scientists not working with the main institutes stopped working on nuclear fission and devoted their efforts to more pressing war related work.

Over time, the HWA and then the RFR controlled the German nuclear energy project. The most influential people in the project were Kurt Diebner, Abraham Esau, Walther Gerlach and Erich Schumann. Schumann was one of the most powerful and influential physicists in Germany. Schumann was director of the Physics Department II at the Frederick William University (later, University of Berlin), which was commissioned and funded by the *Oberkommando des Heeres* (OKH, Army High Command) to conduct physics research projects. He was also head of the research department of the HWA, assistant secretary of the Science Department of the OKH and *Bevollmächtiger* (plenipotentiary) for high explosives. Diebner, throughout the life of the nuclear energy project, had more control over nuclear fission research than did Walther Bothe, Klaus Clusius, Otto Hahn, Paul Harteck or Werner Heisenberg.

**1945: Alsos Mission and Operation Epsilon**



Farm Hall, God Manchester

Alsos Mission was an Allied effort commanded by the Russian-American Colonel Boris T. Pash. He reported directly to General Leslie Groves, commander of the Manhattan Engineer District, which was developing atomic weapons for the United States. The chief scientific advisor to Alsos Mission was the physicist Samuel Goudsmit. Goudsmit was selected for this task because he had physics knowledge, he spoke German, and he personally knew a number of the German scientists working on the German nuclear energy project. He also knew little of the Manhattan Project, so, if he were captured, he would have little intelligence value to the Germans.

The objectives of the Alsos Mission were to determine if the Germans had an atomic bomb program and to exploit German atomic related facilities, intellectual materials, materiel resources, and scientific personnel for the benefit of the US. Personnel on this operation generally swept into areas which had just come under control of the Allied military forces, but sometimes they operated in areas still under control by German forces.

Berlin had been a location of many German scientific research facilities. To limit casualties and loss of equipment, many of these facilities were dispersed to other locations in the latter years of the war. The *Kaiser-Wilhelm-Institut für Physik* (KWIP, Kaiser Wilhelm Institute for Physics) had mostly been moved in 1943 and 1944 to Hechingen and its neighboring town of Haigerloch, on the edge of the Black Forest, which eventually became the French occupation zone. This move, some scheming, and a fast-moving American task force allowed them to take into custody a large number of German scientists associated with nuclear research. The only section of the institute which remained in Berlin was the low-temperature physics section, headed by Ludwig Bewilogua (1906–83), who was in charge of the exponential uranium pile.

Nine of the prominent German scientists who published reports in *Kernphysikalische Forschungsberichte* as members of the *Uranverein* were picked up by Operation Alsos and incarcerated in England under Operation Epsilon: Erich Bagge, Kurt Diebner, Walther Gerlach, Otto Hahn, Paul Harteck, Werner Heisenberg, Horst Korsching, Carl Friedrich von Weizsäcker and Karl Wirtz. Also incarcerated was Max von Laue, although he had nothing to do with the nuclear energy project. Goudsmit, the chief scientific advisor to Operation Alsos, thought von Laue might be beneficial to the postwar rebuilding of Germany and would benefit from the high level contacts he would have in England.

Heisenberg had been captured and arrested by Colonel Pash at Heisenberg's retreat in Urfeld, on 3 May 1945, in an alpine operation in territory still under control by German forces. He was taken to Heidelberg, where, on 5 May, he met Goudsmit for the first time since the Ann Arbor visit in 1939. Germany surrendered just two days later. Heisenberg did not see his family again for eight months. Heisenberg was moved across France and Belgium and flown to England on 3 July 1945.

The 10 German scientists were held at Farm Hall in England. The facility had been a safe house of the British foreign intelligence MI6. During their detention, their conversations were recorded. Conversations thought to be of intelligence value were transcribed and translated into English. The transcripts were released in 1992. Bernstein has published an annotated version of the transcripts in his book *Hitler's Uranium Club: The Secret Recordings at Farm Hall*, along with an introduction to put them in perspective. A complete, unedited publication of the British version of the reports appeared as *Operation Epsilon: The Farm Hall Transcripts*, which was published in 1993 by the Institute of Physics in Bristol and by the University of California Press in the US.

The Farm Hall transcripts reveal that Heisenberg, along with other physicists interned at Farm Hall including Otto Hahn and Carl Friedrich von Weizsäcker, were glad the Allies had won World War II, but regretted failing to create an atomic bomb. Upon hearing that the Allies had succeeded in creating atomic bombs and had dropped them in Japan, the German scientists speculated how the bomb was made and discussed their own failure. Heisenberg mentioned some misconceptions regarding the construction of an atomic bomb, such as the critical mass necessary to trigger a nuclear reaction. The morality of creating a bomb for the Nazis was also discussed. Only a few of the scientists expressed genuine horror at the prospect of nuclear weapons, and Heisenberg himself was cautious in discussing the matter. In his book *Alsos*, Samuel Goudsmit states that the German scientists were willing to work for the Nazis to develop an atomic weapon, and attributed their failure to scientific misconception. Paul Lawrence Rose argues in *Heisenberg and the Nazi Atomic Bomb Project: a Study in German Culture* that Heisenberg is intentionally misleading in his report of the atomic bomb project in order to protect his own reputation.

**After 1945**

On 3 January 1946, the 10 Operation Epsilon detainees were transported to Alswede in Germany, which was in the British occupation zone. Heisenberg settled in Göttingen, also in the British zone. In July, he was named director of the *Kaiser-Wilhelm-Institut für Physik* (KWIP, Kaiser Wilhelm Institute for Physics), then located in Göttingen. Shortly thereafter, it was renamed the *Max-Planck-Institut für Physik*, in honor of Max Planck and to assuage political objections to the continuation of the institute. Heisenberg was its director until 1958. In 1958, the institute was moved to Munich, expanded, and renamed *Max-Planck-Institut für Physik und Astrophysik* (MPIFA). Heisenberg was its director from 1960 to 1970; in the interim, Heisenberg and the astrophysicist Ludwig Biermann were co-directors. Heisenberg resigned his directorship of the MPIFA on 31 December 1970. Upon the move to Munich, Heisenberg also became an *ordentlicher Professor* (ordinarius professor) at the University of Munich.

Just as the Americans did with Operation Alsos, the Soviets inserted special search teams into Germany and Austria in the wake of their troops. Their objective, under the Russian Alsos, was also the exploitation of German atomic related facilities, intellectual materials, materiel resources and scientific personnel for the benefit of the Soviet Union. One of the German scientists recruited under this Soviet operation was the nuclear physicist Heinz Pose, who was made head of Laboratory V in Obninsk. When he returned to Germany on a recruiting trip for his laboratory, Pose wrote a letter to Werner Heisenberg inviting him to work in the USSR. The letter lauded the working conditions in the USSR and the available resources, as well as the favorable attitude of the Soviets towards German scientists. A courier hand delivered the recruitment letter, dated 18 July 1946, to Heisenberg; Heisenberg politely declined in a return letter to Pose.

In 1947, Heisenberg presented lectures in Cambridge, Edinburgh and Bristol. Heisenberg also contributed to the understanding of the phenomenon of superconductivity with a paper in 1947 and two papers in 1948, one of them with Max von Laue.

In the period shortly after World War II, Heisenberg briefly returned to the subject of his doctoral thesis, turbulence. Three papers were published in 1948 and one in 1950.

In the post-war period, Heisenberg continued his interests in cosmic-ray showers with considerations on multiple production of mesons. He published three papers in 1949, two in 1952, and onein 1955.

On 9 March 1949, the *Deutsche Forschungsrat* (German Research Council) was established by the *Max-Planck Gesellschaft* (MPG, Max Planck Society, successor organization to the *Kaiser-Wilhelm Gesellschaft*). Heisenberg was appointed president of the *Deutsche Forschungsrat*. In 1951, the organization was fused with the Notgemeinschaft der Deutschen Wissenschaft (NG, Emergency Association of German Science) and that same year renamed the *Deutsche Forschungsgemeinschaft* (DFG, German Research Foundation). With the merger, Heisenberg was appointed to the presidium.

In 1952, Heisenberg served as the chairman of the Commission for Atomic Physics of the DFG. Also that year, he headed the German delegation to the European Council for Nuclear Research (CERN).

In 1953, Heisenberg was appointed president of the *Alexander von Humboldt-Stiftung* by Konrad Adenauer. Heisenberg served until 1975. Also, from 1953, Heisenberg's theoretical work concentrated on the unified field theory of elementary particles.

In late 1955 to early 1956, Heisenberg gave the Gifford Lectures at St Andrews University, in Scotland, on the intellectual history of physics. The lectures were later published as *Physics and Philosophy: The Revolution in Modern Science*.

During 1956 and 1957, Heisenberg was the chairman of the *Arbeitskreis Kernphysik* (Nuclear Physics Working Group) of the *Fachkommission II "Forschung und Nachwuchs"* (Commission II "Research and Growth") of the *Deutschen Atomkommission* (DAtK, German Atomic Energy Commission). Other members of the Nuclear Physics Working Group in both 1956 and 1957 were: Walther Bothe, Hans Kopfermann (vice-chairman),Fritz Bopp, Wolfgang Gentner, Otto Haxel, Willibald Jentschke, Heinz Maier-Leibnitz, Josef Mattauch, Wolfgang Riezler, Wilhelm Walcher and Carl Friedrich von Weizsäcker. Wolfgang Paul was also a member of the group during 1957.

In 1957, Heisenberg was a signatory of the manifesto of the *Göttinger Achtzehn* (Göttingen Eighteen).

From 1957, Heisenberg was interested in plasma physics and the process of nuclear fusion. He also collaborated with the International Institute of Atomic Physics in Geneva. He was a member of the Institute's Scientific Policy Committee, and for several years was the Committee's chairman.

In 1973, Heisenberg gave a lecture at Harvard University on the historical development of the concepts of quantum theory.

On 24 March 1973, Heisenberg gave a speech before the Catholic Academy of Bavaria, accepting the Romano Guardini Prize. An English translation of its title is "Scientific and Religious Truth." And its stated goal was "In what follows, then, we shall first of all deal with the unassailability and value of scientific truth, and then with the much wider field of religion, of which – so far as the Christian religion is concerned – Guardini himself has so persuasively written; finally – and this will be the hardest part to formulate – we shall speak of the relationship of the two truths."  A more detailed insight into Heisenberg's view on religion has been discussed by Wilfried Schröder in "Natural science and religion" (Bremen 1999, Science edition) and Wilfried Schröder "Naturerkenntnis und Religion" (Bremen, science edition 2008).

**Personal life**

In January 1937 Heisenberg met Elisabeth Schumacher (1914–1998) at a private music recital. Elisabeth was the daughter of a well-known Berlin economics professor, and her brother was the economist E. F. Schumacher, author of *Small Is Beautiful*. Heisenberg married her on 29 April. Fraternal twins Maria and Wolfgang were born in January 1938, whereupon Wolfgang Pauli congratulated Heisenberg on his "pair creation" – a word play on a process from elementary particle physics, pair production. They had five more children over the next 12 years: Barbara, Christine, Jochen, Martin and Verena. Jochen became a physics professor at the University of New Hampshire.

Heisenberg enjoyed classical music and was an accomplished pianist.

Heisenberg was raised and lived as a Lutheran Christian, publishing and giving several talks reconciling science with his faith.

In his speech Scientific and Religious Truth (1974) while accepting the Romano Guardini Prize, Heisenberg affirmed:

"In the history of science, ever since the famous trial of Galileo, it has repeatedly been claimed that scientific truth cannot be reconciled with the religious interpretation of the world. Although I am now convinced that scientific truth is unassailable in its own field, I have never found it possible to dismiss the content of religious thinking as simply part of an outmoded phase in the consciousness of mankind, a part we shall have to give up from now on. Thus in the course of my life I have repeatedly been compelled to ponder on the relationship of these two regions of thought, for I have never been able to doubt the reality of that to which they point." (Heisenberg 1974, 213)

"Where no guiding ideals are left to point the way, the scale of values disappears and with it the meaning of our deeds and sufferings, and at the end can lie only negation and despair. Religion is therefore the foundation of ethics, and ethics the presupposition of life." (Heisenberg 1974, 219).

In his autobiographical article in the journal *Truth*, Henry Margenau (Professor Emeritus of Physics and Natural Philosophy at Yale University) pointed out: "I have said nothing about the years between 1936 and 1950. There were, however, a few experiences I cannot forget. One was my first meeting with Heisenberg, who came to America soon after the end of the Second World War. Our conversation was intimate and he impressed me by his deep religious conviction. He was a true Christian in every sense of that word."

Heisenberg also enjoyed mountaineering. In his autobiography, he included photographs from this activity.

Heisenberg died of cancer of the kidneys and gall bladder at his home, on 1 February 1976. The next evening, his colleagues and friends walked in remembrance from the Institute of Physics to his home and each put a candle near the front door He is buried at Munich Waldfriedhof.

Honors and awards

Heisenberg was awarded a number of honors:

* Honorary doctorates from the University of Bruxelles, the Technological University of Karlsruhe, and the University of Budapest.
* Order of Merit of Bavaria
* Romano Guardini Prize
* Grand Cross for Federal Service with Star
* Knight of the Order of Merit (Civil Class)
* Elected a Foreign Member of the Royal Society (ForMemRS) in 1955
* Member of the Academies of Sciences of Göttingen, Bavaria, Saxony, Prussia, Sweden, Romania, Norway, Spain, The Netherlands (1939), Rome (Pontifical), the *Deutsche Akademie der Naturforscher Leopoldina* (Halle), the Accademia dei Lincei (Rome), and the American Academy of Sciences.
* 1932–Nobel Prize in Physics "for the creation of quantum mechanics, the application of which has, inter alia, led to the discovery of the allotropic forms of hydrogen".
* 1933–*Max-Planck-Medaille* of the *Deutsche Physikalische Gesellschaft*

*Research Reports in Nuclear Physics*

The following reports were published in *Kernphysikalische Forschungsberichte* (*Research Reports in Nuclear Physics*), an internal publication of the German *Uranverein*. The reports were classified Top Secret, they had very limited distribution, and the authors were not allowed to keep copies. The reports were confiscated under the Allied Operation Alsos and sent to the United States Atomic Energy Commission for evaluation. In 1971, the reports were declassified and returned to Germany. The reports are available at the Karlsruhe Nuclear Research Center and the American Institute of Physics.

* Robert Döpel, K. Döpel, and Werner Heisenberg *Bestimmung der Diffusionslänge thermischer Neutronen in Präparat 38* G-22 (5 December 1940)
* Robert Döpel, K. Döpel, and Werner Heisenberg *Bestimmung der Diffusionslänge thermischer Neutronen in schwerem Wasser* G-23 (7 August 1940)
* Werner Heisenberg *Die Möglichkeit der technischer Energiegewinnung aus der Uranspaltung* G-39 (6 December 1939)
* Werner Heisenberg *Bericht über die Möglichkeit technischer Energiegewinnung aus der Uranspaltung (II)* G-40 (29 February 1940)
* Robert Döpel, K. Döpel, and Werner Heisenberg *Versuche mit Schichtenanordnungen von D2O und 38* G-75 (28 October 1941)
* Werner Heisenberg *Über die Möglichkeit der Energieerzeugung mit Hilfe des Isotops 238* G-92 (1941)
* Werner Heisenberg *Bericht über Versuche mit Schichtenanordnungen von Präparat 38 und Paraffin am Kaiser Wilhelm Institut für Physik in Berlin-Dahlem* G-93 (May 1941)
* Fritz Bopp, Erich Fischer, Werner Heisenberg, Carl-Friedrich von Weizsäcker, and Karl Wirtz *Untersuchungen mit neuen Schichtenanordnungen aus U-metall und Paraffin* G-127 (March 1942)
* Robert Döpel *Bericht über Unfälle beim Umgang mit Uranmetall* G-135 (9 July 1942)
* Werner Heisenberg *Bemerkungen zu dem geplanten halbtechnischen Versuch mit 1,5 to D2O und 3 to 38-Metall* G-161 (31 July 1942)
* Werner Heisenberg, Fritz Bopp, Erich Fischer, Carl-Friedrich von Weizsäcker, and Karl Wirtz *Messungen an Schichtenanordnungen aus 38-Metall und Paraffin* G-162 (30 October 1942)
* Robert Döpel, K. Döpel, and Werner Heisenberg *Der experimentelle Nachweis der effektiven Neutronenvermehrung in einem Kugel-Schichten-System aus D2O und Uran-Metall* G-136 (July 1942)
* Werner Heisenberg *Die Energiegewinnung aus der Atomkernspaltung* G-217 (6 May 1943)
* Fritz Bopp, Walther Bothe, Erich Fischer, Erwin Fünfer, Werner Heisenberg, O. Ritter, and Karl Wirtz *Bericht über einen Versuch mit 1.5 to D2O und U und 40 cm Kohlerückstreumantel (B7)* G-300 (3 January 1945)
* Robert Döpel, K. Döpel, and Werner Heisenberg *Die Neutronenvermehrung in einem D2O-38-Metallschichtensystem* G-373 (March 1942)

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* *Cassidy, David C. (2001). Werner Heisenberg : A Bibliography of His Writings (2nd ed.). Whittier. ISBN 1-57604-115-8.*
* *Cassidy, David C. "Werner Heisenberg: A Bibliography of His Writings, 1922–1929, Expanded Edition".*
* Mott & Peierls 1977
* *Ludovico, Anna (2001). Effetto Heisenberg. La rivoluzione scientifica che ha cambiato la storia. Roma: Armando. p. 224. ISBN 88-8358-182-2.*
* *Blum, Barbara; Heisenberg, Helmut; Ludovico, Anna (2006). Per Heisenberg. Roma: Aracne. p. 96. ISBN 88-548-0636-6.*