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Bernd Schuh
50 Classics: Scientists
From Aristotle to Crick & Watson

Translated by Allison Brown

Mutter der Radioaktivität

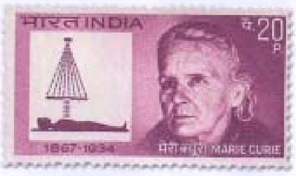
Marie Curie

1867–1934

»Wenn man die Fortschritte ins Auge fasst, die die Physik seit zehn Jahren gemacht hat, ist man erstaunt über den Umschwung, der sich in unserer Auffassung über die Elektrizität und die Materie vollzogen hat.« Mit diesen Worten begann Marie Curie am 5. November 1906 ihre Antrittsvorlesung an der Pariser Sorbonne. In der Tat war einiges geschehen, und die frisch gebackene Professorin und seit kurzem verwitwete Marie Curie hatte selbst entscheidend dazu beigetragen. Zu den erstaunlichsten Funden der Physik in den vorangegangenen zehn Jahren gehörten Röntgens (s. S. 168) X-Strahlen und die noch immer rätselhafte Strahlung, die Henri Becquerel (s. S. 176) kurz nach Röntgen an Uransalzen beobachtet hatte. Ebendiese Erscheinung hatte die junge Physikerin Marie Curie noch im Jahre 1896 zum Thema ihrer Doktorarbeit gewählt. Ausgangsmaterial für ihre Untersuchung war Pechblende, ein stark uranhaltiges Mineral, das sie und ihr Mann Pierre Curie später in größeren Mengen gegen Erstattung der Transportkosten von einer Hütte in St. Joachimsthal geliefert bekamen. Zunächst stand den beiden nicht mehr als eine Tasse voll für ihre Untersuchungen zur Verfügung. Mithilfe eines Geräts zur Messung der neuen Strahlung, das ihr Mann ersonnen hatte, fand Marie Curie heraus, dass die Pechblende noch weitere Strahlungsquellen als das Uran enthalten musste. Dem gesamten Phänomen gab sie den Namen Radioaktivität, also Strahlenaktivität, und die beiden neuen radioaktiven Elemente, die sie nach und nach isolieren konnte, erhielten die Namen Polonium, zu Ehren ihrer Heimat, und Radium. Letzteres entpuppte sich als besonders starker Strahler, war aber in der Pechblende in nur winzigen Mengen enthalten. Mit bewundernswerter Ausdauer bereiteten die beiden Curies in vierjähriger Arbeit eine halbe Tonne Pechblende so weit auf, dass sie einige Zehntelgramm reinen Radiums präsentieren konnten. Doch nicht diese mühevolle Laborarbeit, die sie weitgehend einem Gehilfen hätten überlassen können, hätten sie einen gehabt, nicht das Rühren und Mischen, Extrahieren und Verdichten begründet ihren Verdienst, sondern die vielen physikalisch-chemischen Untersuchungen, die sie mit dem Radium anstellten und die zu der eigentlich wesentlichen Erkenntnis führten: Die neu entdeckte Radioaktivität war eine Naturerscheinung, die sich durch keinerlei äußere Eingriffe beeinflussen ließ. Nicht Druck, nicht Wärme, nicht Kälte, keine chemischen oder elektrischen Manipulationen können die Strahlungsaktivität verändern. Diese hängt einzig und allein von der Menge Radium ab, von der die Strahlung ausgeht. Die Radioaktivität ist ein im Wortsinn elementares Phänomen. Dass sich dieses Phänomen auch in anderen Elementen durch äußere Eingriffe, gewissermaßen »künstlich« hervorrufen lässt, sollte erst dreißig Jahre später Pierre und Marie Curies Tochter Irène herausfinden und damit endgültig den Weg zur Kernphysik und der Atombombe ebnen.

Für die Entdeckung der »natürlichen« Radioaktivität wurden das Ehepaar Curie und Henri Becquerel im Jahr 1903 mit dem No-

■ Marie Curie um 1900 im Laboratorium. Zu dieser Zeit war sie damit beschäftigt, die Elemente Polonium und Radium zu isolieren.



■ Für ihre Verdienste wurde Marie Curie weltweit gewürdigt, hier auf einer indischen Briefmarke.

SCHEUE MARIE IM RAMPENLICHT

Marie Curie war zeitlebens eine sehr zurückhaltende, scheue und bescheidene Person, die ihre große Popularität nur sehr begrenzt genoss. In ihrer Kindheit hatte ihr die Nähe der Mutter gefehlt, die schon lange vor ihrem Tod sich aller Zärtlichkeiten zu den Kindern enthielt, weil sie um ihre ansteckende Erkrankung (Tuberkulose) wusste. Als einzige Professorin an der Sorbonne und Nobelpreisträgerin stand Marie Curie dagegen naturgemäß im Rampenlicht, und auch die Medien interessierten sich sehr für sie. Kurz vor Verleihung ihres zweiten Nobelpreises wurde ihre Affäre mit dem Physiker Paul Langevin in der Klatschpresse breitgetreten, sodass sie vom Nobelkomitee aufgefordert wurde, vor Entgegennahme des Preises ihr Privatleben in Ordnung zu bringen. Marie Curie verbat sich diese Einmischung.

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Genius and Superstition

Natural scientists in today's sense of the term have existed only since the Age of Enlightenment. That marked the beginning of the systematic examination of nature according to set rules and methodology, with specific hypotheses and goals. Science became a social venture that contributed directly to securing human existence.

Today, vaccinations prevent epidemics that once took the lives of millions of people and medical imaging procedures help in healing broken bones or removing tumors. This is all possible thanks to the efforts of scientists such as Louis Pasteur, Robert Koch, and Wilhelm

Roentgen. And as we move around the earth at previously unheard-of velocities and communicate across vast distances as fast as lightning, then anything like this would have been virtually inconceivable without the efforts of men such as Isaac Newton, Heinrich Hertz, or Werner Heisenberg, who laid the foundations for overcoming the limits of time and space.

Even before the Enlightenment there were thinkers, researchers, and healers who sought knowledge about nature and made natural forces accessible to their contemporaries. Archimedes, for example, investigated buoyancy in liquids and left to posterity one of the first fundamental laws of physics that have retained validity to today. Of course the motives of most scientists are rarely to serve the public good. Even Archimedes developed military devices for his rulers; and it has been common knowledge at the latest since J. Robert Oppenheimer that one reason why the great physicists of modernity participated in designing weapons of mass destruction was pure scientific pleasure. Oppenheimer, who led the U.S. atom bomb program referred to his work on the bomb as "technically sweet."

The true motivation of the scientists usually lies in a boundless thirst for knowledge. You can call it a love of truth or stubbornness—scientists have often given their intellectual demands priority over their own comfort. Their maxims could be summarized as "truth above all." Galileo's conflict with the Catholic church about the truth of his worldview ultimately—despite his abjuration— brought him much humiliation and he had to live out the rest of his life under house arrest. It is certainly not the case for all "discoveries" and considerations, however, that "scientific knowledge" necessarily represents the "truth," not even in the sense that it retains its validity. Aristotle, for example, had—in today's terms—preposterous notions about the effects of gravity, which were not corrected until Galileo. Against this background, it makes sense to occasionally stand back and think about what of today's "scientific truths" will remain valid in the future. Einstein drafted a superb theory of space, time, and matter, though it is clear today that it cannot represent wisdom's last word. And some early teachings of modern molecular biology have already had to be abandoned.

The more recent the scientific findings, the clearer it becomes that science does not exist in a vacuum of truth. Scientists (as a rule) can only ask questions that are understood in their time and whose answers (as a rule) are sought. And their insights will only become common knowledge if their colleagues accept them and adopt, modify, expand, and often later abandon them. The natural sciences are not always the rational undertaking as which they appear to the layperson. And even the greatest of scientists are the progeny of a long history and of their age. For example, Isaac Newton's estate included a suitcase filled with alchemist writings. And deceptions, forgeries, and fraud are not unknown to scientists, since they are not immune to cravings for recognition, to greed and lust for power. Robert Koch, for instance, is correctly honored as one of the founding fathers of modern bacteriology, but he had dubious motives for marketing a supposed vaccine against tuberculosis that hurt more than it helped. Science, seemingly comprised of objective truths, is thus a profoundly human undertaking, and its representatives are human beings with needs and weaknesses, irrational fears, beliefs and superstitions. And that is what ultimately makes studying their biographies so exciting.

Photo captions:

Michael Faraday made a great contribution to the basic understanding of electrical phenomena. Steel engraving, around 1860.

Isaac Newton on a trading card of the Liebig Meat Extract Company.

Austrian postage stamps from 1978 commemorating the 100th birthday of Lise Meitner.

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pp. 192–197

Marie Curie: The Mother of Radioactivity

1867–1934

"When one considers the progress that has been made in physics in the last decade, one is surprised by the changes it has produced in our ideas about electricity and matter." With these words, Marie Curie opened her inaugural lecture at the Sorbonne in Paris on November 5, 1906. Much had indeed happened and the brand-new professor and recently widowed Marie Curie had contributed so much. Among the most amazing finds in physics over the preceding ten years were Roentgen's (see p. 168) X-rays and the still mysterious radiation that Henri Becquerel (see p. 176) had observed in uranium salts a short time after Roentgen's discovery. It was precisely this phenomenon that Marie Curie wrote her doctoral thesis on as a young physicist in 1896. She based her research on pitchblende, a material rich in uranium, which she and her husband Pierre Curie later had delivered in large quantities from a smelting works in St. Joachimsthal for nothing but the cost of the transport. At first they had no more than a cupful available for their experiments. Using a device for measuring the new radiation, which her husband had devised, Marie Curie discovered that the pitchblende had to contain additional sources of radiation besides the uranium. She named the entire phenomenon *radioactivity*, and the two new radioactive elements that she was gradually able to isolate were given the names polonium, in honor of her native Poland, and radium. The latter turned out to be extremely radioactive, but it was present in pitchblende in only minuscule quantities. The Curie couple showed amazing perseverance, spending four years processing half a ton of pitchblende until they were able to isolate and present a few tenths of a gram of pure radium. And yet it was not this difficult, time-consuming laboratory work, which they could have largely had an assistant do, if they had had one, not the stirring and mixing, the extracting and consolidating that was so deserving of credit, but the many physics and chemical experiments that they conducted on the radium, which led to the truly essential finding: The newly discovered radioactivity occurred naturally; it could not be influenced by any external intervention. Neither pressure, nor heat, nor cold nor chemical or electrical manipulations can alter the radioactivity, which is dependent solely on the amount of radium emitting the radiation. Radioactivity is literally an elementary phenomenon. Not until thirty years later did Pierre's and Marie's daughter Irène discover that this phenomenon could also be created as it were "synthetically" in other elements through external intervention. This then ultimately paved the way to nuclear physics and the atomic bomb.

Pierre and Marie Curie and Henri Becquerel were honored with the Nobel prize in physics in 1903 for the discovery of "naturally occurring" radioactivity. The prize was a large sum and very sought-after, but it did not yet enjoy the renown that it does today. With the award, Pierre Curie was able finally to establish his own laboratory—his previous one resembled more of a shed—and he received a professorial chair at the Sorbonne, but Marie was only officially hired and paid to run her husband's laboratory.

Three years had already passed before Marie Curie held her inaugural lecture in 1906. She was named an associate professor only due to a tragic event: Her husband was run over by a horse-drawn dray and killed that past May. At first the authorities only wanted to give Marie a—however generous—state pension. It seemed too strange at that time to imagine a woman teaching in the hallowed halls of the Paris universities. Another two years therefore went by before she was able to assume her deceased husband's professorship. Marie Curie continued her research on radioactive materials, isolated radium in pure metallic form, and developed a method of weighing minuscule amounts of the element. In view of the high radioactivity of this material, small differences in amount could lead to huge effects. The newly discovered phenomenon had to be handled with care, as all three discoverers had already learned firsthand. Both Becquerel and Marie Curie suffered burns when handling radium, and Pierre Curie deliberately burned himself when experimenting on himself to see the effects. It was thus absolutely essential to be able to determine the exact weight precisely, also for controlled medical use of radioactivity as a therapy to destroy cancerous tumors. Because of the prospects of this use, the Curies' discovery was celebrated as a miracle weapon against cancer. For a while it was even called the "Curie therapy." Like Wilhelm Conrad Roentgen, Marie Curie and her husband also deliberately refrained from protecting their discovery by means of a patent, in order not to hinder further research. During the First World War Madame Curie, as she was and is often referred to publicly, even organized a mobile X-ray service for French soldiers and she trained X-ray personnel.

In 1911 she was again awarded a Nobel prize, this time in chemistry in honor of her chemical research on radium. The prize was a welcome consolation for an affront that she had suffered a short time earlier because of sexism in academia in France: By a one-vote majority she was refused membership in the elite circle of the French Academy of Sciences.

Marie Curie was exceptional, both as a physicist and as a woman. Consequently, her husband Pierre was undeservedly overshadowed by her. He too was an excellent physicist and even before he noticed the talented Polish woman, he had conducted interesting experiments on crystals and their magnetism. He thereby encountered piezoelectric materials that reacted to pressure by generating an electrical potential and, conversely, their volume changed when an electrical potential was applied. This effect led Pierre Curie and his brother Jacques to construct a sensitive electrometer to measure electrical charges. It was this instrument that later enabled Marie Curie to determine the precise charge emitted by uranium.

In his experiments on solid-state magnetism, Pierre also noticed that the magnetic properties of crystals change with temperature. The transition point beyond which these properties disappear is thus called the "Curie temperature." The name Curie also refers to a no-longer-used unit of radioactivity, in commemoration of the work of Marie Curie. One curie used to denote the activity of one gram of pure radium. The unit was officially replaced by the becquerel on January 1, 1986.

MARIE CURIE

HER LIFE AND WORK

Maria Salome Sklodowska was born on November 7, 1867, in Warsaw. She was the youngest of five children. Her father was a high school teacher and, to supplement the family income, her mother ran a boarding school for girls. Maria was raised in close, rather modest conditions. A brilliant student, she finished her secondary schooling at sixteen. Her mother had already died several years earlier and Maria and her sisters ran the household and gave private tutoring to support the family. Maria worked for six years in Krakow and Warsaw as a governess and financially supported her sister Bronia, who was studying medicine in Paris. In 1891 Maria also went to Paris, where her sister then supported her, to study the natural sciences. Once she moved to Paris, she called herself Marie. In 1893 she graduated first in her class in physics and received a scholarship for her doctoral studies. She meanwhile met Pierre Curie, eight years her senior, who ran a laboratory at the Paris School for Industrial Physics and Chemistry. They married in 1895. Pierre had since become a professor and Marie worked in his laboratory for no pay. Two years later their daughter Irène was born, and Marie had meanwhile started working on her doctoral thesis on the radiation discovered by Henri Becquerel in 1896. In her small laboratory, a drafty shed on university property, she determined that pitchblende, the mineral from which uranium and thorium—the only radioactive elements known at that time—are extracted, must also contain another element that is far more *radioactive*, a term introduced by the Curies. Marie and Pierre Curie spent years of hard, painstaking work isolating the new element, which they called radium. For this work, together with Henri Becquerel they were awarded the 1903 Nobel prize in physics. As a result, Marie Curie, an already internationally known scientist, also became famous in France. Pierre became a professor at the Sorbonne and Marie was in charge of his laboratory. In 1906 Pierre Curie was killed in a traffic accident. Two years later his widow was finally allowed to take over his professorship. She continued to research radium, developed a method for weighing out minuscule amounts of it, thereby making an important contribution toward use of radioactive materials in radiation therapy. In 1911 Marie Curie received a second Nobel prize, this time in chemistry and she was the sole recipient. She received numerous international honors and traveled to many conferences; her laboratory became the center of radioactivity research. In 1932 she passed it on to her daughter Irène. Marie Curie had long been suffering from rheumatism, muscle pain, and anemia. Her bone marrow was destroyed by the radioactive radiation she was exposed to without protection throughout her life. She died on July 4, 1934, in a Swiss sanatorium, one year before her daughter and son-in-law were awarded the Nobel prize for their research on radioactivity.

RECOMMENDATIONS

Worth reading:

Peter Ksoll, Fritz Vögtle, *Marie Curie* (Reinbek: Rowohlt, 1997).

>>Françoise Giroud, *Marie Curie, a life*, trans. Lydia Davis (New York: Holmes & Meier, 1986).

Pierre Radvanyi, *Pour la Science*, “Les génies de la science. Les Curie. Deux couples radioactifs,” no. 9, November 2001-February 2002.

>>Per Olov Enquist, *The Book about Blanche and Marie*, trans. Tiina Nunnally (Woodstock, NY: Overlook Press, 2006).

Worth seeing:

Madame Curie, dir. Mervyn Le Roy; starring Greer Garson, Walter Pidgeon, Henry Travers, Albert Bassermann; USA 1943.

Worth visiting:

The Musée Curie in the Curie Institute in Paris

TO THE POINT

Marie Curie received two Nobel prizes, but was never accepted into the French Academy of Sciences. Her rare brilliance could not protect her from sexism.

SHY MARIE IN THE LIMELIGHT

Marie Curie was a very reserved, shy, and modest person all her life and she had some difficulty enjoying her great popularity. As a child she lacked her mother's closeness. Her mother knew she had a very contagious disease (tuberculosis), so long before she died she refrained from showing her children any physical affection. As the only female professor at the Sorbonne and a Nobel prize recipient, Marie Curie was of course in the limelight, and the media showed great interest in her. Shortly before she was awarded her second Nobel prize, her affair with physicist Paul Langevin was splashed across the headlines of the tabloid press, so she was told by the Nobel committee to straighten out her private life before accepting the prize. Marie Curie did not stand for such an intrusion of her privacy.

EXPENSIVE WISH

Marie Curie's worldwide fame was due mostly to her discovery that enabled great advances in cancer treatment (the "Curie therapy"). Her selfless efforts for the French military during the First World War also contributed to her popularity. She became very popular in the United States as well on her two trips there, each time being received by the current president. She admitted to an American journalist in 1921 that her greatest wish was to have "a gram of radium to experiment with." The journalist, Mrs. Marie Meloney, launched a donation campaign and successfully raised the necessary $100,000.

Photo captions:

Marie Curie around 1900 in her laboratory. She was working at the time to isolate the elements polonium and radium.

Marie Curie was honored around the world for her achievements. Here she appears on a postage stamp in India.

The scientist couple Marie and Pierre Curie in their laboratory, around 1900.

Marie Curie (r.) and her daughter Irène Joliot-Curie with members of the US Army Signal Corps, after 1920.

Irène Joliot-Curie and Albert Einstein in Einstein’s home in Princeton, NJ. One year after her mother’s death, Irène also received a Nobel prize for her research on radioactivity.

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pp. 242–247

Werner Heisenberg: Master of Uncertainty

1901–1976

When a car drives into a thick wall, the result is a totaled car and the wall gets scratched at most—usually. It is part of a physics student’s routine, however, to calculate the probability of the car passing through the wall undamaged. Contrary to expectations, the seemingly absurd question about passing through a wall definitely makes sense, and reality is not what common sense makes it out to be.

We owe this knowledge to Werner Heisenberg and others. He is one of the fathers of quantum mechanics, an innovative description of reality, which—similar to Einstein’s (see p. 220#) theory of relativity—turned accustomed ideas in physics totally upside-down, thereby fundamentally revising our physical view of the world.

The worldview had already started to totter in the early twentieth century, when increasingly precise ideas about the structure of atoms demanded new laws to describe the experiments—laws that Niels Bohr (see p. 226#) first formulated and which could not be explained within the scope of classical physics. But even Bohr’s model of the atom from 1913 gradually proved to be inadequate and were inapplicable for too many measurements. In 1925, then twenty-four-year-old Werner Heisenberg finally succeeded in formulating a theory that broke with classical ideas, such as that the atom is like a solar system with electrons that travel around the nucleus in orbits.

Heisenberg’s theory instead concentrated on measurable quantities such as the frequencies of light that appeared in the radiation spectrums of the atoms. Because the new system of mechanics provided an optimal description of the “quantum jumps” of the electrons in Bohr’s atomic model, it was soon called quantum mechanics.

The new system demanded courage because it broke with familiar calculating rules. The important values in the theory could not be multiplied like common numbers. For example, the result was dependent on the order in which the multiplication was carried out. Put simply, it suddenly made a difference whether A was multiplied by B, or B by A. This was not a mathematical trick; instead, it brought out a natural property that had been unknown up to that then: In the microworld of atoms different laws evidently applied than for classical, “large” particles. Measurements of various quantities such as position and velocity of a quantum mechanical particle were no longer commutable. The first measurement brought the electron (the “system”) into a new state, so that subsequent measurements of the other quantities yielded a different value than if they had been measured first.

The noncommutability of certain measured values proved to be particularly significant in the so-called Heisenberg Uncertainty Principle, named after Heisenberg since he was the first one to formulate it in 1927. According to this principle, position and velocity (or momentum) of a quantum particle cannot be accurately measured at the same time. The more precisely the position of a particle is determined, the less one can say about the momentum measurement, and vice versa. Mathematically, the uncertainty relation has the form of an inequality: The product of the two measurement accuracies is larger than a certain value that defines Planck’s (see pp. 186#) constant.

So quanta were lurking everywhere, and adherents of classical mechanics had a hard time accepting the theory. Even for the discoverers it was not easy to interpret. Discussion on it continued for years, especially with Niels Bohr in Copenhagen. This resulted in the “Copenhagen interpretation” of quantum mechanics, but it was never formulated clearly in a joint paper by Heisenberg and Bohr, the fathers of the theory. Independent of its philosophical interpretations, however, the description brought together so many measurements and data that were previously incomprehensible that there was hardly any doubt as to its correctness. Shortly after Heisenberg, the Austrian Erwin Schrödinger even came to the same conclusions using a totally different mathematical approach. The Schrödinger equation describes quantum mechanical systems as waves whose intensity yields something like the system’s probability of finding the particle at a certain position. That also explains apparently nonsensical questions like the one posed at the beginning about tunneling through a wall. A quantum system cannot be viewed as a particle with a fixed position; instead it is located, with a certain probability, everywhere—that is, also behind the wall. A measurement of the position would be necessary to fix the state of the system and determine on what side of the wall it is located.

The notion that a physical system does not *have* any measurable properties, but first *acquires* them in the measurement process—that is, that it goes through a transition from a state of potentiality to one of reality—was hard for many physicists to grasp, and it still is. Especially Einstein did not want to accept this element of built-in chance in the world ("God doesn't play dice"). He therefore considered quantum mechanics to be an incomplete theory and kept devising examples to point out its internal contradictions, though in the end he was unsuccessful. In view of many experiments that had been carried out in the preceding decade, the brilliant scientist finally had to admit defeat.

The great success of the theory was immediately rewarded, so that Werner Heisenberg already received the Nobel prize in physics for his discovery in 1932. At hardly thirty years old he had already achieved everything that other physicists dream about for a lifetime. Heisenberg soon turned his interest to nuclear physics and understanding the atomic nucleus. He became the director of the so-called Uranium Club, a group of German scientists who were supposed to test the technical capability of nuclear fission, which had been discovered in 1939.

The discoverer of uncertainty was himself very uncertain with respect to a question that was posed after World War II: Why didn't the German physicists build a nuclear reactor and a German atomic bomb? The Uranium Club was led in name only by Otto Hahn (see pp. 216#), who discovered nuclear fission, but Heisenberg was considered the genius of the group, who was in charge of research. The research was spread out among nine laboratories. The rudiments of a reactor existed, but Heisenberg had been mistaken about the necessary structure so a German reactor never came within grasp. After the war Heisenberg and his comrade-in-arms Carl Friedrich von Weizsäcker tried to give the impression that they had intentionally attempted to delay the construction of a reactor in order not to pave the way for Hitler to acquire the atom bomb. This is not supported by wire-tap transcripts of conversations between German scientists that were recorded by the British during the internment of the scientists. The taped conversations showed Heisenberg less shocked about the atom bomb having been dropped on Hiroshima and Nagasaki, and more interested in knowing how the Americans managed to build the bomb. Suspicions cannot be totally cleared up that Heisenberg *wanted* to build the bomb but was simply not successful—lucky for the world.

WERNER HEISENBERG
HIS LIFE AND WORK

Werner Karl Heisenberg was born on December 5, 1901, in Würzburg. The family moved to Munich in 1909. Werner was an excellent student and particularly gifted in mathematics. Because of the chaos of the First World War he didn't finish secondary school with the *Abitur* examination until 1920 and he then studied theoretical physics and mathematics at the university in Munich. Three years after commencing his studies, he already received his doctorate and in 1924 he completed his post-doctoral studies. He worked as an assistant to Max Born in Göttingen and had a teaching position in Copenhagen at Niels Bohr's institute. In 1928 Heisenberg assumed his first professorial chair, in Leipzig. Heisenberg was prevented by the Nazis from receiving a professorship in Munich in 1937 since he spoke out in support of "Jewish physics," such as Einstein's theory of relativity. In 1942 he became a professor at the Kaiser Wilhelm Institute in Berlin. As one of the creators of quantum mechanics, he was awarded the 1932 Nobel prize in physics. He is famous for the Uncertainty Principle, which he formulated in 1927. During World War II he was a leading member of the Uranium Club, a German research group working on building a nuclear reactor. Consequently, Heisenberg was interned in England for a short time after the war. The role he played in the attempt to build a German atomic bomb has not been completely clarified to this day. In 1946 he was appointed director of the Kaiser Wilhelm Institute for physics in Göttingen, which a short time later became the Max Planck Institute for Physics and Astrophysics. In 1958 Heisenberg moved to Munich along with his institute. He taught and researched there until he retired in 1970. He married Elisabeth Schuster in 1937; she met Heisenberg, who was also an excellent pianist, at a private concert. They had seven children. In response to the question why he did not leave Nazi Germany even though he received numerous offers from abroad, he always mentioned his large family as a reason for staying. In the postwar period Heisenberg unsuccessfully tried to develop a unified theory of elementary particles. His efforts, which were marketed as a "world formula," or "theory of everything (TOE)," have meanwhile been forgotten. Werner Heisenberg died of cancer on February 1, 1976, in Munich.

INTERESTING FACTS

The Uncertainty Principle

The uncertainty principle, also known as the Heisenberg indeterminacy principle, is often illustrated by means of a thought experiment (Heisenberg also made use of such aids). In order to determine the precise position of an electron under a microscope, one would need to illuminate it. As soon as it is struck by light particles, however, its momentum would necessarily change. In fact, however, such illustrations are misleading, since they still work with classical conceptions, such as the notion that an election has a specific location and is hit by light particles and thus thrown from its path. This gives rise to the misconception that limitations of the measuring process make it impossible to determine both position and momentum precisely. This is not the case. The uncertainly is basic, and no measurement—no matter how precise—can ever overcome this fundamental uncertainty.

RECOMMENDATIONS

Worth reading:

>>Werner Heisenberg, *Physics and Beyond: Encounters and Conversations*, trans. Arnold J. Pomerans (New York: Harper and Row, 1971).

Werner Heisenberg: *Liebe Eltern Briefe aus kritischer Zeit 1918-1945* (Munich, 2003).
Ernst P. Fischer: *Werner Heisenberg* (Munich, 2002).

>>Armin Hermann: *Werner Heisenberg*, 1901–1976, trans. Timothy Nevill (Bad Godesberg: InterNationes, 1976).
>>Michael Frayn: *Copenhagen* (New York: Anchor Books, 2000).

Worth visiting:

The Atomkeller Museum in Haigerloch with an exhibition on Werner Heisenberg

TO THE POINT

Werner Heisenberg revolutionized classical physics with his quantum mechanics. As the main person responsible for the construction of a German atom bomb, he saved the world from a disaster—though it has never been clarified whether due to his own failure or good intentions.

UNBELIEVABLE SPOOK

One of the many incompatibilities between quantum theory and common sense is the so-called spooky action at a distance. It says that the particles in a quantum mechanical system—such as a pair of light particles from the same source—do not "forget" their memories of their common past state, but remained entangled, even when they are separated by a great distance. Consequently, measuring one particle immediately effects the state of the other, distant particle. Today, developers of a new generation of computers—so-called quantum computers—are trying to make use of this property.

MYSTERIOUS VISIT

In connection with the unclarified role Werner Heisenberg played in German efforts to build an atom bomb, a visit that Heisenberg paid Niels Bohr in Copenhagen in winter 1941 has become legendary. Heisenberg, who supposedly went to Copenhagen on invitation of the German embassy to hold a lecture, took advantage of the opportunity to meet his friend and past mentor. No one knows what the two men really discussed. Whereas Heisenberg later claimed that he wanted to set Bohr's mind to rest as regards the prospects of a German atom bomb, Bohr was extremely unsettled after the conversation and urged the U.S. Manhattan Project to build the bomb.

Photo captions:

Werner Heisenberg, around 1970. "We could no longer really talk about anything else but quantum theory, as we were so imbued with its successes and inner contradictions," said Heisenberg about his time as a student in Göttingen.

The four Nobel prize winners Victor Hess, Werner Heisenberg, Carl Anderson, and Arthur Compton (from left) discussing a device for measuring radiation phenomena in space. Chicago 1939.

Model of a nuclear reactor in the Atomkeller Museum in Haigerloch. German physicists, including Heisenberg, Bothe, Weizsäcker, and Jungk, experimented in 1944–45 with generating energy through nuclear fission.

At a commemoration of Max Planck's hundredth birthday on April 25, 1958, in the Congress Hall in West Berlin, Werner Heisenberg (at the podium) explains the projection of his much-discussed "World Formula," which he first introduced on February 28, 1958. This theory of elementary particles combines the general theory of relativity with quantum theory to form a unified field theory, but it attracted no lasting interest.

Heisenberg (left) and Niels Bohr at a conference of nuclear scientists in Geneva, 1952.