Lise Meitner and the Discovery of Nuclear Fission

by Ruth Lewin Sime

One of the discoverers of fission in 1938, Meitner was at the time overlooked by the Nobel judges. Racial persecution, fear and opportunism combined to obscure her contributions

When scientists first recognized, in late 1938, that a neutron could split an atom's core, the discovery came as a complete surprise. Indeed, no physical theory had predicted nuclear fission, and its discoverers had not the slightest foreknowledge of its eventual use in atomic bombs and power plants. That much of the story is undisputed.

The question of who deserved credit for the breakthrough, however, has long been debated. Physicist Lise Meitner and two chemists, Otto Hahn and Fritz Strassmann, conducted a four-year-long investigation that resulted in the discovery of fission in their laboratory in Berlin. Meitner fled Nazi Germany in 1938 to escape the persecution of Jews, and soon after, Hahn and Strassmann reported the discovery. Meitner and her nephew, Otto R. Frisch, published the correct theoretical interpretation of fission a few weeks later. But the 1944 Nobel Prize in Chemistry was awarded to Hahn alone.

That Strassmann did not get the Nobel with Hahn is probably because he was the junior investigator on the team, and Nobel committees tend to favor senior scientists. But Meitner and Hahn held equal professional standing. Why was she excluded? Hahn offered what became the standard account, which was uncritically accepted for many years. According to him, the discovery had relied solely on chemical experiments that were done after Meitner left Berlin. She and physics, he maintained, had nothing to do with his success, except perhaps to delay it.

Strassmann, who was very much in Hahn's shadow, disagreed. He insisted that Meitner had been their intellectual leader and that she remained one of them through her correspondence with Hahn, even after she left Berlin. The available documents support Strassmann's view. Scientific publications show that the investigation that led to the discovery of fission was intensely interdisciplinary. Questions from nuclear physics initiated the work. Data and assumptions from both chemistry and physics guided and misguided their progress. And private letters reveal that Meitner made essential contributions until the very end.

By any normal standards of scientific attribution, the Nobel committees should have recognized her influence. But in Germany the conditions were anything but normal. The country's anti-Jewish policies forced Meitner to emigrate, separated her from her laboratory and prohibited her from being a co-author with Hahn and Strassmann in reporting the fission result. Because of political oppression and fear, Hahn distanced himself and fission from Meitner and physics soon after the discovery took place. In time, the Nobel awards sealed these injustices into scientific history. Recently released documents show that the Nobel committees did not grasp the extent to which the result relied on both physics and chemistry, and they did not recognize that Hahn had distanced himself from Meitner not on scientific grounds but because of political oppression, fear and opportunism.

Other factors also served to marginalize Meitner, including her outsider status as a refugee in Sweden, a postwar unwillingness in Germany to confront Nazi crimes, and a general perception—held much more strongly then than it is now—that women scientists were unimportant, subordinate or wrong. Publicly, Meitner said little at the time. Privately, she described Hahn's behavior as "simply suppressing the past," a past in which they had been the closest of colleagues and friends. She must have believed that history would be on her side. Fifty years later, it is.

Investigating Uranium

Born and educated in Vienna, Lise Meitner moved to Berlin in 1907 at the age of 28. There she teamed up with Otto Hahn, a chemist just her age, to study radioactivity, the process by which one nucleus is transformed into another by the emission of alpha or beta particles. Their collaboration was capped by their discovery in 1918 of protactinium, a particularly heavy radioactive element. As their careers progressed, they remained equals scientifically and professionally: both were professors at the Kaiser Wilhelm Institute for Chemistry, and each maintained an independent section in the institute—his for radiochemistry, hers for physics.

During the 1920s, Hahn continued developing radiochemical techniques, whereas Meitner entered the new field of nuclear physics. Hahn later described this period as a time when her work, more than his, brought international recognition to the institute. Her prominence, and her Austrian citizenship, shielded Meitner when Hitler came to power in 1933; unlike most others of Jewish origin, she was not dismissed from her position. And although many of her students and assistants were Nazi enthusiasts, Meitner found the physics too exciting to leave. She was particularly intrigued by the experiments of Enrico Fermi and his co-workers in Rome, who began using neutrons to bombard elements throughout the periodic table.

Fermi observed that when a neutron

COURTESY OF ARCHIV ZUR GESCHICHTE DER MAX-PLANCK-GESELLSCHAFT, BERLIN

LISE MEITNER (shown at left in about 1930, at the age of 50) was regarded as one of the leading nuclear physicists of her day. Although she smoked and worked with radioactivity all her adult life, she lived to the age of 90. Otto Hahn and Meitner (*right*), photographed in their laboratory at the University of Berlin around 1910, were colleagues and good friends from 1907 until Meitner was forced to flee from Germany in 1938.

PORTRAIT © ATELIER LOTTE MEITNER-GRAF; PHOTO COURTESY OF ARCHIV ZUR GESCHICHTE DER MAX-PLANCK-GESELLSCHAFT, BERLIN

COURTESY OF DEUTSCHES MUSEUM, MUNICH

MEITNER'S PHYSICAL APPARATUS was used by the Berlin team from 1934 to 1938 for work that resulted in the discovery of nuclear fission. Beginning in the 1950s, it was displayed in the Deutsches Museum for some 30 years as the "Worktable of Otto Hahn," with only a passing reference to Fritz Strassmann and no mention of Meitner.

reaction occurred, the targeted nucleus did not change dramatically: the incoming neutron would most often cause the target nucleus to emit a proton or an alpha particle, nothing more. Heavy elements, he found, favored neutron capture. That is, a heavy nucleus would gain an extra neutron; if radioactive, the heavier nucleus would invariably decay by emitting beta rays, which transformed it into the next higher element. When Fermi irradiated the heaviest known element, uranium, with neutrons, he observed several new beta emitters, none with the chemical properties of uranium or the elements near it. Thus, he cautiously suggested that he had synthesized new elements beyond uranium. All over the world, scientists were fascinated.

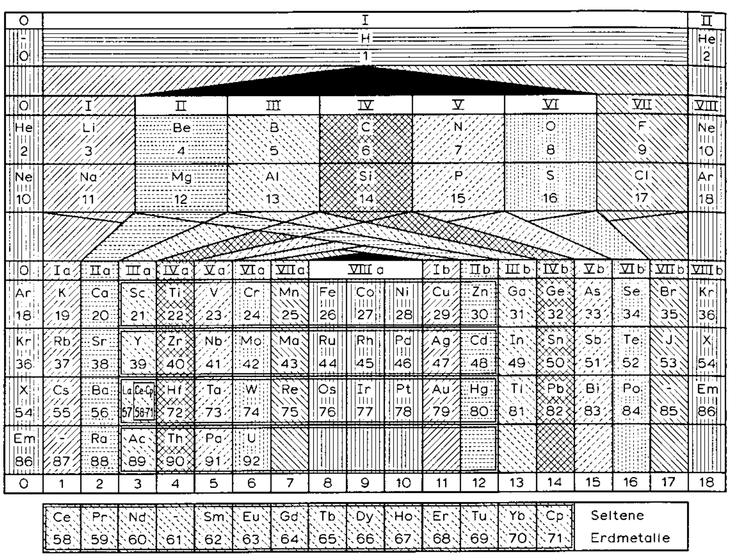
Meitner had been verifying Fermi's results up to this point. The work perfectly suited her interests and expertise, and she was then in her prime: one of the first women to enter the upper ranks of German science, she was a leading nuclear physicist of her day. To study these new "transuranics" in detail, however, Meitner needed an outstanding radiochemist. Hahn, though reluctant at first, agreed to help, and Fritz Strassmann, an analytical chemist from the institute, also joined the collaboration. The three were politically compatible: Meitner was "non-Aryan," Hahn was anti-Nazi, and Strassmann had refused to join the National Socialist–associated German Chemical Society, making him unemployable outside the institute.

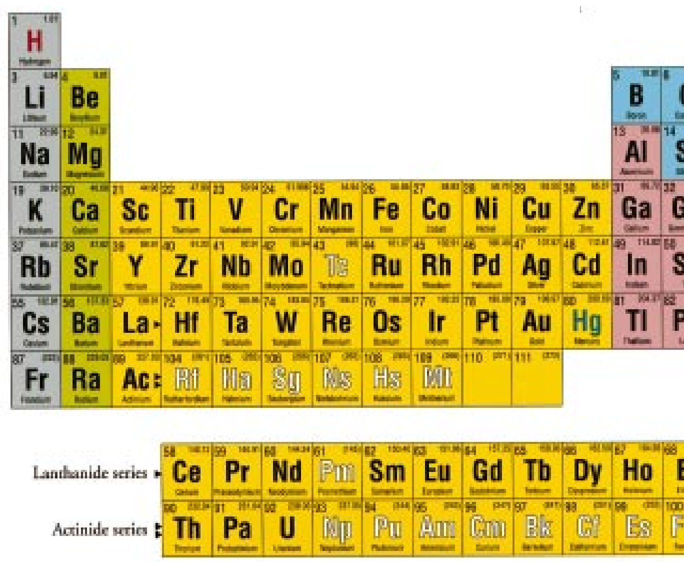
By the end of 1934, the team reported that the beta emitters Fermi observed could not be attributed to any other known element and that they behaved in a manner expected for transuranics: they could be separated out of the reaction mixture along with transition metals, such as platinum and rhenium sulfides. Thus, like Fermi, the Berlin scientists tentatively suggested that these activities were new elements beyond uranium. As it turned out, the interpretation was incorrect: it rested on two assumptions—one from physics and one from chemistry—that would prove false only several years later.

From physics, it had until then been observed that only small changes could take place during nuclear reactions, leaving an event such as fission unimaginable. And from chemistry it appeared that transuranic elements would be

PERIODIC TABLE of the 1920s and 1930s (*below left*) led researchers to expect that the elements following uranium would be transition elements. After the discovery of several transuranic elements in the 1940s, Glenn T. Seaborg recognized that the actinides form a second rare-earth series homologous to the lanthanides (*1995 periodic table, below right*). Element 109 was named meitnerium in 1994.

FROM *The Periodic System of Chemical Elements*, by J. W. Van Spronsen, Elsevier, Amsterdam, 1969 (*left*); COURTESY OF LAWRENCE BERKELEY NATIONAL LABORATORY, UNIVERSITY OF CALIFORNIA (*right*)





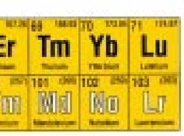
transition elements. It was a simple mistake: the chemistry of thorium and uranium is quite similar to that of transition elements, so chemists in the 1930s also expected that the elements beyond uranium would be transitionlike, resembling rhenium, osmium, iridium and platinum.

Untangling Decay Chains

The two false assumptions reinforced each other, misleading the investigation for several years. Later Hahn blamed physicists and their mistaken faith in small nuclear changes for obstructing the discovery. If anything, however, the scientific publications indicate that the chemists were complacent and the physicists were more skeptical. Physics did not predict fission, to be sure, but it detected discrepancies that chemistry could not.

The Berlin scientists had tried to separate the presumed transuranics, which had extremely weak activities, from uranium and its decay products, which had much stronger, natural radioactivity. After irradiating a uranium sample with neutrons, they would dissolve the sample and then separate from the solution just those activities with the chemistry of transition metals, generally by using transition-metal compounds as carriers. The precipitate itself was a mixture of several beta emitters, which the Berlin team painstakingly began to disentangle.

Over two years, they identified two parallel beta-decay chains, which they referred to as processes one and two [*see box at right*]. The sequence of these decays corresponded to the properties expected for the elements following uranium: they resembled the transition elements rhenium, osmium and so on. The fit between the sequences and the predicted chemistry seemed too good not to be true. Publishing in *Chemische Berichte* in 1936 and 1937, with Hahn as the senior author, the elated group repeatedly referred to these transuranics as "unquestionable," there being "no doubt" about their existence and "no need for further discussion."



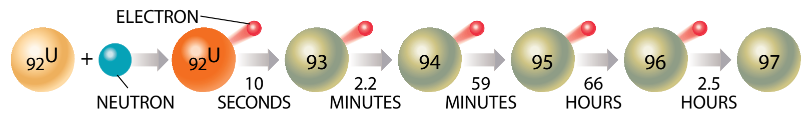
All the while, the data were stretching physical theories thin. Meitner struggled to integrate the results from chemistry, radiochemistry and her own physical measurements into a cogent model of the nuclear processes involved. She established that thermal—exceedingly slow—neutrons enhanced the yield of processes one and two, evidence that these events involved neutron capture. But fast neutrons generated the same results. Thus, she concluded that both processes originated with the most abundant uranium isotope, uranium 238. She also identified a third process—involving the capture of moderately slow neutrons—for which there was no long beta chain.

Meitner regarded it as odd that three different neutron-capture processes all originated from the same uranium 238 isotope. She suspected that something was very wrong with processes one and two. From theoretical considerations, she could not understand how the capture of a single neutron could produce such great instability that it would take four or five beta emissions to relieve it. And it was even harder to understand that the two long beta-decay chains paralleled each other for several steps. Theory offered no explanation. In a 1937 report to *Zeitschrift für Physik*, Meitner concluded that the results were

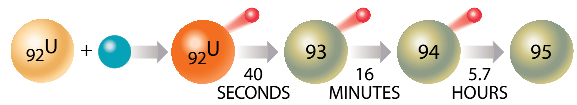
Discovering Fission

The Berlin group found that a large number of beta emitters (radioactive nuclei that emit electrons) were formed when neutrons hit uranium nuclei. The researchers proposed two chains, which they believed consisted of elements beyond uranium, each with its own rate of beta decay:

Process 1

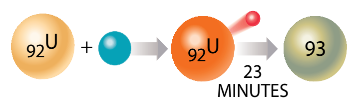


Process 2

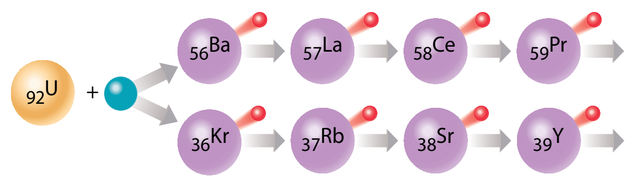


In addition, they identified a simpler reaction:

Process 3



Meitner regarded process three as the most understandable, and later it was shown to be correct. But she was puzzled by processes one and two because the decay chains were so long and paralleled each other. Ultimately, when Hahn and Strassmann identified one of the reaction products as barium, Meitner and Frisch realized that the uranium nucleus had split into nuclei of barium and krypton, which began a series of beta emissions:



JARED SCHNEIDMAN DESIGN

These nuclei and other fission fragments account for the decay chains of processes one and two. Meitner and Frisch proposed the name "nuclear fission," published the first theoretical explanation of the process and predicted the enormous energy released.

—*R.L.S.*

COURTESY OF ARCHIV ZUR GESCHICHTE DER MAX-PLANCK-GESELLSCHAFT, BERLIN

IN THE 1920s Meitner, as professor and head of her own section for physics at the Kaiser Wilhelm Institute for Chemistry, became prominent in nuclear physics. In this photograph, taken in 1920 when Niels Bohr first visited Berlin, are some of her closest colleagues and friends; nearly half would win Nobel Prizes. *Front row:* Otto Stern (Nobel, 1943), James Franck (1925), Bohr (1922). *Second from right:* Gustav Hertz (1925). *To Meitner's right and back:* Hahn (1944) and George de Hevesy (1943).

“difficult to reconcile with current concepts of nuclear structure.”

Once fission was recognized, researchers understood that processes one and two were fission processes: the uranium splits into fragments that are highly radioactive and form a long sequence of beta decays. (There can be many such decay chains because uranium can split in many ways.) Meitner regarded process three as the most normal, and later this was shown to be correct: the uranium 239 isotope formed in this neutron-capture reaction decays by beta emission to element 93. In 1940 it was identified by Edwin McMillan and Philip Abelson and later named neptunium. Had the Berlin scientists been able to detect neptunium, they would have found that it is a rare-earth element, and they would have realized that the activities in processes one and two are not transuranics. But they did not detect it; their neutron sources were too weak.

AIP EMILIO SEGRÈ VISUAL ARCHIVES, *PHYSICS TODAY* COLLECTION

OTTO R. FRISCH and Meitner were the first to explain, in 1939, the fission process. In England in 1940 he and fellow émigré Rudolf Peierls analyzed the potential of nuclear fission for use in weapons and helped to launch the Allied atomic bomb project.

Identifying Barium

The most serious error the Berlin team made was that the investigators separated out and studied only those activities with transition-metal chemistry, ignoring all others. In 1938 in Paris, Irène Curie and Pavel Savitch used a different technique to examine the entire mixture of uranium products and found a new, strong activity whose chemistry they could not ascertain. Like the presumed transuranics, its yield was enhanced by thermal neutrons. By the time the Berlin team looked into it in October 1938, however, Meitner had been forced to flee Germany for Stockholm. Hahn and Strassmann analyzed the Curie activity alone and, finding that it followed a barium carrier, identified it as an isotope of radium.

Meitner and Hahn corresponded constantly, and mail between Stockholm and Berlin was delivered overnight. She could scarcely believe the radium result. To form radium, the uranium nucleus would have to emit two alpha particles. Meitner was convinced that it was energetically impossible for a thermal neutron to knock out even one alpha particle—and certainly not two. In November 1938 Meitner visited Niels Bohr's Institute for Theoretical Physics in Copenhagen, and Hahn met her there on November 13. Outside the city their meeting was kept secret to avoid political difficulties for Hahn, and he never mentioned it later in his memoirs. But we know from Hahn's own pocket diary that they met, and we know that Meitner objected strenuously to the radium result. That was the message Hahn brought back to Strassmann in Berlin.

According to Strassmann, Hahn told him that Meitner “urgently pleaded” that they verify the radium one more time. “Fortunately, her opinion and judgment carried so much weight with us that we immediately began the necessary control experiments,” Strassmann remembered. With these experiments, they intended to verify the presence of radium by partially separating it from its barium carrier. But no separation occurred, and they were forced to conclude that their “radium” was in fact an isotope of barium, an element much lighter than uranium.

In December 1938, just before Christmas, Hahn told Meitner about the barium. It was a “frightful result,” he wrote. “We know uranium cannot really break up into barium!” He hoped she could propose “some fantastic explanation.” Meitner answered by return mail. Although she found it difficult to think of a “thorough-going breakup,” she assured him that “one cannot unconditionally say: it is impossible.” Her letter must have been the best Christmas present he ever received. She had vehemently objected to the radium result, but she was ready to consider the barium result as expanding, rather than contradicting, existing theory.

Later, Hahn was known to say that if Meitner had still been in Berlin, she might have talked him out of the barium result and might have “forbidden” him from making the discovery. But Meitner's letter, which Hahn always had in his possession, demonstrates that the opposite is true. And at the time, Hahn clearly found her letter reassuring, because only after he received it did he add a paragraph to the galley proofs of his barium publication, suggesting that the uranium nucleus had split in two. Meitner was bitterly disappointed that she could not share in this "beautiful discovery," as she called it, but they all knew that it was impossible to include a "non-Aryan" in the publication.

Revising Nuclear Theory

For Christmas, Meitner visited a friend in western Sweden, and her nephew, Otto Frisch, a physicist at Bohr's institute, joined her. When Meitner and Frisch came together, so, too, did the various strands of nuclear theory. Both were accustomed to thinking of the nucleus as a liquid drop, but now they visualized it as a wobbly, oscillating drop that was ready to split in two. Frisch realized that the surface tension of a nucleus as large as uranium might be vanishingly small. Meitner did the mass defect calculation in her head and estimated the lost mass that was converted to enormous energy when the nucleus split. Everything fell into place: the theoretical interpretation itself was a beautiful discovery—and it was recognized as such. The physics community immediately adopted the term "fission" that Meitner and Frisch proposed, and Bohr used their work as a starting point for a more extensive theory.

Hahn and Strassmann's barium finding appeared in *Naturwissenschaften* in January 1939; Meitner and Frisch published their interpretation in *Nature* a few weeks later. On the surface, the discovery of fission was now completely divided—chemistry from physics, experiment from theory, Germans from refugees. To those who did not understand the science or who did not care to understand the politics, it might appear that chemists had discovered fission, whereas physicists had only interpreted it.

In the weeks following the discovery, Hahn exploited that artificial division. He knew Meitner's forced emigration was unjust. He knew she had fully participated in the discovery. But he could not say so. He was afraid for himself and for his position and terribly afraid that others would find out that he and Strassmann had continued to collaborate with Meitner after she left Berlin. He decided that the discovery of fission consisted of just those chemical experiments that he and Strassmann had done in December. In February 1939 he wrote to Meitner, "We absolutely never touched on physics, but instead we did chemical separations over and over again." He described fission as a "gift from heaven," a miracle that would protect him and his institute.

As it turned out, it may not have been necessary for Hahn to divorce himself from Meitner and physics to make the "miracle" come true. That spring the German military took an active interest in the potential uses of the new discovery, and by the summer of 1939 Hahn and his institute were secure. Later he recalled that "fission saved that whole situation."

After the atomic bomb, fission was more sensational than ever, and Hahn was a very famous man. In postwar Germany, he was a major public figure for a generation, lionized as a Nobel laureate and a decent German who never gave in to the Nazis, a scientist who did not build a bomb. His treatment of Meitner, however, was anything but decent. Not once in his numerous articles, interviews, memoirs or autobiographies did he mention her initiative for the uranium project, her leadership of their team in Berlin or their collaboration after she left. He died in Göttingen in 1968 at the age of 89.

In Sweden during the war, Meitner's professional status was poor. Her friends believed that she almost surely would have been awarded a Nobel Prize had she emigrated anywhere else. In 1943 she was invited to Los Alamos to work on the atomic bomb, but she refused. For a brief period after the war ended, she was a celebrity in the U.S. and Britain, miscast as the Jewish refugee who escaped the Nazis with the secret of the bomb. But Meitner was a private person who detested publicity. She never wrote an autobiography or authorized a biography. She left Stockholm for Cambridge, England, in 1960 and died there in 1968, a few days before her 90th birthday. Sadly, she died some 30 years before she received proper recognition for her work. SA

COURTESY OF IRMGARD STRASSMANN

FRITZ STRASSMANN worked with Meitner and Hahn on the investigations that led to the discovery of nuclear fission. His knowledge of analytical chemistry was crucial to the identification of barium. A courageous anti-Nazi, he helped to save the life of a Jewish friend during the war.

The Author

RUTH LEWIN SIME was born in New York City in 1939. She received a bachelor's degree in mathematics from Barnard College in 1960 and obtained a doctorate in chemistry from Harvard University in 1964. Since 1968, she has taught chemistry at Sacramento City College. Her interest in Lise Meitner began some 25 years ago, when she taught a class on women in science and discovered that little scholarly attention had been paid to Meitner's life and work. Her biography *Lise Meitner: A Life in Physics* was published in 1996 by the University of California Press.

Further Reading

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