

LISE MEITNER (1878-1968): PROTACTINIUM, FISSION, AND MEITNERIUM.

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The door to the nuclear age was opened with the startling interpretation of experimental data in 1938 by Lise Meitner and Otto Frisch that nuclear fission had occurred.

Lise Meitner:

Lise Meitner was born in 1878 in Vienna to Jewish parents. She finished middle school at age 14. In Vienna at that time women were not permitted to continue on to high school or university. It was later when these barriers fell that Meitner earned her high school qualifications and at age 23 entered the University of Vienna. Here she was influenced by Ludwig Boltzmann. Her nephew Otto Robert Frisch later wrote, Boltzmann “gave her the vision of physics as a battle for ultimate truth, a vision she never lost.” She was awarded her doctorate degree in 1906 for work which showed that Maxwell’s formula for the conduction of electricity in an inhomogeneous solid also applies to the conduction of heat. (Lise Meitner: R. L.Sime, 1996).

It was around this time on the suggestion of Stefan Meyer that Meitner measured the absorption of alpha and beta radiation emitted by thorium and actinium in foils of various metals. This work served to introduce her to several radioactive substances and to the leaf electroscope.

In 1907 Meitner left for Berlin to study with Max Planck at the university. At the physics department seminars she met Otto Hahn. Both were of the same age. Hahn, with a Ph.D. in organic chemistry from the University of Marburg, was carrying out research on radioactivity in the chemistry institute of Emil Fischer.

Meitner and Hahn started their collaboration which Sir James Chadwick called “one of the most fruitful partnerships in the history of science.” Their skills complemented each other, Meitner a physicist who lacked experience in chemistry and Hahn a chemist and a superb experimentalist while lacking strength in theoretical physics. Both together and separately they carried out chemical and physical investigations throughout their 30 year partnership, until interrupted by the Nazi period. At the start of their collaboration women were not allowed into the Chemistry Institute so it was arranged that Meitner work in a basement room accessible by a separate entrance. The restriction on women entering the institute was lifted two years later. In 1912 Meitner and Hahn moved to the new Kaiser-Wilhelm-Institute in Dahlem. Meitner became assistant to Max Planck in 1912 and director of an independent physics department in the chemistry institute in 1917. The work of both Hahn and of Meitner was interrupted by service in the First World War.

Protactinium:

Hahn: “In 1917 I was transferred to Supreme Headquarters, and in this capacity had official contact with the military research carried out in Haber’s Institute in Dahlem. This provided an opportunity to look in at the nearby Kaiser Wilhelm Institute and to think about science a little. Lise Meitner had also returned from her war service and we tentatively resumed our work, returning to our search for the mother substance of actinium, the unknown homologue of tantalum.

Our first search was for suitable raw material. We inspected the leftover material that results from the treatment of pitchblende with nitric acid. The substance remaining consists mainly of silicon dioxide, which does not dissolve in nitric acid. Careful work revealed that it contained very small quantities of radium, radiolead, and ionium, but also virtually all the tantalum-like substances of the pitchblende. Therefore the substance we were looking for could be expected to be somewhat more enriched than radium in the same preparation. This suspicion was somewhat strengthened by the observation that the pitchblende residue produced considerably earlier gave off some actinium emanation in addition to weak thorium emanation.

The suspicion that pitchblende residue was a useful raw material turned out to be correct. We succeeded in finding the unknown element and in proving it to be the mother substance of actinium. We proposed the name of proto-actinium (later contracted to protactinium).”

The formation of protactinium was proved by the alpha ray curves that were established; the measurements of actinium emanation, the steady increase of which could be observed daily for a period of several months; and the active deposit which could be found in increasing amounts on negatively charged plates. The search for the mother substance of actinium had taken five years.

In 1926 Meitner became the first woman university physics professor in Germany.

Fission:

David Nachmansohn: “To return to the research of neutron effects on uranium, Hahn and Meitner’s interest was enhanced, as mentioned before, by the suggestion that protactinium might be produced. Hahn was by then one of world’s most foremost authorities on radiochemistry. The chemical identification of the elements produced by neutron bombardment of uranium was obviously a great challenge to his ingenuity and skill and promised to clarify the actual effect on the uranium structure. The work eventually became a turning point in science and one of the most fateful experiments ever performed, with effects nobody had foreseen. As we will see, they were destined to change the future of mankind for better or worse; they may lead to devastating effects on our planet and wipe out whole civilizations, or they may open a new era of inestimable benefit for mankind.

For several years Hahn and Meitner, and joined by Fritz Strassmann, devoted their efforts to identify chemically the “transuranium” products. Hahn soon excluded the possibility of protactinium formation. It was in the middle of these activities when Meitner was forced to leave. Hahn and Strassmann continued the work. ” (German-Jewish Pioneers of Science, 1979.)

Fritz Strassmann is the only German chemist honored with a tree in the Avenue of the Righteous, at the Yad Vashem Holocaust Memorial in Jerusalem. In 1933 he resigned from the Society of German Chemists when it became part of a Nazi controlled public corporation. He was blacklisted. Hahn and Meitner found an assistantship for him at half pay. Strassmann considered himself fortunate, for “despite my affinity for chemistry, I value my personal freedom so highly that to preserve it I would break stones for a living.” During the war he and his wife Maria Heckter Strassmann concealed a Jewish friend in their apartment for months, putting themselves and their three year old son at risk.

In July 1937, Lise Meitner with the help of scientist friends escaped to Holland. In the fall of 1938 she received an invitation to continue her work at the Nobel Institute in Stockholm. She remained in Sweden for 22 years. In 1960 she retired to England.

Otto Frisch, himself a Jewish refugee from Germany and then working with Bohr, recalled his visit with his aunt in the small township of Kungälv, near Göteborg, Sweden, during the 1938 Christmas vacation. It was here that she made her most known contribution to science. (O. Frisch: What Little I Remember, 1979).

“Until 1938 nobody dreamt that there was yet another way for a heavy nucleus to react to the mutual repulsion of its many protons, namely by dividing itself into two roughly equal halves. It was mere chance that I became involved in the discovery of that ‘nuclear fission’, which for the first time showed a way to make a huge number of nuclei give up their hidden energy; the way to the atom bomb and to atomic power.

Let me first explain that Lise Meitner has been working in Berlin with the chemist Otto Hahn for about

thirty years, and during the last three years they had been bombarding uranium with neutrons and studying the radioactive substances that were formed. Fermi, who had first done that, thought he had made ‘transuranic’ elements—that is elements beyond uranium (the heaviest element then known to the chemists), and Hahn the chemist was delighted to have a lot of new elements to study. But Lise Meitner saw how difficult it was to account for the large number of different substances formed, and things got even more complicated when some were found (in Paris) that were apparently lighter than uranium. Just before Lise Meitner left Germany, Hahn had confirmed that this was so, and that three of those substances behaved chemically like radium. It was hard to see how radium—four places below uranium—could be formed by the impact of a neutron, and Lise Meitner wrote to Hahn, imploring him not to publish that incomprehensible result until he was completely sure of it. Accordingly, Hahn, together with his collaborator, the chemist Fritz Strassmann, decided to carry out thorough tests in order to make quite sure that those substances were indeed of the same chemical nature as radium.

When I came out of my hotel room after my first night in Kungälv, I found Lise Meitner studying a letter from Hahn and obviously worried by it. I wanted to tell her of a new experiment I was planning, but she wouldn’t listen; I had to read that letter. Its content was indeed so startling that I was at first inclined to be skeptical. Hahn and Strassmann had found that those three substances were not radium, chemically speaking; indeed they had found it impossible to separate them from the barium which, routinely, they had added in order to facilitate the chemical separations. They had come to the conclusion, reluctantly and with hesitation, that they were isotopes of barium.

Was it a mistake? No, said Lise Meitner; Hahn was too good a chemist for that. But how could barium be formed from uranium? No larger fragments than protons or helium nuclei (alpha particles) had ever been chipped away from nuclei, and to chip off a large number not nearly enough energy was available. Nor was it possible that the uranium nucleus could have been cleaved right across. A nucleus was not like a brittle solid that can be cleaved or broken; George Gamow had suggested early on, and Bohr had given good arguments that a nucleus was much more like a liquid drop. Perhaps a drop could divide itself into two smaller drops in a more gradual manner, by first becoming elongated, then constricted, and finally being torn rather than broken in two? We knew that there were strong forces that would resist such a process, just as the surface tension of an ordinary liquid drop tends to resist its division into two smaller ones. But nuclei differed from ordinary drops in one important way: they were electrically charged, and that was known to counteract the surface tension.”

Frisch and Meitner sat down on a tree trunk in the snow and started to calculate on scraps of paper. “The charge of a uranium nucleus, we found, was indeed large enough to overcome the effect of the surface tension almost completely; so the uranium nucleus might indeed resemble a very wobble unstable drop, ready to divide itself at the slightest provocation, such as the impact of a single neutron.

But there was another problem. After separation, the two drops would be driven apart by their mutual electric repulsion and would acquire high speed and hence a very large energy, about 200 MeV in all; where could that energy come from? Fortunately Lise Meitner remembered the empirical formula for computing the masses of nuclei and worked out that the two nuclei formed by the division of a uranium nucleus together would be lighter than the original uranium nucleus by about one-fifth the mass of a proton. Now whenever mass disappears energy is created, according to Einstein’s formula $E=mc^2$, and one-fifth of a proton mass was just equivalent to 200MeV. So here was the source for that energy; it all fitted!”

The similarity of the picture described for dividing up the nucleus to the process by which bacteria multiply caused them to apply the phrase “nuclear fission” in their first publication.

Frisch rapidly demonstrated experimentally that the uranium atom had indeed been split by the action of neutrons. Two papers were mailed to England on January 16, 1939, the first on the interpretation of the barium appearance as atom splitting by Meitner and Frisch, the second on the experimental confirmation by Frisch. The first paper appeared on February 11, the second on February 28.”

Meitner and Frisch were extremely anxious to find out what Bohr’s opinion would be. Frisch showed Bohr the notes and interpretations that they had prepared for him.

Bohr immediately grasped the concept—the atom had been split—and appreciated the enormity of the discovery. Bohr promised to keep the information confidential until the publications concerning the breakthrough had appeared. Due to error on his part, other physicists soon learned about the breakthrough and rushed to confirm the findings. One of these had already detected fission fragments by January 25, 1939.

Hahn and Strassmann could not include Meitner’s name on the papers of the barium findings, let alone admit that they were collaborating with a Jew in exile. Strassmann later expressed the sentiment about Meitner’s role in those key experiments, “Her initiative was the beginning of the joint work with Hahn” and she “was bound to us intellectually from Sweden ... and was the intellectual leader of our team.”

Hahn: “The correct explanation was published (Nature, vol 143, p 239, 1939), by Lise Meitner and O.R. Frisch, to whom we had communicated our results by letter before they were published. They, in turn, passed on their conclusions to Neils Bohr before their contribution saw print. Neils Bohr mentioned their results at a meeting of the American Physical Society on January 26, 1939, thus enabling several of the scientists present to repeat the experiment of uranium fission the same day, just ten days after Frisch had carried it out. Unfortunately, the report by Frisch and Meitner was not printed until March of that year, while the reports by American researchers, who had done their work later, were published before that date.

Otto Hahn was awarded the Nobel Prize in Chemistry for the year 1944 “for his discovery of the fission of heavy nuclei.” Lise Meitner never received this honor. She received numerous nominations for the Prize in both the physics and chemistry categories, including that of Max Planck for physics and that of Niels Bohr for chemistry. In 1948 Otto Hahn nominated Lise Meitner and Otto Frisch for a joint prize in physics. (I. Hargittai: The Road to Stockholm, 2002).

Nachmansohn: Unfortunately the claim of Meitner and Frisch to have been the first to recognize and to confirm experimentally one of the most momentous events in the history of science—and mankind—remained unknown and in doubt for a long time. It was many years before they received credit for their brilliant contribution. It was a monumental documentation of the ingenuity and vision of Meitner that she found the right interpretation of experimental facts that seemed incompatible with prevailing concepts. If one accepts Einstein’s and Planck’s views on decisive importance of intuition and imagination in recognizing the significance of experimental facts, here was a striking example and almost classical confirmation of their ideas.”

In 1994, in a tribute to Lise Meitner, element 94 was named *Meitnerium*.