Part 3
Fission

Hahn and Strassman (1938)

Lise Meitner and Otto Hahn had been at the Kaiser Wilhelm Institute (KWI) in Berlin since its formation in 1912. They had worked together for nearly thirty years and had become close friends. Both were leaders in their respective fields, she in nuclear physics and he in radiochemistry, but in 1934 they were working in separate labs.

Lise was excited, but skeptical about Fermi's discovery of transuranic elements. To explore his results further, she began replicating his experiments, but to identify the radioactive products he was finding, she needed chemical expertise and recruited Hahn and a young chemist, Frans Strassman, to work with her on the problem.

Fermi had used a process of elimination to conclude that he had created transuranic elements, but fellow physicist and chemist, Ida Noddack noted that he had not eliminated elements lighter than lead. She conjectured that "…the nucleus breaks up into several large fragments, that would, of course, be isotopes of known elements, but would not be neighbors [on the periodic table] of the irradiated element." Noddack had correctly predicted the splitting of the uranium atom, but the scientific community mostly ignored her theory.

In the summer of 1938, Meitner, Hahn, and Strassman were getting close to identifying the products of uranium bombardment when Hitler marched into Austria. German annexation of her native country had a chilling effect on Lise. Her Austrian passport no longer protected her and, due to her Jewish ancestry, pressure grew for her to be fired from the KWI. Although she had been head of the physics department since before the Nazis took power, it became clear to her that she must resign and leave Germany, but without a passport that seemed impossible.

In July, two Dutch physicists, friends of Neils Bohr, went to Berlin to help her escape. Together they boarded a train; Lise was carrying only two small suitcases and ten marks, about twenty-five dollars. Trembling with fear, they rode across Germany. At the Dutch border, officials had been bribed and they crossed without incident. Lise was safe, but her entire life's work had been left behind.

Hahn and Strassman were stunned. They had lost their leader and the idea of continuing without her physics expertise added to their stress. Lise was in Sweden, in a state of deep depression. "One dare not look back; one cannot look forward" she wrote to Hahn. For the next six months, their correspondence was their only solace. Otto wrote of their progress and Lise offered suggestions. To Hann and Strassman, Meitner was still a member of their team, still their leader.

In November, 1938, Lise and Otto met with Neils Bohr in Copenhagen and discussed the progress of their work. In the meantime, in France, Irene Joliot-Curie thought she had discovered radioactive barium as a byproduct of the bombardment of uranium, but no one believed it could yield elements so far apart on the periodic table (barium is thirty-six places from uranium). Just before Lise fled Germany, she and Otto repeated Irene's experiment and thought the product must be radium, a much closer element, but they were not sure. When Hahn returned to Berlin, he and Strassman conducted the experiment once again.

In his December 19, 1938 letter to Lise, Hahn concluded that the product could not be radium. Chemically it looked more like barium, but, like Fermi and Joliot-Curie, he thought the result impossible. By Christmas, they were looking at the very disturbing conclusion that the irradiation of uranium had produced radioactive barium. How could this be?

Hahn and Strassman and their chemistry colleagues held two assumptions strongly: first that any transmutation of elements could only be small — a movement of two or, at most four places on the periodic table — and that the chemical properties of transuranic elements would be like uranium. Now both ideas seemed in jeopardy.

Meitner and Frisch (1939)

The nucleus is an improbable balance of forces. Its components have either a positive charge or no charge at all, so it should not exist. Its positively-charged pieces should repel one another with great force, but they do not. Something, some force, holds them together.

Neils Bohr likened the force (known today at the strong force or the strong nuclear force) to the surface tension that allows a drop of water to maintain its shape. In most lighter elements, the strong force dominates and the nuclei are stable. As a nucleus becomes more massive, the balance between the repulsive electromagnetic force and the attractive strong nuclear force, becomes more tenuous.

Bohr characterized the nucleus of U^{235} as at a tipping point — wobbly. The addition of a single neutron could cause the delicate balance to be upset. As the unstable nucleus lengthened, the repulsive force of the protons would overcome the attractive strong force and eventually, within a few billionths of a second, it would split into two smaller nuclei that would fly apart at great speed. Most of the energy released by nuclear fission is the kinetic energy of these two rapidly departing nuclei.

Lise Meitner spent Christmas, 1938 with friends in the small Swedish town of Küngalv. She was joined by her cousin and fellow physicist, Otto Frisch and together they discussed Hahn's letter. As they strolled in the snow, she on foot and he on skis, they recalled Bohr's water droplet theory and envisioned a nucleus pinching in the middle and dividing, creating two new atoms[1]. They now believed this is what had happened in Hahn and Strassman's Berlin lab. The uranium atom had split into two new atoms of similar size, one of which was barium.

They stopped on the snowy trail, searched for pieces of scrap paper and, using a tree trunk as their writing table, began to calculate. Yes, it seemed possible that a precarious uranium nucleus could divide. They then set to adding up the masses of the products of this division and discovered a tiny amount was missing[2]. They used Einstein's equation, $E=mc^2$, to calculate the energy of this missing mass and came up with two hundred million electron volts (200 Mev)[3], a huge amount of energy from a single atom of uranium!

Hahn and Strassman published the results of their fall experiments, the finding of barium from irradiated uranium, in January 1939 (*Naturwissenschaften* vol. 27, pg. 11-15) and the next month, Meitner and Frisch published a paper explaining that Hahn and Strassman had split the uranium atom (*Nature* vol. 143, pg. 239-240).

Up until Christmas Eve, 1938, the world operated with energies in the range of a few electron volts (ev) per atom. The burning of coal, or water turning a generator, or the explosion of TNT, produced heat, electricity, or death by releasing only a tiny amount of the energy bound up in the atom. Now man had released energy thirty-three-million times greater[4]. After Christmas 1938, the world changed. On the day of Meitner and Frisch's walk in the snow, the duality of nuclear energy became apparent; it could be used to provide almost unlimited power or bring almost unlimited destruction. Frisch wrote to his mother, "I feel as if I had caught an elephant by its tail, without meaning to…And now I don't know what to do with it."

[1] Frisch would later liken the division to the partition of a biological cell, and used the term, fission, to describe the splitting of the atom.

[2] The laws of the conservation of mass and conservation of energy say that neither can be created or destroyed, only changed in form. Before fission, matter and energy were, for all practical purposes, separate, but once the forces holding the nucleus together were released, matter became energy.

[3] When Hahn and Strassman bombarded an atom of U^{235} with a neutron, the uranium atom split into one atom of $barium^{141}$ and one atom of $krypton^{92}$ and released two neutrons and 180 million electron volts. ($U^{235} + n > Ba^{141} + Kr^{92} + 2n + 180$ Mev.) There are more than one hundred other combinations of fission byproducts, all of which are radioactive.

[4] The mass of one atom of U^{235} less that of Ba^{141} and of Kr^{92} and two neutrons (the end products of uranium fission) when converted to energy by $E=mc^2$ is 33 million times more powerful than the burning of one atom of carbon.