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Meitner & Frisch On Nuclear Fission

Lise Meitner, an Austrian scientist, and her nephew Otto Frisch, an Austrian physicist, first developed a theory for nuclear fission in 1938. This excerpt from the book, "The Uranium People," written by Manhattan Project scientist Leona Marshall Libby, describes how Frisch and his aunt conceived of the idea for nuclear fission while walking through the woods in Sweden.

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From *The Uranium People* by Leona Marshall Libby

In the spring of 1938, Lise Meitner, being a Jew, had to leave Berlin and went to a job offered her by Manne Siegbahn in the Nobel Institute of Stockholm. Being Austrian, she had not up until then been seriously affected by Hitler's persecution of Jews; however, in the spring of 1938, Austria was annexed by Hitler and she had to get out of the country. Dutch colleagues smuggled her into Holland without a visa and thence to Sweden. The German team would have to carry on without her.

[Otto] Hahn and [Fritz] Strassman continued working together and found they had to assume, from the production of so many different half-lives, that the uranium atom broke into several smaller pieces, belonging probably to elements in the region of platinum, which they thought they could fit to the chemical characteristics of the “transuranium” activities. They wrote this conclusion to Lise Meitner before their results were published in 1938.

Lise Meitner was lonely in Sweden. Her nephew, Otto Frisch, was working in Copenhagen, and he went to visit her at Christmas in 1938. He found her at breakfast, in a small hotel near Göteborg, brooding over a letter from Hahn. The letter said that barium was one of the fragments formed by neutron irradiation of uranium. Frisch remembers that “we walked up and down in the snow, I on skis and she on foot (she said and proved that she could get on just as fast that way), and gradually the idea took shape that this was no chipping nor cracking of the nucleus but rather a process to be explained by Bohr’s idea that the nucleus was like a liquid drop; such a drop might elongate and divide itself.”

Frisch wanted to discuss his plan for his next experiment, so he suggested that Hahn’s results were wrong. Lise shook her head and said that Hahn was too good a chemist to be wrong; his results must be correct, “But how can one get a nucleus of barium from one of uranium?” Frisch remembers, “We walked up and down in the snow trying to think of some explanation. Could it be that the nucleus got cleaved right across with a chisel? It seemed impossible that a neutron could act like a chisel, and anyhow, the idea of a nucleus as a solid object that could be cleaved was all wrong; a nucleus was much more like a liquid drop. Here we stopped and looked at each other.”

They remembered the already classical liquid-drop model of the nucleus and imagined that a drop might get pulled out into a dumbbell shape with a waist in the middle, and then elongate more until the waist was so thin that the drop might break into two pieces. At first, they thought that the surface tension would keep on pulling it back into round, but then they sat down on a log and began to calculate from the liquid-drop model of a nucleus how much was the surface tension of a uranium nucleus containing 92 protons.

Because all the protons were repelling each other by reason of their positive electric charges, they realized that the surface tension was canceled out by this electrical repulsion. The drop, necked out, would consist of two pieces that would soon begin to repel each other as elongation increased to the point of division into two separate pieces, say, barium and krypton (charges 56 and 36), or perhaps rubidium and cesium

(37 and 55), as chance might have it, or zirconium and tellurium (40 and 52), and so on. Here was a plausible explanation why neutron irradiation of uranium produced so many radioactive species; namely, although the charges of the separated drops would be correct for nuclei of barium, krypton, rubidium, cesium, zirconium, tellurium, and so on, the drops would have an excess of neutrons and so would be unstable against beta-ray emissions or other radioactivity until they attained the neutron-proton ratio of stable nuclei in the periodic system. Frisch goes on to remark, “It could have been foreseen if only we had been clever enough.”

More or less, in their words, a classical picture of these new disintegration processes suggests itself. On account of their close packing and strong energy exchange, the particles in a heavy nucleus would be expected to move in a collective way that has some resemblance to the movement of a liquid drop. If the movement is made sufficiently violent by adding energy, such a drop may wiggle about until it divides itself into two smaller drops. It therefore seems possible that the uranium nucleus after neutron capture may divide itself into two nuclei of roughly equal size, the ratio of the sizes depending partly on chance; energy from the difference in stability between uranium and elements around barium would be released in an amount estimated at about 200 million electron volts (compared with natural alpha particle energies of about 5 million electron volts).

Frisch estimated how the split of electric charge would decrease the surface tension of the drop, allowing it to divide, and Meitner calculated that the energy emitted by division would be about 200 million electron volts. They spent the Christmas holidays getting the explanation straight, and then Frisch returned to Bohr’s Institute at Copenhagen and told Bohr the result just as Bohr was about to catch a ship to New York. He recalls, “I had hardly begun to tell him about Hahn’s experiments and the conclusions Lise Meitner and I had come to when he struck his forehead with his hand and exclaimed, ‘Oh, what idiots we have been! We could have foreseen it all! This is just as it must be!’ And yet even he, perhaps the greatest physicist of his time, had not foreseen it.”

How should one name this new kind of nuclear reaction? Frisch asked a biologist at the Bohr Institute what the word was for bacterial division and was told it was called fission, whereupon he took that word for the splitting of uranium upon neutron irradiation. He wrote the article about fission of uranium as deduced from Hahn’s results and read it over the telephone to Lise Meitner. “It was an expensive phone call, all the way to Sweden (from Copenhagen, about 300 miles), and it took quite a while because she had her own suggestions on how we should put matters. But in the end, we agreed about everything, and I got the article typed, ready to be sent off to the editor of *Nature*."

Frisch, a refugee from Austria, had learned to read Italian so that he could follow the papers of the Fermi group closely. These papers were coming out at a rate of almost one per week in the Italian and British journals. Frisch had repeated the Italian measurements that demonstrated the slowing down of fast neutrons to room temperature by rattling around with atoms of water until, like billiard balls, they became sluggish in their movements. Considering his Christmas visit with his aunt, Lise Meitner, during the week when they figured out the theory of fission of uranium, it is interesting that in the 40 years elapsed since then, the theory of fission has advanced very little beyond what they put together that week. He says it was much a matter of chance that he was there to help her figure it out.

Curiously, 3 years earlier, it was also a matter of chance that he, a refugee from the Nazis, had been present at the seminar when Niels Bohr conceived of the theory of the compound nucleus and the liquid-drop model of the nucleus. He considers it "good luck that I was there when the news came from Berlin. And it wasn't my contribution alone, it was the result of a discussion into which Lise Meitner more or less forced me—I would much rather have talked about my own work. Also at that moment it was clear that lots of other people would have had the same idea; it wasn't really a particularly bright idea, I feel." And he did not follow it up in all its ramifications. Instead, "all I did was to do a simple measurement—into which I was prodded—to show that (after fission) the barium nuclei *did* move off as fast as expected." He didn't go beyond that measurement because "I had the feeling that whatever I started, I wouldn't be able to finish a very difficult project such as finding out how many neutrons are created in fission—I didn't even know how to tackle that."

Instead, Frisch found a job in England at the Birmingham laboratory of Mark Oliphant to escape from the war that was fast enveloping the Continent; however, Germany declared war on England soon after Frisch reached Birmingham. He began to work on the problem of separating two isotopes of uranium—uranium-235 and uranium-238—by thermal diffusion, using a vertical tube with a hot central wire containing uranium hexafluoride gas. He and another emigré, Rudolf Peierls, computed from the success of this separation that it was entirely possible, with 100,000 such tubes, to separate a few pounds of uranium-235, enough for a bomb.