Lise Meitner and Otto Frisch, "Disintegration of Uranium by Neutrons" (1939)

Abstract

Chemists Otto Hahn and Fritz Strassmann discovered nuclear fission in December 1938, in the process of bombarding uranium nuclei with neutrons. Initially, however, they were unsure about how to interpret their results. Hahn contacted his former colleague, the nuclear physicist Lise Meitner, who had been forced into exile in Copenhagen on account of the anti-Semitic policies of the National Socialists. Together with her nephew Otto Frisch, Meitner published this letter to the editor, in English, in the leading journal *Nature* in February 1939. Meitner and Frisch explain how energy was released by neutron bombardment during the fission of the uranium nuclei.

Source

Nature, February 11, 1939
Letters to the Editor

Disintegration of Uranium by Neutrons: a New Type of Nuclear Reaction

On bombarding uranium with neutrons, Fermi and collaborators[1] found that at least four radioactive substances were produced, to two of which atomic numbers larger than 92 were ascribed. Further investigations[2] demonstrated the existence of at least nine radioactive periods, six of which were assigned to elements beyond uranium, and nuclear isomerism had to be assumed in order to account for their chemical behaviour together with their genetic relations.

In making chemical assignments, it was always assumed that these radioactive bodies had atomic numbers near that of the element bombarded, since only particles with one or two charges were known to be emitted from nuclei. A body, for example, with similar properties to those of osmium was assumed to be eka-osmium (Z = 94) rather than osmium (Z = 76) or ruthenium (Z = 44).

Following up an observation of Curie and Savitch[3], Hahn and Strassmann[4] found that a group of at least three radioactive bodies, formed from uranium under neutron bombardment, were chemically similar to barium and, therefore, presumably isotopic with radium. Further investigation[5], however, showed that it was impossible to separate these bodies from barium (although mesothorium, an isotope of radium, was readily separated in the same experiment), so that Hahn and Strassmann were forced to conclude that *isotopes of barium* (Z = 56) *are formed as a consequence of the bombardment of uranium* (Z = 92) *with neutrons.*

At first sight, this result seems very hard to understand. The formation of elements much below uranium has been considered before, but was always rejected for physical reasons, so long as the chemical evidence was not entirely clear cut. The emission, within a short time, of a large number of charged particles may be regarded as excluded by the small penetrability of the 'Coulomb barrier', indicated by Gamov's theory of alpha decay.

On the basis, however, of present ideas about the behaviour of heavy nuclei[6], an entirely different and essentially

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 which has some resemblance to the movement of a liquid drop. If the movement is made sufficiently violent by adding energy, such a drop may divide itself into two smaller drops.

In the discussion of the energies involved in the deformation of nuclei, the concept of surface tension of nuclear matter has been used[7] and its value has been estimated from simple considerations regarding nuclear forces. It must be remembered, however, that the surface tension of a charged droplet is diminished by its charge, and a rough estimate shows that the surface tension of nuclei, decreasing with increasing nuclear charge, may become zero for atomic numbers of the order of 100.

It seems therefore possible that the uranium nucleus has only small stability of form, and may, after neutron capture, divide itself into two nuclei of roughly equal size (the precise ratio of sizes depending on finer structural features and perhaps partly on chance). These two nuclei will repel each other and should gain a total kinetic energy of *c.* 200 Mev., as calculated from nuclear radius and charge. This amount of energy may actually be expected to be available from the difference in packing fraction between uranium and the elements in the middle of the periodic system. The whole 'fission' process can thus be described in an essentially classical way, without having to consider quantum-mechanical 'tunnel effects', which would actually be extremely small, on account of the large masses involved.

After division, the high neutron/proton ratio of uranium will tend to readjust itself by beta decay to the lower value suitable for lighter elements. Probably each part will thus give rise to a chain of disintegrations. If one of the parts is an isotope of barium[5], the other will be krypton (Z = 92 - 56), which might decay through rubidium, strontium and yttrium to zirconium. Perhaps one or two of the supposed barium-lanthanum-cerium chains are then actually strontium-yttrium-zirconium chains.

[...]

It might be mentioned that the body with half-life 24 min.[2] which was chemically identified with uranium is probably really ^{239}U, and goes over into an eka-rhenium which appears inactive but may decay slowly, probably with emission of alpha particles. (From inspection of the natural radioactive elements, ^{239}U cannot be expected to give more than one or two beta decays; the long chain of observed decays has always puzzled us.) The formation of this body is a typical resonance process[9]; the compound state must have a life-time a million times longer than the time it would take the nucleus to divide itself. Perhaps this state corresponds to some highly symmetrical type of motion of nuclear matter which does not favour 'fission' of the nucleus.

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[1] Fermi, E., Amaldi, F., d'Agostino, O., Rasetti, F., and Segrè, E. *Proc. Roy. Soc.*, A, 146, 483 (1934).

[2] See Meitner, L., Hahn, O., and Strassmann, F., *Z. Phys.,* 106, 249 (1937).

[3] Curie, I., and Savitch, P., *C.R.,* 208, 906, 1643 (1938).

[4] Hahn, O., and Strassmann, F., *Naturwiss.,* 26, 756 (1938).

[5] Hahn, O., and Strassmann, F., *Naturwiss.,* 27, 11 (1939).

[6] Bohr, N., NATURE, 137, 344, 351 (1936).

[7] Bohr, N., and Kalckar, F., *Kgl. Danske Vid. Selskab, Math, Phys. Medd.,* 14, Nr. 10 (1937).

[8] See Meitner, L., Strassmann, F., and Hahn, O., *Z. Phys*., 109, 538 (1938).

[9] Bethe, A. H., and Placzek, G., *Phys Rev*., 51, 450 (1937).

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