

CLASSICS



We reproduce here, the path-breaking paper by the Featured Scientist of this issue – Lise Meitner*, which she wrote together with Otto Frisch, her collaborator and nephew. The discovery of the neutron in 1932, opened up new possibilities in nuclear physics. Soon afterwards, the results of the experiments bombarding neutrons on uranium, became quite a puzzle for the scientists. It was expected that new elements with Z (atomic number) close to that of uranium will be produced, but Hahn and Strassman conclusively showed that the product was barium, having mass nearly half that of uranium. Lise Meitner was the first to recognize that ‘uranium atom had been split’ in this reaction. The idea germinated when Meitner and Frisch were spending Christmas vacation together in 1938. Discussing about the recent results during a long walk in the snow, considering Bohr’s suggestion of nucleus as a liquid drop, they solved the mystery of why uranium bombarded with a tiny neutron can yield fragments of much lower atomic number. Sitting on a tree trunk, Meitner estimated the energy release in this breakup process, which they later named ‘fission’. After the vacation, Frisch returned to his home institute in Copenhagen and discussed with Bohr, who immediately appreciated the explanation. Frisch experimentally measured the ionizing power of the fragments, and showed that the energy released corresponded to the mass difference of uranium and products, as per Einstein’s mass-energy equivalence relation. This paper describes the physics of fission, treating nucleus as a classical object. This seminal discovery had a profound influence on the field of nuclear physics and society. As the article on our Featured Scientist (p.193) elaborates, Meitner’s role was not recognized in the award of Nobel Prize for the discovery of nuclear fission.

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Letters to the Editor

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NOTES ON POINTS IN SOME OF THIS WEEK'S LETTERS APPEAR ON P. 247.

CORRESPONDENTS ARE INVITED TO ATTACH SIMILAR SUMMARIES TO THEIR COMMUNICATIONS.

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

On bombarding uranium with neutrons, Fermi and collaborators¹ found that at least four radioactive substances were produced, two of which atomic numbers larger than 92 were ascribed. Further investigations² 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 Savitch³, Hahn and Strassmann⁴ 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 investigation⁵, 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 nuclei⁶, 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 used⁷ 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 barium⁸, 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 is possible⁹, and seems to us rather probable, that the periods which have been ascribed to elements beyond uranium are also due to light elements. From the chemical evidence, the two short periods (10 sec. and 40 sec.) so far ascribed to ²³⁹U might be masurium isotopes ($Z = 43$) decaying through ruthenium, rhodium, palladium and silver into cadmium.

In all these cases it might not be necessary to assume nuclear isomerism; but the different radioactive periods belonging to the same chemical element may then be attributed to different isotopes of this element, since varying proportions of neutrons may be given to the two parts of the uranium nucleus.

By bombarding thorium with neutrons, activities are obtained which have been ascribed to radium and actinium isotopes⁶. Some of these periods are approximately equal to periods of barium and lanthanum isotopes⁶ resulting from the bombardment of uranium. We should therefore like to suggest that these periods are due to a 'fission' of thorium which is like that of uranium and results partly in the same products. Of course, it would be especially interesting if one could obtain one of these products from a light element, for example, by means of neutron capture.

It might be mentioned that the body with half-life 24 min.² which was chemically identified with uranium is probably really ²³⁹U, 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, ²³⁹U 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 process³; 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, L., and Savitch, P., *C.R.*, **203**, 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).

