ENRICO FERMI AND URANIUM FISSION

by
Otto Hahn

Being asked to write something for the International Atomic Energy Agency to commemorate 2 December 1942 gives me a strange feeling. There is really nothing to connect me directly with that momentous date, since Germany's scientific contacts with foreign countries - England in the first place and America soon afterwards - came to an end, at least as far as nuclear research was concerned, on the outbreak of the Second World War in September 1939.

Western periodicals ceased publishing anything having to do with uranium fission, which had been announced in January 1939. When, shortly afterwards, it was demonstrated that in uranium fission a few neutrons were "evaporated" in addition, the scientific world knew that harnessing nuclear energy by building up a "chain reaction" had entered the realm of the conceivable. In war, every means that can be developed to weaken or destroy the enemy takes precedence over any beneficent application. Such was the case here too: the possibility of an atomic bomb was discussed. (1)

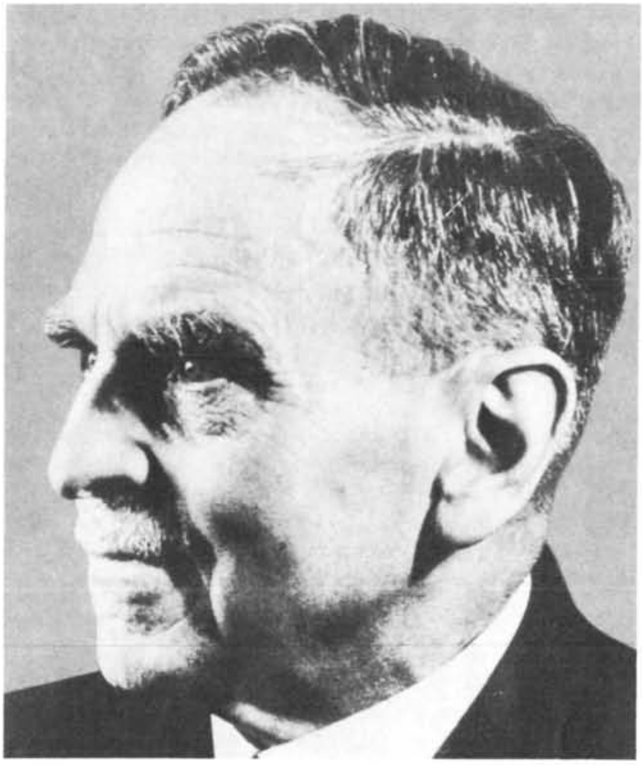
I remember many a conversation with my friend Fritz Strassmann, in which we talked about our fear that a bomb might be built. We consoled ourselves with the thought that it would probably be another twenty years or more before humanity could come into possession of such a weapon, so that its employment in the present war was out of the question.

We had then no inkling of the success of Enrico Fermi and his numerous collaborators, and were happy to be able to continue and publish our purely scientific work on clarifying the many processes occurring during the splitting of the uranium nucleus.

I have therefore really no right and no occasion to commemorate the day on which the Fermi reactor went critical, the day, that is, on which it was proved that a chain reaction can be established, permitting effective exploitation of the energies slumbering in atomic nuclei.

Nevertheless, I have good reason to remember the name of Enrico Fermi. For in 1934 Fermi was the factor motivating the decision by my colleague and friend of many years' standing, Lise Meitner, and myself, to verify Fermi's experiments on uranium irradiation by neutrons.

Discussion had arisen on the interpretation of Fermi's experiments. Fermi had had the attractive idea of using the uncharged neutrons to induce artificial nuclear transformations, instead of the positively-charged α-particles or protons hitherto employed. He and his colleagues had accordingly bombarded with neutrons practically all the elements in the periodic table up to uranium, and had obtained artificial nuclear transformations in the course of which the nucleus, enlarged by the neutron, was transmuted into the next higher element with emission of β-rays.



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Since in the case of uranium irradiation also artificial nuclear species had been detected by Fermi, his conclusion had been that one or even several elements beyond uranium - hence "transuranic" elements - were formed. This conclusion was, however, disputed by my former colleague A. V. Grosse, who had been the first to succeed in producing pure protactinium. Grosse and Agruss did not believe in the presence of atomic species with a nuclear charge higher than 92, but considered the species reported by Fermi to be forms of element 91, in fact to be isotopes of protactinium. As Lise Meitner and myself were well acquainted with the properties of protactinium, and as I had myself discovered many years

(1) See in this connection: S. Flügge, Die Naturwissenschaften **27**, *402-410 (1939)*

previously a β-emitting protactinium isotope, uranium Z, we were very interested in reproducing Fermi's experiments in order to verify whether Fermi or Grosse was right, i.e. whether the new artificial nuclear species corresponded to elements with an atomic number higher than 92, or to element 91, protactinium. Using uranium Z as a tracer for element 91, Lise Meitner and I were able to demonstrate conclusively that the Fermi substances were not isotopes of protactinium and that therefore the inference that they were elements beyond uranium, transuranic elements, was justified. (The elements thorium [90] or actinium [89] had been excluded previously.) Our explanation of the processes was therefore as follows:

When uranium is subjected to neutron bombardment, a neutron is absorbed by the uranium nucleus and an artificial uranium isotope with a mass greater by one unit is created. Hence a neutron in the nucleus is converted into a proton. With emission of a β-particle the uranium isotope becomes an isotope of element 93, i.e. a transuranic element. Fermi and his collaborators discovered not merely one but several simultaneously-formed β-emitters, including a 10-second and a 40-second product. All experience with the other elements in the periodic system indicated that these must therefore be short-lived uranium isotopes, which evidently then changed into further artificial products.

Lise Meitner and I confirmed and extended the experiments of the Fermi group. It transpired that the processes were extremely complex, and in association with Fritz Strassmann we worked out, over a period of four years, two extensive series of artificial transuranic elements with postulated nuclear charges from ekarhenium 93 to ekaplatinum 96. One series began with Fermi's 10-second uranium isotope and the other with the 40-second product. As the transformation products resulting from these isotopes were all precipitable from a strongly-acid solution by means of hydrogen sulphide the "transuranic" elements were in good agreement, as regards their chemical properties, with the hypothesis of ekarhenium 93 and the platinum metal homologues eka-osmium 94, ekairidium 95 and ekaplatinum 96.

Yet the entire structure of our "transuranic" elements rested on the almost tragic error represented by postulation of Fermi's short-lived uranium isotopes of 10 and 40 seconds' half-life. Fermi's conclusion when he carried out his neutron irradiation of uranium in 1934 was correct and our long transformation series appeared to be equally correct. Fermi could not know that under neutron bombardment a completely different process takes place in the case of uranium than in that of the lower elements in the periodic table. Further results were required - which at first only increased the confusion - before the events occurring during uranium irradiation received their proper explanation.

I shall limit myself to a very brief description of our continued mistaken course and ultimate success. Under certain irradiation conditions Lise Meitner and I found, in addition to the 10- and 40-second substances regarded by Fermi as uranium isotopes, an artificial product of 23 minutes' half-life which, with the aid of the tracer technique, we were able to identify unequivocally as a genuine uranium isotope. Since it emitted β-rays it must of necessity transmute into element 93, ekarhenium. Owing to our weak radiation source we were unable, despite our efforts, to discover this ekarhenium. At that time, however, it was in any case of no particular interest to us, since we believed that we already possessed forms of ekarhenium in the shape of transformation products of Fermi's short-lived uranium isotopes. Here again we have a repetition of the near-tragic misunderstanding connected with these products, but for which we should have taken a great deal of trouble with the transformation product of the 23-minute uranium isotope. By repeatedly separating the 23-minute uranium and hence enriching its unknown transformation product, we should probably have discovered the ekarhenium in process of formation and seen to our astonishment that it possessed none of the properties we were obliged to assume for it on the basis of our Fermi transformations. McMillan and Abelson found the true element 93 after uranium fission had been discovered. It was called by its discoverers neptunium.

But back to 1938. The number of artificial nuclides resulting directly or indirectly from uranium irradiation became greater still when Strassmann and myself, in examining a 3.5 hr product described by Curie and Savitch, were able to demonstrate the existence of no fewer than four new substances, all of which we had to describe as artificial isotopes of radium. From their chemical reactions they could only be either radium or the barium which had been added for their precipitation. The latter was of course excluded on the basis of all nuclear physics experience gained up to that point.

But now at last there followed the experiments which led to enlightenment. We tried to separate our artificial "radium" from the inactive barium ballast material by fractional crystallization, because we wished to have thinner layers for studying the β-radiation. The result is well-known: despite the most varied techniques, long familiar to us, we failed to separate the "radium" from the barium, and tracer experiments with natural radium isotopes, such as mesothorium and thorium-X, and our artificial "radium" finally forced us to the conclusion that the latter was not radium at all but barium. During neutron bombardment the uranium had "split" into medium weight elements, one of which was barium, the other being shown shortly afterward to be krypton, both elements appearing in the form of several isotopes.

The first explanation of this "split" was provided by Lise Meitner and O. R. Frisch. It is as a result of their suggestion that the process is known today as "fission".

At the beginning of this brief historical account I stated that I had really nothing to do with 2 December 1942, the day on which Fermi's nuclear reactor became critical. That is quite true. With Fermi himself however, my colleagues Lise Meitner and Fritz Strassmann and I myself had a great deal to do. Fermi's short-lived transformation products, considered to be isotopes of uranium, were the starting point of four years' work in common. And although, once the true processes had been clarified, these short-lived uranium isotopes stood revealed as an illusion which was unavoidable at the time, the systematic effort nevertheless led to success in the end. Had it not been for Fermi, Hahn, Meitner and Strassmann might never have taken an interest in uranium.

Our gratitude to Fermi today is therefore due less perhaps for his reactor than for his experiments using uncharged neutrons in order to bring about artificial nuclear processes.