DEUTERON-INDUCED FISSION*

MECHANISM OF DEUTERON-INDUCED FISSION

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IN nuclear transformations initiated by deuteron impact, two types of processes are, as well known, to be taken into consideration. In the process of the first type (process I), the intermediate state is formed by the capture of the whole deuteron by the nucleus; in the process of the second type (process II), the deuteron breaks up during the impact with the result that the proton escapes and only the neutron is taken up in the compound nucleus. As originally pointed out by Oppenheimer and Phillips¹ and more closely discussed by Bethe², the cross-section for the formation of the compound system may, in certain circumstances, be considerably larger in process II than in process I. Still, a clear discrimination between the two types of processes by means of ordinary nuclear transformations seems so far to have met with difficulties, and it may, therefore, be of interest to point out that the study of deuteron-induced fission of heavy nuclei offers new possibilities for such a discrimination.

Not only is fission easily distinguished from other possible transformations but, in particular, a certain critical excitation energy different for different nuclei is necessary for fission to occur. Just as regards the excitation of the compound nucleus, the processes I and II differ essentially. While the excitation obtained by process I will be far greater than the neutron binding energy for all nuclei concerned, it will, in process II, on the average be smaller than this energy. Since, for the abundant uranium isotope, as well as for thorium, the critical fission energy is higher than the neutron binding energy, it was concluded³ that a considerable output of nuclear fission in thorium and uranium could only be expected in processes of type I. Even if, in certain deuteron energy regions, processes of type II should be more probable, they would almost entirely result in a permanent capture of a neutron with formation of radioactive uranium and thorium isotopes with well-known periods.

One of the possibilities of testing these arguments is offered by a comparison between the fission yields in uranium and thorium. This is possible because the probability of fission of the compound nucleus in process I may be estimated with a high degree of approximation. In fact, the excitation energy in process I will not only be sufficient for fission to occur in competition with neutron escape, but even the excitation of the residual nucleus left after the escape of a neutron will be large enough to make a fission quite probable. The total probability for fission of the compound nucleus in such successive

transformations was thus estimated⁴ to be nearly 1 for uranium and about 0.8 for thorium. These expectations seemed confirmed by the experiments reported by Jacobsen and Lassen⁵ who found that the ratio of the fission cross-sections in uranium and thorium at 9-Mev. deuteron energy was approximately 0.7.

In a later discussion of these experiments⁶, however, it has been realized that the cross-section for the formation of the compound system in process I, because of the smaller nuclear charge, must be expected to be 25 per cent greater in thorium than in uranium. If the whole fission effect in both elements was due to processes of this type, the theoretically estimated ratio of the fission yields in thorium and uranium should, consequently, instead of 0.8, be about 1.0. The difference between this last figure and the measured value 0.7 seems too great to be explained, unless it is assumed that a considerable part of the effect, at any rate in uranium, is due to processes of type II. A support of this conclusion is also offered by a closer comparison of the fission effects in thorium and uranium for smaller deuteron energies. Thus, in the experiments of Jacobsen and Lassen the fission cross-section for deuteron energies about 8 Mev. is relatively higher in uranium than in thorium, as would be expected if a part of the effect in uranium sets in for lower energy values.

A contribution of process II to the fission effects which is relatively greater in uranium than in thorium may be expected from the fact that the critical fission energy of the compound nucleus for thorium is almost 2 Mev. higher than the neutron binding energy, while, for the abundant uranium isotope (238), the difference is smaller than 1 Mev. Moreover, in the energy region concerned, where the fission cross-section is less than 1 per cent of the geometrical nuclear cross-section, it is possible that a not inconsiderable contribution is due to the lighter rare uranium isotope (235). Since, for this isotope, the critical fission energy of the compound nucleus in process II is about 1 Mev. lower than the neutron binding energy, the probability of fission may, for the low excitations obtained by such a process, be far greater than for the heavy isotope.

To clear up the different questions raised, it would be very desirable that experiments on deuteron-induced fission be extended to a region of greater deuteron energies, and, especially, that such experiments be performed with separated uranium isotopes and with protactinium, for which the critical fission energy of the compound nucleus is nearly equal to the neutron binding energy⁷.

¹ Oppenheimer, J. R., and Phillips, M., *Phys. Rev.*, **48**, 500 (1935).

² Bethe, H. A., *Phys. Rev.*, **53**, 39 (1938).

³ Bohr, N., and Wheeler, J. A., *Phys. Rev.*, **56**, 449 (1939).

⁴ Bohr, N., *Phys. Rev.*, **53**, 864 (1940).

⁵ Jacobsen, J. C., and Lassen, N. O., *Phys. Rev.*, **53**, 867 (1940).

⁶ Jacobsen, J. C., and Lassen, N. O., *Det Kgl. Danske Vidensk. Selsk. Math.-fys. Medd. (Math.-phys. Comm., Acad. Sci. Copenhagen)*, in print.

⁷ Wheeler, J. A., and Bohr, N., *Phys. Rev.*, **56**, 1065 (1939).

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