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Fission Asymmetry as a Function of
Excitation Energy of the Compound Nucleus

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A preliminary investigation of asymmetry of fragment mass distribution from proton induced fission has been made as a function of energy in the range 11-18 mev. Foils of normal uranium (11 mg/cm^2) separated by aluminum were bombarded at a fixed radius with the internal beam of the 86-inch cyclotron. In different experiments, the energy of the proton beam at the bombarding radius was found from the known p,n and p,2n excitation curves of $\text{Cu}^{63(1)}$ and the range energy relations in copper. The $2.5 \text{ cm} \times 0.6 \text{ cm}$ foils of uranium and aluminum were supported behind a 11 mil window of a water cooled Al probe, and the energy of the protons at each foil was found to ± 1.0 mev from the incident proton energy and the range energy curves in U and Al.

For each U foil, the fission yields of Mo^{99} and Ag^{111} relative to Ba^{140} were determined by use of radiochemical procedures.⁽²⁾ Mo^{99} and Ba^{140} occur at the peaks of the thermal neutron fission mass distribution; Ag^{111} occurs in the valley of this distribution. Relative yields were obtained in terms of known yields by performing the identical radiochemical analysis for thermal neutron fission in similar quantities of normal uranium. Neutron fission background was found in foils placed beyond the proton range.

The ratio, $\text{Yield Mo}^{99} / \text{Yield Ba}^{140}$, is almost constant as a function of proton energy and is the order of 60 per cent higher than in the case of thermal neutron fission in U^{235} . The ratio, $\text{Yield Ag}^{111} / \text{Yield Ba}^{140}$, varies with proton energy in such a way as to indicate that the probability of symmetrical fission increases rapidly with excitation energy.

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In Fig. 1, the asymmetry of fission as produced in a number of ways is compared. As ordinate on log scale, the ratio, $\text{Yield Ag}^{111}/\text{Yield Ba}^{140}$, is plotted against the quantity $[E - 5]^{-1/2}$, where E is the bombarding particle energy plus its binding energy in Mev. The binding energies are calculated from semi-experimental mass tables.⁽³⁾ The abscissa, which varies inversely as the square root of energy, suggests reciprocal nuclear temperature. The quantity 5 mev which is subtracted from the excitation energy to give a linear relationship on the semilog plot is interpreted as the effect of cooling of the nucleus as it is distorted to give fission. This checks with the γ -ray fission threshold which is about 5 mev.

With $[E - 5]^{1/2} = bT$ where T is the nuclear temperature of the distorted nucleus, Fig. 1 shows $\text{Yield Ag}^{111}/\text{Yield Ba}^{140}$ varies as $3.5 \exp \frac{-9.6}{bT}$. Since in the case of nuclear phenomena as well as in atomic phenomena, the relative probability of two states separated in energy by ΔE is of the form $\exp - \Delta E/T$, $9.6/b$ is interpreted as the energy difference between the asymmetrical mode of oscillation of the distorted uranium nucleus and the symmetrical mode. Nuclear temperature, defined by $T = \frac{d \ln \omega(E)}{dE}$, can be estimated from the expression for nuclear level densities; $\omega(E) = C \exp 2(E/a)^{1/2}$. For Uranium $a = .244$ (mev) gives the observed 5 electron volt spacing of levels at excitation energy of about 6 mev. Under the assumption that the energy level density in the distorted nucleus varies in the same way, b becomes $(.244)^{-1/2}$ and ΔE is 4.7 mev. Fig. 1 then indicates that the symmetrical mode of fission requires the order of 4.7 mev more energy than the asymmetrical mode.

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Caption

Fig. 1. Fission Asymmetry as a Function of Excitation Energy of the Compound Nucleus. (*) Average over neutron energy spectrum. References: 1. W. F. Jones, J. L. Fowler, J. H. Paehler, Bulletin Southeastern Section of Amer. Phys. Soc., 1952; 2. Rev. Mod. Phys. 18, 513, 1946; 3. R. W. Spence, B.N.L.-C-9 (A.E.C.U. 645); 4. A. S. Newton, Phys. Rev. 75, 17, 1949; 5. A. Turkevich and J. B. Hiday, Phys. Rev. 84, 52, 1951; 6. Appendix B, National Nuclear Energy Series, The Fission Products, Div. IV, Vol. 9; 7. P. R. O'Connor and G. T. Seaborg, Phys. Rev. 74, 1189, 1948.

Footnotes

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