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THE FISSION ENERGY BARRIER

by

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PHYSICS--FISSION

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PHYSICS--FISSION

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THE FISSION ENERGY BARRIER

Introduction

The energy which would have to be supplied to a heavy nucleus in order to induce fission has been calculated by Bohr and Wheeler[1] and more recently and in more detail by Frankel and Metropolis.[2] This energy barrier has been taken to be the energy difference between the initial spherical nucleus and the somewhat elongated shape at the saddle point of the potential energy surface. The distortion from a spherical shape is assumed to increase the surface energy of the nucleus (as $1/A^{2/3}$) and to decrease the coulomb energy (as $Z^2/A^{1/3}$). The theory then predicts quite a strong dependence of the fission energy barrier on Z and A of the fissioning nucleus. The purpose of this paper is to point out that there is now some experimental evidence indicating a somewhat less strong dependence of the fission energy barrier on Z and A than that given by the above theory.

Photofission Thresholds

The experimental photofission threshold data of Koch, McElhinney and Gasteiger,[3] together with the corresponding thresholds predicted by Frankel and Metropolis, are reproduced below in Table I.

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Table I

Fissioning nucleus	Experimental threshold (Mev)	Threshold predicted by F. and M. (Mev)
U^{238}	5.08 ± 0.15	7.0
U^{235}	5.31 ± 0.25	6.1
Pu^{239}	5.31 ± 0.27	4.9
U^{233}	5.18 ± 0.27	5.7
Th^{232}	5.40 ± 0.22	8.5

Koch et al measured the least gamma ray energy sufficient to produce fission in the nuclei indicated, using a fission chamber for detection. The value for U^{238} has recently been checked at the University of Illinois, using a catcher technique for detection.[4] The threshold obtained in the latter experiment was 5.2 ± 0.15 Mev, in agreement with Koch et al. The threshold for photoneutron emission from uranium was also observed to be 5.2 Mev although the threshold for the $U^{238}(\gamma,n)U^{237}$ reaction had been independently determined to be 5.95 Mev.[5]

The measured photofission thresholds are remarkably constant, showing very little dependence on Z and A. They differ markedly from the values predicted by Frankel and Metropolis which are given in the last of Table I.

It should be noted that the liquid drop model values quoted throughout this paper are "classical" values in that

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two quantum effects which surely are of some importance have been neglected. These are the zero point energy of the vibration which leads to fission, and the penetrability of the potential barrier. Frankel and Metropolis estimate that these two effects might lower the classical values quoted above by as much as 0.4 Mev. Even so, the disagreement with experimental results would remain.

Neutron-Induced Fission

When the nucleus (Z,A-1) captures a neutron, the nucleus (Z,A) is formed with excitation energy equal to the sum of the kinetic energy of the neutron and the neutron binding energy in (Z,A). If this excitation energy exceeds the energy barrier to fission, then fission may occur. One can, therefore, get information concerning the energy barrier from neutron fission cross sections provided that the neutron binding energy is known. The neutron binding energies in many isotopes of the heavy elements can be calculated from the neutron binding energies in the lead isotopes, which are known quite well,[6,7,8] by using the disintegration energies along the radioactive series. Such calculations have been made by a number of people. The values obtained differ slightly but the author does not believe that the differences affect the conclusions reached below. The binding energies used here have been taken

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from unpublished calculations of J. R. Huizenga.

Thermal Neutron Fission

For most nuclei which are known to undergo thermal neutron fission, the excitation energy produced by neutron capture exceeds the energy barrier predicted by the liquid drop model. For a few nuclei, however, the predicted threshold energy is greater than the neutron binding energy and yet thermal neutron fission is observed. These cases are listed in Table II.

Fast Neutron Fission

Experiments have placed upper limits on the neutron energy necessary to produce fission in certain nuclei which do not undergo thermal neutron fission. These are listed in Table III. These experiments do not give sharp thresholds, so the values given are strictly upper limits on the energy barriers. The nuclei listed apparently have thresholds lower than those predicted by the liquid drop model.

Spontaneous Fission

The spontaneous fission rates of certain heavy nuclei have been measured. These are given in Table IV.

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Table II*

(Z,A-1) in which neutron is captured.	Neutron binding energy in (Z,A) (Mev)	Observed fission cross section (barns)	Threshold predicted by F. and M. (Mev)
Th^{229}	6.7	~ 45	7.7
Pa^{232}	6.6	700	7.1
Np^{237}	5.3	0.02	5.8
U^{235}	6.4	546	6.8

* All data on neutron cross sections are taken from the summary report ORNL-86 compiled by G. Haines and K. Way.

Table III*

(Z,A-1) in which neutron is captured	B_n Neutron binding energy in (Z,A) (Mev)	E_n Neutron energy to produce fission (Mev)	E_n plus B_n	Threshold predicted by F. and M. (Mev)
Pa^{231}	5.4	≤ 0.3	≤ 5.7	6.8
Th^{232}	4.9	≤ 1.1	≤ 6.0	8.9
U^{238}	4.6	≤ 1.0	≤ 5.6	7.8

* The author is indebted to Katherine Way for calling attention to these experiments.

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Table IV

Fissioning nucleus	Spontaneous fission rate (dis./gm hr)	Threshold predicted by F. and M. (Mev)
Th^{232}	<1.5	8.5
U^{235}	1.3 ± 0.6	6.1
U^{236}	~ 600	6.7
U^{238}	20	7.0
Pu^{238}	7.7×10^{6}	4.6
Pu^{240}	1.6×10^{6}	5.0
Cm^{242}	3×10^{10}	~ 3.5

The process of spontaneous fission is considered to go by penetration of the potential barrier. Frankel and Metropolis give the expression below for the probability of penetration as a function of the height of the barrier.

$$G = 10^{-7.85 \times \Delta E}$$

where ΔE is the barrier height. This expression would predict a variation in rate by a factor of 10^{20} among the nuclei listed in Table IV. The variation observed is a factor of 10^{10}. This would indicate less variation in ΔE among the nuclei listed than predicted by the liquid drop model, or else the dependence on ΔE given is not correct. U^{236} and U^{235} are also inverted over the predicted order.

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In summary, the admittedly meager experimental data do not appear to show the large variation in the fission energy barrier predicted by the liquid drop model. This is perhaps not surprising in view of the failure of this theory to account for another striking feature of low energy fission, namely, its asymmetry.

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