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Author

Seaborg, Glenn T.

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Glenn T. Seaborg

July 25, 1951

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SOME COMMENTS ON THE MECHANISM OF FISSION

Glenn T. Seaborg
Radiation Laboratory and Department of Chemistry
University of California, Berkeley, California

July 25, 1951

ABSTRACT

A correlation of spontaneous fission rates with Z and A is made to show that these rates depend on the nuclear type. Some suggestions as to the mechanisms are given and it is also shown how these relate to the mechanism of slow neutron and photo fission.

SOME COMMENTS ON THE MECHANISM OF FISSION

Glenn T. Seaborg
Radiation Laboratory and Department of Chemistry
University of California, Berkeley, California

July 25, 1951

A number of spontaneous fission rates are now known and a study of the relation of these to Z and A should make it possible to come to a better understanding of this process which in turn should lead to a better understanding of the slow neutron fission mechanism as well. A number of spontaneous fission rates are summarized in Table 1.

Our attempts to correlate these rates with the existing theoretical expectations[1,2] have not been successful and therefore it seems worthwhile to attempt to study the data from the point of view of finding their empirical relationship.

Figure 1 shows a plot of the logarithm of the "half-life" for spontaneous fission versus the fissionability parameter, Z^2/A, and leads to some very interesting conclusions. The points for the even-even nuclides, with some exceptions, seem to indicate that the rate for this nuclear type depends exponentially in a simple way on the parameter Z^2/A. It is tempting to assume that the rate of spontaneous fission is controlled by a Boltzmann type factor in which the required activation energy for fission depends on Z^2/A; the form of the plot would suggest that this might be a linear dependence with a negative coefficient for Z^2/A. However, another type such as an inverse dependence of fission activation energy on Z^2/A also fits nearly as well over the range of data plotted. In any case it is interesting to note that extrapolation of the line in Figure 1 to the

Table 1

Summary of Spontaneous Fission Rates

Nuclide	Fissions/gram/hour	Half-life (years)	References
Th^{230}	≤ 1.4	$\geq 1.5 \times 10^{17}$	3
Th^{232}	0.15 1.2	1.4×10^{18} 1.7×10^{17}	3 4
Pa^{231}	≤ 20	$\geq 10^{16}$	3
U^{232}	≤ 25000	$\geq 8 \times 10^{12}$	3
U^{233}	< 0.7	$> 3 \times 10^{17}$	3
U^{234}	< 30	$> 7 \times 10^{15}$	3
U^{235}	1.2	1.9×10^{17}	3
U^{236}	10 ± 8	$\sim 2 \times 10^{16}$	5
U^{238}	24.8 ± 0.9	8.0×10^{15}	6,3
Np^{237}	≤ 5	$\geq 4 \times 10^{16}$	3
Np^{239}	≤ 40000	$\geq 5 \times 10^{12}$	3
Pu^{238}	5.1×10^{6} 4.1×10^{6}	5.4×10^{10} 4.9×10^{10}	3 7
Pu^{239}	36	5.5×10^{15}	3
Pu^{240}	1.66×10^{6}	1.2×10^{11}	8
Am^{241}	≤ 14000	$\geq 1.4 \times 10^{13}$	3
Cm^{242}	3×10^{10} 2.7×10^{10}	6.5×10^{6} 7.2×10^{6}	9 10
Cm^{244}	0.7×10^{10}	3×10^{7}	11

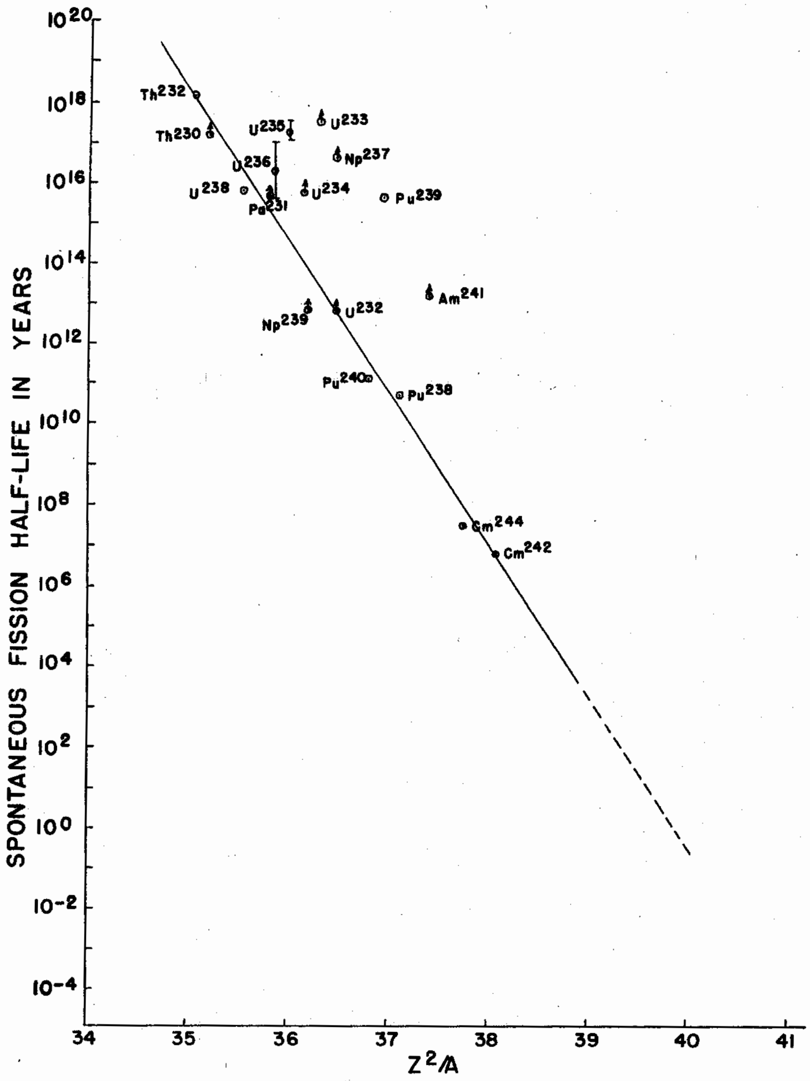

Fig. 1

PLOT OF SPONTANEOUS FISSION RATES

($\overset{\uparrow}{\circ}$ signifies lower limit to half-life) region of instantaneous rate of spontaneous fission (that is, half-life of order of 10^{-20} seconds) gives a value of about 47 for Z^2/A, which corresponds with the predicted limiting value[1] for Z^2/A.

The data seem also to indicate that on the average for a given value of Z^2/A, the rate is greater for an even-even nuclide than one with an odd number of nucleons. Since Z^2/A is a representation of Z^2/r^3, where r is the nuclear radius, the slower rates for the odd-neutron nuclides may be related to their expected larger nuclei; on this basis the largest departure of an odd-nucleon nuclide from the line in Figure 1 corresponds to the order of one percent larger radius than for the "hypothetical" corresponding even-even nuclide. Thus the slower rates may result from the lower zero-point energy of the modes of vibration which lead to fission associated with the nuclei with the larger radii.

Similar considerations may be useful in interpreting some of the results from the study of slow neutron fission probabilities. The slow neutron fission probabilities of the even-even nuclides in the transuranium region seem to be lower than expected on the simple theory.[1] For example, a nucleus like Cm^{242} has a slow neutron fission cross section of less than 5 barns[12] in spite of the fact that the critical fission energy of the intermediate Cm^{243} is of the order of 4 Mev, much less than the estimated 6 Mev of neutron binding energy. It is possible that the time for fission is lengthened for such an odd-nucleon intermediate nucleus to the point where the (n,γ) reaction is able to compete more successfully than is the case for even-odd nuclides like U^{235}, Pu^{239}, etc., where the intermediate fissioning nuclei are of the even-even type.

The effect of an odd nucleon in slowing the fission process may also explain the photofission results of H. W. Koch, J. McElhinney, and E. L. Gasteiger[13] who found, for example, higher effective energetic thresholds for U^{235}, U^{233}, and Pu^{239} than for U^{238}, contrary to expectations from existing theory.[1,2]

It will be interesting to see whether even-even nuclei with abnormally small nuclear radii due to closed sub-shells will have especially high rates of spontaneous fission. Thus a nucleus such as 100^{248} which would have two closed sub-shells on the Mayer picture,[14] 100 protons and 148 neutrons, might be expected to exhibit such an abnormally high rate. Similarly, the large slow neutron fission cross section[12] of a nuclide like Am^{242} might be connected with the sub-shell of 148 neutrons in the intermediate Am^{243}.

The above considerations may make it possible to predict with a fair degree of confidence, especially for the even-even nuclides, the spontaneous fission rates for undiscovered nuclides and hence make it possible to plan experiments more intelligently for their detection.

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