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February 21, 1955

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SYSTEMATICS OF NEUTRON CAPTURE CROSS SECTIONS

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February 21, 1955

There appears to exist a rough correlation between the neutron cross sections of heavy (trans-lead) nuclei and the binding energy of the captured neutron. In Figure 1 the sum of capture and fission cross section (where fission occurs) for each nuclide is plotted against the neutron binding energy.¹

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1. R. A. Glass, S. G. Thompson, G. T. Seaborg, J. Inorg. and Nuclear Chem., to be published.
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The correlation is best for the even-even nuclides. Odd-even nuclei, forming odd-odd compound nuclei, have larger cross sections for a given binding energy than even-evens which form even-odd compound nuclei. Conversely, even-odd nuclei, which form even-even compound nuclei, appear to have smaller cross sections than might be expected. The cross sections of Pb^{208} and Bi^{209} are unusually low, which is presumably a consequence of their closed-shell configurations.

To a rough approximation, the thermal capture cross section is given by $\sigma_{th} = \frac{\zeta^2 \Gamma_{rad}}{D} \times 1100 \text{ barns}^{2,3}$ where $\zeta^2 \approx 1$, and D is the level

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2. J. M. Blatt and V. F. Weisskopf, Theoretical Nuclear Physics, John Wiley and Sons, New York, 1952.
 3. D. Bogart, Nucleonics, October 1952, page 36.
-

distance in ev in the compound nucleus. For heavy nuclei, Γ_{rad} always is close to 0.1 ev. Very roughly, therefore, $\sigma_{\text{th}} = \frac{110}{D}$.

For nuclei of comparable type, D , and therefore σ_{th} , will be determined mainly by the excitation of the compound nucleus, and hence by the neutron binding energy. The separation of different nuclear types in Figure 1 suggests that the level density decreases in the order odd-odd nuclei > even-odd > even-even, which is not unexpected.

However, the rate of increase of σ with binding energy E is much greater than expected from a semi-empirical level spacing formula of the type $1/D = C \exp(2\sqrt{aE})$, using reasonable values of the coefficients c and a . The cross sections plotted in Figure 1 are, however, not thermal neutron values, but in most cases were measured with a reactor neutron energy distribution. Corrections for epi-thermal resonance capture will generally be much greater for nuclei with big cross sections whose resonances are closer to thermal energies.³ This should increase the slope of the line, but the effect is probably not very large.

There seems to be a tendency for cross sections to reach a limiting value of a few thousand barns, regardless of how large the binding energy may be. This phenomenon might be due to the level separation D becoming equal to, or even less than Γ_{rad} . The problem may then be treated by continuum theory, giving $\sigma = (R + \chi)^2 \frac{4\pi kK}{(k + K)^2}$, K being of the order of 10^{13} cm^{-1} , χ and k the wavelength and wavenumber of the neutron, and R the nuclear radius. For reactor neutrons, $\chi = 10^{-8}$ to 10^{-9} cm , which gives $\sigma \approx 10^3$ to 10^4 barns, in reasonable agreement with the experimental results.

It is a pleasure to acknowledge the interest of Glenn T. Seaborg, Stanley G. Thompson, and Albert Ghiorso in this work.

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Nuclide	$\sigma_{n, \gamma}$ (barns)	σ_f (barns)	Binding energy next neutron (Mev)	Reference
Pb ²⁰⁸	0.0006	-	3.87	a
Bi ²⁰⁹	0.017	-	4.65	a
Em ²²⁰	<0.5	-	4.57	b
Em ²²²	0.72	-	4.12	a
Ra ²²⁴	12	-	5.03	c
Ra ²²⁶	20	<0.0001	4.5	a
Ra ²²⁸	36	<2	4.78	a
Ac ²²⁷	500	<2	4.97	a
Th ²²⁷	?	1500	7.07	a
Th ²²⁸	125	<0.3	5.44	c, a
Th ²²⁹	?	45	6.68	a
Th ²³⁰	35	<0.001	5.12	a
Th ²³²	7.7	<0.0002	5.06	a
Th ²³³	1400	?	6.00	a
Th ²³⁴	1.8	<0.01	4.64	a
Pa ²³⁰	?	1500	6.76	a
Pa ²³¹	260	0.010	5.45	a
Pa ²³²	50	700	6.74	a
Pa ²³³	?	<0.1	5.24	a
U ²³⁰	?	25	5.99	a
U ²³¹	?	250	7.21	a
U ²³²	300	80	5.94	a
U ²³⁴	72	<0.65	5.31	a
U ²³⁵	197	580	6.39	a
U ²³⁸	2.8	-	4.83	a
U ²³⁹	22	?	5.86	a
Np ²³⁴	?	900	7.00	a
Np ²³⁷	170	0.019	5.37	a
Np ²³⁸	?	1600	6.21	a

Nuclide	$\sigma_{n, \gamma}$ (barns)	σ_f (barns)	Binding energy next neutron (Mev)	Reference
Pu ²³⁸	425	18	5.66	a
Pu ²³⁹	315	750	6.38	a
Pu ²⁴¹	400	1080	6.14	a
Pu ²⁴²	30	-	5.10	d
Pu ²⁴³	100	?	5.92	d
Am ²⁴¹	700	3.2	5.47	a
Am ²⁴²	4500	3500	6.31	a
Am ²⁴³	115 140 ± 50	<0.1	5.14	e f
Cm ²⁴²	?	<5	5.72	a
Cm ²⁴⁴	25 ± 10	-	5.68	e
Cm ²⁴⁵	200 ± 100	?	6.41	e
Cm ²⁴⁶	15 ± 10	-	5.19	e
Bk ²⁴⁹	350 1100 ± 300	-	4.77	g f
Cf ²⁴⁹	270	630	6.57	f
Cf ²⁵⁰	1500	-	5.14	g
Cf ²⁵¹	3000	?	6.06	g
Cf ²⁵²	30 25	-	5.00	f g
Cf ²⁵⁴	<2	-	4.42	f
99 ²⁵³	160	-	4.97	f
99 ²⁵⁴	<15	?	6.07	f

a = U.S. Atomic Energy Commission Unclassified Document AECU-2040
and 3 supplements.

b = G. C. Hanna and B. G. Harvey, unpublished.

c = A. P. Baerg, to be published in Phys. Rev.

d = M. H. Studier, et al., Phys. Rev. 93, 1433 (1954).

e = C. M. Stevens, et al., Phys. Rev. 94, 974 (1954).

f = B. G. Harvey, et al., Phys. Rev. 95, 581 (1954).

g = L. B. Magnusson, et al., Phys. Rev. 96, 1576 (1954).

FIGURE CAPTIONS

Fig. 1. Relationship between neutron cross-section and binding energy of ingoing neutron.

Fig. 1