Capture Cross Sections for Thermal Energy Neutrons. II

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Cross sections for capture of slow neutrons by a number of elements were measured by determining the intensity of the β-activity induced under standard neutron irradiation. The number of neutrons was measured by using as standard the activity induced in Mn, the cross section for capture by Mn being taken from former experiments. Data are reported for neutron capture by Na^{23}, Al^{27}, P^{31}, K^{41}, V^{51}, Cu^{63}, Cu^{65}, As^{75}, Br^{79}, Sb^{121}, I^{127}.

SINCE the early observations on the activity induced by slow neutrons, the activities have usually been reported as "strong" or "weak," but more quantitative data are very meager. Relatively accurate measurements are available only for those elements that, like Rh or Ag, possess a large cross section for activation.

It was considered worth while to perform a series of measurements on other elements, in order to determine the cross section for the neutron capture reaction. The use of a radium-beryllium source limited the investigation to the stronger activities. The work could be greatly extended if a stronger source, as afforded by a cyclotron, were available.

The source was placed inside a paraffin block, 3 cm below the surface. The detectors, 5×5 cm^2 in size, were placed above the source, on the surface of the paraffin, and covered with another paraffin block, to increase the activation by thermal neutrons.

The β-activity was measured by a small, thin-walled glass counter, the flat detectors being placed along the side of the counter, in an accurately reproducible position. The background effect was about 8 counts per minute, the measured activity seldom giving less than one hundred pulses per minute, and often a great deal more. Each activity was followed through at least one decay period in order to be certain of its identity.

It is believed that the main sources of error in the present work are due to the difficulty of securing thin uniform layers of the substances used as detectors, and to back scattering of electrons by the detector itself and by its support. Metal foils were used when possible. Compounds were generally melted on a thin Al or Ni foil, and fairly uniform thin layers were obtained by tilting the support before the substance had solidified. The activity of the Al or Ni support was negligible under the circumstances. Na and K were rolled into thin sheets between Al foils to prevent their oxidation.

No attempt was made to correct for back scattering by the support. Absorption and scattering by the detector itself and by the counter wall were accounted for by assuming an exponential "absorption," with an empirically determined coefficient. This coefficient is given, for about the same type of geometry, by Amaldi *et al.*,[1] except for a few cases where it was experimentally determined. The value used is given in Table I. No dependence of the mass "absorption" coefficient upon atomic number was considered, the experimental values generally referring to aluminum.

Since the measurements were effected inside the paraffin, it was necessary to ascertain that the presence of the detector or its support did not appreciably alter the density of the thermal neutrons. In all doubtful cases, this was checked by observing whether the activity of a rhodium detector was appreciably decreased by placing under it the substance to be investigated. No decrease of more than a few percent was recorded.

As part of the activity is generally due to resonance neutrons, a measurement was also taken with the detector covered by Cd on both sides, and the number of counts thus recorded was subtracted from the total. In some cases the activity with Cd was too weak to be measured.

To express the activity in terms of a cross section, one must know the number of thermal

[1] E. Amaldi, O. D'Agostino, B. Pontecorvo, F. Rasetti and E. Segrè, Proc. Roy. Soc. **A149**, 522 (1935).

TABLE I. *Capture cross sections for thermal neutrons.*

ELEMENT AND ISOTOPE	COMPOUND USED	G/CM² OF ISOTOPE	G/CM² OF COMPOUND	DECAY PERIOD OF ACTIVE ISOTOPE	SATUR. ACTIV. IMPULSES PER MINUTE	PERCENTAGE OF ACTIV. DUE TO RESONANCE NEUTRONS	ACTIVITY DUE TO THERMAL NEUTRONS	ASSUMED ABSORPTION COEFFICIENT OF ELECTRONS CM²/G	ACTIVITY CORRECTED FOR ABSORPTION IN DETECTOR AND COUNTER	$\sigma\times10^{24}$ CM²	$\sigma\times10^{24}$ CM² L.R.
Mn^{55}	Mn	0.032	0.032	2.6 hr.	3700	0.04	3500	5.0	5100	**9.4**	**9.4**
Na^{23}	Na	0.07	0.07	15 hr.	350	<0.03	350	10	980	0.35	
Al^{27}	Al	0.18	0.18	2.4 min.	750	0.02	700	4.3	1300	0.21	
P^{31}	P	0.028	0.028	14 day	~70	—	~70	7	~120	~0.2	1
K^{41}	K	0.003	0.045	15 hr.	~45	—	~45	4.0	~100	~1.4	
V^{51}	V_2O_5	0.012	0.021	3.8 min.	850	<0.02	850	4.1	1100	5.2	6.8
Cu^{63}	Cu	0.27	0.40	12.8 hr.	100	~0.03	100	27	5000	1.8	
Cu^{65}	Cu	0.13	0.40	5 min.	1000	0.03	970	5.6	3300	1.2	
As^{75}	As	0.068	0.068	27 hr.	2000	0.20	1600	4.5	2600	3.1	6.5
Br^{79}	NaBr	0.0035	0.009	18 min.	280	0.29	200	5.8	290	7	
Br^{79}	NaBr	0.0035	0.009	4.4 hr.	220	0.23	170	5.8	250	6	
Sb^{121}	Sb	0.073	0.13	2.8 day	1060	0.42	600	8	1850	3.3	
I^{127}	PbI_2	0.009	0.017	25 min.	450	0.35	300	6.3	440	6.5	6.8

neutrons traversing the detector per second. This can be determined by employing a detector whose capture cross section is already known from absorption measurements. The capture cross section of Mn^{55} ($\sigma_{Mn}=9.4\times10^{-24}$ cm²) was taken as standard since its value is one of the best known from the earlier measurements.[2] The cross section σ for any isotope is then given by

$$\sigma=\sigma_{Mn}\frac{N_{Mn}}{N}\frac{A}{A_{Mn}},$$

A being the activity (corrected for absorption), N the number of atoms of the isotope per cm², A_{Mn} and N_{Mn}, respectively, the same quantities for Mn.

Table I summarizes the results. The headings of the columns are self-explanatory. The cross section is referred to the isotope responsible for the capture process and not to the whole element. The last column gives the values found by Lapointe and Rasetti[2] in those cases where comparison is possible.

The agreement for V^{51} and I^{127} is as good as can be expected. For As^{75}, the present value is about half as large as that previously reported. A discrepancy by a factor of two cannot be altogether excluded as due to experimental errors; however, this discrepancy is more likely to be accounted for by the complex structure[3] of the β-spectrum of As^{76}. The absorption coefficient used, 4.5 cm²/g, would roughly correspond to a simple distribution with maximum energy of 2.7 Mev. In addition to this distribution, there appears to be a large number of low energy electrons, which are scarcely effective in the present experiment because of the thickness of the detector and of the counter wall. The higher value of the cross section from absorption measurements is, therefore, believed to be more accurate. For the other radioactive isotopes investigated, it is unlikely that a possible complexity of the β-spectrum will introduce a considerable error in the measurement of the activity. For the case of phosphorus, the measurement of the capture cross section from absorption was rather inaccurate, the effect being only about five times the statistical error. The present measurements indicate a considerably lower value, which is probably more accurate.

The cross sections given for Br^{79} are partial cross sections for the production of the two radioactive isomers. The difference in the fraction of the activity which is due to resonance neutrons for each of the two isomers is not significant, being within the experimental error.

[2] C. Lapointe and F. Rasetti, Phys. Rev. **58**, 554 (1940).

[3] G. L. Weil and W. H. Barkas, Phys. Rev. **56**, 485 (1939).