curves show that electrons sidescattered from Lucite are only slightly less energetic than those sidescattered from lead, while at 90° electrons diffusing from Lucite are almost totally degraded, being very much lower in energy than electrons diffusing from lead.

Figure 7 indicates that the diffusion effect increases materially with Z while the side scattering remains relatively constant. It can be argued that at small angles of incidence and emergence, while the mean deflection necessary for emergence will be reached after many more collisions in a low Z material than in a high Z material, the electron has roughly the same probability of emerging from a low Z material as from a high Z material, although it will be slightly less energetic upon emerging from the low Z material.

Miller[11] has made calculations of the ratio β^-/β^+, using Bartlett and Watson's and Massey's cross section calculations in a classical multiple scattering theory originally given by Bothe[12] for electrons. He estimates $\beta^-/\beta^+=1.16$ for mercury. The experimental results show $\beta^-/\beta^+=1.3$ for $Z=80$, which is in fair agreement with Miller's results, especially since the initial conditions in Bothe's derivation are not exactly those of the present experiments. In any case an excess of electron backscattering over positron backscattering is to be expected.

The isotropic initial conditions of the experiments are those most commonly encountered in actual practice in radioactivity measurements. It is therefore quite important to recognize that the backscattering is anisotropic, so that the proper backscattering correction can be made, depending on the geometry used. The curves of Fig. 2 should be especially helpful to those working with C^{14}, S^{35} and other low energy beta-emitters, where a 2π windowless counter is often used.

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[11] W. Miller, Phys. Rev. 82, 452 (1951).

[12] W. Bothe, Ann. Physik 6, 44 (1949).

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Thermal Neutron Capture Cross Sections

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The thermal neutron capture cross sections of more than one hundred isotopes, including all the isotopes of 24 elements, plus several others, have been measured with the Oak Ridge National Laboratory pile oscillator.

THE thermal neutron capture cross sections of the elements have been measured by many techniques, but the cross sections for the individual isotopes[1] of those elements have been determined for the most part only by activation methods. Activation methods may be used only with roughly half of all stable isotopes, namely, those that become radioactive upon thermal neutron capture, and other techniques must be used for the remainder. A few measurements have been made by determining with a mass spectrometer the depletion produced by prolonged neutron bombardment, and some measurements have recently been made by counting directly the neutron capture gamma-rays; in both these methods natural samples can be employed. This paper reports on work with the Oak Ridge National Laboratory pile oscillator, which can measure directly the thermal neutron capture of any stable isotope sample. The more than one hundred enriched isotopic samples used in these measurements were produced by electromagnetic separation in the Stable Isotope Research Division of Oak Ridge National Laboratory.

The pile oscillator has been previously described and has been used to measure the cross sections of 69 elements.[2] It operates by pulsing the current of a boron-coated ionization chamber by moving the sample back and forth through the chamber, and by integrating these pulses which are proportional to the capture area of the sample. By operating in the reflector of the graphite reactor, the pile oscillator uses principally thermal neutrons; the cadmium ratio on indium is about 30, indicating that even for as unfavorable a case as indium the nonthermal capture contributions are at most 3.2 percent. The thermal capture cross sections for the isotopes as for the elements have been measured relative to gold for which the cross section has been taken to have a value of 95 barns for neutrons of 2200 m/sec velocity.[2]

The values of the isotopic cross sections are listed in Table I. The isotopic cross sections are for the pure isotopes; the atomic cross sections listed in the last column are the contributions of the isotopes to the natural elements and are found by multiplying the isotopic cross sections by the natural relative abundances. The errors are estimated from the average per-

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[1] Cross section values with bibliographical references may be found in *Nuclear Data*, Nat. Bur. Standards Circular No. 499 (1950).

[2] H. Pomerance, Phys. Rev. 83, 641 (1951).

TABLE I. Thermal neutron capture cross sections (in barns).

Isotope	Isotopic value	Estimated error (percent)	Atomic value[a]
Magnesium 24	0.033	30	0.026
25	0.27	30	0.027
26	0.06	100	0.006
Silicon 28	0.081	30	0.075
29	0.27	30	0.012
30	0.41	100	0.013
Potassium 39	1.87	8	1.74
40	66.	30	0.01
41	1.19	8	0.08
Calcium 40	0.22	20	0.21
42	39.7	8	0.25
Titanium 46	0.57	30	0.05
47	1.62	20	0.13
48	8.0	8	5.86
49	1.8	25	0.10
50	0 (+0.4)	—	0
Chromium 50	16.3	8	0.73
52	0.73	8	0.61
53	17.5	8	1.65
54	0 (+0.3)	—	0
Iron 54	2.17	8	0.13
56	2.55	8	2.34
57	2.4	12	0.05
58	2.5	80	0.02
Nickel 58	4.2	8	2.87
60	2.54	8	0.67
61	1.9	50	0.02
62	14.6	15	0.54
Copper 63	4.3	8	2.96
65	2.11	8	0.65
Gallium 69	1.99	8	1.20
71	4.9	8	1.95
Germanium 70	3.25	8	0.69
72	0.94	10	0.26
73	13.7	8	1.08
74	0.60	10	0.22
76	0.35	20	0.02
Selenium 74	48	15	0.42
76	82	8	7.42
77	40	10	3.05
78	0.4	100	0.09
80	0.59	10	0.29
82	2.0	70	0.19
Zirconium 90	0.1	70	0.06
91	1.52	8	0.17
92	0.25	30	0.04
94	0.08	50	0.01
96	0.1	100	0
Molybdenum 92	0 (+0.3)	—	0
95	13.4	8	2.11
96	1.2	50	0.20
97	2.1	30	0.20
98	0.4	100	0.09
100	0.5	100	0.05
Silver 107	29.9	8	15.4
109	84	8	40.6
Antimony 121	5.7	8	3.25
123	3.94	8	1.69
Tellurium 120	68	100	0.07
122	2.7	35	0.07
123	390	8	3.49
124	6.5	20	0.30
125	1.49	10	0.10
126	0.77	25	0.14
128	0.3	100	0.09
130	0.5	50	0.18
Barium 134	2	100	0.06
135	5.6	15	0.37
136	0.4	100	0.03
137	4.9	8	0.55
138	0.68	15	0.49
Cerium 136	25	100	0.05
138	8.7	70	0.02
140	0.63	10	0.56
142	1.76	15	0.20
Neodymium 142	18.5	12	5.01
143	292	8	35.67
144	4.8	12	1.15
145	52	8	4.28
146	9.8	8	1.68
148	3.3	30	0.19
150	2.9	50	0.16
Hafnium 174	500	100	0.9
176	15	100	0.8
177	375	8	69.3
178	72	15	19.5
179	50	50	6.9
180	13	40	4.5
Tungsten 180	30	−100, +400	0.03
182	19.2	10	4.95
183	10.9	10	1.55
184	1.97	15	0.60
186	34.1	8	9.95
Rhenium 185	100	8	37.3
187	63	8	39.6
Thallium 203	11.0	8	3.20
205	0.77	10	0.55
Lead 204	0.9	70	0.01
206	0.1	100	0.03
207	0.70	10	0.15
208	0 (+0.03)	—	0
Thorium 232	7.0	5	7.0

[a] The atomic value is the product of the isotopic value with the relative abundance of that isotope in the natural element.

formance of the pile oscillator and from the adequacy of the available sample of enriched material.

The limit of detection of the pile oscillator is a capture area of somewhat less than 0.1 mm^2, and the limit of precision is the same, but for this report exactly 0.1 mm^2 was used. This means that a sample of 0.5 mm^2 capture area was assumed to be measured with a precision of 20 percent, and 1.0 mm^2 with a precision of 10 percent. Although the values for the elements were thought to be accurate to 5 percent, a limit of 8 percent is listed for the isotopic measurements, principally because only one sample of each material was available. The extra 3 percent refers to the problem of getting an adequate chemical analysis of a small sample without destroying a large part of it. If the sums of the isotopic contributions to the natural element values are compared with the previously published values for the elements, it will be seen that 8 percent is a fair estimate of the error.

The cross section values of Table I are not original data for the samples but are derived numbers, because the enrichment was not usually sufficient to insure that all the capture came from the enriched isotope. For each element a set of simultaneous equations was solved, using the isotopic assays of the samples and the pile oscillator measurements as the primary data. The isotopic assays, performed by the Assay Department of the Y-12 plant, were more precise than the pile oscillator work and contributed no error to the final values of the cross sections. The computational data are not given in Table I, but the estimated errors allow for the contributions of the various isotopes to the total for the sample that was employed.

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