Total X-Ray Attenuation Coefficients from 40 kev to 412 kev*

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The total attenuation coefficients for a variety of materials have been measured in the energy range between 40 and 412 kev. The unique angular and energy resolution of the DuMond curved crystal spectrometer were employed in the analysis of the scattered radiation. While the results are in general agreement with earlier tabulations at energies above the K-absorption edge, the present values are higher than most earlier estimates at energies below the K edge.

INTRODUCTION

THE theoretical and experimental work on the x-ray attenuation coefficients has been reviewed and compared in a number of relatively recent publications.[1–3] Although the evaluation of these coefficients has been approached by a variety of theoretical and experimental techniques, considerable uncertainty appears to exist as is evidenced by the change[1,2] in some values by as much as 100%. It was therefore thought to be worthwhile to re-measure the attenuation coefficients for a wide variety of elements with a "good geometry" arrangement.

The total absorption coefficient, μ, may be defined from the following relationship, $I=I_0e^{-\mu t}$. I is the intensity of the monoenergetic x radiation which passes through an absorbing material of thickness t without any form of interaction. I_0 is of course the incident intensity of the radiation. In general, there will be contributions to μ from the Compton process, photoelectric effect, elastic scattering, etc. It is of importance, experimentally, to take great care to exclude from the measurements of I those quanta which have suffered small angular deflection or small energy change in passing through the absorber.

APPARATUS

In the present work, the DuMond[4] bent-crystal spectrometer was the analyzer of the transmitted radiation. This instrument has nearly ideal characteristics for the present measurements. While the intensity of the analyzed beam is determined by the solid angle subtended by the whole bent crystal, the question as to whether or not a quantum of the proper energy will be analyzed is determined by the angle which the radiation makes with the crystal planes. Thus, for example, a quantum of the proper energy will be lost if it is deflected through an angle greater than 2×10^{-4} radian in the horizontal plane. The vertical scattering angle required to reject a quantum of the proper energy is $\sim2\times10^{-2}$ r. Thus the "effective solid angle of acceptance" for scattered radiation is $\sim3\times10^{-7}$ sr. The energy resolution of this instrument is extremely good. (The full width of a line varied from several hundred electron volts at the lowest energies studied to several thousand electron volts at the higher energies.)

The radiation which was analyzed by the bent crystal was detected by a 3-in. NaI(Tl) crystal with an energy resolution $\sim12\%$.

PROCEDURE

The influence of the position of the absorbing material was investigated by varying the position of the absorber from 10 cm to 1.5 m from the source. The measured counting rate of the transmitted radiation was found to be independent of the absorber position. For convenience, most solid samples were set to intercept the gamma rays at a distance of 50 cm from the source.

Long-lived radioactive species which contained well separated characteristic x-ray or gamma-ray lines were selected as the source of radiation. The bent-crystal

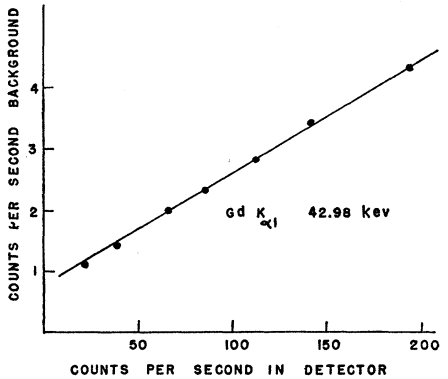

FIG. 1. Background data for the 42.98-kev x-ray line.

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[1] G. W. Grodstein, National Bureau of Standards Circular No. 583 (U. S. Government Printing Office, Washington, D. C., 1957).

[2] R. T. McGinnies, National Bureau of Standards Circular Suppl. No. 583 (U. S. Government Printing Office, Washington, D. C., 1957).

[3] C. M. Davisson, *Beta- and Gamma-Ray Spectroscopy*, edited by K. Siegbahn (Interscience Publishers, Inc., New York, 1955), p. 24.

[4] J. W. M. DuMond, *Beta- and Gamma-Ray Spectroscopy*, edited by K. Siegbahn (Interscience Publishers, Inc., New York, 1955), p. 100.

TABLE I. Total x-ray attenuation coefficients for a number of solids. The uncertainties in the values due to impurities, statistics, etc. are expected to be less than 2%. The values are expressed in cm^2/g. The energy (in kev) of the radiation, E, is given at the top of each column.

E /	39.52	40.12	41.53	42.98	45.40	50.00	57.52	66.98	67.87	68.84	70.81	77.97	80.26	86.54	105	123	158	208	412
Be		0.169		0.165	0.162	0.154	0.153		0.144	0.144	0.145			0.137	0.127	0.124	0.119	0.109	0.0828
C		0.209		0.201	0.189		0.177		0.170	0.165	0.163			0.156	0.144	0.141	0.131	0.121	0.0925
Al		0.555		0.480	0.427	0.365	0.282		0.236	0.233	0.224			0.186	0.172	0.150	0.136	0.120	0.0907
Fe		3.57		2.95	2.56					0.843	0.847			0.510					
Co		3.78		3.08	2.60	2.08	1.42		0.936		0.841			0.510	0.376	0.258			
Ni		4.57		3.68	3.23	2.58	1.68	1.10	0.987	1.03	0.980			0.590		0.285	0.201		
Cu	5.08	4.79	4.33	3.93	3.27	2.53	1.78		1.15		1.01			0.630	0.419	0.303	0.205	0.152	0.0917
Nb		12.1		10.0	8.60	6.67	4.54		2.91		2.54			1.54		0.682			
Mo	13.9	13.1	12.2	10.8	9.45	7.44	4.95	3.27	3.07		2.81			1.64	1.01	0.684	0.389	0.231	0.109
Ag	17.8	16.9	15.3	14.2	12.2	9.63	6.51		4.15	3.98	3.70			2.15	1.30	0.859	0.481	0.278	0.111
Cd		17.6		14.6	12.5	9.73	6.60		4.33		3.79			2.22	1.36	0.897	0.491	0.279	0.109
In				15.5			7.03		4.43		4.00			2.35	1.62	0.955			
Sn		19.4		16.0	13.7	10.8	7.20		4.66	4.60	4.08			2.45		0.981	0.531		
Ta	10.4	9.91	9.06	8.28	7.17	5.88	3.95	2.62	11.5	11.1	10.3	8.01	7.53	6.10	3.78	2.54	1.32		
W		10.5		8.82	7.55	5.99	4.10		2.68	2.59	10.9	8.42	7.77	6.40	3.81	2.59	1.37	0.713	0.182
Pt	12.8	12.2	11.2	10.1	8.72	6.77	4.88		3.00		2.74	2.20	8.79	7.14	4.23	2.84	1.51	0.787	0.193
Au		12.7		10.5	9.22		4.98		2.91		2.88		2.28	7.45	4.86	3.02			
Pb	14.2	13.4	12.6	11.3	9.88	7.46	5.33		3.78	3.28	3.07		2.26	1.85	4.59	3.15	1.72	0.894	0.216
Th		18.4		15.6	13.0	10.6	7.12		4.72		4.22			2.56	1.63	3.90	2.13		

spectrometer was then adjusted to the peak of the appropriate line as was the discriminator for the scintillation detector. The counting rate could then be obtained as a function of absorber thickness without further adjustment of the apparatus.

BACKGROUND

The detector background consisted of two components. First, a constant part arising from circuit noise, room radiation, and radiation arising from the source and scattered from walls, etc. Second, radiation from the source which was incoherently scattered from the crystal, mounting, etc. into the detector. This second component was dependent upon absorber thickness and was found to vary linearly with the intensity of the radiation which was analyzed by the bent crystal, Fig. 1. The background was measured for each gamma ray studied. This was obtained by readjusting the spectrometer to a position 1 m-Å from the peak of the line. (Physically this amounts to moving the source one millimeter.) The background counting rate was of the order of 2 to 5% of the analyzed radiation for most of the runs.

RESULTS

The total attenuation coefficients for the solid absorbers are given in Table I.

DISCUSSION

The experimental values for the total attenuation coefficients, Table I, are in good agreement with the earlier values tabulated by the National Bureau of Standards[1] at energies higher than the K-absorption edge. This tabulation was obtained by fitting the available experimental data and theoretical results to a smooth curve in the energy regions between absorption edges.

Recent data at energies below 40 kev have prompted a rather drastic revision of all attenuation coefficients for energies below the K-absorption edge.[2] For example, the total absorption coefficient for Pb at an energy of 88 kev (just below its K-absorption edge) has been revised from 1.30 to 1.85 cm^2/g. The need for these revisions has been ascribed to the lack of adequate experimental results in this energy region and to the failure of the hydrogen-like approximation when applied to the L and M shells.

The present experimental results are in general agreement with the revised tabulations.

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