DETERMINATION OF X-RAY TOTAL ATTENUATION COEFFICIENT IN Zr, Ag, In FOR ENERGY RANGE BETWEEN 10.5–111.9 keV

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(Received December 4, 1997; revised version March 2, 1998)

The total X-ray attenuation coefficients in elements Zr, Ag, and In for K_α and K_β characteristic lines of elements with different Z ($33 \leq Z \leq 92$) were estimated by measuring attenuation in transmission method. The intensity of K X-rays was monitored by a Ge(Li) detector with energy resolution 190 eV at 5.9 keV. The experimentally measured attenuation coefficients were found in good agreement with the theoretical values of attenuation coefficients calculated by Storm, Israel and Hubbell, Seltzer.

PACS numbers: 32.80.–t

1. Introduction

For many X-ray based techniques the knowledge of X-ray attenuation coefficients is an effectual value limiting the precision of the method. The total attenuation coefficients are important atomic data of interest both in fundamental physics and in many applied fields. The experimental measurements of the total attenuation coefficients have been performed by several investigators [1–3]. A great number of experimental data have been obtained in a wide energy range and tabulated in publications [4]. We measured total attenuation coefficients in Ti, Fe, Ni, Zn for X-ray energy region between 4.5–111.9 keV [5]. Theoretical values of the total attenuation coefficients were calculated and tabulated [6, 7]. Certain discrepancies in currently available experimental data have caused an upsurge of interest in precise total attenuation coefficients measurements.

The present work describes the determination of the total attenuation coefficients in Zr, Ag, and In for X-ray energy region between 10.5–111.9 keV by using transmission method.

2. Experimental

The X-ray total attenuation coefficients were determined by measuring transmission of the fluorescent K characteristic lines with known energy through targets of known thickness. The experimental arrangement is shown in Fig. 1. Secondary targets of elements with different Z ($33 \leq Z \leq 92$) were irradiated, in turn, with

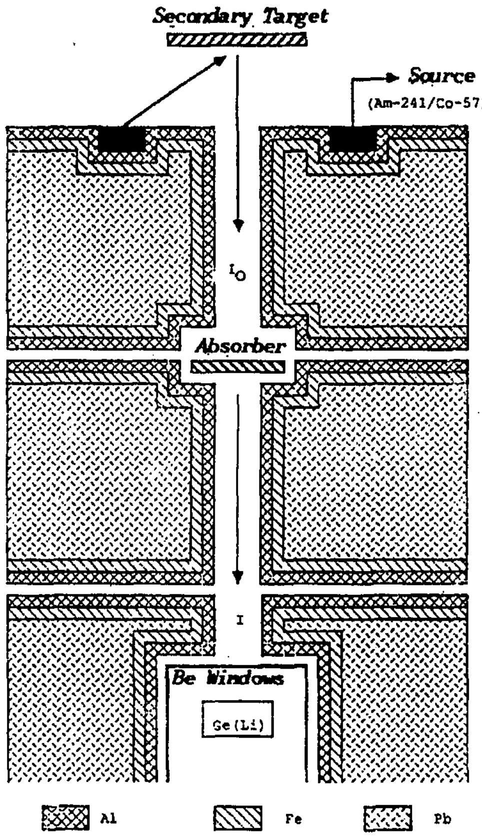

Fig. 1. Experimental arrangement geometry.

59.57 keV gamma rays from ^{241}Am source (for $Z \leq 65$ elements) and 122 keV gamma rays from 10 mCi ^{57}Co sources (for $Z > 65$ elements). The emitted K fluorescent X-rays were collimated by the lead collimator shielded with aluminium and iron to fall on the absorbers of Zr, Ag, and In cut from their high purity (99.00–99.99%) foils. The thicknesses of the absorbers were 25 μm. This thickness, t, satisfies the condition $\mu t < 1$, where μ is an attenuation coefficient. Thus, effects of multi-scattered photons in the targets were reduced. To minimise the effect of small-angle scattering in the absorber, the transmitted K X-rays were further collimated by the lead collimator shielded with aluminium and iron and counted using a Ge(Li) detector with energy resolution 190 eV at 5.9 keV. A typical spectrum is given in Fig. 2.

Spectra were recorded with and without the absorber for different energies of K fluorescent lines. For some target–absorber combinations used in the present measurements (e.g. Zr target, Zr absorber) the target and absorber spectra overlap. The fluorescent X-rays produced in the absorber by the 59.57 keV gamma rays scattered from the secondary target were also counted together with the sec-

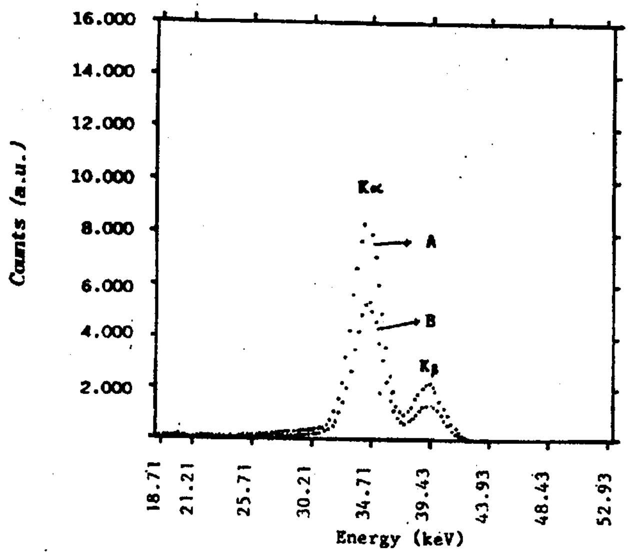

Fig. 2. X-rays spectra of Ce K characteristic lines. A — without absorber and B — with Ag absorber.

ondary target fluorescent X-rays transmitted through the absorber. The measured attenuation coefficients therefore need to be corrected for the contribution to the absorber fluorescent intensity of the X-rays produced by gamma rays scattered from the target. This contribution was measured experimentally by replacing the experimental target with equivalent Al target which does not produce characteristic fluorescent lines in this range of energy, only scatter radiation and spectra were corrected for this contribution. Average energies for K_α and K_β characteristic lines of elements were taken from Storm and Israel [6].

The counts for the measurements of each X-ray group were taken in the following sequence: no absorber (I_0), absorber (I). In an ideal transmission experiment, the photon once scattered in the absorber, even at very small angle, should not be detected. We assumed that in the experimental arrangement we satisfied this condition.

Total linear attenuation coefficients (μ_l) [cm^{-1}] of elements were calculated from the following equation obtained from $I = I_0 \exp(-\mu_l t)$:

$$\mu_l = -\frac{1}{t}\left(\ln \frac{I}{I_0}\right), \tag{1}$$

where t (cm) is the thickness of target; I and I_0 are areas under the peak for the absorber and no absorber respectively.

Total attenuation coefficients σ_T (barns/atom) were calculated by using the total linear attenuation coefficients from the following equation:

$$\sigma_\mathrm{T} = 10^{24}\frac{\mu_l}{\rho}\frac{M}{N_0}, \tag{2}$$

where μ_l are total linear attenuation coefficients in cm^{-1}; ρ (g/cm^3) is the density of element; μ_l/ρ are the mass attenuation coefficients in cm^2/g, M is the atomic mass of element and N_0 is the Avogadro number. N_0/M describes numbers of atoms per gram. 10^{24} factor comes from 1 barn equal to 10^{-24} cm^2.

3. Results and discussion

The experimental values of the total attenuation coefficients are listed together with the theoretical values of Storm and Israel [6] and Hubbell and Seltzer [7] in Table. These values were presented in Figs. 3–5. The uncertainties in the values of the total attenuation coefficients are estimated approximately < 5%. These are due to counting statistics < 1%, thickness determination < 1%, scattering contribution < 2% and peak area determination < 1%. As shown in Table and Figs. 3–5, our experimental values are in good agreement with the theoretical values.

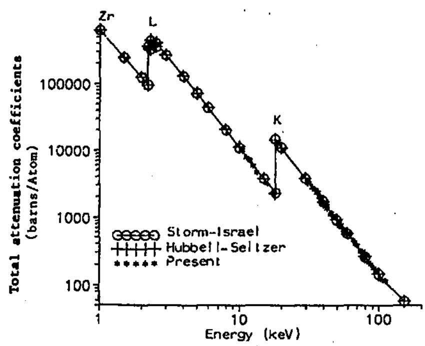

Fig. 3. Comparison of present experimental values and theoretical values for Zr.

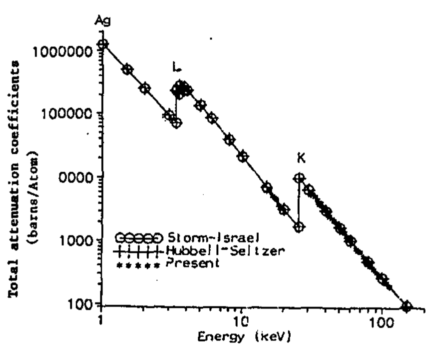

Fig. 4. Comparison of present experimental values and theoretical values for Ag.

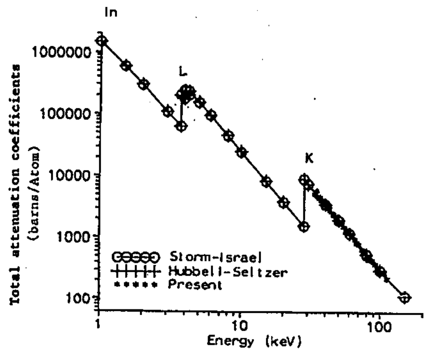

Fig. 5. Comparison of present experimental values and theoretical values for In.

TABLE

Total attenuation coefficients in Zr, Ag, and In in barns/atom.

Secondary exciter			Zr		Ag		In	
	Lines	Energy [keV]	Present	Theor.	Present	Theor.	Present	Theor.
As	K_α	10.532	9981	9570 [6]	–	–	–	–
			±210	9758 [7]				
As	K_β	11.730	7321	7164 [6]	–	–	–	–
			±130	7280 [7]				
Se	K_α	11.210	7818	8093 [6]	–	–	–	–
			±150	8236 [7]				
Se	K_β	12.503	5878	6035 [6]	–	–	–	–
			±120	6120 [7]				
Br	K_α	11.907	7026	6882 [6]	–	–	–	–
			±140	6990 [7]				
Zr	K_α	15.746	3129	3239 [6]	6324	6194 [6]	–	–
			±65	3270 [7]	±125	6280 [7]		
Zr	K_β	17.700	2284	2351 [6]	4576	4518 [6]	–	–
			±45	2379 [7]	±95	4576 [7]		
Nb	K_α	16.584	–	–	5326	5386 [6]	–	–
					±110	5340 [7]		
Nb	K_β	18.661	–	–	3769	3918 [6]	4762	4629 [6]
					±75	3967 [7]	±90	4699 [7]

TABLE (cont.)

Total attenuation coefficients in Zr, Ag, and In in barns/atom.

Secondary exciter			Zr		Ag		In	
	Lines	Energy [keV]	Present	Theor.	Present	Theor.	Present	Theor.
Mo	K_α	17.443	–	–	4817 ±100	4700 [6] 4659 [7]	5153 ±110	5553 [6] 5639 [7]
Mo	K_β	19.648	–	–	–	–	4028 ±80	4028 [6] 4088 [7]
Te	K_β	31.103	3492 ±75	3401 [6] 3413 [7]	5534 ±120	5964 [6] 5974 [7]	–	–
Cs	K_α	30.851	3187 ±60	3476 [6] 3490 [7]	5947 ±125	6093 [6] 6104 [7]	–	–
Cs	K_β	35.131	2534 ±40	2445 [6] 2453 [7]	4138 ±100	4324 [6] 4335 [7]	4748 ±75	5004 [6] 5000 [7]
Ba	K_α	32.062	3245 ±55	3132 [6] 3143 [7]	5669 ±105	5504 [6] 5515 [7]	–	–
Ba	K_β	36.535	2335 ±40	2196 [6] 2206 [7]	4118 ±75	3899 [6] 3911 [7]	4647 ±95	4515 [6] 4517 [7]
La	K_α	33.297	2756 ±60	2827 [6] 2837 [7]	5111 ±90	4982 [6] 4993 [7]	5223 ±110	5759 [6] 5745 [7]
La	K_β	37.966	2047 ±45	1981 [6] 1988 [7]	3619 ±70	3523 [6] 3534 [7]	4184 ±90	4082 [6] 4088 [7]
Ce	K_α	34.564	2576 ±50	2555 [6] 2563 [7]	4604 ±80	4514 [6] 4525 [7]	5905 ±120	5222 [6] 5215 [7]
Ce	K_β	39.431	1697 ±30	1788 [6] 1794 [7]	3249 ±55	3188 [6] 3199 [7]	3526 ±80	3696 [6] 3706 [7]
Pr	K_α	35.858	2282 ±45	2313 [6] 2321 [7]	3859 ±85	4097 [6] 4108 [7]	4628 ±95	4742 [6] 4741 [7]
Pr	K_β	40.930	1648 ±30	1614 [6] 1620 [7]	2770 ±50	2885 [6] 2896 [7]	3308 ±70	3348 [6] 3358 [7]
Nd	K_α	37.179	2046 ±40	2097 [6] 2104 [7]	3645 ±70	3724 [6] 3711 [7]	4153 ±80	4313 [6] 4317 [7]
Nd	K_β	42.460	1361 ±25	1458 [6] 1465 [7]	2553 ±45	2613 [6] 2624 [7]	2861 ±60	3035 [6] 3043 [7]
Sm	K_α	39.906	1693 ±35	1731 [6] 1736 [7]	3081 ±65	3089 [6] 3100 [7]	3729 ±65	3582 [6] 3593 [7]
Sm	K_β	45.622	1119 ±25	1196 [6] 1202 [7]	2199 ±44	2152 [6] 2164 [7]	2537 ±45	2504 [6] 2510 [7]

TABLE (cont.)

Total attenuation coefficients in Zr, Ag, and In in barns/atom.

Secondary exciter			Zr		Ag		In	
	Lines	Energy [keV]	Present	Theor.	Present	Theor.	Present	Theor.
Gd	K_α	42.390	1494	1431 [6]	2411	2565 [6]	3069	2980 [6]
			±30	1437 [7]	±50	2577 [7]	±65	2988 [7]
Gd	K_β	48.918	1027	986 [6]	1716	1782 [6]	1958	2078 [6]
			±15	993 [7]	±35	1794 [7]	±40	2082 [7]
Dy	K_α	45.714	1176	1189 [6]	2076	2140 [6]	2411	2491 [6]
			±20	1196 [7]	±43	2152 [7]	±50	2497 [7]
Dy	K_β	52.352	746	819 [6]	1436	1485 [6]	1718	1732 [6]
			±15	824 [7]	±30	1494 [7]	±36	1735 [7]
Ho	K_α	47.242	1072	1086 [6]	2019	1958 [6]	2331	2281 [6]
			±20	1093 [7]	±45	1970 [7]	±50	2286 [7]
Ho	K_β	54.123	776	748 [6]	1411	1358 [6]	1539	1584 [6]
			±14	752 [7]	±25	1365 [7]	±30	1587 [7]
Er	K_α	48.801	1017	992 [6]	1828	1794 [6]	1958	2091 [6]
			±23	999 [7]	±35	1806 [7]	±43	2096 [7]
Er	K_β	55.930	662	684 [6]	1219	1244 [6]	1331	1450 [6]
			±15	688 [7]	±25	1249 [7]	±35	1452 [7]
Yb	K_α	52.014	828	833 [6]	1541	1511 [6]	1828	1762 [6]
			±20	839 [7]	±32	1520 [7]	±40	1766 [7]
Yb	K_β	59.652	580	574 [6]	1065	1046 [6]	1175	1219 [6]
			±11	576 [7]	±18	1049 [7]	±20	1221 [7]
Ta	K_α	57.078	633	647 [6]	1131	1178 [6]	1411	1373 [6]
			±14	650 [7]	±20	1182 [7]	±30	1375 [7]
Ta	K_β	65.529	451	444 [6]	763	811 [6]	967	947 [6]
			±10	447 [7]	±13	814 [7]	±20	948 [7]
W	K_α	58.832	561	596 [6]	1050	1086 [6]	1296	1265 [6]
			±10	599 [7]	±21	1089 [7]	±30	1268 [7]
W	K_β	67.564	423	409 [6]	708	747 [6]	858	872 [6]
			±8	411 [7]	±18	749 [7]	±15	873 [7]
Au	K_α	68.133	395	400 [6]	697	730 [6]	841	853 [6]
			±7	402 [7]	±13	733 [7]	±20	854 [7]
Au	K_β	78.367	256	273 [6]	474	500 [6]	607	586 [6]
			±4	276 [7]	±10	498 [7]	±15	586 [7]

TABLE (cont.)

Total attenuation coefficients in Zr, Ag, and In in barns/atom.

Secondary exciter			Zr		Ag		In	
	Lines	Energy [keV]	Present	Theor.	Present	Theor.	Present	Theor.
Hg	K_α	70.103	380	370 [6]	690	676 [6]	812	780 [6]
			±8	372 [7]	±15	678 [7]	±17	791 [7]
Hg	K_β	80.656	265	253 [6]	472	463 [6]	481	542 [6]
			±5	255 [7]	±9	465 [7]	±12	542 [7]
Pb	K_α	74.159	310	317 [6]	563	581 [6]	660	679 [6]
			±6	320 [7]	±13	583 [7]	±15	678 [7]
Pb	K_β	85.370	211	218 [6]	387	398 [6]	454	465 [6]
			±4	220 [7]	±8	400 [7]	±10	467 [7]
Bi	K_α	76.246	305	294 [6]	517	539 [6]	610	630 [6]
			±7	297 [7]	±12	541 [7]	±13	630 [7]
Bi	K_β	87.796	198	202 [6]	353	369 [6]	449	431 [6]
			±4	204 [7]	±8	371 [7]	±10	433 [7]
Th	K_α	92.050	177	179 [6]	314	325 [6]	390	379 [6]
			±2	181 [7]	±6	328 [7]	±8	382 [7]
Th	K_β	106.169	119	127 [6]	217	225 [6]	277	261 [6]
			±2	127 [7]	±4	227 [7]	±6	264 [7]
U	K_α	96.977	159	156 [6]	278	283 [6]	322	329 [6]
			±3	158 [7]	±5	286 [7]	±6	333 [7]
U	K_β	111.898	116	111 [6]	195	198 [6]	223	229 [6]
			±3	113 [7]	±4	200 [7]	±5	232 [7]

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