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L X-RAY FLUORESCENCE CROSS-SECTIONS MEASUREMENTS FOR ELEMENTS $56 \leqslant Z \leqslant 66$ IN THE ENERGY RANGE 11-41 keV

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Abstract:- The L X-ray fluorescence cross-sections (σ_{L_α}, σ_{L_β} and σ_{L_γ}) have been measured for ten elements ($56 \leqslant Z \leqslant 66$) at various photon energies in the range of 11-41 keV. A good agreement is found between the measured results and the theoretically calculated values of L XRF cross-sections using various physical parameters based on relativisitc theory.

Introduction:- Information on X-ray fluorescence (XRF) cross-sections is important because of its wide use in many areas of basic and applied science, notably in the fields of atomic, molecular and radiation physics and in the non-destructive elemental analysis of materials using XRF technique. A limited work has been done in the direction of measurement of L XRF cross-sections (Garg et al 1985, 1986, 1987, Kumar et al 1985, Singh et al 1987 a,b). It was observed that for the elements ($56 \leqslant Z \leqslant 71$), the experimental results of L XRF cross-sections are, in general, higher than the theoretical estimates. It was therefore, thought worthwhile to measure the L XRF cross-sections for more elements at different excitation energies in this atomic region so as to develop some statistical basis for looking deeply into the observed discrepancy, between the experimental and theoretical L XRF cross-sections. Keeping this in mind, L XRF cross-section of Ba, La, Ce, Pr, Nd, Sm, Eu, Gd, Tb and Dy have been measured as a function of incident photon energy between 11-41 keV.

Experimental Method:- The experimental arrangement for our annular source geometry both in 'direct' and 'secondary' excitation modes have been described elsewhere (Garg et al 1984). In this arrangement low energy photon sources of ^{241}Am (300 mCi) and ^{109}Cd (25 mCi) along with exciter system (NER-496) obtained from New England Nuclear USA have been used.

The spectra from various targets were recorded with Si(Li) detector (FWHM 170 eV at 5.9 keV), coupled to 4096 channel ND-100 analyser. Three sets of observations were taken for each target. A relative efficiency curve for Si(Li) detector in the energy range 4-80 keV was generated as described by Garg et al (1985). The error in the efficiency values in the energy region of interest (4-15 keV) are estimated to be less than 3%.

Results and Discussions:- The measured values of L XRF cross-sections (σ_{L_α}, σ_{L_β} and σ_{L_γ}) for elements with atomic number $56 \leqslant Z \leqslant 66$ at different incident photon energies (11-41 keV) are listed in table. The overall error in the measured values are estimated to be of the order of 6-10%. This error is attributed to

the uncertainties in different parameters used to evaluate L XRF cross-sections using equation 1 of Singh et al (1987b).

The experimental values of L XRF cross-sections are compared with theoretical values calculated using the formulation of Close et al (1973) as described by Garg et al (1984). In the present calculations the values of L_i-subshell photoionisation cross-sections (σ_{L_i}) are taken from Scofield (1973), the fractional radiative rates (F_{ij}) are from Scofield (1974). Two sets of values of fluorescence yields (ω_i) and Coster Kronig transition probabilities (f_{ij}) are chosen. First are semi-emperical fitted values of Krause (1979) and second are the values taken from the tables of Chen et al (1981), based on relativisitic Dirac Hartee-Slater calculations. Chen et al (1981) have tabulated values of (ω_i) and (f_{ij}) for Ba, Nd and Eu only. The values for other elements were calculated using Cubic spline interpolation (Forsythe et al 1977). It is evident from table, that the experimental values of L XRF cross-sections are in general higher than the theoretical estimates, when ω_i and f_{ij} given by Krause et al (1979) are used. The agreement between the experimental and theoretical results are found to be better when ω_i and f_{ij} are taken from the table's of Chen et al (1981). It may therefore be pointed out that the theoretical values of L XRF cross-sections should be calculated using ω_i and f_{ij} from Chen et al (1981). Also the experimental values of L XRF cross-sections, can be used with more confidence for any type of applications, where the values of L XRF cross-sections are required.

Table 1 : Comparison of experimental and theoretical L XRF cross-sections (barns/atom) for Ba, La, Ce, Pr, Nd, Sm, Eu, Gd, Tb and Dy at 11.4, 15.2, 17.8, 22.6, 25.8 and 41.0 keV excitation energies

Energy (keV)	σ_{L_α} (a)	(b)	(c)	σ_{L_β} (a)	(b)	(c)	σ_{L_γ} (a)	(b)	(c)
Ba(56)									
11.4	1097(94)	1097	1256	833(100)	1058	1156	-		
15.2	528(38)	482	555	503(47)	503	550	76(13)	85	92
17.8	291 (21)	304	352	297(22)	332	362	42(8)	57	61
22.6	168(10)	151	175	182(12)	176	192	33(2)	31	33
25.8	133(9)	102	119	129(8)	123	135	-		
La(57)									
11.4	1411(93)	1260	1424	1215(111)	1207	1319	-		
15.2	614(41)	556	632	635(43)	575	628	84(14)	99	107
17.8	387(25)	351	401	391(28)	379	414	62(12)	67	72
22.6	198(13)	174	200	225(14)	201	219	36(3)	36	39
25.8	132(9)	118	136	150(10)	141	154	31(4)	26	28
Ce(58)									
11.4	1469(96)	1442	1622	1297(94)	1369	1505	-		
15.2	678(56)	639	722	663(50)	654	718	118(15)	111	121
17.8	396(25)	404	458	419(27)	431	474	78(7)	75	81
22.6	221(14)	201	229	263(16)	229	252	55(4)	41	44
25.8	155(11)	136	156	171(11)	161	177	30(2)	29	31
Pr(59)									
11.4	1660(107)	1636	1834	1555(106)	1543	1709	-		
15.2	820(52)	726	818	793(55)	738	817	134(24)	125	137
17.8	497(32)	460	520	492(33)	488	540	82(10)	84	93
22.6	260(16)	229	260	294(18)	259	287	49(3)	46	51
25.8	181(12)	155	177	187(13)	182	202	41(7)	33	36

Nd(60)									
11.4	2065(134)	1861	2076	1724(121)	1732	1933	-		
15.2	930(58)	829	928	856(54)	873	926	121(11)	141	156
17.8	569(36)	526	590	520(33)	549	613	80(10)	95	105
22.6	297(18)	263	296	331(20)	292	326	69(5)	52	58
25.8	211(13)	178	201	213(15)	205	229	31(3)	37	41
Sm(62)									
11.4	2351(161)	2343	2618	2344(154)	2192	2458	-		
15.2	1125(71)	1047	1174	1227(79)	1052	1179	137(15)	179	199
17.8	699(44)	666	749	796(51)	697	782	95(11)	121	134
22.6	374(23)	334	378	429(27)	372	417	64(4)	66	74
25.8	242(15)	227	257	295(21)	262	294	52(6)	47	53
Eu(63)									
11.4	2822(179)	2642	2939	2321(156)	2488	2781	-		
15.2	1323(83)	1180	1318	1236(79)	1194	1336	194(20)	201	223
17.8	848(54)	752	842	841(54)	792	886	103(14)	136	151
22.6	443(27)	378	425	460(28)	423	474	71(5)	75	83
25.8	284(18)	257	290	307(21)	298	333	46(4)	53	59
41.0	77(5)	66	75	82(5)	86	97	17(2)	16	18
Gd(64)									
11.4	3177(201)	2945	3280	2814(178)	2749	3074	340(39)	455	507
15.2	1538(97)	1319	1476	1433(90)	1324	1482	210(18)	227	253
17.8	953(60)	842	943	935(58)	880	986	135(10)	154	171
22.6	511(32)	423	477	537(33)	471	527	94(6)	85	94
25.8	327(20)	288	325	353(23)	332	372	56(4)	61	67
41.0	87(6)	75	85	99(6)	98	110	18(2)	19	21
Tb(65)									
11.4	3536(225)	3301	3601	3026(194)	3052	3161	511(49)	500	513
15.2	1646(108)	1484	1645	1538(97)	1478	1653	221(16)	251	279
17.8	952(59)	947	1053	945(59)	983	1100	162(11)	170	189
22.6	543(34)	478	533	584(36)	527	590	91(6)	94	104
25.8	354(22)	325	364	406(25)	372	416	65(8)	67	74
41.0	99(6)	84	95	115(7)	108	121	25(2)	21	23
Dy(66)									
11.4	3651(230)	3697	4044	3353(211)	3420	3788	457(39)	561	618
15.2	1752(109)	1668	1833	1689(106)	1667	1848	263(23)	283	312
17.8	1140(71)	1067	1175	1156(72)	1111	1231	151(11)	192	212
22.6	610(38)	539	596	655(40)	597	661	95(6)	106	117
25.8	384(24)	367	407	439(27)	421	467	72(5)	76	83
41.0	104(7)	95	107	127(8)	123	136	20(2)	23	25

- These measurements were not done due to poor statistics of the data under L_γ group of X-ray peaks.

a Present measured experimental values of L XRF cross-sections.

b Values calculated using ω_i and f_{ij} taken from Krause et al (1979).

c Values calculated using ω_i and f_{ij} taken from Chen et al (1981).

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