Evidence against projectile induced L_i-subshell vacancy rearrangement effect for α-particle ionization in Pb and Bi

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Abstract.

Experimental data on L_i subshell ionization cross -sections in Pb and Bi have been compared with the ECPSSR and SCA theoretical predictions.The L_1 and L_2 subshell ionization cross-sections have opposite deviations when compared with the results of ECPSSR theory whereas,the L_3 cross-sections are in good agreement .The SCA theory,however,provides excellent agreement with the experimental data for L_2 ionization cross-sections whereas,the cross-sections for L_1 and L_3 deviate in the same direction,the theory being higher by (10-35)%.The ECPSSR results although indicate presence of projectile induced intrashell transition ($L_1 \rightarrow L_2$) effect in the collision process,the SCA theory does not.

Introduction

In recent years much effort has been devoted to the study of ion induced L_i-subshell ionization,both from the theoritical and the experimental point of veiw (Vigilante et al 1990,Cohen et al 1990). As compared to the proton case ,the heavy ions (Z≥2) have indicated large L_i-subshell anomaly when the experimental results were compared with the ECPSSR predictions .Many efforts have been devoted for the explanation of the discrepancies.Cohen (1983,1984)suggested a method of empirical L-subshell coulomb deflection factors to overcome the L_i -subshell anomaly within the ECPSSR formalism but later he and his collague (Harrigan and Cohen 1986) found that the large discrepancies could not be explained solely by invoking the coulomb deflection effects .They indicated that the discrepancies are most remarkable for the L_2 subshell and reduced ion velocities less than about 0.5 which corresponds to ~3.0MeV for ^{4}He-ion impact on the elements in the region of Pb.

Opposite deviation of L_1 and L_2 subshell ionization cross-sections from ECPSSR theory at low energies have been explained by Sarkadi and Mukoyama by taking into account the coupling between L_i-subshells (Sarkadi and Mukoyama 1980,1981,1984,1991, Sarkadi 1986).As shown by Sarkadi and Mukoyama the ionization process cannot be treated independently for individual L_i-subshells,because the projectile can induce intrashell transition between different subshells.Semaniak et.al.(1993) have recently measured the L_i-subshell ionization cross-sections for selected heavy elements ($72 \leq Z_2 \leq 83$) for the bombardment of ^{3}He and ^{4}He in the energy range of ($0.8 \leq E \leq 4.0$)MeV.Their results showed large deviation of L_2 subshell ionization cross-sections from both ECPSSR and SCA results .They tried to incorporate the intrashell transition effect and the united atom(UA) model for the binding correction to correct the ECPSSR results for the ^{4}He ionization. Although the corrections have improved the L_2subshell discrepancy the L_1 subshell discrepancy remained unchanged.

In the present study we tried to make a comparison of our experimental results (Dhal et al.1993)with both SCA and ECPSSR theoretical calculations inorder to see into the real cause of the L-subshell anomaly.Our measurements were carried out using α-particles in the energy range (2.2-8.2)MeV.

Theoretical Calculations:

The ECPSSR calculations were those of Cohen and Harrigan (1985) based on the original theory by Brandt and Lapicki(1981),without taking the united atom into account for the binding correction and also no intrashell transition effects were included .The SCA calculations were made by Trautmann(1993) by taking into account hyperbolic classical trajectories,with recoil term and with relativistic hydrogenic electron wave-functions for united atom and target Z_{eff} according to Slater recipe.

Results and Discussion

Experimental L_i subshell ionization cross-sections normalized by corresponding SCA and ECPSSR values are plotted in figs.1 & 2 as a function of α-particle energy .The individual ionization cross-sections are presented in tables 1 and 2.The experimental L_1 and L_2 subshell ionization cross-sections deviate in opposite directions from the ECPSSR results whereas the L_3 cross-sections show good agreement .However, comparison with the SCA theory shows good agreement for the L_2 subshell but the experimental data for L_1 and L_3 subshells are (10-35)% lower than the theory .From this comparison it is evident that the two theories do not lead to same conclusion .The ECPSSR theory suggests that projectile induced vacancy rearrangement is taking place between L_1 and L_2 subshells

but the SCA theory does not give any evidence in favour of such a rearrangement mechanism.We therefore feel that previous attempts of explaining the opposite deviations of L_1 and L_2 ionization cross-sections through intrashell transition effects just by comparing the experimental data with the ECPSSR theory alone is not correct. It is necessary to look for some other effects which can explain the present discrepancy .From the present scenario it appears that a state dependent correction is needed for providing good agreement with the experimental data .In any case an attempt should be made such that the same mechanism leads to good agreement of the experimental data with both the theories.

For a further check of the theoretical calculations we have compared the subshell ionization cross-section ratios $\frac{\sigma_{L_1}}{\sigma_{L_2}}$ and $\frac{\sigma_{L_3}}{\sigma_{L_2}}$ with the predictions of the ECPSSR and SCA theories in figs. 3 & 4 . As is seen from fig.3,the SCA theoritical result for $\frac{\sigma_{L_1}}{\sigma_{L_2}}$ ratio is in better agreement with the experimental data .It also predicts the position of the minimum at the correct place as given by the experiment.Comparison of the $\frac{\sigma_{L_3}}{\sigma_{L_2}}$ ratio (see fig.4) indicates that both the theoretical results are similar and the theoretical values are higher than the experimental data.The deviations of the experimental $\frac{\sigma_{L_3}}{\sigma_{L_2}}$ ratios from the theoretical predictions become more pronounced as the projectile energy decreases .However,in the present experiment we did not see any drop in the ratio at the low energy region ,which was seen in previous studies(Chang et al.1974,Li et al.1976,Datz et al.1974). For bringing agreement with the experimental $\frac{\sigma_{L_3}}{\sigma_{L_2}}$ ratio one needs to bring down the L_3 ionization cross-section of the SCA theory and increase the L_2 cross-section of ECPSSR theory.It is not clear how this conflicting theoretical situation can be solved through inclusion of any common additional effect such as projectile induced intrashell transition into the collision process.

In summary we would like to say that efforts are necessary to improve the presently available coloumb ionization theories for providing good agreement with the experimental data on L_i-subshell ionization.Present theories only give partial agreement with the data. Although comparison with the ECPSSR theory shows deviations in support of projectile induced vacancy rearrangement mechanism there is no such evidence when the data is compared with the SCA theory.The two theories provide different kinds of agreement with experimental data and hence cannot give complete agreement with the data by introducing any common additional effect to the ionization mechanism.It is therefore first necessary to reconcile the two theoretical results before invoking the idea of projectile induced intrashell transition effect .

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Figure Captions:

Fig.1 Ratios $R_i = \frac{\sigma^{L_i}_{expt}}{\sigma^{L_i}_{th}}$ for the experimental data of Dhal et al.(1993) with the ECPSSR and SCA theories plotted as a fnnction of α-particle energy for lead target.

Fig.2 Ratios $R_i = \frac{\sigma^{L_i}_{expt}}{\sigma^{L_i}_{th}}$ for the experimental data of Dhal et al(1993) with the ECPSSR and SCA theories plotted as a function of α-particle energy for bismuth target.

Fig.3 Ratios of L_1- to L_2-subshell ionization cross-sections for (a)lead and (b) bismuth are plotted as a function of α-particle projectile energy.Theoretical predictions of ECPSSR (solid curve) and SCA (dashed curve) are also plotted for comparison with the experimental data.

Fig.4 Ratios of L_3- to L_2-subshell ionization cross-sections for (a)lead and (b) bismuth are plotted as a function of α-particle projectile energy.Theoretical predictions of ECPSSR (solid curve) and SCA (dashed curve) are also plotted for comparison with the experimental data.

Table 1: L_i subshell ionization cross-section in Pb

α-particle energy MeV/amu	σ_{L_1} (barn)			σ_{L_2} (barn)			σ_{L_3} (barn)		
	Expt.	ECPSSR	SCA	Expt.	ECPSSR	SCA	Expt.	ECPSSR	SCA
0.571	1.16	1.60	1.94	1.33	0.81	1.02	4.73	4.87	6.58
0.757	2.25	2.84	3.25	3.65	2.4	3.27	13.41	13.3	18.1
0.937	2.84	3.83	4.06	7.80	5.14	7.02	28.8	26.3	35.5
1.224	3.56	4.54	4.68	13.8	9.28	12.6	47.2	44.9	59.7
1.306	4.07	5.07	5.34	21.2	14.6	19.9	71.3	67.6	88.5
1.492	4.78	5.73	6.83	31.1	21.4	29.0	99.2	95.3	122
1.675	7.01	6.86	9.42	40.9	29.2	39.4	131	126	160
1.863	11.4	8.78	13.5	53.3	38.5	51.4	165	162	201
2.046	14.6	11.7	19.2	67.0	48.6	64.2	205	200	245

Table 2: L_i subshell ionization cross-section in Bi

α-particle energy MeV/amu	σ_{L_1} (barn)			σ_{L_2} (barn)			σ_{L_3} (barn)		
	Expt.	ECPSSR	SCA	Expt.	ECPSSR	SCA	Expt.	ECPSSR	SCA
0.571	1.12	1.41	1.81	1.20	0.67	0.88	4.05	4.17	5.56
0.757	1.73	2.55	2.94	2.89	2.03	2.71	9.84	11.5	15.6
0.937	2.44	3.49	3.73	5.82	4.34	5.89	21.0	23.0	30.8
1.224	3.18	4.18	4.30	10.9	7.89	10.7	36.4	39.4	52.1
1.306	3.18	4.67	4.85	15.5	12.5	17.0	51.0	59.6	77.8
1.492	4.02	5.22	6.01	24.4	18.3	24.8	80.0	84.2	108
1.675	5.39	6.09	8.05	33.8	25.2	33.9	112	112	141
1.863	6.64	7.61	11.3	44.7	33.3	44.5	142	144	179
2.046	11.2	9.95	15.9	56.8	42.2	55.9	175	178	218

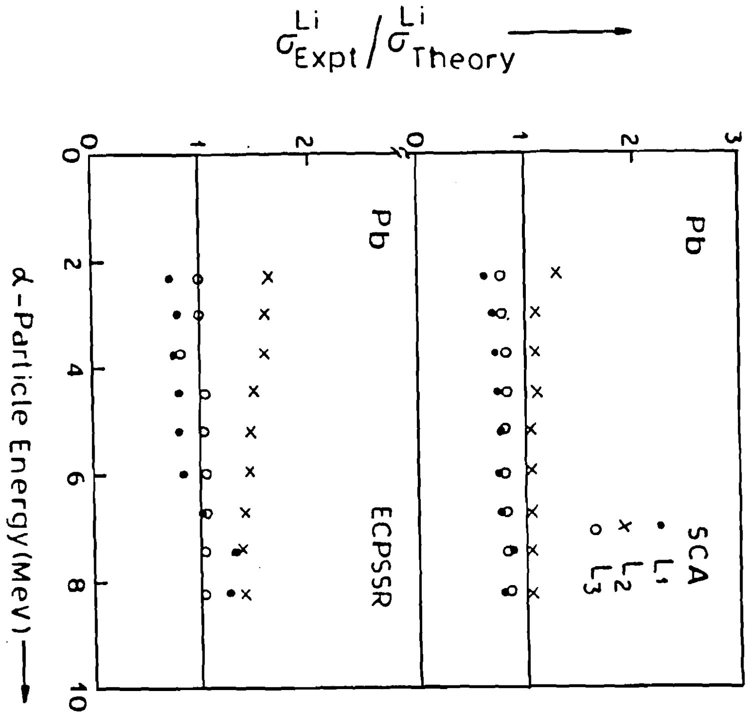

Fig. 1

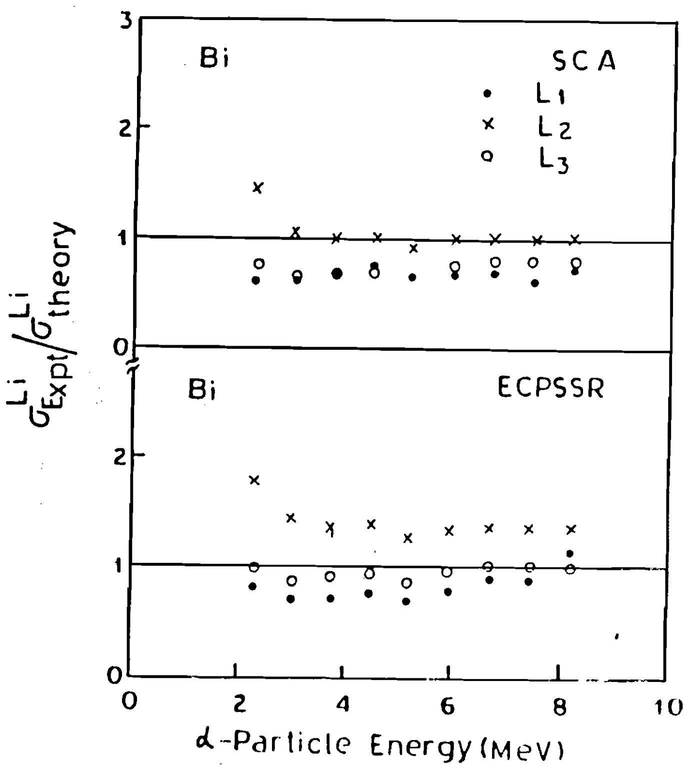
Bi
SCA
L1
L2
L3
Bi
ECPSSR
α-Particle Energy (MeV)

Fig. 2

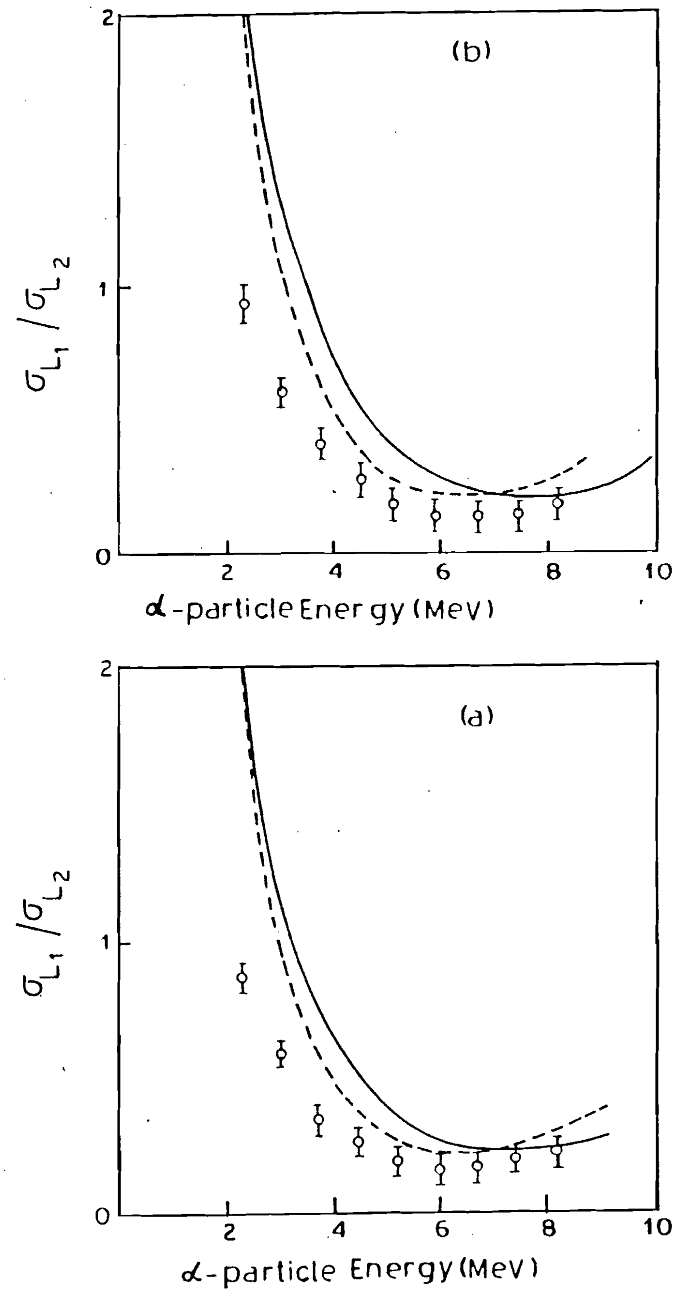
(b)
(a)
α-particle Energy (MeV)

Fig. 3

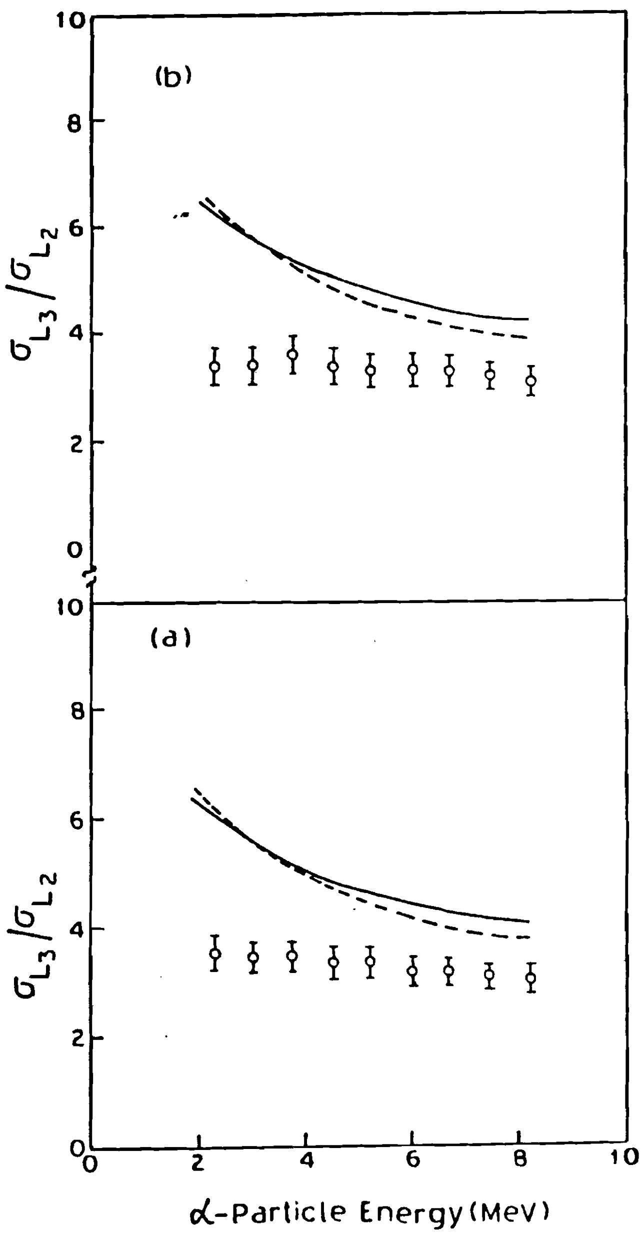

Fig. 4