Proton induced L X-ray relative intensity measurements in high Z elements

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Abstract

The L X-ray relative intensity measurements in Au, Pb and Bi are performed using proton in the energy range 220 to 400 keV. These studies indicate that in case of L-shell ionization, there is not only a lack of experimental data but there also exists large discrepancies between the experimental measurements and the theoretical calculations. Their energy variation and comparison with theoretical calculations will also be discussed.

1. Introduction

The ionization of an inner shell by an energetic ion is a basic problem in atomic physics. The interaction of ions with atoms results in the emission of characteristic X-rays from the target atom. These investigations are important as these provide the basis for an analytical technique, known as proton induced X-ray emission (PIXE). In ion-atom collisions, proton induced L X-ray relative intensity measurements are also important for theoretical understanding of the inner-shell ionization process [1-3].

2. Experimental procedure and data analysis

The beam from Van de Graaff accelerator has been used. The H^+ beam current on the target is measured by current integrator Elcor-A309F, which has high sensitivity, accuracy, low drift and an internal calibrating source. The high purity Germanium (HPGe) detector placed at right angle to the beam is used to detect the L X-rays. To ensure the precision of the relative intensities, the experiment is repeated at each beam energy. The spectra with good statistics for Au, Pb and Bi - L_α are collected. These spectra consist of four peaks of L X-ray groups corresponding to L_ℓ, L_α, L_β and L_γ, which are well separated from each other. Their relative intensity are derived at various energies, as described in our earlier work [2]. The error in the measured ratios is conservatively estimated at 10-12% and is attributed to the uncertainties in the peak area evaluation, charge collection, target thickness and the X-ray attenuation coefficients.

3. Theoretical evaluation

In low energy regime ECPSSR [3] theory for the ionization of bound atomic electrons by incident light ions is widely used, which is basically a plane wave Born approximation (PWBA) calculation, with a number of modifications. In recent times, further amendments have been suggested. The thrust for their introduction lay in the reported differences between experimental data and the predictions of the basic ECPSSR theory. The modification is the united atom correction which describes the interaction of projectile and target such that they are momentarily ‘‘united’’, thereby influencing the electron binding energies [4]. In the ECPSSR theory, the binding-energy correction term $\varsigma_s(\xi_s)$ is given by,

$$\varsigma_s(\xi_s) = \frac{U_{2s}(Z_{2s}) + \Delta U_{2s}(Z_{2s})}{U_{2s}(Z_{2s})} = 1 + \frac{\Delta U_{2s}}{U_{2s}}$$

$$= 1 + \frac{2Z_1}{Z_{2s}\theta_s}(g_s(\xi_s) - h_s(\xi_s)),$$

where U_{2s} is the subshell binding energy (s = subshell); Z_1, Z_{2s} are the projectile and effective nuclear charges, respectively; $\xi s = (2E_1/M_1)^{1/2}(Z_{2s}/U_{2s}) = v_1 Z_{2s}/U_{2s}$ with E_1, v_1, M_1 being the energy, velocity and mass of the projectile, respectively, is the reduced projectile velocity; the reduced subshell binding energy is θ_s and $g_s(\xi_s)$ and $h_s(\xi_s)$ are analytical functions that account for the velocity dependence of the correction; $h_s(\xi_s)$ is related to polarization effects on the binding energy due to the presence of the projectile ion in the atom. Using this correction, θ_s is replaced by $\zeta_s\theta_s$. Vigilante *et al* [5] realizing that the original ECPSSR theory overvalued the binding effect for decreasing projectile velocities, proposed to ‘‘saturate’’ the binding correction at a value which corresponds to the binding energy of the united atom (UA); i.e. projectile plus nucleus. In this paper, we have theoretically calculated the UA effect using procedure given by Cipolla [4]. This UA effect increases rapidly as proton energy decreases and will play a crucial role.

4. Results and Discussion

To analyze the energy variation, our measurements along with other experimental works are compared with theories; these are shown in following Figs. 1 - 3.

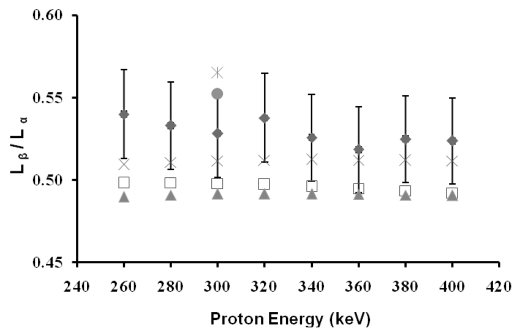

Fig 1. Relative L X-ray line measurement in Au. ♦, our experiment; □, Ref. [6] ; x, Ref. [7]; ▲, Ref. [8].

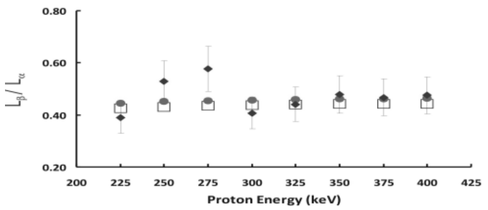

Fig 2. Relative L X-ray line measurement in Pb. ♦, our experiment; □, Ref. [9]; ●, Ref. [10].

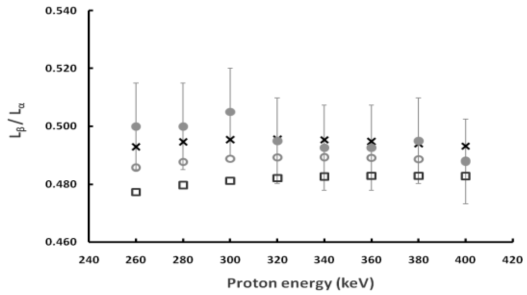

Fig 3. Relative L X-ray line measurement in Bi. ●, our experiment; □, Ref. [11]; x, Ref. [12]; o, Ref. [13].

From these Figs., it is clear that although there is a wide-range concurrence between theory and experiment in this energy regime, but refinements are still required in the theoretical calculation. The divergence in the low impact velocity regime (where the largest inconsistency between theory and experiment are observed) the collision is almost adiabatic. McGuire et al [14] derive expressions for probabilities for 2s-2p intra-shell excitations in the case of proton impact and obtained that in the case of low collision energies, transition probabilities dominate. Based on this, a coupled-channel calculation was developed by Sarkadi and Mukoyama [15] for all the L-shell electrons and obtained the L-sub shell ionization cross sections for ions with the sub shell coupling effect. These refinements will help to explain the discrepancies prevailing in this region.

5. Conclusion

It is inspiring to observe that amount of experimental data in this low energy region is very small, but this region is very significant as it provides a testing ground for theories. It is also likely that the already existing theories, may involve further refinements. These investigations have yielded a data in the low energy region, which helps in better understanding of proton induced X-ray emission phenomenon.

Acknowledgement

We gratefully acknowledge the financial support for this research work from Department of Science and Technology (DST), New Delhi, India under the Project No. SR/S2/LOP-0015/2010(G).

References

[1] X Zhou, Y Zhao, R Cheng, Y Wanga, Yu Lei, X Wanga, Y Sun, *Nucl. Instr. Meth. B* 299 (2013) p. 61.
[2] H Mohan, A K Jain, G Kaur, Parjit S. Singh, S Sharma, *Rad. Phys. Chem.* 81 (2012) p. 1833.
[3] W Brandt and G Lapicki, *Phys. Rev. A* 23 (1981) p. 1717.
[4] S J Cipolla, *Nucl. Instr. Meth. B* 261 (2007) p. 142.
[2] M Vigilante, P Cuzzocrea, N De Cesare, F Murolo, E Perillo, G Spadaccini, *Nucl. Instr. Meth. B* 51 (1990) p. 232.
[6] D Bhattacharya, S K Bhattacherjee, S K Mitra, *J. Phys. B* 13 (1980) p. 967.
[7] J Q Xu, *Phys. Rev. A* 44 (1991) p. 373.
[8] J Q Xu, *Phys. Rev. A* 43 (1991) p. 4771.
[9] Y C Yu, C W Wang, E K Lin, T Y Liu, H L Sun, J W Chiou and G Lapicki, *J. Phys. B: At. Mol. Opt. Phys.* 30 (1997) p. 5791.
[10] W Jitschin, G Materlik, U Werner and P Funke, *J. Phys. B: At. Mol. Phys.* 18 (1985) p. 1139.
[11] J L Campbell, *At. Data Nucl. Data Tables* 95 (2009) p. 115.
[12] H-U Freund and R W Fink, *Phys. Rev.* 178 (1969) p. 1952.
[13] M Weksler and A G de Pinho, *Rev. Bras. Fis.* 3 (1973) p. 291.
[14] J H McGuire and P Richard, *Phys. Rev. A* 8 (1973) p. 1374.
[15] L Sarkadi and T Mukoyama, *Phys. Rev. A* 37 (1988) p. 4540.