L-SUBSHELL IONIZATION CROSS SECTIONS OF Ag by PROTON IMPACT OF ENEGRY RANGE 1 Mev. – 5 Mev.

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In the present work, we have calculated the L-subshell ionization cross section of Ag by proton impact in the energy range of 1 Mev. – 5 Mev. Using Semi classical approximation (SCA) model. It is seen that there is good agreement between theory and experiment for Ag for all three –sub-shells. It is therefore concluded that the SCA model provides a reasonably good and reliable estimates of the L-sub-shell ionization cross-section to start with in order to understand the ionization process occurring in the collisions between proton and the heavy atoms in the considered impact energy range.

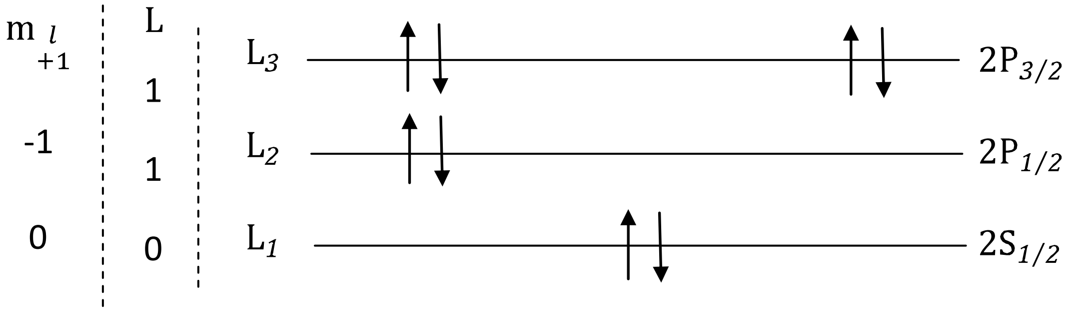
Keywords : Cross Section, Impact, Collision.

INTRODUTION :

Measuements of L-subshell cross section are relatively complicated compared with that of K-shell. This is because of two basic reasons –

(1) Experimental difficulties arise due to low L-x-ray energies for sufficient accuracy and resolution.

(2) L-shell contains 3-sub-shells $2P_{3/2}$, $2P_{1/2}$, $2S_{1/2}$ which makes the energy levels more complicated in comparison to that of a K-shell.

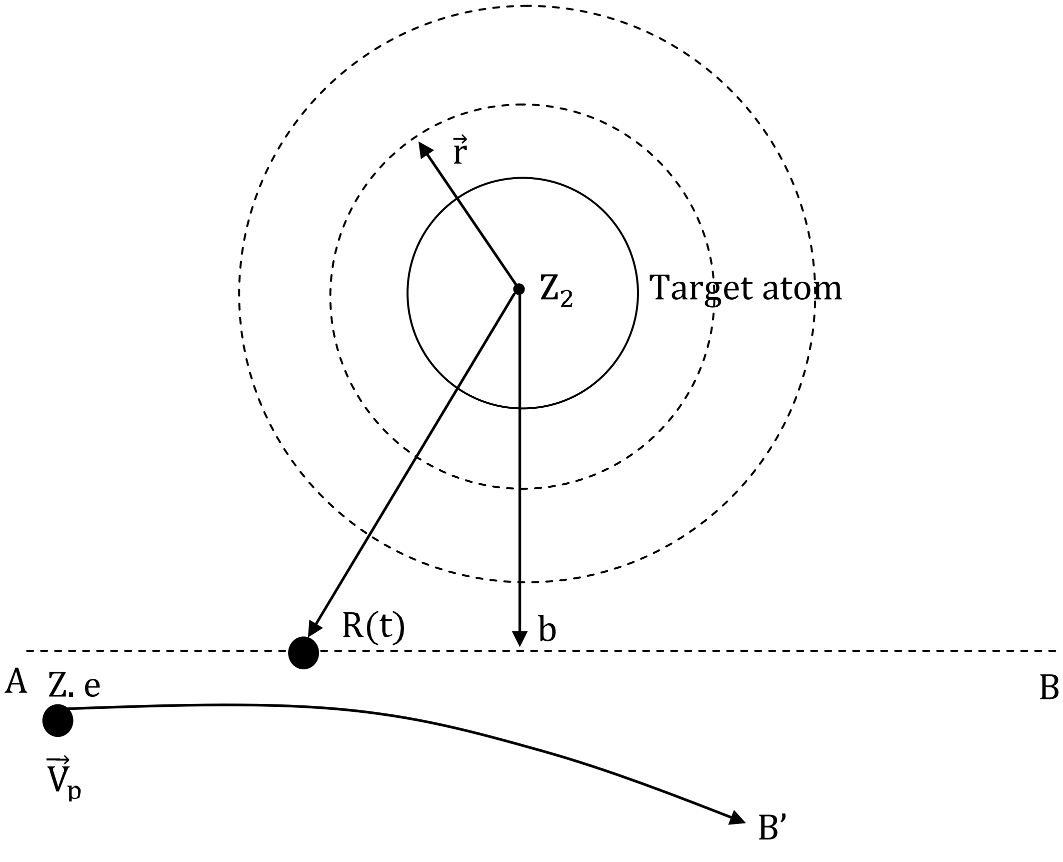


The L-sub-shell x-ray production cross section of Ag by proton impact in the energy range of 0.6 – 5.0 MeV have been measured by Rosato.[1]

In the present work, we have calculated the L-sub-shell ionization cross section for Ag. By proton impact in the energy range of 1 Mev – 5 Mev using the semi-classical approximation (SCA) model.[3]

The results of calculation have been compared with experimental data of Rassto.

THEORETICAL FORMULATION AND CALCULATIONS



Historically, the semi-classical approximation method was introduced with the aim teddy the projectile deflection and retardation effects, the classical impact parameter ‘b’ entered into the formalism through the assumption of classical projectile trajectories, the decisive parameter which imposes condition for validity of the (SCA) model is governed by the relation.

$$N = \frac{2d}{\lambda}\ N = \frac{2Z_1Z_2e^2}{\hbar V_p} > > 1 \qquad (1)$$

Where, $d = \frac{Z_1Z_2e^2}{M_0V_p^2}$

$$\text{or,}\quad N = \frac{2d}{\lambda}$$

$$\lambda = \frac{h}{M_0V_p}$$

d is half distance of closest approach in the head on collision. V_p is the incident velocity of projectile.

Z_1 and Z_2 are atomic numbers of the projectile and the target atom respectively and λ is de-Broglie wave length of the projectile. M_0 is reduced mass of the collision system.

Following conditions are specified by the SCA model :

(1) Point charge (Z_1e) behaves as a centre of force which moves along the classical trajectory (say a straight) line or a parabola (AB or AB').

(2) The electronic states of the target atom are represented by the hydrogenise wave function.

(3) The approximation consider only one electron in the ionization process.

(4) The experimental binding energy of the active electron is taken to be the threshold ionization energy.

(5)

SCALING RELATIONS :

The straight line semi-classical approximation may be written in terms of special variables, leading to approximate relation between the functions I_b for different target atoms.

For a given sub-shell A,

the hydrogenic wave function n_A, I_A the ionization probability I_b can be found from the generalized ionization probability function I_{nAlA} (X_A, B_A).

$$I_b = \frac{2J_A + 1}{2I_A + 1} \cdot \frac{1}{Z_A^2 \theta_A} \cdot I_{n_A, l_A} \quad (X_A, B_A) \qquad (2)$$

Where Z_A is the screened atomic number of the target atom with nuclear charge Z_2 and screening parameter Z_A^S.

$$Z_A = Z_2 - Z_A^S \qquad (3)$$

Z_2 $--$ Atomic number.

If θ_A is the ratio of experimental and ideal Binding energies.

$$\theta_A = \frac{E_{B(A)} n_A^2}{13.6 . z_A^2} \qquad (4)$$

$E_{B(A)}$ $-$ target electron binding energy (Electron Volt).

In Eqn. (2), $\frac{2J_A+1}{2I_A+1}$ is simple statistical factor, and

X_A, B_A chosen as dimensionless quantity.

$$\mathrm{X_A} = \frac{\mathrm{Z_A \theta_A}}{\mathrm{n_A\ E^{1/2}}} \qquad (5)$$

Where E is the magnitude of the projectile energy in Million electron volts.

$$\mathrm{B_A} = \mathrm{bZ_A/n_A a_0} \qquad (6)$$

With $\mathrm{a_0}$ denoting the Bohr Radius $\mathrm{a_0} = 5.29 \times 10^{-11}\mathrm{m}$

$\mathrm{n_A}$ represents multiplicity of state.

The total cross section –

$$\sigma_\mathrm{A} = \frac{2\mathrm{J_A}+1}{2\mathrm{I_A}+1} \cdot \frac{1}{\mathrm{Z_A^4 \theta_A}} \cdot \mathrm{F}_{\mathrm{n_A},l_\mathrm{A}}\ (\mathrm{X_A}) \qquad (7)$$

Where,

$$\mathrm{F}_{\mathrm{n_A},l_\mathrm{A}}\ (\mathrm{X_A}) = 2\pi \mathrm{a_0^2 n_A^2} \int \mathrm{B_A dB_A\ I}_{\mathrm{n_A},l_\mathrm{A}}\ (\mathrm{X_A B_A}) \qquad (8)$$

These latter functions thus have the dimension of length squared length-

The total cross-section σ_A is thus given in barn-

It should be stressed that the scaling relation represented by eqn. (5) and (7) is not exact.

However for most of the projectile energy region of interest the scaling procedure is valid to within a few percent.

For high energy region $\mathrm{X} \leq 5$, the scaling relation gradually breakdown.

Eqn. (2) can be written as-

$$I_b = \frac{2J_A + 1}{2I_A + 1} \cdot \frac{1}{Z_A^2 \theta_A} \cdot I_{n_A,} l_A \ (X_A, B_A), \mu_{n_A} l_A \ (\theta_A, X_A) \qquad (9)$$

The multiplicative correction factor μ_{n_l} depend on (θ and X). These factors should be used also for scaling the generalized ionization probability functions.

Total cross section by (7) can be re-written as

$$\sigma_A = \mu_{n_A} l_A(\theta_A, X_A) \frac{2J_A + 1}{2I_A + 1} \cdot F_{n_A,} l_A \ (X_A) \ \frac{1}{Z_A^4 \theta_A} \qquad (7)$$

All computations are based on non-relativistic hydrogen like electron wave functions.

The relevant values of the screening parameter Z_A S.

Table -1 : Screening Parameter (experimental data of Rosato[2])

Sub-shell	$\mathbf{Z_A^S}$
K	0.3
L_1, L_2, L_3	4.15
M_1, M_2, M_3	11.25
M_4, M_5	21.15

For heavy naked projectile with charge Z_1e and velocity V_1.

The coulomb interaction produce between this projectile and the target electron to be ejected.

In the (SCA) picture, we have following relation the corresponding results for protons with the same velocity.

$$\frac{dI_b}{dE_f}(Z_1, V_1) = Z_1^2 \frac{dI_b(Z_1 = 1, V)}{dE_f}$$

Which makes extension to other bare projectile easy.

The theoretical SCA values are dependent on the projectile velocity. Therefore, in the case of projectile heavier than protons, the quality E is Eqn. (5) should be replaced by the magnitude of the incident energy per atomic unit.

$1\ \mathbf{MeV}\ \mathbf{H}^+ - \mathbf{Ag}$

Quantity	**L_1**	**L_2**	**L_3**
E_B	3805	3524	3357
θ_A	0.609	0.564	0.536
X_A	13.03	12.08	11.48
$\frac{2J_A + 1}{2l_A + 1} \cdot \frac{1}{Z_A^4 \theta_A}$	9.74×10^{-7}	3.50×10^{-7}	7.37×10^{-7}
σ_A(in cm^2) (in barn)	1.18×10^{-21} 1.18×10^3	1.5×10^{-21} 1.5×10^3	2.12×10^{-21} 2.12×10^3
Experimental In cm^2	1.0×10^3 1.0×10^{-21}	1.5×10^3 1.5×10^{-21}	2.3×10^3 2.3×10^{-21}

$2\ \mathbf{MeV}\ \mathbf{H}^+ - \mathbf{Ag}$

Quantity	**L_1**	**L_2**	**L_3**
E_B	3805	3524	3357
θ_A	0.609	0.564	0.536
X_A	9.25	8.56	8.14
$\frac{2J_A + 1}{2l_A + 1} \cdot \frac{1}{Z_A^4 \theta_A}$	9.74×10^{-7}	3.50×10^{-7}	7.37×10^{-7}
σ_A(in cm^2) (in barn)	3.15×10^{-21} 3.15×10^3	3.36×10^{-21} 3.36×10^3	7.07×10^{-21} 7.07×10^3
Experimental In cm^2	3.3×10^{-21} 3.3×10^3	3.8×10^{-21} 3.8×10^3	6.0×10^{-21} 6.0×10^3

$\mathbf{3\ MeV\ H^+ - Ag}$

Quantity	**L_1**	**L_2**	**L_3**
E_B	3805	3524	3357
θ_A	0.609	0.564	0.536
X_A	7.57	6.98	6.63
$\frac{2J_A+1}{2l_A+1}\cdot\frac{1}{Z_A^4\theta_A}$	9.74×10^{-7}	3.50×10^{-7}	7.37×10^{-7}
σ_A(in cm^2) (in barn)	3.98×10^3 3.98×10^{-21}	3.8×10^3 3.8×10^{-21}	8.60×10^3 8.60×10^{-21}
Experimental (born)	5.0×10^3	6.0×10^3	9.0×10^3

$\mathbf{4\ MeV\ H^+ - Ag}$

Quantity	**L_1**	**L_2**	**L_3**
E_B	3805	3524	3357
θ_A	0.609	0.564	0.536
X_A	6.52	6.04	5.74
$\frac{2J_A+1}{2l_A+1}\cdot\frac{1}{Z_A^4\theta_A}$	9.74×10^{-7}	3.50×10^{-7}	7.37×10^{-7}
σ_A(in cm^2) (in barn)	4.01×10^3 4.01×10^{-21}	4.13×10^3 4.13×10^{-21}	8.01×10^3 8.01×10^{-21}
Experimental (born)	6.6×10^3	4.4×10^3	8.0×10^3

$\mathbf{5\ MeV\ H^+ - Ag}$

Quantity	**L_1**	**L_2**	**L_3**
E_B	3805	3524	3357

θ_A	0.609	0.564	0.536
X_A	5.85	5.41	5.14
$\frac{2J_A+1}{2l_A+1}\cdot\frac{1}{Z_A^4\theta_A}$	9.74×10^{-7}	3.50×10^{-7}	7.37×10^{-7}
σ_A(in cm^2) (in barn)	3.9×10^{3} 3.9×10^{-21}	4.2×10^{3} 4.2×10^{-21}	8.62×10^{3} 8.62×10^{-21}
Experimental (born)	7.5×10^{3}	6.0×10^{3}	10.0×10^{3}

RESULTS & CONCLUSIONS :

Our calculations using the SCA model have been performed for different collision systems. The experimental data of Rosato[2] are shown in the figure by circles for direct comparison with our calculations.

It is seen that there is a good agreement between theory and experiment for two targets, namely Ag for all three L-sub-shells.

It is, therefore, concluded that the SCA model provides a reasonably good and reliable estimates of the L-sub-shell ionization cross sections to start with in order to understand the ionization process occurring in the collusions between proton and the heavy forget atoms in the considered impact energy range.

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