Proton Impact K-Shell Ionisation of Atoms in Modified Binary Encounter Model

Dr. Gopal Jee
Department of Physics,
L.S. College, Muzaffarpur-842001, Bihar, India.

Abstract: *The Binary Encounter Approximation has been used for calculations of Proton impact K-Shell ionization cross-sections of atoms. The effects of coulomb deflection of the incident projectiles and increase in binding of the target electrons have been investigated. Hartree-Fock velocity distributions for the target electrons have been used in the present calculations. The calculated cross-sections have been compared with experimental result and other theoretical calculations wherever available. The present calculations give a good account of experimental observations.*

Keywords: **K-Shell ionization cross-sections, Binary Encounter Approximation, Coulomb deflection, Hartree-Fock velocity distribution.**

1. Introduction:

Investigation of inner shell ionization of atoms by heavy charged particles impact has long been an interesting subject in the field of atomic collisions. The study of inner-shell ionization remained almost slow between 1940 to seventies. This field receieved considerable attention in seventies, mainly due to improvement in the experimental technique e.g. improved availability of accelerated heavy ions and much improved experimental counters based on coincidence technique (See Hansteen[1], Burhop[2]). A good number of experimental and theoretical studies of inner-shell ionization of atoms by the impact of heavy charged particles is available in the literature.

The inner-shell ionization and x-ray production by charged particles has been extensibly studied in the last few decades, mainly because of its importance for the particle induced x-ray emission (PIXE) in analytical studies. Theoretical studies of these processes are of much practical importance as they provide cross-sections for the emission of x-rays from various inner shells which can be used for the interpretation of experimental data (Sarter et al.[3]). These cross sections find applications in characterization of ionizing atomic collisions, trace-element analysis of biological and environmental samples and accurate determination of beam intensities in various particle accelerators experiments (Hardt and Watson[4]).

Ionization from inner-shell of an atomic target takes place due to impact of heavy energetic structureless charged particles when these penetrate deep into the atomic inner shell.

The contribution to the ionization cross-sections come from the direct coulomb excitation of the target electron by the projectiles. Theoretical investigations of inner-shell ionization of atoms by incident heavy charged particles involving direct coulomb excitation have been done initially in the plane wave Born approximation (PWBA) (See Merzbacher and Lewis[5]) and in the semi Classical approximation (SCA) (See Bang an Hansteen[6]). In recent past the same processes has been investigated by Garcia[7a,b] in the Binary Encounter Approximation (BEA). This being an impulse approximation gives results similar to those obtained in PWBA at high impact energies (Hansteen[1]). Specially, in case of inner shell ionization, apart from its simplicity the BE cross sections are competing with those obtained using SCA and PWBA and are in agreement with experimental observations (See Bearse et al[8]).

The Theoretical values of inner-shell ionization cross-sections due to heavy charged particle impact in any one of the above mentioned approximations do not show agreement with the experimental observations. The discrepancy between theory and experiment can be reduced to a large extent by incorporating two important physical processes. These two processes are coulomb deflection of the projectile in the field of target nucleus and increase in binding of the target electron in the presence of the projectile (See Brandt et al9).

Garcia[7] has incorporated the effect of coulomb deflection of the incident proton in the binary encounter approximation. The effects of increase in binding of the target electron as well as coulomb deflection of the projectile in BEA calculations of heavy positively charged particle impact inner-shell ionisation cross-section of atoms have been incorporated by *Singhal and Singh*[10] kumar and Roy[11], Chatterjee et al[12], Shrivastava and Roy.[13] Kumar and Roy[11] have used the correct expression for $\sigma_{\Delta E}$(Cross-sections for energy transfer ΔE by the projectile to the target) as given by vriens[14a,b] in their calculations but the factor used by them for the increase in binding of the target electron is independent of impact velocity, which is not physical justified. Later on Shrivastava dn Roy[13] used a velocity dependent correction factor incorporating the effects of increase in the binding of the target electron (See Basbas et el[15], Brandt and Lapicki[16a,b]) in their calculations of heavy charged particle impact K-Shell ionization cross-section of atoms.

Keeping in view the above mentioned fact, I consider it worthwhile to calculate K-Shell ionization cross-sections of atoms due to impact of protons taking into account the physical processes properly along with accurate quantum mechanical velocity distribution for the target electron (See Shrivastava and Roy[13]).

2. Theoretical Considerations

Vriens[14] expressions for ionization Cross-sections of atoms by proton impact have been used by incorporating the coulomb repulsion of the proton in the field of target nucleus suggested by Thomas and Garcia[17] (See also Kumar and Roy[11]). The effect of coulomb repulsion is introduced analytically through the relation (See Shrivastava et al.[13a,b] Chatterjee et al[12])

$$\sigma(E_1) = \sigma(E_1') \left[\frac{1}{2} + \frac{1}{2}\left(1 - \frac{Z_1 Z_{2k} e^2}{E_1 a_2 k}\right)^{1/2}\right] \quad (1)$$

where $\sigma(E_1')$ is the ionisation cross-section at the reduced energy.

$$E_1' = E_1 - \frac{Z_1 Z_{2k} e^2}{a_{2k}}$$

and $Z_{2k} = Z_2 - S_{2k}$

Z_1 and Z_2 are the nuclear charges of the projectile and of the target under consideration respectively a_{2k} and S_{2k} are the radius and the screening constant for the K-Shell respectively.

The effect of the increase in binding of the target electron in the presence of the positively charged particle (protons) can be incorporated in the ionization expression for cross-sections by replacing the unperturbed binding energy U_{2k} of atomic K-shell by $U_C = \in U_{2k}$, where U_C is the corrected binding energy and $\in$ is a correction factor given by (See Brandt and Lapicki[16a,b])

$$\in = 1 + \left(\frac{2Z_1}{Z_{2k}\theta_{2k}}\right) g \quad (2)$$

Were θ_{2k} is the reduced binding energy and for K-shell electron it is given by

$$\theta_{2k} = \frac{U_{2k}}{Z_{2k}^2(13.6)} \quad (3)$$

The factor g is a velocity dependent term and for K-shell it is given by (See Basbas et al.[15a,b,c])

$$g = \frac{(1+5x+7.14x2+4.27x^3+0.94x^4)}{(1+x)^5} \quad (4)$$

where $x = \frac{V_1}{\left(\frac{1}{2}\theta_{2k} V_{2k}\right)}$

Finally Vriens[14] expressions for ionization cross-sections incorporating the contributions of above mentioned effects in terms of two dimensionless variables s and t (see Catlow and McDowell)[18], can be expressed as

$$Q(s,t) = \begin{cases} \frac{(s+s')^2 Z_1^2}{s^2 s'^2 U_c^2}\left(1+\frac{2t^2}{3}-\frac{1}{4(s'^2-t^2)}\right)\pi a_0^2; 1 \le 4s'(s'-t) \\ \frac{(s+s')^2 Z_1^2}{2s^2 s'^2 U_c^2 t}\left[\frac{1}{4(s'+t)}+t+\frac{2}{3}\left\{2s'^3+t^3-(1+t^2)^{\frac{3}{2}}\right\}\right]\pi a_0^2; \\ \qquad 4s'(s'-t) \le 1 \le 4s'(s'+t) \\ 0 \qquad | > 4s'(s'+t) \end{cases} \quad (5)$$

The two dimenionless variable have been defined

as $t^2 = \frac{\vartheta_{2k}^2}{\vartheta_0^2}, s^2 = \frac{\vartheta_1^2}{\vartheta_0^2}$ and $s'^2 = s^2 - (1.058 Z_1 Z_{2k})/(1836\, M a_{2k} U_C$

$\vartheta_0^2$is the corrected ionization energy in Rydberg units of the shell under consideration $\vartheta_1, \vartheta_{2k}, \vartheta_0$, and M (Mass of Projectile) are expressed in atomic units.

The resulting expression for ionization cross-sections have been integrated over Hartree-Fock Velocity distribution for the bound electron, reduces to

$$Q(s) = \quad n_e \int_0^\infty Q(s,t) f(t) U_c^{1/2} dt$$

Where n_e is the number of equivalent electron in the shell under consideration and f(t) is momentum distribution functions for the target electrons constructed by Hartree-Fock radial function which is given by clement & Roetti19 (See Kumar and Roy[11]). The binding energies of the target electrons have been taken from the table of clement and Roetti.[19] The quantum-mechanical values of the points of maximum radial probability reported by Desclaux[20] have been used as the shell radii. For K-Shell, the screeing constant has been taken equal to 0.30 (See slater[21], Basbas et al[15], Langerberg[22]).

3. Results and Discussion

Proton impact K-Shell ionization Cross Sections for Ne, Mg, Cl and Ar have been calculated along the line discussed in Sec. 2 (Theoretical consideration). Three sets of calculation have been done for every target atoms and the result of which are presented in figures1 to 4 and tables

1 to 4. The experimental results of K-Shell ionization cross-sections (σ_1) for atoms have been determined from x-ray production cross-section (σ_x) .

$\sigma_1 = \frac{\sigma_x}{W_k}$ where W_k is the fluorescence yield of the K-shell of the atomic target.

In the present work, the values of W_k for different targets has been taken from the review article by Lapiciki.[23] The present calculations of K-Shell ionization cross-sections have been compared with the experimental Observations of different workers and different calculations in ECPSSR as reported in the review article of Lapicki.[23]

In case of proton impact K-Shell ionization cross-sections of Neon (Ne), three sets of present calculations along with two sets of experimental observations and one other theoretical results have been presented in fig. 1 and table 1. The two sets of experimental observations have been reported by Lapicki[23], one set due to Harrison et al.[24] which is limited to low energy region (48.0 KeV to 135.0 KeV) whereas the other set due to Langenberg and VanEck[25] is in the energy range 125.0 KeV to 1000 KeV. Present results including all modifications overestimate the experimental results at low impact energies but the agreement improves with increase in impact energy. It is a general feature of cross-sections calculated in the BEA. The present results including all modifications are always within a factor of two as compared to the experimental observations. The present calculated cross-section are also in reasonably good agreement with the calculation of ECPSSR throughout energy range. Further, it is observed that inclusion of effects of coulomb deflection of the projectile in the field of target nucleus and the effect of increase in binding of the target electron in the presence of the project lowers the cross-sections at low impact energies. With increase in impact energy the effects of these two physical processes on the ionization cross-sections decrease and at high impact energies, the three sets of calculations give cross-sections which are very close to each other. These observations are as expected from the physical considerations. At high impact energies, the projectile will get little time to be deflected appreciably form its path. Moreover, the probability of formation of quasi molecule leading to increase in binding of the target electron is also very small at high impact energies.

Present results of atomic magnesium have been presented in table-2 and fig. 2 along with the experimental observations of Khan et al[26], Shima[27] and Khan and Potter.[28] The calculated results using ECPSSR theory are also shown in Fig. Experimental results due to Shima[27] have been reported only for two impact energies whereas those of khan and potter28 are over a limited energy ranges (60.0 KeV to 500.0 KeV). Observations of Khan et. al[26] are available over an extended energy range (50.0 KeV to 1700.0 KeV). The present calculations show reasonably good agreement with all the three sets of experiments, always being within a factor of two to the observed values. The present calculated cross-sections are also in reasonable agreement with the results of ECPSSR calculations. As far as the effects of the physical processes included in the present calculations are concerned, the observations are similar as in the case of neon.

Experimental values of K-Shell ionization cross-section for atomic chlorine are available over the energy range 800 KeV to 5000 KeV (As reported by Lapicki)[23]. Experiments have been performed by the three group of workers- Avaldi et. al[29], Olabanji and Martinsson[30] and Szokefalvi-Nagi and Demeter[31] which are spread over the impact energy range 600.0 KeV to 5000.0 KeV. The present calculations of cross-sections, over the energy range used by Experimentalist mentioned here, have been performed and presented the results along with the experimental observations and calculationis in ECPSSR in Table 3 and fig. 3. The overall agreement of the present calculations with the experimental observations is reasonably good. Present results are higher than the experimental cross sections but always within a factor of 2. The present calculations also show satisfactory agreement with the values of cross-sections calculated in ECPSSR.

In case of argon, the proton impact K-Shell ionization cross-sections have been reported from 125.0 KeV to 1000.0 KeV by Langerberg and VanEck[25] whereas from 1500.0 KeV to 5000.0 KeV by winters et al.[32] Winters et.al[33] have performed experiments for 1500.0 KeV to 5000.0 KeV impact energies. Present calculations have seen carried out from 125.0 KeV to 5000.0 KeV impact energies. The results have been presented along with the experimental observations and ECPSSR values in table 4 and fig. 4 At low impact energies the present calculated results of cross-sections are higher than that of the experimental values but with increase in impact energy the agreement improves. This is the general trend of BEA cross sections. Over all the agreement of my calculated results with the experiment is satisfactory. They are always within a factor of 2. The present results are also in satisfactory agreement with the values of cross-sections calculated using ECPSSR.

4. Conclusion:

A critical study of the results presented in See 3 it is concluded that Binary Encounter Approximation (BEA) incorporating the corrections for two physical effects namely the coulomb deflection of the projectile in the field of the target nucleus and increase in binding of the target electron in the presence of the projectile gives a reasonable estimate of K-Shell ionization cross-sections of atomic targets due to impact of heavy bare nuclei. The present results in general overestimates the experimental cross-sections, which is more prominent at low impact energies. As the impact energy increases, the calculated cross-sections come closer to the experimental observations.

The present method is simple and gives results in reasonable agreement with experiments and complex calculations like ECPSSR. Hence the method is useful whenever fast calculations of such cross sections are required.

Acknowledgement

The Author is thankful to Dr. S.N. Chatterjee, Professor of Physics, B.R.A. Bihar University (Retd.), Muzaffarpur for his fruitful discussions & suggestions in preparing the manuscript.

Table-1

H^+ impact K-Shell ionization cross sections of Ne

(in units of 10^{-23} Cm^2)

Impact Energy (KeV)	Exp. Of Harrison et.al[24]	Exp. Of Langenberg and VanEck[25]	Cal (Cm^2) ECPSSR (D)	Present Cal (cm^2)		
				A	B	C
48.0	7.83		6.93	35.8	19.3	9.71
58.0	14.8		15.2	62.3	33.2	21.0
68.0	26.0		28.5	158.0	72.1	43.0
77.0	43.5		45.8	118.0	102.0	81.2
97.0	99.4		105.0	283.0	210.0	184.0
116.0	183.0		192.0	376.0	289.0	242.0
125.0		178.0	245.0			
135.0	300.0		315.0	571.0	421.0	385.0

150.0		317.0	424.0	1420.0	620.0	522.0
200.0		694.0	925.0	1580.0	1380.0	1210.0
300.0		1770.0	2250.0	3760.0	2950.0	2820.0
400.0		3130.0	3660.0	4880.0	4580.0	4350.0
500.0		3910.0	4920.0	6830.0	5430.0	5400.0
600.0		4650.0	6010.0	7430.0	6710.0	6600.0
700.0		5330.0	6010.0	7880.0	7290.0	7240.0
800.0		5830.0	7630.0	8590.0	8180.0	8130.0
900.0		6770.0	8840.0	9730.0	9280.0	9230.0
1000.0		7220.0	8690.0	10002.0	9630.0	9580.0

Figure-1

H^+ impact K-Shell ionisation Cross-Sections of Ne

(in units of 10^{-23} Cm^2)

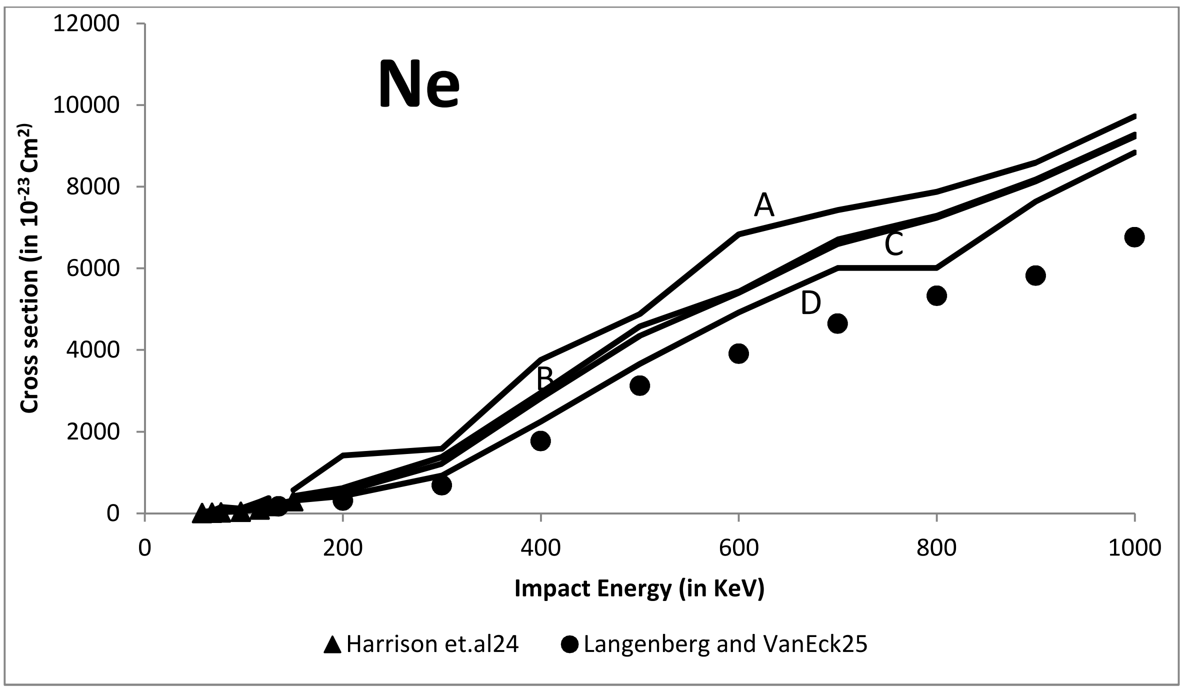


Table-2

H^+ impact K-Shell ionization cross sections of Mg

(in units of 10^{-24} Cm^2)

Impact Energy (KeV)	Exp of Khan et.al[26]	Exp. Of Shima[27]	Exp. Of Khan and Potter[28]	Cal (Cm^2) ECPSSR (D)	Present Cal (cm^2)		
					A	B	C
50.0	7.57	6.67		7.80	48.6	26.3	18.2
60.0	14.8	16.0	11.7	17.5	92.4	50.2	27.8
70.0	28.4			33.8	152.0	91.8	49.2
80.0	61.7			58.1	242.0	155.0	81.4
90.0	80.3			92.2	326.0	226.0	132.0
100.0	115.0		93.3	137.0	461.0	322.0	175.0
150.0			400.0	575.0	1820.0	1120.0	700.0
200.0			933.0	1420.0	2750.0	2120.0	1720.0
300.0			3130.0	4210.0	5420.0	4950.0	4680.0
400.0			6000.0	7930.0	14200.0	9530.0	9210.0
500.0			6670.0	12000.0	18300.0	15300.0	13800.0
600.0	14200.0			16200.0	25600.0	20200.0	18300.0
686.0	15000.0			19300.0	28300.0	23200.0	22100.0
800.0	16900.0			23200.0	33100.0	27300.0	26500.0
900.0	19200.0			26200.0	36100.0	31200.0	29300.0
1000.0	21400.0			28800.0	37500.0	35200.0	33800.0
1100.0	24200.0			31400.0	43200.0	38700.0	35200.0
1200.0	25800.0			33300.0	44400.0	39500.0	37200.0
1300.0	29300.0			35200.0	46200.0	40200.0	39200.0
1400.0	31500.0			36400.0	45100.0	41200.0	40100.0
1500.0	34300.0			37500.0	44200.0	38800.0	38300.0
1600.0	35700.0			39000.0	42000.0	35800.0	35600.0
1700.0	38000.0			40000.0	40100.0	34500.0	34200.0

Figure-2

H^+ impact K-Shell ionization cross sections of Mg

(in units of 10^{-24} Cm^2)

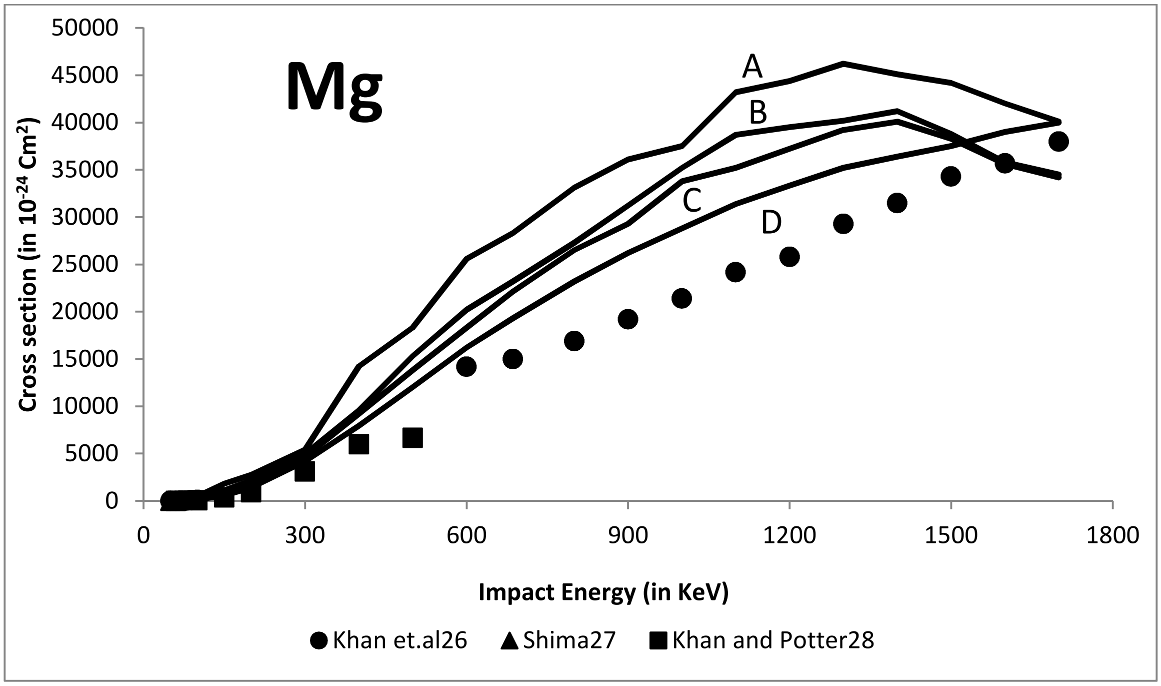


Table-3

H^+ impact K-Shell ionization cross sections of CI

(in units of 10^{-21} Cm^2)

Impact Energy (KeV)	Exp. Of Avaldi et.al[29]	Exp. Of Szokefalvi-Nagi and Demeter[31]	Exp. Of Olabanji and Martinsson[30]	Cal (Cm^2) ECPSSR (D)	Present Cal (cm^2)		
					A	B	C
800.0	1.68			1.51	4.91	3.64	2.6
1000.0	2.72		2.77	2.31	7.20	5.42	3.93
1200.0	2.89			3.10	8.78	6.70	5.21
1300.0			4.12	3.43	9.36	6.26	5.42
1400.0	3.41	3.74		3.86	9.96	7.84	5.42

1500.0		3.86		4.22	10.1	8.23	5.94
1600.0	4.31	4.14		4.56	10.6	8.52	6.66
1700.0		4.57		4.90	11.1	8.84	6.96
1800.0	4.95	5.41		5.20	10.9	8.89	7.17
1900.0		5.31	6.28	5.50	10.6	9.21	7.37
2000.0	5.48	5.30		5.76	10.5	9.30	7.42
2200.0	5.63			6.28	10.4	9.43	7.67
2250.0			6.84	6.39	10.3	9.43	7.73
2400.0	5.49			6.72	10.4	9.75	8.06
2550.0			7.44	7.02	10.3	9.85	8.35
2600.0	5.89			7.14	9.67	9.60	8.35
2800.0	5.70		7.86	7.48	9.62	9.63	8.60
3000.0			8.33	7.78	9.68	9.66	8.87
3500.0			8.68	8.35	9.42	9.73	8.18
4000.0			9.64	8.76	9.15	10.0	9.46
4500.0			10.2	9.11	9.02	9.10	8.43
5000.0			10.5	9.21	9.91	9.92	8.83

Figure-3

H^+ impact K-Shell ionization cross sections of CI

(in units of 10^{-21} Cm^2)

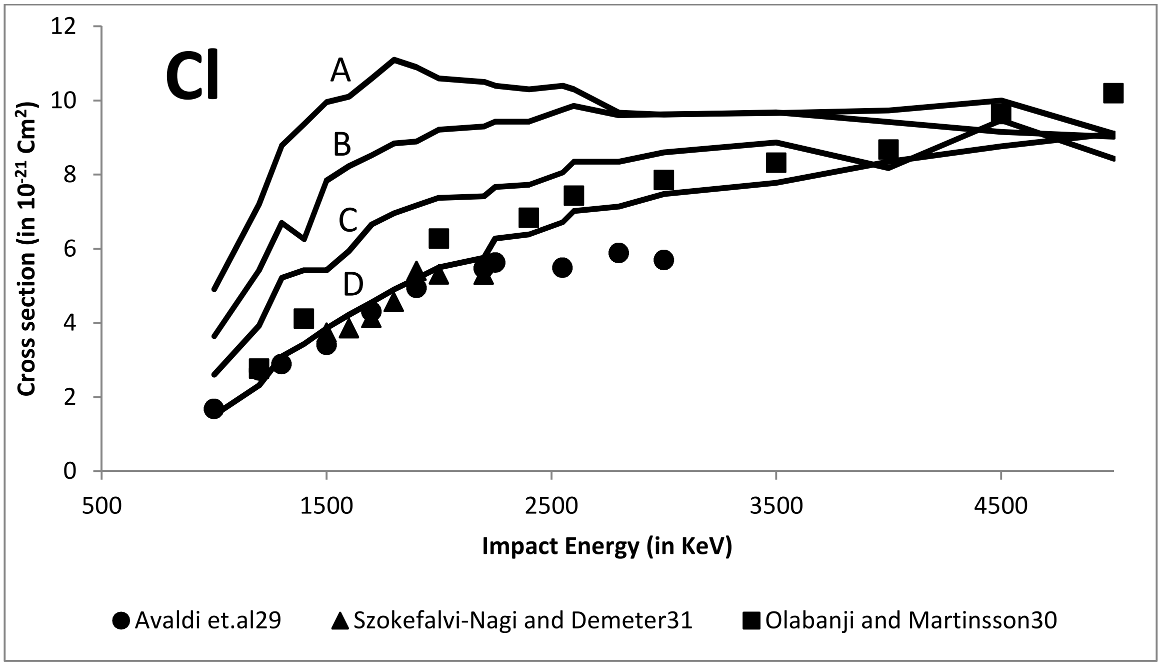


Table-4

H^+ impact K-Shell ionization cross sections of Ar

(in units of 10^{-24} Cm^2)

Impact Energy (KeV)	Exp. Of Langenberg and VanEck[25]	Exp. Of Winters et.al[32]	Exp. Of Winters et.al[33]	Cal (Cm^2) ECPSSR (D)	Present Cal (cm^2)		
					A	B	C
125.0	2.64			2.22	13.5	7.10	4.44
150.0	5.02			4.78	26.6	14.1	9.10
200.0	13.5			14.7	71.5	39.7	26.5
250.0	30.2			32.8	151.0	83.7	55.8
300.0	55.2			61.2	241.0	242.0	97.9
400.0	134.0			152.0	563.0	331.0	228.0

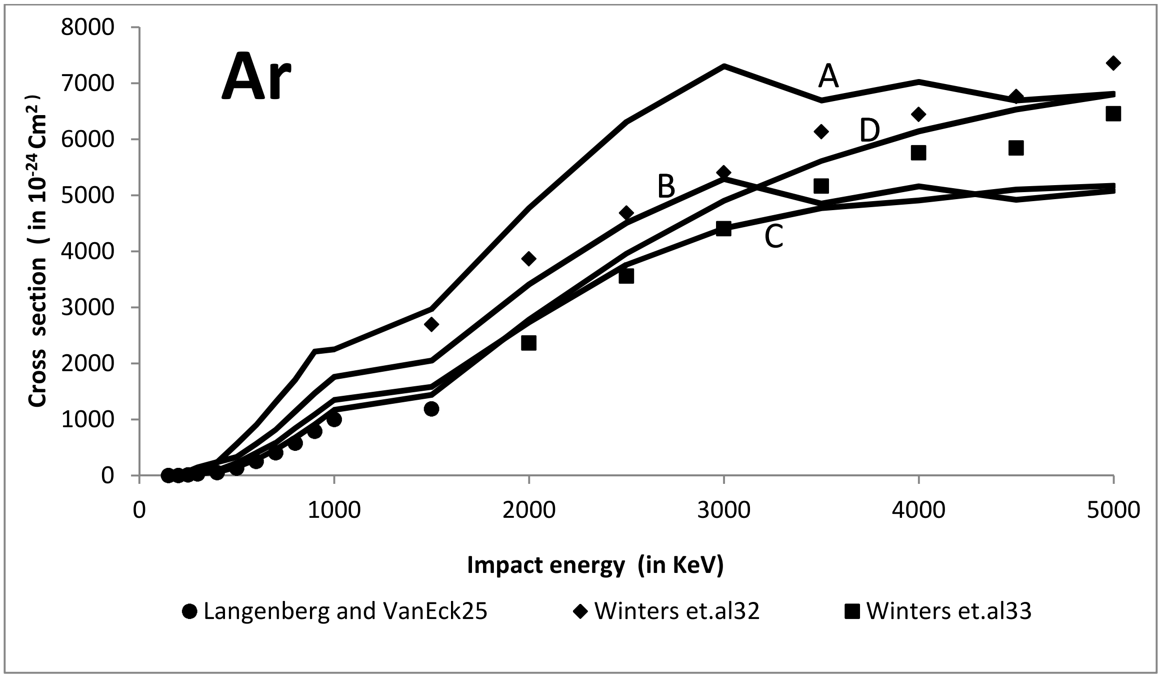
ISSN NO: 0776-3808

500.0	254.0			288.0	902.0	564.0	403.0
600.0	406.0			465.0	1310.0	819.0	585.0
700.0	581.0			677.0	1710.0	1140.0	846.0
800.0	792.0			911.0	2210.0	1470.0	1090.0
900.0	1000.0			1170.0	2250.0	1760.0	1350.0
1000.0	1190.0			1440.0	2970.0	2050.0	1580.0
1500.0		2700.0	2370.0	2780.0	4770.0	3410.0	2730.0
2000.0		3870.0	3560.0	3960.0	6310.0	4510.0	3760.0
2500.0		4690.0	4410.0	4900.0	7300.0	5290.0	4410.0
3000.0		5410.0	5170.0	5610.0	6690.0	4850.0	4770.0
3500.0		6140.0	5760.0	6140.0	7020.0	5160.0	4910.0
4000.0		6450.0	5850.0	6530.0	6690.0	4920.0	5100.0
4500.0		6770.0	6460.0	6800.0	6810.0	5080.0	5170.0
5000.0		7360.0		7010.0	6910.0	5160.0	5190.0

Figure-4

H^+ impact K-Shell ionization cross sections of Ar

(in units of 10^{-24} Cm^2)



References:

1. *J.M.Hansteen, Adv.At. Mol. Phys.* ***11****, 299 (1975).*

2. *E.H.Burhop. Adv. At. Mol. Phys.* ***15,*** *329 (1979).*

3. *W.Sarter, H.Mommsen, M.Sankar, P.Schwekes and A. Waller, J. Phys. B : At. Mol. Phys.* ***14,*** *2843 (1981)***.***

4. *T.L.Hardt and R.L. Watson, Phys. Rev. A.* ***14,*** *137 (1976).*

5. *E.Merzbacher and H. Lewis, Encyclopedia of Physics (Springer-Verlag, Berlin)* ***34,*** *166 (1958).*

6. *J.Bang and J.M. Hansteen, Mat. Phys. Medd.* ***37,*** *No. 10 13 (1959).*

7a. *J.D. Garcia, Phys. Rev. A.* ***1,*** *280 (1970).*

7b. *…….., Phys. Rev. A.* ***1****, 1402 (1970).*

8. *R.C. Bearse, D.A. Close, J.J. Malamiby and C.J. Umbarger, Phys. Rev. A* ***7,*** *1269 (1973).*

9. *W.Brandt. R.Laubert and I.Sellin, Phys. Rev.* ***151,*** *56 (1966).*

10. *R.P.Singhal and V.Singh, Physica 7****8, 343 (1979).***

11. *A.Kumar and B.N.Roy, J.Phys. B: At. Mol. Phys.* ***11,*** *1435 (1978).*

12. *S.N.Chatterjee, A.Kumar and B.N.Roy, Physica,* ***112, C,*** *275 (1983)****.***

13a. *S.K.Shrivastava and B.N.Roy, Physica,* ***124 C,*** *127 (1984).*

13b. *A.K.Kingston, Phys. Rev.* ***135****, 1537 (1960).*

14a. *L.Vriens, Proc. Phys. Soc.,* ***90****, 935 (1967).*

14b. *…….., Case studies in Atom. Collision Phys. Vol. I (North-Holland, Amsterdam) 337 (1969).*

15a. *G.Basbas, W.Brandt and R.H. Ritchi, Phys. Rev. A. 7, 1971 (1973)*

b. *G.Basbas, W.Brandt and R.Laubert, Phys. Rev. A.* ***17*** *1955 (1978)*

16a. *W.Brandt and G.Lapicki, Phys. Rev. A* ***20****, 465 (1979).*

16b. *………., Phys. Rev. A* ***23****, 1717 (1981).*

17. *B.K.Thomas and J.D. Garcia, Phys. Rev.* ***170,*** *94 (1969).*

18a. *G.Catlow and M.R.C. Mc Dowell, Proc. Phys. Soc.* ***92,*** *875 (1967).*

18b. *S.K.Shrivastava, A.Kumar and B.N.Roy Physics 124C(184) 127-134.*

19. *E.Clemanti and C.Roetti, Atomic Data and Nucl. Data Table 14, 185 (1974).*

20. *J.D. Desclaux, Atomic Data and Nucl Tables* ***12****, 325 (1973).*

21. *J.C.Slater, Phys. Rev.* ***36,*** *57 (1930)****.***

22. *A.Langerberg, Ph.D. Thesis; Phys. Lab. Rijksuniverstait, Utrecht (1978).*

23a. *G.Lapicki, J.Phys. Chem. Ref. Data* ***18*** *No. 1 (1989).*

b. *G.Lapicki, J.Phys. B At. Mol. Opt. Phys.* ***41*** *115201 (2008)*

24. *K.G.Harrison, H. Tawara and F.J. De Heer, Physica* ***66,*** *6 (1973).*

25. *A.Langenberg and J. VanEck, J.Phys. B* ***9,*** *2421 (1976).*

26. *J.M.Khan, D.L. Potter and R.D. Worley, Phys. Rev.* ***139****, A, 1735 (1975).*

27. *K.Shima, Phys. Lett. A. 67, 351 (1978).*

28. *J.M.Khan and D.L. Potter, Phys. Rev.* ***133****, A, 890 (1964).*

29. *Avaldi, M.Milazzo, A.Rota and G.Riccobona, J.Phys. B.* ***14****, 2223 (1981).*

30. *S.O. Olabanji and B.G. Martinsson, Nucl. Inst. And Methods B* ***24/25,*** *81 (1987)*

31. *Z.Szokefalvi-Nagy and I. Demeter, Nucl. Inst. And Methods* ***181,*** *1 (1981).*

32. *L.M.Winters, R.Macdonald, D. Brown, L.D. Ellswarth and T. Chio, Phys. Rev. A, 7, 1276 (1973).*

33. *L.M.Winters, L.D. Ellswarth, T. Chio and J.R. Macdonald Proc. Int. Conf. on Inner Shell Ionization Phenomenna, Atlanta, 1977.*