IONIZATION CROSS SECTIONS OF NEON BY ELECTRON IMPACT

Naveen Kumari [1,2], S.P.Sharma [1]

[1]Department of Chemistry, Baba Mast Nath University, Rohtak,

[2]Department of Biomedical Engineering, DCRUST, Murthal, Sonepat (HR)

ABSTRACT

From low to high energy (10 KeV) absolute electron impact ionization cross section of neon is determined via modified Jain-Khare semi-empirical approach. In this literature the absolute ionization cross section data have compared with available data. It is found that the existing results are in good agreement for the ionization cross sections up to higher energy. Presently there is no theoretical or experimental available data for SDCS and DDCS for neon. The single and double differential cross sections of neon are also calculated.

KEYWORDS

Absolute Ionization Cross Section, Electron impact ionization, Single and double differential cross section.

INTRODUCTION

Times to time various investigations have been made in rare gases for the efficiency of ionization by electron impact [1-14]. In 1930 measurement of Smith for neon and argon are made experimentally [1]. In 1960 the measurement of relative ionization cross section for argon, krypton and xenon are made by Tozer and Craggs [16] using Lozier apparatus over the electron energy range upto 100 ev. However, many works have been done on neon [25]. Some have evaluated the partial and absolute total ionization cross section of neon experimentally from threshold to intermediate energy and some others intermediate to higher energy. There are many applications of electron impact ionization cross sections in the field of plasma processes, vacuum technology, ionosphere, gas discharges, in biomedical research as well as in basic theory of atomic and molecular collisions and others [17]. There are various theoretical formalism to determine the partial and total ionization cross sections [18]. For better accuracy, we use the modified Jain-Khare semi-empirical approach [19-21] to determine absolute and differential ionization cross section of neon.

THEORETICAL METHODOLOGY

The absolute ionization cross section is determined via modified Jain-Khare approach. It gives ionization cross section to the production of an ith type of ion in the ionization of an atom by an incident electron of energy E solving the following given equations [20, 27-29].

We have developed the MATLAB programming codes for the calculation of huge numeral of molecular ionization cross sections.

$$Q_iE = \frac{4\pi\, a_0^2\, R}{E}\left[\frac{E}{E-Ii}\left(Mi^2 - \frac{R}{E}\,Si\right) ln[1+Ci(E-Ii)] + \frac{R(E-Ii)}{E}\,Si \times \int_0^{(E-Ii)/2} \frac{1}{\varepsilon^3+\varepsilon_0^3}\left(\varepsilon - \frac{\varepsilon^2}{(E-\varepsilon)} + \frac{\varepsilon^3}{(E-\varepsilon)^2}\right) d\varepsilon\right]$$

----------- Eq. (1)

Where

W, I_i , a_0, ε_0, C_i , S_i, R are energy loss suffered by the incident electron, Ionization Potential, Bohr radius, Mixing parameter, collision parameter, number of ionizable electrons and Rydberg energy respectively.

And oscillator strength df_i/dw is the key parameter. We have taken the experimental values of oscillator strength available up to electron energy 250 eV [22].

Thus, for higher energies, the same data have been extrapolated by the TRK sum rule, within 10% error bars [23-24]. The ionization potential for neon is 21.6 eV [16]. The value of the collision parameter and mixing parameter are (C_i= 0.03796) and (ε_0=60) respectively.

In this literature, we have calculated the absolute ionization cross section over the secondary electron energy varying from 0 to (E-I)/2 using equations (1). We have calculated the single and double differential ionization cross section using the equation (2) and (3) which are given below [20, 29].

$$Q_{i(E,W)} = \frac{4\pi\, a_0^2 R}{E}\left[\left(1-\frac{\varepsilon}{E-Ii}\right)\left(\frac{R}{W}\right)\times\frac{dfi(w,0)}{dw}\, ln[1+Ci(E-Ii)] + \frac{R}{E}\,Si \times \frac{(E-Ii)}{\varepsilon^3+\varepsilon_0^3}\left(\varepsilon-\frac{\varepsilon^2}{(E-\varepsilon)}+\frac{\varepsilon^3}{(E-\varepsilon)^2}\right)\right]$$

----------- Eq. (2)

$$Q_{i\,(E,W,\theta)} = \frac{4\pi\, a_0^2 R^2}{E}\left[\frac{8R^2Z^2}{W^3}\left(1-\frac{\varepsilon}{E-Ii}\right)\sqrt{\left(1-\frac{W}{E}\right)}\times \sin\theta\,\frac{dfi(w,0)}{dw}\, ln[1+Ci(E-Ii)] + Si \times \frac{(E-Ii)}{E} \times \frac{1}{\varepsilon^3+\varepsilon_0^3}\left(\varepsilon-\frac{\varepsilon^2}{(E-\varepsilon)}+\frac{\varepsilon^3}{(E-\varepsilon)^2}\right)(\sin\theta)/2\right]$$

----------- Eq. (3)

RESULTS AND DISCUSSION

In this literature, we have calculated the absolute ionization cross section of neon via the modified Jain-Khare semi-empirical approach using Equations (1) to (3) by means of MATLAB programming codes. Calculated ionization cross section from 30 eV to 10 KeV of incident electron energy is tabulated in Table 1 and presented graphically in Fig. 1. We have compared the total ionization cross sections with available data [26] also shown in Fig.1**.** All these are in good agreement from threshold up to high energies.

Table 1: Present Result for Absolute total Ionization cross-section of Neon (10^{-17} cm^2)

Energy (eV)	TICS	Energy (eV)	TICS	Energy (eV)	TICS
30	0.1049	460	4.9384	2700	1.3946
35	0.2251	470	4.8768	2800	1.3547
40	1.0706	480	4.8172	2900	1.3172
45	2.1203	490	4.7586	3000	1.2819
50	2.9807	500	4.7015	3100	1.2485
55	3.6908	520	4.5913	3200	1.2170
60	4.2843	540	4.4866	3300	1.1872
65	4.7827	560	4.3864	3400	1.1588
70	5.2049	580	4.2910	3500	1.1319
75	5.5643	600	4.1996	3600	1.1064
80	5.8723	620	4.1123	3700	1.0820
85	6.1373	640	4.0289	3800	1.0588
90	6.3658	660	3.9487	3900	1.0366
95	6.5632	680	3.8721	4000	1.0154
100	6.7357	700	3.7985	4100	0.9951
110	7.0030	720	3.7277	4200	0.9757
120	7.1731	740	3.6599	4300	0.9570
130	7.2737	760	3.5945	4400	0.9391
140	7.3233	780	3.5317	4500	0.9220
150	7.3347	800	3.4711	4600	0.9054
160	7.3174	850	3.3290	4700	0.8896
170	7.2783	900	3.1989	4800	0.8742
180	7.2227	950	3.0793	4900	0.8595
190	7.1548	1000	2.9690	5000	0.8453
200	7.0778	1050	2.8669	5200	0.8183
210	6.9942	1100	2.7721	5400	0.7931
220	6.9059	1150	2.6839	5600	0.7695
230	6.8144	1200	2.6015	5800	0.7474
240	6.7211	1250	2.5244	6000	0.7266
250	6.6256	1300	2.4522	6200	0.7070
260	6.5311	1350	2.3842	6400	0.6885
270	6.4359	1400	2.3203	6600	0.6710
280	6.3424	1450	2.2599	6800	0.6545
290	6.2492	1500	2.2029	7000	0.6388
300	6.1582	1550	2.1488	7200	0.6238
310	6.0679	1600	2.0976	7400	0.6097
320	5.9802	1650	2.0490	7600	0.5961
330	5.8934	1700	2.0028	7800	0.5833
340	5.8093	1750	1.9587	8000	0.5709
350	5.7263	1800	1.9167	8200	0.5592
360	5.6460	1850	1.8766	8400	0.5479
370	5.5669	1900	1.8383	8600	0.5371
380	5.4903	1950	1.8017	8800	0.5268
390	5.4150	2000	1.7666	9000	0.5169
400	5.3416	2100	1.7006	9200	0.5074

410	5.2700	2200	1.6398	9400	0.4982
420	5.2002	2300	1.5835	9600	0.4894
430	5.1326	2400	1.5312	9800	0.4809
440	5.0662	2500	1.4826	10000	0.4727
450	5.0015	2600	1.4371	-	-

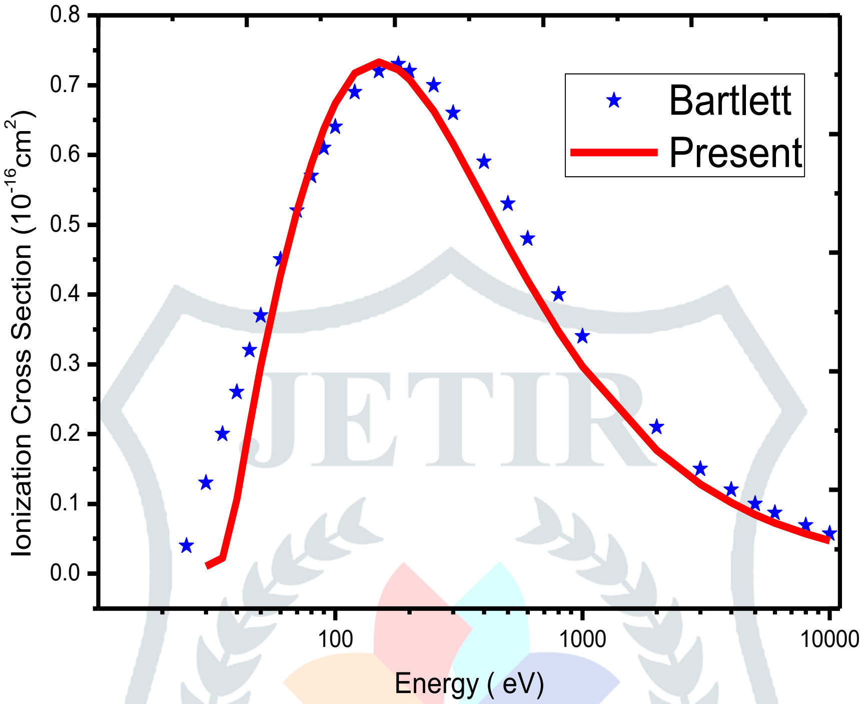

Fig.1: Absolute total ionization cross section in Å^2 of Neon.

Solid line, Present result; star , Bartlett et al. [26]

The results are evaluated for SDCS as a function of secondary electron energy at fixed incident electron energies 100 eV, 200 eV and 500 eV are given in table 2 and shown in Fig. 2- 4 respectively.

Table 2 : Single differential ionization cross-section of Neon by electron impact at fixed electron energy E=100 eV, 200 eV and 500 eV with respect to secondary electron energy

W (eV)	E=100 eV	E=200 eV	E=500 eV
25	2.52E-18	1.91E-18	1.11E-18
30	2.26E-18	1.77E-18	1.04E-18
35	1.86E-18	1.51E-18	9.02E-19
40	1.51E-18	1.27E-18	7.66E-19
45	1.25E-18	1.1E-18	6.7E-19
50	1.01E-18	9.13E-19	5.62E-19
55	8.48E-19	7.89E-19	4.9E-19
60	7.29E-19	6.87E-19	4.31E-19
65	6.47E-19	5.99E-19	3.8E-19
70	6.08E-19	5.24E-19	3.36E-19
75	6.22E-19	4.64E-19	3.01E-19
80	6.99E-19	4.05E-19	2.65E-19
85	8.79E-19	3.59E-19	2.37E-19

90	1.22E-18	3.16E-19	2.09E-19
95	1.85E-18	2.8E-19	1.86E-19
100	3.09E-18	2.51E-19	1.65E-19
120		1.83E-19	1.05E-19
140		1.87E-19	6.93E-20
160		2.92E-19	4.79E-20
180		6.77E-19	3.42E-20
200		2.81E-18	2.54E-20
250			1.54E-20
300			1.36E-20
350			1.8E-20
400			3.54E-20
450			1.11E-19
500			1.35E-18

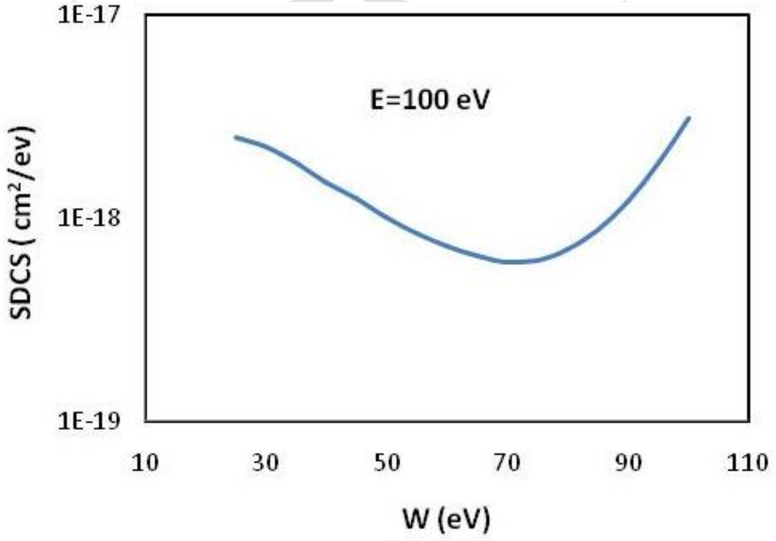

Fig.2: Single differential cross section (SDCS) of Neon at fixed incident electron energy 100 eV.

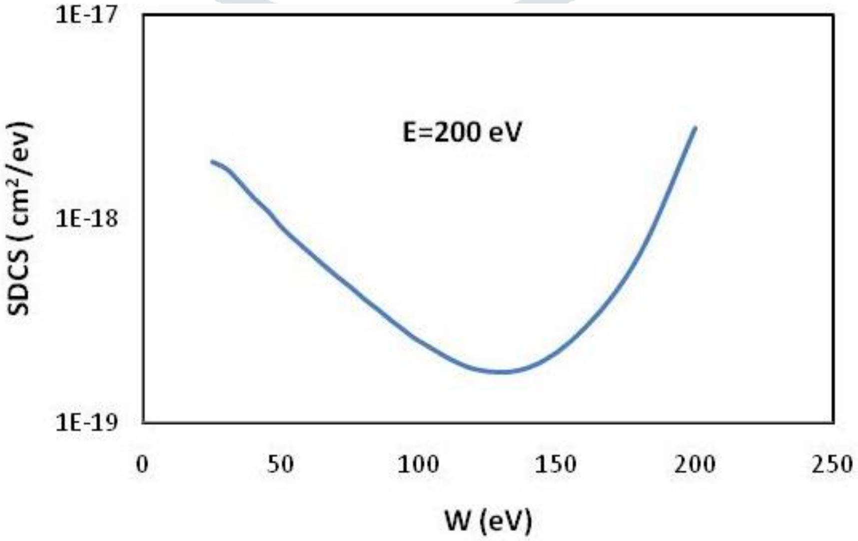

Fig.3: Single differential cross section (SDCS) of Neon at fixed incident electron energy 200 eV.

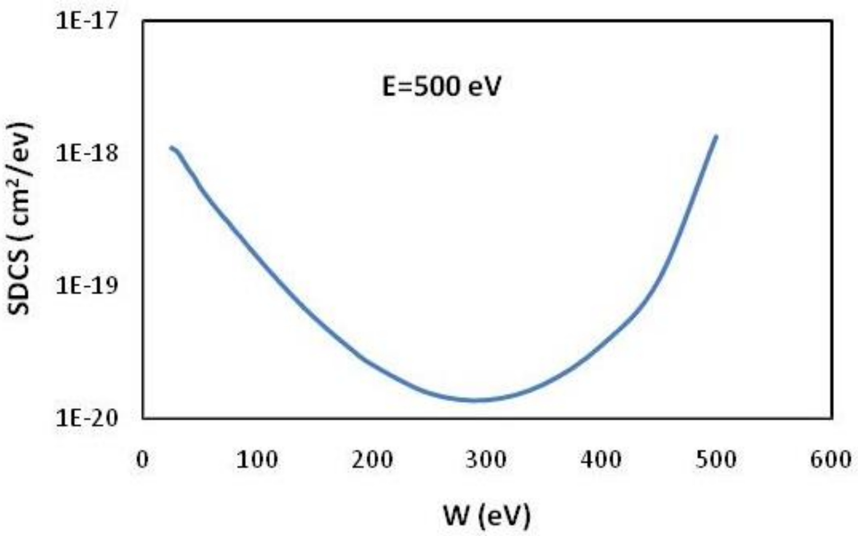

Fig.4: Single differential cross section (SDCS) of Neon at fixed incident electron energy 500 eV.

DDCS is evaluated as a function of secondary electron energy and with respect to the fixed incident angles 30̊, 60̊ and 90̊ of an electron at the fixed incident electron energies 100 eV, 200 eV and 500 eV are represented in figure 5 to 7and their respective tables are given from tables 3 to 5.

Table 3: Double differential ionization cross-section of Neon at E=100 eV with respect to secondary electron energy at fixed angles 30̊, 60̊ and 90̊.

W (eV)	θ, 30̊	θ, 60̊	θ, 90̊
25	2.55E-18	4.42E-18	5.11E-18
30	1.51E-18	2.62E-18	3.02E-18
35	8.72E-19	1.51E-18	1.74E-18
40	5.2E-19	9E-19	1.04E-18
45	3.35E-19	5.81E-19	6.71E-19
50	2.21E-19	3.82E-19	4.42E-19
55	1.61E-19	2.79E-19	3.22E-19
60	1.28E-19	2.22E-19	2.57E-19
65	1.13E-19	1.95E-19	2.25E-19
70	1.11E-19	1.92E-19	2.21E-19
75	1.22E-19	2.12E-19	2.44E-19
80	1.5E-19	2.6E-19	3E-19
85	2.02E-19	3.51E-19	4.05E-19
90	2.94E-19	5.1E-19	5.89E-19
95	4.59E-19	7.94E-19	9.17E-19
100	7.72E-19	1.34E-18	1.54E-18

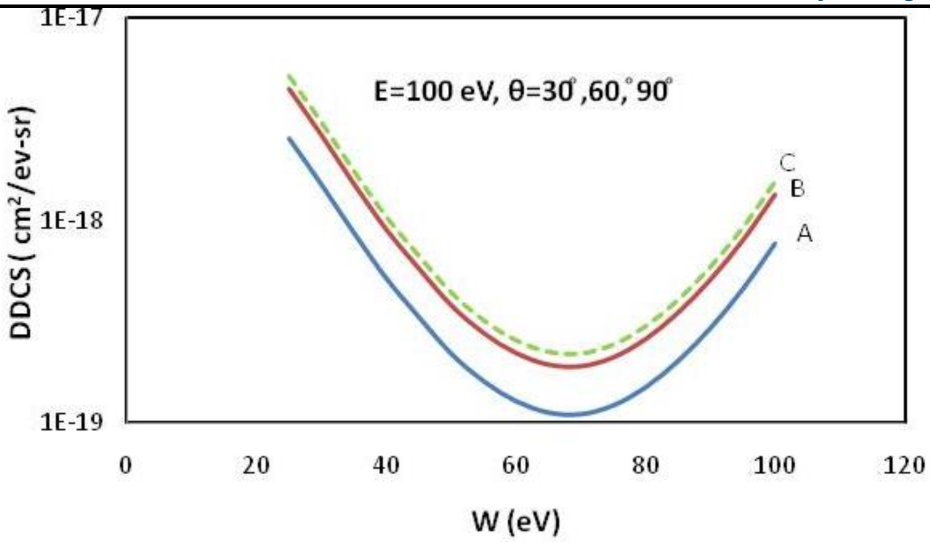

Fig.5: DDCS of Neon at fixed incident electron energy 100 eV with fixed incident angle A, 30°; B, 60°; C, 90°.

Table 4: Double differential ionization cross- section of Neon at E=200 eV with respect to secondary electron energy at fixed angles 30̊, 60̊ and 90̊

W (eV)	θ, 30̊	θ, 60̊	θ, 90̊
25	2.1E-18	3.64E-18	4.2E-18
30	1.31E-18	2.28E-18	2.63E-18
35	8.03E-19	1.39E-18	1.61E-18
40	5.06E-19	8.77E-19	1.01E-18
45	3.43E-19	5.94E-19	6.86E-19
50	2.33E-19	4.04E-19	4.66E-19
55	1.71E-19	2.97E-19	3.43E-19
60	1.32E-19	2.28E-19	2.64E-19
65	1.05E-19	1.82E-19	2.1E-19
70	8.63E-20	1.49E-19	1.73E-19
75	7.31E-20	1.27E-19	1.46E-19
80	6.23E-20	1.08E-19	1.25E-19
85	5.44E-20	9.43E-20	1.09E-19
90	4.8E-20	8.31E-20	9.59E-20
95	4.3E-20	7.45E-20	8.6E-20
100	3.92E-20	6.79E-20	7.84E-20
120	3.3E-20	5.71E-20	6.59E-20
140	4.03E-20	6.98E-20	8.06E-20
160	7E-20	1.21E-19	1.4E-19
180	1.68E-19	2.91E-19	3.36E-19
200	7.02E-19	1.22E-18	1.4E-18

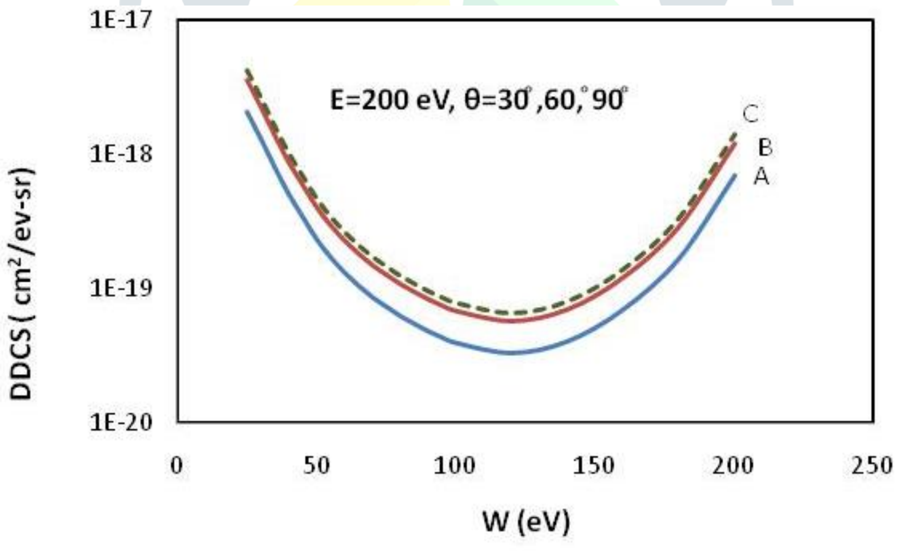

Fig.6: DDCS of Neon at fixed incident electron energy 200 eV with fixed incident angle A, 30̊; B, 60̊; C, 90̊.

Table 5: Double differential ionization cross-section of Neon at E=500 eV with respect to secondary electron energy at fixed angles 30°, 60° and 90°

W (eV)	θ, 30°	θ, 60°	θ, 90°
25	1.27E-18	2.21E-18	2.55E-18
30	8.18E-19	1.42E-18	1.64E-18
35	5.12E-19	8.87E-19	1.02E-18
40	3.3E-19	5.71E-19	6.59E-19
45	2.27E-19	3.93E-19	4.54E-19
50	1.56E-19	2.69E-19	3.11E-19
55	1.15E-19	1.99E-19	2.29E-19
60	8.81E-20	1.53E-19	1.76E-19
65	6.97E-20	1.21E-19	1.39E-19
70	5.67E-20	9.82E-20	1.13E-19
75	4.75E-20	8.24E-20	9.51E-20
80	3.99E-20	6.91E-20	7.98E-20
85	3.43E-20	5.95E-20	6.87E-20
90	2.95E-20	5.11E-20	5.91E-20
95	2.57E-20	4.45E-20	5.14E-20
100	2.25E-20	3.9E-20	4.51E-20
120	1.4E-20	2.43E-20	2.8E-20
140	9.37E-21	1.62E-20	1.87E-20
160	6.65E-21	1.15E-20	1.33E-20
180	4.97E-21	8.61E-21	9.95E-21
200	3.91E-21	6.78E-21	7.83E-21
250	2.73E-21	4.73E-21	5.46E-21
300	2.8E-21	4.85E-21	5.6E-21
350	4.19E-21	7.25E-21	8.38E-21
400	8.7E-21	1.51E-20	1.74E-20
450	2.77E-20	4.79E-20	5.53E-20
500	3.38E-19	5.86E-19	6.76E-19

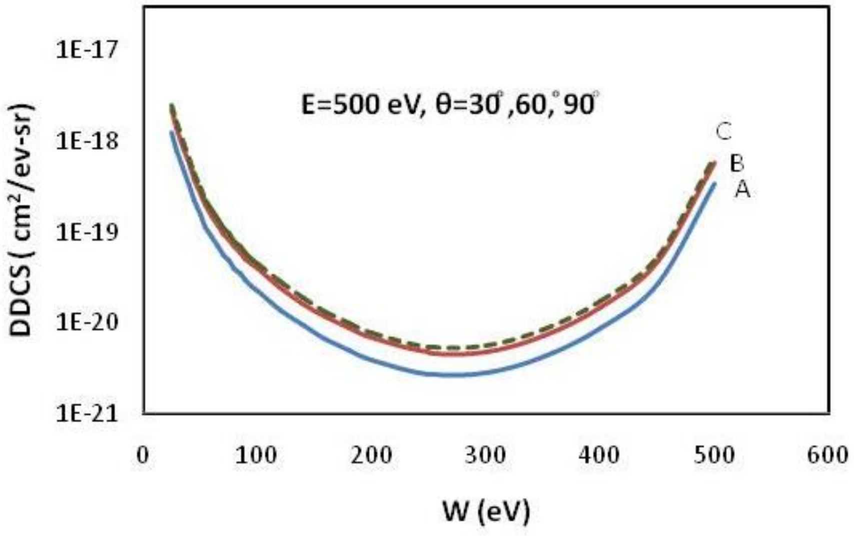

Fig.7: DDCS of Neon at fixed incident electron energy 500 eV with fixed incident angle A, 30°; B, 60°; C, 90°.

We have also determined the angular behavior of DDCS at fixed incident electron energies 100, 200, and 500 eV with fixed secondary electron energies 10 eV and 20 eV by altering scattering angle from 0° to 180° are also given in figure 8-10 and tabulated in table 6.

Table 6: Double differential ionization cross-section of Neon at E=100 eV, 200 eV and 500 eV with respect to angle θ at constant secondary electron energy ε=10 eV and 20 eV.

Angle θ	E=100 eV		E=200 eV		E=500 eV	
	ε=10 eV	ε=20 eV	ε=10 eV	ε=20 eV	ε=10 eV	ε=20 eV
20	8.22E-19	2.89E-19	7.31E-19	2.87E-19	4.59E-19	1.88E-19
30	1.2E-18	4.22E-19	1.07E-18	4.2E-19	6.71E-19	2.75E-19
40	1.54E-18	5.43E-19	1.37E-18	5.4E-19	8.63E-19	3.54E-19
50	1.84E-18	6.47E-19	1.64E-18	6.43E-19	1.03E-18	4.22E-19
60	2.08E-18	7.32E-19	1.85E-18	7.27E-19	1.16E-18	4.77E-19
70	2.26E-18	7.94E-19	2.01E-18	7.89E-19	1.26E-18	5.17E-19
80	2.37E-18	8.32E-19	2.1E-18	8.27E-19	1.32E-18	5.42E-19
90	2.4E-18	8.45E-19	2.14E-18	8.4E-19	1.34E-18	5.5E-19
100	2.37E-18	8.32E-19	2.1E-18	8.27E-19	1.32E-18	5.42E-19
110	2.26E-18	7.94E-19	2.01E-18	7.89E-19	1.26E-18	5.17E-19
120	2.08E-18	7.32E-19	1.85E-18	7.27E-19	1.16E-18	4.77E-19
130	1.84E-18	6.47E-19	1.64E-18	6.43E-19	1.03E-18	4.22E-19
140	1.54E-18	5.43E-19	1.37E-18	5.4E-19	8.63E-19	3.54E-19
150	1.2E-18	4.22E-19	1.07E-18	4.2E-19	6.71E-19	2.75E-19
160	8.22E-19	2.89E-19	7.31E-19	2.87E-19	4.59E-19	1.88E-19

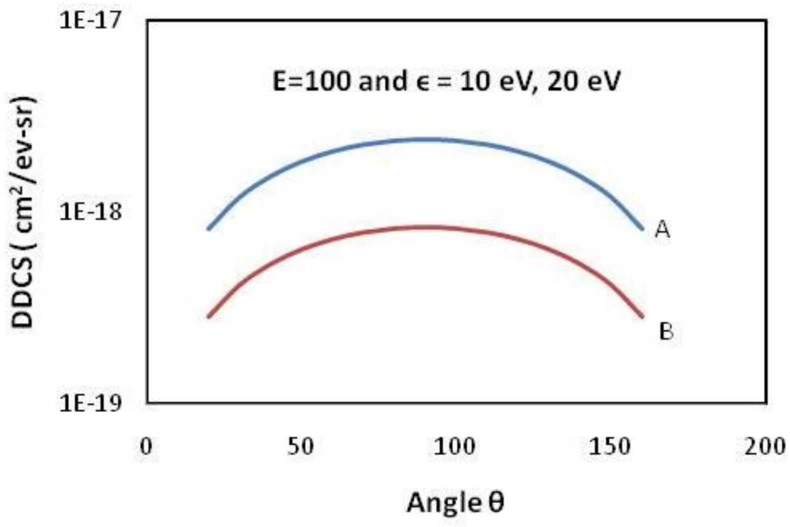

Fig.8: DDCS of Neon at fixed incident electron energy 100 eV

with fixed secondary electron energy A, 10 eV; and B, 20 eV.

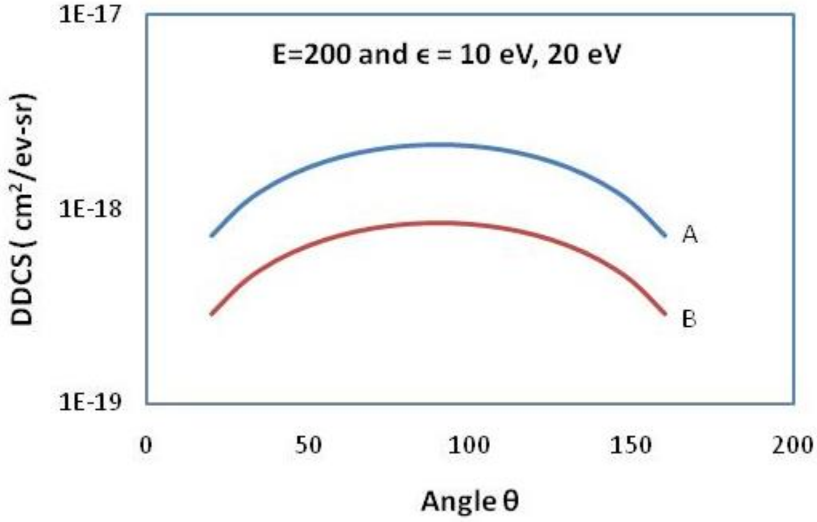

Fig.9: DDCS of Neon at fixed incident electron energy 200 eV with fixed secondary electron energy A, 10 eV; and B, 20 eV

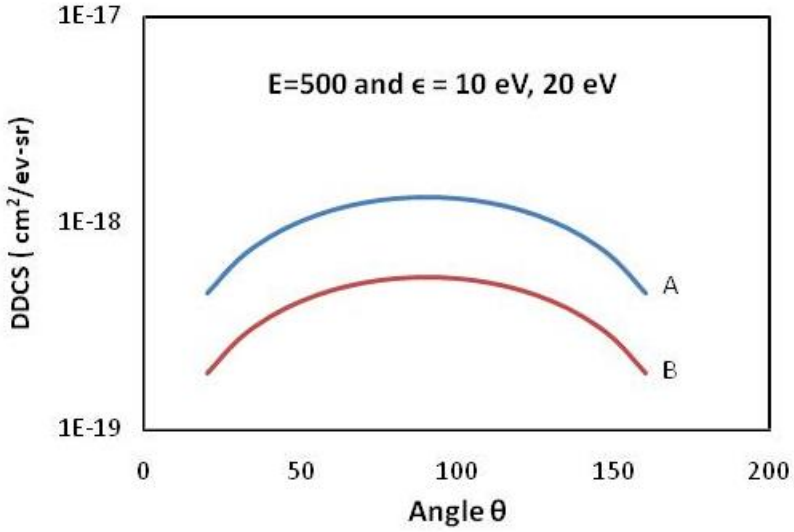

Fig.10: DDCS of Neon at fixed incident electron energy 500 eV with fixed secondary electron energy A, 10 eV; and B, 20 eV.

CONCLUSION

We have calculated the absolute total ionization cross sections of neon via modified Jain-Khare formalism and compared with available data from threshold energy to high energy [26]. Its in pleasing agreement with compared data curves. Thus, from the compared graph, we can say that the results are very reliable in strength and shape and establish that present method and developed programming can produce reliable cross sections even for complex clusters also. The SDCS are also determined as a function of secondary electron energy. Here, the DDCS is determined as a function of secondary electron energy and the incident angle of an electron at the fixed incident electron energies 100 eV, 200 eV and 500 eV, with respect to the fixed angles 30̊, 60̊ and 90̊ and also calculated the DDCS with respect to the incident electron angle 0̊ -180̊. To the best of my knowledge, no other experimental and/or theoretical data for single and double differential cross sections are available for comparison, till now. However, the qualitative behavior of the cross sections is the same as for other atoms. Thus, it is believed that the present data is reliable and could be used in the plasma process and other applications.

REFERENCES

[1]. Asundi, K. K., & Kurepa, M. V. (1963). Electronics section: Ionization cross sections in the, Ne, Ar, Kr and Xe by electron impact. *Journal of Electronics and Control*, *15*(1), 41–50. https://doi.org/10.1080/00207216308937549

[2]. Bleakney, W. (1930). Ionization potentials and probabilities for the formation of multiply charged ions in helium, neon and argon. Physical Review, 36(8), 1303–1308. https://doi.org/10.1103/PhysRev.36.1303

[3]. Nagy, P., Skutlartz, A., & Schmidt, V. (1980). Absolute ionisation cross sections for electron impact in rare gases. Journal of Physics B: Atomic and Molecular Physics, 13(6), 1249–1267. https://doi.org/10.1088/0022-3700/13/6/028

[4]. Rapp, D., & Briglia, D. D. (1965). Total cross sections for ionization and attachment in gases by electron impact. II. Negative-ion formation. The Journal of Chemical Physics, 43(5), 1480–1489. https://doi.org/10.1063/1.1696958

[5]. Bleakney, W. (1930). Ionization potentials and probabilities for the formation of multiply charged ions in helium, neon and argon. Physical Review, 36(8), 1303–1308. https://doi.org/10.1103/PhysRev.36.1303

[6]. Stuber, F. A. (1965). Multiple ionization in neon, argon, krypton, and xenon. The Journal of Chemical Physics, 42(8), 2639–2643. https://doi.org/10.1063/1.1703217

[7]. Stephan, K., Helm, H., & M, T. D. (1985). Determination of partial electron impact ionization cross sections of He , Ne , Ar and Kr from threshold up to 180 e V. 3763(1980). https://doi.org/10.1063/1.440606

[8]. Wetzel, R. C., Baiocchi, F. A., Hayes, T. R., & Freund, R. S. (1987). Absolute cross sections for electron-impact ionization of the rare-gas atoms by the fast-neutral-beam method. Physical Review A, 35(2), 559–577. https:// doi.org/ 10.1103/ PhysRevA. 35.559

[9]. Rouvellou, B., Rioual, S., & Pochat, A. (2011). Near Threshold Electron Impact Ionization of Neon and Argon. New Directions in Atomic Physics, 258, 185–189. https://doi.org/10.1007/978-1-4615-4721-1_15

[10]. Schram, B. L. (2002). Partial ionization cross sections of noble gases for electrons with energy 0.5–18 keV. Physica, 32(1), 197–208. https://doi.org/10.1016/0031-8914 (66)90116-9

[11]. Kheifets, A. S., Naja, A., Casagrande, E. M. S., & Lahmam-Bennani, A. (2008). DWBA-G calculations of electron impact ionization of noble gas atoms. Journal of Physics B: Atomic, Molecular and Optical Physics, 41(14), 145201. https:// doi.org/ 10.1088/0953-4075/41/14/145201

[12]. Rejoub, R., Lindsay, B. G., & Stebbings, R. F. (2002). Determination of the absolute partial and total cross sections for electron-impact ionization of the rare gases. Physical Review A, 65(4), 042713. https://doi.org/10.1103/PhysRevA.65.042713

[13]. Montanari, C. C., & Miraglia, J. E. (n.d.). Antiproton , proton and electron impact multiple ionization of rare gases. 105201. https://doi.org/10.1088/0953-4075/45/10/ 105201

[14]. Jones, A. C. L., Makochekanwa, C., Caradonna, P., Slaughter, D. S., MacHacek, J. R., McEachran, R. P., Fursa, D. V. (2011). Positron scattering from neon and argon. Physical Review A - Atomic, Molecular, and Optical Physics. https://doi.org/ 10.1103 /PhysRevA.83.032701

[15]. Straub, H. C., Renault, P., Lindsay, B. G., Smith, K. A., & Stebbings, R. F. (1996).

[16]. Tozer, B. A., & Craggs, J. D. (1960). Cross sections for ionization of the inert gases by electron impact. Journal of Electronics and Control, 8(2), 103–109. https://doi.org/ 10.1080/00207216008937257

[17]. Tiwari, N., & Tomar, S. (2011). K-shell ionization cross sections of light atoms due to electron impact 1 Introduction, 2(2), 109–116.

[18]. Sharma, R., Sharma, S. P., & Kumari, N. (2017). Electron Impact Ionization Cross Section-Semi-empirical approach : 36(2), 45–53. https://doi.org/10.5958/2320-320X. 2017.00006.1

[19]. S P Khare and B D Padalia (1970), H., Journals, C., Contact, A., Top science, M., & Address, I. P. (n.d.). Total ionization cross sections of He, N, H, and 0, 1073.

[20]. Kumar Rajeev Electron Ionization Cross Sections of PF3 Atom. Journal of Applied Mathematics and Physics Journal of Applied mathematics and Physics, 3(3), 1671–1678. https://doi.org/10.4236/jamp.2015.312192

[21]. Khare, S. P., & Meath, W. J. (1987). Cross sections for the direct and dissociative ionization of NH3, H2O, and H2S by electron impact. Journal of Physics B: Atomic and Molecular Physics, 20(9), 2101–2116. https://doi.org/10.1088/0022-3700/ 20/9/021

[22]. Chan, W. F., Cooper, G., Guo, X., & Brion, C. E. (1992).

[23]. G.D. Zeiss, W.J. Meath, J.C.F. MacDonald, D.J. Dawson, Can. J. Phys. 55 (1977) 2080

[24]. Double differential cross sections of ethane molecule R Kumar AIP Conference Proceedings 1953 (1), 140039, 2018

[25]. Zhang, Y.-Z., & Zhou, Y.-J. (2013). Ionization cross sections for electron scattering from metastable rare-gas atoms (Ne and Ar). Chinese Physics B, 22(7), 073402. https://doi.org/10.1088/1674-1056/22/7/073402

[26]. Bartlett, P. L., & Stelbovics, A. T. (2004). Electron-impact ionization cross sections for elements Z ¼ 1 to Z ¼ 54 q, 86, 235–5.https://doi.org/10.1016/j.adt.2003.11.006.

[27]. Satyendra Pal, Manoj Kumar, Rajbeer Singh, Neeraj Kumar. "Evaluation of Electron-Impact Ionization Cross Sections for Molecules", The Journal of Physical Chemistry A, 2019

[28]. Sharma, R., & Kumari, N. (2019). Electron-Impact Ionization Cross Section, 6(2), 339–344

[29]. Evaluation of electron ionization cross-sections of methyl halides R Kumar, S Pal Rapid Communications in Mass Spectrometry 27 (1), 223-237, 2013