Born-Bethe approximation to study the process of excitation atoms by electron impact

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Abstract

In this paper, Born-Bethe approximation had been used to calculate the generalized oscillator strength (GOS) and cross sections (CS's) in terms of the diploe oscillator strength (OS) for electron impact excitation of some atoms of inert gases such as He, Ne, Ar. Since the cross section depend in its formula on the GOS, it appears to us that the CS's of He were more accurate than those of Ne & Ar atoms when we made a comparison with the experimental data, since the GOS of He was better in delicacy than Ne & Ar atoms .

Keywords: excitation; cross section; generalized oscillator strength; inert gases; electron impact; Born-Bethe approximation.

1- Introduction

A tremendous importance is appear in the study of electrons collision with atomic and ionic targets when we made modelling processes for astrophysics, plasma and also in many industrial applications [1,2]. In the field of radiation the collision of electrons with atoms happens with two processes by excitations and de-excitations. The determination of matter's state can be done by calculating the collision cross sections in the area of radiation. The structure of gas clouds, galaxies and stars in turn can be studied using those calculated data of scattering cross sections which is relevant to the study of spectroscopy [3].

The inelastic scattering of electrons with inert gases represented by the excitation process has many applications in many fields, for instance the nuclear fusion controlling and gaseous electronics in plasma [4].

Emissions from level of optical plasma from inert gases can be useful in diagnosing the parameters of plasma such as distribution function of electrons energy and the temperature of electrons [5-8]. Lines of spectra emitted from inert gases also can be useful to examining the properties of plasma in a technique called trace emission spectroscopy for rare gases TRG-OES [9-11].

The most important issues in the theoretical and experimental studies of electron collision with atomic targets like rare gases are the generalized oscillator strength [12-14] and the integral cross sections [15, 16].

The processes of excitation could be grouped according to the potential of interaction which is responsible for the transitions and also it can be grouped according to the multipole moment. The excitation of electron-atom interaction including the following processes: dipole transitions, quadrupole transitions, magnetic dipole transitions and exchange scattering. The dipole transitions are concerned with the allowed transitions, whereas the other processes are concerned with the forbidden ones.

In this paper we applied Born-Bethe approximation to study excitation of some inert atoms by electron impact. We use ground and excited wave function of slater type to represent the orbital atomic levels [17].

2-Theory

The simplest approximation in collisions for poorly reacted electron with targets like atom is the first Born approximation. The integrated Born cross section is given by[18]

$$\sigma_n^B = \frac{4\pi a_0^2}{T/R}\,\frac{R}{E_n}\int_{\ln(K_{min}a_0)^2}^{\ln(K_{max}a_0)^2} f_n(K)\,d(\ln(Ka_0)^2) \quad \ldots(1)$$

Where $f_n(K)$ the generalized oscillator strength is can be written as

$$f_n(K) = \frac{E_n}{R}\,\frac{\left|\left\langle \Psi_n \middle| \sum_j e^{i\vec{K}.\vec{r}_j} \middle| \Psi_0 \right\rangle\right|^2}{(Ka_0)^2} \quad \ldots(2)$$

T is the incident energy of electron, E_n excitation energy, R Rydeberg Energy and k_{min}, k_{max} minimum and maximum momentum transfer.

To ensure that Bethe approximation have proper behavior at energies we need Born approximation to be highly reliable. For different modeling studies its expression is suited well for using it in studying a specific transition for one or two optional energies [19].

Bethe cross section is the crucial part of Born approximation and it given in term two parameters A_n and B_n [20].

$$\sigma_n = \frac{4\pi a_0^2}{T/R}\left[A_n \ln\left(\frac{T}{R}\right) + B_n\right] \quad \ldots(3)$$

Where A_n and B_n Bethe coefficients are dependent only on the properties of the target and do not depend on the incident energy T or on the type of the incident particle. Defined by

$$A_n = f_n \, {}^{R}/_{E_n} \qquad \ldots(4)$$

$$B_n = A_n \ \ln \frac{4R^2 Q_0}{E_n^2} \qquad \ldots(5)$$

Where f_n is the optical oscillator strength and Q_0 is the cutoff parameter.

3- Results and Discussion

a- Generalized Oscillator Strength

We begin the discussion of our results with generalized oscillator strength of rare gases, which is one of the most studied processes, both theoretically and experimentally. The generalized oscillator strength for helium atom is given in Fig. 1, our predictions were compared with theoretical data of Kim & Inokuti [21]. A comparison of generalized oscillator strength of neon atom is presented in Fig. 2,with the results of Chenge et.al [22]. Finally the generalized oscillator strength for Argon atom is given in Fig.3, a comparison have been made with the results of Zhu et.al[23].

In general the agreement in the three figures were good and we notice that GOS for He was better in agreement with the compared data than Ne and Ar, which means that the wave function of the excited orbital was more accurate than the other two atoms in the transitions under investigation .

b- Cross Section

As we mentioned before that the oscillator strength is the principal factor used in predicting the cross sections of excitation process for electrons collide in-elastically with atoms. In Fig. 4 the cross section of the Helium atom is presented where our predictions has been compared with the experimental data of Westerveld et.al & Shemansky et.al [24,25] and the theoretical data of Kim [26]. In Fig. 5 our results of excitation cross section for Neon atom which compared with theoretical results of Philips et.al [27].finally the excitation cross section of Argon atom is presented in Fig.8, which compared with the experimental data of Schappe et.al [28] and the theoretical data of Madison et.al [29].

In general the He atom cross section in Fig.4 showed a very good agreement with the experimental data and theory as well, this matching put down the good results of GOS data. Whereas the excitation cross section for Ne & Ar atoms in Figures 5 & 6 its agreement with data had compared with was reliable, and this is because of the modest results of its GOS.

4-Conclusions

In this paper we use Born-Bethe approximation to calculate the excitation cross sections in term of electron impact energy. We have made a reliable comparison with other theories and experimental measurement, and we noticed that our method was very effective at many energy ranges of the cross section and modest at others, but we need more recent data to ensure that efficiency which is not available at now.

It is clear that we had included the dipole transition process only in this study among the four processes mentioned previously which in turn maybe effect on the agreement for the calculated parameters and cross section we had made in comparson with other researchers data.

Table I: The calculated oscillator strength

Atom	Transition	Oscillator Strength
Helium	$1s^2$-1s3p	0.07843
Neon	$2P^6$-$2P^5$3S(3/2)	0.0119
Argon	$3P^6$-$3P^5$4S(3/2)	0.0663

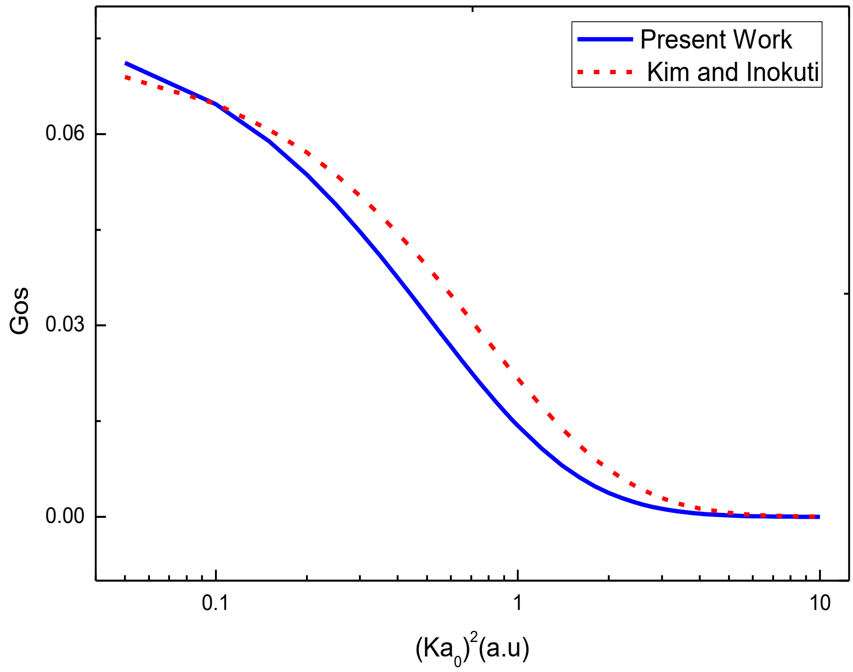

Fig. 1 Generalized oscillator strength of Helium atom for transition $1s^2$-1s3p

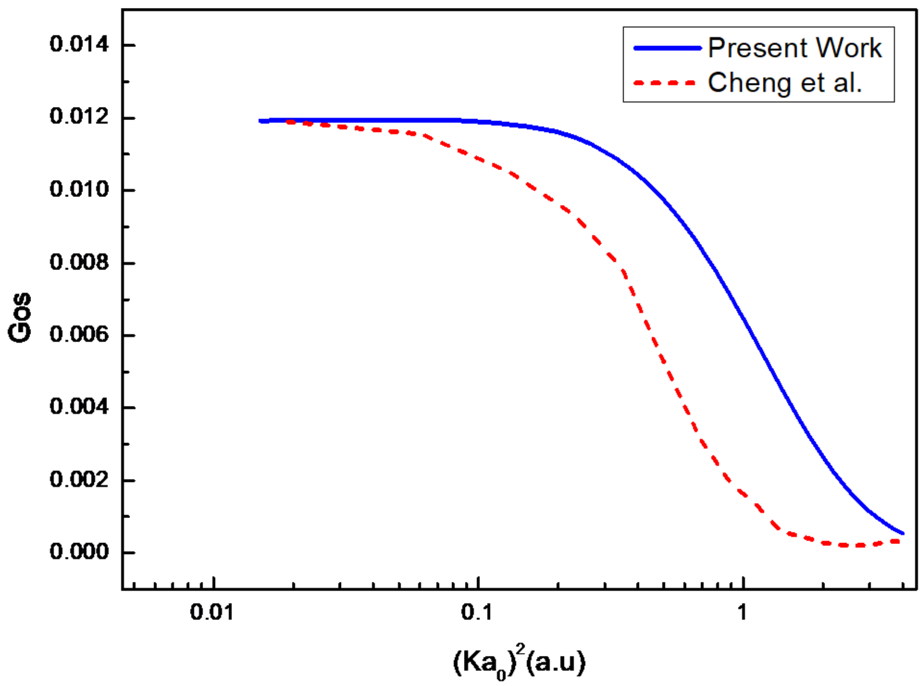

Fig. 2 Generalized oscillator strength of Neon atom for transition $2p^6$-$2P^5 3s(3/2)$

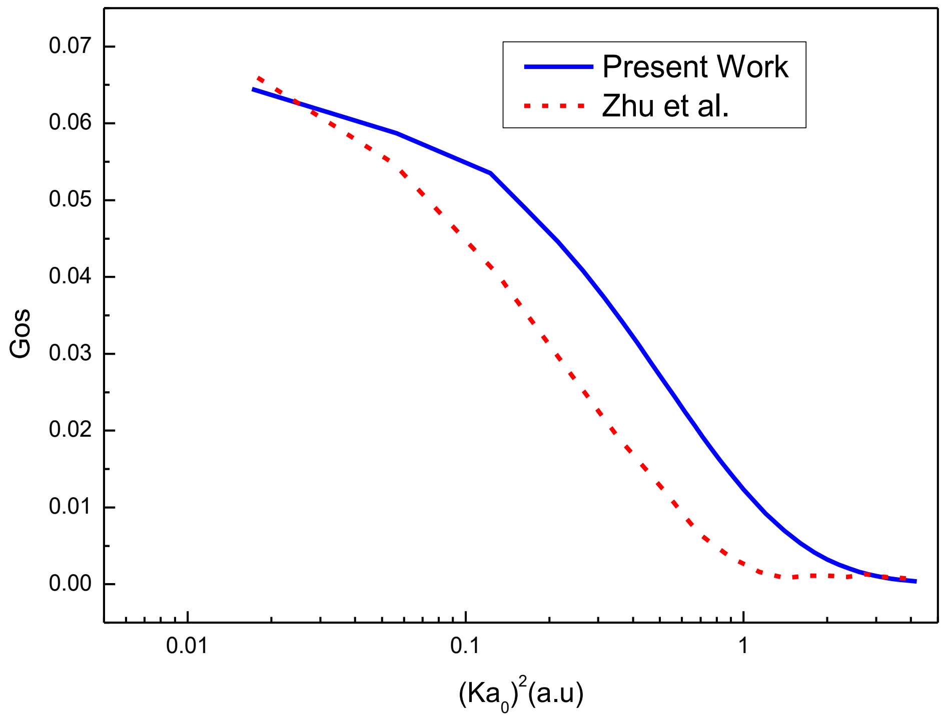

Fig. 3 Generalized oscillator strength of Argon atom for transition $3p^6$-$3P^5 4s(3/2)$

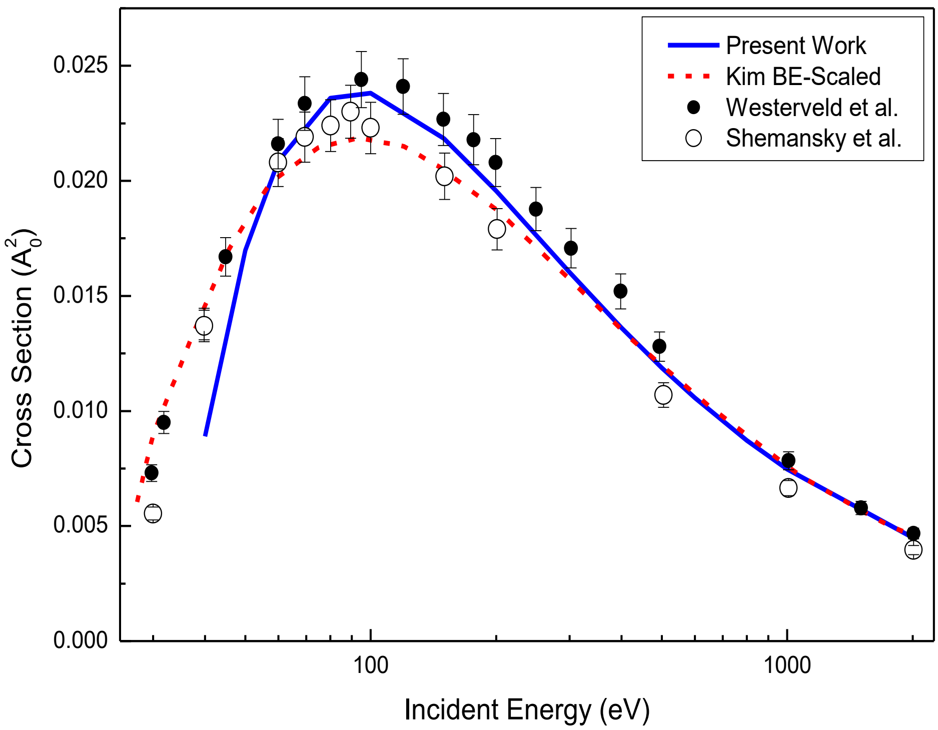

Fig. 4 Cross Section of Helium atom for transition $1s^2$-$1s3p$

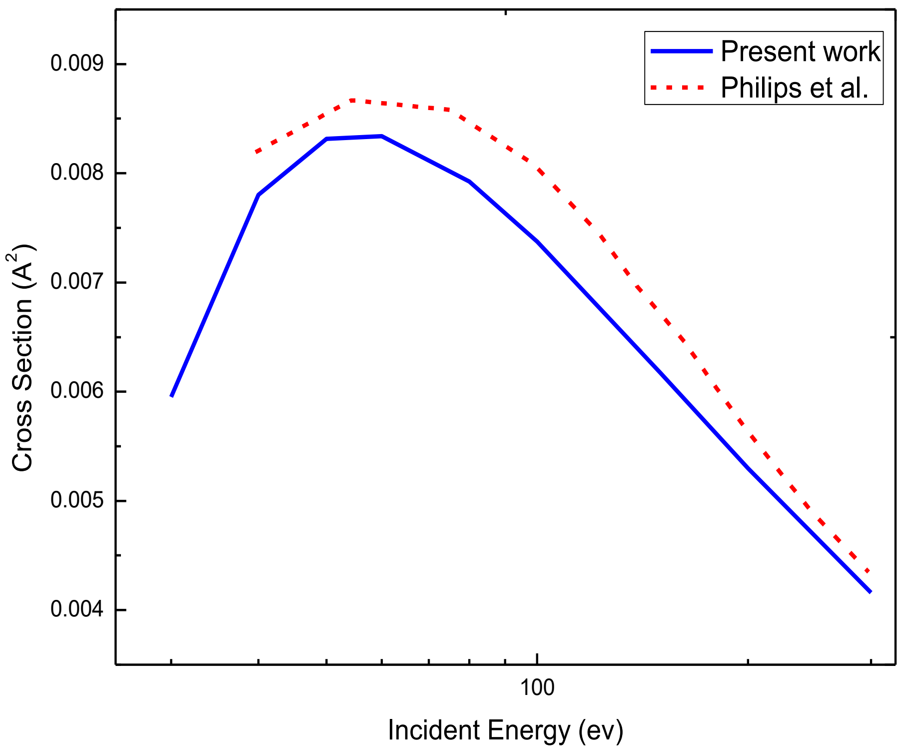

Fig. 5 Cross Section of Neon atom for transition $2p^6$-$2P^5 3s(3/2)$

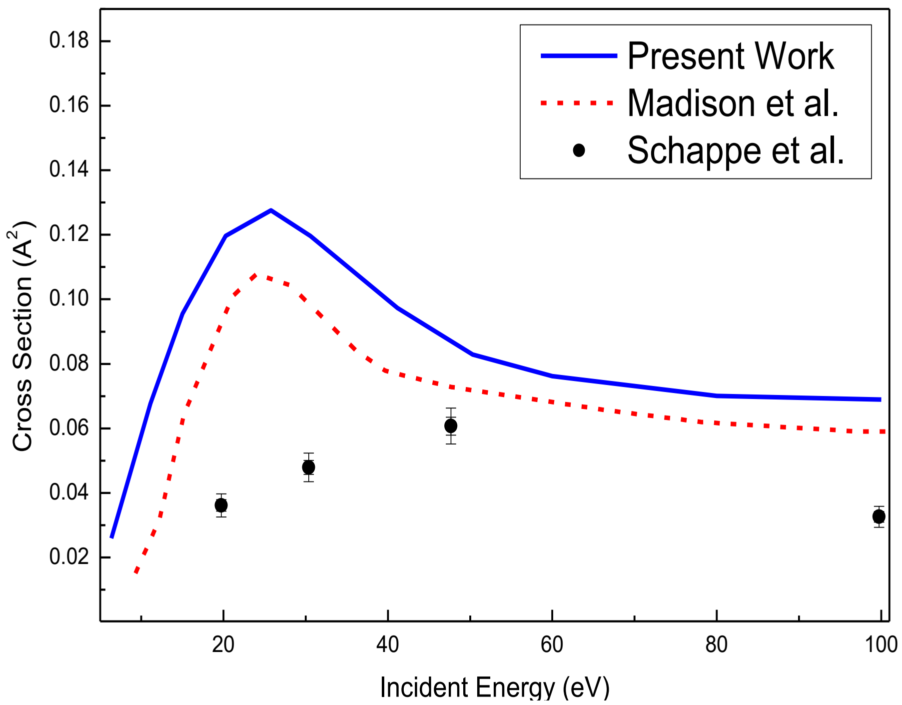

Fig. 6 Cross Section of Argon atom for transition $3p^6$-$3P^5 4s(3/2)$

5- References

[1].J B Boffard, C C Lin, and C A DeJoseph Jr, Application of excitation cross sections to optical plasma diagnostics. Journal of Physics D: Applied Physics,. 37(12) (2004), R143-R161.

[2].E Gargioni, and B Grosswendt, Electron scattering from argon: Data evaluation and consistency. Reviews of Modern Physics, 80(2) (2008) 451-480.

[3].O Zatsarinny, H Parker, and K Bartschat, Electron-impact excitation and ionization of atomic calcium at intermediate energies. Physical Review A,. 99(1) (2019) 012706(9).

[4].C P Ballance , and D C Griffin, Electron-impact excitation of neon: a pseudo-state convergence study. Journal of Physics B: Atomic, Molecular and Optical Physics, 37(14) (2004) 2943-2957.

[5].R K Gangwar, L Sharma, R Srivastava, and A D Stauffer., Electron-impact excitation of krypton: Cross sections of interest in plasma modeling. Physical Review A, 82(3) (2010). 032710(6).

[6]. Z Navrátil1, P Dvořák1, O Brzobohatý2 and D Trunec, Determination of electron density and temperature in a capacitively coupled RF discharge in neon by OES complemented with a CR model. Journal of Physics D: Applied Physics,. 43(50) (2010) 505203(11).

[7]. Z Navrátil, D Trunec, V Hrachová and A Kanka, Collisional–radiative model of neon discharge: determination of E/N in the positive column of low pressure discharge. Journal of Physics D: Applied Physics,. 40(4) (2007) 1037-1046.

[8]. Dirk Dodt, Andreas Dinklage, Rainer Fischer, Klaus Bartschat, Oleg Zatsarinny and Detlef Loffhagen, Reconstruction of an electron energy distribution function using integrated data analysis. Journal of Physics D: Applied Physics,. 41(20) (2008), 205207(13).

[9].Samukawa, S., Development of high-density plasma reactor for high-performance processing and future prospects. Applied surface science,. 192(1-4) (2002), 216-243.

[10].Donnelly, V., Plasma electron temperatures and electron energy distributions measured by trace rare gases optical emission spectroscopy. Journal of Physics D: Applied Physics , 37(19)(2004) R217-R236.

[11]. R O Junga, Garrett A Piechb, M. L. Keelerc, John B Boffardd, L W Anderson, and Chun C Lin, Electron-impact excitation cross sections into Ne(2p53p) levels for plasma applications. Journal of Applied Physics,. 109 (12) (2011), 123303(8).

[12]. Lin-Fan Zhu, Hui Yuan, Wei-Chun Jiang, Fang-Xin Zhang, Zhen-Sheng Yuan, Hua-Dong Cheng, and Ke-Zun Xu, Generalized oscillator strengths for some higher valence-shell excitations of argon. Physical Review A,. 75(3) (2007), 032701(1).

[13]. Zhu Lin-Fan, Zhang Fang-Xin, Cheng Hua-Dong, Yuan Hui, Yuan Zhen-Sheng, Li Wen-Bin, Liu Xiao-Jing, Generalized oscillator strengths for some higher valence-shell excitations of krypton atom. Chinese Physics,. 16(10) (2007) 2063-2067.

[14].Z Chen, and A Z Msezane, Minima and maxima in generalized oscillator strengths of Ne, Kr and Xe. Journal of Physics B: Atomic, Molecular and Optical Physics,. 33(23): (2000) 5397-5402.

[15]. John B Boffard, M L Keeler, Garrett A Piech, L W Anderson, and Chun C Lin, Measurement of electron-impact excitation cross sections out of the neon 3 P^{2} metastable level. Physical Review A,. 64(3) (2001), 032708(10).

[16].A Mityureva, and V Smirnov, Electron impact excitation with the cascade population of the 4p 5 5s levels of the krypton atom. Optics and Spectroscopy,. 121(6) (2016), 804-809.

[17].J Snijders,, P Vernooijs, and E Baerends, Roothaan-Hartree-Fock-Slater atomic wave functions: single-zeta, double-zeta, and extended Slater-type basis sets for 87Fr-103Lr. Atomic Data and Nuclear Data Tables,. 26(6) (1981), 483-509.

[18].Y KKim, "Theory of electron-atom collisions", in: Physics of ion-ion and electron-ion collisions. F. Brouillard and J.W. McGowan (eds.), Plenum press, New York (1983) 101-165.

[19].Y K Kim, and K-t Cheng, Beth cross sections for the sodium isoelectronic sequence. Physical Review A,. 18(1) (1978), 36-47.

[20].Y K Kim, J P Santos, and F Parente, Extension of the binary-encounter-dipole model to relativistic incident electrons. Physical Review A,. 62(5) (2000), 052710(14).

[21].Y K Kim, and M Inokuti, Generalized oscillator strengths of the helium atom .I. Physical Review,. 175(1) (1968), 176-188.

[22].Hua-Dong Cheng, Lin-Fan Zhu, Zhen-Sheng Yuan, Xiao-Jing Liu, Jian-Min Sun, Wei-Chun Jiang, and Ke-Zun Xu. Generalized oscillator strengths for the valence-shell excitations of neon. Physical Review A, , 72 (2005), 012715(7).

[23]. Lin-Fan Zhu, Hua-Dong Cheng, Zhen-Sheng Yuan, Xiao-Jing Liu, Jian-Min Sun, and Ke-Zun Xu., Generalized oscillator strengths for the valence-shell excitations of argon. Physical Review A, 73(4) (2006), 042703(9).

[24].W Westerveld, H Heideman, and J. Van Eck, Electron impact excitation of 11S→ 21P and $1^1S \rightarrow 3^1P$ of helium: excitation cross sections and polarisation fractions obtained from XUV radiation. Journal of Physics B: Atomic and Molecular Physics,. 12(1) (1979), 115-135.

[25]. D E Shemansky, D T Hall,J M Ajello, & B Franklin, Vacuum ultraviolet studies of electron impact of helium Excitation of He n1P0 Rydberg series and ionization-excitation of He (+) nl Rydberg series. The Astrophysical Journal,. 296 (1985) 774-783.

[26]Y K Kim, Scaling of plane-wave Born cross sections for electron-impact excitation of neutral atoms. Physical Review A,. 64(3) (2001) 032713(10).

[27].M H Phillips, L Anderson, and C C Lin, Electron excitation cross sections for the metastable and resonant levels of Ne ($2p^5 3s$). Physical Review A,. 32(4) (1985) 2117-2127.

[28]. R Scott Schappe, M Bruce Schulman, L W Anderson, and Chun C Lin, Measurements of cross sections for electron-impact excitation into the metastable levels of argon and number densities of metastable argon atoms. Physical Review A, 50(1) (1994), 444-461.

[29] D. H. Madison, C M Maloney, and J B Wang, Integral and differential cross section for electron-impact excitation of 12 of the lowest states of argon. Journal of Physics B: Atomic, Molecular and Optical Physics,. 31(4) 1998,873-893.

تقريب Born- Bethe لدراسة عملية أثارة الذرات بواسطة الالكترونات

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الخلاصة

في هذا العمل, تم استخدام تقريب Born-Bethe في حساب قوة المذبذب المعمم والمقاطع العرضية بأستخدام قوة المذبذب ثنائي القطب للاثارة بتأثير الالكترون لبعض ذرات الغازات الخاملة مثل الهيليوم والنيون والارجون. وحيث ان المقاطع العرضية تعتمد في صيغتها الرياضية على المذبذب التوافقي المعمم فقد ظهر لنا ان مقاطع ذرة الهليوم كانت اكثر دقة من حيث التوافق من تلك التي لذرتي النيون والآركون عند المقارنة مع القراءات العملية وذلك تبعا لكون المذبذب المعمم لذرة العليوم كانت اكثر دقة منها لذرتي النيون والآركون.