CALCULATION OF THE IONIZATION CROSS SECTIONS FOR ION – ATOM COLLISION BY USING THE CDW-EIS MODEL.

Aileen **Y**owaresh **E**you[1] And **B**adal **H**aydar **E**lias[2]
[1] Physics Dept., Faculty of Science, University of Duhok, Kurdistan - Region, Iraq.
[2] Physics Dept., Faculty of Science, University of Duhok, Kurdistan - Region, Iraq.
(Accepted for publication: June 9, 2013)

Abstract

In this paper we calculate total cross sections for proton and alpha particle-impact ionization of neutral atoms H , He, Ne and Ar for the energies ranging from 10keV to 10MeV.Also, we calculate theoretical singly, doubly differential ionization cross sections in collisions between proton particle and helium atoms at different impact energies. The provided theoretical model for the program user is based on quantum mechanical approximations which have proved to be very successful in the study of ionization in ion–atom collisions. is on continuum distorted-wave eikonal-initial-state (CDW-EIS) approximation. The results are in reasonable agreement with available experimental data.

1-Introduction

Ionization cross sections is a measure of the probability that gives ionization process occurs when an atom or molecule interacts with an electron, ion and photon. Knowledge of ion-atom ionization cross sections is of great importance for many accelerator applications. In this paper, we investigate theoretically the ionization cross-sections due to fast ion impact for selected target atoms such as (H, He, Ne and Ar) by using the continuum distorted wave-eikonal initial state (CDW-EIS) model.

One of the main features of the model is that the long range coulomb interaction is taken into account. Due to the continuum distortion, the electron is described as moving in the combined field of the projectile and the target which is referred to as two–center effects (TCE). Indeed in our analytical approximation the initial bound state wavefunction is represented by Roothan-Hartree-Fock wavefunctions. The continuum state, on the other hand, is described by a hydrogenic wavefunction with an effective charge chosen from the energy of the initial bound state. The scattering amplitude, considered here, is obtained in closed analytical form.

A computer code (ADMF) proposed by O̓Rourke et al., (2000), is based upon the published codes of (ADSE) by McSherry et al., (2003), and (ADJI) by Nesbitt et al. (1998), were used in present work. All of these codes calculate total, single and double differential cross sections for the single ionization of atoms light or heavy ion impact where the projectile ions are assumed to be structureless. (ADSE) extends the range of the target that can be considered allowing atoms up to and including argon to be examined.

Theoretical Description of the CDW-EIS Model

We restrict our discussion to the process of single ionization by charged particle impact for neutral target atoms (H, He, Ne, and Ar). Our analysis is within the semiclassical rectilinear impact parameter (ρ), and time-dependent (t) formalism. This is depicted in figure (I). We consider the problem of three charged particles where an ion of nuclear charge Z_P and mass M_p impinges with a collision velocity v on a neutral target atom with nuclear charge Z_T and mass M_p will be considered (Whelan, Mason, 2005 and Crothers 2008)

As $M_{T,\,P} >> 1$, the motion of the nuclei can be uncoupled from that of the electron(McDowell and Coleman, 1970) .The trajectory of the projectile is then characterized by two parameters $\boldsymbol{\rho}$ and the impact velocity $\mathbf{v}$ such that $\boldsymbol{\rho}\,.\,\mathbf{v}=0$. The internuclear coordinate is defined by:

$$\mathbf{R}=\mathbf{r}_T-\mathbf{r}_P=\boldsymbol{\rho}+\mathbf{v}t \qquad (1)$$

and

$$\mathbf{r}=\frac{1}{2}(\mathbf{r}_T+\mathbf{r}_P) \qquad (2)$$

Where $\mathbf{r}_T, \mathbf{r}_P$, and $\mathbf{r}$ are the position vectors of the electron relative to the target nucleus, projectile nucleus, and their midpoint, respectively.

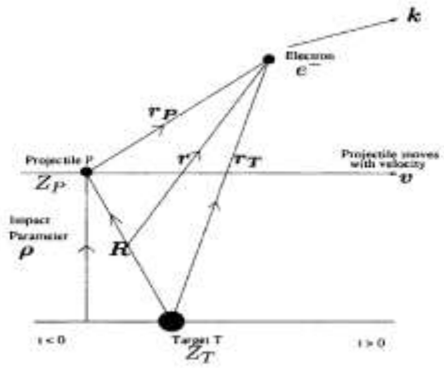

Figure (I) The coordinate system for the three body problem. Here a projectile traveling with velocity $\boldsymbol{\upsilon}$ impinges upon the electron-target subsystem. $\mathbf{R}$ is the internuclear separation and $\boldsymbol{\rho}$ is the impact parameter. In general, the vectors $\mathbf{r}_T, \mathbf{r}_P$ and r do not lie in the same plane as $\boldsymbol{\rho}$, $\mathbf{R}$ and $\boldsymbol{\upsilon}$ (Whelan and Mason, 2005).

We assume that each electron is ionized independently of the others that are assumed to be frozen during the collision. So we solve, in the impact parameter approximation, a one-electron problem defined through the electronic Hamiltonian:

$$H_{el} = T_{el} + V_T(r_T) + V_P(r_P) \tag{3}$$

$$H_{el} = -\frac{1}{2}\nabla_r^2 - \frac{Z_T}{r_T} - \frac{Z_P}{r_P} \tag{4}$$

where T_{el} is the electron kinetic energy operator, $V_T(r_T)$ the Hartree – Fock potential of the target and $V_P(r_P)$ the Coulomb interaction with the projectile, the internuclear potential have been removed by a phase transformation (Bransden and McDowell, 1992). The superscripts plus and minus refer to outgoing and incoming Coulomb boundary conditions respectively. Of course χ_i^+ and χ_f^- are not exact solutions of the three-body Schrödinger equation, but in fact are the asymptotic forms of the wave functions. It should be noted that since the potentials appearing in equation (4) are pure Coulomb potentials, they continue to affect the relevant wave functions even at infinity. We adopt an independent electron model to approximate the neutral target atom, Therefore, as in any independent electron model, no explicit electron correlation in the initial state is considered. As such, the electronic Hamiltonian for the projectile/neutral target atom collision system is modified from the original monoelectronic CDW-EIS approximation. The initial target bound state is represented by a Roothan-Hartree-Fock wave function and the final target continuum by a Coulombic continuum factor with an effective charge, in which the electron residual target interaction $-Z_T / \mathbf{r}_T$ is replaced by a Coulombic potential with an effective charge $-\hat{Z}_T$. We do this as (Belkic et al., 1979) by making the assumption that the emitted electron, which is ionized from an orbital of Roothan-Hartree-Fock energy ε_i, moves in a residual target potential of the form:

$$\boldsymbol{V}_T(\mathbf{r}_T) = -\frac{\tilde{Z}_T}{\mathbf{r}_T} \tag{5}$$

The effective target charge is given by (Prigogine, Rice, 2002 and Bates, 1991):

$$\tilde{Z}_T = \sqrt{-2n^2\varepsilon_i} \tag{6}$$

Where ε_i is the binding energy of the neutral target atom, and n is the principal quantum number. The initial and final CDW-EIS wave functions are defined as (Prigogine, Rice, 2002 and Bates, 1991):

$$\left|\chi_i^+\right\rangle = \varphi_i\left(\mathbf{r}_T\right)\exp(-\frac{1}{2}i\mathbf{v}\cdot\mathbf{r} - \frac{1}{8}i\upsilon^2 t - i\varepsilon_i t)\exp(-i\nu\,\ln(\upsilon\, r_P + \mathbf{v}\cdot\mathbf{r}_P)) \tag{7}$$

$$\left|\chi_f^-\right\rangle = (2\pi)^{-3/2}N^*(\varepsilon)N^*(\zeta)\exp(i\mathbf{k}\cdot\mathbf{r}_T - \frac{1}{2}i\mathbf{v}\cdot\mathbf{r} - \frac{1}{8}i\upsilon^2 t - iE_k t)$$
$$\times\ {}_1F_1(-i\varepsilon;1;-ik\,r_T - i\mathbf{k}\cdot\mathbf{r}_T)\ {}_1F_1(-i\zeta;1;-ip\,r_p - i\mathbf{P}\cdot\mathbf{r}_p) \tag{8}$$

Here,

$$E_k = \frac{1}{2}k^2 \tag{9}$$

is the electron energy in the final continuum state. The momentum $\mathbf{p}$ of the ejected electron relative to the projectile is given by:

$$\mathbf{P} = \mathbf{k} - \mathbf{v} \qquad (10)$$

Where $\mathbf{k}$ is the momentum of the ejected electron with respect to a reference frame fixed on the target nucleus. We note that the polar axis for reference is taken along the incident beam direction so that:

$$d\mathbf{k} = k^2 dk \sin\theta d\theta d\phi \qquad (11)$$

The spherical coordinates of the ejected electron momentum $\mathbf{k}$ are k, θ, and ϕ, where $\theta = \cos^{-1}(\hat{\mathbf{k}}.\hat{\mathbf{v}})$. Because the impact velocity lies along the Z axis, $\mathbf{v} = \upsilon\,\hat{\mathbf{Z}}$. The three sommerfeld parameters are defined by

$$\varepsilon = \frac{\tilde{Z}_T}{k} \qquad (12)$$

$$\nu = \frac{Z_P}{\upsilon} \qquad (13)$$

$$\zeta = \frac{Z_P}{P} \qquad (14)$$

And

$$N(a) = \exp\left(\frac{\pi a}{2}\right)\Gamma(1 - ia) \qquad (15)$$

Represents the Coulomb density of states factor. Instead of $\tilde{a}_{if}(\boldsymbol{\rho})$, it is easier to calculate its two - dimensional Fourier transform $R_{if}(\eta)$ as a function of the transverse heavy - particle relative momentum transfer η; thus, the scattering amplitude is:

$$R_{if}(\eta) = \frac{1}{2\pi}\int d\rho \exp(i\eta.\rho)\,\tilde{a}_{if}(\rho) \qquad (16)$$

Where $\eta.\mathbf{v} = 0$. Then application of Parseval's theorem (Sneddon, 1951) gives the triple differential cross section, which can be written in the form:

$$\alpha(\mathbf{k}) = 2\pi a_0^2 \int d\eta \left|R_{if}(\eta)\right|^2 \qquad (17)$$

From the scattering amplitude $R_{if}(\eta)$ as a function of the transverse momentum η we may obtain the probability that for a certain fixed value of η, the electron initially in a bound state of the target will be emitted to a continuum state with momentum $\mathbf{k}$. The integration over ϕ gives the double differential cross section as a function of the ejected electron energy E_k and angle θ **:**

$$\frac{d^2\sigma}{dE_k d(\cos\theta)} = k\int_0^{2\pi} \alpha(\mathbf{k}) d\phi \qquad (18)$$

By further integrations over the energy or angle of the emitted electron, we obtain the single differential cross section as a function of the angle and energy of the emitted electron, respectively:

$$\frac{d\sigma}{d(\cos\theta)} = \int_0^{\infty} k^2\, dk \int_0^{2\pi} \alpha(\mathbf{k})\, d\phi \qquad (19)$$

$$\frac{d\sigma}{dE_k} = \int_0^{\pi} k \sin\theta d\theta \int_0^{2\pi} \alpha(k)\, d\phi \qquad (20)$$

Finally, the total cross section may be calculated by performing the last integration, in equation (20) over $d(\cos\theta)$ or the last integration in equation (19) over dE_k; that is, we obtain:

$$\sigma = \int_0^{\infty} kdk \int_0^{\pi} k \sin\theta d\theta \int_0^{2\pi} \alpha(k) d\phi \qquad (21)$$

CDW-EIS Scattering Amplitudes

We consider a generalization of the original CDW-EIS model, which was originally designed to calculate the single ionization from a 1s orbital for the monoelectronic case of hydrogen to consider single ionization of any multielectronic atom ranging from helium up to and including argon by charged particle impact. The scattering amplitudes considered here are obtained in a closed analytical form. The advantage of our analytical method is that the extension to multielectronic targets in the frozen core approximation is straightforward, and computation of the various cross sections is very fast. Numerical model of the CDW-EIS theory, requiring greater computational effort than the analytical model, have been considered by (Gulyas et al., 1995) using Hartree-Fock-Slater target potentials and more recently by (Gulyas et al.,2000)using target potentials obtained from the optimized potential method of Engel and Vosko ,(1993). The validity of our analytical model for the multielectronic targets lies in the description of the bound and continuum states of the target atom. The analytical form of the scattering amplitude is derived by representing the initial-target bound state by a linear combination of Slater-type orbitals. The coefficients of these expansions are obtained by using the tables of Clementi, and Roetti, (1974).The continuum states of the target atom are represented by a hydrogenic wavefunction with effective charge chosen from the energy of the initial bound state. This, of course, means that the initial and final states correspond to different potentials and, hence, are not orthogonal. Let us first consider the single ionization of the argon atom by ion impact. The electronic configuration of argon is $1s^2$ $2s^2$ $2p^6$ $3s^2$ $3p^6$. Thus, to provide a description of the target wavefunctions for all the atoms ranging from the monoelectronic case of hydrogen to the multielectronic atoms from helium to argon, we first require the post form of the CDW-EIS scattering amplitude for the $1s$, $2s$, and $3s$ orbitals in the K, L, and M shells (corresponding to the values n = 1, 2 and 3 of the principal quantum number, respectively). Secondly, we require post form of the CDW-EIS scattering amplitude for the $2p$ and $3p$ orbitals in the L and M shells (corresponding to the principal quantum numbers $n=2$ and 3, respectively). The post form of the square of the CDW-EIS scattering amplitude for the $1s$, $2s$ and $3s$ orbitals is given by this equation:

$$\left|R_{if}(\eta)\right|^2 = \frac{\left|N(\varepsilon)(\zeta)N(\nu)\right|^2}{2\pi^2\alpha^2\gamma^2\upsilon^2} Z_P^2\tilde{Z}_T^2 A \left| {}^{S}A_I \; {}_2F_1(i\nu; i\zeta; 1; \tau) \right.$$

$$\left. -i\nu \; {}^{s}A_{II} \; {}_2F_1(i\nu+1; i\zeta+1; 2; \tau) \right|^2 \qquad (22)$$

Next turning to the $2p$ and $3p$ Roothan-Hartree-Fock orbitals, the post form of the square of the CDW-EIS scattering amplitude may be given as (Prigogine, Rice, 2002 and Wilson, Toburen, 1973).

$$\left|R_{if}(\eta)\right|^2 = \frac{\left|N(\varepsilon)N(\zeta)N(\nu)\right|^2}{2\pi^2\upsilon^2\alpha^2\gamma^2} Z_p^2\tilde{Z}_T^2 A \times \left| {}^{p}A_I \; {}_2F_1(i\nu; i\zeta; 1; \tau) \right.$$

$$\left. -i\nu \; {}^{p}A_{II} \; {}_2F_1(i\nu+1; i\zeta+1; 2; \tau) \right|^2 \qquad (23)$$

Results and Discussion:

1-Total cross section (TCS)

Our calculation of the total cross section for proton-impact ionization once and helium ion once again of neutral atoms (H, He, Ne and Ar), at the intermediate to high energies, typically from 10keV/u to 10MeV /u, and we notice from figure (1) to (2) when the projectile proton impact for K-shell atoms (H, He, Ne and Ar) the curve shape are similar but the difference is only found in values where as the more the ionization energy increases, the more the cross section decreases. Where the cross section of (H) is larger than the cross section of (He) and so on, thus the cross section curve starts to increase and getting up till it reaches the optimum value and this increase is fast and after that, it starts decreasing slowly. The calculated values of cross section differ, when the projectile is the helium ion as in the same figures (1) to (4) for the atoms of shell K, where we notice that the cross section values when collided with helium ion are larger than cross section when the projectile is a proton. It is worth to mention that the helium ion charge is +2, so the more the projectile charge increases, the more the cross section increases. As for the curve shape, it is similar when the projectile is a proton.

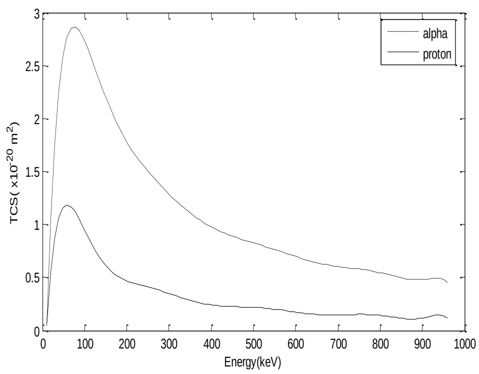

Figure (1). Total cross sections (TCS) as a function of projectile energy for collisions of alpha and proton particles with H (1s)

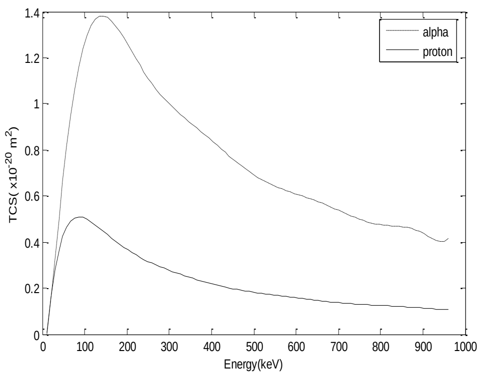

Figure (2). Total cross sections (TCS) as a function of projectile energy for collisions of alpha and proton particles with He (1s)

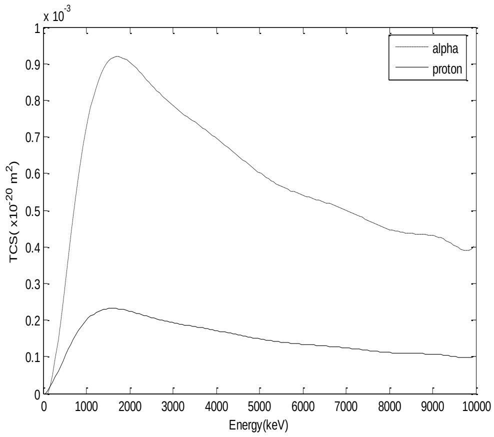

Figure (3). Total cross sections (TCS) as a function of projectile energy for collisions of alpha and proton particles with Ne (1s)

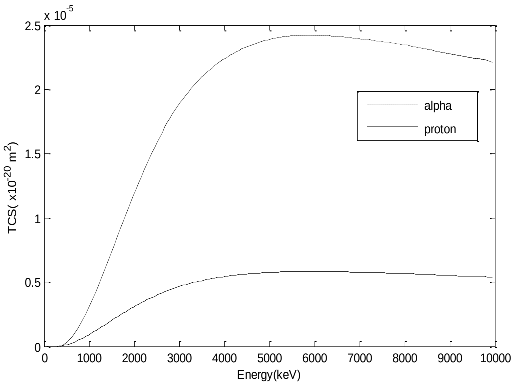

Figure (4). Total cross sections (TCS) as a function of projectile energy for collisions of alpha and proton particles with Ar (1s)

Also, the figures from (5) to (10), we show the calculated total cross sections values for ionization of (Ne) and (Ar) (L, M)-shells for impact energies between 10keV/u and 3MeV/u, our present results are compared with experimental data and we find a very good agreement. In figures from (1) to (10), we notice that the highest value of the total cross section appears when the incident particle velocity equals the electron's velocity at the target orbit ($\upsilon_p / \upsilon_e = 1$). The projectile target collision process will take a short time and the reaction time decreases as the projectile velocity increases. Therefore, the ionization cross section will decrease by increasing the projectile velocity and reverse than when $\upsilon_p < \upsilon_e$, the electron rotation around the target nucleus is too much faster than the reaction time, and the transfer momentum from the projectile to the target atom's electron, due to the electron's rotation velocity for this cross section will decrease when the projectile velocity decreases, and this is why the cross section takes the highest value when ($\upsilon_p / \upsilon_e = 1$).

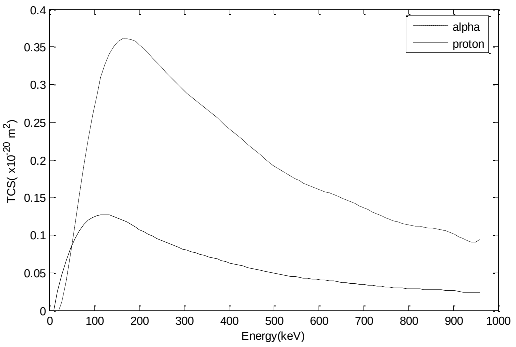

Figure (5). Total cross sections (TCS) as a function of projectile energy for collisions of alpha and proton particles with Ne (2s)

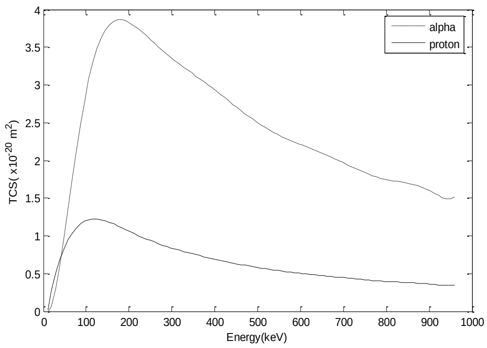

Figure (6). Total cross sections (TCS) as a function of projectile energy for collisions of alpha and proton particles with Ne (2p)

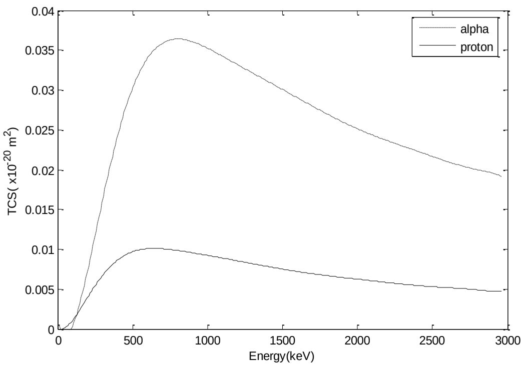

Figure (7). Total cross sections (TCS) as a function of projectile energy for collisions of alpha and proton particles with Ar (2s)

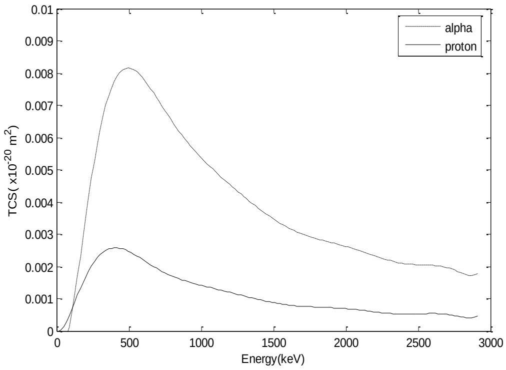

Figure (8). Total cross sections (TCS) as a function of projectile energy for collisions of alpha and proton particles with Ar (2p)

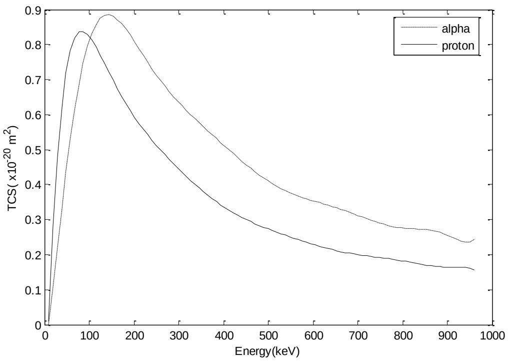

Figure (9) Total cross sections (TCS) as a function of projectile energy for collisions of alpha and proton particles with Ar (3s)

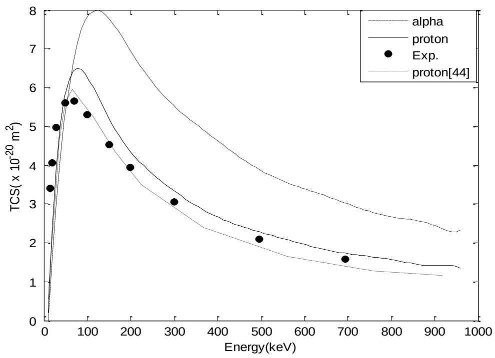

Figure (10). Total cross sections (TCS) as a function of projectile energy for collisions of alpha and proton particles with Ar (3p) compared to CDW-EIS present work. and the theoretical CDW-EIS results are taken from 1[7], Experimental data is taken from[18].

2-Doubly differential cross sections (DDCS)

In figure (11) doubly differential cross sections for electron emission in 25 MeV/u Mo^{40+} + He collisions were calculated as a function of the electron energy. The electron spectra reveal different regions which can be associated with specific electron production mechanisms as shown in figure (11). The soft collision (Sc) process which involves dipole type transitions in glancing collisions, is dominant for the emission of electrons at low energies (< 10eV). Speak of two center electron emission (TCEE) when the fields of both collision partners are significant for the ejected electron. The electron capture to the continuum (ECC), this essentially means that the electron after being ionized from the target atom moves like a continuum electron with respect to the projectile ion. Cleary, the electron velocity (υ_e) will have to be very close to the projectile velocity (υ_p) to enable them to move away together in convoy from the residual target ion. The binary encounter (BE) process, involving a two-particle collision between the incident ion and a (quasi) free electron. Also from figure(11) noted that the high incident energy is essential, since the regions due to the (sc) and (BE) processes increase in separation as the projectile energy increases.

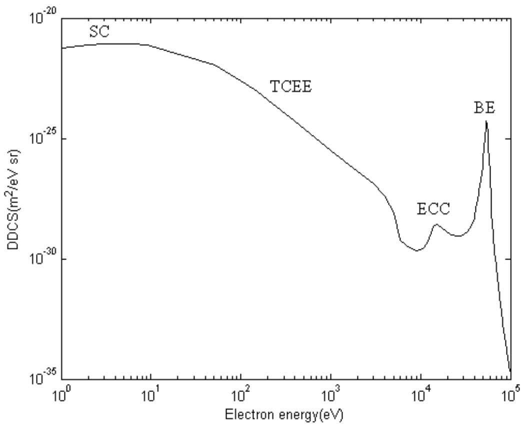

Figure (11) Doubly differential cross sections for electron emission in 25 MeV/u Mo^{40+} on He collisions at $5°$ calculated by means of the CDW-EIS theory. The labels denote soft collisions (SC); two-centre electron emission (TCEE); electron capture to continuum (ECC); and binary encounter (BE).

Figures (12) show comparisons between experimental and theoretical cross section as a function of electron emission angle for c^{6+} impact. The theoretical results are obtained using Plane-wave Born approximation (PWBA) and CDW-EIS for the present work. For all electron energies (2eV, 15eV, 150eV and 900eV), it is seen that the PWBA underestimates the experimental data at forward angles and overestimates them at backward angles. To explain these discrepancies it is recalled that the PWBA describes accurately one-center effects. The observed discrepancies can be associated with two-center effects where the projectile is likely to perturb the active electron in the final state. In contrast to the PWBA, the CDW-EIS shows good agreement with the experiment in the complete angular range and at all mentioned energies. It shows that the present theoretical CDW-EIS approach describes well the specific features of the two-center effects occurring at high projectile velocities. It is noted that the best agreement between PWBA and experimental data is observed for relatively high electron energies of 150eV and 900eV. At the energy (15eV), the binary encounter peak is deviated with respect to the PWBA results, also, figures (12) show that the peak of low-energy (2eV) electrons PWBA method is affected by an angular deviated which, in turn and produces an asymmetry of the angular distribution with respect to 90^0. For 2eV and 15eV, the CDW-EIS calculations fall above the data at small angles and at large back word angles. The excellent overall agreement is between experiment and the CDW-EIS theory. It is interesting to search for remaining discrepancies at 150eV and 900eV for the collisions of forward and backward angles.

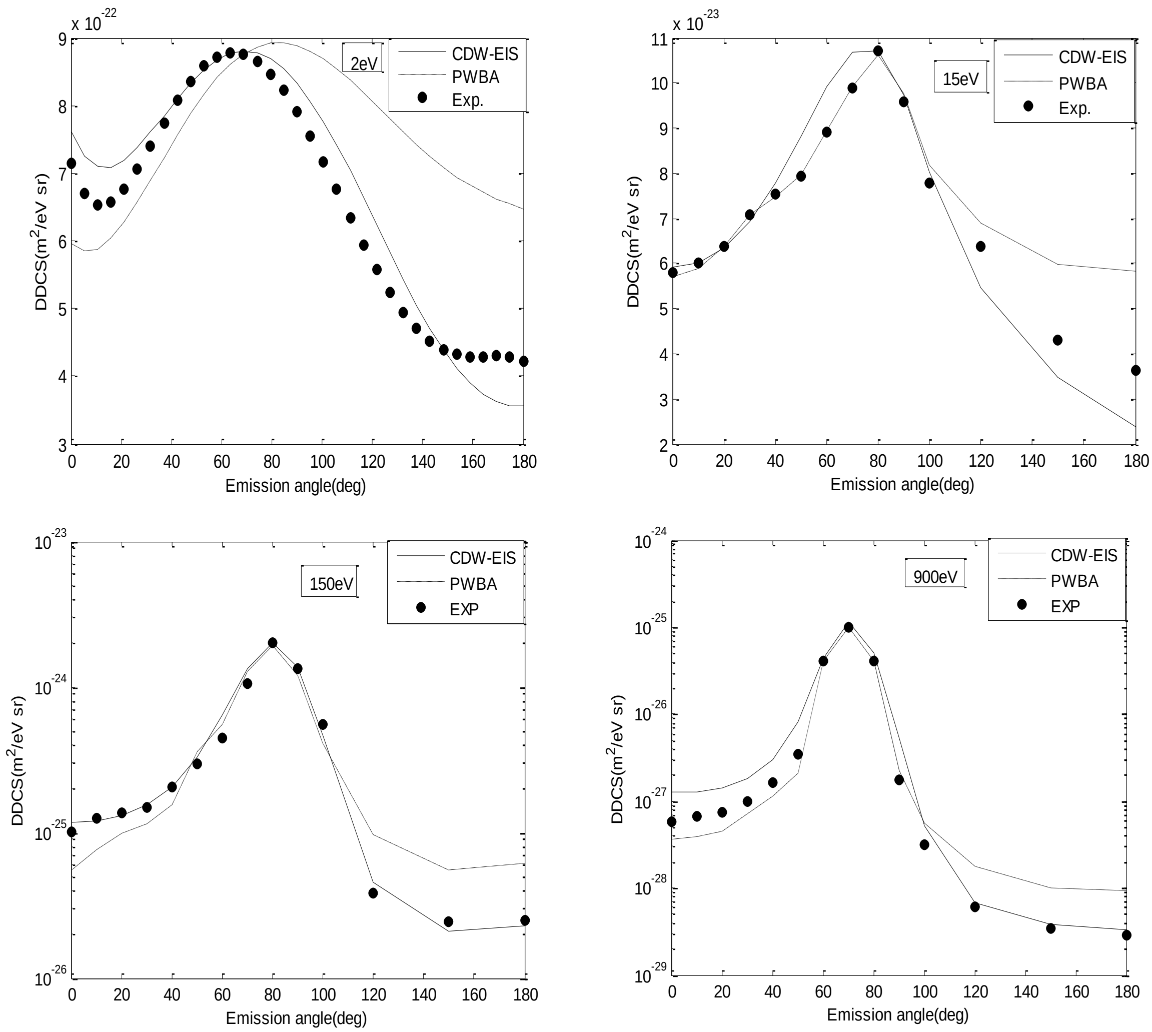

Figure (12) Double differential cross sections for electron emission in 5MeV/u c^{6+} + He(1s) collisions As a function of the electron observation angle. A few electron energies are selected as indicated. The experimental results (Wilson and Toburen, 1973) are compared with calculations using the PWBA and the CDW-EIS present work.

3-Singly Differential Cross Sections (SDCS)

Experimental data Rudd et al., (1992) are compared with the Distorted-Wave Born Approximation (DWBA) calculations described Bates, (1993) and the Classical–Trajectory Monte Carlo (CTMC) calculation Pedersen et al., (1990) at incident proton energies of 100keV, 400keV and 1MeV as shown in figure (13). At 1MeV the DWBA is in very good agreement with experimental over the entire energy range of the ejected electron. At this energy, the Classical–Trajectory Monte Carlo result is in excellent agreement with experiment for the higher electron energies but falls below the experiment for the lower energies where the cross sections are larger. The continuum-distorted-wave eikonal-initial-state (CDW-EIS) approximation in the present work falls below the experimental data. At 400keV the Classical – Trajectory Monte Carlo calculation is in excellent agreement with experiment than the DWBA. Here, the Classical – Trajectory Monte Carlo calculation is in excellent agreement with experiment over the entire secondary–electron energy range, while the DWBA is, somewhat, too large for low electron energies. The continuum-distorted-wave eikonal- initial - state (CDW-EIS) approximation in the present work falls below the experimental data. At the lowest incident energy considered, 100keV, the DWBA is; again, in somewhat in better agreement with experiment than the Classical–Trajectory Monte Carlo approach. The continuum distorted wave-eikonal initial state (CDW-EIS) approximation in the present work is in good agreement with the experiment data for low electron energy < 10eV.

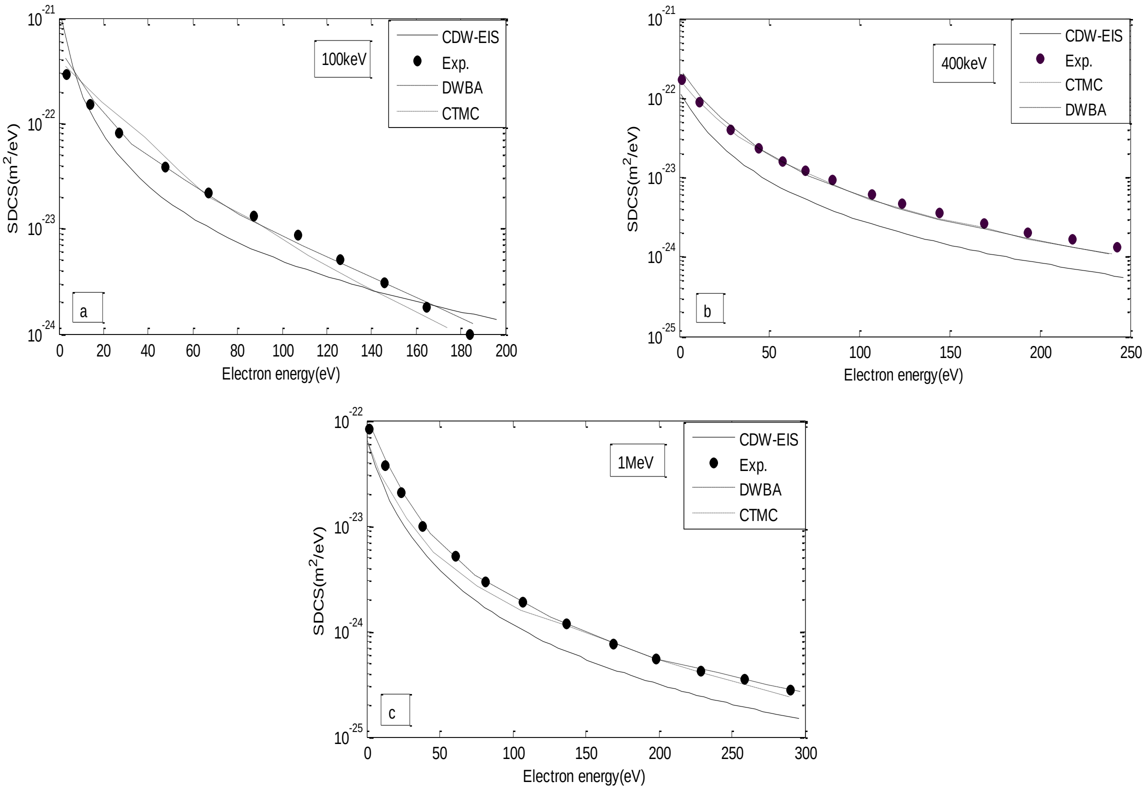

Figure (13) Singly differential cross sections for ionization of He(2s) by a (100keV), b (400keV), and c (1MeV) proton. The solid line, CDW-EIS present work; long-dashed line, distorted- wave Born approximation Bates, (1993); short-dashed line, Classical-Trajectory Monte Carlo Pedersen et al., (1990); symbols, Experimental data Rudd et al., (1992).

4-Saddle Point Ionization

In figure (14) the experimental double differential cross sections for electron emission at zero degrees of a neon target in collision with 80keV protons are compared to theoretical data of the present work. Again, we have quite good agreement between experimental results McSherry et al., (2001) and the CDW-EIS of the present work, in which we see that there is no suggestion of saddle point mechanisms.

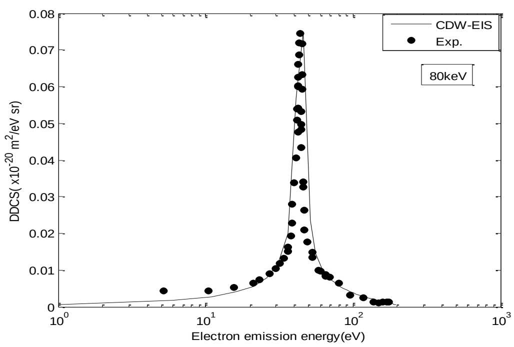

Figure (14) Double differential cross sections $d^2\sigma/d\Omega dk$ (DDCS) of 80keV proton impact on Ne (2s) at 0° emission angle. The theoretical values were calculated using our CDW-EIS model. Experimental data McSherry et al., (2001).

Conclusions

Applying continuum – distorted - wave eikonal –intial -state (CDW-EIS) approximations for computing differential and total cross sections for single ionization of atoms and molecular by bare-ion impact. Our calculations agree with the experimental measurement, and much better than the calculation of other theories, such as (PWBA and CTMC).Most of the information is lost in the total cross section than the single and double differential cross sections which are of primary interest for fundamental scientific research in to ion-atom collision theory.

Double differential cross sections as a function of the electron emission angle and energy exhibits several distinct characteristic regions arising due to the two-center effects. These regions can be identified by various mechanisms. The first is the well-known soft collision peak. The second is the electron capture to the continuum mechanism.. Thirdly, the binary encounter mechanism.. It has been suggested that there may be a fourth feature associated with the emission of the electrons through a "saddle-point mechanism." This process arises from the possibility that the ejected electron is stranded on the saddle point of the two-center potential between the residual target and receding ion. This saddle is formed by the combined Coulomb potentials of the collision partners having a perpendicular to the internuclear axis and a maximum along it. The saddle point emission mechanism corresponds to an electron distribution centered at an electron velocity close to half the projectile velocity.

Reference

Bates, S. D. 1991. Advance in Atomic, Molecular, and Optical Physics, Vol 28, Bederson, New York.

Belkic, D. Z., Gayet, R. and Salin,A.1979.Phy. Rev. 56, 279.

Belkic, D.Z. 1978. J. Phys. B11, 3529. Bates, S.D. 1993. Advance in Atomic, Molecular, and Optical Physics, Vol 30, Bederson, New York.

Bransden, B. H. and McDowell, M.R.C. 1992. Charge Exchange and the Theory of Ion-Atom Collisions, Clarendon press, Oxford.

Clementi, E. and Roetti,C. 1974.At. Data Nucl. Data Tables 14, 177.

Crothers, D.S.F. 2008.Semiclassical Dynamics and Relaxation, Springer series on Atomic, Optical, Plasma physics, Vol 47, Springer, Business media, LLC.

Engel, E. and Vosko, S. H., 1993. Phys. Rev. A 47, 2800.

Gulyas, L. Fainstein, P. D. and Salin, A. 1995. J. Phys. B: At. Mol. Opt. Phys. 28, 245.

Gulyas, L. Kirchner,T. Shirai, T and Horbatsch , M. 2000. Phys. Rev. A 63.

McDowell M.R.C. and Coleman, J.P. 1970. Introduction to the Theory of Ion-Atom Collisions Amsterdam: North Holland.

McSherry,D.M.,O'Rourke,S.F.C.,Crothers,D.S.F. 2003.Computer Phys. Commun 155,158

McSherry, D. M. O'Rourke, S. F. McGrath, C. C. Shah M. B. and Crothers, D. S. F. 2001. CP576, Applications of Accelerators in Research and Industry, in: J.L Duggan, I.L. Morgan (Eds.), 16th Internet.Conf., The American Institute of physics, pp. 168-171.

Nebitt ,B.S., O'Rourke, S.F.C. and Crothers, D.S.F. 1998. Comput. Phys.Commun. 114, 385.

O'Rourke, S.F.C., McSherry, D.M. and Crothers, D.S.F. 2000. Comput.Phy.Commun. 131, 129

Pedersen, J. O. Havelplund, P. P. Petersen, A. G. and Fainstein, P. D. 1990. J. Phys. B: At. Mol. Phys. 23, L 597.

Prigogine, I.and Rice, S. A. 2002. Advances in chemical physics, Vol 121, An Interscience by John Wiley and Sons, Inc., New York.

Rudd, M.E. kim,Y.K. Medison,D.H. and Gay,T.J. 1992. Rev. Mod. Phys. 64, 441-490.

Sneddon,I. N. 1951. Fourier Transforms. McGraw- Hill, New York.

Stolterfoht, N. Platten,H. Schiwietz, G. And Schneider, D. 1995. Phys. Rev. A 52.

Whelan,C.T.and Mason,N.J. 2005. Electron Scattering, Kluwer Academic, New York.

Wilson, W. E. and Toburen, L. H. 1973.Phys. Rev. A 7, 1535.

حساب المقطع العرضي للتأين لتصادم أيون– ذرة باستخدام نموذج (CDW-EIS)

الخلاصة

تم في هذاالبحث حساب مساحة المقطع التأيّن العرضي الكلي لتصادم البروتون وجسيمات الفا بمجموعة مختارة من ذرات الهدف مثل الهايدروجين،الهليوم،النيون والاركون ولطاقات تتراوح من10keV الى 10MeV . تم حساب أطياف طاقةِ الألكترون لمقاطع عرضية تفاضلية منفردة ومقاطع عرضية تفاضلية مزدوجة للتأيّن المنفرد وذلك من خلال تصادم جسيم البروتون بذرة الهليوم لمختلف طاقات التاثير وذلك باستعمال نموذج

Continuum Distorted Wave-Eikonal Initial State (CDW-EIS)

القائم على استخدام تقريب الميكانيك الكمي وتبين بأن النموذج(CDW-EIS) مفيد جدا عند دراسة التاين لتصادم (أيون – ذرة).عما تبين أيضا بان النتائج التي تم الحصول عليها متطابقة الى حد معقول مع النتائج العملية المتوفرة.

هژمارتن پانە برِكێ يايۆنبوونێ بو لێكدانا ئايۆن – گەرديلە ب بكارئينانا ڤێ نموونێ(CDW-EIS)

بوختە

لەم ڕاپۆرتەدا ڕووبەری پانە برگە هەژمارکراوە کە پانە ئایۆنی گشتی دەنوێنێ . کە لە ئەنجامی بەریەك کەوتنی تەنۆلکە ووردەکانی ئەلفا جارێك وە پرۆتۆن جارێکی تر بە شوێن ئامانجی دیاریکراو وەك (H ، He ، Ne ، Ar) بۆ بەریەك کەوتنی ووزە ئاست جیاوازەکان دێتەکایەوە کە بوارەکەی لە نێوان 10 کیلۆ ئەلکترۆن فۆلت و 10 مێگا ئەلکترۆن فۆلت دایە . وە هەروەها شەبەنگی ووزەی ئەلکترۆنی بۆ پانە برِگەی داتاشراوی تاك هەژمارکراوە، لە گەل پانە برِگەی داتاشراوی جووت بۆ ئایۆن بوونی تاك . بۆ بەریەك کەوتنی تە نۆلکەی پرۆتۆن بە گەردیلەی هیلێوم بە ووزەی ئەلکترۆنی ئاست جیاواز، ئەمەش بە بەکارهێنانی ئەم نمونەیەی خوارەوە دەبێت.

Continuum Distorted Wave-Eikonal Initial State (CDW-EIS)

کە بەکار هێنانی نزیك کراوەی میکانیکی کوانتەمە . ئەم نمونەیە لە ڕێك کەوتن نامەی نایاب لەگەل بەرهەمی تاقی کردنەوەیی یە بۆ زایننی پانە برگە کانی بە ئایۆن بوونی بەریەك کەوتن (ئایۆنی _ گەردیلە) .ئەمەش کە ئەنجامەکانی وەرگیراوەتەوە و بەدەست هاتووە هەمان ئەنجامی هەیە کە برێکی گونجاوە لەگەڵ ئەنجامە زانستیەکان .