Study of the relationship between principle quantum number of H atom and single differential cross section for electron emission in proton-H atom collision

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Abstract

Single differential cross section (SDCS) has been calculated for electron emission in collision of different Protons energies with Hydrogen atom for electrons emission energies (1-1000 eV). SDCS has been calculated for ground state (n=1) and exited states (n=2, 3). SDCS for n=1 level less than SDCS for n=2, 3 levels at the range of electron energy less than 10eVand SDCS"s for different levels have the same values at the electron energy more than 10eV. SDCS as a function to the binding energy (where the binding energy for nth-level for H-atom $E_b = 1/2n^2$ in atomic units) has been studied. The SDCS is independent on large principle quantum number and it is decreasing with impact energy.

1. Introduction

Electron emission from a target atom by charge particle impact has been the subject of intense investigation since the beginning of detailed studies of ion-atom collision. This long standing interest is due to the fundamental importance of ionization in various fields of physics including plasma, radiation physics, atmospheric physics, and astrophysics. Differential cross section for electron emission is the major application and basic quantity which is calculated in theoretical treatments of inelastic scattering of charged particles with atoms and molecules[1-4].

Binary-encounter electron approximation considers the target electron as a free electron. In this approximation, all energy losses from fast ion transfer into the target electron as a virtual photon[5,6]. There are relationship between electron emission in fast collision and the electron emission in photoabsorption process and Compton scattering. When the energy losses from incident ion transfer to the active electron and residual target ion, this process is similar to photoabsorption but when the energy losses from incident ion transfer to the active electron only, this process is similar to Compton scattering[7,8].

Compton scattering describes by Compton profile $J(p_z)$ which depends on the state electron momentum density $\rho(p)$ and it is related to the integral of two-dimension of electron momentum density,

$$J(p_z) = \iint \rho(p) dp_x dp_y$$

or equivalently a one- dimension of electron momentum density along the direction of the scattering vector p_z of the incident ion. The above equation which is used in much of the analysis of Compton profile is obtained within the framework of the impulse approximation. The fundamental scattering process considered the impulse approximation is the scattering a photon (virtual photon) collection of free electron. The impulse approximation is expected to valid when the energy transferred in the scattering process is much large than the binding energy of the electronic state involved [9,10]. In this work we shall study the dependence of Single differential cross section for electron emission on principle quantum number of H atom in proton-collision process.

Atomic unit ($\hbar = e = m_e = 1$) are used in this work.

2. Theory

Single differential cross section (SDCS) for electron emission with energy E into solid angle $d\Omega = \sin\theta d\theta d\phi$ is given by[2]

$$\frac{d\sigma}{dE} = \frac{4Z_p^2}{v_p^2 k^3} J(p_z) d\Omega \quad \cdots \quad (1)$$

Where Z_p and v_p is the projectile charge and projectile velocity respectively, and the momentum transfer k is given by

$$k = \sqrt{2E + 2E_b} \quad \cdots (2).$$

Where E is the energy of emitted electron and $E_b = 1/2n^2$ is the binding energy of electron, $J(p_z)$ is the Compton profile of the initial state of electron as a function of initial momentum component along the beam direction p_z.

$J(p_z)$ is given by[9]

$$J(p_z) = \int |\phi_i(p)|^2 d^2 p_\perp \quad \cdots (3)$$

Where the $\phi_{i(p)}$ is the initial state in momentum space, $p_\perp$ is initial momentum component perpendicular to the incident beam direction.

So p_z is given by

$$p_z = k\cos\theta - K_{\min} \quad \cdots (4)$$

Where θ is emission angle of electron and the minimum momentum transfer $K_{\min}$ is obtained as

$$K_{\min} \approx \frac{\Delta E}{v_p}$$

Where the energy transfer ΔE is given by[11]

$$\Delta E = E + E_b \quad \cdots (5)$$

From equation (4)

$$d\theta = \frac{dp_z}{k\sin\theta} \quad \cdots(6)$$

The solid angle $d\Omega = \sin\theta d\theta d\phi$.

After applied some substitution in equation (1) and the integral over the azimuth angle give 2π, equation (1) becomes

$$\frac{d\sigma}{dE} = \frac{4Z_p^2}{v_p^2 k^3} 2\pi \int J(p_z)\sin\theta d\theta \quad \cdots(7)$$

By using equation (6), the single differential cross section becomes

$$\frac{d\sigma}{dE} = \frac{8\pi Z_p^2}{v_p^2 k^3} \int J(p_z)\sin\theta \frac{dp_z}{k\sin\theta}$$

Or

$$\frac{d\sigma}{dE} = \frac{8\pi Z_p^2}{v_p^2 k^4} \int J(p_z)\mathrm{dp_z} \quad \cdots(8)$$

By taking the normalization of Compton profile $\int J(p_z)dp_z = 1$ equation (8) becomes

$$\frac{d\sigma}{dE} = \frac{8\pi Z_p^2}{v_p^2 k^4} \quad \cdots(9)$$

From equation (2), $k^4 = 4\Delta E^2$ by using this relation; equation (9) becomes

$$\frac{d\sigma}{dE} = \frac{2\pi Z_p^2}{v_p^2 \Delta E^2} \quad \cdots(10)$$

Equation (10) is used to calculate the single differential cross section for electron emission in ion-atom collision.

3. Result and discussion

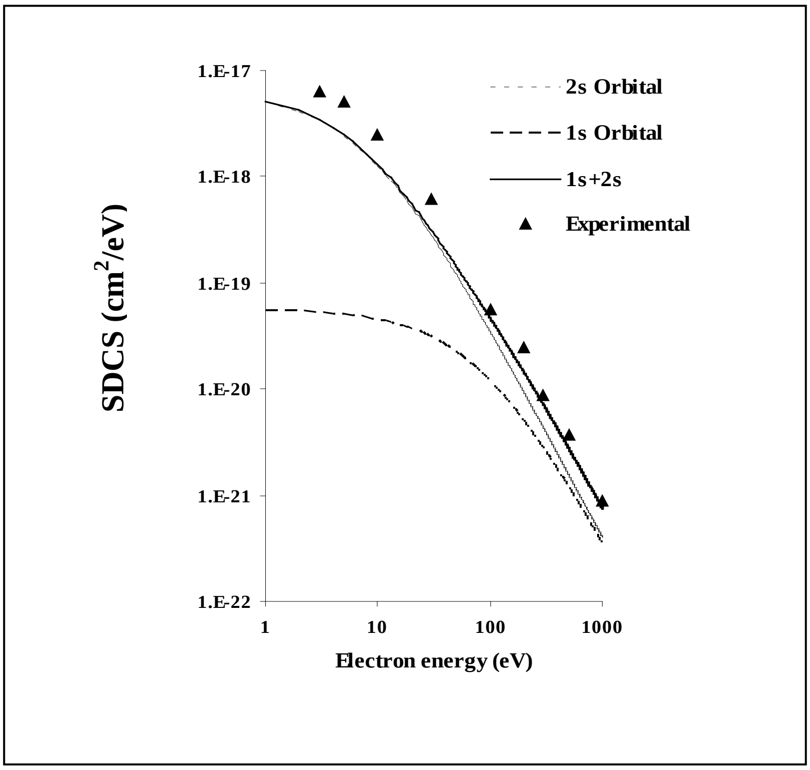
In order to calculate the SDCS for electron emission in proton –Hydrogen atom collision, a computer program has been built and applied, at the first, to the collision between 95 MeV/u Ar^{+18} with Li-atom to check the validity of the program since we have the experimental result of this collision, then this program is used in this work.

Fig. 1 shows the energy distribution of SDCS of ionized electron in (95 MeV/u Ar^{18+} with Li atom). This figure also shows the contributions of 1s-orbital (n=1), 2s-orbital (n=2), (1s+2s) orbitals and experimental result. There are a good agreements between theoretical and experimental results of (1s+2s).

SDCS has been calculated for electron emission in (100 KeV, 300 eV and 1 MeV/u) proton with H atom and SDCS for electron emitted form n=1 (ground 1s state) and n=2, 3 (exited 2s and 3s states) of H atom. Fig. (2) shows the energy distribution for electron emission in different impact energies. SDCS for n=1 level less than SDCS for n=2,3 levels at the range of electron energy less tan 10eV and SDCS"s for different levels reach into together value at the electron energy more than 10eV because the transfer energy $(\Delta E = E_b + E)$ at high electron energy $(E >> E_b)$ is approximately equal to electron energy, i.e. $(\Delta E \approx E)$.

SDCS as a function to the binding energy (where the binding energy for nth-levels for H Atom $E_b = 1/2n^2$ in atomic units) for electron energy 3eV at different impact energy illustrated in Fig. (3).From this figure SDCS independent on the principle quantum number n at large n because the value of $^1/_{2n^2}$ approach to zero, therefore the transfer energy in formula (10) $(\Delta E \approx E)$ at large n.

Fig. (4) shows the SDCS for emitted electron from ground state (n=1) as a function of proton energy in KeV/u at energy of emitted electron E=3eV. SDCS decreases exponentially with increasing of impact energy of proton.



Fig(1) Single cross section for electron emission in 95-MeV/u Ar^{18+}+Li collision from 1s orbital ,2s orbital and 1s+2s compare with experimental data▲ [3].

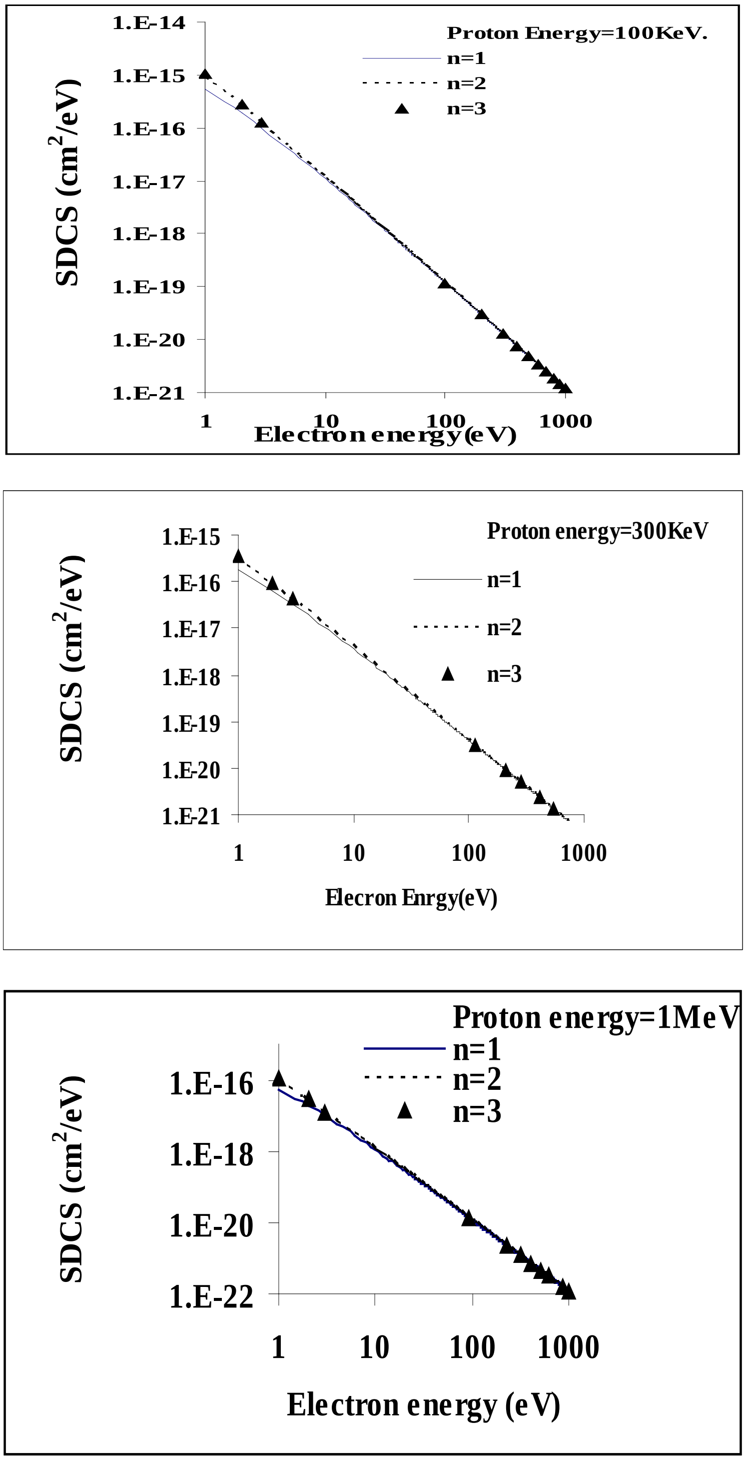


Fig.(2) Single differential cross section for electron emission in proton + H-atom collision from(n=1,2,3) orbital for different proton energies

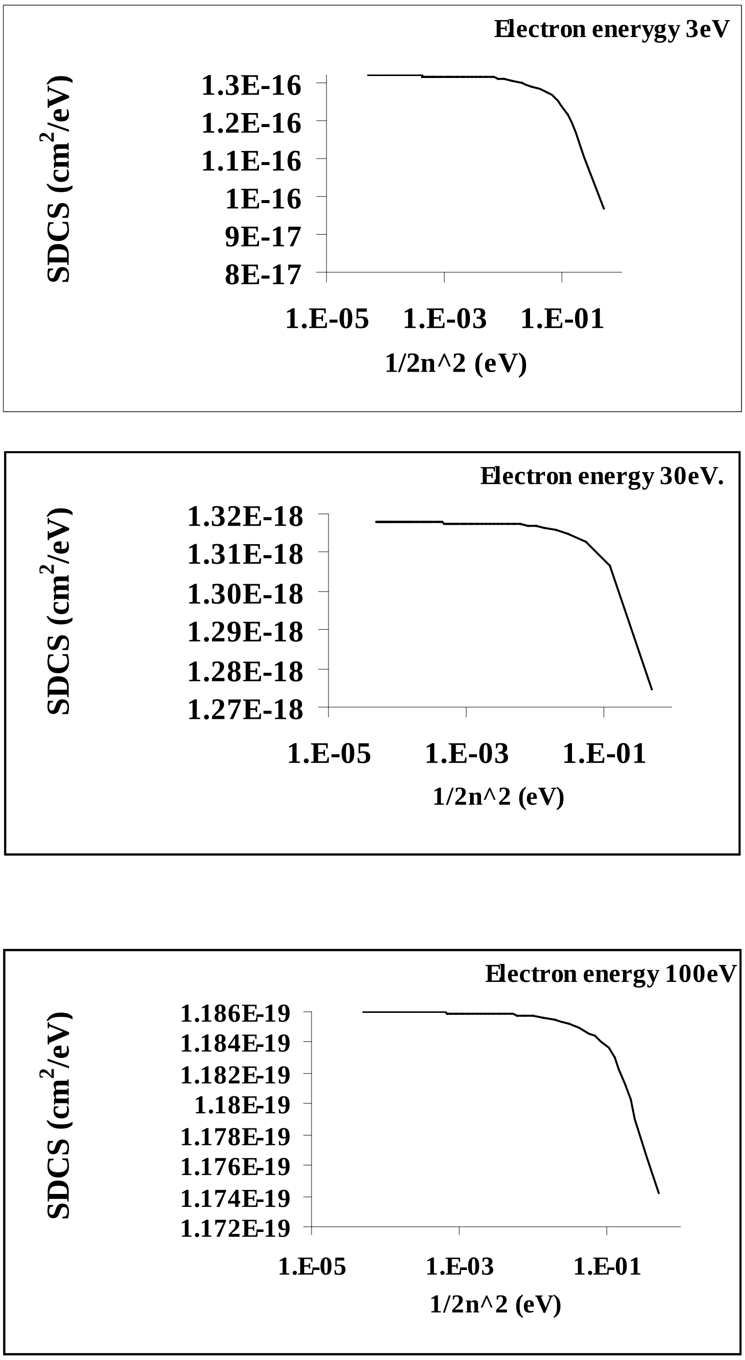


Fig.(3) Relationship between $1/2n^2$ and SDCS for electron emitted with different energies in 100KeV proton +H atom collision

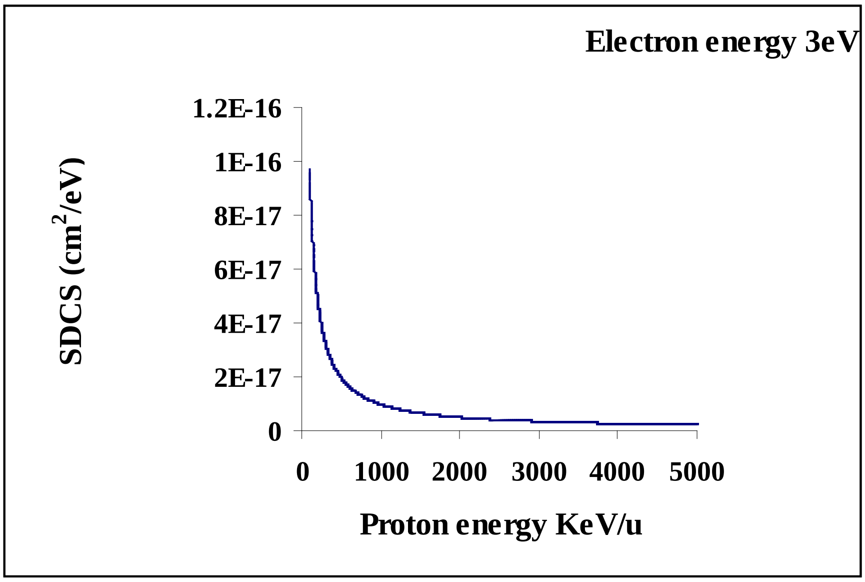


Fig. (4) SDCS for ground state (n=1) as a function to proton energy at electron energy E=3eV .

4.Conclusions

1-SDCS for n=1 level less than SDCS for n=2,3 levels at the range of Energy of electron emitted less than 10eV.

2- SDCS"s for different levels have the same values at the energy of emitted electron more than 10eV.

3- SDCS independents on the principle quantum number n at large n.

4- SDCS decreases with increasing of impact energy of proton.

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دراسة العلاقة بين العدد الكمي الرئيس لذرة الهيدروجين والمقطع العرضي التتفاضلي المنفرد للالكترونات المنبعثة في تصادم البرتونات وذرة الهيدروجين

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الخلاصة:

تم حساب المقطع العرضي التفاضلي المنفرد (SDCS) للالكترونات المنبعثة في عملية تصادم البروتونات وبطلقات تصادم مختلفة مع ذرة الهيدروجين وبمدى طاقات انبعاث (1-1000 eV). حسب (SDCS) للحالة الأرضية (n=1) والحالتين المثارة (n=2,3) . وجد بان (SDCS) للحالة الأرضية (n=1) اقل من (SDCS) للحالتين المثارتين (n=2,3) عند طاقات انبعاث اقل من 10eV وتصل قيم (SDCS) لمختلف المستويات لنفس القيمة عند طاقات انبعاث أكبر من 10eV. درس SDCS كدالة لطاقة الترابـــــط (حيث إن طاقة الترابط للمستوى n لذرة الهيدروجين $E_b = 1/2n^2$ بالوحدات الذرية) ووجد بان SDCS لا يعتمد على n عند القيم العالية للعدد الكمي الأساس كذلك إن SDCS يتناقص مع زيادة طاقة التصادم للبروتون.