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Research Article

Formation of 2s-State Hydrogen Atom in Proton-Lithium Inelastic Scattering

S. A. Elkilany[1,2]

[1] *Department of Mathematics, College of Science, Kafrelsheikh University, Kafrelsheikh, Egypt*
[2] *Department of Mathematics, College of Science, Ad Dammam University, P.O. Box 838, Ad Dammam, 31113, Saudi Arabia*

Correspondence should be addressed to S. A. Elkilany; sabbelkilany@yahoo.com

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Elaborate coupled static formalism is employed for treatment of proton-lithium collisions at wide range of incident energies between 10 and 1000 Kev. Coupled static and frozen core approximations are employed for calculating partial and total cross sections. Only elastic and formation of excited hydrogen, H(2s), channels are considered. Total cross sections are calculated using seven partial waves Green's function expansion technique of total angular momentum ℓ ($0 \leq \ell \leq 6$). Proposed iterative approach allows for reliable representation of the core potentials using elaborate variational calculation of target orbitals. Polarization potential of lithium atom is taken into consideration in calculating corresponding total cross sections. Quite interesting reliable results were obtained in comparison with other theoretical approaches.

1. Introduction

There has been a growing interest in the investigation of electron capture from alkali-metal atom. As an example, charge-transfer process with Li has been suggested to occur in plasma diagnostic probes [1]. Besides, alkali-metal atoms are many-electron systems that can be simplified to be one-electron systems due to a single valence electron. Theoretical calculations as well as experimental measurements have been carried out for ionization of and electron capture from alkali-metal atoms by proton impact [1, 2]. Investigation of elastic scattering of positrons from noble gases using an iterative Green's function partial wave expansion formalism and a model static and polarization potentials are derived for describing the interactions of positrons with closed shell atoms [3, 4]. The formation of excited hydrogen atom (H(2s)) in the process $H^+ + Li \rightarrow H(2s) + Li^+$ has been studied only in low energy ranges. The electron capture cross sections from Li by high energy (for heavy particle collision on atoms, the ratio of the projectile velocity to the orbital electron velocity is much larger than 1) incident protons in energy range between 200 and 10000 Kev have been investigated by using the continuum distorted wave (CDW) approximation [5]. The formation of excited hydrogen atom (H(2s)) in Oppenheimer Brinkman and Kramer (OBK) approximation is investigated [6]. The differential and total cross sections have been investigated in the formation of H-atom in the 2s-excited state of proton-lithium scattering by using the Coulomb projectile Born (CPB) approximation in the energy range from 50 to 10000 Kev [7]. Proton-alkali atom (Na, K, Rb, and Cs) collision has also studied in the wave formulation of impulse approximation in the energies ranging from 50 to 500 Kev [8]. The polarized orbital method (POM) has been applied to study elastic scattering of positrons by large atoms, finding that this method is extremely successful in the treatment of elastic scattering of positrons by noble gases [9]. The POM yields a considerable improvement in static phase shifts which were always shifted towards the variational ones [10]. The improvement was due to the effect of the polarization potentials which play an important role in the real physical picture of the considered collision process.

In this work, an elaborate coupled static formalism is employed [11] for the treatment of proton-lithium collisions at wide range of incident energies from 10 to 1000 Kev. The proposed iterative approach allows for reliable representation of the core potentials using elaborate variational calculation

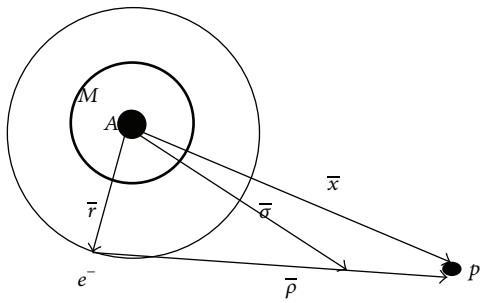

Figure 1: Configuration space of p-Li scattering.

of the target orbitals. The effect of "switching on" polarization potential of lithium atom on their coupled static cross sections is investigated. We assume that the elasticity and the formation of H(2s) channels are open and that all other channels of target are closed. Quite interesting reliable results were obtained in comparison with other theoretical approaches.

2. Theoretical Formalism

The two-channel scattering problems under investigation can be sketched by [11]

$$p + \mathrm{Li}\{2s\} = \begin{cases} p + \mathrm{Li}\{2s\} & \text{(elastic channel)} \\ \mathrm{H}\{2s\} + \mathrm{Li}^+ & (\mathrm{H}(2s) \text{ formation channel}). \end{cases} \tag{1}$$

The total Hamiltonian of the first channel, elastic channel (in Rydberg units and frozen core approximation), has the following form:

$$\begin{aligned} H = H^{(1)} &= H_{\mathrm{Li}(2s)} - \frac{1}{2\mu_M}\nabla_x^2 + V_{\mathrm{int}}^{(1)} \\ &= -\frac{1}{2\mu_m}\nabla_r^2 - \frac{2}{r} - \frac{1}{2\mu_M}\nabla_x^2 + V_{\mathrm{int}}^{(1)}, \end{aligned} \tag{2}$$

where μ_m, μ_M are reduced masses of the target and first channel, respectively. $\overline{x}$ and $\overline{r}$ are the position vectors of projectile proton and valence electron of target with respect to center of mass of target, $\overline{\rho}$ is the position vector of projectile proton with respect to valence electron of target, and $\overline{\sigma}$ is the position vector of center of mass of H(2s) from target nucleus (see Figure 1). M_A is mass of the nucleus of target and $V_{\mathrm{int}}^{(1)}$ denotes the interaction between the incident proton and target atom; that is,

$$V_{\mathrm{int}}^{(1)} = \frac{2}{x} - \frac{2}{|x - r|} + V_{c\mathrm{Coul}}(x), \tag{3}$$

where

$$\begin{aligned} V_{c\mathrm{Coul}}(x) &= -V_{c\mathrm{Coul}}(r)\big|_{r=x}, \\ V_{c\mathrm{Coul}}(r) &= \left\langle \Phi_{\mathrm{Li}(1s)}(r_i) \left| \frac{2}{|r - r_i|} - \frac{2}{r} \right| \Phi_{\mathrm{Li}(1s)}(r_i) \right\rangle, \end{aligned} \tag{4}$$

and the corresponding total energy in first channel is determined by

$$E = E^{(1)} = E_{\mathrm{Li}(2s)} + \frac{1}{2\mu_M}k_1^2, \tag{5}$$

where $(1/2\mu_M)k_1^2$ is the kinetic energy of incident proton relative to target nucleus. $|\Phi_{\mathrm{Li}(1s)}(r_i)\rangle$, $i = 1, 2$, is the wave function of ith electron in 1s-orbital and $|\Phi_{\mathrm{Li}(2s)}(r)\rangle$ is the wave function of valence electron. They are expanded following Clementi and Roetti [12] and adjusted such that the binding energy of the valence electron $E_{\mathrm{Li}(2s)}$ is minimum; that is,

$$E_{\mathrm{Li}(2s)} = \left\langle \Phi_{\mathrm{Li}(2s)}(r) \left| H_{\mathrm{Li}(2s)} \right| \Phi_{\mathrm{Li}(2s)}(r) \right\rangle. \tag{6}$$

The total Hamiltonian of the second channel, H(2s) formation, is expressed (in Rydberg units and frozen core approximation) as

$$\begin{aligned} H = H^{(2)} &= H_{\mathrm{H}(2s)} - \frac{1}{2\mu_{M'}}\nabla_\sigma^2 + V_{\mathrm{int}}^{(2)} \\ &= -\frac{1}{2\mu_{m'}}\nabla_\rho^2 - \frac{2}{\rho} - \frac{1}{2\mu_{M'}}\nabla_\sigma^2 + V_{\mathrm{int}}^{(2)}, \end{aligned} \tag{7}$$

where $\mu_{m'}, \mu_{M'}$ are reduced masses of H(2s) and the second channel, respectively. $V_{\mathrm{int}}^{(2)}$ represents the interaction between the particles of H(2s) and rest of target atom; that is,

$$V_{\mathrm{int}}^{(2)} = \frac{2}{x} - \frac{2}{r} + V_{c\mathrm{Coul}}(x) + V_{c\mathrm{Coul}}(r) + V_{cex}(r), \tag{8}$$

where

$$V_{cex}(r) = \left\langle \Phi_{\mathrm{Li}(2s)}(r_i) \right| \frac{2}{|r - r_i|} - \frac{2}{r} \left| \Phi_{\mathrm{Li}(2s)}(r_i) \right\rangle, \tag{9}$$

and the total energy of second channel is determined by

$$E = E^{(2)} = E_{\mathrm{H}(2s)} + \frac{1}{2\mu_{M'}}k_2^2, \tag{10}$$

where $(1/2\mu_{M'})k_2^2$ is the kinetic energy of center of mass of H(2s) with respect to nucleus of target. It is related to the energy of the incident proton by

$$\frac{k_2^2}{2\mu_{M'}} = \left(E_{\mathrm{Li}(2s)} + \frac{1}{2\mu_M}k_1^2 - E_{\mathrm{H}(2s)} \right), \tag{11}$$

where $E_{\mathrm{H}(2s)} = -0.25\,\mathrm{Ry}$ is the ground state energy of H(2s) and $k_2^2/2\mu_{M'} > 0$ means that H(2s) channel is open; otherwise, it is closed. Thus, H(2s) formation is only possible if $k_1^2 > 2\mu_M(E_{\mathrm{H}(2s)} - E_{\mathrm{Li}(2s)})$.

The coupled static approximation states that the solution of the two-channel scattering problem under consideration is subjected to the following conditions [11]:

$$\begin{aligned} \left\langle \Phi_{\mathrm{Li}(2s)} \right| H - E \left| \Psi \right\rangle &= 0, \\ \left\langle \Phi_{\mathrm{H}(2s)} \right| H - E \left| \Psi \right\rangle &= 0, \end{aligned} \tag{12}$$

where $|\Psi\rangle$ is the total wave function describing each scattering process; that is,

$$|\Psi\rangle = \left|\Phi_{\mathrm{Li(2s)}}(r)\right\rangle \left|\psi_1(x)\right\rangle + \left|\Phi_{\mathrm{H(2s)}}(\rho)\right\rangle \left|\psi_2(\sigma)\right\rangle, \tag{13}$$

where $\Phi_{\mathrm{H(2s)}} = (1/\sqrt{32\pi})(2-\rho)\exp(-\rho/2)$ is the ground state wave function of H(2s), $\psi_1(x)$ is the wave function describing scattered protons, and $\psi_2(x)$ is the scattering wave function of second channel.

Substituting (3)–(5) in (2), we obtain

$$\frac{1}{2\mu_M}\left(\nabla_x^2 + k_1^2\right)\left|\psi_1\right\rangle = U_{st}^{(1)}(x)\left|\psi_1\right\rangle + \left\langle \Phi_{\mathrm{Li(2s)}}\left|H^{(2)} - E^{(2)}\right|\Phi_{\mathrm{H(2s)}}\psi_2\right\rangle. \tag{14}$$

Substituting (4) and (8)–(10) in (7), we obtain

$$\frac{1}{2\mu_{M'}}\left(\nabla_\sigma^2 + k_2^2\right)\left|\psi_2\right\rangle = U_{st}^{(2)}(\sigma)\left|\psi_2\right\rangle + \left\langle \Phi_{\mathrm{H(2s)}}\left|H^{(1)} - E^{(1)}\right|\Phi_{\mathrm{Li(2s)}}\psi_1\right\rangle, \tag{15}$$

where Schrödinger's equations of the target and H(2s) are employed. The potentials $U_{st}^{(1)}(x)$ and $U_{st}^{(2)}(\sigma)$ are defined by

$$U_{st}^{(1)}(x) = \left\langle \Phi_{\mathrm{Li(2s)}}(r)\left|V_{\mathrm{int}}^{(1)}\right|\Phi_{\mathrm{Li(2s)}}(r)\right\rangle, \qquad U_{st}^{(2)}(\sigma) = \left\langle \Phi_{\mathrm{H(2s)}}(r)\left|V_{\mathrm{int}}^{(2)}\right|\Phi_{\mathrm{H(2s)}}(r)\right\rangle. \tag{16}$$

In order to test the effect of polarization of lithium, we switch on the polarization potential of lithium atom, that is, $V_{\mathrm{pol}}^{\mathrm{Li(2s)}}(\sigma)$. This can be done by replacing $U_{st}^{(2)}(x)$ by a potential $U^{(2)}(x)$ such that

$$U^{(2)}(x) = U_{st}^{(2)}(\sigma) + \lambda_1 V_{\mathrm{pol}}^{\mathrm{Li(2s)}}(\sigma), \tag{17}$$

where $\lambda_1 = 1$ if the polarization is switched on (Model II) and $\lambda_1 = 0$ otherwise (Model I). We choose $V_{\mathrm{pol}}^{\mathrm{Li(2s)}}(\sigma)$ in the Peach form [13],

$$V_{\mathrm{pol}}^{\mathrm{Li(2s)}}(x) = -\frac{\alpha}{x^4}\left\{1.0 - \left(1.0 + \gamma x + \frac{(\gamma x)^2}{2}\right)e^{-\gamma x}\right\}, \tag{18}$$

where $\alpha = 0.19$ and $\gamma = 3.91$.

Using partial wave expansions of the scattering wavefunctions $|\psi_1\rangle$ and $|\psi_2\rangle$ in (14) and (15) that solutions are given (formally) by Lippmann-Schwinger equation [14]

$$\left|\xi\right\rangle = \left|\xi_0\right\rangle + G_0\left|\zeta\right\rangle, \tag{19}$$

where G_0 is Green operator $(E - H_0)^{-1}$ and $|\xi_0\rangle$ is solution of the homogeneous equation:

$$(E - H_0)\left|\xi_0\right\rangle = |0\rangle. \tag{20}$$

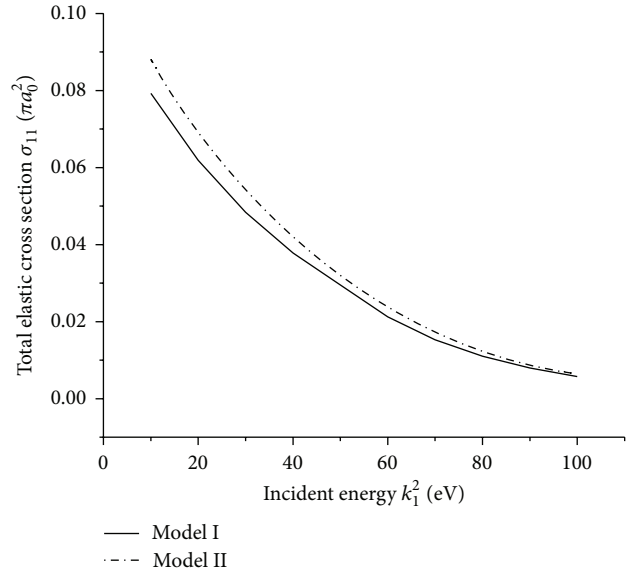

Figure 2: Total elastic cross sections (σ_{11} in πa_0^2) of proton-lithium scattering by coupled static approximation for the two models.

The partial wave expansions of Green operators corresponding to operators on the two differential equations enable us to write their solutions in integral form that can be solved by iterative numerical technique; then, we obtain reactance matrix R^ν that is related to transition matrix T^ν by

$$T^\nu = R^\nu\left(I - \widetilde{i}R\right)^{-1}, \tag{21}$$

where ν is order of iteration, I is a 2×2 unit matrix, and $\widetilde{i} = \sqrt{-1}$. Partial cross sections obtained in an iterative way are determined (in πa_0^2 units) using the relation

$$\sigma_{ij}^{(\ell,\nu)} = \frac{4(2\ell+1)}{k_i^2}\left|T_{ij}^\nu\right|^2, \quad i = 1, 2. \tag{22}$$

Finally, the total cross sections (in πa_0^2 units) are expressed (in νth iteration) by

$$\sigma_{ij}^\nu = \sum_{\ell=0}^{\infty}\sigma_{ij}^{(\ell,\nu)}, \quad i, j = 1, 2, \ \nu > 0. \tag{23}$$

3. Results and Discussion

We start our investigation by testing the variation of static potentials of two channels, $U_{st}^{(1)}(x)$ and $U_{st}^{(2)}(\sigma)$, and the polarization potential $V_{\mathrm{pol}}^{\mathrm{Li(2s)}}(\sigma)$ of lithium atom, with increase of σ and x. Values of σ and x have been chosen such that $\sigma = x = 1/16, 2/16, 3/16, \ldots, 512/16$ where $h = 1/16$ is the mesh size (or Simpson's step) employed for calculating integrals appearing in integral equations using Simpson's rule.

Calculation of cross sections of proton-lithium (p-Li) scattering has been proceeded by investigating variation of elements of R^ν with increase of integration range (IR) and

Table 1: Partial and total elastic cross sections (σ_{11} in πa_0^2) of proton-lithium scattering by coupled static approximation. Integration range (IR = $32a_o$), number of iterations ($\upsilon = 50$) (Model I).

k^2 kev	$L = 0$	$L = 1$	$L = 2$	$L = 3$	$L = 4$	$L = 5$	$L = 6$	Total
10	$4.7641E-02$	$1.9057E-02$	$7.6225E-03$	$3.0490E-03$	$1.2196E-03$	$4.8784E-04$	$1.9514E-04$	$7.9271E-02$
20	$3.7220E-02$	$1.4888E-02$	$5.9550E-03$	$2.3820E-03$	$9.5283E-04$	$3.8112E-04$	$1.5245E-04$	$6.1931E-02$
30	$2.9077E-02$	$1.1631E-02$	$4.6524E-03$	$1.8609E-03$	$7.4438E-04$	$2.9776E-04$	$1.1910E-04$	$4.8382E-02$
40	$2.2717E-02$	$9.0864E-03$	$3.6347E-03$	$1.4539E-03$	$5.8155E-04$	$2.3262E-04$	$9.3051E-05$	$3.7799E-02$
50	$1.7747E-02$	$7.0990E-03$	$2.8396E-03$	$1.1358E-03$	$4.5434E-04$	$1.8174E-04$	$7.2694E-05$	$2.9530E-02$
60	$1.2778E-02$	$5.1113E-03$	$2.0445E-03$	$8.1780E-04$	$3.2712E-04$	$1.3085E-04$	$5.2340E-05$	$2.1262E-02$
70	$9.2007E-03$	$3.6801E-03$	$1.4720E-03$	$5.8882E-04$	$2.3553E-04$	$9.4212E-05$	$3.7685E-05$	$1.5309E-02$
80	$6.6242E-03$	$2.6497E-03$	$1.0598E-03$	$4.2395E-04$	$1.6958E-04$	$6.7832E-05$	$2.7133E-05$	$1.1022E-02$
90	$4.7695E-03$	$1.9078E-03$	$7.6311E-04$	$3.0524E-04$	$1.2209E-04$	$4.8839E-05$	$1.9535E-05$	$7.9361E-03$
100	$3.4340E-03$	$1.3736E-03$	$5.4944E-04$	$2.1978E-04$	$8.7910E-05$	$3.5164E-05$	$1.4065E-05$	$5.7140E-03$

Table 2: Partial and total excited hydrogen formation cross sections (σ_{12} in πa_0^2) of proton-lithium scattering by coupled static approximation. Integration range (IR = $32a_o$), number of iterations ($\upsilon = 50$) (Model I).

k^2 kev	$L = 0$	$L = 1$	$L = 2$	$L = 3$	$L = 4$	$L = 5$	$L = 6$	Total
10	$4.9994E-03$	$1.9997E-03$	$7.9989E-04$	$3.1996E-04$	$1.2798E-04$	$5.1193E-05$	$2.0477E-05$	$8.3186E-03$
20	$3.9058E-03$	$1.5623E-03$	$6.2491E-04$	$2.4997E-04$	$9.9986E-05$	$3.9994E-05$	$1.5998E-05$	$6.4989E-03$
30	$3.0513E-03$	$1.2205E-03$	$4.8821E-04$	$1.9529E-04$	$7.8114E-05$	$3.1246E-05$	$1.2498E-05$	$5.0772E-03$
40	$2.3838E-03$	$9.5353E-04$	$3.8142E-04$	$1.5257E-04$	$6.1027E-05$	$2.4411E-05$	$9.7640E-06$	$3.9665E-03$
50	$1.8624E-03$	$7.4496E-04$	$2.9798E-04$	$1.1920E-04$	$4.7677E-05$	$1.9071E-05$	$7.6283E-06$	$3.0989E-03$
60	$1.3410E-03$	$5.3637E-04$	$2.1455E-04$	$8.5816E-05$	$3.4327E-05$	$1.3731E-05$	$5.4924E-06$	$2.2312E-03$
70	$9.6543E-04$	$3.8619E-04$	$1.5447E-04$	$6.1790E-05$	$2.4716E-05$	$9.8864E-06$	$3.9545E-06$	$1.6064E-03$
80	$6.9514E-04$	$2.7805E-04$	$1.1122E-04$	$4.4489E-05$	$1.7796E-05$	$7.1182E-06$	$2.8472E-06$	$1.1567E-03$
90	$5.0050E-04$	$2.0020E-04$	$8.0079E-05$	$3.2031E-05$	$1.2813E-05$	$5.1251E-06$	$2.0500E-06$	$8.3280E-04$
100	$3.6036E-04$	$1.4414E-04$	$5.7657E-05$	$2.3063E-05$	$9.2251E-06$	$3.6900E-06$	$1.4760E-06$	$5.9961E-04$

Table 3: Partial and total elastic cross sections (σ_{11} in πa_0^2) of proton-lithium scattering by coupled static approximation. Integration range (IR = $32a_o$), number of iterations ($\upsilon = 50$) (Model II).

k^2 kev	$L = 0$	$L = 1$	$L = 2$	$L = 3$	$L = 4$	$L = 5$	$L = 6$	Total
10	$5.2934E-02$	$2.1174E-02$	$8.4694E-03$	$3.3878E-03$	$1.3551E-03$	$5.4204E-04$	$2.1682E-04$	$8.8079E-02$
20	$4.1355E-02$	$1.6542E-02$	$6.6167E-03$	$2.6467E-03$	$1.0587E-03$	$4.2347E-04$	$1.6939E-04$	$6.8812E-02$
30	$3.2308E-02$	$1.2923E-02$	$5.1693E-03$	$2.0677E-03$	$8.2709E-04$	$3.3084E-04$	$1.3233E-04$	$5.3758E-02$
40	$2.5241E-02$	$1.0096E-02$	$4.0385E-03$	$1.6154E-03$	$6.4617E-04$	$2.5847E-04$	$1.0339E-04$	$4.1999E-02$
50	$1.9719E-02$	$7.8878E-03$	$3.1551E-03$	$1.2620E-03$	$5.0482E-04$	$2.0193E-04$	$8.0771E-05$	$3.2811E-02$
60	$1.4198E-02$	$5.6792E-03$	$2.2717E-03$	$9.0867E-04$	$3.6347E-04$	$1.4539E-04$	$5.8155E-05$	$2.3625E-02$
70	$1.0223E-02$	$4.0890E-03$	$1.6356E-03$	$6.5424E-04$	$2.6170E-04$	$1.0468E-04$	$4.1872E-05$	$1.7010E-02$
80	$7.3602E-03$	$2.9441E-03$	$1.1776E-03$	$4.7106E-04$	$1.8842E-04$	$7.5369E-05$	$3.0148E-05$	$1.2247E-02$
90	$5.2994E-03$	$2.1198E-03$	$8.4790E-04$	$3.3916E-04$	$1.3566E-04$	$5.4266E-05$	$2.1706E-05$	$8.8179E-03$
100	$3.8156E-03$	$1.5262E-03$	$6.1049E-04$	$2.4420E-04$	$9.7678E-05$	$3.9071E-05$	$1.5628E-05$	$6.3489E-03$

the number of iterations. We fix h at 1/16 and have obtained all the results presented below with 512 mesh points (i.e., IR = $32a_0$). It is found that excellent convergence can be obtained with $\nu = 50$, and this demonstrates stability of our iterative method. Final calculations have been carried out for seven partial waves corresponding to $0 \leq \ell \leq 6$ at values of k_1^2 representing the kinetic energy region ($10 \leq k_1^2 \leq 1000$ Kev).

In Table 1, we find the partial and total elastic cross sections σ_{11} of p-Li scattering (Model I). The table demonstrates that the S-wave scattering cross sections contribute with main part of total cross sections. The table shows also that the P- and D-waves are the most important partial waves after S-wave. This table emphasizes that the total elastic cross section decreases smoothly with the increase of the incident energy.

Table 2 contains the partial and total excited hydrogen, H(2s), formation cross sections σ_{12} (Model I). The table illustrates that the main contribution to σ_{12} is due to the S-wave scattering cross sections. The remaining contributions to σ_{12} are due to P- and D-waves. The total excited hydrogen,

Table 4: Partial and total excited hydrogen formation cross sections (σ_{12} in πa_0^2) of proton-lithium scattering by coupled static approximation. Integration range (IR = $32a_o$), number of iterations ($\upsilon = 50$) (Model II).

k^2 kev	$L = 0$	$L = 1$	$L = 2$	$L = 3$	$L = 4$	$L = 5$	$L = 6$	Total
10	$5.8816E-03$	$2.3526E-03$	$9.4105E-04$	$3.7642E-04$	$1.5057E-04$	$6.0227E-05$	$2.4091E-05$	$9.7866E-03$
20	$4.5950E-03$	$1.8380E-03$	$7.3519E-04$	$2.9408E-04$	$1.1763E-04$	$4.7052E-05$	$1.8821E-05$	$7.6458E-03$
30	$3.5898E-03$	$1.4359E-03$	$5.7437E-04$	$2.2975E-04$	$9.1899E-05$	$3.6760E-05$	$1.4704E-05$	$5.9732E-03$
40	$2.8045E-03$	$1.1218E-03$	$4.4873E-04$	$1.7949E-04$	$7.1796E-05$	$2.8719E-05$	$1.1487E-05$	$4.6665E-03$
50	$2.1911E-03$	$8.7642E-04$	$3.5057E-04$	$1.4023E-04$	$5.6091E-05$	$2.2436E-05$	$8.9745E-06$	$3.6458E-03$
60	$1.5776E-03$	$6.3102E-04$	$2.5241E-04$	$1.0096E-04$	$4.0385E-05$	$1.6154E-05$	$6.4617E-06$	$2.6250E-03$
70	$1.1358E-03$	$4.5434E-04$	$1.8173E-04$	$7.2694E-05$	$2.9078E-05$	$1.1631E-05$	$4.6524E-06$	$1.8899E-03$
80	$8.1781E-04$	$3.2712E-04$	$1.3085E-04$	$5.2340E-05$	$2.0936E-05$	$8.3743E-06$	$3.3497E-06$	$1.3608E-03$
90	$5.8882E-04$	$2.3553E-04$	$9.4211E-05$	$3.7684E-05$	$1.5074E-05$	$6.0295E-06$	$2.4118E-06$	$9.7976E-04$
100	$4.2395E-04$	$1.6958E-04$	$6.7832E-05$	$2.7133E-05$	$1.0853E-05$	$4.3412E-06$	$1.7365E-06$	$7.0543E-04$

Table 5: Present total cross sections (σ_{12} of Model I and Model II in πa_0^2) for excited hydrogen formation (H(2s)) with different theoretical results [5–7].

k^2 kev	Model I	Model II	[5]	[6]	[7]
50	$3.0989E-03$	$3.6458E-03$		$6.5E-01$	$3.596E-03$
60	$2.2312E-03$	$2.6250E-03$		$1.0E-03$	
70	$1.6064E-03$	$1.8899E-03$		$4.9E-03$	
80	$1.1567E-03$	$1.3608E-03$		$2.8E-03$	
100	$5.9961E-04$	$7.0543E-04$			$6.746E-04$
150	$1.1602E-04$	$1.3649E-04$			$1.294E-04$
200	$2.5849E-05$	$3.0410E-05$	$1.048E-05$		$3.294E-05$
250	$4.3437E-06$	$5.1103E-06$			$1.327E-05$
300	$2.9857E-06$	$3.5126E-06$			$8.489E-06$
500	$8.0153E-07$	$9.4297E-07$	$5.212E-07$		$9.828E-07$
800	$4.2587E-07$	$5.0102E-07$	$7.711E-08$		$2.278E-07$
1000	$3.9981E-08$	$4.7027E-08$	$2.906E-08$		$9.366E-08$

H(2s), formation cross section decreases also smoothly with the increase of k_1^2.

Table 3 presents the partial and total elastic cross sections σ_{11} of Model II. The main contributions to σ_{11} are to the S- and P-waves. The seven partial waves employed are quite satisfactory for calculating σ_{11} in a high degree of accuracy within the framework of coupled static approximation.

Table 4 shows partial and total excited hydrogen, H(2s), cross sections σ_{12} of p-Li scattering of Model II. On considering the variation of σ_{12}, with respect to incident energy, we notice that it has its maximum value at $k_1^2 = 10$ Kev and decreases smoothly thereafter. The values of total excited hydrogen, H(2s), cross sections σ_{12} in table give larger values than of Model I.

The total elastic cross sections of proton-lithium scattering for the two models are presented in Figure 2. In Figure 3, the present total hydrogen formation cross sections of proton-lithium scattering for Model I are displayed with that of Model II. The present results keep decreasing with the increasing of energy and its values of Model II are higher than that of Model I.

Comparison between total excited hydrogen, H(2s), cross sections σ_{12} of p-Li scattering of the two Models (I and II) and those determined by Banyard and Shirtcliffe [5], Ferrante et al. [6], and Tiwari [7] are tabulated in Table 5. Our results of Model II are found in reasonably good agreement with the above mentioned theoretical results specially with Tiwari calculations [7].

4. Conclusions

Proton-lithium scattering is studied using the coupled static approximation. Our interest is focused on the influence of polarization potential of the lithium atom. The switching on $V_{\text{pol}}^{\text{Li(2s)}}(\sigma)$ in Model II has positive influence upon total excited hydrogen formation cross sections σ_{12}. The present calculations for excited hydrogen formation cross sections,

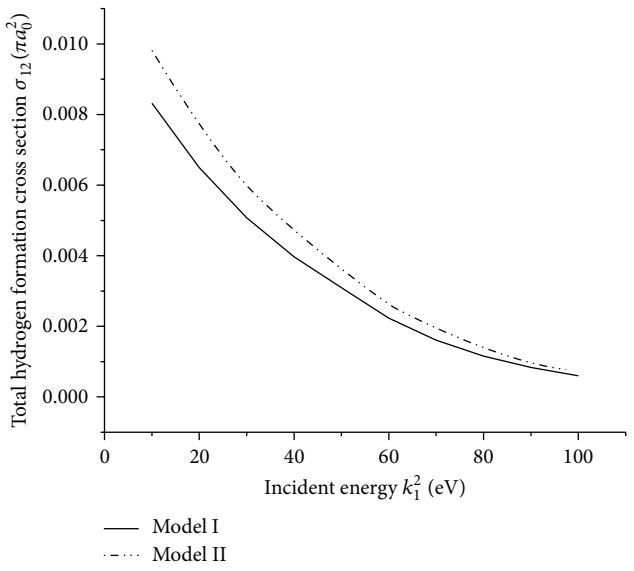

Figure 3: Total excited hydrogen (H(2s)) formation cross sections (σ_{12} in πa_0^2) of proton-lithium scattering by coupled static approximation for the two models.

using Model II, show reasonable agreement with available theoretical calculations in wide energy region.

Conflict of Interests

The author declares that there is no conflict of interests regarding the publication of this paper.

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