Original Research Article

Charge Exchange ofProton-PotassiumAtomCollision

ABSTRACT

The coupled static approximation is modified for the first time to make it applicable to multi-channels problem of the collision of the proton by alkali atom. The possibility of producing more hydrogen during the proton-alkali atom collision is investigated. The formation of hydrogen H (1s) and excited hydrogen (in 2s- and 2p-states) of p-Kcollisionis treated to test the convergence of our method. The modified method is used to calculate the total cross-sections of seven partial waves($0 \le \ell \le 6$, where ℓ is the total angular momentum) at a range of energy between 50 and 1000 keV. Our p-K results are compared with previous ones.

Keywords: proton-alkali,proton-potassium, hydrogen formation, excited hydrogen formation, cross-sections.

PACSNos.: 34.80.Dp . 34.80.Gs . 34.80.Ht

1.INTRODUCTION

The most interesting phenomenon in quantum mechanics is the intermediate states that appear in a nuclear reaction.Most theoretical and experimental studies of proton-atom interactions are discussed in the last decade by calculating differential and total cross-sections as functions of incident energies.Choudhury and Sural [1] have studied p-alkali atom (Na, K, Rb, Cs) scattering in the wave formation of impulse approximation at arange of energy from 50 to 500 keV. . Daniele et al. [2]have been reported the total cross-sections for high energy proton scattering by alkali atom using eikonl - approximations. Ferrante and Fiordilino [3] have been discussed the eikonl-approximation to study high-energy proton collision with alkali atom. Ferrante et al. [4] have also studied the total H-formation cross-sections in p-alkali atom scattering using OBK approximation. Tiwari [5] have been investigated the differential and total cross-sections ofH-formation of the collision of p-Li and p-Na atom using the Coulomb-projected Born approximation.

The present work is to explore the possibility of producing more hydrogen during the proton-potassium atom collision. For this reason, it is important to discuss the scattering of p-K atom . In the present paper, the CSA method used by Elkilany ([6]-[8]) will be modified to make it applicable to discuss the MCSA problem (n=4) of the collision of p-K atom at intermediate energies of the projectile.A numerical procedure will generalized to solve the obtained multi-coupled equations. Throughout this paper Rydberg units have been used and the total cross-sections are expressed in units of πa_0^2 $(=8.8\times10^{-17} cm^2)$ and energy units of keV.

2.THEORETICAL FORMALISM

The MCSA of protonsscattered byalkali atoms can be written by(see Fig. 1)

$$\mathrm{p}+A=\begin{cases}\mathrm{p}+A & \text{Elastic channel (first channel)}\\ H(n\ell)+A^{+} & H(n\ell)\ \text{formation channels}\ ((n-1)\text{ - channels})\end{cases} \quad (1)$$

Wherep is the proton, A is an alkali target atom, $H(n\ell)$ is hydrogen formation of $n\ell-$states and n is the number of open channels.

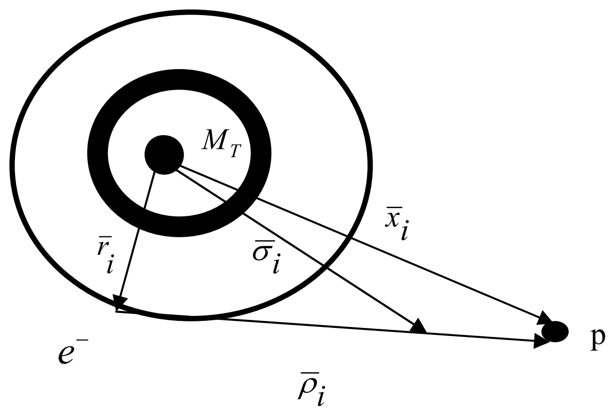

Fig.1 Configuration space of p-atom collision: $\bar{x}_i$ and $\bar{r}_i$ are the vectors of the proton and the valence electron of the target with respect to the center of mass of the target, $\bar{\rho}_i$ is the vector of the proton with respect to the valence electron of the target , $\bar{\sigma}_i$ is the vector of the center of mass of H from the target, M_T = mass of the nucleus of the target.

The Hamiltonian of the elastic channelis given by:

$$\mathrm{H} = \mathrm{H}^{(1)} = \mathrm{H}_T - \frac{1}{2\mu_1}\nabla^2_{x_1} + V^{(1)}_{\text{int}}(x_1) = -\frac{1}{2\mu_T}\nabla^2_{r_1} - \frac{2}{r_1} + V_c(r_1) - \frac{1}{2\mu_1}\nabla^2_{x_1} + V^{(1)}_{\text{int}}(x_1), \quad (2)$$

where H_T is theHamiltonian of the target atom. μ_T is the reduced mass of the target atom.

The Hamiltonian of the (n-1)-rearrangement channels are expressed by:

$$\mathrm{H} = \mathrm{H}^{(i)} = \mathrm{H}_i - \frac{1}{2\mu_i}\nabla^2_{\sigma_i} + V^{(i)}_{\text{int}}(\sigma_i) = -\frac{1}{2\mu_i}\nabla^2_{\rho_i} - \frac{2}{\rho_i} - \frac{1}{2\mu_i}\nabla^2_{\sigma_i} + V^{(i)}_{\text{int}}(\sigma_i), \quad i = 2,3,4,\ldots\ldots\ldots n \quad (3)$$

where H_i, $i = 2,3,4,......n$ are the Hamiltonians of the hydrogen formation atoms, $H(nl)$, respectively. μ_i, $i = 2,3,4,......n$ are the reduced masses of (n-1)- channels, respectively. $V_c(r_1)$ is a screened potential and $V_{\text{int}}^{(1)}(x_1)$ is the interaction potential of the first channeland are given by:

$V_c(r_1) = V_{cCoul}(r_1) + V_{cex}(r_1)$ (4)

Where $V_{cCoul}(r_1)$ and $V_{cex}(r_1)$ are the Coulomb and exchange parts of the core potential, respectively(see ref. [8]), and

$$V_{\text{int}}^{(1)}(x_1) = \frac{2}{x_1} - \frac{2}{\rho_1} + V_{cCoul}(x_1) \text{ where } V_{cCoul}(x_1) = -V_{cCoul}(r_1) \quad (5)$$

and $V_{\text{int}}^{(i)}(\sigma_i)$, $i = 2,3,4,.......n$, are the interaction potentials of the (n-1)-hydrogen formation channels, respectively and are given by:

$$V_{\text{int}}^{(i)}(\sigma_i) = \frac{2}{x_i} - \frac{2}{r_i} + V_{cCoul}(x_i) + V_{cCoul}(r_i) + V_{cex}(r_i), \quad i = 2,3,4,.......n \quad (6)$$

The total energies E ofthe n-channelsare defined by:

$$E = E_i + \frac{1}{2\mu_i} k_i^2, \quad \text{i} = 1,2,3.........n \quad (7)$$

where $\frac{1}{2\mu_1} k_1^2$ is the kinetic energy of theincident proton relative to the target and $\frac{1}{2\mu_i} k_i^2$, $i = 2,3,4,......,n$ are the kinetic energy of the center-of-mass of thehydrogenformation atoms, $H(n\ell)$, respectively, with respect to the nucleus of the target. E_1 is the binding energy of the target atom, and E_i, $\mathrm{i}=2,3,4,\ldots\ldots,n$ refer to the binding energies of the hydrogen formation atoms, respectively.

In themulti-channels coupled-static approximation (MCSA), it is assumed that the projections of the vector $(\mathrm{H}-E)|\Psi\rangle$ onto the bound state of the n-channels are zero. Thus, the following conditions:

$$\langle\Phi_i|(\mathrm{H}-E)|\Psi\rangle=0, \quad i=1,2,3,\ldots.,n \qquad (8)$$

are satisfied. The total wavefunction $|\Psi\rangle$ is expressed by:

$$\Psi=\sum_{i=1}^{\mathrm{n}}|\Phi_i\psi_i\rangle, \qquad (9)$$

$$\psi_1=\sum_{\ell}\ell(\ell+1)f_{\ell}^{(1)}(x_1)Y_{\ell}^{0}(\hat{x}_1), \qquad (10)$$

$$\psi_i=\sum_{\ell}\ell(\ell+1)g_{\ell}^{(i)}(\sigma_i)Y_{\ell}^{0}(\hat{\sigma}_i), \quad i=2,3,\ldots\ldots n \qquad (11)$$

Where $f_{\ell}^{(1)}(x_1)$ and $g_{\ell}^{(i)}(\sigma_i)$, $i=2,3,\ldots\ldots n$ are the radial wavefunctions of the elastic and the hydrogen formation atoms, respectively, corresponding to the total angular momentum ℓ. $Y_{\ell}^{0}(x_1)$ and $Y_{\ell}^{0}(\hat{\sigma}_i)$ $i=2,3,\ldots\ldots.,n$ are the related spherical harmonics. $\hat{x}_1$ and $\hat{\sigma}_i$, $i=1,2,3,\ldots.,n$ are the solid angles between the vectors $\hat{x}_1,\hat{\sigma}_i, i=2,3,\ldots\ldots.n$ and the z-axis, respectively. ψ_i, $i=1,2,3,\ldots\ldots.n$ are the corresponding scattering wavefunction of the n-channels, respectively. Φ_1 is the wavefunction for the valence electron of the target atom which is calculated using ref. [9]. Φ_i, $i=2,3,4,\ldots\ldots,n$ are the wavefunctions of the hydrogen formation atoms, $H(n\ell)$, respectively, which are defined using hydrogen like wavefunction.

The multi-channels coupled static approximation (MCSA) (eq. (8))can be solved by considering the n- integro-differential equations

$$[\frac{d^2}{dx_1^2}-\frac{\ell(\ell+1)}{x_1^2}+k_1^2]f_\ell^{(1)}(x_1)=2\mu_1 U_{st}^{(1)}(x_1)f_\ell^{(1)}(x_1)+\sum_{\alpha=2}^{n}Q_{1\alpha}(x_1), \quad (12)$$

$$[\frac{d^2}{d\sigma_i^2}-\frac{\ell(\ell+1)}{\sigma_i^2}+k_i^2]g_\ell^{(i)}(\sigma_i)=2\mu_i U_{st}^{(i)}(\sigma_i)g_\ell^{(i)}(\sigma_i)+\sum_{\alpha=1}^{n}{}' \mathrm{Q}_{i\alpha}(\sigma_i), \quad i=2,3,\ldots\ldots,n, \quad (13)$$

where the prime on the summation sign means that $i \neq \alpha$, and

$$Q_{1\alpha}(x_1)=\int_0^\infty K_{1\alpha}(x_1,\sigma_\alpha)g_\ell^{(\alpha)}(\sigma_\alpha)d\sigma_\alpha, \quad \alpha=2,3,\ldots.,n \qquad (14)$$

$$\mathrm{Q}_{i1}(\sigma_i)=\int_0^\infty K_{i1}(\sigma_i,x_1)f_\ell^{(1)}(x_1)dx_1, \quad i=2,3,\ldots.,n \qquad (15)$$

$$\mathrm{Q}_{i\alpha}(\sigma_i)=\int_0^\infty K_{i\alpha}(\sigma_i,\sigma_\alpha)g_\ell^{(\alpha)}(\sigma_\alpha)d\sigma_\alpha, \quad i,\alpha=2,3,\ldots\ldots,n, \quad i\neq\alpha \qquad (16)$$

the Kernels $K_{i\alpha}, \quad i=1,2,3,\ldots\ldots,n, \; i\neq\alpha$ are expanded by:

$$K_{1\alpha}(x_1,\sigma_\alpha)=2\mu_1\,(8x_1\sigma_\alpha)\iint \Phi_1(r_1)\Phi_\alpha(\rho_\alpha)[-\frac{1}{2\mu_\alpha}(\nabla_{\sigma_\alpha}^2+k_\alpha^2)+V_{\text{int}}^{(\alpha)}]Y_\ell^o(\hat{x}_1)Y_\ell^o(\hat{\sigma}_\alpha)d\hat{x}_1 d\hat{\sigma}_\alpha, \; \alpha=2,3,\ldots n, \quad (17)$$

$$K_{i1}(\sigma_i,x_1)=2\mu_i\,(8\sigma_i x_1)\iint \Phi_i(\rho_i)\Phi_1(r_1)[-\frac{1}{2\mu_1}(\nabla_{x_1}^2+k_1^2)+V_{\text{int}}^{(1)}]Y_\ell^o(\hat{\sigma}_i)Y_\ell^o(\hat{x}_1)d\hat{\sigma}_i d\hat{x}_1, \; i=2,3,\ldots\ldots.n, \quad (18)$$

$$K_{i\alpha}(\sigma_i,\sigma_\alpha)=2\mu_i\,(8\sigma_i\alpha_\alpha)\iint \Phi_i(\rho_i)\Phi_\alpha(\rho_\alpha)[-\frac{1}{2\mu_\alpha}(\nabla_{\sigma_\alpha}^2+k_\alpha^2)+V_{\text{int}}^{(\alpha)}]Y_\ell^o(\hat{\sigma}_i)Y_\ell^o(\hat{\sigma}_\alpha)d\hat{\sigma}_i d\hat{\sigma}_\alpha, \; i,\alpha=2,3,\ldots\ldots n, \; i\neq\alpha. \quad (19)$$

The static potentials $U_{st}^{(1)}(x_1)$ and $U_{st}^{(i)}(\sigma_i), \quad i=2,3,\ldots\ldots,n$ are defined by

$$U_{st}^{(1)}(x_1)=<\Phi_1(r_1)|V_{\text{int}}^{(1)}|\Phi_1(r_1)>, \qquad U_{st}^{(i)}(\sigma_i)=<\Phi_i(\rho_i)|V_{\text{int}}^{(i)}|\Phi_i(\rho_i)> \qquad (20)$$

The equations (12,13) are inhomogeneous equations in x_i, and σ_i, $i = 1,2,3,.......,n$ and are possessing the general form

$$(\varepsilon - \mathrm{H}_0)|\chi> = |\eta\rangle \qquad (21)$$

where ε is $k_i^2 (i = 1,2,......, n)$. H_0 is $-\frac{d^2}{dx_1^2} + \frac{\ell(\ell+1)}{x_1^2}$ or $-\frac{d^2}{d\sigma_i^2} + \frac{\ell(\ell+1)}{\sigma_i^2}, i = 2,3,..., n$. $|\chi\rangle$ is $\left|f_\ell^{(1)}(x_1)\right\rangle$ or $\left|g_\ell^{(i)}(\sigma_i)\right\rangle$, $i = 2,3,...,n$. $|\eta\rangle$ is the right-hand side of the equations, respectively.

The solution of eqs. (12,13) are given (formally) by Lippmann-Schwinger equation in the form

$$|\chi> = |\chi_0\rangle + G_0|\eta> \qquad (22)$$

where G_0 is Green operator $(\varepsilon - \mathrm{H}_0)^{-1}$ and $|\chi_0\rangle$ is the solution of the homogeneous equation

$$(\varepsilon - \mathrm{H}_0)\ |\chi_0\rangle\ = |0\rangle\ , \qquad (23)$$

Using Green operator G_0, the solutions of (12,13) are given formally by

$$f_\ell^{(1,j)}(x_1) = \{\delta_{j1} + \frac{1}{k_1}\int_0^\infty \tilde{g}_\ell(k_1x_1)[2\mu_1 U_{st}^{(1)}(x_1) f_\ell^{(1,j)}(x_1) + \sum_{\alpha=2}^{n} Q_{1\alpha}^{(j)}(x_1)]dx_1\}\tilde{f}_\ell(k_1x_1)$$
$$+\{-\frac{1}{k_1}\int_0^\infty \tilde{f}_\ell(k_1x_1)[2\mu_1 U_{st}^{(1)}(x_1) f_\ell^{(1,j)}(x_1) + \sum_{\alpha=2}^{n} Q_{1\alpha}^{(j)}(x_1)]dx_1\}\tilde{g}_\ell(k_1x_1),\ j = 1,2,3,....,n$$

(24)

$$g_\ell^{(i,j)}(\sigma_i) = \{\delta_{ji} + \frac{1}{k_i}\int_0^\infty \tilde{g}_\ell(k_i\sigma_i)[2\mu_i U_{st}^{(i)}(\sigma_i) g_\ell^{(i,j)}(\sigma_i) + \sum_{\alpha=1}^{n}{}' Q_{i\alpha}(\sigma_i)]d\sigma_i\}\tilde{f}_\ell(k_i\sigma_i)$$
$$+\{-\frac{1}{k_i}\int_0^\infty \tilde{f}_\ell(k_i\sigma_i)[2\mu_i U_{st}^{(i)}(\sigma_i) g_\ell^{(i,j)}(\sigma_i) + \sum_{\alpha=1}^{n}{}' Q_{i\alpha}^{(j)}(\sigma_i)]d\sigma_i\}\tilde{g}_\ell(k_i\sigma_i),\ i = 2,3,....,n\ j = 1,2,3,....,n$$

(25)

where the delta functions δ_{ji}, $i,j=1,2,3,....,n$, specify two independent forms of solutions for each of $f_\ell^{(1,j)}(x_1)$ and $g_\ell^{(i,j)}(\sigma_i)$, i =2,3,….,n . The functions $\tilde{f}_\ell(\eta)$ *and* $\tilde{g}_\ell(\eta)$, $\eta=k_1x_1, or\ \eta=k_i\sigma_i$ $i=2,2,3,.....,n$ are related to the Bessel functions of the first and second kinds, i.e. $j_\ell(\eta)$ and $y_\ell(\eta)$, respectively, by the relations $\tilde{f}_\ell(\eta)=\eta\, j_\ell(\eta)$ and $\tilde{g}_\ell(\eta)=-\eta\, y_\ell(\eta)$.

The iterative solutions of Eqs.(24, 25) are calculated by:

$$f_\ell^{(1,j,\nu)}(x_1)=\{\delta_{j1}+\frac{1}{k_1}\int_0^{X_1}\tilde{g}_\ell(k_1x_1)[2\mu_1 U_{st}^{(1)}(x_1)f_\ell^{(1,j,\nu-1)}(x_1)+\sum_{\alpha=2}^{n}Q_{1\alpha}^{(j,\nu-1)}(x_1)]dx_1\}\tilde{f}_\ell(k_1x_1)$$
$$+\{-\frac{1}{k_1}\int_0^{X_1}\tilde{f}_\ell(k_1x_1)[2\mu_1 U_{st}^{(1)}(x_1)f_\ell^{(1,j,\nu-1)}(x_1)+\sum_{\alpha=2}^{n}Q_{1\alpha}^{(j,\nu-1)}(x_1)]dx_1\}\tilde{g}_\ell(k_1x_1),\ j=1,2,3,....,n;\nu\geq 1.$$

(26)

$$g_\ell^{(i,j,\nu)}(\sigma_i)=\{\delta_{ji}+\frac{1}{k_i}\int_0^{\Sigma_i}\tilde{g}_\ell(k_i\sigma_i)[2\mu_i U_{st}^{(i)}(\sigma_i)g_\ell^{(i,j,\nu)}(\sigma_i)+\sum_{\alpha=1}^{n}{}' Q_{i\alpha}^{(j,\nu)}(\sigma_i)]d\sigma_i\}\tilde{f}_\ell(k_i\sigma_i)$$
$$+\{-\frac{1}{k_i}\int_0^{\Sigma_i}\tilde{f}_\ell(k_i\sigma_i)[2\mu_i U_{st}^{(i)}(\sigma_i)g_\ell^{(i,j,\nu)}(\sigma_i)+\sum_{\alpha=1}^{n}{}' Q_{i\alpha}^{(j,\nu)}(\sigma_i)]d\sigma_i\}\tilde{g}_\ell(k_i\sigma_i),\ \ i=2,3,....,n,\ j=1,2,3,....,n,\ \nu\geq 0.$$

(27)

where X_1, Σ_i , $i=2,.........n$ specify the integration range away from the nucleus over which the integrals at equations (26,27) are calculated using Simpson's expansions.

Taylor expansion of $U_{st}^{(1)}(x_1), \tilde{f}_\ell(k_1x_1)$ and $\tilde{g}_\ell(k_1x_1)$ are used to obtain starting value of $f_\ell^{(1,j,0)}(x_1)$ (see ref. [8]).

Equations (26 , 27) can be abbreviated to

$$f_\ell^{(1,j,\nu)}(x_1)=a_1^{(j,\nu)}\tilde{f}_\ell(k_1x_1)+b_1^{(j,\nu)}\tilde{g}_\ell(k_1x_1),\quad j=1,2,3,.....n;\ \ \nu>0 \quad (28)$$

$$g_{\ell}^{(i,j,\nu)}(\sigma_i) = a_i^{(j,\nu)} \tilde{f}_{\ell}(k_i\sigma_i) + b_i^{(j,\nu)} \tilde{g}_{\ell}(k_i\sigma_i), \quad i = 2,....,n, j = 1,2,3,.....n; \ \nu > 0 \qquad (29)$$

The preceding coefficients of eqs (28,29) are elements of the matrices a^{υ} and b^{υ} which are given by:

$$\left.\begin{array}{l} (a^{\upsilon})_{ij} = \sqrt{2\mu_{m_i}/k_i}\, a_i^{(j,\upsilon)} \\ (b^{\upsilon})_{ij} = \sqrt{2\mu_{m_i}/k_i}\, b_i^{(j,\upsilon)}, \quad i,j = 1,2,....,n, \quad \nu > 0 \end{array}\right] \qquad (30)$$

and we can obtain the reactance matrix, R^{υ}, using the relation:

$$\{\mathrm{R}^{\upsilon}\}_{\beta\gamma} = \left\{ b^{\upsilon}\left(a^{\upsilon}\right)^{-1} \right\}_{\beta\gamma}, \quad \beta,\gamma = 1,2,3,.......,n \quad \nu > 0\,. \qquad (31)$$

The partial and totalcross sections in the present work are determined (in πa_0^2) by:

$$\sigma_{\beta\gamma}^{(\ell,\nu)} = \frac{4(2\ell+1)}{k_1^2}\left|\mathrm{T}_{\beta\gamma}^{\nu}\right|^2, \quad \beta,\gamma = 1,2,3,.......,n \quad \nu > 0 \qquad (32)$$

where k_1 is the momentum of the incident protons, ν is the number of iterations and $\mathrm{T}_{\beta\gamma}^{\nu}$ is the elements of the $n \times n$ transition matrix T^{ν} which is given by:

$$\mathrm{T}^{\nu} = \mathrm{R}^{\nu}\left(\mathrm{I} - \tilde{i}\,\mathrm{R}^{\nu}\right)^{-1}, \quad \nu > 0\,, \qquad (33)$$

where R^{ν} is the reactance matrix and I is a n x n unit matrix and $\tilde{i} = \sqrt{-1}$.

The total cross sections (in πa_0^2 units) can be obtained (in ν^{th} iteration) by:

$$\sigma_{ij}^{\nu} = \sum_{\ell=0}^{\infty} \sigma_{ij}^{(\ell,\nu)}, \quad i,j = 1,2,3, ... ,n \quad \nu > 0 \qquad (34)$$

3-PROTON POTASSIUM COLLISION

We are going toapply our MCSAin the case of n=4 (four channels CSA) to the scattering of p-K atoms. Our problem can be written in the form:

$$p + K(4s) = \begin{cases} p + K(4s) & \text{Elastic channel (first channel)} \\ H(1s) + K^{+} & H(1s) \text{ formation channel (second channel)} \\ H(2s) + K^{+} & H(2s) \text{ formation channel (third channel)} \\ H(2p) + K^{+} & H(2p) \text{ formation channel (fourth channel)} \end{cases} \quad (35)$$

$\Phi_1(r_1)$ is the valence electron wavefunction of the target (potassium) atom which is calculated using (Clementi's tables [9]), and $\Phi_i(\rho_i),\ i = 2,3,4$ are the wavefunctions of the hydrogen formation which are given by:

$$\Phi_2 = \frac{1}{\sqrt{\pi}}\exp(-\rho_2)\ ,\ \Phi_3 = \frac{1}{\sqrt{32\pi}}(2-\rho_3)\exp(-\rho_3/2) \text{ and } \Phi_4 = \frac{1}{\sqrt{32\pi}}\rho_4\cos\theta_{\rho_4,\sigma_4}\exp(-\rho_4/2)$$

(36)

4. RESULTS AND DISCUSSION

We start our calculations of p-K scattering by testing the variation of the static potentials $U_{st}^{(1)}(x_1)$ and $U_{st}^{(i)}(\sigma_i),\ i = 2,3,4$ of the considered channels with the increase of $x_1, \sigma_i\ (i = 2,3,4)$. It is found the excellent convergence of the calculated integrals can be obtained with Simpson's interval h=0.0625 , and number of points 512 which give integration rangeIR $=32a_0$ andwith iterations, $\nu = 50$. We have calculated thetotal cross sections of p-K corresponding to $0 \le \ell \le 6$ at incident energies between 50 and 1000 keV.

Table 1 shows the present total cross-sections of p-K scattering with those ofChoudhury and Sural [1],Daniele et al.[2], Ferrante et al. [4] in the energy range (50-1000 keV). Our results and those of comparing results in the range of energy (500-1000 keV.)are also displayed in Figs. (2-4).In Fig.5 we also show the present results of the total cross-sections of the four channels (elastic and the hydrogen formation (H(1s), H(2s),H(2p)) in the range of energy (50-1000 keV.). The present values of the total cross-sections of the four channels have similar trends of the comparison results.Our values of the total cross-sections of the four channels decrease with the increase of the incident energies.The calculated total cross-sections σ_{12} of H(1s) are about (9.6%-11.8%) lower than the Choudhury and Suralresults[1] and about (2.9%-13.2%) higher than those of Elkilany [8].The total cross-sections σ_{13} of H(2s) are slightly about (7.4%-9.7%) lower than those of Choudhury and Sural [1] and about (3.2%-22.6%) higher than those of Elkilany [8].Our values of the total cross-sections σ_{14} of H(2p) are about (7.1%-29.6%) lower than the available values of Choudhuryand Sural [1]. The present calculations show that, we have more H-formed if we are open more excited channels of H-formed in the collision of p-K atoms. The present calculated total cross sections have the same trend of the comparison results and give good agreement with the available previous results of Choudhury and Sural [1].

5. CONCLUSION

p-K scattering is studied using MCSA as a fourchannelproblem (elastic, H(1s), H(2s) and H(2p)). Our interest is focused on the formation of ground, $H(1s)$, and excited hydrogen, $H(2s)$, and $H(2p)$ in $p-K$ inelastic scattering. The difference between the fourchannelproblem and the three or twochannel problems (which are used by Elkilany ([6]-[8] is in improving the total cross sections of the considered channel by adding the effect of more kernels of the other three channels (in two channelproblem, we have only one kernel and in three channels, we have two kernels).

REFERENCES

[1] Choudhury, K. B.and Sural, D. B. Electron Capture in Ground and Excited States inProton-Alkali-Metal-Atom Collisions.1992 ; J. Phys. B25, 853-867.

[2]Daniele, R., Ferrante, G.and Fiordilino, E. Cross-Section of High-Energy Proton-Alkali Atom Charge Exchange in the Eikonal Approximation . 1979; IL NuovoCimento B54, 185-196.

[3] Ferrante,G. and Fiordilino, E.Proton-Alkali Atom Charge Exchangein the Eikonal Approximation.1980; IL NuovoCimento B57, 1-10.

[4] Ferrante,G., Fiordilino, E.and Zarcone, M. Valence and Core Electron Capturein Proton-Alkali Atom Collisions. 1979;IL nuovo Cimento B52, 151-164.

[5] Tiwari, Y. N. Formation of H-Atom in 2s Excited State of Proton-Lithium and Proton-Sodium Scattering. 2008; Pranama-journal of physics.,70,753-758.

[6] Elkilany, S. A.Effect of Polarization Potential on Proton–Sodium Inelastic Scattering. 2014;Brz. J. Phys., 44(6), 629-637.

[7] Elkilany, S. A. Formation of hydrogen atom in 2s state in proton–sodium inelastic scattering. 2015;Chin. Phys. B24(3), 033402-033407.

[8] Elkilany, S. A.Formation of Ground and Excited Hydrogen Atoms in Proton–Potassium Inelastic Scattering. 2016;Pramana-J Phys.,5,78-87.

[9]Clementi, E. and Roetti, C. Roothaan-Hartree -Fock Atomic Wave Functions.1974;Atomic Data Nuclear Data Tables, 14, 177-478.

Table 1. Present σ_{12}, σ_{13}, and σ_{14} (in πa_0^2) of p-K scattering with the results of [1], [2], [4] and [8].

k^2 keV.	Present σ_{11} Elastic	Present σ_{12} 1s	Choudhury [1] 1s	Daniele [2] 1s	Ferrante et al. [4] 1s	Elkilany [8] 1s	Present σ_{13} 2s	Choudhury [1] 2s	Elkilany [8] 2s	Present σ_{14} 2p	Choudhury [1] 2p
50	3.9912E-03	2.6012E-03	2.91E-03			2.5110E-03	5.8342E-04	6.38E-04	4.6134E-04	3.4652E-04	3.73E-04
100	1.7304E-03	4.9638E-04	5.51E-04	1.0862E-03	3.4992E-3	4.6494E-04	4.0021E-05	4.34E-05	3.0972E-05	2.2881E-05	3.19E-05
150	5.9509E-04	1.3581E-04	1.52E-04			1.3045E-04	9.6954E-06	1.06E-05	7.6303E-06	5.0585E-06	6.52E-06
200	9.8816E-05	4.6745E-05	5.30E-05			4.5405E-05	3.3239E-06	3.68E-06	2.6438E-06	1.3163E-06	1.87E-06
250	7.4749E-05	4.0914E-05				3.7385E-05	2.2665E-06		2.1942E-06	1.0957E-06	
300	5.7265E-05	3.7593E-05				3.0467E-05	2.0208E-06		1.7726E-06	4.9739E-07	
350	4.3379E-05	2.6831E-05				2.3289E-05	1.4868E-06		1.3497E-06	2.2509E-07	
400	3.0505E-05	1.6885E-05				1.5708E-05	9.7862E-07		9.2164E-07	1.2308E-07	
450	9.9314E-06	9.0918E-06				8.2370E-06	6.2442E-07		4.9136E-07	3.8615E-08	
500	3.1596E-06	8.6363E-07	9.55E-07			8.2923E-07	7.4507E-08	8.05E-08	5.8735E-08	1.7367E-08	2.06E-08
550	5.7985E-07	4.1476E-07					4.4936E-08			1.4209E-08	
600	2.8166E-07	1.9702E-07					2.2458E-08			8.7431E-09	
650	1.9051E-07	1.3089E-07					1.3457E-08			6.7504E-09	
700	1.5603E-07	1.0745E-07					7.2316E-09			3.1171E-09	
750	1.0531E-07	7.7671E-08					4.0742E-09			1.7424E-09	
800	6.0302E-08	4.3181E-08					2.8408E-09			1.2134E-09	
850	3.4993E-08	2.3842E-08					1.5941E-09			9.1426E-10	
900	1.3314E-08	9.1924E-09					1.3325E-09			6.3453E-10	
950	8.4385E-09	6.1925E-09					9.7984E-10			3.0241E-10	
1000	5.2655E-09	3.685E-09					5.9991E-10			1.3694E-10	

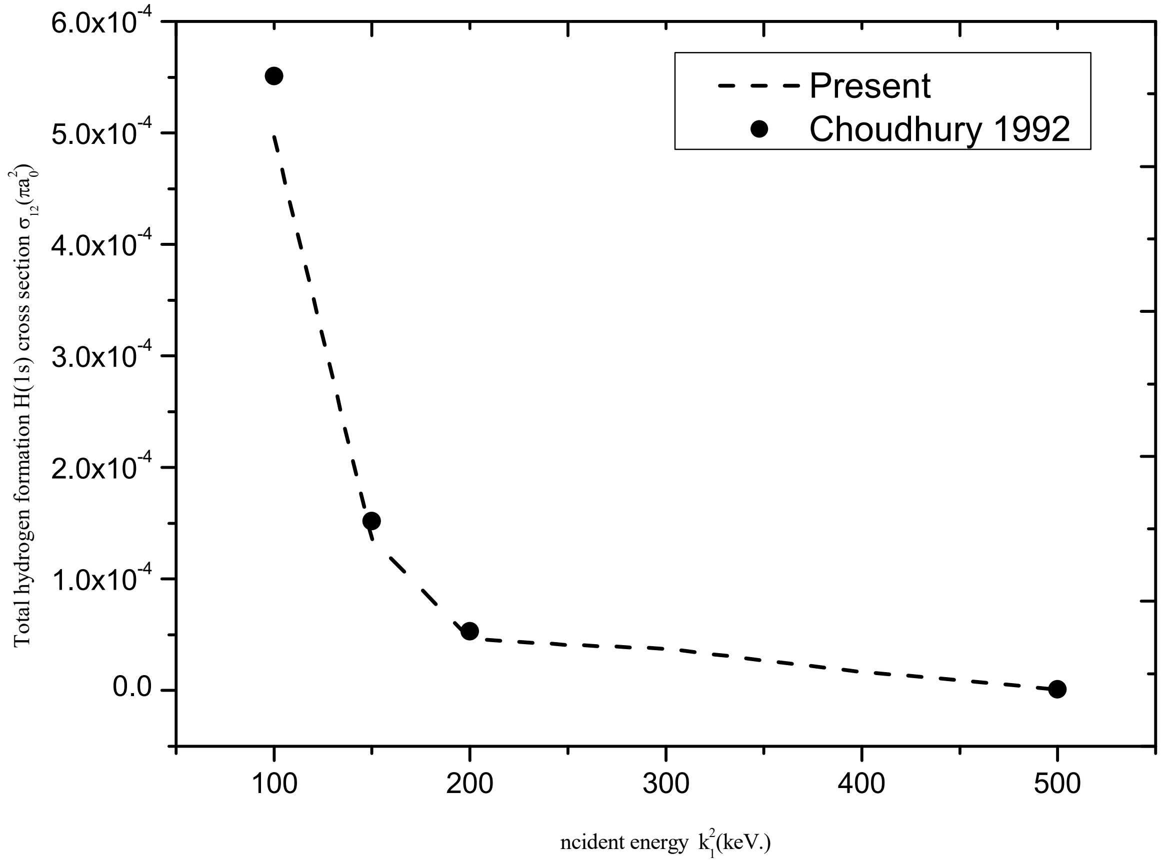

Fig. 2 σ_{12} (in πa_0^2) of $\mathrm{p-K}$ scattering with those of Choudhury and Sural [1].

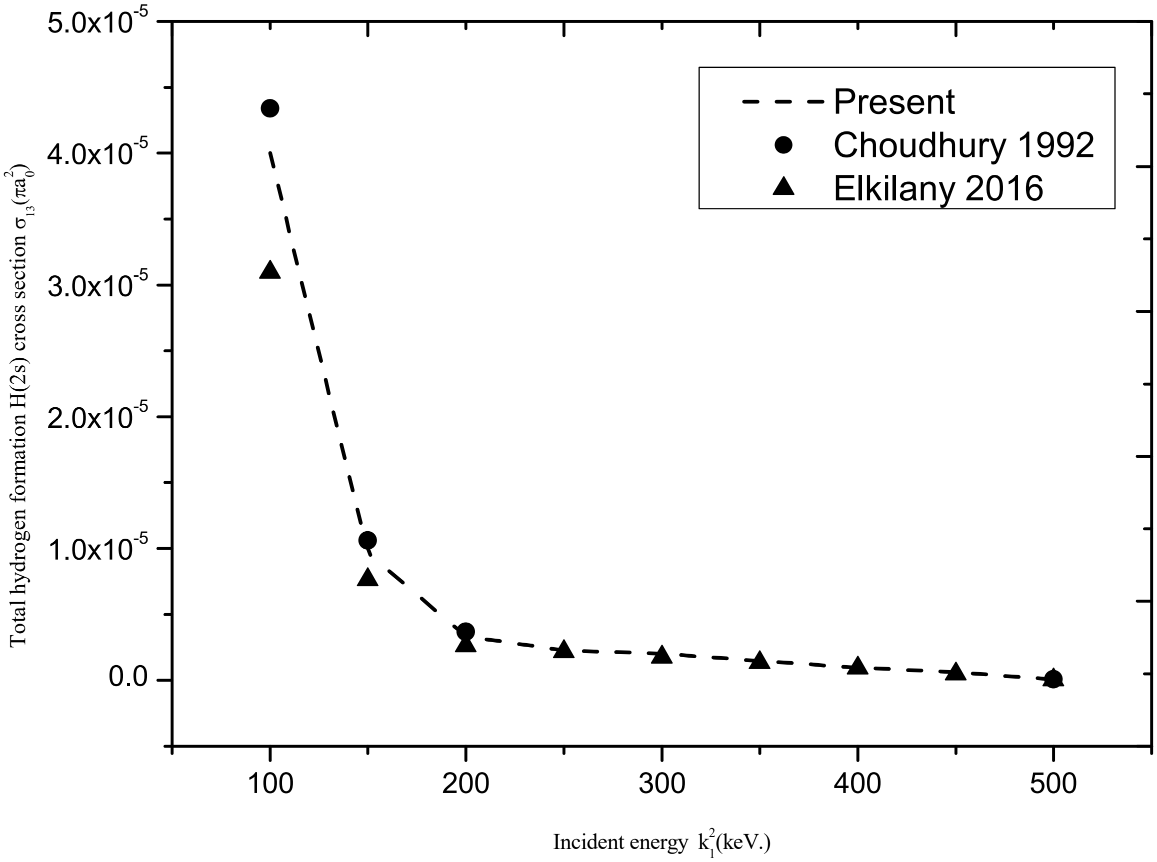

Fig. 3 σ_{13} (in πa_0^2) of $\mathrm{p-K}$ scattering with those of Choudhury and Sural [1].

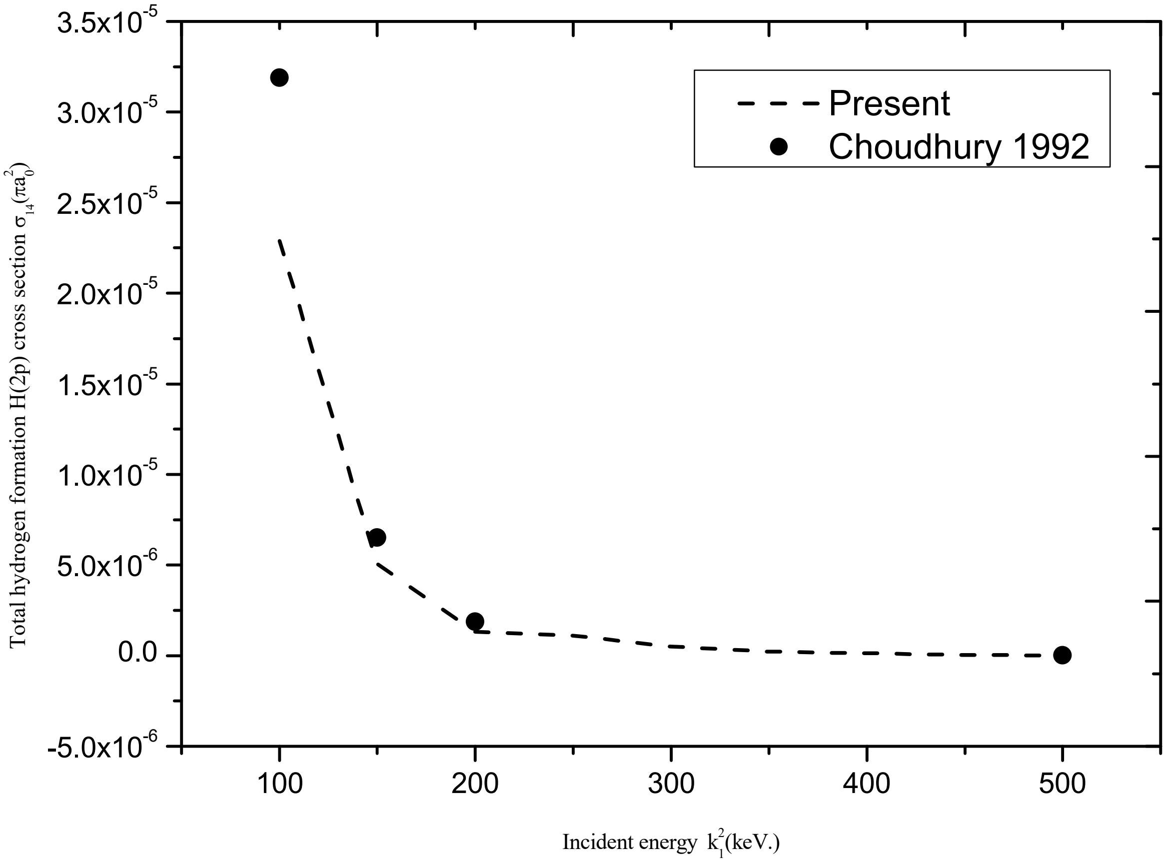

Fig. 4 σ_{14} (in πa_0^2) of $p-K$ scattering with those of Choudhury and Sural [1].

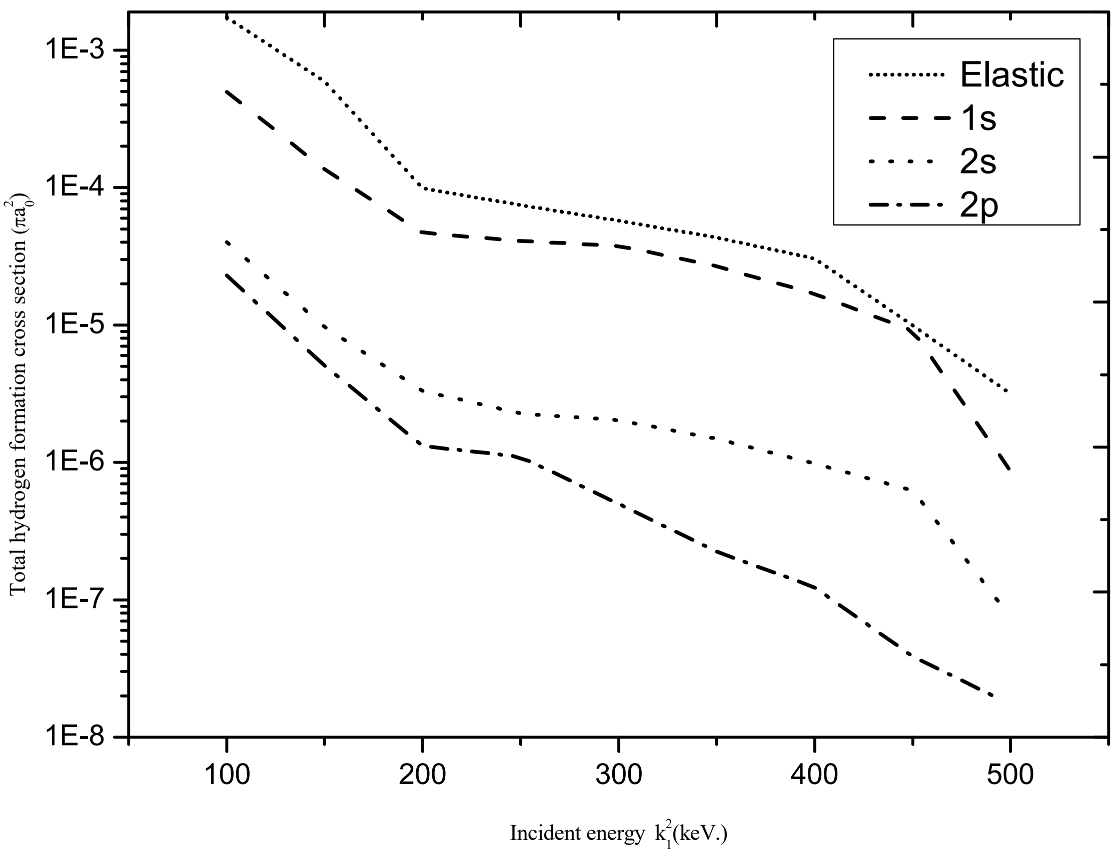

Fig. 5 Elastic, $H(1s)$, $H(2s)$ and $H(2p)$ cross sections (in πa_0^2) of $p-K$ scattering.