

In the case of the  $4^3D$  and  $3^3D$  channels the Wigner<sup>7)</sup> threshold law has been found to be valid over at least the first electronvolt above threshold. In the case of other channels studied the law does not seem to hold.

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#### 1.11 Elastic and inelastic differential cross sections in ion — atom collisions

R. McCARROLL and R. D. PIACENTINI\*, *Observatoire de Paris, 92-Meudon, France*

We report a series of investigations on differential cross sections in ion-atom collisions. The starting point is the impact parameter eikonal approximation<sup>1)</sup> which allows one to use standard impact parameter techniques to compute the differential cross section as a function of the angle. It will therefore be assumed throughout this work that if for a given impact parameter  $\varrho$  the probability amplitude of exciting state  $j$  is  $b_j(\varrho)$ , then the differential cross section  $\sigma_j(\vartheta)$  may be written as

$$\sigma_j(\vartheta) = 2\pi\mu^2v^2 \left| \int_0^\infty b_j(\varrho) J_m \left( 2\mu v \varrho \sin \frac{\vartheta}{2} \right) \varrho d\varrho \right|^2, \quad (1)$$

where  $\mu$  is the reduced mass of the colliding system,  $v$  is the velocity and  $m$  is the magnetic quantum number of state  $j$ .

Although (1) is a small-angle approximation, its range of validity covers the range of energy  $E$  and scattering angle  $\theta$  studied experimentally by Helbig and Everhart<sup>2)</sup> for  $H^+ - H$  collisions ( $E \gtrsim 150$  eV,  $\theta \gtrsim 6^\circ$ ).

In the energy range  $E \gtrsim 5$  keV, a molecular orbital expansion provides the most convenient representation of the wave function of the colliding system. For, since non-adiabatic effects are associated with the degeneracy of the  $2^2\Sigma_u$  and  $2^2\Pi_u$  electronic states of the molecule  $H^+$  in the limit of small internuclear separations, it suffices to use the  $2^2\Sigma_u$ ,  $2^2\Pi_u$  and  $2^2\Sigma_g$  states as our basis set<sup>3)</sup>. Using such a three-state molecular representation, we have computed the differential cross sections for elastic scattering, charge transfer and excitation (direct or exchange) of the 2p state of hydrogen.

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A selection of our results are given in Figures 1, 2 and 3. Fig. 1 illustrates the variation of the charge exchange probability  $P^{ex}$  as function of the angle for a given energy, Fig. 2 the variation of  $P^{ex}$  as a function of the energy for a fixed

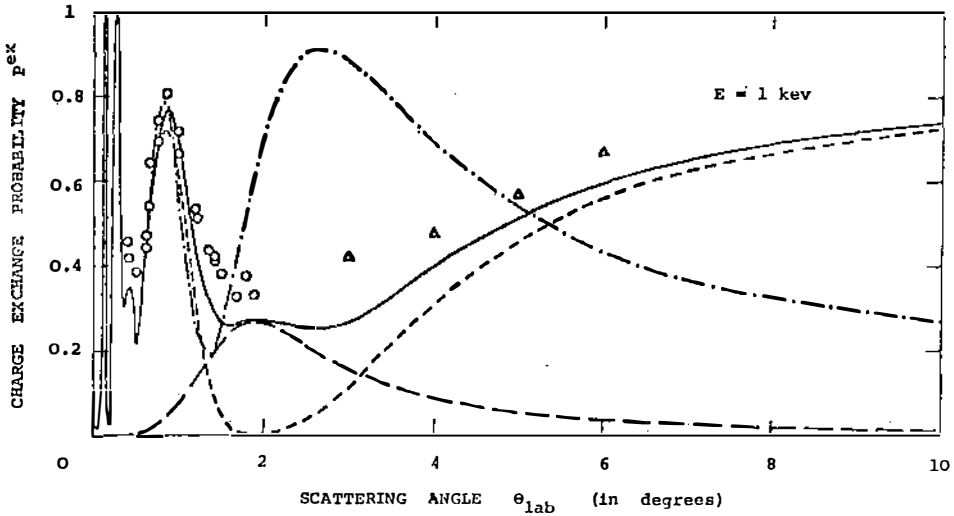


Fig. 1. Charge exchange probabilities (---)  $P_{1s}^{ex}$ , (---)  $P_{2p}^{ex}$  and its sum (—)  $P^{ex}$  as a function of the scattering angle for an energy of 1 keV. o and  $\Delta$ , experimental results<sup>2)</sup> (Also plotted are the computed values of  $P^{ex}$  (— · — · —) in the adiabatic approximation).

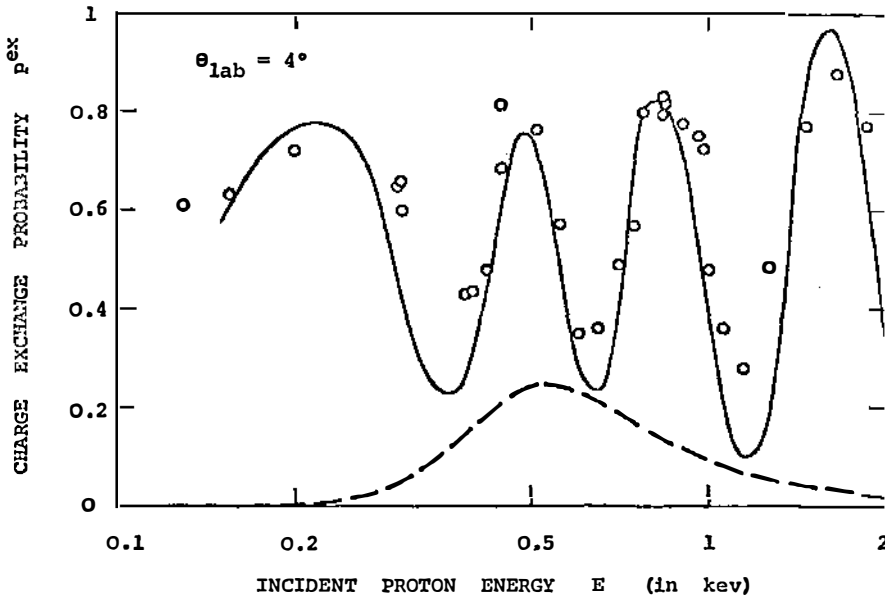


Fig. 2. Charge exchange probabilities (---)  $P_{2p}^{ex}$  and (—)  $P^{ex}$  as a function of the incident proton energy for a given scattering angle of 4 degrees. o, experimental results<sup>2)</sup> (Note:  $P_{1s}^{ex}$  may be obtained by subtracting  $P_{2p}^{ex}$  from  $P^{ex}$ ).

scattering angle, and Fig. 3 the mapping of the maxima and minima of  $P^{ex}$  in the  $(E, \theta)$  plane. The agreement with experiment is everywhere very satisfactory.

Of particular interest is the influence of non-adiabatic effects. Thus, for  $E\theta \lesssim 1$  keV · degree, the adiabatic theory is valid, but as  $E\theta$  increases beyond, non-adiabatic effects dephase completely the oscillations of  $P^{ex}$ .

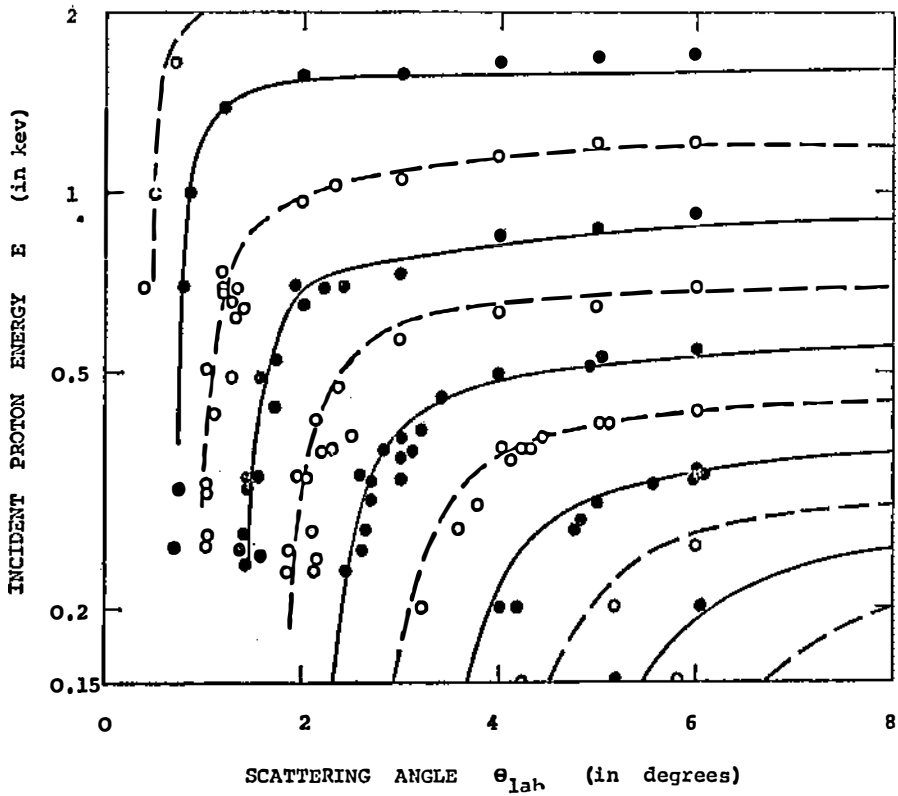


Fig. 3. Mapping of the experimental (●) and theoretical (—) maxima and experimental (○) and theoretical (---) minima of the charge exchange probability  $P^{ex}$  in the  $(E, \theta)$  plane for  $H^+ - H$  collisions.

An extension of these calculations to the treatment of the  $He^+ - He$  collisions<sup>4)</sup> in a two-state molecular expansion employing analytic potentials proposed by Chen, Wang and Watson<sup>5)</sup> gives good agreement with the elaborated experimental results of Nagy, Fernandez and Pollack<sup>6)</sup> in the corresponding energy range of  $E\theta \lesssim 4$  keV · degree (see Fig. 4).

In conclusion, our work provides a striking illustration of how the impact parameter eikonal approximation may be used to explain with remarkable preci-

sion the detailed characteristics of  $H^+ - H$  (and  $He^+ - He$ ) collisions over a wide range of energy and scattering angle<sup>7,8</sup>).

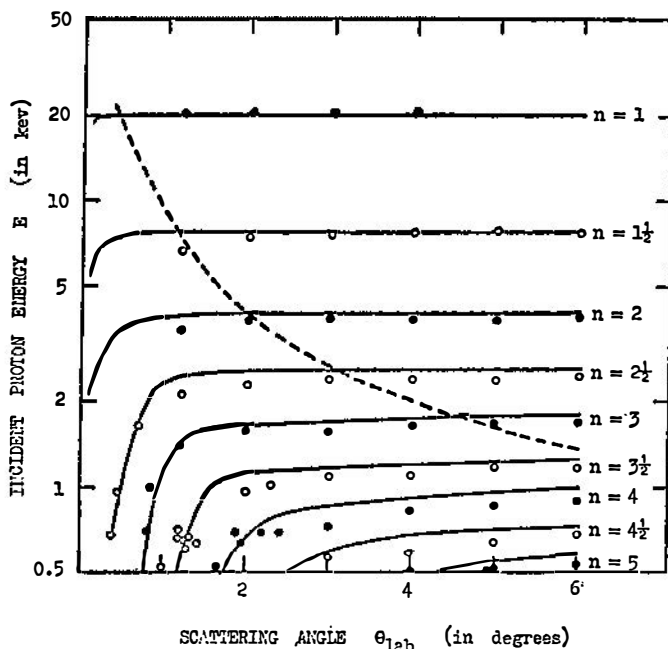


Fig. 4. Single charge exchange probability  $P_0$  as a function of the angle of scattering for an energy of 1 keV. ●, experimental results of Nagy, Fernandez and Pollack<sup>6</sup>); ○, experimental results of Lockwood, Helbig and Everhart<sup>9</sup>); ——— present results [( - - - ) designates the region of  $E\theta$  for which the two-state molecular calculations are not valid].

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