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CROSS SECTION AND POLARIZATION OF BALMER-ALPHA RADIATION PRODUCED IN CHARGE-EXCHANGE COLLISIONS OF PROTONS WITH N_2†

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Measurements of the cross section for production of Balmer-alpha radiation in charge-exchange collisions of 2- to 35-keV protons with N_2 and the associated polarization of the Balmer-alpha radiation are reported here. The cross section has been measured twice previously.[1,2] However, because of the finite radiative lifetimes associated with the $n = 3$ states of hydrogen and the relatively short collision chambers used, the previous measurements could, at best, rely on estimates of relative populations of $3s$, $3p$, and $3d$ states in determining the cross section. The measurements reported here were made at a point sufficiently far from the entrance of the proton beam into the collision chamber that a knowledge of the above relative populations was unnecessary. These measurements have revealed structure in the cross section.

Neglecting processes involving two or more collisions and contributions from cascade effects, the change in number density of excited hydrogen atoms can be described by the equation

$$dn_m/dz + A_m v^{-1} n_m = nn^+\sigma_m, \tag{1}$$

where n_m is the number density of hydrogen atoms in the state m, A_m is the spontaneous transition probability from the state m to all lower energy states, v is the velocity of the protons, n is the number density of N_2 molecules, n^+ is the number density of protons in the beam, and σ_m is the cross section for excitation of the state m of hydrogen in charge-exchange collisions of protons with N_2. Under the conditions of our experiment, $A_m/v \gg \alpha$, where $\alpha = n\sigma_c$ and σ_c is the total charge-exchange cross section for protons in N_2. The solution of Eq. (1) subject to this condition is

$$n_m = n\sigma_m n^+ v A_m^{-1}[1-\exp(-A_m z/v)], \tag{2}$$

where z is the distance from the entrance of the collision chamber. When $z \gg v/A_m$, as in this experiment, the only change in n_m with z is that due to the decrease in n^+ from charge-exchange collisions. Under such conditions the observed volume emission rate is given by

$$I = nn^+v(\sigma_{3s} + 0.118\sigma_{3p} + \sigma_{3d}) = nn^+v\sigma_\alpha, \tag{3}$$

where σ_α is the cross section for the production of Balmer-alpha radiation and is the cross section reported here.

The Balmer-alpha detector was a photometer using a well-blocked interference filter having a bandpass of 12 Å centered at 6563 Å. The measurements were carried out at a point 1 m from the entrance of the proton beam into the collision chamber. Target gas pressures were about 10^{-4} Torr and the energy resolution of the 0.01- to 2.0-μA beam was 20 to 50 eV for proton energies below 15 keV.

The results are shown in Fig. 1 along with the uncorrected cross sections measured by Philpot and Hughes[1] and by Sheridan and Clark.[2] Each of our points represents an average of about 10 data points. The relative scatter in

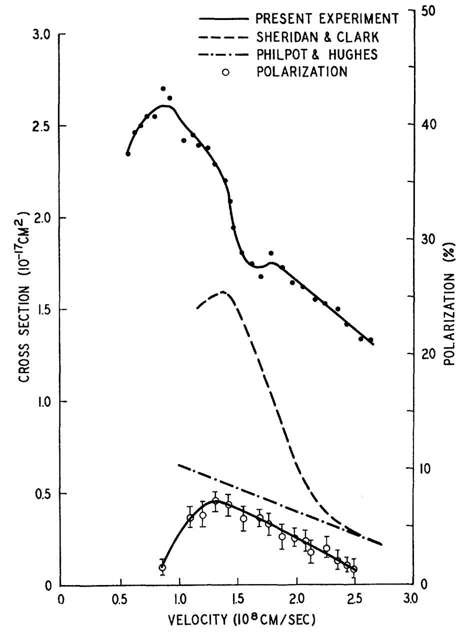

FIG. 1. Measured Balmer-alpha cross sections and polarization of Balmer-alpha radiation produced in proton-nitrogen collisions.

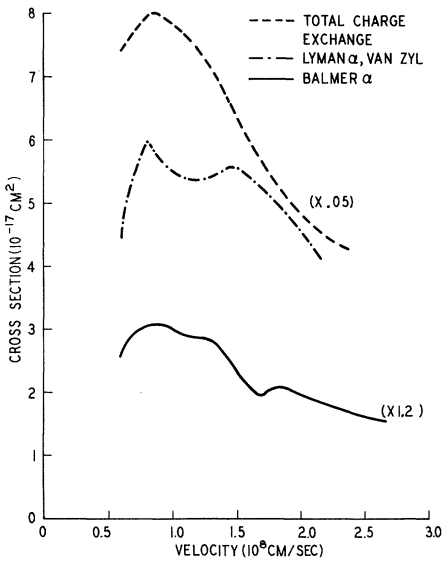

FIG. 2. Comparison of Balmer-alpha, Lyman-alpha, and total charge-exchange cross sections for proton-nitrogen collisions.

our cross-section data was less than ±5% under a wide range of conditions. The estimated systematic error in our cross section is ±25%. The polarization measurements indicate a nearly isotropic distribution in Balmer-alpha radiation and a maximum in the polarization at about the same velocity as the maximum in the cross section.

The significance of the structure in our measured cross section is shown in Fig. 2 where it is compared with the Lyman-alpha cross section measured by Van Zyl[3] and our measured total charge-exchange cross section. The low-energy maximum in the Balmer-alpha cross section appears at the same velocity as the maximum in the total charge-exchange cross section and the low-energy maximum in the Lyman-alpha cross section. The "bump" in our Balmer-alpha cross section at 1.3×10^8 cm/sec appears at about the same velocity as the second maximum observed by Van Zyl. The maximum in the Balmer-alpha cross section at 1.85×10^8 cm/sec appears where the adiabatic maximum rule, i.e., $v_{\text{max}}=a\Delta E/h$, would predict a maximum with $a = 5.5$ Å. The presence of the observed structure can be accounted for by coupling of the $n=3$ states to the $n=2$ and $n=1$ states of hydrogen or by the existence of three discrete characteristic elastic energy losses analogous to results first observed by Morgan and Everhart[4] and explained by a statistical model for the collision. Both of these descriptions of the collision reaction may be essentially equivalent in the prediction of structure such as that reported here.

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