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Author
Bae, Y.K.

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EXCITATION CROSS SECTIONS OF HYDROGEN RELEVANT TO NEUTRAL-BEAM DIAGNOSTICS

Y.K. Bae, C.F. Burrell, and R.H. MacFarland

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Excitation Cross Sections of Hydrogen Relevant to Neutral-Beam Diagnostics

Y. K. Bae, C. F. Burrell, R. H. MacFarland

Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720

The Balmer-alpha radiation emitted by hydrogen and deuterium beams has been used by a number of laboratories\textsuperscript{1,2,3} as a diagnostic of neutral beam parameters. One important neutral beam parameter is the species mix between \(H^+, H_2^+,\) and \(H_3^+\) ion currents produced by the ion source and accelerator. This species mix can be measured by analysis of the Balmer-alpha radiation if the beam is observed along an off-normal optic axis with sufficient spectral resolution to separate the Doppler shifted components of the beam.

An impediment to this approach to measuring the ion species is that some of the required cross sections have not been measured. Hughes\textsuperscript{4} and coworkers have measured the cross sections for the production of \(H\) atoms in the 3s, 3p and 3d states for a proton beam incident on a molecular hydrogen target at energies from 10 to 120 keV. Hughes et al.\textsuperscript{5} have also measured the cross section for the production of \(H\) atoms in the 3s state by the dissociation of \(H_2^+\) and \(H_3^+\) ions incident on a molecular hydrogen target. There is however no published data for the excitation of \(H\) atom projectiles, dissociation of \(H_2^+\) and \(H_3^+\) projectiles into the 3p or 3d states of the \(H\) atom, or measurements of the collisional destruction cross section for the \(n=3\) levels in the energy range between 40 and 120 keV.

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To study these cross sections we have constructed the experimental apparatus shown in the schematic diagram. The experimental system used in this research included a 250 keV TNC (Texas Nuclear Corporation) R.F. ion source accelerator. The ion beam is magnetically analyzed, focused, chopped and steered into a gas cell. The gas cell is defined by a movable 1/16 inch diameter aperture so that the distance the beam travels through the gas cell before it is optically analyzed can be varied. The pressure was measured by a Barocel pressure gauge which was calibrated by an oil manometer. The beam current can be monitored in two ways. A Faraday cup which is protected against secondary electron emission by a crossed magnetic field measures the ion current. A pyroelectric detector responds to both the charged and neutral fractions of the beam.

Chopping of the ion beam at 4.3 Hz allows for phase sensitive amplification of the pyroelectric detector output and for gating of the photomultiplier tube output to measure background and signal over the same time interval. The integrated beam current, scaler and timer outputs are recorded by a model 9845-B Hewlett Packard computer in which the data is analyzed and plotted automatically.

The beam light is observed at an angle of 55° to the beam axis. This simplifies the correction for polarization and permits us to observe both the dissociative excitation of the target gas and the Doppler shifted beam radiation. The lines are resolved by a 0.3 m monochromator which utilizes a 82 mm diameter lens and a Littrow mounted grating and was designed to have a high throughput. The light signal is detected by a photomultiplier tube (EMI 9862) which is cooled to -25°C. Operating at an anode voltage of 1900 v the tube has sufficient gain for single photoelectron counting and has a dark current of 5 counts per second.
Our experimental program is to measure the photon emission rate as a function of distance into the gas cell and the gas pressure for incident $H^+$, $H_2^+$, and $H_3^+$ ion beams. The rate of photon emission for an $H^+$ ion beam traversing a thin target is proportional to:

$$I = \sum_i A_{ij} \sigma_i^* N_a I_b \left( 1 - \exp\left(\frac{-x}{\nu \tau_i}\right)\right) \left(1/\tau_i\right)$$

where $N_a$ is the target gas density, $I_b$ is the beam current, $\nu$ the beam particle velocity, $\tau_i$ the radiative lifetime, $A_{ij}$ the radiative transition rate and $\sigma_i^*$ is the cross section for excitation of the level $i$; $i$ is summed over the 3s, 3p and 3d levels. A least squares fit to the data can determine the cross sections.

In a thick target the photon emission from the target atoms should be proportional to:

$$I = N_a I_b \left( \sigma_+^* y_+ + \sigma_0^* y_0 \right)$$

where $\sigma_+^*$ and $\sigma_0^*$ are the cross sections for $H^+$ and $H_0^+$ respectively and $y_+$ and $y_0$ are the ionic and neutral fractions in the beam. Expressing $y_+$ and $y_0$ in terms of the charge exchange cross sections $\sigma_{10}$ and $\sigma_{10}$ we have:

$$I = N_a I_b \left( \sigma_+^* \left( F_{1\infty} + F_{0\infty} e^{-G_1} \right) \right)$$

$$+ \sigma_0^* \left( F_{0\infty} \left(1 - e^{-G_1} \right) \right)$$

where $F_{1\infty} = \sigma_{01}/\sigma_T$, $F_{0\infty} = \sigma_{10}/\sigma_T$, $\sigma_T = \sigma_0 + \sigma_{10}$ and $x$ is the target thickness to the point of observation. We have found this gives a good fit to the data and permits us to measure the cross section for an $H$ atom beam as well as a proton beam.
Balmer-α Excitation Cross Section
Schematic Diagram

Grating
Lens
PM.T.

Pyroelectric detector/Faraday cup
54.76°

Movable aperture
(1/16")

Two O-rings

Accelerator
Large chamber
D.P.
Ion G
4 inch
Barocel

To electronics
Gas inlet
D.P.
References


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