Laboratory Measurements of Solar-Wind/Comet X-Ray Emission and Charge Exchange Cross Sections

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The detection of X-rays from comets such as Hyakutake, Hale-Bopp, d'Arrest, and Linear as they approach the Sun has been unexpected and exciting [1,2]. This phenomenon, moreover, should be quite general, occurring wherever a fast solar or stellar wind interacts with neutrals in a comet, a planetary atmosphere, or a circumstellar cloud. The process is, $O^{8+} + H_2O \rightarrow O^{7+*} + H_2O^+$, where the excited O^{7+*} ions are the source of the X-ray emissions. Detailed modeling has been carried out of X-ray emissions in charge-transfer collisions of heavy solar-wind HCIs and interstellar/interplanetary neutral clouds [3]. In the interplanetary medium the solar wind ions, including protons, can charge exchange with interstellar H and He. This can give rise to a soft X-ray background that could be correlated with the long-term enhancements seen in the low-energy X-ray spectrum of ROSAT. Approximately 40% of the soft X-ray background detected by Exosat, ROSAT, Chandra, etc. is due to CXE [3]: our whole heliosphere is glowing in the soft X-ray due to CXE.

Comet-modeling calculations to date have (a) used an approximate, over-barrier expression for the charge-exchange (CXE) cross section, (b) assumed a flat energy dependence of cross section, and (c) neglected multiple charge exchanges. To understand the intensity and spatial extent of the X-ray emissions, X-ray emission cross sections and absolute CXE cross sections for process such as defined in Eq. (1) have been measured using the charge-exchange beam line at the JPL Highly-Charged Ion Facility (HCIF) [4]. The projectiles have been partially- and fully-stripped H, He, C, N, O, Ne, and Fe ions interacting with the comet molecules He, H_2, CO, CO_2, and H_2O. Absolute CXE cross sections have been measured, and normalized X-ray emission cross sections reported for the major HCI components of the solar wind [5-8]. The heavier HCI components will produce high-energy X-rays. Data have been acquired on $Fe^{(5-13)+}$ [9].

A schematic of the CXE beam line is shown in Fig. 1. Experimental details are given in Refs. [7,8]. Briefly, the HCI beam enters the gas collision cell through a series of beam-collimating apertures **A**. Charge exchange takes place, and the charges of the exiting ions are analyzed using a retarding potential- difference method with the grids **RA**. Absolute CXE cross sections are obtained by knowledge of the incident and transmitted beam currents, the gas density in the cell (with corrections for effusion from the cell's entrance and exit apertures, and thermal transpiration), and the effective cell length. Checks are made to ensure full angular collection of the retarded ion beams by varying aperture sizes in **RA**; and for the presence of metastable levels in the incident HCI beam by carrying out CXE measurements with quenching gas in the beam line. Recent experimental results [6] for CXE of H^+, He^+ and He^{2+} on H_2O are shown in Fig. 2.

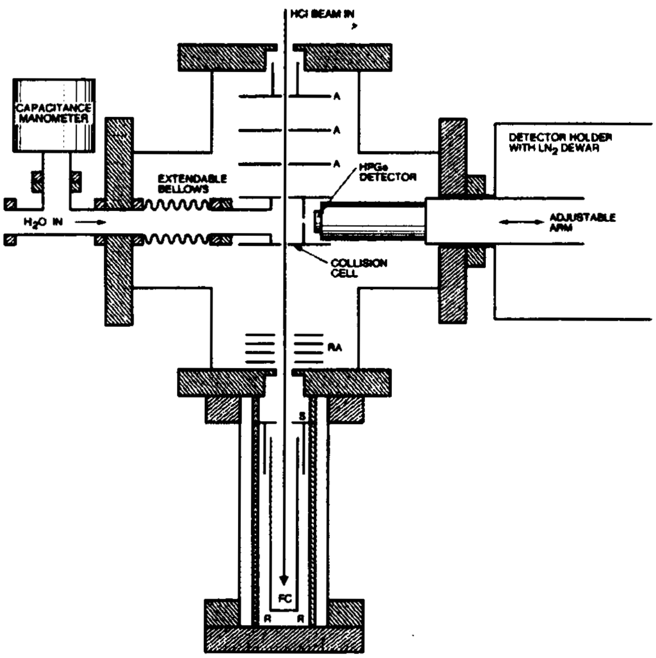

Figure 1. Detail of the JPL HCIF charge-exchange beamline. The legend is: (**A**) input HCI beam-defining apertures, (**RA**) retarding-field apertures, (**S**) secondary electron shield, (**FC**) Faraday cup, (**R**) support rods, (**LN$_2$**) liquid nitrogen cooling for the HPGe detector crystal.

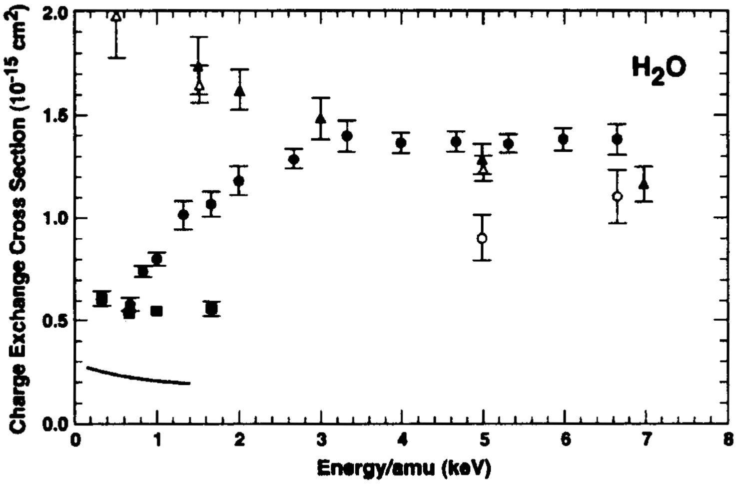

Figure 2. Absolute single charge exchange cross sections of H^+ (▲), He^+ (■), and He^{2+} (●) in H_2O. Data by others are given for H^+ (△ and ▬) and for He^{2+} ○). See Ref. [6] for details.

Placed orthogonal to the incident HCI beam direction is an HPGe X-ray detector which views the X-ray emissions from the gas cell. Gaussian profiles centered on the known transition energies are fitted to the observed spectra. The estimated FWHM of these fits is 102 ± 2 eV, which is narrower than the 170 eV width of Si-Li detectors used in other measurements. A series of X-ray spectra for the collisions of O^{7+}, O^{8+}, Ne^{9+}, and Ne^{10+} with H_2O is shown in Fig. 3. Spectra for collisions of Ne^{10+} with He, H_2, CO_2, and H_2O are shown in Fig. 4. Prominent in the spectra are the Lyman transitions $np \rightarrow 1s (n = 2 - 5)$ which are important contributors to the observed cometary X-ray emissions. Future work will be extended to Mg^{q+} charge states, and include as well H and NH_3 as targets.

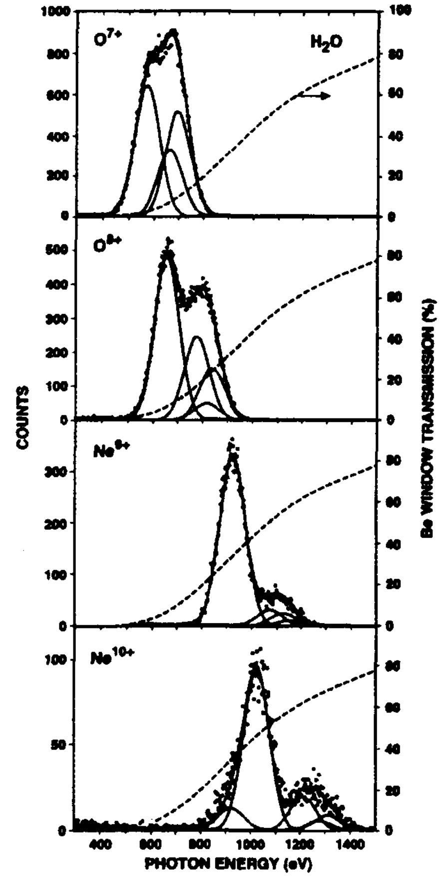

Figure 3. X-Ray emission spectra for the collision of the indicated ions with H_2O at energies of 70 keV. Data are uncorrected for the Be window transmission, shown by the dashed line (- - -). The underlying curves are the Lyman transitions np → 1s (n=2-4 and 5).

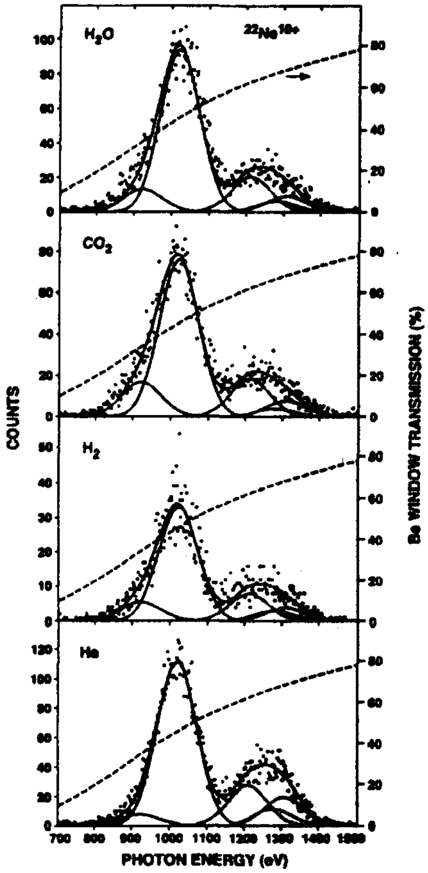

Figure 4. X-Ray emission spectra for the collision of $^{22}Ne^{10+}$ ions with He, H_2, CO_2, and H_2O at 70 keV energy. Data are uncorrected for the Be window transmission, shown by the dashed line (- - -). The underlying curves are the Lyman transitions np → 1s (n=2-5).

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