UV photoabsorption cross sections of CO, N_2, and SO_2 for studies of the ISM and planetary atmospheres

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Abstract

We report high-resolution laboratory measurements of photoabsorption cross sections of CO, N_2, and SO_2 in the wavelength range 80 to 320 nm. The motivation is to provide the quantitative data that are needed to analyze observations of absorption by, and to model photochemical processes in, the interstellar medium and a number of planetary atmospheres. Because of the high resolution of the spectrometers used, we can minimize distortion of the spectrum that occurs when instrument widths are greater than the widths of spectral features being measured. In many cases, we can determine oscillator strengths of individual rotational lines – a unique feature of our work. Abstract text here.

1. Carbon Monoxide (CO)

CO is the second most abundant interstellar molecule after H_2. Because CO is readily observed, it is used as a tracer of molecular material. However, estimates of abundances of CO are poorly determined observationally and not well understood theoretically. Incomplete or inconsistent molecular parameters contribute to many of the difficulties. Consequently, the acquisition of improved photoabsorption cross section and spectroscopic data for CO at VUV wavelengths has been a major focus of our research program in the past few years (Smith *et al.* 1994; Yoshino *et al.* 1995; Stark *et al.* 1999a).

Recently, we have studied the absorption spectrum of five weaker intersystem (spin-changing) bands in order to provide line oscillator strengths (f-values) for absorption features seen by Federman *et al.* (1994) and Sheffer *et al.* (2002). f-values can be difficult to calculate for these weak bands because each upper level is perturbed by a number of vibrational levels of the A state. Therefore, we have emphasized direct measurements with the 6.65-m 6VOPE normal-incidence spectrometer at the Photon Factory, a synchrotron radiation source in Tsukuba, Japan. This spectrometer has a resolving power of about 170,000 and an order-sorting predisperser that greatly reduces spurious signal. An example of our data is shown in Figure 1; the instrument resolution was greater than the Doppler dominated width of the spectral lines, so the line shapes are somewhat distorted in this spectrum.

Our line f-values for the $d(7)$-$X(0)$ and $e(4)$-$X(0)$ bands are given by Stark *et al.* (2002). These are the first direct measurements of individual line f-values for an intersystem band of CO. Our measured values generally confirm the band simulations of Rostas *et al.* (2000) and those determined by Sheffer *et al.* (2002) from observations of interstellar absorption.

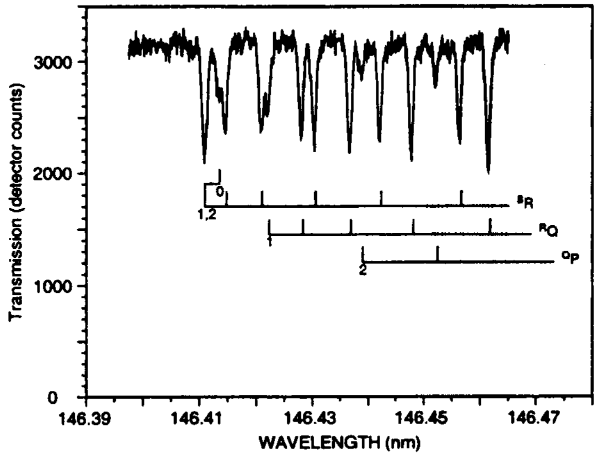

Figure 1. CO $d(7)$-$X(0)$ bandhead region.

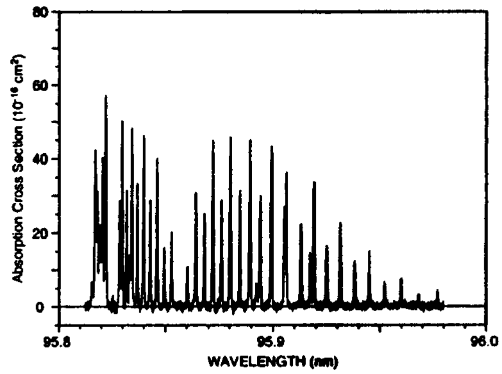

Figure 2. Measured photoabsorption cross section for the $c_4'(0) - X(0)$ band of N_2.

2. Molecular Nitrogen (N_2)

The strongest band of N_2, $c_4'(0) - X(0)$ at 95.9 nm, is in the FUSE wavelength range and is not blended with CO or H_2 features. The most prominent EUV emission features in the airglows of Titan and Triton, where N_2 is the major atmospheric constituent, originate from the $c_4'\,{}^1\Sigma_u^+(v' = 0)$ level. Like many of the VUV lines of N_2, those of the $c_4' - X$ band are extremely sharp, with natural line widths much less than the Doppler widths. Line f-values cannot be reliably calculated from band f-values and Hönl-London factors because of perturbations: measurements are required. The highest possible resolving power is necessary to minimize distortions of the spectrum and concomitant obscuration of saturation effects.

We again used the 6.65-meter spectrometer at the Photon Factory. Data for the the $c_4'(0) - X(0)$ band of N_2 are shown in Figure 2. Our results (Stark *et al.* 2000) are the first measurements of individual line f-values for this band. Our data are available in our N_2 data archive at http://cfa-www.harvard.edu/amdata/ampdata/N2ARCHIVE/n2home.html. We have also measured band f-values and line widths for a number of the ~ 100 bands of N_2 in the 80 to 100 nm wavelength region. These bands are important for understanding the temperature-density profiles of the atmospheres of Titan and Triton. Analysis of these data is in progress.

3. Sulfur Dioxide (SO_2)

Analysis of the UV spectrum of Io and modelling of the chemical composition and photochemical processes in its atmosphere require knowledge of the photoabsorption cross section of SO_2 over a wide wavelength range at temperatures from 110 to ~500 K. Our laboratory program, which also supports HST observations of the atmosphere of Venus, is producing such data over the wavelength range 190 to 325 nm with orders of magnitude higher resolving power than previous work.

The ultraviolet spectrum of SO_2 is dominated by two broad regions of absorption: 175 to 230 nm, which is the stronger, and 250 to 320 nm. Because the upper electronic states participating in these transitions are strongly perturbed, no comprehensive rotational analyses exist or are likely in the near future. This means that the temperature dependence of the SO_2 absorption spectrum, needed for analyses of planetary atmospheres, cannot be reliably modelled but must be measured. The region is exceedingly complex at room temperature; previous photoabsorption measurements have been unable to fully resolve it.

We used the VUV Fourier transform (FT) spectrometer at Imperial College, London (Thorne et al. 1987) for two sets of measurements. Cross section data for the 198 to 220 nm region have been published (Stark *et al.* 1999); results for the region 220 to 235 nm are reported here (see also Rufus *et al.* 2002). Figure 3 shows recent data plotted on linear and log scales; note that the structure (see inset) is essentially all real, *i.e.*, not noise. Our data are compared to those of Manatt & Lane (1993) and Wu *et al.* (2000) over a limited spectral region in Figure 4.

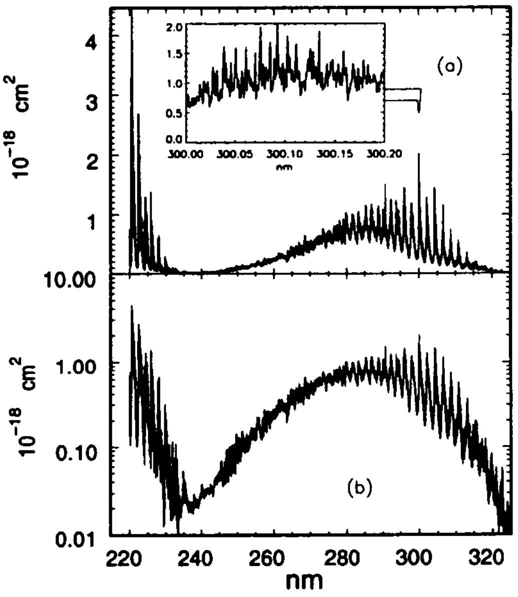

Figure 3. Photoabsorption cross section of SO_2 at 295 K measured with a resolution of 4 to 32 mÅ. Inset shows structure in a 0.2 nm region. Note that the *SNR* for this measurement was about 100, so the structure shown in the inset is real.

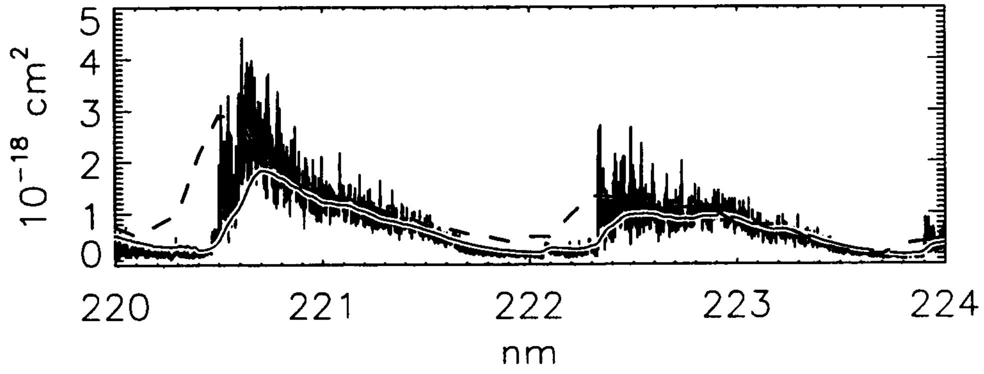

Fig. 4.— Comparison of our results (highly structured line) with those of Manatt and Lane [1993] (dashed line) and Wu et al. [2000] (smooth solid line with white border). Note that, on the average, the data roughly agree, but that our values for the peak cross sections are about a factor of two larger.

Acknowledgments

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