

# VUV Absorption Spectrum of Acetylene for Diagnosis of Atmosphere of Titan and Saturn

*Absorption cross sections of gaseous acetylene, C<sub>2</sub>H<sub>2</sub>, at 298 and 85 K were measured in wavelength range 110-155 nm with a slit-jet system coupled to a synchrotron as a source of VUV light. The cross sections of C<sub>2</sub>H<sub>2</sub> are applicable to determine properties sensitive to temperature for diagnostic work on Saturn and Titan.*

B.-M. Cheng  
NSRRC, Taiwan

Spectral observation in the vacuum-ultraviolet (VUV) range is effective for the identification and determination of abundances of hydrocarbon species in space; VUV spectra thus provide a powerful means that has been applied during spacecraft missions. In addition, to assess the photochemically induced changes in stellar media, one must have quantitative information about the absorption cross sections of pertinent planetary molecular species in the VUV range. For this purpose, we have determined the absorption cross sections of several interstellar molecular species in the VUV range, but most measurements were made near 300 K.

The temperatures of various astronomical environments differ much from 300 K; for instance, the relevant atmospheric temperature is ~170 K for Jupiter, ~140 K for Saturn, ~120 K for Titan, ~50 K for Triton, and even lower for Neptune and Uranus. Molecular cross section values might vary significantly with temperature, especially for sharp absorption features. Molecular absorption cross sections measured under our ambient conditions are hence generally inadequate to explain the observed spectral features and to allow an accurate determination of the abundance of atmospheric constituents in cold outer space. Therefore, measurements of absorption cross sections of interstel-

lar molecules are hence preferable at both high resolution and low temperature.

The Cassini Ultraviolet Imaging Spectrograph (UVIS) recorded VUV spectra of targets in exploring the Saturn system. During the Titan flyby, the UVIS detected six compounds – CH<sub>4</sub>, C<sub>2</sub>H<sub>2</sub>, C<sub>2</sub>H<sub>4</sub>, C<sub>2</sub>H<sub>6</sub>, HCN and C<sub>4</sub>H<sub>2</sub> – in the atmosphere of Titan. The observed spectrum was compared with the simulation and served to extract abundances of the six absorbers; the comparison of laboratory and atmospheric observation data looks encouraging, but it is imperfect.

For the resonance features of C<sub>2</sub>H<sub>2</sub>, the observed spectrum shows much deeper absorption in the UVIS data than is produced in a synthesis with experimental cross sections. Shemanky *et al.* considered that the laboratory measurements were undertaken with inadequate spectral resolution resulting in cross sections determined from saturated data, or that incomplete temperature dependence of cross sections affected the accuracy of the results.<sup>1</sup>

The absorption cross sections of C<sub>2</sub>H<sub>2</sub> are sensitive to temperature. The least temperature at

which absorption cross sections of gaseous acetylene in the VUV region have been recorded appears to be 150 K, which is still not low enough for an understanding of the astrophysical spectral properties of C<sub>2</sub>H<sub>2</sub> in cold space. An accurate measurement of VUV absorption cross section of gaseous C<sub>2</sub>H<sub>2</sub> at temperatures below 150 K is thus required.

To undertake such measurements of the cross sections in the VUV region of gaseous molecules at temperatures below 100 K, we have constructed a slit-jet absorption system that is connected to a VUV beamline at the National Synchrotron Radiation Research Center (NSRRC) in Taiwan; for which a systematic layout is displayed in Fig. 1.

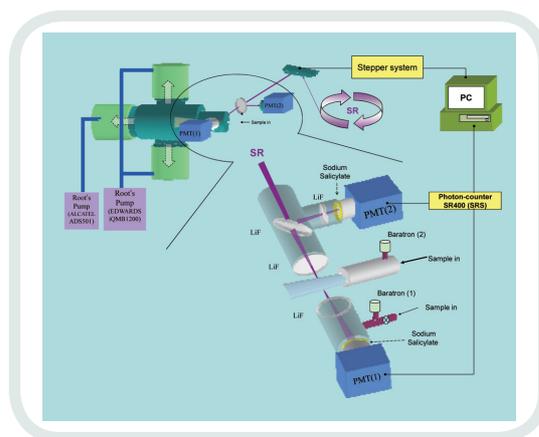


Fig. 1: Schematic layout of the experiment.

The gaseous stream from the jet intersected the VUV radiation into the absorption chamber. The intensity of VUV light was monitored through light reflected from a LiF beamsplitter placed before the absorption chamber and at 45° from the beam line. A small fraction of the reflected light beam passed one additional LiF plate and impinged on a glass window coated with sodium salicylate. The luminescent signal subsequently detected with a photomultiplier tube in a photon-counting mode was employed for normalization.

The absorption cross section of gaseous  $C_2H_2$  near 298 K was measured with the gas absorption cell charged with a gaseous sample, not from the jet. The density of  $C_2H_2$  in the cell was determined from the gaseous pressure monitored with a capacitance manometer; the temperature was measured with a thermocouple. The absorption cross section,  $\sigma$ , is calculated from the absorbance according to an equation  $\ln(I_o/I) = n \sigma l$ , in which  $I_o$  and  $I$  are incident and transmitted light intensities, respectively;  $n$  is the gas density, and  $l$  is the length of the absorbing path.

Considering all possible systematic errors, we estimate the experimental uncertainties of cross sections to be within 10 % of our reported values. Our values of cross sections differ from previous data and display diverse agreements for various states.<sup>2</sup> An integration of absorption cross section over a spectral range including all bands of a system yields an oscillator strength  $f$  that is formally independent of experimental bandwidth, and that might be comparable among various experiments. Although absorption maxima and bandwidths of the various Rydberg transitions varied substantially compared to previous reports, our derived  $f$  values are almost identical

with those of previous works.<sup>2</sup> The agreement of the  $f$  values among different experiments indicates that the dissimilar absorption cross sections observed in specific lines are due to resolution effects.

For the gas flowing through the slit jet, we obtained the corresponding absorption spectrum of acetylene in spectral range 110 – 155 nm at stagnation pressure 200 Torr. We examined the absorption profile of acetylene in the jet-expanded condition and simulated the absorption spectra of  $C_2H_2$  from 50 K to 100 K at intervals 5 K. Finally, we matched the experimental jet spectrum at  $85 \pm 5$  K.

Although we could measure the absorption spectrum of jet-expanded  $C_2H_2$  at 85 K, but we didn't know the exact optical path length and number density for this cold gaseous stream. Therefore, we cannot directly measure the cross sections of acetylene under such condition. As temperature varies, the absorption reveals a distinct variation of profile and value, but an integration of absorption cross section over a spectral range yields the oscillator strength that is formally independent of temperature. In this manner, the cross sections of absorption bands become comparable at various temperatures. As our absorption spectra of  $C_2H_2$  at 298 K and for jet-expanded conditions were measured with the same optical parameters, we thus derive the absorption cross section of the jet-expanded temperature based on the oscillator strength obtained from 298 K. By this means, we derived all cross sections in spectral range 110-155 nm, as shown in

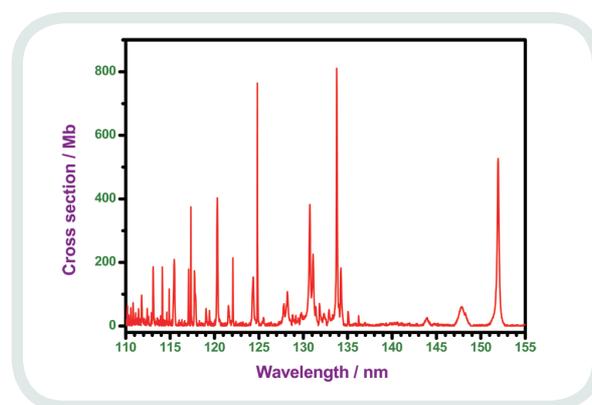


Fig. 2: Absorption cross section of  $C_2H_2$  at 85 K in wavelength range 110-155 nm.

Fig. 2.

Our values of the absorption cross section of  $C_2H_2$  at 85 K from the slit-jet absorption are thus valuable for astrophysical applications. Our values of cross sections for the transitions to states  $3R_0$  and  $3R'_0$  at 151.94 and 133.76 nm are 527 and 811 Mb at 85 K, respectively; these values are greater than 472 and 514 Mb, respectively, reported by Wu *et al.* at 150 K.<sup>2</sup> This result might explain the discrepancies in these two features of  $C_2H_2$  between simulated and observed spectra of Shemanky *et al.* Our low-temperature absorption cross sections of  $C_2H_2$  can thus serve to determine properties sensitive to temperature for diagnostic work on Saturn and Titan.<sup>3</sup>

### Beamline 03A1 BM - (HF-CGM) SJAS end station

#### References

1. D. E. Shemansky, A. I. F. Stewart, R. A. West, L. W. Esposito, J. T. Hallett, X. Liu, *Science* **308**, 978 (2005).
2. C. Y. R. Wu, F.-Z. Chen, and D. L. Judge, *J. Geophys. Res.* **106**, 7629 (2001).
3. B.-M. Cheng, H.-F. Chen, H.-C. Lu, H.-K. Chen, M. S. Alam, S.-L. Chou, and M.-Y. Lin, *Astrophys. J. Suppl. Series* **196**, 3 (2011).

#### Contact E-mail

bmcheng@nsrrc.org.tw