RevMexAA (Serie de Conferencias), **9**, 148–150 (2000)

SEARCH FOR THE SHAPE RESONANCE IN THE NEGATIVE ION OF HYDROGEN IN ASTROPHYSICAL PLASMAS

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RESUMEN

El espectro de absorción en el visible y cercano infrarrojo del ión negativo del hidrógeno (H^-) es relativamente suave, con un umbral cercano a 1644 nm y un máximo ancho cerca de 840 nm. Sin embargo, en el ultravioleta en el vacío uno encuentra, metido en el contínuo, una "región resonante" de estados de singulete P doblemente excitados que corresponden a electrones amarrados a estados del hidrógeno excitado. La resonancia más prominente, a menudo llamada "resonancia de forma", está compuesta por un electrón amarrado a un potencial con tres puntos de inflexión asociado al dipolo eléctrico del primer estado excitado del hidrógeno. Este estado de vida corta interfiere de forma constructiva con el contínuo para formar un perfil asimétrico de Fano con un ancho de 0.22 nm. La resonancia, con una sección recta de cerca de 8×10^{-17} cm^2. Después de la autoseparación es el estado n=2 que es él poblado preferencialmente, bombeando la emisión de Lyman alfa. Una resonancia de Feshbach cercana, delgada pero bien definida, puede aumentar su visibilidad bajo ciertas condiciones. A pesar del supuesto papel que jugaría este ión en las atmósferas estelares, no existen muestras claras de estas resonancias en los fenómenos astrofísicos.

ABSTRACT

In the visible and near infrared, the photoabsorption spectrum of H^-, the negative ion of hydrogen, is relatively featureless, with a threshold near 1644 nm and a broad maximum at about 840 nm. However, in the vacuum ultraviolet one finds, embedded in the continuum, a "resonance region" of doubly-excited, singlet P, H^- states corresponding to electrons bound to excited hydrogen states. The most prominent of these resonances, the "shape resonance," is formed by an electron bound in a potential with three classical turning points formed by the first excited state of hydrogen. This short-lived state interferes, mostly constructively, with the continuum, to form an asymmetric Fano profile with a width of about 0.22 nm. The shape resonance peak cross section is about 8×10^{-17} cm^2. Upon autodetachment the n=2 state is preferentially populated, in effect, pumping Lyman alpha emission. A nearby narrow, but distinctive, Feshbach resonance could enhance the absorption feature's visibility under certain conditions. In spite of the presumed role of this ion in stellar atmospheres, so far no clear signature for these resonances has been found in astrophysical phenomena.

Key Words: **ATOMIC PROCESSES — LINE: FORMATION — TECHNIQUES: SPECTROSCOPIC — ULTRAVIOLET: GENERAL**

In 1974, Theodore P. Snow, Jr., reported an unsuccessful search for the shape resonance in the VUV

Astrophysical Plasmas: Codes, Models, and Observations (Mexico City, 25-29 October 1999)
Editors: Jane Arthur, Nancy Brickhouse, & José Franco

spectrum of the star Chi Ophiuchi (Snow 1975). Since progress has been made, both experimentally and theoretically, in the understanding of the structures in the H^- spectrum, it seems appropriate to reexamine astrophysical data for evidence of resonant features. By far the strongest feature in photoabsorption by H^- in the VUV, the shape resonance arises from a long range repulsive interaction combined with a short range attractive interaction between the first excited state of atomic hydrogen and a low energy electron (Bryant et al. 1983; Lindroth 1995). The cross section for this resonance embedded in the $^1P^o$ photodetachment continuum can be reasonably modeled in the neighborhood of the resonance by a Fano profile of the form:

$$\sigma(\varepsilon) = \sigma_a \frac{(q+\varepsilon)^2}{1+\varepsilon^2} + \varepsilon_b, \quad \text{where} \quad \varepsilon = \frac{E - E_0}{\Gamma/2}. \tag{1}$$

Contrary to early fears that small electric fields would quench it, the shape resonance has turned out to be amazingly robust. In fact it thrives in electric fields! For "small" fields, 120 to 240 kV cm^{-1}, the resonance even narrows by about 3%, according to one experimental observation (Comtet 1987). Recently, a remarkable calculation (Ho 1998) has shown that the field behavior of the shape resonance is unexpectedly complex. The magnetic substates are split by the electric field into a M=0 state and two degenerate states, M=±1. Moreover at a field of about 250 kV/cm an additional M=±1 resonance appears, a Field-Induced Shape Resonance (FISR). The theoretical results by Ho appear to be consistent with earlier measurements of Bryant et al. (1983), and those of Butterfield (1984). The parameters for the Fano profile are given in Table I (cross-section parameters are taken from Bryant et al., table IV, and corrected to agree with values calculated by Broad and Reinhardt 1976). The energy of pole number is based on a measurement of the Feshbach resonance by Balling et al. (1996), using the shape-Feshbach energy difference measured by Bryant et al. (1983). Another estimate based on a measurement by MacArthur et al. (1985), of 10.9703 ± 0.0005 eV, is regarded the more likely to suffer from a systematic error. The two numbers differ by 1.9 ±0.9 meV, or 0.2 ± 0.1 Å. Lindroth (1995), in her computation, finds the pole to be at 10.970 eV and the peak to be at 10.972 eV.

TABLE 1

Parameter	Value	Units
σ_a	$(5.94 \pm 0.12) \times 10^{-19}$	cm^2
σ_b	$(9.31 \pm 0.30) \times 10^{-18}$	cm^2
Energy of Pole	10.9724 ± 0.0007	eV
	(1129.96 ± 0.07)	(Angstroms)
Gamma	21.2±1.1	meV
	(2.2 ±0.1)	(Angstroms)
Q	4.92±0.33	dimensionless

Los Alamos National Laboratory is operated by the University of California for the US Department of Energy under contract W-7405-ENG-36. Work has been supported by the US Department of Energy, Division of Chemical Sciences, Office of Basic Energy Sciences under grant No. DE-FG03-93ER14326.

REFERENCES

Balling, P., Kristensen, P., Andersen, H. H., Pedersen, U. V., Petrunin, V. V., Prstegaard, L., Haugen, H. K., & Andersen, T. 1996, Phys. Rev. Lett., 77, 2905
Broad, J. T., & Reinhardt, W. P. 1976, Phys. Rev. A,14, 2159
Bryant, H. C., et al. 1983, Phys. Rev. A, 27, 2889
Butterfield, K. B. 1984, Ph.D. thesis, UNM, (Los Alamos Report LA-10149-T)
Comtet, G. 1987, Phys. Rev. A, 35, 1547
Ho, Y. K. 1998, Phys. Rev. A, 57, 2235
Lindroth, E. 1995, Phys. Rev. A, 52, 2737

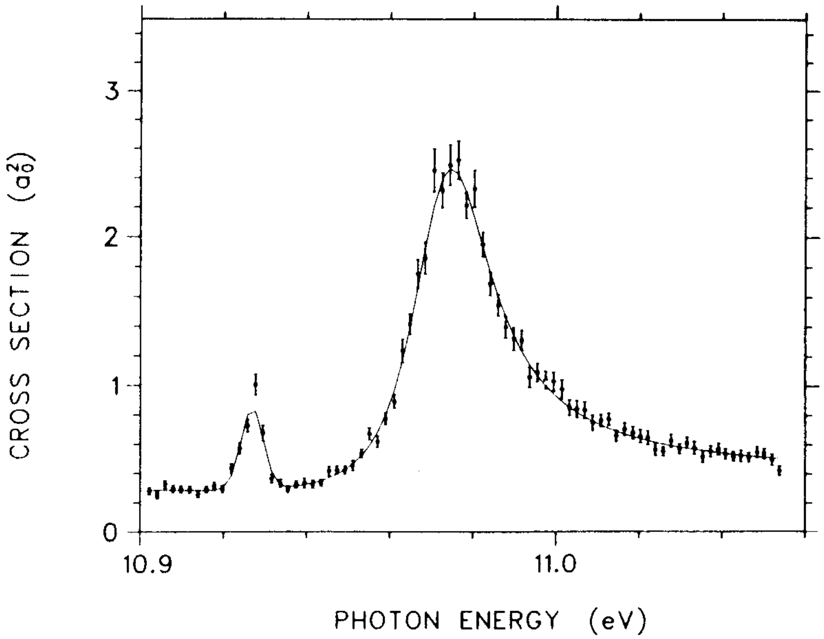

Fig. 1. The experimental shape resonance absorption cross section (Bryant et al. 1983, Fig. 6b) normalized to the Broad and Reinhardt calculation vs photon energy. The first Feshbach resonance, 46 meV below the shape, demonstrates the experimental resolution. Although only 30 microvolts wide, this structure, because of its Fano shape, with a dip to almost zero absorption, could have a definite impact on a photoabsorption spectrum.

MacArthur, D. W., Butterfield, K. B., Clark, D. A., Donahue, J. B., Gram, P. A. M., Bryant, H. C., Harvey, C. J., Smith, W. W., & Comtet, G. 1985, Phys. Rev. A, 32, 1921

Snow, T. P. Jr. 1975, ApJ, 198, 361

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