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Observation of the partial decay into $H^0(n'=2)$ by excited H^- near the $n=3$ and 4 thresholds

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Two resonances in the photodetachment spectrum of H^-, one just below the $n=3$ threshold and the other just below the $n=4$ threshold, were observed decaying into $H^0(n'=2)+e$. The $n=3$ resonance shows a preference for the $n'=2$ channel when compared with total-detachment measurements. Fano-line-shape fits give central energies of 12.652 ± 0.003 eV for $H^{-**}(3)$ and 13.338 ± 0.004 eV for $H^{-**}(4)$. These values are in good agreement with current theoretical calculations.

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The experimental study of H^- interacting with photons provides a fundamental way to learn about electron correlations. The resulting resonances $H^{-**}(n)$—"quasibound" states that may be thought of as an electron bound to a hydrogen atom in excited state n—are formed as a direct consequence of strong electron correlations. These states lie in energy above that needed to remove the more weakly bound electron. Their interaction with the continuum of free-electron states then allows the $H^{-**}(n)$ states to autodetach into a free electron plus a neutral hydrogen atom $H^0(n')$. For the Feshbach-type resonances with which we are concerned, n' is less than n.

Previous experiments [1] monitored production of ${}^1P^o$ $H^{-**}(n)$ for $n=2$, 3, 5, 6, 7, and 8. The states are labeled as follows. The $H^{-**}(n)$ resonances are those which converge from below on the energy threshold for production of $H^0(n)$ plus an electron. Below each threshold an infinite series of resonances is predicted if relativistic and spin effects are neglected [2].

Most previous experiments measured total autodetachment rates. Branching ratios for transitions into the different available $H^0(n')$ levels have not yet been measured. The resonances are expected to prefer a transition into the closest lower channel [3–6], but theories have not been adequately tested. Conceptually, one can expect such behavior because the spatial overlap of wave functions is greatest between a resonance and its next lowest continuum [3]. The $n=3$ resonance does seem to display this tendency as mentioned below. We have made the first step toward a quantitative study of these ratios by observing the cross section for both the $H^{-**}(3)$ and $H^{-**}(4)$ decaying into $H^0(2)$ as depicted in Figs. 1 and 2. Our observation of an $n=4$ resonance in H^- is made possible by a two-laser-beam method for excitation of the ion and the neutral atom. Previous experiments relied on field stripping by a magnet which was not strong enough to strip $H^0(4)$.

The high-resolution laser-induced photodetachment technique as developed at LAMPF is described in detail elsewhere [7]. A second laser beam has recently been introduced to excite the detached neutral hydrogen atoms from the low-n' levels into $H^0(11)$, which can then be stripped by our electron spectrometer and detected with a scintillator–photomultipler-tube combination. In this way just the $H^0(2)$ states, for example, can be observed. Similarly we can promote just $H^0(3)$ or $H^0(4)$, and branching fractions can be done.

TABLE I. Predicted and experimental Fano line-shape parameters for the first resonances near $n=3$ and 4 thresholds. E_0 is the central energy, q is the asymmetry parameter, and Γ is the width. Experimental values of Γ have been adjusted to take into account our energy resolution of 0.007 eV by subtracting the resolution in quadrature [10].

n	Parameter	Theory	This experiment
3	E_0 (eV)	12.6494 [14], 12.6605 [15], 12.6623 [16], 12.6470 [20]	12.652 ± 0.003
	Γ (eV)	0.0325 [17], 0.0316 [18], 0.0325 [20]	0.030 ± 0.003
	q		-1.6 ± 0.2
4	E_0	13.3448 [14], 13.3502 [15], 13.3435 [16], 13.3422 [21]	13.338 ± 0.004
	Γ	0.0275 [18] , 0.0339 [19], 0.0367 [21]	0.015 ± 0.006
	q		0.7 ± 0.3

The resonance profiles (cross sections versus photon energy) were fit to a Fano function [8]. Positions and widths are in good agreement with recent R-matrix calculations by Sadeghpour, Greene, and Cavagnero [9] [Figs. 1(b) and 2(b)] as well as other theoretical calculations. Table I compares the experimental parameters with theoretical predictions. In particular we note that the line-profile asymmetry for the $n=4$ resonance is as predicted in Ref. [9] [Fig. 2(b)]. That is, in the profile of the $n=4$ resonance the dip occurs at a lower energy than the peak, whereas the $n=3$ profile is just the opposite. Figure 3 shows that the $n=3$ peak is enhanced over the dip in this channel, which is not the case in previous total-resonance cross-section measurements [10]. We attribute this enhancement to the aforementioned preference for decay into the nearest available channel.

The resonance energies were calibrated to the $n=2$

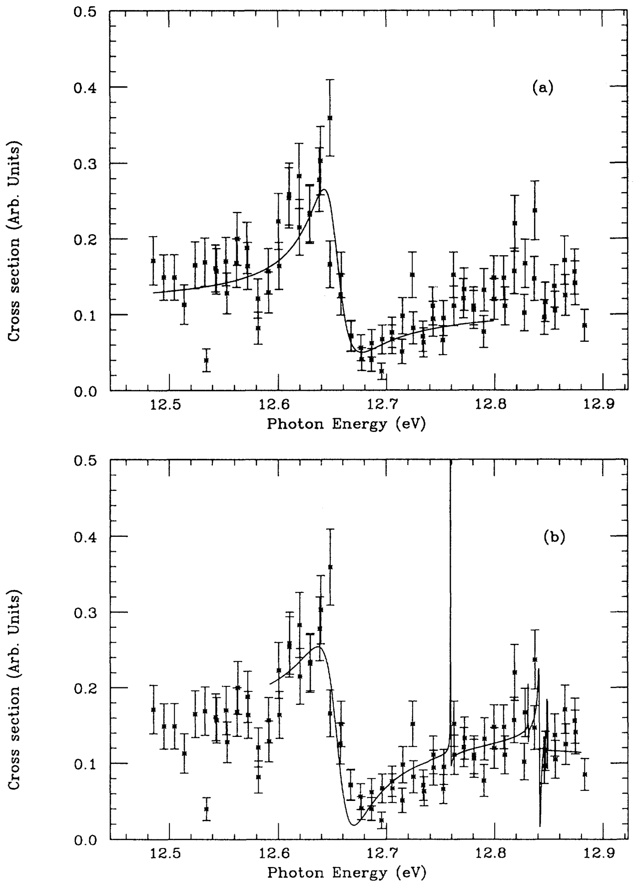

FIG. 1. Photodetachment partial cross section vs photon energy below the $n=3$ threshold. Only $H^0(2)$'s were detected resulting from H^- photodetachment. Raw data were normalized to beam current and number of laser shots per energy. Error bars are statistical only. (a) Fit to a Fano function. The fit was stopped at 12.80 eV, so it would not be dragged up by the second $n=3$ resonance at 12.837 eV [1]. (b) Theoretical profile [9] (7-meV experimental resolution folded in) overlaid on data with background levels matched.

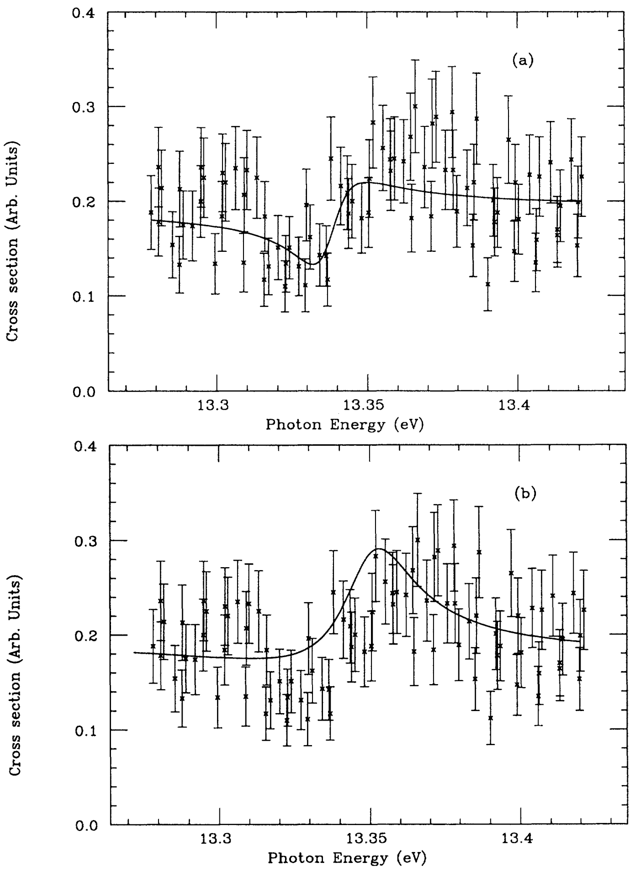

FIG. 2. Photodetachment partial cross section vs photon energy below the $n=4$ threshold. Raw data were normalized to beam current and number of laser shots per energy. Error bars are statistical only. (a) Fit to a Fano function. (b) Theoretical profile [9] overlaid on data with background levels matched. The numerical results are not fully converged for the $n=4$ resonance because of the necessity to include more basis states in the expansion [3].

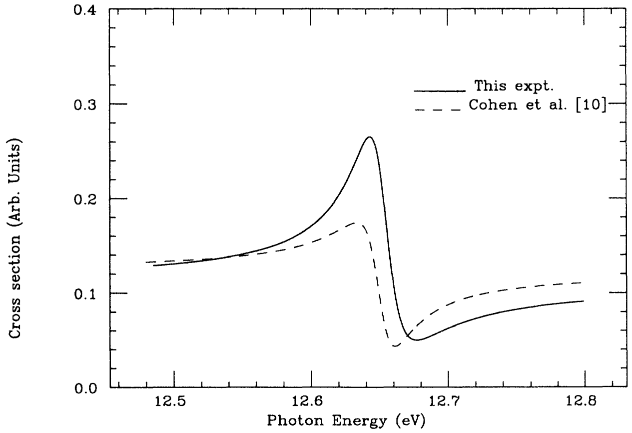

FIG. 3. A comparison of Fano line shapes for total decay channel (dashed line) and $n=2$ decay channel (solid line). Background levels have been matched to aid the eye in line-profile comparison. The magnitude of the line-profile parameter q for the $n=2$ channel is more than twice that for total decay and the peak-to-valley amplitude is about $1\frac{1}{2}$ times as large, indicating that the channel is preferred [3].

Feshbach peak whose energy is well known from experiment [11]. Since it is effectively a delta function (30 μeV) [12], its observed width demonstrated our energy resolution of 0.007 eV.

H^- beam fluctuations and inhomogeneities caused random fluctuations in the cross section which is dependent on the spatial and temporal overlap of the H^- beam with the laser [13]. These can be somewhat reduced in the analysis by binning and smoothing the data. However, we have chosen to use the raw data in our plots.

In summary, our group has now measured the most dominant quasibound states of H^- in each series from $n=2$ through 8. Our recent observation of $H^{-**}(n=3)\rightarrow H^0(2)+e$ showed a preference for decay into this channel.

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