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THE PRODUCTION AND DESTRUCTION OF NEGATIVE IONS

Progress Report

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1. Introduction

During the present grant period we have continued our study of the photodetachment of atomic negative ions using cross-beam photoelectron detachment spectroscopy. This technique involves the measurement of energies, yields and angular distributions of photoelectrons ejected from the interaction region between perpendicularly crossed laser and negative ion beams. Both structural and collisional properties of the negative ions are determined from the measured quantities. Measurements of the kinetic energies of the photoelectrons, for example, permits determinations of electron affinities of the parent atoms whereas combined photoelectron yield and angular distribution measurements allow differential and angle-integrated photodetachment cross sections to be evaluated.

2. Collisions

Most of the work during the current period has been taken up with measurements that will eventually lead to the determination of, as a function of photon energy, the absolute cross sections for photodetachment of atomic negative ions. The major sources of uncertainty in our measurements arise from the large background of non-photoelectrons associated with forward-directed electron spectroscopy of fast moving beams. A synchronous detection scheme has been developed which greatly enhances the signal-to-noise figure for the photoelectron measurements but even though most of the background electrons are not counted they still continually bombard the channel electron multiplier (CEM) detector. Care must be taken to avoid any count-rate-dependent changes in the detector gain or pulse pile-up during the comparison of photoelectron yields between the ions under study and reference ions. It is also suprisingly easy to saturate the photodetachment processes even though the cross sections are small compared to those for resonance transitions. For each photodetachment channel one must experimentally determine the maximum laser power that can be used while still staying below the saturation threshold. During the course of this grant period out measurement technique has evolved.

We have concentrated our efforts on photodetaching the metastable He^- $(2\,^4P)$ ion. This process can leave the residual atom in either the He $(2\,^3S)$ or He $(2\,^3P)$ states at the visible photon energies used in the present measurements. Figure 1 shows a typical photoelectron spectrum. Photoelectron yields and angular distributions are needed to determine the cross sections. We began the work by measuring the angular distribution of photoelectrons ejected via each of the two cited exit channels. The apparatus was first tested by studying the angular distributions of electrons from the photodetachment of D^-. At all photon energies the measurements agreed with theory. The angular distribution work formed the basis of the Ph.D. thesis of the graduate student, Jeffrey Thompson. The results for the He (^3P) and He(^3S) exit channels are shown in Figures 2 and 3 respectively. We are presently preparing a manuscript describing these measurements. The spectral dependence of the asymmetry parameter, β, indicates that significant correlation effects are causing deviations from single-electron approximation predictions.

The ratio of the partial cross sections for photodetaching He^- via the He $(2\,^3S)$ and He $(2\,^3P)$ exit channels can be determined from the yields of the two peaks in the photoelectron spectra if the appropriate corrections for different angular distributions and solid angle transformation factors are made. Theory predicts that $\sigma(^3P)$ should drop off faster than $\sigma(^3S)$ over the visible region and this is observed in Figure 4. The accuracy of these ratio measurements are however, limited by the fact that the relative efficiencies for collection and detection of electrons at the two peak energies are assumed to be equal. Our present measurement technique avoids this assumption by kinematically shifting the energies of all electrons so that they are measured at the same laboratory energy thus ensuring equal efficiencies. Figure 5 shows three photoelectron peaks of different origins, all occuring at the same energy, ~ 11eV, in the laboratory frame. The top peak is associated with photodetachment of He^- via the He (^3S) exit channel. In this case the He^- ion beam energy was chosen to be ~ 30keV to obtain the correct kinematic shift. Similarly, the bottom peak shows photodetachment via the He(^3P) exit channel. In this case an ion beam energy of ~ 50 keV has needed to shift the peak to a laboratory energy of ~ 11eV. The middle peak is associated with the photodetachment of the reference beam of D^- ions whose energy was ~ 20keV. Our measurement procedure now involves taking the ratio of the yields of each of the He^- peaks to that of the D^- peak. The cross section for photodetachment of D^- is known from theory to ~ 3% and so an "absolute" scale for the He^- photodetachment cross sections can be established. Corrections to the yields must be made to account for changes in photon flux and ion densities (the data is normalized channel-by channel to the photon and ion beam intensities). Corrections are also made for the different angular distributions and kinematic factors. The ion beam velocities, from which the kinematic factors are calculated, are obtained in situ from the separations of the peaks in the photoelectron spectra.

We are currently measuring, at a photon energy of 1.780 eV, the ratios of the cross sections for photodetaching He- (^4P) ions via the He (^3S) and He (^3P) exit channels to the known cross section for photodetaching the reference ion D^- (^1S) via the D (^2S) exit channel. If one chooses the theoretical value of $\sigma(^2S) = 3.81 \times 10^{-17}$ cm^2 [Stewart, J. Phys. B 11, 3851 (1978), estimated error less than 3%], we are able to establish an "absolute"scale for our measurements. The preliminary results are $\sigma(^3S) = (2.4 \pm 0.4) \times 10^{-17}$ cm^2 and $\sigma(^3P) = (1.2 \pm 0.2) \times 10^{-17}$ cm^2. We expect to be able to reduce the uncertanities on our final values after a thorough analysis of systematic errors is completed.

Similarly, we have measured the ratio of the cross section for photodetaching $B^-(^3P)$ via the $B(^2P)$ channel to that of $He^-(^4P)$ via the $He(^3P)$ exit channel. The preliminary value in this case is $\sigma(^2P) = (1.8 \pm 0.4) \times 10^{-17}$ cm^2. Again, we expect to be able to reduce the uncertainty on this preliminary result.

3. Structure

Some time has been spent trying to develop techniques capable of making precise measurements of the electron affinities of atoms via analysis of the spectra of detached photoelectrons. Kinematic effects associated with the fast moving beam source have been exploited. Only energy differences of close-lying peaks can be measured with confidence since unknown offsets such as contact and surface potentials will always be present to some extent. In general, in a measurement of this kind, there will be two unknown quantities: the electron affinity and the ion beam energy. In a single spectrum, three peaks whose separations in the ion rest frame are known can be used to determine both of these quantities simultaneously. As a test we have made preliminary measurements of the electron affinity of He using this technique. Figure 6 shows an electron spectrum arising from He^- photodetachment. Peaks 1 and 2 are a kinematically-doubled pair whose energy is the same in the ion frame. The measured separation of these peaks in the laboratory frame is related in a simple manner to the electron affinity and the ion beam energy. Similarly, the measured separation of peaks 2 and 3, whose separation in the ion frame is well known, are also related to the electron affinity and ion beam energy. Together the two measured peak separations yield the ion beam energy and an electron affinity of He of 76 ± 3 meV. This preliminary result is used as a test case for the technique. The accuracy can certainly be improved by studying potential sources of systematic uncertainties by varying, for example, the ion and photon beam energies. Even at this stage the result is in agreement with the more accurate theoretical value of 77.51 ± 0.04 meV.

The other technique that we are developing for determining electron affinities involves the use of three peaks in two different spectra, one spectrum from ions whose electron affinity is to be determined and the other from reference ions. In this case there are two possibilities. Either the reference spectrum contains one peak and the unknown spectrum two peaks or vice versa. We have made preliminary measurements of the electron affinity at B using a reference spectrum of He which has two peaks in it of known separation in the ion frame. The spectra are shown in Figure 7. We have assumed that the electron affinity of He is the theoretical value of 77.51 meV. Under these conditions the electron affinity of B is measured to be 281 ± 10 meV. Again, this is only a preliminary result and it can certainly be improved by investigating systematic uncertainties. We have also attempted to use the electron spectrum from the photoelectron detachment of D^- as a reference spectrum to measure the electron affinity of He.

Photodetachment of He^- at 40 keV

λ=595.5 nm

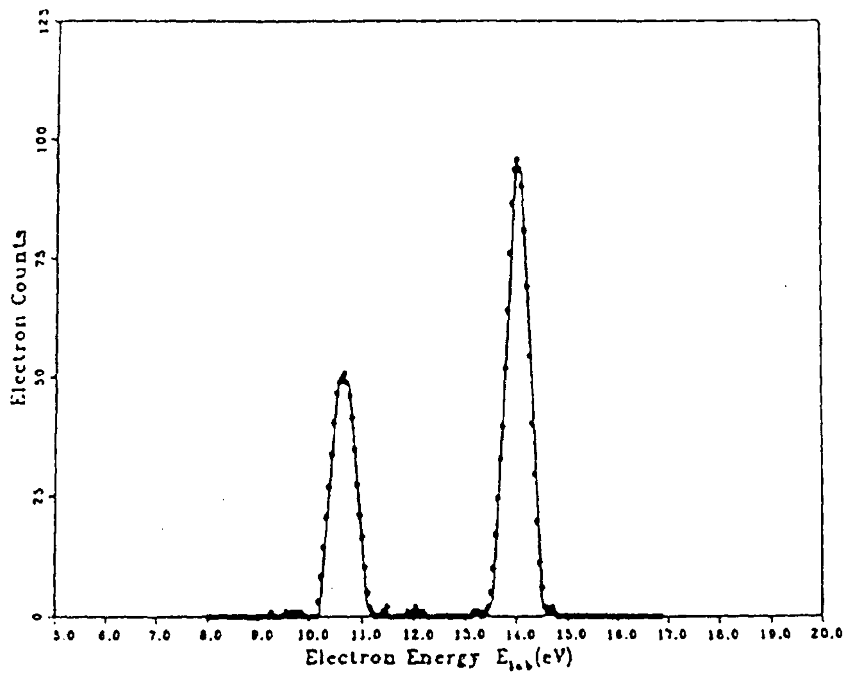


FIGURE 1

Spectral Dependence of the Asymmetry Parameter

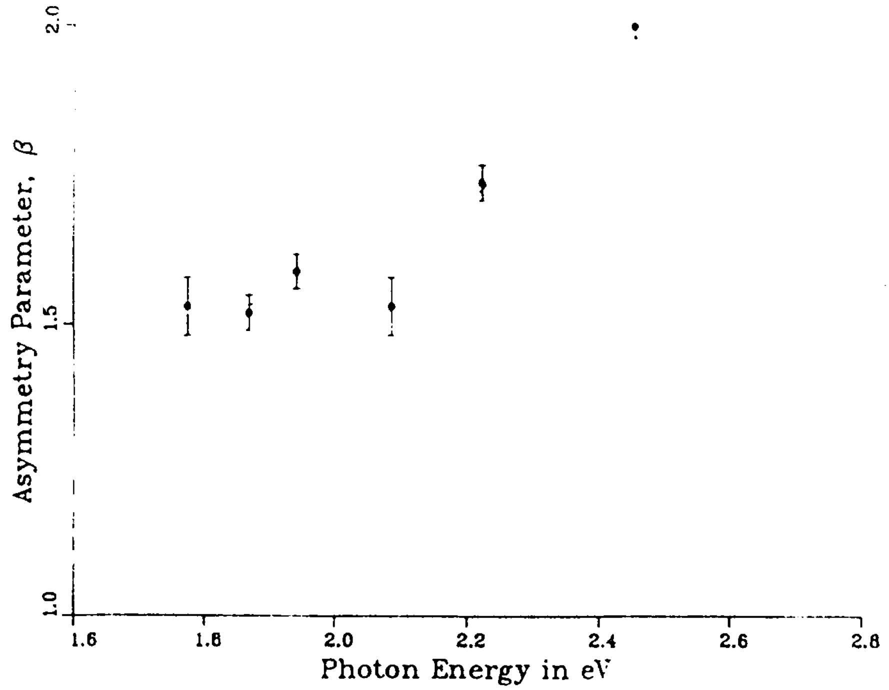


FIGURE 2

Spectral Dependence of the Asymmetry Parameter

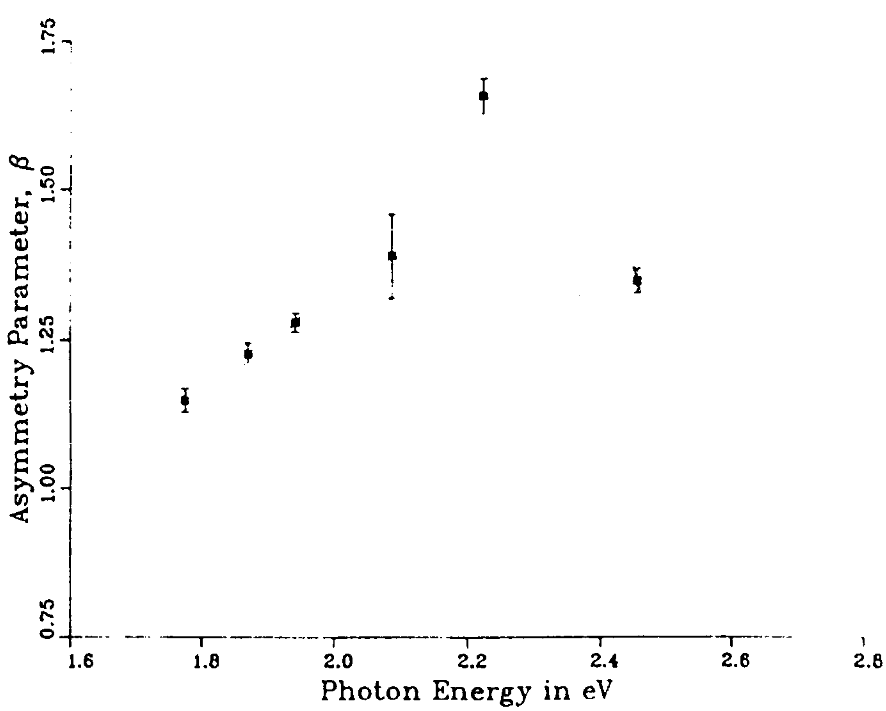


FIGURE 3

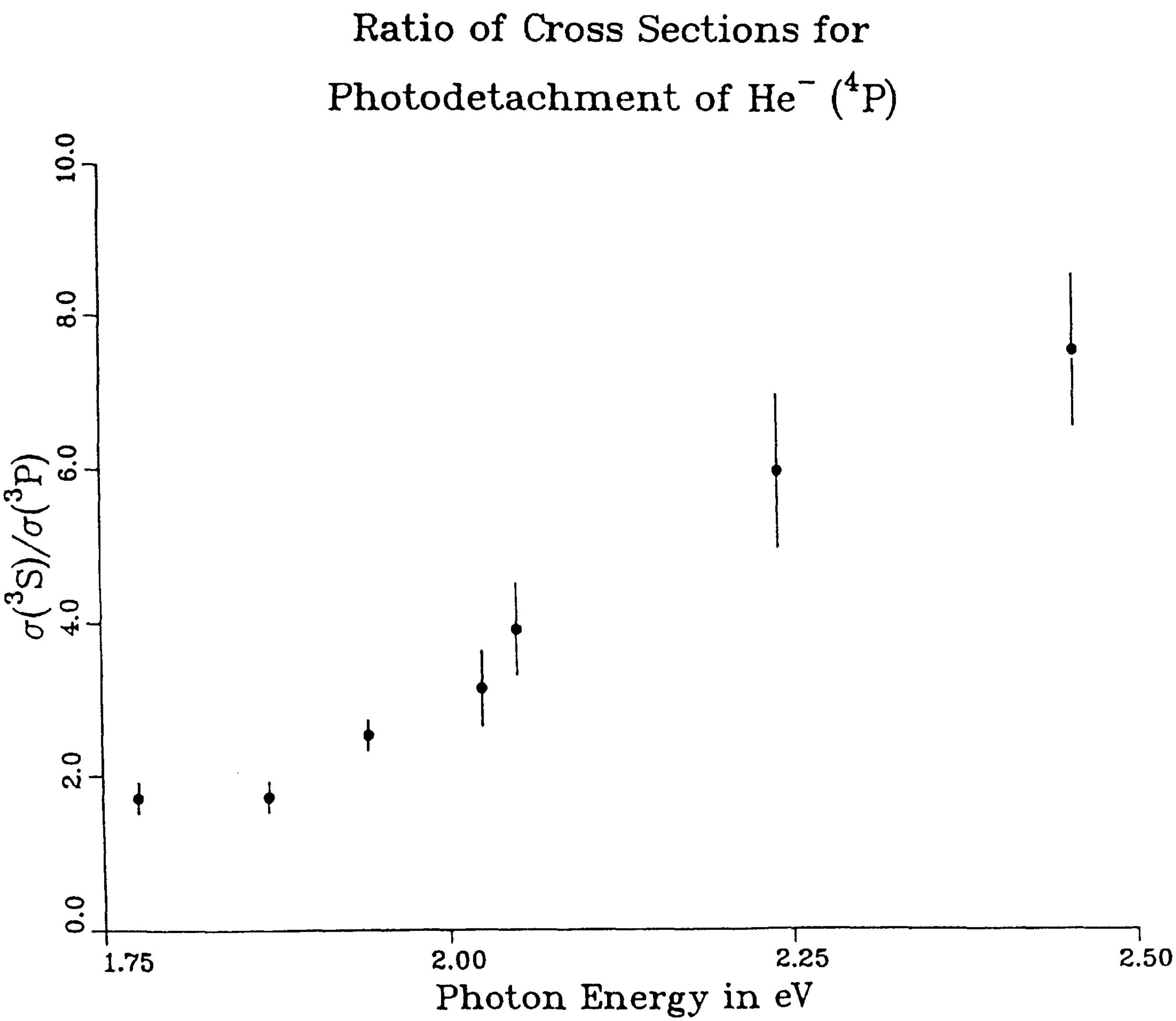

Ratio of Cross Sections for
Photodetachment of He⁻ (⁴P)
σ(³S)/σ(³P)
0.0
2.0
4.0
6.0
8.0
10.0
1.75
2.00
2.25
2.50
Photon Energy in eV

FIGURE 4

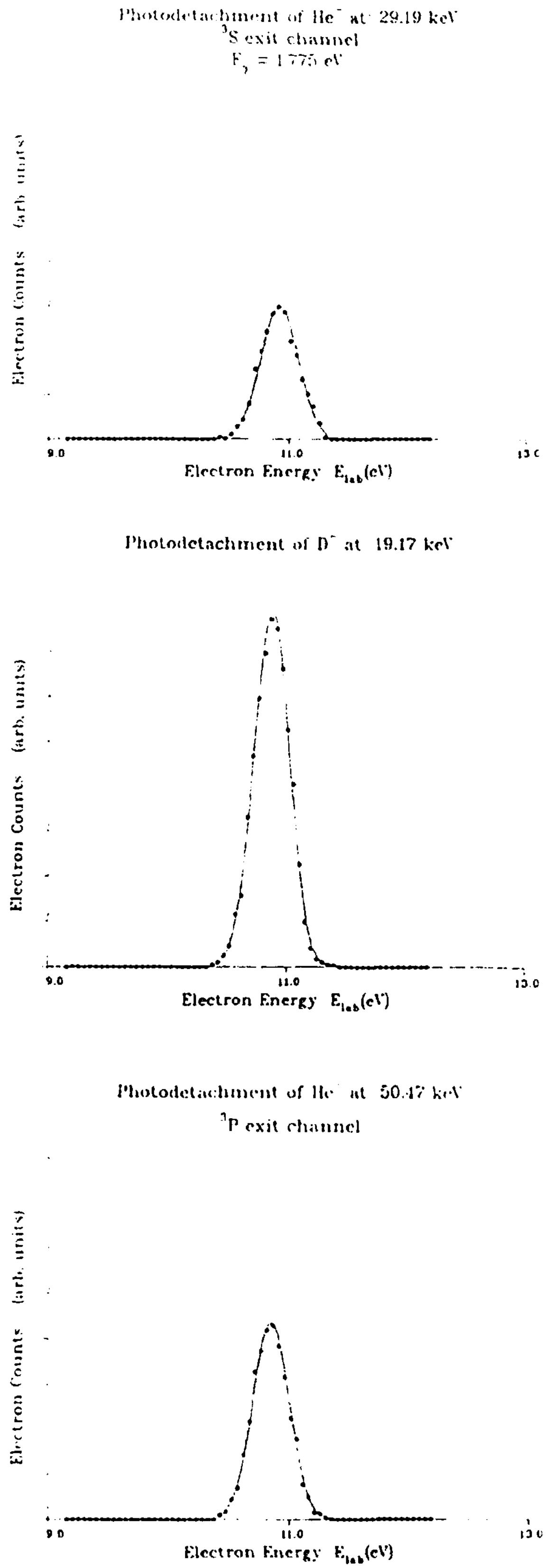
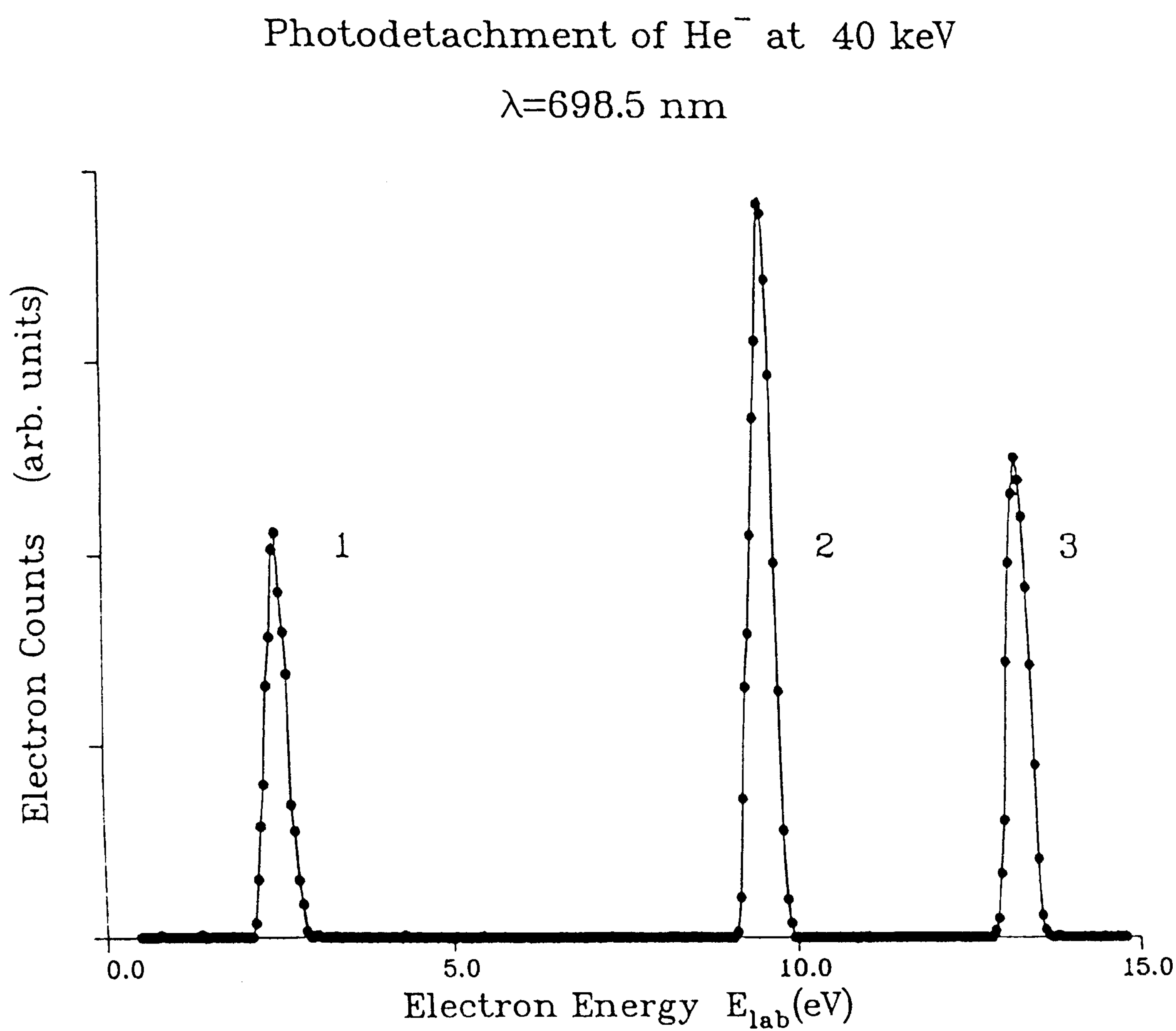

Photodetachment of He⁻ at 29.19 keV
³S exit channel
E_γ = 1.775 eV
Electron Counts (arb. units)
9.0
11.0
13.0
Electron Energy E_lab(eV)
Photodetachment of D⁻ at 19.17 keV
Electron Counts (arb. units)
9.0
11.0
13.0
Electron Energy E_lab(eV)
Photodetachment of He⁻ at 50.47 keV
³P exit channel
Electron Counts (arb. units)
9.0
11.0
13.0
Electron Energy E_lab(eV)

FIGURE 5

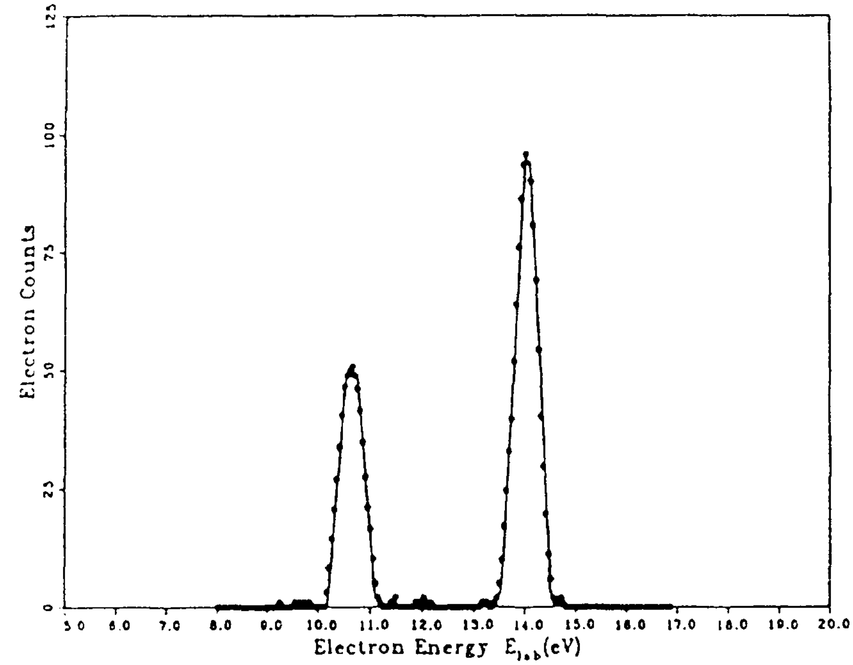


Photodetachment of He⁻ at 40 keV
λ=698.5 nm
Electron Counts (arb. units)
1
2
3
0.0
5.0
10.0
15.0
Electron Energy E_lab(eV)

FIGURE 6

Photodetachment of He^- at 40 keV

λ=595.5 nm



Photodetachment of B^- at 40 keV

λ=595.4 nm

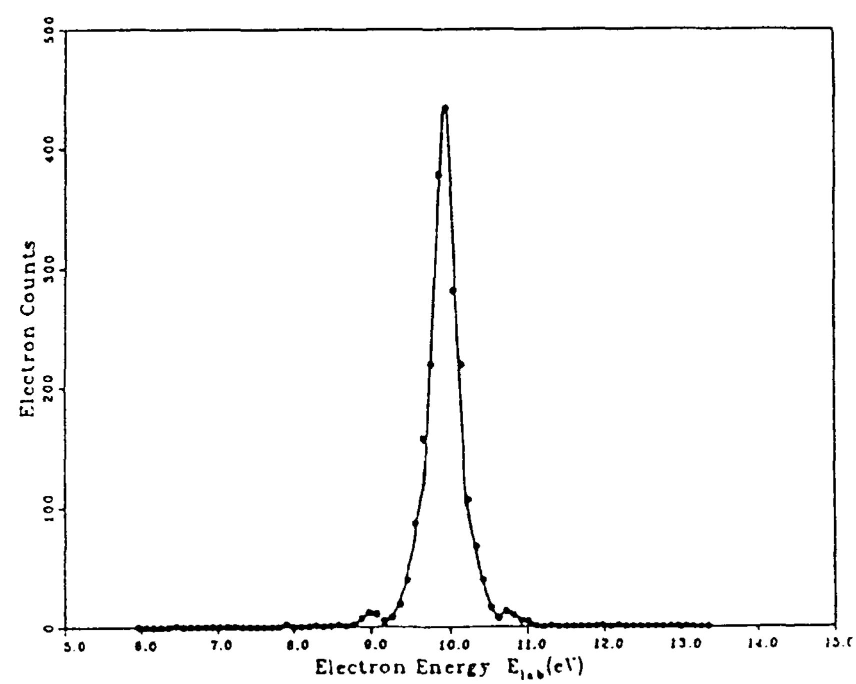


FIGURE 7

List of Publications (September 1, 1988 - April 10, 1989)

A. Journals and Published Proceedings

Report No: DOE/ER/13456-18

"The Structure of the Stable Negative Ion of Calcium," D. J. Pegg, J. S. Thompson, R. N. Compton and G. D. Alton, in Resonance Ionization Spectroscopy 1988 (edited by T. Lucatorto and J. Parks, Institute of Physics Press, Bristol, UK, 1989) pp. 13-16).

Report No: DOE/ER/13456-19

"Energy-and Angle-Resolved Photoelectron Spectroscopy of Negative Ions," D. J. Pegg, J. S. Thompson, R. N. Compton and G. D. Alton, Nuclear Instruments and Methods (to be published).

B. Conference Abstracts

Report No: DOE/ER/13456-20

"Fast-Beam Photoelectron Detachment Spectroscopy," D. J. Pegg, Southeastern Section of the APS, Raleigh, N.C., Nov. 1988: Bull. Am. Phys. Soc. 33, 2192 (1988).

Report No: DOE/ER/13456-21

"Cross Section for Photodetachment of B^-," J. S. Thompson, D. J. Pegg, J. Dellwo and G. D. Alton, DAMOP Meeting, Windsor, Ontario, Canada, May, 1989: Bull. Am. Phys. Soc. 34, 1411 (1989).

Report No: DOE/ER/13456-22

"Partial Cross Sections for the Photodetachment of Metastable He^-," D. J. Pegg, J. S. Thompson, J. Dellwo, G. D. Alton and R. N. Compton, DAMOP Meeting, Windsor, Ontario, Canada, May, 1989: Bull. Am. Phys. Soc. 34, 1411 (1989).

Report No: DOE/ER/13456-23

"Photodetachment of He^-," J. S. Thompson, D. J. Pegg, J. Dellwo, R. N. Compton and G. D. Alton, XVI ICPEAC, New York City, N.Y., July, 1989.