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PHOTODETACHMENT OF He^-: ANGULAR DISTRIBUTIONS OF PHOTOELECTRONS

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ABSTRACT

Energy- and angle-resolved photoelectron detachment spectroscopy has been used to study the spectral dependence of the angular distributions of electrons photodetached from a beam of He^- ions.

INTRODUCTION

In this paper, we report on a recent study of the spectral dependence of the angular distributions of electrons ejected from metastable He^- ions in the photodetachment process: $h\nu + He^-(1s2s2p\ ^4P) \rightarrow He\ (1s2p\ ^3P) + e\ (kp)$. The threshold for this detachment channel is 1.22 eV. Our measurements were made in the photon energy range 1.77 – 2.46 eV. With the exception of H^-, He^- represents the simplest system for probing the effects of correlation on electron emission following photodetachment. Spin-dependent interactions are small for a light ion such as He^-. Configuration interaction calculations show that the lowest He^- state, $(1s2s2p)^4P$, is 96% pure.[1] Correlation effects in the initial state are therefore small.

EXPERIMENTAL TECHNIQUE

The apparatus used in the energy- and angle-resolved spectroscopic measurements on the detached electrons has been described in detail by Pegg et al.[2] It consists of a fast beam of He^- ions that is crossed perpendicularly by a beam of photons from a pulsed dye laser. The tenuous He^- ion beam is produced by sequential double charge transfer when a momentum-analyzed beam of He^+ ions is passed through a Li vapor cell. Photoelectrons, ejected from the interaction region in the direction of motion of the ion beam, are energy analyzed by means of an electron spectrometer. The angular distributions of the photoelectrons were measured by determining the yield of electrons as a function of the angle θ, between the fixed collection direction and the variable direction defined by the electric field vector of the linearly polarized laser beam. For linearly polarized radiation and a randomly polarized target, the shape of the emission pattern should take the form,

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$f(\theta) = 1 + \beta P_2(\cos\theta)$ in the electric dipole approximation. The quantity, β, is the asymmetry parameter and $P_2(\cos\theta)$ is the second-order Legendre polynomial. The apparatus was tested by measuring the spectral dependence of the angular distribution of electrons produced by photodetaching a beam of $D^-(H^-)$ ions under the same experimental conditions. Since all the photon energies used were below the threshold for leaving the residual D atom in an excited state, the emission process should be well described by an independent electron model which neglects correlation. The observed $\cos^2\theta$ ($\beta = 2$) distribution at all photon energies is in agreement with the predictions of Cooper and Zare.[3] A kinematic correction to the angular distributions is made in all cases. In general, this transformation from the laboratory frame to the ion frame involves amplitude and phase constants that depend on the velocity of the ion beam. In forward-directed electron spectroscopy, the phase factor is zero.

RESULTS AND DISCUSSION

The spectral dependence of the asymmetry parameter, β, is shown in Figure 1. At the highest photon energy used, the measured value of $\beta = 2$ is consistent with the predictions of the independent electron model. As the photon energy is reduced, however, the value of β is seen to decrease sharply over a small range of energies and then level off at $\beta \approx 1.6$. Correlation, in some form, appears to be the cause of a depolarization of the ejected electrons as the threshold is approached. In photoionization studies, this kind of behavior is commonly explained in terms of an anisotropic final state interaction between the outgoing electron and the residual ion. The electron could be re-oriented, for example, by an exchange of angular momentum via electrostatic multipole forces. In the present photodetachment study, the residual

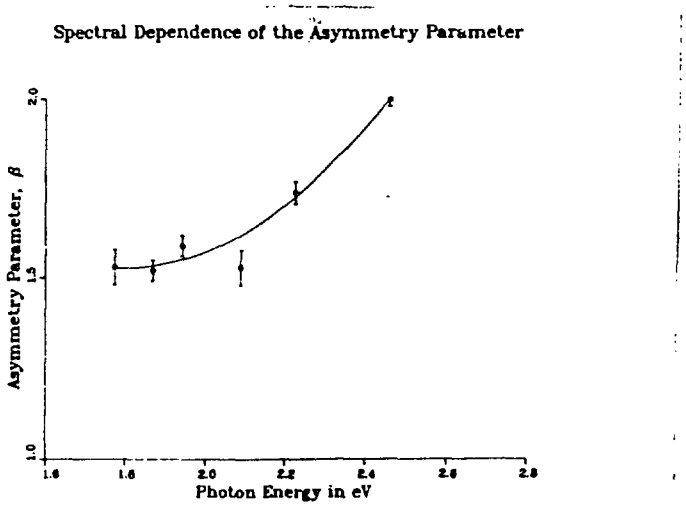

Fig. 1. The spectral dependence of β for the process: $h\nu + He^-(1s2s2p\ ^4P) \rightarrow He(1s2p\ ^3P) + e$. The solid line a weighted least squares polynomial fit to the data.

excited He atom is nonspherical and the electron-atom interaction should be dominated by the quadrupole force which, in principle, can exert a "torque" on the outgoing electron. The permanent and induced dipole moments are expected to be small for this non-hydrogenic system.

An alternative explanation of the observed spectral dependence of β involves the consideration of the influence of the $(1s2p^2)^4P$ shape resonance on the emission process. This resonance has been found by Peterson et al.[4] to lie ~11 meV above the $(1s2p)^3P$ threshold. Our measurements correspond to a range of energies that lie ~0.5 — 1.0 eV above this resonance. The resonance is, however, very strong and it appears from a calculation by Watanabe[5] that it can make a non-negligible contribution to the photodetachment cross section in the energy range of our measurements. In our experiment, this resonance will be anisotropically excited. The photoexcitation process is necessarily state selective as a result of the use of linearly polarized incident radiation and the restriction imposed on the possible final states by the Pauli exclusion principle. The electrons subsequently ejected in the autodetachment of this resonance will carry away the anisotropy. The emission pattern, in this case, will be characterized by a value of β that is considerably smaller than those observed in our measurements. One intriguing possibility is that the shape of the spectral dependence of β observed in the photodetachment of He^- arises from an interference between direct and resonant photodetachment pathways to the common $(1s2skp)^4P$ final state. The measured value of β at any particular photon energy would, in this model, be the result of an appropriate weighting of the β's from the two different pathways. These weighting factors, which will be determined by the relative cross sections for the two interfering processes, are expected to change as a function of the photon energy.

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REFERENCES

1. A. V. Bunge and C. F. Bunge, Phys. Rev. 19, 452 (1979).
2. D. J. Pegg, J. S. Thompson, R. N. Compton, and G. D. Alton, Phys. Rev. Lett. 59, 2267 (1987).
3. J. Cooper and R. N. Zare, in Lectures in Theoretical Physics: Atomic Collision Processes, ed. by S. Geltman, K. T. Mahanthappa, and W. E. Brittin (Gordon and Breach, New York, 1969), Vol. XI-C, pp. 317-337.
4. J. R. Peterson, Y. K. Bae, and D. L. Huestis, Phys. Rev. Lett. 55, 692 (1985).
5. S. Watanabe, Phys. Rev. 25, 2074 (1982).