PHYSICAL REVIEW LETTERS

VOLUME 22 7 APRIL 1969 NUMBER 14

SIMULTANEOUS PHOTOEXCITATION AND PHOTOIONIZATION OF HELIUM*

James A. R. Samson
Experimental Physics Laboratory, GCA Corporation, Bedford, Massachusetts 01730
(Received 11 February 1969)

The probability of simultaneously photoexciting and photoionizing helium has been measured near threshold at a wavelength of 186 Å. It was found that about $(8 \pm 2)\%$ of the ions formed at that wavelength were excited into the $n = 2$ state.

Double-electron excitation processes have been observed by Madden and Codling in helium.[1] They identified a Rydberg series of doubly excited states leading to the $n = 2$ state of the helium ion. However, no observations exist on what fraction of the ions will be formed in the $n = 2$ state. Since the evaluation of the Lamb-shift energy requires a knowledge of the oscillator strengths for transitions to all states which can be reached by dipole transitions from the ground state, it is important to know the contribution of double-electron excitation processes. In the most recent calculations of the Lamb shift in helium, Dalgarno and Stewart[2] and Salpeter and Zaidi[3] have included the contributions for transitions such as $(1s^2)$-$(2s, \epsilon p)$ and $(1s^2)$-$(2p, \epsilon s)$. They have argued that the most probable of these simultaneous excitation and ionization transitions is the $(1s^2)$-$(2s, \epsilon p)$ transition, at least, for large energies. However, Crownfield[4] has stated that "it is approximately an order of magnitude more likely that the ejected electron is an s electron." It may be possible to decide which argument is correct by measuring the angular distribution of the ejected electrons.[5]

In the present Letter we wish to report an absolute measurement of the photoionization cross section at 186 Å for the transition to the $n = 2$ state of the ion. The technique of photoelectron spectroscopy was used. That is, by measuring the kinetic energies of the ejected photoelectrons it is possible to determine the number of ions left in the $n = 2$ state relative to the number left in the $n = 1$ state. Since the ratio of the number of electrons within each group is equal to the ratio of the photoionization cross sections for these two processes, the cross section for the $n = 2$ transition can be found when the total photoionization cross section is known for that wavelength. However, in the present experiment, it was not possible to distinguish between the $(1s^2)$-$(2s, \epsilon p)$ and the $(1s^2)$-$(2p, \epsilon s)$ transitions as these levels are separated by only 0.0007 eV.

The photoelectron spectrometer was similar to that described previously.[6] A grazing incidence monochromator was used with a light source which produced an intense emission line of N V at 186.153 Å (66.602 eV). The threshold for the $n = 2$ transition occurs at 189.577 Å (65.399 eV). Thus when helium is ionized by radiation of 186.153 Å, two groups of electrons will appear, one with an energy of 1.203 eV for the $n = 2$ transition and another with an energy of 42.015 eV for the $n = 1$ transition. These two groups of electrons were observed with the expected energies. The number of low-energy electrons was 0.08 ± 0.02 of the total number of electrons. The total photoionization cross section of helium at 186 Å

is 1.1×10^{-18} cm^2.[7] Thus the photoionization cross section for the $n=2$ transition is $(9\pm2)\times10^{-20}$ cm^2. The calculated value for the $(1s^2)$-$(2s,\epsilon p)$ transition given by Salpeter and Zaidi is 8.4×10^{-20} cm^2. Dalgarno and Stewart simply quote the ratio of the cross sections calculated at the respective spectral heads, namely, 1:0.0618. On taking the ratio of the experimental cross section for the $n=1$ transition at its spectral head[8] to that of the present experimental cross section for the $n=2$ transition a value of 1:0.012 is obtained.

It is expected that the absorption of radiation by helium of wavelengths shorter than 189 Å will populate the radiative $2p\,^2P_{3/2}$ and $^2P_{1/2}$ states of the ion (a) by direct absorption to those states and (b) by absorption into the metastable $2s\,^2S_{1/2}$ state with subsequent quenching caused by collisional processes. The energy radiated is the important 303.781 and 303.786-Å He II resonance radiation. In the upper atmosphere helium is one of the major constituents. Thus, the helium can act as a continuous absorber of radiation of wavelength less than 189 Å and re-emit this integrated energy into the 303.78-Å line.

*Work supported by the National Aeronautics and Space Administration.

[1]R. P. Madden and K. Codling, Phys. Rev. Letters 10, 516 (1963), and Astrophys. J. 141, 364 (1965).

[2]A. Dalgarno and A. L. Stewart, Proc. Phys. Soc. (London) 76, 49 (1960).

[3]E. E. Salpeter and M. H. Zaidi, Phys. Rev. 125, 248 (1962).

[4]F. R. Crownfield, in Fifth International Conference on the Physics of Electronic and Atomic Collisions, Leningrad, July, 1967 (Leningrad Nauka Publishing House, Leningrad, U.S.S.R., 1967), p. 621.

[5]J. A. R. Samson, in Proceedings of a Symposium on Photoelectron Spectroscopy, London, January, 1969 (to be published).

[6]J. A. R. Samson and R. B. Cairns, Phys. Rev. 173, 80 (1968).

[7]J. F. Lowry, D. H. Tomboulian, and D. L. Ederer, Phys. Rev. 137, A1054 (1965).

[8]J. A. R. Samson, in Advances in Atomic and Molecular Physics, edited by D. R. Bates and I. Estermann (Academic Press, Inc., New York, 1966), Vol. 2, p. 177.

ULTRASONIC ATTENUATION IN LIQUID HELIUM AT 1 GHz †

J. S. Imai and I. Rudnick
Department of Physics, University of California, Los Angeles, California 90024
(Received 5 March 1969)

The attenuation of first sound in liquid helium was measured with an acoustical interferometer. Two results are of particular interest: the temperature dependence of the attenuation in the critical behavior region near the lambda point, and contrary to recent Brillouin scattering measurements, agreement with a theory of Khalatnikov and Chernikova in the region below about 2 K.

The purpose of this Letter is to present the results of an investigation of ultrasonic attenuation in liquid helium which is unique in two experimental aspects.[1] Firstly, the frequency is the highest used in helium measurements—Woolf, Platzman, and Cohen[2] obtained results at 0.56 and 0.72×10^9 Hz using a Brillouin-scattering technique, and more recently Heinicke, Winterling, and Dransfeld,[3] at 0.65×10^9 Hz, also using a Brillouin-scattering technique. Secondly, the attenuation is absolutely determined by obtaining the exponential decrease in amplitude as the distance between the source and receiver transducers is increased. The central experimental problem stems from the fact that the acoustic wavelength is only approximately 2000 Å, and accuracy of alignment usually associated with optical, rather than acoustical, interferometry must be maintained throughout the experiment. But it is the results of the measurements which are of primary interest and it will be shown that, among other things, at this elevated frequency the critical region around the lambda transition is delineated in a way not possible at much lower frequencies.[4,5] Further, our measurements yield greater detail and accuracy than has been previously reported.

The measurements are made with a pulse two-transducer (cadmium-sulfide thin film on a quartz substrate) acoustic interferometer of variable path length. The primary purpose of pulsing is to reduce the duty cycle to the point