Photoionization of helium from the excited state $4p\,^1P_1$

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The cross section for the photoionization of helium from the excited state $4p\,^1P_1$ by radiation of wavelength 1.06 μm is experimentally found to be $\sigma = (3.9 \pm 1.5) \times 10^{-18}$ cm^2.

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Using a new experimental setup, in which radiation of a laser plasma is employed to investigate photoatomic processes, we measured the cross section for the photoionization of helium from the excited state $^4p^1P_1$ by a quantum of energy 1.17 eV (λ = 1.06 μm). To our knowledge, no experimental investigations of the photoionization of atoms from short-lived states with energy exceeding several electron volts have been made so far.

Helium at a pressure 5×10^{-4} Torr was bombarded by a pulsed monochromatic photon beam in the wavelength range 54—47 nm and by a pulsed beam of photons of wavelength 1.06 μm. The fact that the He atom was ionized from the excited state under the simultaneous action of both beams was revealed by the production of the singly charged He^+ ions. Figure 1a shows the level scheme of He with the optical transitions that lead to the ionization. The geometry of the gas bombardment is illustrated by Fig. 1b.

The source of the vacuum ultraviolet (VUV) photons was a plasma produced on a tantalum target by a single pulse from a neodymium laser, with energy 80 J at a flux density 2×10^{13} W/cm^2. The plasma radiation was made monochromatic by a spectrometer constructed in accordance with the Seiya-Namioka scheme, and was directed into the photoionization chamber containing the helium. The flux density of the VUV quanta, measured by the method of[1], was $\sim 5 \times 10^{17}$ nm^{-1} sec^{-1} cm^{-2}. The singly charged hydrogen ions were separated

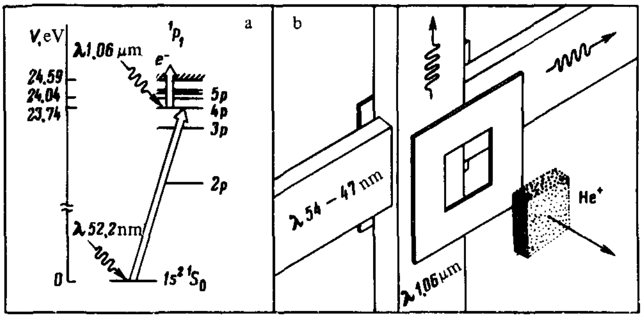

FIG. 1. a) Optical transitions in He, leading to ionization of the $4p\,^1P_1$ state, b) geometry of gas irradiation and ion collection.

with a time-of-flight spectrometer, and their trace on the screen of a broadband long-persistence oscilloscope revealed a peak with amplitude proportional to the number of ions.

The dashed curve of Fig. 2 shows the yield of He^+ ions when the gas is bombarded only by a flux of VUV photons. The radiation wavelength in the first order of the spectral resolution varies in the range 54—47 nm. The appearance of He^+ ions at λ 50.4 nm is due to ionization of He by radiation in the second order of the resolution. In the wavelength region $\lambda < 50.4$ nm, the He is ionized by the radiation in both orders. The position and profile of the absorption edge of He (Fig. 2) were used to graduate the spectrometer in wavelengths and to determine the degree of monochromaticity $\Delta\nu$ of the VUV-photon beam.

The beam of ionizing photons of wavelength 1.06 μm was produced by diverting part of energy of the neodymium-laser radiation intended for plasma production.

The solid curve in Fig. 2 shows the yield of the He^+ ions as a function of the VUV radiation wavelength following the joint action of both light beams. The resonant increase of the yield of the He^+ ions near the spectral point $\lambda = 52.2$ nm (the left-hand peak) attests to the ionization of He from the excited state

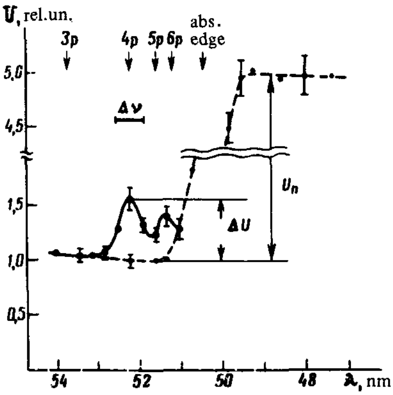

FIG. 2. Yield U of singly charged helium ions vs the wavelength λ of the VUV radiation near the He absorption edge (dashed curve). The λ scale corresponds to the first order of the spectral resolution. Solid curve—yield of He^+ following the joint action of VUV radiation and radiation with $\lambda = 1.06$ μm.

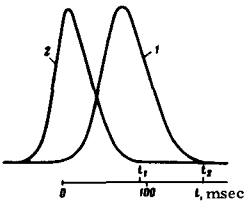

FIG. 3. Oscillograms of VUV (1) and ionizing (2) radiation pulses.

$4p\,^1P_1$. The right-hand maximum seems to correspond to ionization of the helium from the state $5p\,^1P_1$ ($\lambda = 51.6$ nm) and higher excited states.

The ratio of the additional ion yield ΔU at $\lambda = 52.2$ nm to the ion yield U_n at $\lambda = 50.4$ nm was used to determine the absolute cross section of ionization of He from the $4p\,^1P_1$ state. The quantity $\Delta U/U_n$ was measured at a fixed ionizing-beam energy, as determined by an IKT-1M calorimeter.

The VUV photon beam passing through the ionization chamber was detected with a secondary electron multiplier VEU-1A, while the beam of photons with $\lambda = 1.06$ μm was detected by a coaxial photocell. The oscillograms of the exciting and ionizing radiation pulses shown in Fig. 3 were obtained in this manner. It is seen from this figure that the ionization of He from the excited state takes place in the time interval from 0 to t_1.

A control measurement of the Ar^+ ion yield has shown that the intensity of the VUV photon flux in the photoionization chamber is practically constant in the wavelength range 54—47 nm.

The number of He atoms excited per second in a unit volume by a VUV photon flux of intensity $I_1(t)$ is equal to $2.65\times 10^{-2} F_{1\text{-}2} n_0 I_1(t) = C n_0 I_1(t)$. Here $F_{1\text{-}2} = 0.028$ is the oscillator strength of the transition $1s^2\,^1S_0 - 1s4p\,^1P_1$, [2] and n_0 is the gas density. The probability per second of ionizing an atom in the excited state and exposed to a photon flux of intensity $I_2(t)$ is

$$w(t) = \frac{\sigma I_2(t)}{w_p + \sigma I_2(t)},$$

where $\omega_p \approx 0.7\times 10^9$ $\sec^{-1}$ is the probability of spontaneous decay of the $4p\,^1P_1$ state and σ is the sought photoionization cross section. Consequently, the additional yield ΔU of the He^+ ions at 52.2 nm is proportional to the integral

$$N_1 = C n_o \sigma \int_o^{t_1} \frac{I_1(t) I_2(t)}{w_p + \sigma I_2(t)}\, dt.$$

On the other hand, the flux of VUV photons with $\lambda = 50.4$ nm, at the same intensity $I_1(t)$, produces within the time t_2 (see Fig. 3) in a unit gas volume a number of He^+ ions equal to

$$N_2 = \sigma_n n_o \Delta\nu \int_o^{t_2} I_1(t)\, dt$$

and proportional to the yield U_n of the ions. Here σ_n is the known threshold photoionization cross section of He from the ground state. [3] Thus, the determination of σ reduces to a solution of the equation

$$C\sigma \int_{0}^{t_1} \frac{I_1(t)\, I_2(t)}{w_p + \sigma I_2(t)}\, dt = \sigma_n \Delta\nu \frac{\Delta U}{U_n} \int_{0}^{t_2} I_2(t)\, dt.$$

The cross section for the photoionization of He from the excited state $4p^1P_1$, obtained at an ionizing-beam energy 0.2 J, turned out to be $\sigma = (3.9 \pm 1.5) \times 10^{-18}$ cm^2.

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