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THREE-PHOTON IONIZATION OF A HELIUM ATOM IN THE EXCITED 2S STATE

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Submitted 9 September 1970
ZhETF Pis. Red. 12, No. 7, 371 - 373 (5 October 1970)

Multiphoton ionization of atoms in the ground state has been under diligent study during the last few years. We have obtained experimental data on multiphoton ionization of the helium atom in an excited state. Observation of such a process was reported in [1]. Besides being of independent interest, an investigation of the multiphoton ionization of an atom in the excited state may contribute greatly to our understanding of the process of multiphoton ionization of an atom from the ground state via a resonant intermediate excited state. In a large number of cases, the transition from the intermediate state to the continuous spectrum has a multiphoton character.

The experiment consisted of the following. The He atoms of a discharge-afterglow plasma, in the excited metastable states 2^1S and 2^3S, were exposed to focused radiation of a Q-switched ruby laser (Fig. 1). The ions produced in the plasma by the laser radiation were registered with a probe [1]. For ionization from the two states, it is necessary to absorb three quanta of ruby-laser radiation. It can be assumed, however, that the probability of ionization from the state 2^1S is much higher, since the energy of the two quanta is close to the energy of the 6^1S level (frequency deviation ~ 30 cm^{-1}). In the case of ionization from the 2^3S state, the frequency deviations are of the order of several hundred cm^{-1}.

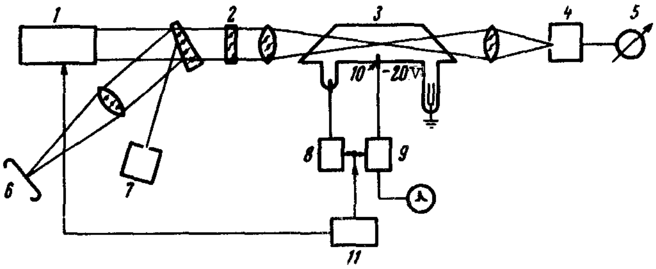

Fig. 1. Experimental setup: 1 - laser, 2 - radiation attenuator, 3 - discharge tube, 4 - calorimeter, 5 - galvanometer, 6 - photographic film; 7 - photocell, 8 - circuit producing the discharge in the tube, 9 - amplifier, 10 - probe, 11 - circuit for synchronizing the discharge shutoff with the laser pulse.

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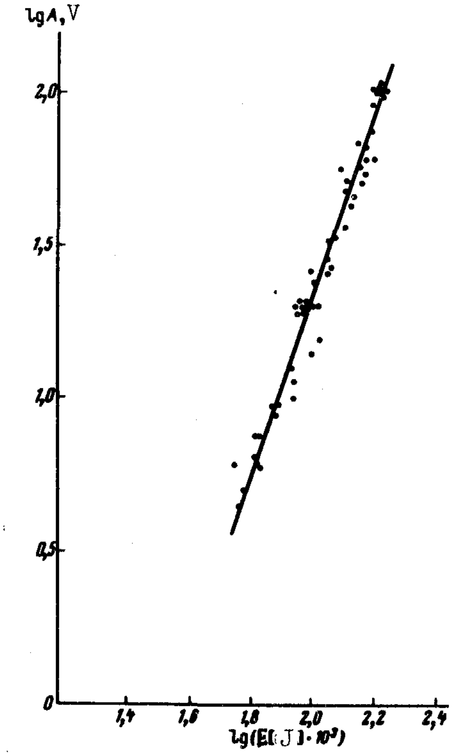

Fig. 2. Amplitude of the probe signal A vs. the energy E of the radiation passing through the discharge-afterglow plasma.

The probability W of the ionization resulting from the absorption of k quanta is connected with the radiation intensity F by the relation $W = \alpha F^k$, where α is the cross section of the k-quantum ionization. In the case of a non-uniform space-time distribution of the radiation, the amplitude of the ion signal from the probe is connected with the cross section as follows:

$$A = cJ_0(\gamma_3)N_i = cJ_0(\gamma_3)N_m \alpha F^k_{max} \int G_1^k(x, y, z)\,dxdydz \int G_2^k(t)\,dt. \quad (1)$$

In (1), c is the probe efficiency, N_m the density of the metastable atoms, N_i the integral density of the ions, $J_0(\gamma_3)$ a Bessel function (its argument is determined by the coordinate γ_3 of the probe) which takes into account the process of ion diffusion from the point of ion production to the probe), and $G_1(x, y, z)$ and $G_2(t)$ are the normalized spatial and temporal distribution functions of the radiation. The maximum radiation intensity is

$$F = E / \int G_1(x, y, z = 0)\,dxdy \int G_2(t)\,dt,$$

where E is the energy radiated in the pulse.

The direct result of the experiment was the measurement of the dependence of the ion-signal amplitude A on the pulsed radiation energy E (Fig. 2). The experimental data were fitted in accord with (1) to the relation $A = \beta E^k$ by least squares, the individual points having weights $\sim 1/A^2$. We obtained $k = 2.9 \pm 0.1$ and $\beta = (3.0 \pm 0.1) \times 10^4$ W/J³ for the field interval $(1 - 3) \times 10^5$ V/cm.

We measured the distribution functions G_1 and G_2, and also the other parameters in formula (1). From these quantities and from β we determined the cross section for three-photon ionization $\alpha = 4.7 \times 10^{-71\pm1}$ cm^{6}sec^{2}photon^{-3}. We have at present no experimental data indicating whether the ionization of the singlet or triplet state makes the main contribution to the observed ion yield. We are currently performing a number of experiments aimed at answering this question.

Calculation of the ionization probability of a helium atom in the excited 2S states, in the field of a ruby laser [2], performed using a semiphenomenological Green's function for the optical electron [3], yielded $\alpha(2^1S) = 5 \times 10^{-77}$ for the ionization from the singlet state and $\alpha(2^3S) = 5 \times 10^{-80}$ for the triplet state.

At present we see no reason why the calculation yields a value much smaller than that observed in the experiment.

The authors thank Professor M. Rabinovich for constant attention to the work, G.A. Delone, N.B. Delone, and N.L. Manakov for valuable discussions, and T.U. Arslambekov for help with the experiment.

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CONSTANCY OF TOTAL CROSS SECTIONS AT HIGH ENERGIES AND K-MESON CHARGE EXCHANGE

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Submitted 11 August 1970
ZhETF Pis. Red. 12, No. 7, 374 - 377 (5 October 1970)

Measurements of the total cross sections for the interaction between π^- and K^0 mesons with protons and deuterons in the IFVE (Institute for High-energy Physics) accelerator [1] have shown that, at least in the incident-meson energy region 25 - 65 GeV in the lab, the cross sections remain constant within the limits of experimental error and contradict the predictions of the Regge-pole model. Some consequences of such a behavior, which lead to violation of the Pomeranchuk theorem, were recently investigated [2] for the charge exchange of π^- mesons and for the regeneration of K mesons. We have made a detailed analysis for the charge exchange of K^- mesons with nucleons, $K^-p \to \bar{K}^0 n$. Verification of the predictions obtained here will ascertain whether the total cross sections $\sigma(K^-p)$ and $\sigma(K^-n)$ depend on the isospin at high energies or not.

Using isotopic invariance, we can relate the charge-exchange and elastic-scattering amplitudes. We normalize the amplitudes in such a way that

$$f^{ce} = -f_{el}(K^-p) + f_{el}(K^-n); \quad \frac{d\sigma}{dt} = \frac{|f|^2}{16\pi K^2}; \quad \sigma = \frac{1}{K}\,\mathrm{Im}\,f, \tag{1}$$

where f is the amplitude of the process, K the meson momentum in the lab, and σ the total cross section.

From the dispersion relations for the elastic forward scattering [7, 10] and from the limitation ensuing from unitarity on the high-energy behavior of the amplitude [4, 5], it follows that at high energies

$$f^{ce}(\omega) = 2\omega\left\{C - \frac{a}{\omega^2} + \frac{K^2}{\pi}\int_{3\,\mathrm{GeV}}^{\infty}\frac{\Delta\sigma(\omega')\,dK'}{\omega'[\omega'^2 - (\omega - i\epsilon)^2]}\right., \tag{2}$$

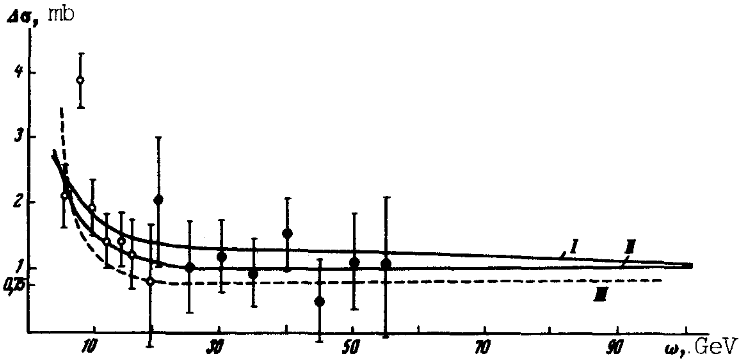

Fig. 1. Different parametrization of $\Delta\sigma = \sigma(K^-p) - \sigma(K^-n)$ (o - from [11], ● - from [12]).

where ω is the meson energy in the lab, C is constant accurate to terms of order m_K^2/ω^2, and

$$a = \frac{1}{\pi}\int_{K_{min}}^{3\,\mathrm{GeV}}\frac{K'\,\Delta\sigma(\omega')}{\omega'(1 - \omega'^2/\omega^2)}\,dK'. \tag{3}$$

The contribution of a to the amplitude is small and it can be estimated from the sum rules at finite energies [8]. Such an estimate yields $a \approx 10$ mb-GeV^2.

To determine C, we can use the experimental value of the