ROLE OF FIELD INTENSITY AND STRUCTURE OF THE ATOM IN THE PROCESS OF MULTIPHOTON IONIZATION

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Introduction. Many experimental data have been published by now concerning multiphoton ionization of an isolated atom in a strong electromagnetic field of optical frequency. The ionization potentials of the investigated atoms, the emission frequencies, and the field intensities used in these investigations corresponded to conditions under which the functional dependence of the ionization probability (W) on the radiation intensity (F) should be in the form of a power-law $W = AF^K$. In accordance with the theory, in which it is assumed that the ionization process is determined by the initial and final states of the electron, and that the intermediate states do not play an important role [1], we get $K = K_0$, where K_0 is the number of the quanta that must be absorbed in accordance with the energy conservation law. Calculations based on perturbation theory, in which account is taken of the concrete spectrum of the intermediate states for the case when the dependence of the Stark shift and level broadening on the field intensity is disregarded, also yield $K = K_0$ [2]. Investigations of the functional dependence were made for the atoms of noble gases, whose ionization was observed at a very large field intensity, $(2 - 5) \times 10^7$ V/cm [3-5]. One of the features of the ionization process under these conditions is the appreciable deviation of the power exponent K from K_0 in all the investigated cases, and we always have $K < K_0$. From our point of view, which was qualitatively confirmed by experiment [5], the cause of this effect is the appreciable influence of the strong field on the structure of the atom. In particular, the upper levels of the atom, which lie closely together, can overlap in a strong field, owing to the Stark splitting, shift, and ionization broadening. An electron falling in this region as a result of absorption of $K < K_0$ quanta has a probability close to unity of going over to the continuous spectrum. Therefore the total probability is determined by the absorption of a smaller number of quanta. An appreciable change in the power-law dependence of the ionization probability on the radiation intensity can also result from a decrease in the difference between the energy of the quasi-resonant level and the energy of the integer number of quanta, as a result of broadening and shifting of the quasiresonant level in the strong field [6].

To verify these hypotheses, we considered it of interest to investigate multiphoton ionization in relatively weak fields, when the phenomena indicated above can be neglected. To this end, we investigated five-photon ionization of the Na atom (I = 5.12 eV) in the radiation field of a neodymium-glass laser ($\hbar\omega$ = 1.18 eV).

Experimental setup. The experimental setup is shown in Fig. 1. We used a laser operating in the giant-pulse regime with Q-switching by a rotating prism. The output mirror in the resonator was a plane-parallel glass plate. A beam of atoms with density 10^{12} at/cm^3 was produced in the chamber with the aid of a multichannel source. A condenser for the beam was located opposite the source and was cooled with running water. The laser radiation was focused by a lens of focal length f = 130 mm with relative aperture 1/15 at the center of the

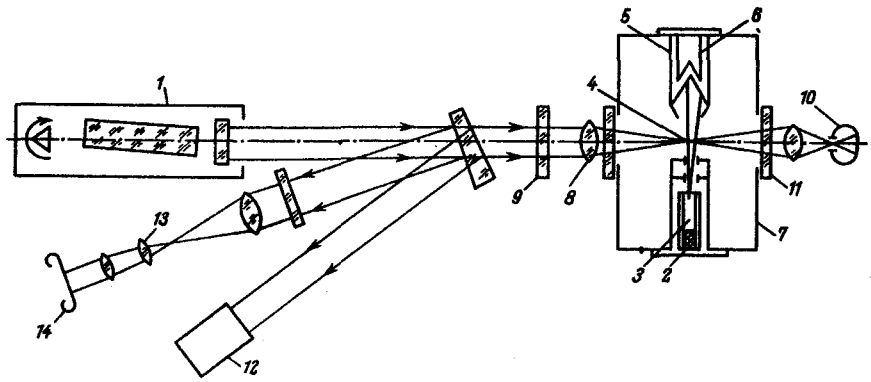

Fig. 1. Experimental setup: 1 - laser, 2 - metallic sodium, 3 - sodium vapor, 4 - beam of sodium atoms, 5 - condenser, 6 - cooling water, 7 - vacuum chamber, 8 - focusing lens, 9 - radiation attenuator, 10 - calorimeter, 11 - windows of vacuum chamber, 12 - coaxial photocell, 13 - microscope, 14 - photographic film.

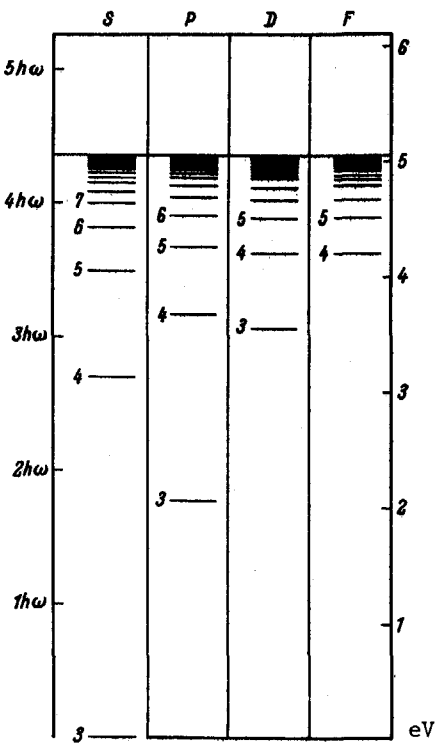

Fig. 2. Level scheme of sodium atom. Right - scale in electron volts, left - in quanta of neodymium-glass emission.

atom beam. A pressure of 10^{-5} mm Hg was maintained in the chamber. The ions produced in the focusing region were accelerated between two electrodes, shaped into a beam by an ion-optical system, divided by masses in a time-of-flight mass spectrometer, and detected with an electron multiplier.

To determine the magnetic field intensity, the energy and the space-time distribution of the radiation intensity in the focusing region were measured in each laser pulse. The method for measuring the space-time distribution of the radiation is described in detail in [3]. The spectral characteristics of the laser radiation were measured with the aid of a modified STF-1 spectrograph. The dispersion of the instrument was measured against the lines of a neon lamp and amounted to 20 Å/mm. The measured wavelength of the emission at the maximum of the intensity was 10 594 Å; the line half-width was 15 Å.

We measured the dependence of the amplitude of the ion signal on the electric field intensity in the region of the focusing of the laser emission. The intensity of the laser radiation was attenuated with filters from the standard colored-glass set, and the linearity of the attenuation was verified experimentally.

Results of experiment. The ionization of the sodium was observed at an electric field intensity in the range from 2 to 5 x 10^6 V/cm. The value of K, defined as the mean-weighted value of a series of measurements, was $K = 4.89 \pm 0.11$. The weighted rms error is given.

Thus, at a field intensity (2 - 5) x 10^6 V/cm, we observed a power-law dependence of the ionization probability on the radiation intensity, with an exponent

$K = K_0$. We recall that this field intensity is smaller by approximately one order of magnitude than the intensity at which ionization of noble gases was observed.

Discussion of results. Let us examine the scheme of the atomic levels of Na. As seen from Fig. 2, only after absorbing four neodymium-laser emission quanta does the electron fall in the region of the closely-lying levels in the atom. In this case the distance to the nearest level 7S in the spectrum of the atom, to which the transition is allowed, is ≈ 250 cm^{-1}. The distance between the levels in this region is ≈ 500 cm^{-1}. The Stark shift of the 7S level was determined from the dipole moments calculated by the Bates and Damgaard method, and amounted to ≈ 10 cm^{-1} in a field of 5×10^6 V/cm. The broadening of the 7S level in such a field was determined by using the Burgess-Seaton method to calculate the ionization probability, and amounted to ≈ 10 cm^{-1}. Comparing all the foregoing quantities, we see that in a field $(2 - 5) \times 10^6$ V/cm the levels of the atom are perturbed relatively weakly, and the difference between the energy of an electron absorbing four quanta and the energy of the 7S level is sufficiently large. Thus, neither the effect of level overlap nor the resonant effects play any role in this case. Comparison of the experimental data and these calculations leads to the conclusion that if the differences between the energy of the integer number of quanta and the energy of the discrete levels in the atom are large and are relatively little changed by the radiation field, then the functional dependence of the ionization probability on the intensity is determined by the quantity K_0.

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DEVELOPMENT OF SELF-FOCUSING FILAMENTS IN SOLID DIELECTRICS

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When powerful laser emission is focused inside a transparent dielectric such as glass, sapphire, and ruby, it is possible to observe damage in the form of thin filaments several