[8] A. A. Kaminskii, Phys. Status Solidi, 1967, in press.

* The indicated values of the threshold excitation energies make due allowance for the length of the crystal and the interelectrode gap of the pump lamp.

MULTIPHOTON IONIZATION OF XENON AND KRYPTON ATOMS AT WAVELENGTH $\lambda = 1.06\ \mu$

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We present here the first results on multiphoton ionization of xenon atoms (I = 12.13 eV) and krypton atoms (I = 13.996 eV) by neodymium-laser emission ($\lambda = 1.06\ \mu$, $\hbar\omega = 1.18$ eV) at a light-wave electric field intensity $E \cong 4 \times 10^7$ V/cm. The experimental setup was similar to that used earlier to investigate multiphoton ionization of the same atoms by ruby-laser emission ($\lambda = 0.69\ \mu$, $\hbar\omega = 1.78$ eV) [1].

At an emission intensity $F = 10^{31.4\pm0.3}$ photons/cm^2-sec ($E \cong 4 \times 10^7$ V/cm), the ionization probability is proportional to the emission intensity raised to the power $K = 8.8 \pm 0.2$ for xenon and $K = 9.1 \pm 0.1$ for krypton.

If the radiation field does not exert a significant effect on the states of the atomic system, then the exponent in the dependence of the ionization probability on the emission intensity should be equal to the number of quanta abosrbed upon ionization, which, in accord with the energy conservation law, is equal to $K_0 = \langle I/\hbar\omega + 1\rangle$, where the symbol $\langle x\rangle$ denotes the integer part of the quantity x. The experimental values of K are much lower than the corresponding values of K_0, which are 11 for xenon and 12 for krypton. Values of K lower than K_0 were obtained earlier at the same electric-field intensity at the ruby-laser wavelength $\lambda = 0.69\ \mu$ [1]. From our point of view, these results are evidence that an appreciable contribution is made to the ionization probability by transitions between bound states, and that the radiation field has a strong influence on these states [1].

A qualitative explanation why the observed value of K is smaller than K_0 is afforded by two effects - lowering of the effective ionization potential by the overlap and merging of the upper energy levels in the atom [2], and change in the width and detuning of the resonance of the intermediate quasiresonant levels [3]. It is interesting to note that although the quantum energy in our experiments differs greatly, the quantity $I - K\hbar\omega$ is independent within the limits of experimental error, of the radiation wavelength and is much larger for krypton than for xenon. In the case of transitions between quasiresonant levels, the quantity $I - K\hbar\omega$ depends on the relative placement of the atomic energy levels and on the energy of an entire number of emission quanta, reckoned from the ground state, and should therefore be a random quantity for different atoms and emission-quantum energies. From this point of view, the difference in the values of $I - K\hbar\omega$ for Xe and Kr is natural, and the independence of the quantum energy can be due only to the randomness. The amount by which

the effective ionization potential is lowered depends on the radiation-field intensity and on the distance between the atomic energy levels. The independence of $I - K\hbar\omega$ of the quantum energy, at an unchanged value of the radiation-field intensity, favors this hypothesis, which is contradicted, on the other hand, by the difference in the values of $I - K\hbar\omega$ for Xe and Kr, whose energy level positions with respect to the boundary of the continuous spectrum are similar. Experiments with other atoms and other emission frequencies are necessary to explain the concrete mechanism of multiphoton ionization.

At emission intensities $F = 10^{31.4\pm0.3}$ photons/cm-sec (field intensity $E \cong 4 \times 10^7$ V/cm), the absolute probability of multiphoton ionization is $W = 10^{7.9\pm1.8}$ sec^{-1} for xenon and $10^{7.5\pm1.8}$ sec^{-1} for krypton.

Comparison of the ionization probabilities obtained at ruby and neodymium-laser frequencies for Xe and Kr atoms shows that, within the limits of experimental error ($10^{\pm3.8}$) the absolute values of the probability do not depend on the emission wavelength. The experimentally observed probabilities exceed by several orders of magnitude the values obtained by L. V. Keldysh's formula [4] which takes into account only transitions between virtual states of the continuous spectrum. This disparity is in qualitative agreement with our assumption that transitions between bound states make an appreciable contribution. The probability of multiphoton ionization resulting from transitions between bound states in the presence of a strong emission field has not yet been calculated. A rough estimate can be obtained by assuming that the absorption of the first K quanta is due to transitions between virtual states of the continuous spectrum [4], and of the last K_0 - K quanta is due to transitions between bound states with probability of the order of unity. Such an estimate gives probability values that agree within the limits of experimental error with those observed in the experiment.

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[1] G. S. Voronov and N. B. Delone, JETP 50, 78 (1966), Soviet Phys. JETP 23, 54 (1966); G. S. Voronov, G. A. Delone, and N. B. Delone, JETP 51, 1860 (1966), Soviet Phys. JETP 24 (1967), in press; G. S. Voronov, G. A. Delone, and N. B. Delone, JETP Letters 3, 480 (1966), transl. p. 313.

[2] G. S. Voronov, M. M. Gorbunkov, G. A. Delone, N. B. Delone, L. V. Keldysh, and M. S. Rabinovich, Paper at 7th Conference on Ionized Gases, Belgrade, 1965.

[3] G. S. Voronov, JETP 51, No. 5 (1966), in press.

[4] L. V. Keldysh, JETP 47, 1945 (1964), Soviet Phys. JETP 20, 1307 (1965).