Double multiphoton ionization of strontium atom

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Results are presented of investigations of multiphoton ionization of strontium atoms of a neodymium laser. The degrees of nonlinearity of the processes of production of singly charged ($K^+ = 5.0 \pm 0.2$) and doubly charged ($K^{2+} = 10.1 \pm 0.6$) ions. It is proposed that the doubly charged ions are produced from the ground state of the atom by simultaneous detachment of the external electrons.

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In all the previously investigated cases of multiphoton ionization of atoms, singly charged ions were observed.[1] We have recently observed the production of doubly charged ions in multiphoton ionization of strontium and barium atoms.[2,3] In principle, doubly charged ions can be produced when an atom is ionized from the ground state (double ionization) or when a singly charged ion is ionized (cascade ionization). The results of the present study prove the existence of double ionization of the strontium atom.

The experiments were performed by the method of intersecting laser and atom beams. A Q-switched neodymium laser operated in a regime in which one transverse and many longitudinal modes were generated, and the space-time distribution of the laser radiation remained constant during the experiment. The maximum laser-beam field intensity reached in the beam-intersection region was 6×10^6 V/cm. The atom concentration in the beam was 10^{10}–10^{11} cm^{-3}

We investigated experimentally the dependence of the numbers of singly and doubly charged ions on the laser intensity. The experimental results are shown in Fig. 1 in logarithmic coordinates, with allowance for the sensitivity of the secondary-electron multiplier to the singly and doubly charged strontium ions.

A least-squares fit of the experimental data to a power law yielded an exponent $K^+ = 5.0 \pm 0.2$ for singly charged ions and $K^{2+} = 10.1 \pm 0.6$ for doubly charged ions.[1)] It follows therefore that the experimentally observed dependence of the yield of the singly charged ions on the radiation intensity corresponds to a five-photon character of this process ($J = 5.7$ eV, $\hbar\omega = 1.17$ eV).

Let us examine in greater detail the production of doubly charged strontium ions. In the cascade process of production of doubly charged ions ($Sr + 5\hbar\omega$

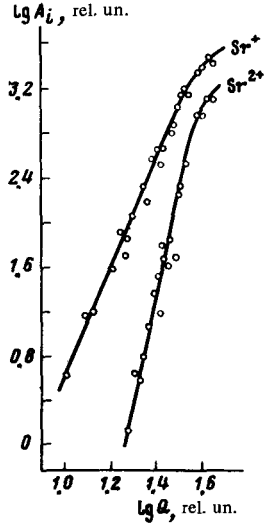

FIG. 1. Amplitudes of signals of singly and doubly charged strontium ions vs the radiation energy.

$\rightarrow Sr^+ + e : Sr^+ + 10\hbar\omega \rightarrow Sr^{2+} + e$) the ion yield is determined by the product of the probabilities of the indicated processes, i.e., $N_i^{2+} \sim F^{15}$. At high effectiveness of the second process, the observed number of singly charged ions should deviate downward from the $N_i^+ \sim F^5$ law. As seen from the experimental data shown in Fig. 1, neither of these effects takes place. The relation observed is $N_i^{2+} \sim F^{10}$; at high intensities when the number of produced singly and doubly charged ions is approximately equal, no deviations from the relation $N_i^+ \sim F^5$ are observed. These data allow us to state that double ionization from the ground state has been observed.

The process of simultaneous detachment of two electrons by a strong optical field has not been described theoretically so far even qualitatively. From our point of view, the large difference between the energy that must be imparted to the atom in double ionization and the energy transferred in cascade ionization can be explained only if the double ionization process has an autoionization character or if the atomic residue is strongly perturbed.

In conclusion, we wish to point out that the double excitation process is highly effective[4,5] in electron excitation and photoabsorption of the strontinum atom.

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[1)]We note that at the maximum intensity realized in this experiment, the number of the produced singly and doubly charged ions was approximately equal

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