Investigation of the excitation of strontium atoms by electron impact from metastable states

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The method of intersecting electron and atom beams was used to perform experiments on stepwise excitation of strontium atoms from metastable states. The excited atoms were produced by passage of the atom beam through a pulsed gas-discharge chamber. We investigated the excitation of four triplet levels from the ground state and excited states. Using as an example the comparison of the excitation functions of the transition $5^3P_2-6^3D_2$ from the ground and metastable states, it is shown that their behavior differs significantly in character. So large a difference between the shapes of the curves is attributed to the fact that the excitation of the investigated level starts from initial states having different multiplicities.

We are not acquainted with any publication reporting direct experiments on the excitation of atoms from excited states (called stepwise excitation). The available information on the effectiveness of such processes[1] is based on investigations of the parameters of a gas-discharge plasma (indirect data), and there is no information whatever on the character of the energy dependences of the cross sections of stepwise excitations. As to theoretical calculations, they have been performed for individual cases,[2] and the degree of their reliability is furthermore unknown.

We performed in our laboratory the first experiments on the direct study of stepwise excitation of one of the elements of the alkaline-earth group (strontium) in an electron beam intersecting an atomic beam. The gist of the method is to use a pulsed gas-discharge chamber in the path of the atomic beam; this produces in the beam two components in the intersection zone, one constant consisting of atoms in the ground state, and one variable with metastable atoms.[1)] The observed radiation was detected by selective amplification at the discharge-modulation frequency.

Our investigations have enabled us to study the energy dependences of the excitation of the most intense spectral transitions from the triplet levels (7^3S_1, $5p^2\,^3P_2$, 6^3D_2, 4^3F_4) from both a ground and a metastable state in the electron energy interval from the thresholds of the processes to 30 eV. In this communication we discuss only excitation of the line $\lambda = 403.2\ nm (5^3p_2 - 6^3D_2)$, the stepwise (and direct) excitation function of which is shown in Fig. 1.

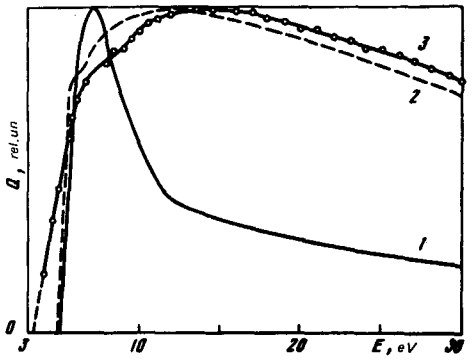

FIG. 1. Energy dependences of the excitation of spectral transitions from the ground state (curves 1 and 2) and from metastable states (curve 3): 1) $\lambda = 403.2\ nm$ $(5^3P_2 - 6^3D_2)$, 2) $\lambda = 554.3\ nm$ $(5^1P_1^0 - 6^1D_2)$, 3) $\lambda = 403.2\ nm$ $(5^3P_2 - 6^3D_2)$.

Before we proceed to the analysis of the results, we note that the strontium atom has not one but three low-lying long-lived states (with $\tau \sim 10^{-4}$ sec), namely 4^1D_2, 5^3P_0, and 5^3P_2 (see Fig. 2). The beam of excited atoms apparently contains them all. It is therefore difficult at present to determine uniquely from which metastable states the excitation of the upper level of the indicated line takes place (without resorting to additional information).

This does not prevent us, however, from stating the following: The level excitation functions from the ground state (curve 1) and metastable state (curve 3) are essentially different in character. Such a great difference in the shape of these curves can apparently be attributed to the fact that excitation of the 6^3D_2 level by electron impact occurs from initial states having different multiplicity. In the case of excitation from the ground state (see Fig. 1) the transition is via electron exchange. For such transitions, the maximum of the process occurs at an electron energy close to the excitation threshold, and then decreases rapidly with increasing energy (see curve 1). When the excitation is from metastable levels, the transition occurs, in all probability, without exchange.

It is well known[3] that processes that occur without exchange are characterized by a gently sloping energy

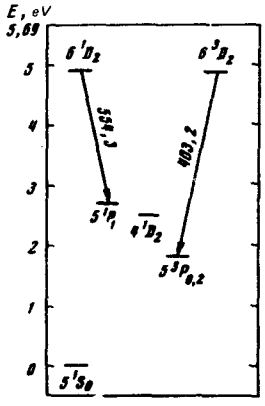

FIG. 2.

dependence with a maximum at three of four energy units. This is precisely the picture we see on curve 3. The same figure shows the excitation function of the singlet line $\lambda = 554.3\ nm$ (curve 2), the upper level 6^1D_2 of which is excited from the ground state without a change of multiplicity. A comparison shows that curves 2 and 3 are similar.[2)]

More detailed information on the setup, the procedures used in the relative and absolute measurements of the cross sections for stepwise excitation will be published subsequently.

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[1)]The short-lived atomic states undergo radiative decay without reaching the region of beam intersection.

[2)]A similar picture is observed also for the other investigated levels.

[1]Spektroskopiya gazorazryadnoi plazmy (Spectroscopy of Gas Discharge plasma), Collection ed. by S. Z. Frish, Nauka, 1970.

[2]Fizika atomnykh stolknovenii (Physics of Atomic Collisions), Collection ed. by D. V. Skobel'tsyn, Nauka, 1970.

[3]N. F. Mott and H. S. W. Massey, Theory of Atomic Collisions, Oxford, 1965.