EXCITATION OF RYDBERG STATES IN He, Ne, Ar, Xe, *AND* Hg *ATOMS DUE TO ELECTRON COLLISIONS*

G. A. SURSKIĬ and S. E. KUPRIYANOV

L. Ya. Karpov Physico-chemical Institute

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An experiment on excitation of Rydberg (highly excited) states in He, Ne, Ar, Xe, and Hg atoms by electron impact is described. The ability of atoms in Rydberg states to become ionized near a metallic surface and in an electric field is exploited for recording the states. Excitation curves are obtained for electron energies lying between the threshold value and 70 eV.

THREE methods are used for registering the Rydberg states of atoms: 1) ionization of excited hydrogen[1] and other atoms[2] in electric and magnetic fields; 2) ionization of unexcited atoms and molecules in the gas phase by excited atoms;[3,4] 3) ionization of excited atoms created by interaction with a metallic surface.[2,4,5]

In all these methods, mass-spectral analysis is employed. In this paper the third method is used for registering the Rydberg states of atoms. The detector scheme is shown in Fig. 1.

Electrons from the cathode 1, after acceleration, pass through three consecutive collimating apertures 2 and then along the axis of an equipotential cylindrical screen to the electron collimator 4. A magnetic field of about 500 G was used for the collimation of the electron beam 3. Because of the collimating apertures and the magnetic field the major part of the electrons participating in the excitation were registered by the electron collector (we registered the current to the collector and the current to the wall of the equipotential box in front of the detector).

Charged components from the source are sorted by a magnetic field, the deflecting plates 5, and a small positive potential on the ionizing copper grid 6. After the ionizing grid is placed an antidynatron grid 7. A positive voltage of up to 400 V relative to ground is applied to the ionizing grid, which serves to accelerate the ions received there. Under these conditions, besides ionization on the grid, ionization in the electric field is possible.[2] The ions falling on the Faraday cylinder 8 are registered by an electrometric amplifier and pen recorder. The voltage that accelerates the electrons is swept automatically. Simultaneously, the voltage on the diagonals of the first bridge is maintained proportional to the electron current with the aid of a second pen recorder, and in this way automatic normalization with respect to current is accomplished.

The excitation functions we obtained are given in Figs. 2 and 3. It is seen from the figures that the excitation thresholds lie close to the ionization potentials, and consequently we are dealing with highly excited hydrogenlike (Rydberg) states. The curves shown for the rare gases are similar to those obtained by Kupriyanov.[5] The existing discrepancies in shape can be explained by the different conditions under which the curves were obtained, as well as by the presence in the present case of normalization with respect to the electron current.

We see that the curves can be divided into two groups. To the first group belong the excitation functions of the lighter atoms: He and Ne; to the second group, the functions of Ar, Xe, and Hg. The shape of the curves of the first group are more characteristic of the excitation functions of singlet states, which in particular, agrees with the experimental measurements of the optical functions of the excitation of helium by electron collision,[6] which show that the fraction of triplet excited state of the atom for any n (the principal quantum number) is small in comparison with the cross sections for excitation of singlet states.

Characteristic of the second group is a rather sharp peak lying between ~ 1.4 and ~ 1.7 times the threshold value of the electron energy E_{thr} and after a drop, a plateau beginning about $3E_{thr}$. If we pursue this division of the given excitation functions into "singlet" and "triplet" types, the functions of the second group must belong to the "triplet" type. This difference in shape of the excitation functions of the rare gases can be explained by the effect of field ionization of excited

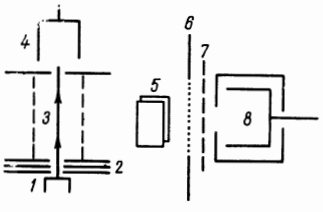

FIG. 1. Scheme for the detection of Rydberg (highly excited) atomic states. 1–cathode; 2–collimating apertures; 3–electron beam; 4–electron collector; 5–deflecting plates; 6–ionizing screen; 7–antidynatron grid; 8–Faraday cylinder.

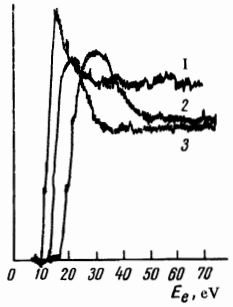

FIG. 2. Dependence of ion current I (in arbitrary units) on electron energy E_e. Curve 1–Hg, 2–Ar, 3–Xe.

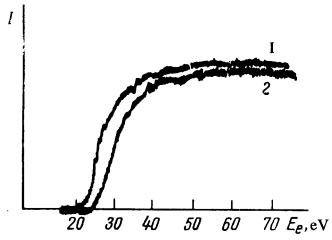

FIG. 3. Dependence of ion current I (in arbitrary units) on electron energy E_e. Curve 1—Ne, 2—He.

states situated between the ionization limits $p^5\ ^2P^0_{3/2}$ and $p^5\ ^2P^0_{1/2}$. This effect increases from Ne to Xe,[7] inasmuch as the highly excited states occupy a band of ~ 0.3 eV about the ionization limits, and the difference in the energies of these limits increases from ~ 0.1 eV for Ne to ~ 1.2 eV for Xe.

The excitation function of the highly excited states of Hg shown in Fig. 2 has a pointed maximum. It is known[7] that in Hg the optical excitation functions have a sharp maximum, irrespective of whether they belong to singlet or triplet states.

All the above curves were taken under conditions of linear dependence of the signal magnitude on pressure. If the pressure is raised up to 10^{-4} Torr and higher, then, as already reported,[5] an additional broad maximum, lying after the first, appears on the curves.

We have made measurements that show that the additional peak is a result of a superposition on the main function of a process that is of second order with respect to pressure, i.e., processes representing the interaction between excited atoms and atoms in the normal state. In this apparatus we observed excitation functions of metastable states of helium atoms, by using the phenomenon of electron emission from a metallic surface when it is struck by metastable atoms. For this, the Faraday cylinder was replaced by a flat collector and the antidynatron grid was supplied by a positive voltage. The results obtained agree well with data in the literature.[8]

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