X radiation accompanying electron capture by oxygen and carbon nuclei in molecular hydrogen

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The emission cross sections for the characteristic x radiation accompanying the capture of an electron by C^{6+} and O^{8+} nuclei in molecular hydrogen at a collision energy $E_0 = 0.6$–8 keV/amu have been measured. It is shown that the electron is captured in a state of the C^{5+} and O^{7+} ions with large principal quantum numbers. This occurs when the population of states with different orbital moments is approximately uniform.

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When nuclei collide with hydrogen molecules, efficient electron capture occurs in excited states of the multiply charged ion. The subsequent decay of these states results in the emission of characteristic x rays. Such processes at collision velocities $V = 3$–12×10^7 cm/sec are very interesting for hot-plasma physics; until now, however, these processes have not been studied because of the difficulty of producing beams of nuclei with low kinetic energies and the difficulty of building sufficiently sensitive equipment for analyzing and recording soft x rays.

We have measured for the first time the energy dependences of the x-ray emission cross sections for collision energies $E_0 = 0.6$–8 keV/amu for the cases C^{6+} and O^{8+}-H_2. The beam of nuclei, which was produced with the aid of the KRION-2 source developed at the Joint Institute for Nuclear Research,[1] was accelerated to the required energy and, after charge segregation in a magnetic mass monochromator, was passed through the collision chamber that was filled with a rarefied-gas target with a density of $\sim 6 \times 10^{11}$ cm^{-3}. The radiation produced as a result of collisions was isolated by means of absorbing filters and detected by a secondary-emission detector with a CsI photocathode.

X rays with $\lambda < 35$ Å were isolated by a 0.6-μm-thick aluminum filter; this gave the total x-radiation cross section $\sigma(nl\text{-}1s)$ for nl-$1s$ ($nl \neq 2s$) transitions. The $2s$ state is long-lived and its decay occurred primarily after the excited ions had left the detector visibility region. The L_α lines of O^{7+} and C^{5+} were isolated by means of Teflon and scandium filters, respectively, giving the cross section $\sigma(2p\text{-}1s)$. Absolute calibration of the equipment was done by measuring the known excitation cross sections of the characteristic K radiation of nitrogen with $\lambda = 31.6$ Å and neon at $\lambda = 14.6$ Å after the electron collision.[2] The calibration errors amounted to 40%.

The results are shown in Fig. 1. As seen from this figure, the x-radiation emission cross sections, i.e., the capture of an electron in excited states, are very large and slightly dependent on the collision energy.

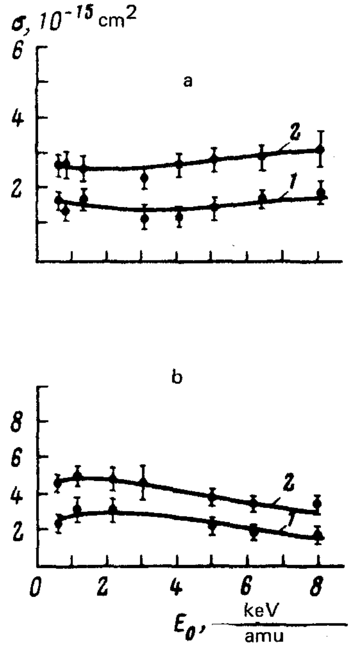

FIG. 1. Collision-energy dependences of the excitation cross section of $2p$–$1s$ (curve 1) and nl–$1s$ ($nl \neq 2s$) (curve 2) transitions produced as a result of electron capture in hydrogen by C^{6+} (Fig. 1a) and O^{8+} (Fig. 1b) ions.

Figure 2 shows the dependences of the relative fraction of $2p$–$1s$ transitions $\xi = \sigma(2p\text{–}1s)/\sigma(nl\text{–}1s)$ on the collision energy of the studied cases. On the basis of the data we can draw conclusions about the populations of states with different orbital moments. Current theory includes two approaches for the determination of the populations of levels with different orbital moments. According to the Salop-Olson model,[3] electron capture occurs as a result of an electron transition in a quasimolecule with no change in the projection of the moment on the internuclear axis. In the case of the C^{+6} ion, transitions occur to the $3d\sigma$ and $4f\sigma$ states, and in the O^{+8} case to the $5g\sigma$ and $6h\sigma$ states. After scattering of particles, the P states of the C^{+5} and O^{+7} ions are maximally populated. Here $\xi = 0.4$–0.5 for all indicated cases. In

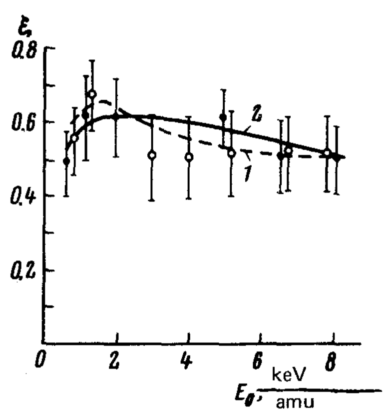

FIG. 2. Relative fraction of $2p$–$1s$ transitions $\xi = \sigma(2p\text{–}1s)/\sigma(nl\text{–}1s)$, plotted as a function of the collision energy for C^{6+}-H_2 (curve 1) and O^{8+}-H_2 (curve 2).

the models[4] which take into account the redistribution of the populations among l values because of rotation of the axis of the quasimolecule, the maximum is in the state with large l. In this case ξ increases to 0.7–0.9. As seen in Fig. 2, the experimental data correspond to the intermediate population in l.

Using absorbing filters of different thicknesses, we have estimated the ratio of the intensities of the lines corresponding to the $4p$–$1s$, $3p$–$1s$, $2p$–$1s$, and $3l$–$2l'$ transitions for C^{6+}-H_2 collisions. Taking into account the probability of various transitions in the decay scheme of the states with $n = 3$ and 4 (Ref. 5), we can conclude from these data that the ratio of the populations of the levels with $n = 3$ and $n = 4$, which are produced via the capture, is 0.3 ± 0.2 for a nearly uniform population of states with different orbital moments.

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