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LETTER TO THE EDITOR

Rydberg levels population in the electron capture collision $O^{6+}+He$ at low velocity

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Abstract. The population of levels with principal quantum numbers n largely in excess of the $n=3$ (most populated level) in the single electron capture by O^{6+} from He (at 60 keV) is reported. The $n=4$ population involves an 'electron promotion mechanism' at small internuclear distances ($R\approx 2.5\ a_0$). Our observations show population of levels up to $n=7$ (Rydberg levels) leaving open the theoretical interpretation.

During the past few years, many experiments have been devoted to the study of the single (SEC) and double electron capture (DC) in the collisional pair $O^{6+}+He$ at low velocities. For the SEC, there is a general agreement that $n=3$ is the most populated level; Roncin *et al* (1990) showed that $n=4$ was a slightly populated level: its population mechanism was explained using 'the electron promotion model' (Shimakura *et al* 1987). It is understood that the potential curve crossing for this transfer is seen at small internuclear distances ($R\approx 2.5\ a_0$) and the projectile is scattered at a large angle (typically: 0.5° in the forward direction, at 9 keV).

In this letter, we focus on the population of even higher levels (Rydberg levels) as seen using VUV photon spectrometry.

The experimental conditions have been described in detail elsewhere (Bliman *et al* 1992) and will only be summarized here. A beam of $O^{6+}(1s^2)^1S_0$ ions accelerated to an energy of 60 keV is made to traverse a differentially pumped thin He gas target ($p=7.5\times10^{-5}$ Torr). Following the SEC terminating in Li-like oxygen states and the DC terminating in Be-like ^1L oxygen states, the ions undergo spontaneous radiative decay; the resulting VUV photons are analysed with a 3 m Rowland mount grazing incidence spectrometer looking at 90° to the ion beam direction (the entrance slit was set parallel to the beam direction and its width was 68 μm).

In these conditions, three transition series were observed: $1s^2ns\,^2S_{1/2}\rightarrow 1s^22p\,^2P^o$, $1s^2np\,^2P^o\rightarrow 1s^22s\,^2S_{1/2}$ and $1s^2nd\,^2D\rightarrow 1s^22p\,^2P^o$, seen within the wavelength interval of the spectrometer (9.5–20 nm).

Accounting for the intensity calibration and given the fact that the most intense line is set equal to 100 (population of $1s^23p\,^2P^o$), figure 1 gives the normalized intensity at each transition plotted against n (principal quantum number), in each series. It should be noted that all levels $1s^2nl\,^2L$ (with $n\geqslant 4$ and $l>2$) decay via cascades to $1s^23d\,^2D$: this causes relatively higher intensities for $nd\,^2D$ transitions from $n=4$

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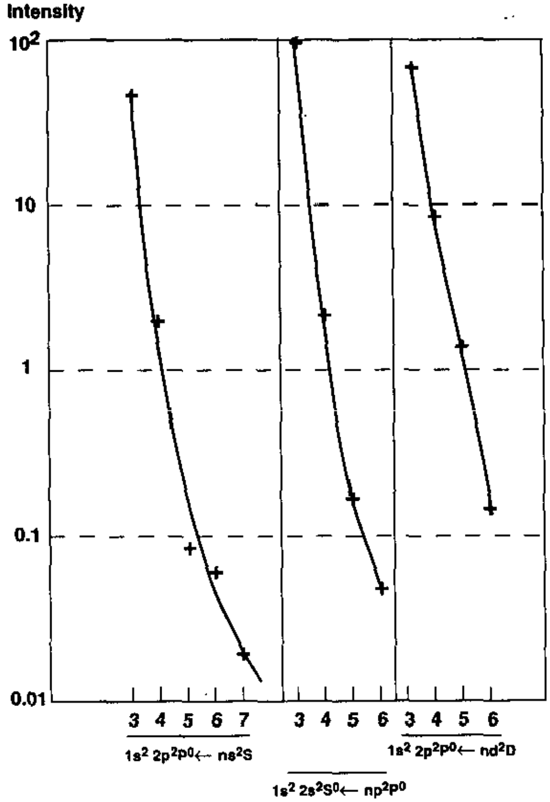

Figure 1. Intensity plotted against n for the spectral transition series: $1s^2np\ ^2P^o \rightarrow 1s^22s\ ^2S$, $1s^2ns\ ^2S \rightarrow 1s^22p\ ^2P^o$ and $1s^2nd\ ^2D \rightarrow 1s^22p\ ^2P^o$.

upwards than $np\ ^2P^o$. It is remarkable that neither the barrier model (Ryufuku *et al* 1980) nor the various Landau–Zener models (Taulbjerg 1986) are appropriate to interpret the population of these high n levels. They describe the population of $n = 3$ (dominant population and exoenergetic channel). The $n = 4$ level population can be understood in terms of the 'electron promotion model' (Shimakura *et al* 1987) where the potential curve crossing effective for the transfer would be at nearly 2.5 a_0. The exit channel is still exoenergetic. All levels with $n > 4$ in these descriptions would be found in endoenergetic exit channels (figure 2).

DC results in doubly excited Be-like states $1s^2(nln'l')\ ^1L$; if we consider the $n = n' = 3$ levels, we see that they are exoenergetic channels (figure 2) and they autoionize to $1s^22s$ and/or $1s^22p$; for the series limits, $1s^23ln'l'$, endoenergetic channels, the autoionization continua are $1s^22s$ and/or $1s^22p$. The feed of autoionization continua such as $1s^27l$ and/or $1s^26l$ would require that $1s^2(nl)^2\ ^1L$ (with $n > 7$) be populated (figure 2). These levels would be more endoenergetic channels than the SEC ones. This seems unlikely. But the branching ratios for autoionization to the different open continua would favour the decay to the lowest levels (Cornille 1992). The experiments have shown that DC has populated $1s^23l3l'\ ^1L$ mostly and that a small fraction went to $1s^23l4l'$ and $1s^23l5l'$ (Boudjema 1990). The autoionization peaks identified as resulting from $1s^22pnl\ ^1L$ (with $n > 5$) do correspond to exoenergetic capture channels and are below $1s^23l3l'\ ^1L$ (Bliman *et al* 1992 and references therein).

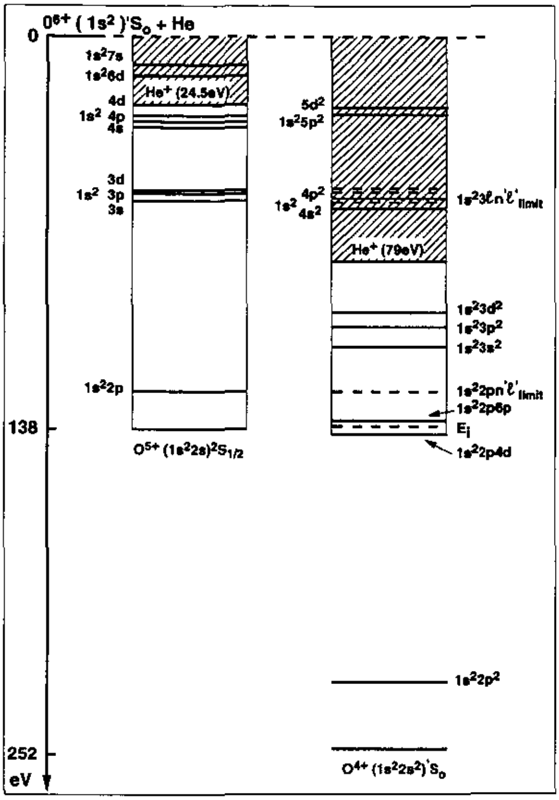

Figure 2. Energy level diagram for $O^{6+} + He \rightarrow O^{5+} + He^{+} \rightarrow O^{4+} + He^{2+}$. Left column, entrance channel; central column, SEC exit channels; right column, DC exit channels; broken lines, series limits; hatched regions in SEC and DC, endoenergetic channels.

Taking into account the calculated transition probabilities (Lindgard and Nielsen 1977) and the branching ratios, it is obvious that all populated levels have totally decayed to either $1s^22s\ ^2S$ and/or $1s^22p\ ^2P^o$ within the time-of-flight of the ions in front of the spectrometer (beam length viewed by the spectrometer, 2 cm; time-of-flight, 2.4×10^{-8} s, level lifetimes of the order 10^{-10} s). Given the partial capture cross sections to 3s, 3p and 3d, we deduce the capture cross sections to individual levels $1s^2nl\ ^2L$. They are shown in table 1. A typical order of magnitude for $\sigma(n=7)/\sigma(n=3)$ is of the order of a few 10^{-4} up to 10^{-3}.

The extension of the 'electron promotion model' to the population of $n > 4$ would lead to transfer internuclear distances of the order of 1 a_0 or less, which are probably unlikely at the present collision velocity. A tentative explanation for these high n

Table 1. Partial capture cross sections to Rydberg states.

$\sigma_{3s} = 3.5 \times 10^{-16}$ cm^2	$\sigma_{3p} = 6.86 \times 10^{-16}$ cm^2	$\sigma_{3d} = 3.98 \times 10^{-16}$ cm^2
$\sigma_{4s} = 1.71 \times 10^{-17}$ cm^2	$\sigma_{4p} = 2.06 \times 10^{-17}$ cm^2	$\sigma_{4d} = 8.91 \times 10^{-17}$ cm^2
$\sigma_{5s} = 1.52 \times 10^{-18}$ cm^2	$\sigma_{5p} = 1.82 \times 10^{-18}$ cm^2	$\sigma_{5d} = 1.25 \times 10^{-17}$ cm^2
$\sigma_{6s} = 1.15 \times 10^{-18}$ cm^2	$\sigma_{6p} = 5.44 \times 10^{-19}$ cm^2	$\sigma_{6d} = 1.34 \times 10^{-18}$ cm^2
$\sigma_{7s} = 3.68 \times 10^{-19}$ cm^2		

channels might be found in terms of the electron translational factor in the transfer: during the transfer to these high n levels, the electron could have a velocity smaller than the approaching highly charged ion. This could well be related to the saddle properties in the three-body problem where the electron is in between the atomic core to which it was attached and the incoming projectile (Rost and Briggs 1991).

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