# Resonances caused by the excitation of a $6^1S_0$–$6^3P_1$ intercombination transition of a thallium ion in the electron-ion collisions

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The excitation of a resonant intercombination line of Tl II, $\lambda = 190.8$ nm, was studied for the first time in crossed electron and ion beams. A resonant structure which stems from the contribution of autoionization states of a thallium atom to the population of the $6^3P_1$ level of a thallium ion has been detected in the near-threshold region.

Recent experimental and theoretical studies have shown that resonance processes resulting from excitation of positive ions by electron impact have an important role. Resonance effects contribute both to the spin-allowed and spin-forbidden transitions, but more significantly to the latter.[1] The study of the excitation of $1^1S_0$–$2^3P_1$ transition of a lithium ion[2] is the only experimental confirmation of a contribution of this sort. Since an intercombination transition $2^3P_1 \rightarrow 1^1S_0$ in $Li^+$ is forbidden in the $LS$ coupling, the authors have drawn some conclusions about the nature of the spin-exchange process from the radiation in the visible part of the spectrum ($\lambda = 548.5$ nm) corresponding to the $2^3P_1 - 2^3P_1$ transition in a lithium ion.

The spin-orbit interaction and the probability for the radiative transitions due to the change in the multiplicity increase because of the relativistic effects in the outer ion shells of the heavy atoms.[3] As a result, the intercombination lines associated with the spin-exchange process inside the ion can be studied experimentally.

In the present letter we study the excitation of the resonant intercombination transition of a thallium ion by electron impact in the vacuum ultraviolet region.

In the experimental arrangement used by us, the electron and ion beams crossed each other at right angles in a vacuum of $5 \times 10^{-8}$ torr. The ion source worked in the discharge regime. We were thus able to reduce to a minimum the production of thallium ions in the metastable $^3P_{0,2}$ states. At an ion energy of 1 keV, the current was 0.6 $\mu$A. In the energy interval 5–300 eV, a three-anode electron gun formed a ribbon-shaped beam with a current of 0.05–1 mA and energy nonuniformity $\Delta E_{1/2} = 0.5$ eV. A 70° Seya-Namioka vacuum monochromator with a concave toroidal grating (1200 lines/mm) was used to spectrally separate the radiation from the collision region. As a radiation detector we used a FÉU-142 photomultiplier operating under single-photoelectron counting conditions. The dark noise of the photomultiplier was reduced to 0.2 $s^{-1}$ by cooling it in a vacuum. The modulation detection system made it possible to single out the useful signal, 0.2–1.0 $s^{-1}$, for a signal-to-noise ratio in the range of 1/3

  

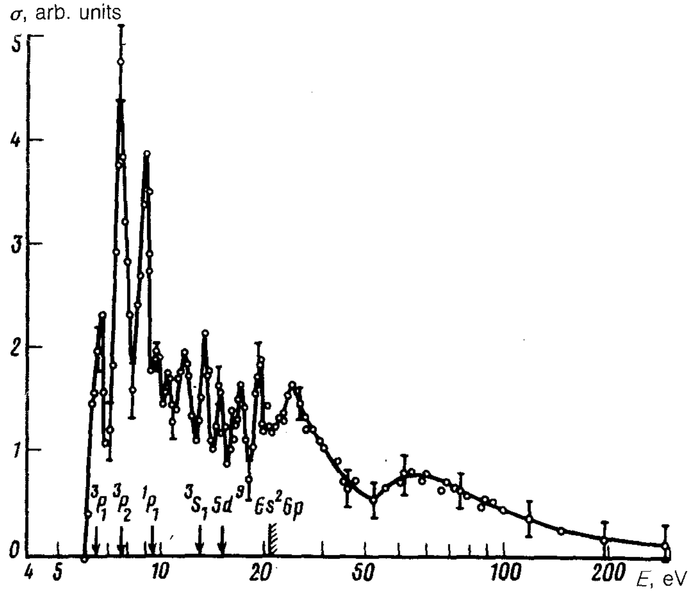


FIG. 1. The excitation function of an intercombination resonance line $\lambda = 190.8$ nm of $Tl^+$.

to 1/50. The energy scale was calibrated to within $\pm 0.2$ eV on the basis of the excitation threshold of the spectral line of hydrogen, $\lambda = 121.6$ nm.

We carried out several lengthy experiments to study in detail the energy dependence of the excitation cross section (the excitation function) of the resonance line, $\lambda = 190.8$ nm, corresponding to the intercombination transition $6^3P_1 \rightarrow 6^1P_0$ of the thallium ion. The excitation function which we obtained is shown in Fig. 1, in which the vertical sections of the curve are the mean-square errors of the relative measurements. We see that the excitation functions of this line have a very sharply defined resonance structure which is particularly pronounced in the near-threshold energy region.

As for the origin of the resonance peaks occurring before the excitation threshold of the $7s^3S_1$ level of $Tl^+$ (i.e., in the region where there are no cascade transitions), we note that they can be linked to the production and subsequent decay of the autoionization states of the neutral atom resulting from the electron-ion collisions. Analysis of the data on photoabsorption[4] and on the spectra of emitted electrons[5] and also a comparison of the energy state of the structure in the excitation function with the energies of the autoionization states of the thallium atom show that at these energies this structure is due primarily to two types of autoionization states: those with a $6s6p(^3P,^1P)np$ configuration and those with a $5d^96s^26P^2$ configuration. Since the states of the first type decay primarily due to the Coulomb autoionization with the production of ground-state ions, the large contribution of these states to the intensity of the intercombination transition can be accounted for only in terms of the competing Koster-Kronig process:

$$\mathrm{Tl}^{**}[6s6p(^3P_2)np] \to \mathrm{Tl}^{+*}[6s6p(^3P_1)] + e,$$
$$\mathrm{Tl}^{**}[6s6p(^1P_1)np] \to \mathrm{Tl}^{+*}[6s6p(^3P_1)] + e. \qquad (1)$$

Type II autoionization states populate the $6^3P_1$ level through the Auger decay:

$$\mathrm{Tl}^{**}(5d^9 6s^2 6p^2) \to \mathrm{Tl}^{+*}[5d^{10} 6s6p(^3P_1)] + e. \qquad (2)$$

Above 13 eV, there are additional pathways by which the $6^3P_1$ level of the thallium ion can be populated due to the cascade transitions from the excited $n^{1,3}L$ levels, from the shifted $5d^{10}6p^2\ ^3P_j$ levels, and from the Baitler $5d^96s^26p$ levels, as well as from the autoionization states of the thallium atom (those converging on these levels and those populating them).

The large diversity of the processes that lead to the population of the $6^3P_1$ level of $\mathrm{Tl}^+$ makes it more difficult to determine the nature of the direct excitation of this level over the entire energy interval studied. We can nevertheless conclude that in the near-threshold energy region the resonance structure dominates over the direct excitation of this level and that the behavior of the energy dependence of the excitation cross section beyond the ionization boundary is different from that predicted by the theory for the intercombination transitions of the $E^{-3}$ decay. The dominating contribution of the resonant effects near the threshold implies that, in contrast with the $\mathrm{Li}^+$ ion,[2] the interference effects are unimportant in the case of excitation of the $6^3P_1$ level of $\mathrm{Tl}^+$. The observable deviation in the decrease of the efficiency of the excitation can be attributed to the fact that among the allowed cascade transitions which populate the $6^3P_1$ level, in addition to the triplet-triplet transitions, there are the singlet-triplet transitions and transitions from the levels of the $5d^96s^26p$ configuration, whose decay law is different from $E^{-3}$.

In summary, our studies have shown that the complex behavior (in terms of energy) of the excitation cross section of the intercombination transition of a thallium ion corresponds to mechanisms which are governed by the relativistic and resonance effects in the outer shells under conditions where several processes compete with each other: a direct transition of an electron from the ground state to the excited state involving a spin flip, population of levels through the autoionization states of the atom, and population of levels due to the cascade transitions.

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