One-photon decay of the states of ions with two internal $L_{2,3}$ vacancies

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(Submitted July 6, 1976)
Pis'ma Zh. Eksp. Teor. **24**, No. 5, 273–276 (5 September 1976)

Characteristic radiation corresponding to the two-electron radiative transition $3s3p-3p^2$ when two $L_{2,3}$ vancancies are filled in the ions Cl and Ar has been observed. The one-photon decay probabilities, which amount to $\sim 10^{-6}$ of the total decay probability of the initial state with two $L_{2,3}$ vacancies, are determined.

PACS numbers: 32.10.Hq

In our preceding study[1] we have observed a new type of Auger transition in which three electrons take part, when two internal $L_{2,3}$ vacancies are filled by two external M electrons, and the entire released energy is carried away by a third M electron. In the present study we have observed a transition wherein the energy of the two vacancies is carried away by a single photon. We have thus investigated both channels of simultaneous decay of two internal vacancies. Observation of one-photon decay of two K vacancies was reported in[2]. Since the fluorescence yield of L vacancies is much lower than that of the K shells, amounting to $\sim 10^{-3}$ for the Cl and Ar ions, [3] one might expect auto-

TABLE I. Energies of $3s3p-2p^2$ transitions.

Particle	Theory[3,5]	Experiment (based on spectral position)	Experiment (based on absorption)
Ar	490	490 ± 20 eV	485 ± 15 eV
Cl	410	425 ± 30 eV	–

ionization to suppress strongly the one-photon decay of two $L_{2,3}$ vacancies. It has turned out, however, that the "fluorescence yield" in two-electron occupation of $L_{2,3}$ vacancies is of the same order as the usual fluorescence yield. An essential result of the present study was the possibility of experimentally determining the probability of the one-photon decay of two internal vacancies, by using the cross sections $\sigma(LL)$, which are known from our earlier measurements,[1,4] for the production of two vacancies in one particle in collisions in which Cl and Ar take part.

We investigated the collisions of Cl and Ar ions with Ar atoms at incident-ion energy 48 keV. The radiation detector was a flow-through proportional counter with quartz window less than 2 μ thick and area 4×18 mm. The use of quartz resulted in a sufficiently high photon registration efficiency ($\gtrsim 10\%$). The high detector sensitivity made it possible to measure cross sections $\sim 10^{-27}$ cm^2. The error in the determination of the cross sections was 40% and was due mainly to the error in the measurement of the transparency of the window.

The intensity of the radiation produced in ordinary $3s-2p$ transitions exceeds the intensities of the investigated $3s3p-2p^2$ transitions by $\sim 10^4$ times. Because of the insufficient resolution of the proportional counter in the investigated quantum energy region, this radiation hindered the observations. To suppress this radiation, besides the material of the counter window, we used two additional aluminum filters each 0.5 μ thick, which attenuated the $3s-2p$ radiation in comparison by 10^9 and 10^7 times, respectively, with the investigated transitions for the emission of the Cl and Ar ions.

It has been established that when an additional filter is introduced, the position of the line in the amplitude spectrum remains unchanged. This indicates that a characteristic peak is observed rather than a filter-separated part of the continuous spectrum.

TABLE II.

Particle	$\sigma(LL-MM)$	$\sigma(LL-MMM)$ [1]	$\frac{\sigma(LL-MM)}{\sigma(LL)}$	$\frac{\sigma(LL-MMM)}{\sigma(LL)}$ [1]	$\frac{\sigma(LL-MM)}{\sigma(LL-MMM)}$
Ar	$4.7\cdot10^{-24}$	$1.1\cdot10^{-21}$	$(1.7-4.3)\cdot10^{-6}$	$(3.8-9.7)\times10^{-3}$	$4.3\cdot10^{-3}$
Cl	$11\cdot10^{-24}$	$9.9\cdot10^{-21}$	$0.7\cdot10^{-6}$	$6.2\cdot10^{-4}$	$1.1\cdot10^{-3}$

The energies of the investigated photons were measured by two methods: by determining the absorption of the radiation in an aluminum filter of exactly known thickness, and by the position of the maximum of the contour in the pulse-height spectrum of the proportional counter. To calibrate the counter in the energy region 400—1500 eV, we used intense K_α lines of N, O, Ne, and Al excited in collisions with the corresponding ions.

The measured photon energies in one-photon decay of two $L_{2,3}$ vacancies in Cl and Ar ions are listed in Table I.

Table I lists also the calculated values of the quantum energies, which were determined as the differences between the energies of the initial and final ion configurations $2p^4 3s^2 3p^n$ and $2p^6 3s 3p^{n-1}$. As established earlier, in the investigated collisions the outer shells are ionized simultaneously with the formation of the internal vacancies. According to[4], the "mean" values of n for Cl and Ar are 3 and 4 respectively. The energies of the ion configurations of interest to us were taken from[3,5]. The agreement between the experimental and calculated photon energy values is good.

Table II lists the cross sections $\sigma(LL-MM)$ for one-photon decay of two vacancies, measured in the present study, as well as the cross sections $\sigma(LL-MMM)$ of the three-electron Auger transitions from[1]. The quantities $\sigma(LL-MM)/\sigma(LL)$ and $\sigma(LL-MMM)/\sigma(LL)$ are the ratios of the probabilities of carrying away the entire energy of the two vacancies by one photon or by one electron, respectively, to the total decay probability, and the principal channel is the ordinary Auger transition. The ratio $\sigma(LL-MM)/\sigma(LL-MMM)$ reflects the relative probability of the radiative channel in the simultaneous decay of two $L_{2,3}$ vacancies, i.e., it is the analog of the "fluorescence yield" for the processes under consideration. It is interesting that the fluorescence yield for ordinary transitions is of the same order of magnitude.[3]

Calculations, by Amus'ya *et al.*[6] of the probability of a two-electron radiative transition in Ar yield a value $W(LL-MM)=3.02\times10^{-7}$ eV. Since the probability of the Auger decay of an $L_{2,3}$ vacancy in the presence of another $L_{2,3}$ vacancy is $W(L-MM)=0.084$ eV,[6] the probability of the decay of any of the two existing vacancies is $2W(L-MM)=0.17$ eV, so that the theoretical value $\sigma(LL-MM)/\sigma(LL)=W(LL-MM)/2W(L-MM)=1.8\times10^{-6}$ is in satisfactory agreement with the experimental values.

The decrease of the ratio $q(LL-MM)/\sigma(LL)$ by a factor 2—6 on going from argon to chlorine may be due to the fact that in Cl^+—Ar collisions the probability of excitation of the 3s subshell of Cl is higher than that of the 3s subshell of Ar in the case of Ar^+—Ar. Since the lifetimes of the $L_{2,3}$ vacancies (10^{-14}—10^{-15} sec) are shorter than the decay times of the autoionization states of the outer shells (10^{-13}—10^{-14} sec[7]), one-photon decay of two internal vacancies is possible when the 3s and 3p levels are still vacant.

The authors thank M. Ya. Amus'ya, N.A. Cherephov, and I.S. Li for discussions and B.I. Makarenko for help with the measurements.

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