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HIGH PRECISION MEASUREMENT OF THE LIFETIME OF THE $^3P_2$ AND $^4P_{5/2}$-STATES IN Ar^{16+} AND Ar^{15+}

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Résumé. Des niveaux de Ar isoélectroniques aux Li et Be dont le déclin est instantané ont été identifiés dans le spectre des rayons X et des électrons, en plus des quatre niveaux metastable déjà connus $(1s2s)^1S_0$, $^3S_1$, $^3P_2$ et $^4P_{5/2}$. L'influence de ces raies sur le spectre a été observée 10^{-9} s après le passage par la cible et pourtant ces niveaux n'ont qu'un temps de vie d'environ 10^{-14} s seulement. Cet effet est expliqué par un phénomène de cascade avec un grand nombre quantique principal n≥14. Le temps de vie mesuré du niveau $^4P_{5/2}$ en tenant compte de l'influence des cascades, est (0,58 ± 0,02) ns et est en accord avec la valeur connue de 0,56 ns, prédite par la théorie. Le niveau $^3P_2$ n'est pas peuplé par le phénomène de cascade à une énergie du faisceau de 56 MeV et son temps de vie est (1,44 ± 0.08) ns.

Abstract. In addition to the four known metastable $(1s2s)^1S_0$, $^3S_1$, $^3P_2$ and $^4P_{5/2}$-states promptly decaying levels in Li- and Be-like Ar could be identified in the delayed x-ray and electron spectrum. Although these states have only a lifetime of about 10^{-14} s the influence of these lines on the spectrum is observed 10^{-9} s after passing the foil.
This effect is explained by cascading processes with high principal quantum number n ≥ 14.
The measured lifetime of the $^4P_{5/2}$-state, considering the influence of cascades, is (0.58 ± 0.02)ns and is in very good agreement with the known value of 0.56 ns, predicted by theory. The $^3P_2$-state is not populated by cascading processes and its lifetime is (1.44 ± 0.08) ns.

INTRODUCTION

For the $^3P_2$- and $^4P_{5/2}$-state the lifetimes have been determined for the He and Li-like ions of the elements with atomic number between 8 and 18. Whereas the lifetimes of the $^3P_2$-state are in agreement with the theoretical values of Lin et al. [1] the experimental values of the $^4P_{5/2}$-state are 10-20 % higher than theoretically predicted by Cheng et al. [2]. The results of a measurement presented in this paper show that in the Ar^{15+}-system cascading processes are the reason for this discrepancy between theory and experiment.

EXPERIMENTAL RESULTS

The apparatus for x-ray and Auger-electron measurement has been described in a previous paper by Dohmann et al. [3] and Dohmann and Mann (to be published Z.f.Phys. [4]). An Ar^{13+}-beam from the UNILAC of the GSI Darmstadt passed through carbon foils with thickness between 10 and 40 μg/cm^2. For different distances behind the foil (see fig. 1) the line profiles of the delayed x-rays are measured using a crystal-spectrometer. The line shape of the Ag-$L\alpha_1$-line was used for a standard (dashed lines in fig. 1 at 1.2 cm behind the foil) because its energy is 2.984 keV and is lying very close to the energies of the transitions in He- and Li- like Ar-ions.

Whereas the left side of the $^3P_2 \rightarrow {}^1S_0$-line follows the predicted line shape, a large deviation from the expected line shape (dashed line in fig. 1 for 1.2 cm behind the foil) appears in the regions of 3.11 and 3.08 keV. These deviations are caused by prompt decaying levels in Li- and Be- like Ar. For the smaller distances of 0.44 cm behind the foil the influence of these prompt lines will be greater.

Although these states have lifetimes of about 10^{-14}s the influence of the prompt lines still is observed 10^{-9}s after passing the foil. Cascading processes are responsible for the delays. Cascading processes were seen first in oxygen and fluorine by Richard et al. [5,6].

The four metastable states $(1s2s)^1S_0$, $^3S_1$, $^3P_2$ and $^4P_{5/2}$ existing in the beam are populated by a cascading electron and give rise to prompt and other metastable lines.

The intensity as function of the distance behind the foil for a spectral line for which the upper state is populated by cascading processes follows a power law (Hopkin et al.[7]).

$$N_c(t) = N\, t^{-\alpha}$$

The measured value is $\alpha = 1.27 \pm 0.08$.
Because the $(1s2s)^3S_1$ has the long lifetime of about 200 ns, the intensity-distances function is given by the power law in the formula. If the spin direction of the 2p-electron is parallel to the

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spin-direction of the electrons in the $^3S_1$-state, this state passes over to a $^4P_{5/2}$-state: $(1s2s)^3S_1+2p \rightarrow (1s2s2p)^4P_{5/2}$. We find an intensity of the $^4P_{5/2}$ decay by cascading processes. Moreover, the following effects - caused by cascades - have to be taken into account: (1) The $^4P_{5/2}$-state is depopulated by the $(1s2s2p)^4P_{5/2}+2p\rightarrow(1s2s2p^2)^3D_{3/2}$ process. (2) Corresponding to their statistical weight factors a 2p-electron, cascading into the $^3S_1$-state, creates the $^4P_{1/2}$- and $^4P_{3/2}$-states: $(1s2s)^3S_1+2p\rightarrow(1s2s2p)^4P_{3/2,1/2}\rightarrow(1s^22s)^2S_{1/2}$.

These two lines have the short lifetimes of about 0.1 ns and 0.03 ns. The $^4P_{3/2,1/2}\rightarrow{}^2S_{1/2}$ transition energies are separated by 3 eV from the $^4P_{5/2}\rightarrow{}^2S_{1/2}$ energy and the spectrometer is not able to separate the lines. The experimental results of the lifetime for the $^4P_{5/2}$ states are given in Fig. 2.

For the $^3P_2$ decay we find deviations from the exponential law only for small distances behind the foil caused by the depolution $(1s2p)^3P_2+2p\rightarrow{}^2D,{}^2P,{}^2S$. The lifetime of the $^3P_2$ is $\tau = (1.44 \pm 0.08)$ ns in agreement with the value theoretically predicted to τ = 1,48 ns by Johnson et al. [8].

In Fig. 3 the Auger-electron spectrum is shown. Beside the known $^4P_{5/2}\rightarrow{}^1S_0$+e line at 1994 eV we find the prompt $(1s2s2p)^2P\rightarrow(1s^2)^1S_0$+e-line in the metastable spectrum. The line is created by population of a 2p-electron to the $(1s2s)^1S_0$ state which decay by a 2E1-transition. This fact is stressed by the time dependence of this line which follows the product of an exponential and power law $I\sim\exp(-t/\tau)\cdot t^{-\alpha}$ with τ = 1.9 ns and α = 1.27. Because the fluorescence yield is only a few percents this line could not be observed in the x-ray spectrum. In fig. 4 the decay curve of the $^4P_{5/2}$ state, determined by observation of the Auger-electrons is shown. Because the $^4P_{3/2}$ and $^4P_{1/2}$ have a fluorescence yield

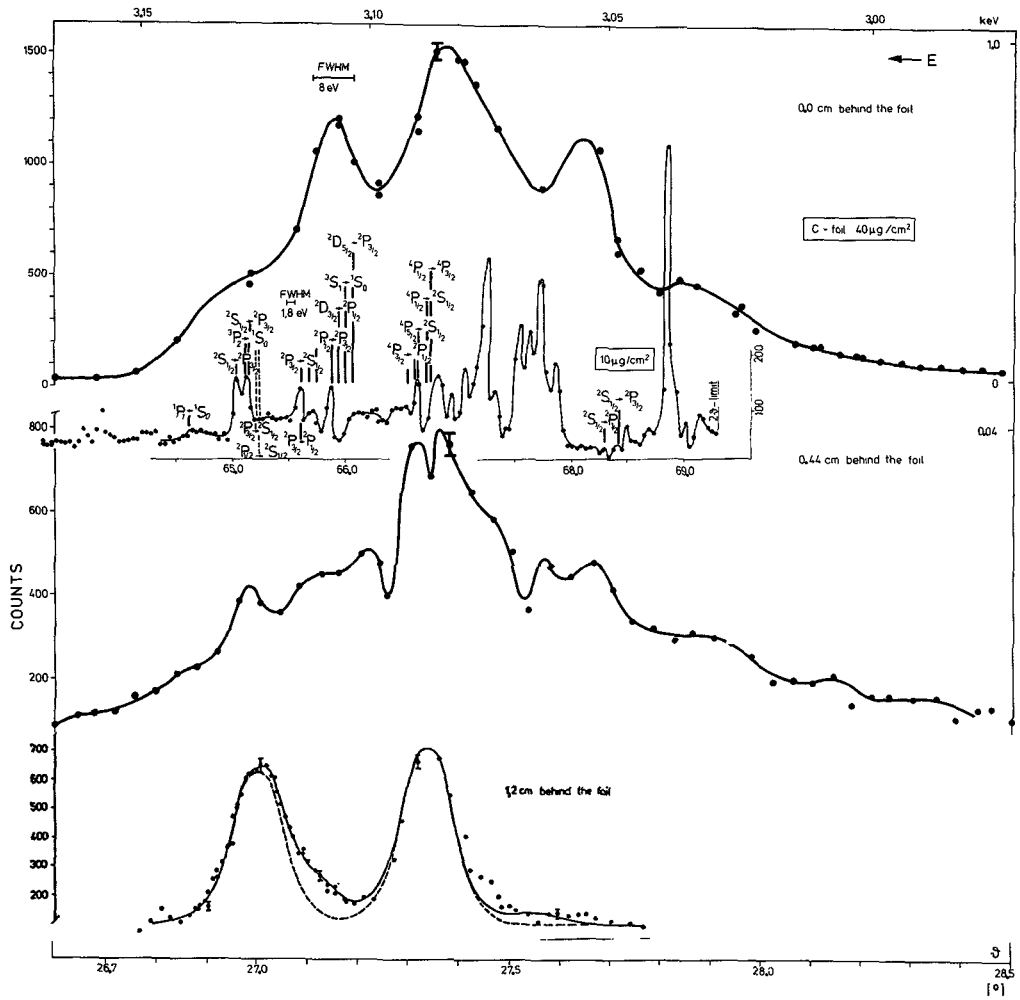

Fig. 1. Prompt and metastable spectrum observed with an Ar-beam of 1.4 MeV/u. The dashed lines would be expected if cascading processes do not exist. The solid line is given by the influence of the indicated prompt lines, produced by cascades. For line identification the prompt spectrum was observed in the second order of reflection.

near unity the deviations from the exponential law at great distances behind the foil are smaller than in the x-ray channel (see fig. 2).

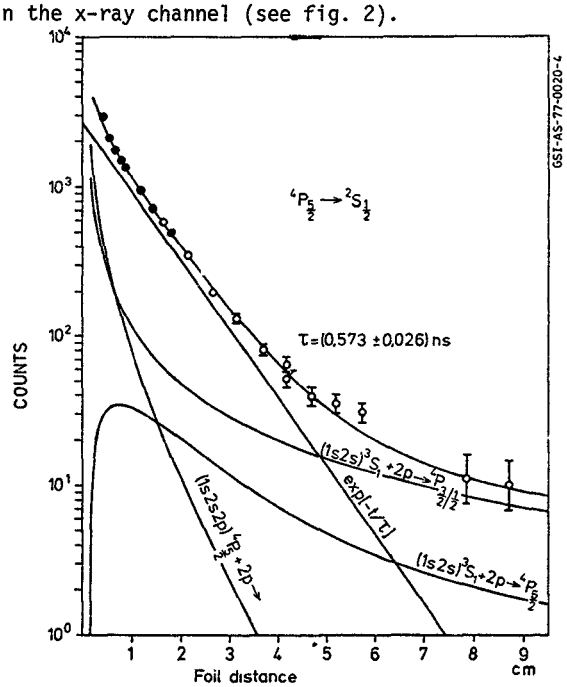

Fig. 2. Decay curve of $^4P_{5/2}$-state of Li-like Ar^{15+}. The deviation from the exponential law is caused by cascading processes populating and depopulating the $^4P_{5/2}$-state.

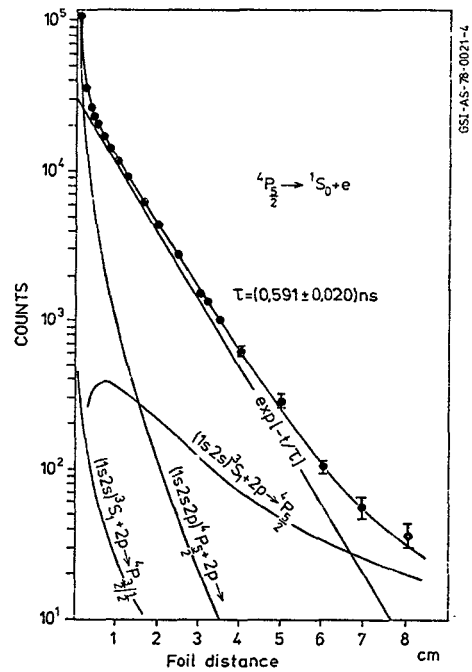

Fig. 4. Experimental and theoretical decay curve of the $^4P_{5/2} \rightarrow {}^1S_0$+e-Auger transition compared with different decay curve of cascades.

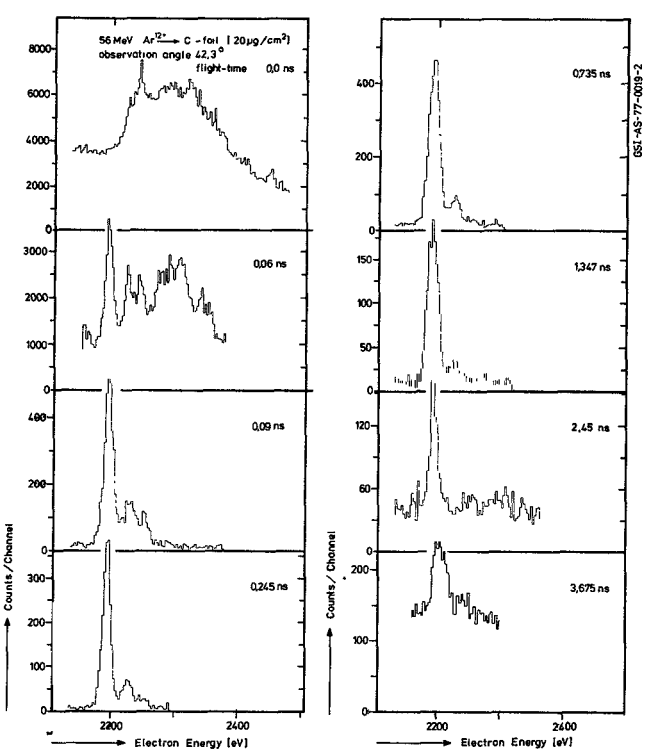

Fig. 3. Prompt and delayed Auger-electron spectrum. Beside the dominant $^4P_{5/2} \rightarrow {}^1S_0$+e-line the influence of other prompt decaying levels in the metastable spectrum are identified.

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