The two-photon decay of the $1s2s\ ^1S_0$ state in heavy He-like ions

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In heavy few-electron systems the atomic structure changes appreciably with the atomic number Z under the influence of the strong central fields. Beyond, the structure information from precision spectroscopy of heavy H-, He-, and Li-like ions, lifetimes of excited metastable states measures the overlap of the wave functions directly. In particular, the two-photon decay of metastable states —$2s\ ^1S_{1/2}$ and $1s2s\ ^1S_0$ for H- and He-like ions, respectively— probes the complete atomic structure since it has to be summed over all intermediate bound and continuum states in calculating the transition probabilities. The phenomenon of the two-photon decay was discussed beginning with Göppert-Mayer [1] nearly 70 years ago. In hydrogenlike ions the wave functions can be calculated analytically by solving the Dirac equation. He-like ions are the simplest multi-electron systems and one has to use varionational methods to determine the atomic structure of these simplest multi-electron systems. For the two-photon decay in He-like systems, the most accurate non-relativistic calculations were performed by Drake [2] for atomic numbers up to $Z = 36$ (Kr). Recently, fully relativistic calculations have been performed for the whole Z range by Derevianko and Johnson [3]. The calculations show a strong dependence of the two-photon energy distribution on the atomic number Z.

In a joint effort of the two accelerator laboratories at ARGONNE and GSI, the spectral shape of the 2E1 decay of the $2\ ^1S_0$ state into the ground state ($1\ ^1S_0$) of He-like heavy ions is being studied as function of the nuclear charge. For the medium heavy ions Ni and Kr [4] and for the very heavy ion Au [5] the spectral energy distribution of the two-photon decay in He-like species has been measured and compared to theory. The total transition energy for the two-photon decay in these ions is in the x-ray region (7.8 and 68.3 keV for Ni and Au, respectively). In a beam foil arrangement the fast He-like projectiles were excited and then the two x-rays registered in coincidence by two solid state detectors (Si(Li) and Ge(i), respectively). In the projectile frame the detectors observed the x rays each under 90^0 to beam direction, i.e. under back to back geometry. For the Au case the decay is so short (0.32 ps) that the emission can be considered as prompt and one has to look with the detectors directly to the target.

In Fig. 1 and 2 the final results for Ni and Au ions are compared with theory. The two-photon distributions are normalized to the total transition energy, $f = \omega/\omega_o$, and divided by

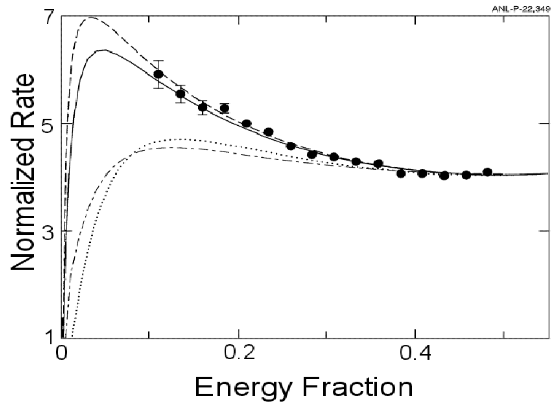

Figure 1: Two-photon decay spectrum measured for He-like Ni. Normalized rate as function of reduced photon energy f. Full line, relativistic calc. for Ni [3]; dashed line, non-relativistic calc. for Ni [2]; dashed-dotted line, relativistic calc. for Au [3]; dotted line, calc. for He [3].

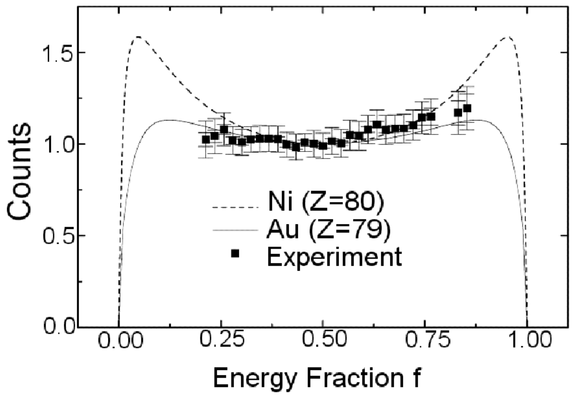

Figure 2: Two-photon decay spectrum in Au compared with fully relativistic calculations [3] for He-like gold ($Z = 79$, full line) and nickel ($Z = 28$, dashed line). (Normalized rate as a function of the reduced photon energy f.)

the parabolic phase factor $f(1-f)$. (Fig. 1 displays only the first half of the distribution symmetric around $f = 1/2$). Beyond a multiplicative factor, this representation gives directly the second order matrix element for the two-photon decay. Comparison of the data for He-like Ni and Au indicates a clear difference between the continuum shapes of these two species. Both set of data agree fairly well with the fully relativistic calculations [3].

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