The two-photon decay in helium-like gold

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Progress on a measurement of the spectral distribution of the two-photon decay of the 2^1S_0 level in helium-like gold is reported. A measurement of the exact shape of the continuous spectrum of the two-photon decay in heavy helium-like ions provides a sensitive test on the details of the complete structure of a helium-like system. In our experiment at GSI, a beam of 106.6 MeV/u Au^{77+} ions is excited by a thin Aluminum foil and the subsequent decays are observed in an array of Ge(i) detectors.

1. Introduction

In helium-like ions the $1s2s\,^1S_0$ state can only decay to the $1s^2\,^1S_0$ ground state by the emission of two photons (2E1) due to the conservation of angular momentum. The energies of the individual photons have a broad continuous distribution with a maximum at half the transition energy. To calculate the probability for such a transition summing over all bound and continuum states of the system is required. For light ions with an atomic number $Z < 40$ only (singlet) ^1P states contribute significantly to that sum. Beyond $Z = 40$, relativistic effects, in particular the two-photon branches via (triplet) ^3P states, have to be taken into account. Such fully relativistic calculations have been performed very recently by Derevianko and Johnson [1], whereas nonrelativistic calculations are available for more than 10 years [2–4]. Figure 1 shows the strong dependence of the two-photon energy distribution on the atomic number Z according to [1]. These changes are the results of the influence of electron–electron correlation and relativistic effects.

The two-photon decay in helium-like Nickel [5] and Krypton [6] has been studied in detail at the heavy ion accelerator ATLAS at the Argonne National Laboratory. To extend our work to higher Z, we measured the spectral shape of the two-photon decay of the $1s2s\,^1S_0$ level in helium-like gold (see figure 2).

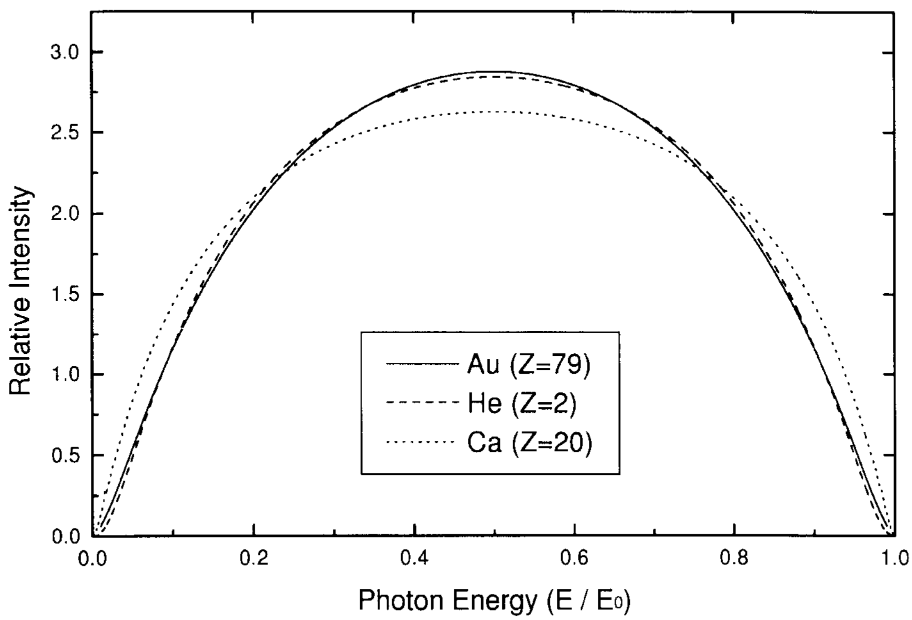

Figure 1. Photon energy distributions for the two-photon decay of helium-like $2\,^1S_0$ states for different nuclear charge Z according to [1]. These curves are normalized to give an area of 2. E/E_0 is the fraction of the energy relative to the transition energy E_0.

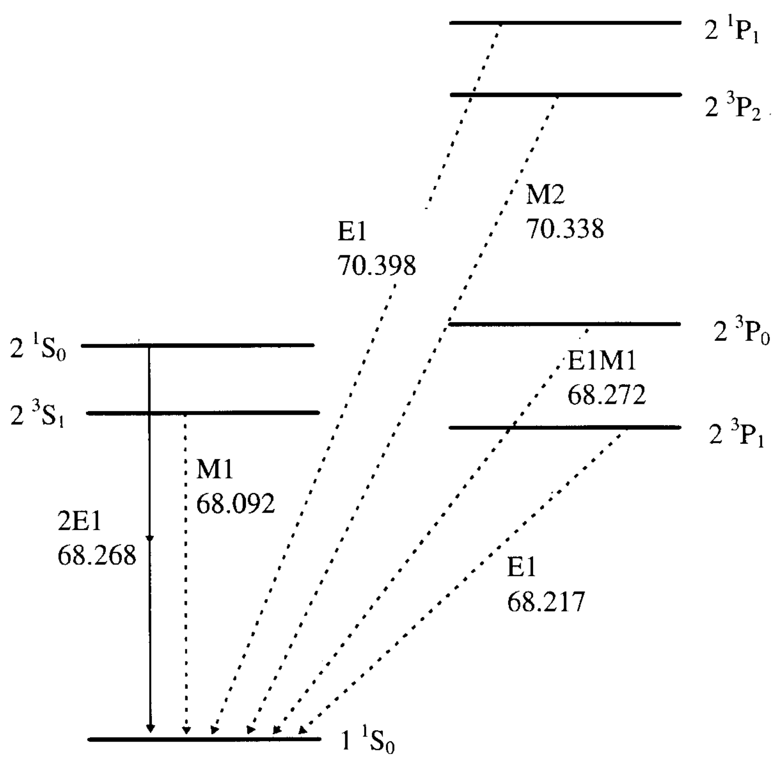

Figure 2. Low-lying energy levels of helium-like Au^{77+} and their decay modes. All energies are given in keV.

2. Experiment

In the experiment a 106.6 MeV/u beam of Au ions was provided by the heavy ion synchrotron SIS of GSI. After the beam was stripped in a 20 mg/cm^2 Al foil the 77+ charge state was directed to our target chamber. Here the ions were excited by a 100 μg/cm^2 Al target. Photon coincidences associated with the decay were observed with an array of two Ge(i) X-ray detectors, each under 60° towards the beam axis (figure 3). This particular setup allowed us to investigate the 2E1 decay for photons with an opening angle of 180° in the projectile system, where the angular distribution has its maximum.

Standard coincidence electronics were used for data collection. The output of the preamplifier on the detectors was directed to both fast and slow amplifiers to give timing and energy signals for each detector. Shaping times of 50 ns and 2 μs were used as a compromise between resolution and rate for the fast and slow amplifiers, respectively. In the experiment a coincidence was defined, if timing pulses of two detectors arrived within 1 μs of each other. These events started the readout of our

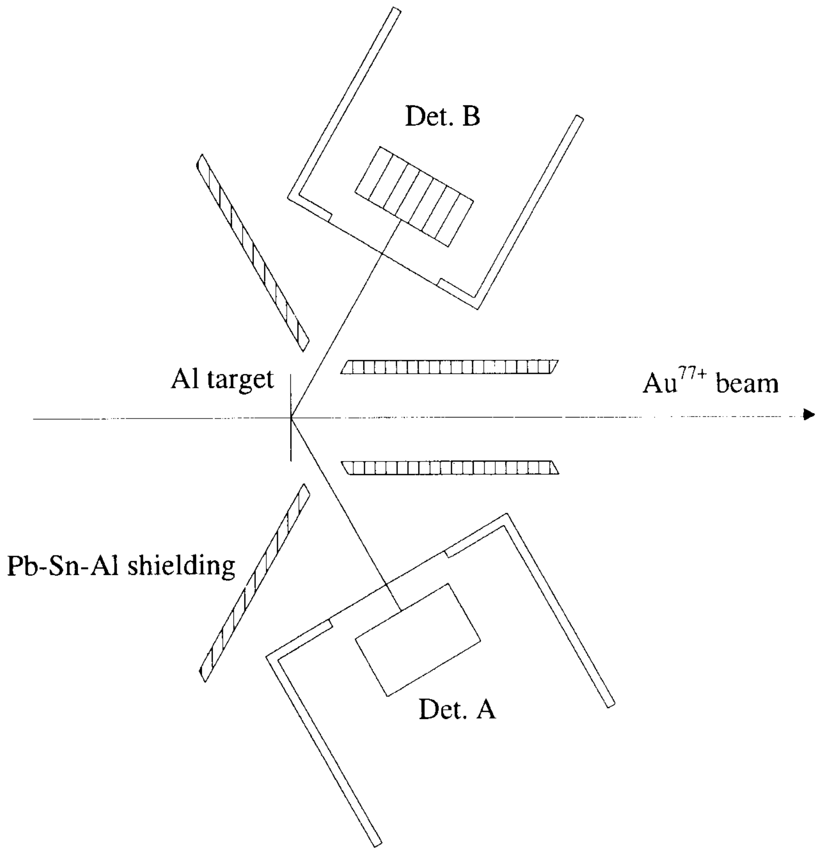

Figure 3. Experimental setup: In order to register the photons we used a nonsegmented 15 mm thick, 500 mm^2 (detector A) and a segmented solid state Ge(i) detector (detector B) consisting of 7 parallel stripes of 3.5 × 25 mm and a thickness of 12 mm. Multi-layer shields of lead, tin and aluminum were used to avoid "cross talk" between the detectors.

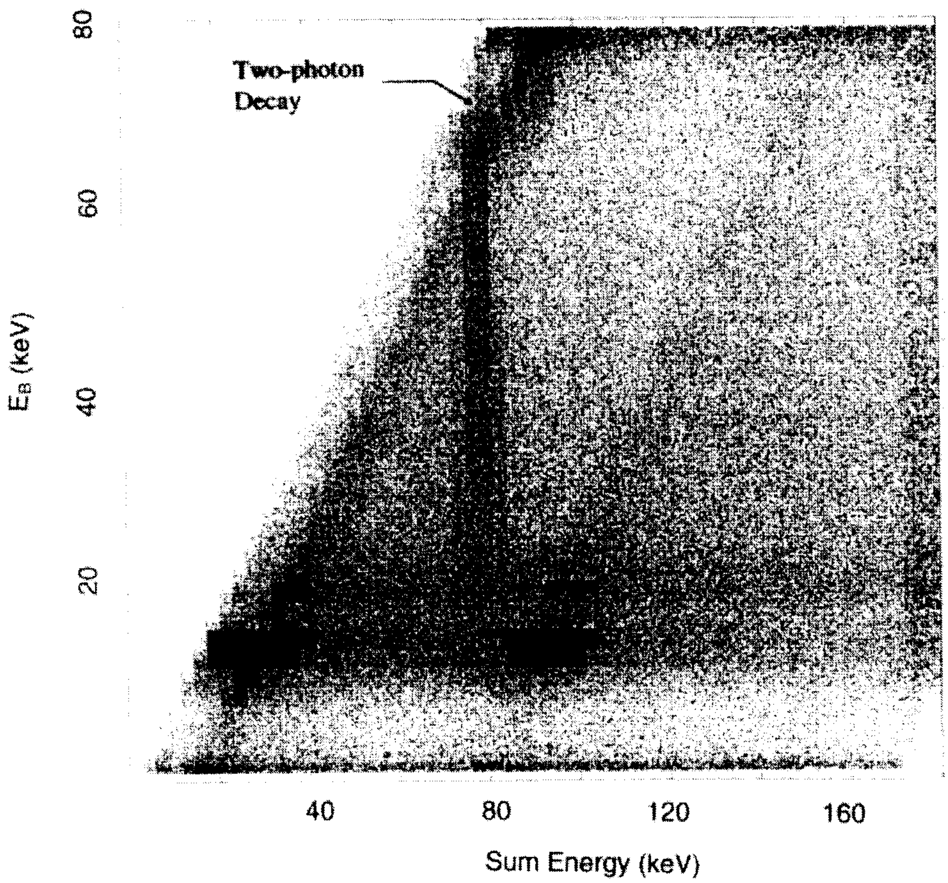

Figure 4. Sum energy ($E_A + E_B$) vs the energy of one detector E_B for true coincidences between detectors A and B.

data acquisition system, all measured parameters were written to tape and accumulated with an on-line data analysis program simultaneously. The total data collection time was 35 hours.

Characterization of the efficiency of the experimental setup as a function energy was very crucial in this experiment. The electronic efficiency was determined in two different ways using radioactive sources and an electronic pulser. The procedure will be decribed elsewhere. The results of both methods are in very good agreement. The intrinsic efficiency of the detectors in the low-energy domain (5–90 keV) was determined relatively to the high-energy domain ($>$ 100 keV), where this determination could be done very precisely. This could be done by using conversion factors of [7] to convert the γ-ray intensities to X-ray intensities for the calibration lines.

3. Results

The data analysis of our experiment is not completed. Our analysis procedure is based on scatter plots comparing the sum-energy to the energy of one detector. Figure 4 shows the correlation between the energies for coincident events. The 2E1 forms a vertical at the sum-energy of 78 keV, due to the Lorentz transformation from the emitter to the laboratory system. The other structures in figure 4 are additional true coincidences from cascade events of populated $n > 3$ states. For further investigation we will divide the two dimensional data into horizontal slices and fit the 2E1 peak with a least-squares fitting routine for each slice separately. With this method we avoid some interferences between the 2E1 peak and other true coincidences.

Our investigation represents the first experiment towards a determination of the spectral distribution of the two-photon decay in very heavy, helium-like ions. The aim is to confirm the relativistic corrections to the spectral shape of the two-photon decay in strong central fields. After final data analysis we will compare the measured 2E1 spectra with a simulation based on the full relativistic treatment of this decay.

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