Photoactivation of ^{180}Ta at Astrophysically Relevant Energies ◇

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The nucleus ^{180}Ta

The extremly rare isotope ^{180}Ta survives in nature in an isomeric state at E*=75.3keV ($K^\pi=9^-$, $t_{1/2}>1.2\text{x}10^{15}$y). The ground state decays with a half-life of 8.2h by electron capture to ^{180}Hf or by β^- to ^{180}W. The direct decay of the $K^\pi=9^-$ isomer to the $K^\pi=1^+$ ground state is highly K-forbidden explaining the long half-life of the isomer. The characteristics of the ground state decay of ^{180}Ta are the Hf K X-rays, the $2^+ \to 0^+$ E2 transition in ^{180}Hf and the $2^+ \to 0^+$ E2 transition in ^{180}W.

Astrophysical aspects

The production and the survival of the ^{180}Ta 9^- isomer during the nucleosynthesis is still unknown. Should the isomer be exposed to an intense photon bath under stellar s-process conditions, it might be depopulated to the ground state via intermediate states. Therefore low-lying intermediate states, yet unknown, connecting the isomer to the ground state would hinder a s-process production of ^{180}Ta. To find these intermediate states, several photoexcitation (real photons) and Coulomb excitation (virtual photons) [1–5] experiments were carried out. In the photoexcitation experiment performed at the S–DALINAC at Darmstadt [1] intermediate states at roughly 2.8 and 3.6 MeV excitation energy were deduced from the measured yield curves. However, the energies of both states are too high for an effective depopulation of the isomer to the ground state at s-process temperatures. The aim of the present collaboration was to search for lower-lying photoexcited intermediate states which are low enough in excitation energy to lead to an effective depopulation of the isomer to the ground state at s-process temperatures.

Experimental procedure

The experiments were performed at a new irradiation facility at the Stuttgart DYNAMITRON accelerator [6]. Typical electron currents of 400–450 μA could be used on the watercooled bremsstrahlung production target. In total 150 mg of Ta-oxide material enriched to 5.45 % in ^{180m}Ta were available. The samples were irradiated by bremsstrahlung photons with endpoint energies in the range of 0.9-3.1 MeV. To verify the enrichment factor a similar natural Ta-oxide target was activated, too. After irradiation the activated samples were analyzed by two high-resolution low-energy germanium photon detectors. To reduce natural background radiation, these detectors were mounted in a high purity lead chamber with an inner compartment made of electrolyte copper. For a quantitative analysis of the measured data, it is necessary to know the photon flux and its energy distribution. An ionisation chamber was used to obtain the energy integrated photon flux. A nuclear resonance fluorescence setup with a mixed target (Al/Cu/LiF) determined the photon energy distribution. Additionally, an ^{115}In-target was used as a flux-monitor. (In ^{115}In a $t_{1/2}$=4.5h isomer can be populated by photons of energies higher than 940 keV.) The measured photon flux is compared to Monte Carlo simulations using the codes GEANT and EGS4. The enriched Ta sample and the optimized experimental setup, incrased the sensitivity of the present study roughly by a factor of 5000 compared to previous experiments [1].

Experimental results

The low-energy photon energy spectra show the characteristic lines of the ^{180}Ta ground state decay with proper intensity ratios. The measured half-life of these transitions is 8.2h, as expected. The measured Hf K X-ray yields as a function of the bremsstrahlung endpoint energy are used to identify the energies of the low-lying intermediate states. Kinks in the yield curve indicate intermediate states at $\leq$1.0 MeV, 1.2 MeV, 1.5 MeV, 2.1 MeV, 2.5 MeV, and 2.8 MeV. From the photon flux energy distribution and the measured yields, the integrated cross sections can be calculated. This calculation is in progress. An attempt to directly observe the astrophysical interesting intermediate state at $\leq$ 1 MeV in a nuclear resonance fluorescence experiment failed. The resonance fluorescence experiment will give an upper limit for the integrated cross section.

References

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