Experimental study of the low-lying isomeric states in ^{178}Ta

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Introduction

The presence of two closely lying isomeric states 1^+ and 7^- in the neutron-deficient Ta isotope ^{178}Ta [1] makes it an interesting prospect of study to understand deformed nuclei and their applications as radiation sources. However, the level scheme of this nucleus has unsolved ambiguities especially in the low-energy regime. Most of the previous experimental studies have focused only on characterizing its high-spin states [2,3]. In order to exclusively study the low-lying levels of ^{178}Ta, we performed an extensive in-beam gamma spectroscopic study. A new reaction, ^{175}Lu(α, n) ^{178}Ta that will yield a good production cross-section for ^{178}Ta was designed using simulation software PACE4. The reaction was performed with different beam energies and irradiation times to observe the various levels populated and their subsequent decay to the daughter states. We report here the details of the experiment and the preliminary results obtained thus far in this study.

Experiment

The in-beam gamma spectroscopy was performed at the Indian National Gamma Array (INGA), VECC. The array is a set-up of 12 Compton-suppressed HPGe clover detectors in three different angles. The target used was a ^{175}Lu target foil of 3.5 mg/cm^3 with dimensions 2.6 x 1.9 cm. As a first of its kind at VECC, channel 1 was used for irradiation as the reaction needed high alpha beam current, while channel 3 was used for the decay studies.

We performed two sets of experiments to explore the low-lying levels of the nuclei. One set of in-beam and decay data were collected with varying beam energies. E_α=21 MeV, the energy at which the yield of ^{178}Ta is expected to be maximum, and E_α=20 & 28 MeV, the lowest and highest energies respectively at which ^{178}Ta would be produced, were used for irradiation. The second set of measurements were taken at two different irradiation times, one for a period of 45 min and the other for 12 h, with a fixed E_α=25 MeV. These multiple sets of data were accumulated in an attempt to populate the two close-lying 1^+ and 7^- states in ^{178}Ta and study their decay to the levels of ^{178}Hf.

Analysis and Observations

The PACE4 calculations also predict other possible reaction products, as seen in Table 1. As the half-lives of these nuclei are much higher than that of ^{178}Ta, we do not expect many intense gammas from those in our spectra. We would therefore be able to study the intended decays, without much interference from the other product nuclei.

Table 1: PACE4 calculations of ^{175}Lu(α, x) reaction at beam energy 20MeV

Product nuclei	Cross-section (mb)	Half-life
^{178}Ta	225	9.31 min/ 2.3 h
^{177}Ta	15.1	56.56 h
^{178}Hf	0.24	Stable

The IUCPIX software package, developed at the UGC DAE CSR, Kolkata Center [4] was used to process and generate the gamma spectra. RADWARE [5], the graphical tool, was utilized for analysis. The decay spectra of long and short

irradiations were generated to deduce the half-lives of the low-lying 1^+ and 7^- isomeric states. The gammas of de-excitation belonging to the daughter nucleus ^{178}Hf were prominently observed in the singles decay spectra. The gammas belonging exclusively to the decay from the 1^+ and 7^- states were identified to calculate the half-lives.

The 93 keV gamma of the daughter nucleus ^{178}Hf results due to decay from both the 1^+ and 7^- states of ^{178}Ta. The intensities of this gamma, in both long and short irradiations, were deduced using RADWARE fits. A plot of counts vs time was generated to determine the half-lives of the decay. The decay constant determined from the long-irradiation plot is λ= -0.00489 min^{-1} which gives a decay $t_{1/2}$ of 2.36 h. This is close to the half-life value of the 7^- isomeric state obtained in previous studies.

Whereas, the decay constant obtained in short irradiation was λ= -0.00478 min^{-1}, and the corresponding $t_{1/2}$ = 2.42 h.

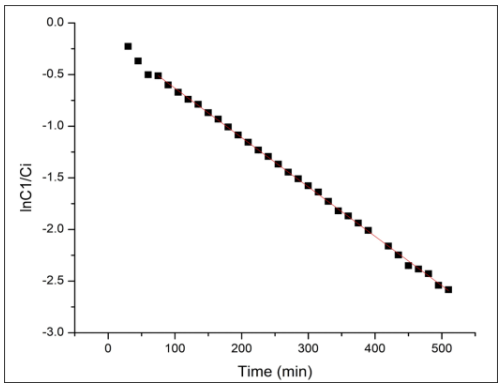

Fig. 1: Plot of counts vs time for the 93 keV γ in short irradiation. The slope is λ = - 0.00478. (R-square = 0.99954)

The initial 45 minutes of the short irradiation gives a visibly different slope. This is a clear indication of the existence of another half-life within that time period. Another observation in the spectra supporting this speculation is the existence of a 1269 keV gamma which is a part of the decay of the 1^+ state of ^{178}Ta, which has a shorter half-life $t_{1/2}$= 9.31 min. [1]. This gamma is seen only in the initial few minutes, after which its intensity diminishes in the spectrum.

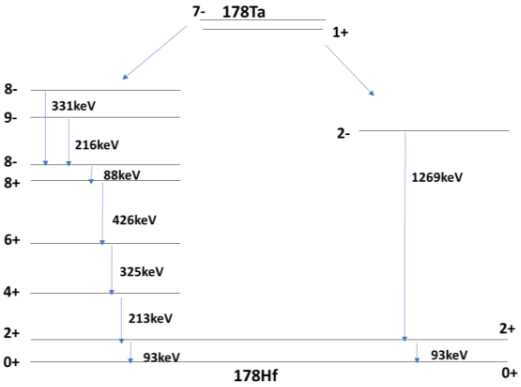

Fig. 2: The possible decay of ^{178}Ta to ^{178}Hf from the two isomeric states 1^+ and 7^-.

Based on these observations, the decay of ^{178}Ta produced in the present reaction can be represented as in fig. 2, wherein, it can be concluded that the reaction has populated both the isomeric states of ^{178}Ta. Further analysis of the initial period of the decay is being performed to throw more light on the levels of ^{178}Ta. The earlier reported theoretical study using Two-Quasi Particle Rotor Model (TQRM) [6] carried out by our group will serve as location guides. The experimental data complemented by the TQRM model calculations may give us enough insight to resolve the ambiguity about the ground state and other isomeric states of ^{178}Ta.

Acknowledgement

This work has been carried out with the support received under the Collaborative Research Scheme (CRS) of the UGC-DAE CSR, Kolkata Centre.

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