COMPETING DECAY MODES OF A HIGH-SPIN ISOMER IN THE PROTON-UNBOUND NUCLEUS $^{158}$Ta*

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An isomeric state at high spin and excitation energy was recently observed in the proton-unbound nucleus $^{158}$Ta. This state was observed to decay by both $\alpha$ and $\gamma$ decay modes. The large spin change required to decay via $\gamma$-ray emission incurs a lifetime long enough for $\alpha$ decay to compete. The $\alpha$ decay has an energy of 8644(11) keV, which is among the highest observed in the region, a partial half-life of 440(70) $\mu$s and changes the spin by $11\hbar$. In this paper, additional evidence supporting the assignment of this $\alpha$ decay to the high-spin isomer in $^{158}$Ta will be presented.

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1. Introduction

The recent observation of an isomer at high spin, 19$^-$, and excitation energy, 2809 keV, in the proton-unbound nucleus $^{158}$Ta [1] raised the possibility of a blurring to the limits of the observable nuclear landscape due to the possible existence of isomers. These isomers can be sufficiently long

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to survive a separator flight time and hence be observed at the focal plane. Both \(\alpha\)- and \(\gamma\)-decay modes have been associated with this isomer, as shown in Fig. 1. In this paper, additional experimental evidence supporting the previous assignment of a new \(\alpha\) decay to this isomer will be presented.

![Partial level scheme of \(^{158}\text{Ta}\) including competing decay branches from the \(19^{-}\) isomer. Both \(\alpha\)- and \(\gamma\)-decay branches lead to the population of \(^{154}\text{Lu}\). Transition energies are in keV.](image)

**Fig. 1.** Partial level scheme of \(^{158}\text{Ta}\) including competing decay branches from the \(19^{-}\) isomer. Both \(\alpha\)- and \(\gamma\)-decay branches lead to the population of \(^{154}\text{Lu}\). Transition energies are in keV.

### 2. Experimental details

The experiment was performed at the University of Jyväskylä accelerator laboratory. The \(^{158}\text{Ta}\) nuclei were produced in excited states using fusion-evaporation reactions induced by \(^{58}\text{Ni}\) ions, with a beam energy of 255 MeV, incident on an isotopically enriched \(^{102}\text{Pd}\) target of thickness \(\sim\)1 mg cm\(^{-2}\). The JUROGAM HPGe spectrometer surrounded the target position and was used to measure prompt \(\gamma\)-ray emissions. The RITU gas-filled separator [2] transported recoiling reaction products to its focal plane and also suppressed unreacted beam. The GREAT spectrometer [3] was situated at the focal plane. Recoiling nuclei that entered GREAT passed through a multiwire proportional counter (MWPC) before being implanted into one of two adjacently mounted double-sided silicon strip detectors (DSSDs). Subsequent radioactive \(\alpha\) decays were detected by the DSSDs but not the MWPC, thus distinguishing between signals associated with recoils and decays. A planar and a Clover Ge detector were used to measure X-rays and \(\gamma\)-rays from the DSSDs that were emitted during decay processes. Data were recorded using a triggerless data acquisition system [4], time stamped with a precision of 10 ns, and events were built in software [5]. Reaction channels were identified using standard tagging techniques [6, 7].
3. Evidence for the $\alpha$-decay branch

Gamma-ray transitions observed at the focal plane revealed the presence of the isomer at high spin and excitation energy, which primarily $\gamma$ decays via a 1002 keV transition [1]. A new $\alpha$ decay ($E_\alpha = 8644(11)$ keV) was observed to decay with a half-life similar to that of this isomer. The decay curves of the $\alpha$- and $\gamma$-decay branches are compared in Fig. 2 (a)–(b). The measured half-life of the $\alpha$-decay branch is $6.4(4)$ $\mu$s, which is consistent with the $6.1(1)$ $\mu$s half-life associated with the $\gamma$-decay branches. The same $\gamma$-ray transitions feeding the isomer are observed in association with both the $\alpha$- and $\gamma$-decay branches. Based on this evidence, the new $\alpha$ decay was assigned to the same high-spin isomer.

Fig. 2. Decay curves for (a) the 1002 keV $\gamma$-ray transition and (b) the 8644 keV $\alpha$ decay, which have consistent half-lives. (c) The energy and (d) decay time of decays following the $\alpha$ decay of the $9^+$ state in $^{158}$Ta. (e) The energy and (f) decay time of decays following the 8644 keV $\alpha$ decay from the high-spin isomer in $^{158}$Ta. The 5331 keV $^{154}$Yb peak appears strongly above the background in both (c) and (e). The $^{154}$Yb decay times in (d) and (f) reveal the unobserved $\beta$ decay of $^{154}$Lu, completing the decay chain from $^{158}$Ta$\rightarrow^{154}$Lu$\rightarrow^{154}$Yb$\rightarrow^{150}$Er, and have consistent peaks. These similarities reinforce the assignment of the 8644 keV $\alpha$ decay to the $19^-$ isomer in $^{158}$Ta.

Further evidence that this $\alpha$ decay originates from $^{158}$Ta can seen in the subsequent decays, which are shown in Fig. 2 (c)–(f). The $\gamma$-decay branches of the isomer feed the $9^+$ low-lying metastable state. The decay of this state is the first step in the following decay chain:

$^{158}$Ta$^{9+} \rightarrow \alpha(6046) \rightarrow ^{154}$Lu$^{9+} \rightarrow \beta^+ \rightarrow ^{154}$Yb$^{0+} \rightarrow \alpha(5331) \rightarrow ^{150}$Er$^{0+}$,
of which, in this experiment, only the $\alpha$ decays could be observed. The 5331 keV $^{154}$Yb $\alpha$ decay [8] is observed strongly above the background following the decay of the 9$^+$ state in $^{158}$Ta. Furthermore, the decay curve reveals the unobserved $\beta$-decay component from $^{154}$Lu. A similar energy and decay curve can be seen following the decay of the 8644 keV $\alpha$ decay, which suggests that it feeds the same decay chain, and thus originates from $^{158}$Ta. A closed $Q$-value loop incorporating the $\alpha$- and $\gamma$-decay branches de-populating the $^{158}$Ta$^{19-}$ isomer and populating the $^{154}$Lu$^{9+}$ state is evidence that the 8644 keV $\alpha$ decay is a direct transition between these two states [1]. The total $Q$-values via the $\alpha$-decay branch and via the $\gamma$-ray branch are 8869(11) and 8870(14), respectively. To account for the change in spin and parity, an angular momentum change of $11\hbar$ occurs as a result of this decay.

4. Summary and acknowledgements

The 8644 keV $\alpha$ decay was previously assigned to the 19$^-$ isomer in $^{158}$Ta based on the feeding $\gamma$-ray transitions, the half-life and the $Q$-value, all of which are consistent with observations associated with the $\gamma$-decay branch. The subsequent radioactive decay data presented in this paper is consistent with a decay from $^{158}$Ta, which reinforces the previous assignment.

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