Survival of ^{180}Ta During the s-Process

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Over the years, many attempts have been made to find a plausible production mechanism for Nature's rarest isotope and only naturally-occurring isomer, the odd-odd nucleus ^{180}Ta. The long-lived ^{180}Ta^m ($J^\pi = 9^-$) is located approximately 75 keV above the $t_{1/2}$ = 8.1 hour ($J^\pi = 1^+$) ground state [1]. The standard s- , r-, and p-processes all fail to quantitatively account for the observed abundance of ^{180}Ta ([^{180}Ta]/[^{181}Ta] = 10^{-4}.) Several detours off the standard s- and r- process paths that could lead to ^{180}Ta have been investigated. The s-process path through the stable Hf isotopes weakly populates a $J^\pi = 8^-$ isomer in ^{180}Hf which can then beta decay to ^{180}Ta^m. However, this route was shown to be too small to account for ^{180}Ta abundance [1]. In principle the r-process could also reach ^{180}Ta. ^{180}Lu produced in the r-process could feed $J^\pi = 8^-$ isomer in ^{180}Hf and then produce ^{180}Ta by beta decay. We have shown with experiments at the Univ. of Washington and at 88" Cyclotron that this branching ratio is too small to account for a significant amount of ^{180}Ta [2,3]. Thus, the production mechanism responsible for ^{180}Ta remains an open question.

Regardless of how ^{180}Ta is actually produced in stars, the question remains as to whether it can survive in the hot dense stellar environment? At the temperatures appropriate to the s- and r-processes, there is an enormous bath of high energy photons present. Such photons could excite ^{180}Ta^m up to a higher-lying level of intermediate spin which subsequently decays though a γ–cascade to the ^{180}Ta ground state. Such photoexcitation could lead to thermal equilibration between the ground state and isomer, with the result that the effective ^{180}Ta half life becomes on the order of days. This would drastically reduce the amount of ^{180}Ta^m that would actually emerge from a stellar environment.

The question of whether or not this process actually happens in nature depends critically on the excitation energy and γ-decay modes of levels in ^{180}Ta . Attempts to photodeexcite ^{180}Ta^m to ^{180}Ta^g using intense sources of ^{137}Cs and ^{60}Co have failed [4]. This suggests that the mediating levels may lie above 1.33 MeV excitation energy. Recent Coulomb deexcitation experiments have observed the production of ^{180}Ta^g from ^{180}Ta^m and suggest that there may in fact be lower lying mediating levels [5].

In order to answer the question of whether or not ^{180}Ta^m can survive in stellar environments, we have populated levels in ^{180}Ta using the ^{176}Yb(^{7}Li,3n) reaction and have used GAMMASPHERE to studying the gamma decays of levels up to approximately 2 MeV excitation energy. Thus far we have been able to place approximately 85 γ-ray transitions among 60 different levels. We observe a family of transitions that ultimately lead to the ^{180}Ta^g and another family that leads to the long-lived ^{180}Ta^m. We have not found any level which has a measurable decay branch to both levels. Thus it may be that ^{180}Ta^m can survive in an s-process environment.

Footnotes and References

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