# Origin of rare isotope Ta-180 in supernova-neutrino nucleosynthesis

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The astrophysical origin of an isotope, $^{180}Ta^{m}$, has remained an unsolved problem. This isotope has two unique features. First this is the rarest isotope in the solar system. Second the ground state decays by $\beta$ decay with a half-life of 8.15 hr, whereas an excited state is a long-lived isomer with a half-life of $\geq 10^{15}$ yr. This nucleus is bypassed by the major nucleosynthesis mechanisms of the *s* and *r* processes. Thus exotic processes have been proposed but they have only underproduced the abundance of the rarest isotope $^{180}Ta$[1,2]. The most popular scenario in recent times is the production in the $\nu$ process via the $^{181}Ta(\nu, \nu'n)^{180}Ta$ and $^{180}Hf(\nu_e, e)^{180}Ta$ neutrino reactions in core-collapse supernovae[3,4]. However, they overproduce the $^{180}Ta$ solar abundance. They noted that the observed $^{180m}Ta$ abundance can not be inferred from their calculations until the branching between the long-lived isomer and the ground state is known.

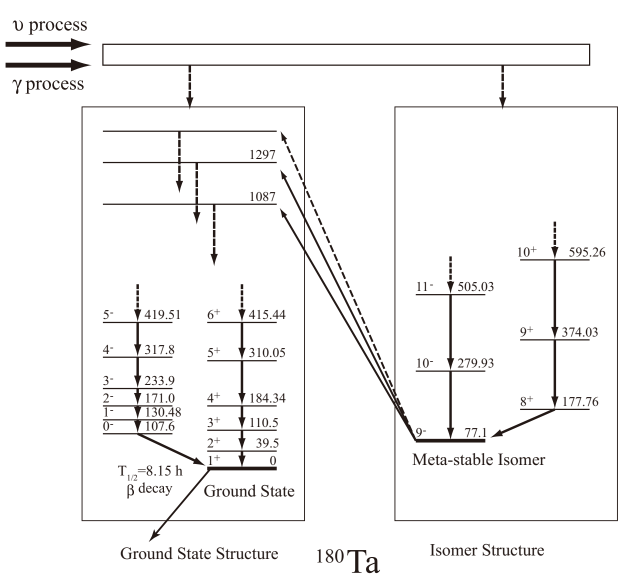


**Figure 1**: Schematic view of nucleosynthesis of $^{180}Ta$.

In the $\nu$ process, low-spin excited states in $^{180}Ta$ are predominantly populated from $^{180}Hf$ by Gamow-Teller transitions and subsequently decay preferentially to the $1^+$ ground state. However, in a high temperature photon bath of supernovae, the meta-stable isomer is excited from the ground state by $(\gamma, \gamma')$ reactions through highly excited states. Moreover, the transition rate between the ground state and the isomer is affected by the changing temperature. Therefore, the final isomeric branching ratio should be evaluated by a time-dependent calculation.

We have proposed a model that the excited states of $^{180}Ta$ as consisting of two sets of nuclear states: 1) the ground state structure, which consists of the ground state plus the excited states with strong transitions to the ground state; and 2) the analogous isomeric structure (see Fig. 1). For $T_9 = 0.1$–$1.0$ all excited states lower than a few hundred keV are populated. After the freezeout each excited state decays to either the ground state or the isomer. In the transitional region, strongly connected states are only partly thermalized and two structures are linked between the weak $\gamma$ transitions. We calculate the time-dependent calculation based on the two structure model taking into account previously measured linking transitions.

We finally obtain the isomer residual ratio of 0.39 at the freeze-out. It should be noted that this ratio is almost independent of the astrophysical parameters such as the supernova neutrino energy spectrum, the explosion energy, the temperature time constant, and the peak temperature in the $\nu$ process layers. With this ratio we can reproduce the solar abundance of $^{180}Ta$ by neutrino nucleosynthesis and an electron neutrino temperature of $kT \approx 4$ MeV[5,6].

## References

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