s-Process Solar Abundance and Presence of Isomers near A ∼ 80

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I Introduction

Nuclei are inter-connected by various creation and destruction channels like proton-capture, neutron-capture, β-decay, α-decay/capture, fission etc. and lead to nucleosynthesis of new elements[1]. Long-lived excited states of nuclei, known as nuclear isomers, may play an important role in nucleosynthesis. Such isomers, which are important in astrophysical environments, have recently been termed as 'astromers' [2, 3]. Neutron-capture nucleosynthesis in asymptotic giant branch(AGB) contributes about half of the elemental abundances between Fe and Bi [4]. But role of nuclear isomers has rarely been considered in s, and r-processes explicitly. More specifically, the isomers at branching point of s-process path could play an important role at extreme temperatures and densities of stellar plasma. It is known that the stellar elemental abundance largely depends on β- decay rates weighted with the Boltzmann statistical factor and neutron-capture rates [5, 6].

In this paper, we focus on branching point nuclei of s-process path in mass region A ∼ 80. We calculate the effect of long-lived isomeric states of branching nuclei like ^{79}Se and ^{80}Br on observed solar abundance of ^{80}Kr.

II Methodology

A nucleus in mass-80 region is mainly created and destroyed by neutron capture or beta-decay during s-process. The corresponding abundance equation for a nucleus (A,Z) is given by [7]:

$$\frac{dN(A,Z)}{dt} = -\lambda_n N(A,Z) + \lambda_n N(A-1,Z) + \lambda_\beta N(A,Z-1) - \lambda_\beta N(A,Z) \tag{1}$$

Here, $N(A,Z)$ is the abundance of nucleus X^A_Z. λ_β is beta-decay rate and $\lambda_n = N_n\langle\sigma v\rangle = N_n v_T\langle\sigma\rangle$ is neutron capture rate. At a constant-temperature T, s-process neutron-exposure rate comes out to be, $\tau = v_T \int N_n(t)\,dt$.

We calculate the stellar beta-decay rates by the equation:

$$\lambda_\beta = \sum P_i \sum \lambda_{ij} \tag{2}$$

Here, P_i is the population probability of the i^{th} state, which is given by:

$$P_i = \frac{N_i}{N} = \frac{(2J_i+1)\exp\left(\frac{-E_i}{kT}\right)}{G} \tag{3}$$

where J_i is the spin of the state i, N_i is number density in state i, and N denotes the total number density and G is nuclear partition function.

We follow the mathematical formulation given in ref.[8] for s-process branch, which starts from ^{78}Se and terminates at ^{82}Kr having branching points at ^{79}Se, and ^{80}Br as shown in Fig. 1.

III Results and Discussion

We consider the branch of ^{79}Se and apply Eq.(1) to calculate the abundance of ^{80}Kr. The effect of the stellar environment on beta-decay rates is calculated by using Eq.(2). This rate is important at temeparture $T \geq T_8$ mainly in AGB stars. We use the value of neutron exposure $\tau = 0.25mb$ and neutron flux $\phi = 10^{17} n.cm^{-2}s^{-1}$ [7, 8].

The s-process contribution to ^{80}Kr is influenced by the branches at ^{79}Se and ^{80}Br. We first consider only the ground state beta-decay rate and neutron capture cross section (Maxwellian-Averaged Cross Sections, MACS at 30 keV using compilation of TENDL-2023) from both branching points. Incorporating the values of β decay branching ratio (with respect to the neutron capture) $f_{-}(^{79}\text{Se}) = 0.2743$, $f_{-}(^{80}\text{Br}) = 0.8859$ and solar abundance of ^{80}Se, $N_s(^{80}\text{Se}) = 33.66$ which contributes 57% abundance to s-process, we obtain the s-process abundance of ^{80}Kr, $N_s(^{80}\text{Kr})_{G.S.} = 1.1075$, when only ground state contributions from the branching points are considered.

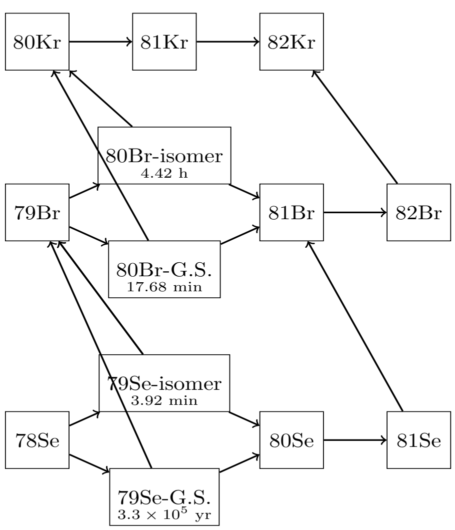

Fig.1: The s-process branches for ^{80}Kr at ^{79}Se and ^{80}Br. Both branching point nuclei have isomeric states at 96 keV and 85 keV, respectively. G.S. represents ground state.

We then estimate the influence of 96 keV ^{79}Se isomer and 85 keV ^{80}Br isomer into the resulting s-process contribution for ^{80}Kr. Using the computed value of stellar beta-decay rate for isomers, λ_β, and cross-section using MACS at T= 30 keV, we obtain the values of isomeric β decay branching ratio $f_{-}(^{79i}\text{Se}) = 0.4936$, $f_{-}(^{80i}\text{Br}) = 0.0334$, here i stands for isomeric level. This results in the final s-process abundance value of $N_s(^{80}\text{Kr})_{isomer} = 0.0578$ due to the isomeric presence at both the branching points. Finally, the total s-process solar abundance for ^{80}Kr is obtained as $N_s(^{80}\text{Kr}) = N_s(^{80}\text{Kr})_{G.S.} + N_s(^{80}\text{Kr})_{isomer} = 1.1653$, which is in reasonable agreement with the observed solar-abundance value of 1.20[9]. These calculations clearly highlight the quantitative role of astromers in the precise solar-abundance estimations. Future work involves various mass regions to understand the quantitative role of astromers in s-process solar abundances.

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