β^- Decay of Bare Atoms in Stellar Environments

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Introduction

In stellar environments the β^- decay scenario is quite different from the usual one. Due to the high temperature (~10^7K-10^9K) and pressure of such environment, there is a probability that the atoms will be in fully ionized states. As a result of the vacant atomic orbitals a new channel of β^- decay, i.e., β^- decay to atomic bound states may come into play.

Bound state β^- decay, which is the time-reversal process of electron capture, is the creation of an electron in the previously unoccupied state of an atom due to the conversion of a neutron into a proton of that nucleus. In the case of fully ionized atoms, the presence of bound state β^- decay causes drastic enhancement in total decay half-life. Henceforth, in various nucleosynthesis processes like s-process, which is the competition between β^- decay and neutron capture, β^- decay to bound state may play significant role.

Motivation

In this work, we have calculated β^- decay rates to the continuum as well as bound states of some fully ionized s-process nuclei. The presence of bare atoms in particular stellar environments is confirmed by solving the Saha ionization equation. Enhancement of β^- decay rate and hence change of effective half-lives for those bare atoms due to the effect of bound state decay channels have been studied. In addition, due to the high temperature in stellar environment the higher energy levels of parent nuclei can get populated which also may decay via β^- emission. This kind of 'new' transitions and their effects on effective half-life of the parent nuclei is also discussed in this work.

Methodology

In this present work, we have chosen a typical s-process stellar environment that consists of 75% ionized H and 25% fully ionized He, temperature 3×10^8 K and, free electron number density 10^{26}/cc. The presence of bare atoms has been confirmed by solving Saha ionization equation. Later, the bound and continuum state β^- decay rates are calculated following the model suggested by Takahashi et. al [1]. In addition, the population of the excited energy levels of the parent nuclei is examined using Boltzmann statistical probability. The possibility of 'New' transitions from these excited levels are confirmed on the basis of beta decay selection rule and energetics. Later, rates of those transitions are calculated and the total beta decay half-life has been modified.

Results and Discussion

In a stellar environment mentioned above it has been found that a large portion of the atoms will be fully ionized. The fig.1 shows the percentage of different ionized state of Nickel.

In case of bare or fully ionized atoms the bound state β^- decay comes into play and as a result total β^- decay becomes the summation of continuum and bound state decay rate. It has been observed that as the Q value of the transition decreases the bound state decay rates dominate over the continuum state decay rate. In fig.2 the variation of the ratio of total β^- decay rate to the neutral β^- decay rate with respect to Q value of that β^-transition has been plotted, in case of a few bare atoms. It has been confirmed that always

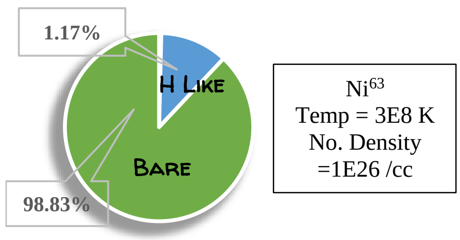

Fig-1: Fractional Percentage of different ionized state of ^{63}Ni.

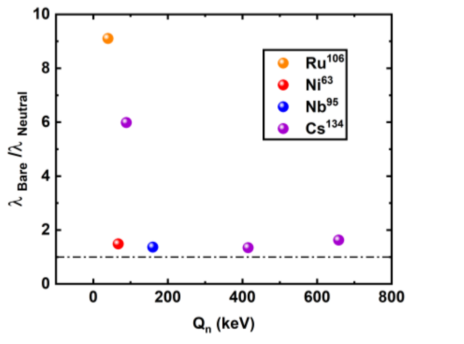

Fig-2: *Bare to neutral atom β⁻ decay rate ratio.*

this ratio is >1 (fig.2); i.e., there must be enhancement in decay rate when an atom gets fully ionized. This enhanced decay rates cause decrement in half-life of bare atoms in comparison to terrestrial half-life (fig.3).

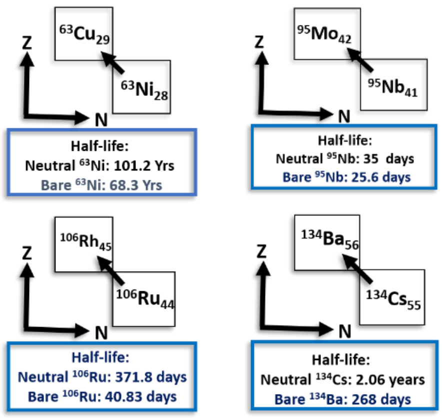

Fig-3: Neutral and Bare atom β⁻ decay half-life of some atom at a stellar environment: ~75% bare H, ~25% bare He, Temp =3E8 K, Free electron number density 1E26/cc.

Boltzmann statistical distribution has been used to get the population of higher energy states of the nuclei of interest. As an example, in fig.4 the case of ^{63}Ni has been shown. In general, the ground state of ^{63}Ni decays via β⁻ emission to the ground state of ^{63}Cu. Wherever, in the case of stellar environment there is possibility that the first two excited levels of ^{63}Ni will be populated. Following energetics and beta decay selection rules these two levels will be decayed via β⁻ emission to the ground state of ^{63}Cu. Since the properties (comparative half-life, branching) are unknown for these levels, random logft values in the interval suggested by Ref [4] has been used to calculate the bound and continuum β⁻ decay rates. It has been observed that due to the presence of these new levels and the bound state decay probability, half-life of bare atom drastically falls.

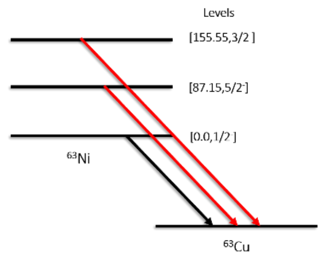

Fig-4: *β⁻ decay transitions of ^{63}Ni. The black line indicates the terrestrially known transition, the two red lines indicate 'new' transitions.*

Due to the inclusion of these new two transitions, there will be large decrement in half-life of ^{63}Ni. The effective half-life will be in the range 50 years – 53 years only instead of neutral ^{63}Ni half-life 101.2 years.

To summarize, in this work we have calculated bound and continuum β⁻ decay rates of some s-process bare nuclei in particular stellar environment. The presence of fully ionized atoms is confirmed by solving Saha ionization equation. In addition, new β⁻ transitions from the excited level of parent nuclei are identified and effective half-life of the nuclei has been calculated. The inclusion of bound state decay channel and the new transitions affect the half-life of the nuclei significantly.

Acknowledgment

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