Q values in *rp*-process and a new mass formula

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The astrophysical rapid proton capture (*rp*) process involves proton rich nuclei at or beyond the proton drip line. This process takes place in hot explosive proton-rich environment such as X-ray bursts. Measurements of mass of these nuclei are very difficult. Even when they have been possible, the measurements have very large errors in many instances. In many other nuclei, one has to depend on the theoretical estimates obtained from various mass formulas. In the present work, we investigate the effect of the mass uncertainty on the final abundance of *rp*-process. We have studied the possible effect of the variation in the mass value, or alternatively the Q-value, of a particular proton capture reaction, on the final abundance at different masses. In this work, we will investigate the effect of the Q value of the reaction $^{64}Ge(p,\gamma)^{65}As$ on the *rp*-process path. In this work, we have used a new phenomenological mass formula[1].

The importance of the nuclear mass in *rp*-process lies mainly in the balance between the forward (p,γ) reaction and its inverse i.e. photodisintegration process. It is well known that, certain N = Z nuclei having the highest abundance in equilibrium in a chain are called the waiting points for the chain. These nuclei have negative or very small positive Q-values for proton capture reaction and therefore, the reverse process dominates over the capture process. In such a scenario, the *rp*-process may get stalled and wait for β-decay to proceed further. At a certain temperature range, depending on the Q- value of the reaction, two proton capture can bridge the waiting point enabling the *rp*-process to continue. In our previous works[2, 3], we have described the role of nuclear mass in bridging of waiting point nuclei.

The rates for the astrophysical processes have been calculated in the microscopic optical model using densities from RMF calculations and DDM3Y potential. The details of calculations have been published earlier[2, 4].

In our present work, we have calculated the Q-value (say, Q_0) using the new phenomenological formula[1] and looked at the variation over the range $Q_0 \pm \sigma$, where σ has been chosen as equal to the rms error of the formula, i.e. 376 keV. The range is large enough to include almost all possible theoretical or systematic predictions. In Fig. 1, we have plotted the change in relative abundances as a function of the Q value of the reaction $^{64}Ge(p,\gamma)^{65}As$ at temperature 1.5 GK. Here, we have plotted only the mass values having final abundances at least 1% of the initial seed. An X-ray burst of duration 100 sec is considered and the proton flux density is assumed to be $10^6 gm/cm^3$. The proton fraction has been assumed to be 0.7. This correspond to the Model-I from the reference[5]. From the figure, it can be observed that at A = 68,72 and 76, i.e. the waiting point nuclei ^{68}Se,^{72}Kr and ^{76}Sr respectively, the abundances tend to fall away about some median value whereas the abundance of the waiting point A = 64 falls rapidly with increasing Q value. This is mainly due to the fact that, at this temperature ($T_9 = 1.5$), the two proton capture phenomena plays the leading role in bridging the waiting point nucleus ^{64}Ge for the Q-value from the mass formula[1]. The process is described in references[2, 3]. The change in abundances in other waiting points (A = 80,88,92 etc.) due to the reaction $^{64}Ge(p,\gamma)^{65}As$ follow the same behaviour as that of A = 68, 72 and 76, though the falling off at higher Q-values is very slow and therefore not shown in the figure. Again, it is observed that at masses which do not contain a

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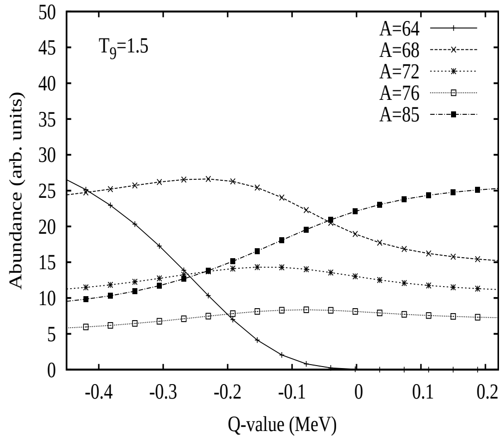

FIG. 1: The abundances as a function of the Q-value of the reaction ^{64}Ge(p,γ) for a constant temperature 1.5 GK.

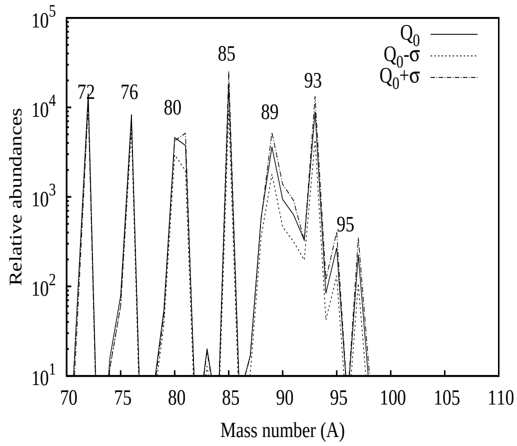

FIG. 2: Relative abundances vs mass number for calculated Q-value of ^{64}Ge(Q_0) along with the extreme $Q_0 \pm \sigma$ cases. (Model-I from reference[5]).

waiting point (For example, A=85 in Fig.1), the variation is larger. This is due to the enhancement of a particular pathway and it is observed that all the nuclei formed in that pathway tend to vary in a similar fashion.

In order to study the effect of Q value of the reaction $^{64}Ge(p,\gamma)^{65}As$ on the *rp*-process path, we have plotted relative abundances with mass number in Fig. 2. We have considered the mass number in each case for which the flux amount drops below 1% of the initial flux. It is evident from Fig. 2 that for Q_0 = -0.116 MeV (continuous line in Fig. 2), A $\approx$ 93 is the region above which the *rp*-process flux fall below the range of our interest. Associating the errors in the calculation also does not change the conclusion. In a previous work[2] , we have shown that a small fluctuation in the mass values of waiting point nuclei in mass 60-80 region may affect the effective half life and thus, proper knowledge of ground state binding energy is necessary to understand the bridging phenomena of a waiting point nucleus below mass 80 region. However, as we move towards the higher mass region, we find that small variations in binding energy do not affect the *rp*-process path significantly and evidently Fig. 2 verifies this statement. Using different density-temperature profiles of a X-ray burster[5–7] we arrive at same conclusion.

Acknowledgments

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