Endpoint of *rp* process with a new mass formula

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Proton capture reactions at very low temperature play an important role in nucleosynthesis. In case of an explosive nucleosynthesis event, such as X-ray burst, rapid proton (rp) process is expected to play an crucial role in producing proton rich nuclei upto mass 110. A typical X-ray burst provides a large proton flux around peak temperatures 1-2 GK. Timescales of such bursts are 10-100 seconds and proton flux density is around 10^6 gm/cc. In nature, most of the nuclei involved in rp-process are not available or can not be produced in terrestrial laboratories with our present day technology. Thus, theoretical inputs play a major part in the calculation. In this work, we have studied the endpoint of rp-process using a newly developed mass formula[1]. In a similar work, Schatz *et al.*[2] calculated the endpoint of rp-process using the reaction rates from Hauser-Feshbach code NON-SMOKER[3] and the mass values from FRDM calculation. They showed that rp-process ends with a SnSbTe cycle. We find that the present calculation produces somewhat different results.

In order to calculate relative abundances of nuclei in the rp-process path the major inputs are proton capture rates of nuclei, reaction Q values for capture reactions and half lives of all the nuclei involved in the process. Relativistic Mean Field calculations (RMF) have proved to be a very reliable tool for describing different features such as ground state energy, deformation, charge radii etc, both for stable and exotic nuclei throughout the periodic table. Our present calculation uses the microscopic optical potential obtained by folding the density dependent M3Y(DDM3Y) interaction with the densities from RMF approach. The Lagrangian density FSU Gold has been utilized for the purpose. The same methodology has been utilized in Refs. [4] and [5]. Reaction Q values are taken from a new mass formula[1]. Experimental half life values are from Audi *et al*[6], whereas in absence of measurements they are adopted from the FRDM calculation[7].

In a previous work[8], we have shown that nuclei upto A=80 can be synthesized easily in a typical X-ray burst environment. A network has been designed to calculate relative abundances of nuclei. The network consists of (p,γ), (γ,p) reactions and β-decay upto mass 80. The present calculation extends the network upto I-isotopes to investigate where the rp-process stops in a typical X-ray burst environment.

In Fig. 1, we have shown the path of the rp-process upto A=110 at 1.5 GK. The lines indicate time integrated reaction flow of nuclei above ^{56}Ni in a X-ray burst environment. We have taken the flux density as 10^6 gm/cc, proton fraction as 0.7 and 100 sec as the duration of the burst. Here, black lines indicate the path along which the major portion of the total flux flows whereas gray lines indicate the relatively weaker but still appreciable pathways.

According to the calculations of Schatz *et al*[2], ^{105}Sn captures a proton to form ^{106}Sb as ^{106}Sb has a sufficient positive proton separation energy. Another proton capture leads to ^{107}Te, which instantly undergoes α-decay to ^{103}Sn. In contrast, our calculation does not go through such an SnSbTe cycle which ends with α-decay. This is mainly because ^{106}Sb is very loosely bound with proton separation energy 119 KeV as derived from the new mass formula[1]. This amount of energy is not large enough for the proton capture reaction (p,γ) to dominate over the reverse process (γ,p) through photodisintegration. As a

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result, any ^{106}Sb that is formed instantly reverts back to ^{105}Sn. Therefore, ^{105}Sn actually decays to ^{105}In and does not enter to the SnSbTe cycle.

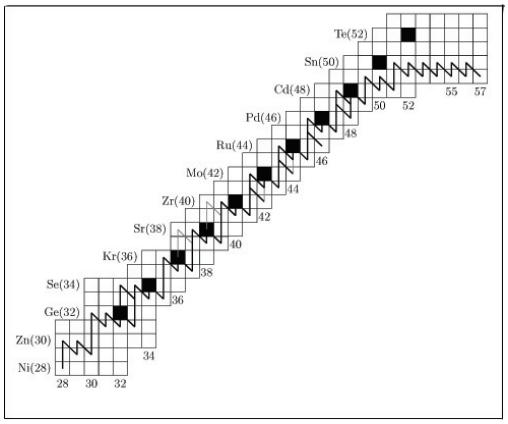

FIG. 1: The time integrated reaction flow above Ni-56 seed and endpoint of rp-process at 1.5 GK.

According to our calculation, only a portion less than 1% of total flux can cross the nucleus ^{92}Pd in the duration of 100 sec. As shown in the figure, above A=100 region, the *rp*-process continues through proton capture by In isotopes and β-decay of Sn isotopes. Here ^{100}In captures a proton to form ^{101}Sn which completely decays to ^{101}In as ^{102}Sb is proton unbound. In turn, ^{101}In undergoes proton capture and further exibits β-decay. The process of proton capture followed by consecutive β-decay continues and relative abundances of nuclei decrease as one proceeds towards higher mass region. Ultimately, less than 0.001% of the total flux reach ^{106}In, as recorded in our present calculation.

As pointed out in [1] the root mean square (r.m.s.) error in the ground state binding energies is 0.376 MeV. Near the valley of stability, this error does not appreciably affect the result, but near the drip lines, it has a greater impact. An error of 376 keV in the proton separation energy of ^{106}Sb as 119 keV implies that ^{106}Sb may be proton unbound or, more importantly, can have a proton separation energy nearly equal to 500 keV.

In a recent measurement[9], the proton separation energy of ^{106}Sb has been obtained as 428(8) KeV. We have repeated the same calculation using this experimental value and found that in this case also no ^{105}Sn is tranformed into ^{106}Sb in the time duration 100 sec. Therefore, no SnSbTe cycle is obtained in this time duration. But the whole scenerio changes if a long burst of duration greater than 150 sec takes place. In this case, we have found that the rp-process ends with SnSbTe cycle, using the separation energy of ^{106}Sb from Elomaa *et al.*[9]. In this case, and the process will end by α-decay of ^{107}Te preventing production of higher masses. Anyway, the parcentage of total flux entering into the SnSbTe cycle is not more than 1%. Thus, we can conclude that it is not possible to reach the SnSbTe cycle with the proton separation energy of ^{106}Sb in an X-ray burst of 100 seconds.

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