# EFFECT OF ATOMIC IONIZATION ON *P*-NUCLEUS SYNTHESIS RATE IN EXTREMELY HEATED SUBSTANCE OF MASSIVE STAR

Kopytin I.V.[1], Kornev A.S.[1], al-Hayali I.A.H.[2]
[1]*Voronezh State University, Voronezh, Russia;* [2]*Mosul University, Mosul, Iraq*
E-mail: i-kopytin@yandex.ru

We performed the calculations of *p*-nucleus abundances on the base of the synthesis process model. This model considers the quasi-equilibrium stages of massive-star evolution. We investigated the high temperature stages of oxygen burning in massive stars when the temperature of the substance reaches the "nuclear" values of 0.2–0.3 MeV in energy units. In these calculations it is significant to take into account all the modes of thermal nuclear beta-transitions (electron capture, electron and positron transitions) and nuclear photobeta-decay. The chain of the beta-decays, $(A; Z) \rightleftarrows (A; Z+1) \rightarrow (A; Z+2)$, is considered. Here under terrestrial conditions the progenitor nucleus, $(A; Z)$, and the *p*-nucleus, $(A; Z+2)$, are stable but the intermediate odd-odd nucleus, $(A; Z+1)$, is multibeta-decay. The *p*-nucleus abundances are found from the set of kinetic equations written for the above chain of the beta-decays. For the $N(\tau)$ final abundance of the *p*-nucleus, $(A; Z+2)$, the analytical solution to the set has the form,

$$N(\tau)/N_0 = 1 - \frac{1}{2}[\exp(-\delta_+\tau/2) + \exp(-\delta_-\tau/2)] - \frac{\lambda_{123}}{\delta}\sinh(\delta\tau/2)\exp(-\lambda_{123}\tau/2). \quad (1)$$

Here, $\tau$ is the stage duration; $N_0$ is the initial abundance of the progenitor $(A;Z)$ nuclei,

$$\delta = (\lambda_{123}^2 - 4\lambda_1\lambda_3)^{1/2}; \delta_\pm = \lambda_{123} \pm \delta; \lambda_{123} = \lambda_1 + \lambda_2 + \lambda_3 .$$

$\lambda_1$ is the total rate of electron beta-transition, $(A; Z) \rightarrow (A; Z+1)$, $\lambda_2$ is the total rate of reverse beta-transition, $(A; Z+1) \rightarrow (A; Z)$ (it includes the positron beta transition and the electron *K* capture) and $\lambda_3$ is the total rate of the electron beta transition, $(A; Z+1) \rightarrow (A; Z+2)$. All these rates depend on medium temperature.

We estimated the effect of almost complete ionization of atoms in the extremely heated substance of a massive star on the magnitudes of *p*-nucleus abundances. In this case *K* capture is strongly suppressed. Therefore the *p*-nucleus abundances were calculated by using Eq. (1) but now the electron *K* capture rate in the $\lambda_2$ total rate was not taken into account. As expected, the suppression of *K* electron capture in extremely heated medium increases the total yield of *p*-nuclei. In some cases, when the electron beta-transition, $(A; Z+1) \rightarrow (A; Z+2)$, was strongly suppressed in the background of the electron capture the increase of abundances is especially noticeable. It is obtained for the following *p*-nuclei, $^{136}$Ce, $^{144}$Sm, $^{156}$Dy, $^{162}$Er, $^{184}$Os, $^{190}$Pt and $^{196}$Hg. As a result, the "solar" abundances of the latter and 20 more isotopes can be received at the stage of the oxygen burning in massive stars.