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Hydrogen burning on Nitrogen isotopes in CNO and HCNO-cycles

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We investigated the radiative proton capture on nitrogen isotopes ^{12}N, ^{13}N, and ^{14}N [1 - 4] in the framework of the MPCM and obtained the reaction rates and their parametrizations. There are two stable nitrogen isotopes ^{14}N and ^{15}N, and among short-lived nitrogen isotopes, the longest-lived are ^{12}N ($t_{1/2}$ = 11 ms) and ^{13}N ($t_{1/2} = 9.965$ min).

We compare the reaction rates to understand the relevance of each process at a given astrophysical temperature. The radiative proton ^{12}N$(p,\gamma)^{13}$O, ^{13}N$(p,\gamma)^{14}$O, ^{14}N$(p,\gamma)^{15}$O, and ^{15}N$(p,\gamma)^{16}$O processes have the same Coulomb barrier, so the reaction rates will differ only due to the different values of the $S(E)$ and reduced mass μ of interacting particles in the entrance channel. The reduced masses of the pairs p^{12}N, p^{13}N, p^{14}N, and p^{15}N are always less than the proton mass and are within the range $0.9294 \leq \mu$(amu) ≤ 0.9439. Therefore, the impact of the reduced mass can be omitted, and the reaction rates depend entirely on the reaction S-factor [4].

The p^{15}N reaction is the fastest, and its rate dominates up to $T_9\tilde{a}0.175$. ^{14}N$(p,\gamma)^{15}$O is the slowest process up to $T_9\tilde{a}0.1$, and it controls the rate and time of nucleosynthesis cycles. The p^{15}N rate becomes dominant at temperature-explosive hydrogen burning scenarios in stars. Only in the temperature windows $0.18 \leq T_9 \leq 1.14$ and $0.66 \leq T_9 \leq 3$ the reaction ^{15}N$(p,\gamma)^{16}$O is slower than ^{13}N$(p,\gamma)^{14}$O and ^{14}N$(p,\gamma)^{15}$O reactions, respectively. Hence the p^{15}N reaction controls the rate and time of cycles of nucleosynthesis in these two temperature windows [4].

The ^{15}N$(p,\gamma)^{16}$O reaction rate shows a strong interference effect but minor sensitivity to the asymptotic constant.

The main difficulty in determining reliable reaction rates of ^{12}N$(p,\gamma)^{13}$O, ^{13}N$(p,\gamma)^{14}$O, ^{14}N$(p,\gamma)^{15}$O, ^{15}N$(p,\gamma)^{16}$O reactions for the CNO cycles is the uncertainty in the very low cross-sections at the Gamow range. Developments within the low-energy underground accelerator facility LUNA [5] and recent improvements in the detection setup [6] make taking direct measurements of nuclear reactions near the Gamow range feasible. This advantage has been demonstrated in the ^{14}N$(p,\gamma)^{15}$O reaction, which was successfully measured down to energies of 70 keV at LUNA [7].

References

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