# Modern Results for the Cosmic Ray Nucleosynthesis of $p$-Nuclei

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We show significantly improved results of the cosmic ray nucleosynthesis (CRN) of proton-rich stable nuclides ($p$-nuclides) [1]. It has been suggested [2] that the CRN produces 13 to 70 percent of the solar abundances of four heavy $p$-nuclides, $^{180m}$Ta, $^{184}$Os, $^{190}$Pt, and $^{196}$Hg using a semi-empirical formula for the spallation cross section [3]. In this study, we obtain realistic results of the CRN of $p$-nuclei based upon detailed treatment of the cosmic ray (CR) nuclear transfer including the nuclear spallation, decay, energy loss, and escape from the Galaxy. Latest nuclear data are compiled, and we adopt the latest semi-empirical formula SPACS for the spallation cross sections which have been set up using recent data at GSI, Darmstadt [4,5]. Effective electron-capture decay rates are calculated using the proper cross sections for recombination and ionization in the whole CR energy region. Isomeric production of unstable nuclei are taken into account. Thus, the modern calculation of the CRN is performed in a nuclear reaction network in the range of mass number $A = [74, 209]$.

Abundances of proton-rich unstable nuclides increase in CRs with increasing energy relative to those of other nuclides since the electron-capture decay is hindered by the ionization. We derive yields of the primary and secondary spallation processes and differential yields from respective seed nuclides. It is then shown that the CR energy region of $\leq \mathcal{O}(100)$ MeV/nucleon predominantly contributes to the total yields. Therefore, atomic cross sections in the low-energy range should be input accurately as treated in this study.

We identify important seed nuclides for all $p$-nuclides. The contribution of CRN is significant only for $^{180m}$Ta, which accounts for about 20 % of the solar abundance. The most important production routes are reactions of $^{181}$Ta, $^{180}$Hf, and $^{182}$W. CRN yields of other $p$-nuclides are typically about $\mathcal{O}(10^{-4}$–$10^{-2})$ of solar abundances.

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