Modified Two- and Three-Body Approaches, Asymptotic Normalization Coefficients and Their Application for Nuclear Astrophysics

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A reliable estimation of rates of different nuclear astrophysical processes responsible for the light element abundance via the pp-chain and the CNO-cycle is one of most important problems of modern nuclear astrophysics. A solution of this problem is in turn impossible without obtaining rather low energy cross sections $\sigma_{aA}(E)$ (or equivalently the astrophysical S factors $S_{aA}(E)$) for these reactions, where E is the relative kinetic energy of colliding particles. For example, reliable information on cross sections $\sigma_{aA}(E)$ (or $S_{aA}(E)$) at solar energies ($E \lesssim 25$ keV for the radiative capture reactions such as $^{7}\mathrm{Be}(p,\gamma)^{8}\mathrm{B}$, $^{12,13}\mathrm{C}(p,\gamma)^{13,14}\mathrm{N}$, $^{2,3}\mathrm{H}(\alpha,\gamma)^{6,7}\mathrm{Li}$, $^{3}\mathrm{He}(\alpha,\gamma)^{7}\mathrm{Be}$ plays a crucial role in the observed abundances of these nuclei in the Sun and in Big-Bang nucleosynthesis calculations.

Despite the impressive improvements in our understanding of these processes made in the past decades, however, some ambiguities connected with both the extrapolation of the measured cross sections for the aforesaid reactions to the stellar energy region and the theoretical predictions for $\sigma_{aA}(E)$ (or $S_{aA}(E)$) still exist and they may considerably influence the predictions of the standard solar model.

One of the possible solutions of this problem is based on the idea that owing to strong Coulomb repulsion of colliding particles (a and A) and rather low value of the binding energy of the captured particles (proton or α-particle), at stellar energies the amplitude of the direct capture $\mathrm{A}(a,\gamma)\mathrm{B}$ reaction of astrophysical interest proceeds through the tail of the overlap integral, and, hence, is completely determined by the Coulomb interaction, binding energy and the respective asymptotic normalization coefficient for $\mathrm{A}+a\to\mathrm{B}$.

In the presented review work, the basic methods of the determination of asymptotic normalization coefficient for $\mathrm{A}+a\to\mathrm{B}$ of astrophysical interest are presented. The results of the application of the specific asymptotic normalization coefficients derived within these methods both for the extrapolation of the astrophysical S factors to experimentally inaccessible energy regions ($E \leq 25$ keV) and for the calculation of the rates at stellar temperatures for the some specific radiative capture $\mathrm{A}(a,\gamma)\mathrm{B}$ reactions of the pp-chain and the CNO cycle are presented and discussed.