Indirect techniques in nuclear astrophysics

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It is very difficult or often impossible to measure in the lab conditions nuclear cross sections at astrophysically relevant energies. That is why different indirect techniques are used to extract astrophysical information. In this talk different experimental possibilities to get astrophysical information using radioactive and stable beams will be addressed.

1. The asymptotic normalization coefficient (ANC) method has proven to be a powerful indirect technique to get astrophysical S factors. Often this method requires the use of radioactive beams. In this talk I will address the application of the ANC technique to determine the astrophysical factors for the key CNO cycle reactions ^{13}N$(p,\gamma)^{14}$O, ^{14}N$(p,\gamma)^{15}$O and Ne-Na cycle reaction ^{20}Ne$(p,\gamma)^{21}$Na. The role of subthreshold states as bound states and resonances will be discussed. It will be shown how to determine the sign of the interference of the direct and resonant terms based on the information about the ANC. The importance of this technique follows from the fact that measurements of the proton ANCs for ^{15}O from the ^{14}N$(^3$He$,d)^{15}$O transfer reaction [1] increased the life time of the globular clusters by 700 million - 1 billion years.

2. It is extremely difficult or impossible to measure the astrophysical S factors for r- processes (n,γ) for radioactive nuclei near closed shells. In many cases direct capture is the main mechanism of the astrophysical r-processes. Radiative neutron captures are determined by the spectroscopic factors (SP). A new experimental technique to determine the neutron SPs will be addressed. This technique is based on two measurements. The first measurement is supposed to determine the neutron ANC from the sub-Coulomb (d,p) reaction. Then the second measurement of the (d,p) reaction (in inverse kinematics for unstable isotopes) at energies significantly higher then the Coulomb barrier will determine the spectroscopic factor. Information about the ANC eliminates any dependence on the single-particle potentials. A few examples will be given.

3. "Trojan Horse" is another unique indirect method, which allows one to extract the astrophysical factors for direct and resonant nuclear reactions at astrophysically relevant energies [3]. Using few-body approach one can obtain a relationship between the measured $2 \to 3$ cross section and extracted sub-reaction $2 \to 2$ one, and determine the impact of the "off-shellity" on the extracted $2 \to 2$ cross section. A new method of determination of the on-shell astrophysical S factor, which is based on the extrapolation of the triple differential cross sections measured using the Trojan Horse technique to the nearest singularity in the transfer momentum (projectile-spectator) plane, will be addressed. The determined cross section is on-shell. Experimental kinematics will be discussed.

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