Nuclear spectroscopy using direct reactions of RI beams

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Direct reactions have been commonly used to populate excited states having characteristic quantum numbers depending on the probes such as proton, deuteron, alpha, Coulomb field, and so on. In RI-beam experiments, these probes are prepared as experimental target and excited states of beam or beam-like nucleus are identified by measuring all the decay products including $\gamma$-rays where the invariant masses are reconstructed to determine the excitation energies. It is noted that the Doppler-shift correction of the $\gamma$-ray from the moving nucleus is equivalent to reconstruct the invariant mass of the $\gamma$ and the residual nucleus. The combination of the inverse kinematics and the invariant mass spectroscopy has several advantages to overcome poor energy resolutions, weak intensities and a poor purity of RI beams. One of the advantages in an experimental point of view is that physical probe can be changed by replacing the experimental target without changing the configuration of the detector system. Another advantage is that spectroscopy of an exotic nucleus via different reaction processes such as inelastic scatterings, stripping and knockout reactions from different nuclei in an RI beam at the same time. Those facts provide us characteristics of excited states by directly comparing excitation spectra from different reactions and/or probes with the same acceptance. Some of the recent experimental results on properties of exotic nuclei are presented.

Since RI beams can have a variety of isospin ($T$), internal energy (mass excess, $\varepsilon$), and spin ($S$), while light stable beams have $T,S \leq 1$ and the minimum internal energies among isobars. With these properties of RI beams, it is possible to reach states which are hardly accessible via the stable-beam induced reactions. For example, an exothermal charge exchange induced by RI beams open new possibilities to probe higher excitation states with small momentum transfer. By using these reactions, we will be able to produce states which have been hardly observed so far, for example, multi-neutron systems, isovector spin monopole resonances, and double Gamow-Teller resonances. In order to perform a high-resolution missing-mass spectroscopy using RI beams, we started the SHARAQ project, where a high resolution SHARAQ spectrometer and a large-dispersive beam line are being constructed in RIBF. The specifications of them are presented and some physics programs on the missing mass spectroscopy are also discussed.