Doppler Shift as a Tool for Studies of Isobaric Analog States of Neutron-Rich Nuclei: Application to ^{7}He

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The purpose of this work is to introduce a new experimental technique that allows the study of exotic neutron-rich nuclei in inverse kinematics using rare beams. The technique has two components: the population of isobaric analog states (IAS) of exotic nuclei through resonant reactions in a thick proton target (in line with ideas discussed in Ref.[1]), and subsequent measurement of the Doppler shift profile of the γ rays emitted after neutron decay of the IAS. This approach allows for the simultaneous measurement of the excitation function of the resonant *(p, n)* process, which leads to the population of IASs over a wide energy range from the initial RIB energy to zero, and provides some information on the double differential cross sections in one self-consistent measurement. The first application of this technique presented for the case of the IAS of ^{7}He in ^{7}Li.

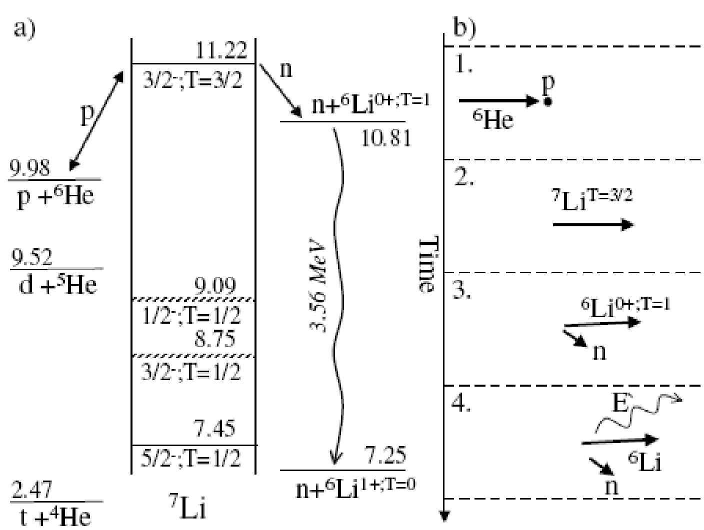

Figure 1. (a) Decay pathways for the T=3/2 resonance in ^{7}Li, and (b) the successive kinematics stages of the reaction.

Fig.1 gives the illustration of the successive transmutations following the proton capture into *T=3/2* resonance state in ^{7}Li. Because of isospin conservation, only two decay channels are allowed for the *T=3/2* state: proton decay to the initial channel and a neutron decay with the population of *T=1* states in the ^{6}Li nucleus. Usually the T> states in the daughter nuclei (3.56 MeV, T=1 in ^{6}Li in our case) populated in the transmutation in question can undergo nuclear decay only through isospin-forbidden channels, and as a result the probability for γ decay is strongly enhanced. In case of ^{6}Li the γ decay dominates (100%).

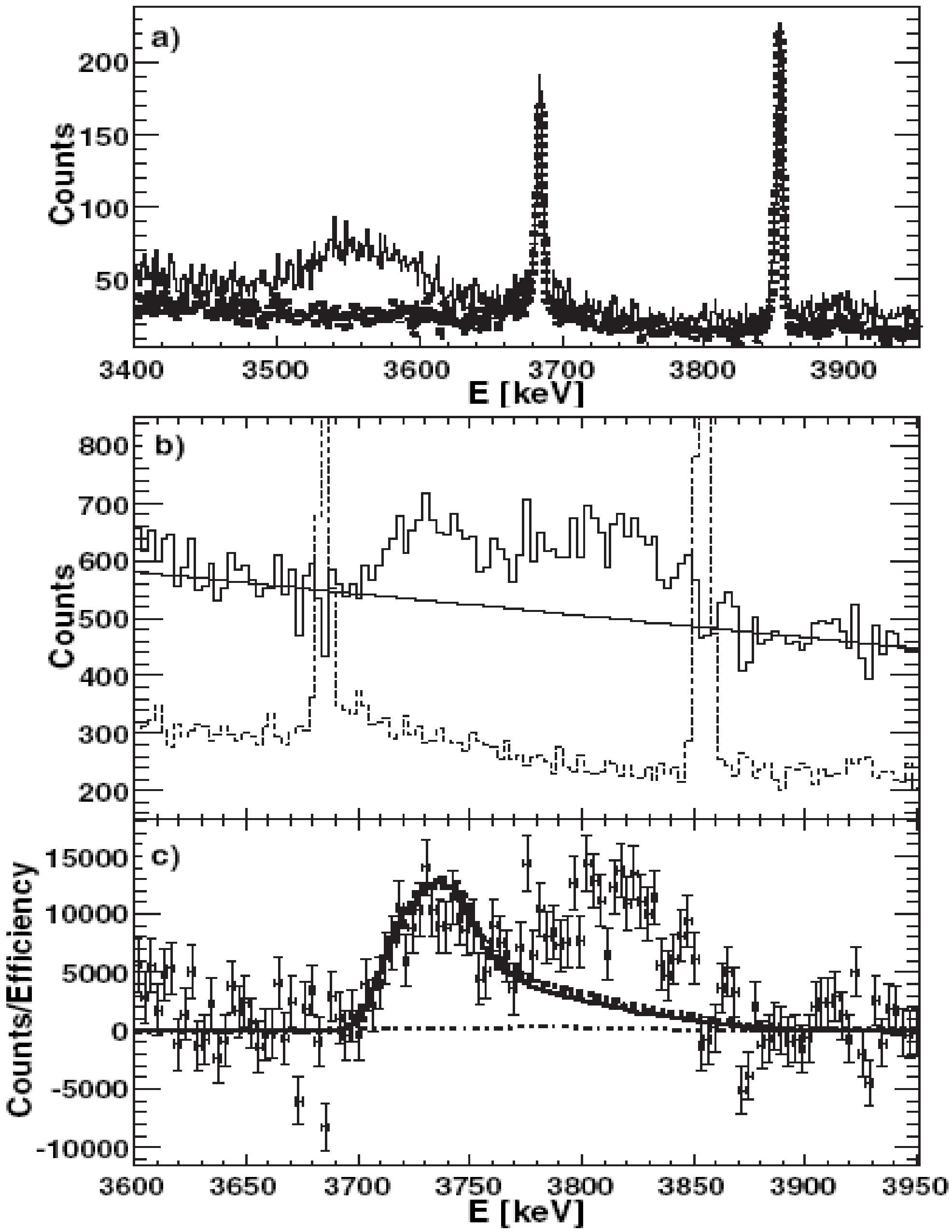

Figure 2. (a) Part of the γ-ray spectrum from the 90^0 Ge detector. The solid curve was obtained with a CH_2 target; the dotted curve was taken with a carbon target. (b) The spectrum in the 0^0 Clover detector obtained by subtraction of the carbon contribution; the dotted curve was taken with a carbon target. The Compton background is approximated by a straight line as shown. (c) The final spectrum of the Doppler-shifted 3.56 MeV γ rays. The solid line shows the contribution from the known $T = 3/2$, $J = 3/2^-$ state in ^{7}Li. The dotted line includes the effect of $T = 1/2$ resonances. The dash-dotted line close to the abscissa axis shows the contribution of the direct charge exchange process.

A ^{6}He beam with an intensity of $2 \cdot 10^5$ pps and an energy of 24 MeV stopped in a 57.4 mg/cm^2 CH_2 target[2]. Two γ-ray detectors were placed around the target: a HPGe Clover at 0^0 and a single-crystal 55% efficiency HPGe detector at 90^0 relative to the beam direction. A portion of the 90^0 γ-ray spectrum is shown in Fig. 2(a). The main features of the spectrum are two narrow peaks at 3.68 and 3.85 MeV, and a broad bump with a centroid at 3.56 MeV. The two narrow peaks are from the decay of ^{13}C excited states populated in the ^{12}C(^{6}He, ^{5}He)^{13}C reaction. The bump at 3.56 MeV is the Doppler broadened 3.56 MeV γ-ray transition from the 0^+ state of ^{6}Li. A γ-ray spectrum obtained with a carbon target is shown by the thick dotted curve. The 3.56 MeV structure is not present in this case, providing clear evidence that it results from the interaction of ^{6}He with protons. The ^{7}He$_{g.s}$.isobaric analog state (IAS) population is shown as a continuous curve in Fig. 2(c). A possible contribution of T=1/2 states in ^{7}Li in the reaction in question is shown as the dotted curve in Fig. 2(c). The second curb at ~3.8 MeV in Fig.2(c) is a clear evidence for the IAS of an excited (unknown) state in ^{7}Li. As a summary, we demonstrated two important advantages of the proposed method: (1) its sensitivity to the single-particle strength of the isobaric analog resonances, coupled with (2) insensitivity to the energy resolution of the radioactive nuclear beam. We also showed that our data are incompatible with the results [3] on a low excited stated in ^{7}He, and brought evidence for the ½$^-$ excited state in ^{7}He at higher excitation energy.

[1] V. Z. Goldberg, in *Proceedings of Exotic Nuclei and Atomic Masses (ENAM98) International Conference*, ed. B. M. Sherrill, D. J. Morrisey, and C. N. Davids (Springer, New York, 1998), p. 319.
[2] G.V. Rogachev *et al.*, Phys. Rev. Lett. **92**, 232502 (2004).
[3] M. Meister *et al.*, Phys. Rev. Lett. **88**, 102501 (2002).