The $(6Li, 6Li')$ reaction at RCNP (e441): An indirect probe of inelastic neutrino-nucleus scattering cross-sections

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Nuclear excitation by neutral-current (NC) neutrino scattering is a critical component of nuclear astrophysics, impacting the evolution of supernovæ (SNe), the site of the r-process, neutrino nucleosynthesis, and possibly even the synthesis of some of the solar system's rarest stable isotopes [2, 3]. However, the measurement of inelastic neutrino-nucleas scattering (INNS) reactions directly is an extreme challenge due to the neutrinos weak coupling to matter [3, 4]. For this reason, indirect measurements that can isolate the allowed Gamow-Teller transition strength for these reactions provide a unique opportunity.

A recent measurement at the Research Center for Nuclear Physics in Osaka, Japan has been performed in which the novel (^{6}Li,^{6}Li[3.56 MeV]) reaction at 100MeV/u was utilized, and wherein pure spin and isospin flip excitations in the inelastic channel (ΔS=ΔT=1, ΔT_z=0) have been identified. This reaction channel was selected by tagging the de-excitation gamma rays with E_γ=3.56 MeV from the outgoing ^{6}Li ejectile. This method was first suggested by Sam M. Austin [1]. Other inealstic probes such as (p, p') and (e, e') have been used in the past, however special considerations must be made to seperate the isoscaler and oribital transfer components from the desired isovector-spin flip transition strength.

The ^{6}Li probe provides direct access to the GT_0 response of nuclei in an unambiguous manner. This selectivity is a distinct feature of this (^{6}Li, ^{6}Li$'$) probe, in contrast to the above-mentioned (p, p') probe, which is of $J_i^\pi = 1/2^+ \rightarrow J_f^\pi = 1/2^+$, and $T_i = 1/2 \rightarrow T_f = 1/2$. A simplified level diagram of ^{6}Li is shown in Fig. 1, which is drawn based on Ref. [5]. This reaction channel is identified by tagging the de-excitation γ ray with $E_\gamma = 3.56\,\text{MeV}$. Although the α threshold is located below this state ($Q_\alpha = -1.47\,\text{MeV}$), the α decay is forbidden, unlike other excited states, as it violates parity invariance [5]. Instead, this state decays directly to the ground state via γ emission, and since it has $J^\pi = 0^+$, the branching ratio to the 3^+ state at 2.19 MeV, as well as the feeding from other higher excited states, is negligible. Therefore, the coincidence measurement with 3.56 MeV γ rays provides a clean event identification.

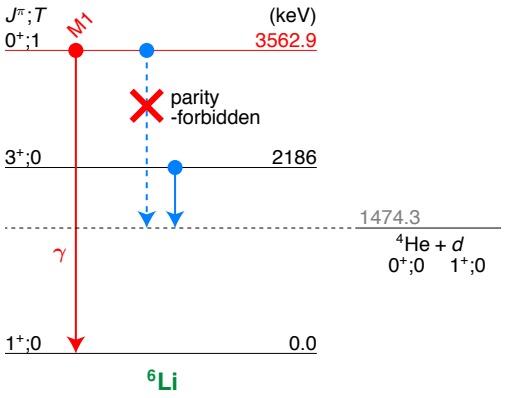

Figure 1: A simplified level diagram of ^{6}Li based on Ref. [5]. The α-decay of the $J^\pi = 0^+$, $T = 1$ state at $E_x = 3.56\,\text{MeV}$ is parity-forbidden, and thus this state mainly decays to the ground state *via* γ emission.

The (^{6}Li, ^{6}Li$'$) inleastic scattering measurement was performed on ^{12}C, ^{24}Mg, ^{56}Fe and ^{93}Nb during the December 2016 run (experiment 441) of the Clover Array Gamma-ray spectrometer at RCNP for Advanced research (CAGRA) and Grand Raiden (GR) campaign. Analysis is presently ongoing.

References

[1] Sam M. Austin, N. Anantaraman, and J. S. Winfield. Heavy-ion reactions as spin probes. *Can. J. Phys.*, 65:609–613, 1987.

[2] W. C. Haxton et al. Neutrino-induced nucleosynthesis and the site of the r process. *Phys. Rev. Lett.*, 78:2694–2697, 1997.

[3] W. R. Hix et al. Supernova science at spallation neutron sources. *J. Phys. G*, 29:2523, 2003.

[4] R. Imlay. New results on electron-neutrino carbon scattering and muon-neutrino carbon scattering at LSND. *Nucl. Phys.*, A629:531–537, 1998.

[5] D. R. Tilley et al. Energy levels of light nuclei $a = 5$, 6, 7. *Nucl. Phys.*, A708:3–163, 2002.