Proton & alpha induced reactions on light nuclei for nuclear structure and astrophysics

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Introduction

Light nuclei offer a unique avenue for investigating quantum many-body systems. In these nuclei, the energy levels are sufficiently spaced apart, showcasing pronounced quantum behaviour - an attribute distinct from heavy nuclei, where energy levels are densely packed. Notably, light nuclei exhibit nuclear structure effects, leading to significant fluctuations in the reaction cross-section at low excitation energies. Reproducing these fluctuations theoretically has been a persistent challenge for researchers, as they are thought to arise from the intricate interplay of nuclear structure properties such as channel couplings, target deformations, and compound nuclear resonances.

The primary objective of this thesis is to delve into the complex interplay of these properties, focusing on the investigation of nuclear structure and reaction dynamics in light nuclei. Within our research group, an ongoing program is dedicated to exploring proton and alpha-particle-induced reactions on light nuclei. An initial experiment involving the inelastic scattering of protons from ^{12}C has already been conducted. The aim is to extend this research to other light nuclei, such as ^{10}B and ^{16}O, utilizing both proton and alpha-particle beams. This study specifically focuses on employing proton and alpha-particle beams to investigate the structure and properties of the ^{16}O and ^{10}B nuclei.

Experiments for the ^{16}O(p,p$'\gamma$)^{16}O, ^{16}O(α,$\alpha'\gamma$)^{16}O, and ^{10}B(p,p$'\gamma$)^{10}B reactions have been carried out. The objective is to measure nuclear structure and reaction properties, encompassing low-lying energy states, angular distributions, and reaction cross-sections. Comparing the cross-sections of (p,p$'\gamma$) and (α,$\alpha'\gamma$) reactions with ^{16}O can offer insights into the iso-spin dependence for the γ-ray cross-sections.

The theoretical analysis of scattering experiments is conducted through the application of Optical Model Potentials (OMPs). We have conducted a detailed optical model analysis to compare the measured cross-sections with calculation. The optical model potential has been constructed, fitting a large body of global data for elastic, total cross-section and polarization data. The potentials obtained were modified by including relevant resonances and fed into the coupled channel formalism. Figure 1 presents the measured and calculated cross-section of only 6.13 MeV γ-ray from ^{16}O. Our calculations of the total cross-sections for the three γ-rays from ^{16}O agree fairly well with the measured values. However, differences exist between theory and experiments regarding finer structures in the cross sections. The discrepancies that persist in terms of finer structure are very likely due to complex and connected structural effects which are yet to be fully understood. There are subtle roles played by both coupling of the channels and resonances, and what may be surmised is that the calculation at these low energies loses much of its predictive power [1].

Efficient detection of γ-rays necessitates cutting-edge detector systems, and our research has employed inorganic scintillation detectors for this purpose.

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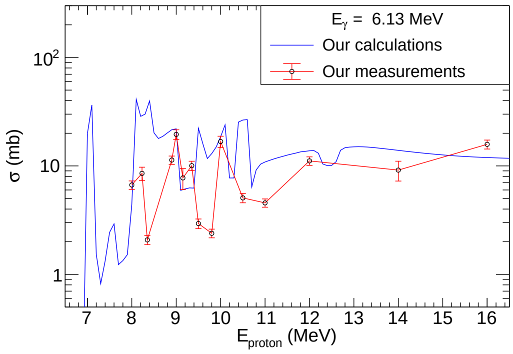

FIG. 1: Measured and calculated cross-section of 6.13 MeV γ-rays from ^{16}O.

Over the past two decades, Lanthanum Halides, specifically Lanthanum Bromide and Lanthanum Chloride, have emerged as the most sought-after inorganic scintillators for γ-ray measurement. The success of Lanthanum Halide detectors has prompted crystal growers and commercial entities to explore new scintillation crystals with comparable or enhanced properties. A recent development involves a hybrid crystal, Lanthanum Bromochloride ($LaBr_{2.85}Cl_{0.15}$:Ce or LBC), containing both Bromine and Chlorine, grown by Scionix Holland BV. The inclusion of Chlorine, with its notably larger neutron cross-section, positions LBC as a potential candidate for a neutron-γ dual detector.

Our research involves characterizing the response of LBC crystals to both γ-rays and neutrons, guided by the expectation that they may perform as well as, or even better than, established $LaBr_3$:Ce crystals.

For γ-rays, our study encompasses crucial crystal properties, including linearity of response, energy resolution up to 4.44 MeV, timing resolutions, quantification of internal activity, and full energy detection efficiencies across a range of γ-ray energies from 0.276 to 4.44 MeV. Utilizing the Monte Carlo simulation toolkit GEANT4, we conducted realistic simulations to estimate the full energy detection efficiency and compared the results with measured values [2].

The detection of neutrons plays a pivotal role in advancing research in the fundamental physics of nuclear structure and reactions, as well as finding critical applications in areas such as nuclear fusion diagnostics, elemental analysis, and nuclear power. In our work, we conducted measurements of the fast and thermal neutron response of LBC, $LaBr_3$:Ce, and NaI:Tl [3].

Continuing our research in detector characterization, we used the Compton Coincidence Technique (CCT) to measure the intrinsic energy resolution of Compton electrons in $CeBr_3$, showcasing its capability to measure energy resolution at arbitrary energies using a single γ-ray source [4].

On the instrumentation front, we have designed, developed, and tested a target cooling system based on the Peltier device, which eliminates the need for liquid coolant. This innovative setup holds promising potential for our group's use in forthcoming experiments involving low-beam energy and high-current conditions.

Acknowledgments

The author would like to acknowledge all collaborators and the staff of BARC-TIFR pelletron accelerator and VECC, K-130 cyclotron, for providing the beam for the entire duration of the experiment.

References

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