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Bridging Reaction Physics and Nuclear Structure: γ-Ray Spectroscopy and Cross-Section Systematics for Nucleon-Induced Reactions

We present here a a comprehensive and systematic study of nuclear γ-ray production cross-sections induced by proton reactions on a series of key nuclei, specifically 24,25,26Mg, 28,29,30Si, 40Ca, and 56Fe [1,2]. These investigations are conducted within the framework of an Algeria-France-South Africa collaboration at the iThemba LABS facility, utilizing the high-resolution AFRODITE gamma-ray spectrometer. The primary objective is to provide high-precision experimental data in a proton energy range of 30-200 MeV [1,3] where existing data are often scarce or inconsistent, yet crucial for multiple scientific domains.
The measured cross-sections serve as a cornerstone for several applications. In medical physics, they are essential for optimizing radioisotope production and improving dose calculations in proton therapy. In nuclear astrophysics, these data are employed to simulate γ-ray line emissions resulting from the interaction of galactic cosmic rays (GCRs) with abundant elements in the interstellar medium (ISM) and solar flares. By comparing laboratory measurements with satellite observations (such as those from INTEGRAL or COMPTEL), we can better determine the chemical composition and understand the energetic processes of the cosmos.
A central technical aspect of this work involves the adjustment of optical model potential (OMP) parameters for nucleon-nucleus interactions. Beyond the primary gamma-ray line analyses following inelastic scattering on target nuclei, our analysis allows for the measurement of production cross-sections for a wide range of residual nuclei. Indeed, the complex interaction mechanisms lead to the observation of various isotopes resulting from nucleon or alpha emission, such as 21,22Ne, 22,23Na, and 24,25,26Al from magnesium and silicon targets, as well as 38,39K, 36,38Ar, 54,55Fe, and 52Cr for heavier targets. To ensure the highest accuracy, the analysis of the γ-ray spectra is complemented, whenever necessary and possible, by a lineshape calculation to account for Doppler effects and peak broadening.
This process is a fundamental approach to better understand the physics of reactions and the complex interactions between the candidates (incident particles and target nuclei). By systematically adjusting the OMP parameters, we can adjust the nuclear level coupling and determine the nuclear deformation parameters (β2 and β4). While the analysis of the 40Ca data is currently in progress-focusing on the optimization of nucleon-induced reactions and their implications for residual Argon nuclei-future objectives aim to extend this methodology to α-particle induced reactions as they are rather scarce. Ultimately, this hierarchical approach - moving from fundamental interaction physics to the adjustment of theoretical models - is needed for improving the predictive accuracy of global nuclear reaction codes such as TALYS.
The experimental and theoretical results obtained and compiled will be presented and discussed.

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