Measurement of the photoabsorption cross section of ^{24}Mg.

J A C Bekker[1,2], L Pellegri[1,2], M Wiedeking[1,2], P Adsley[1,2], R Neveling[1], L M Donaldson[1]

[1]SSC Laboratory, iThemba LABS, P.O. Box 722, Somerset West 7129, South Africa.
[2]School of Physics, University of the Witwatersrand, Johannesburg 2050, South Africa.

E-mail: 1390529@students.wits.ac.za

Abstract. Accurate nuclear data is a key factor in determining the suitability and reliability of many theoretical nuclear models and large-scale calculations. One of the main ingredients of these calculations is how nuclei respond to an electromagnetic field. The excitation of the isovector giant dipole resonance (GDR) is of particular importance in both nuclear structure studies as well as being the main mode of interaction of ultra-high-energy cosmic rays with the extra-galactic medium. This study investigates the photoabsorption cross section in the region of the GDR in ^{24}Mg through the use of proton inelastic scattering and the equivalent virtual photon method. The K600 spectrometer at the iThemba LABS facility was used to obtain high resolution, low background ^{24}Mg(p,p')^{24}Mg* inelastic scattering data. The virtual photon absorption method is described and the result of applying the method is presented and compared to a previous real photon absorption cross section.

1. Introduction

The field of nuclear astrophysics provides numerous instances where precise experimental data is crucial to replicate and describe physical systems accurately. One notable example is the simulation of ultra-high-energy cosmic rays (UHECR) and their propagation. These cosmic rays possess energies significant enough to Lorentz boost the cosmic microwave background, resulting in photodisintegration [1]. Simulating this phenomenon necessitates input from numerous nuclei with masses below A=56. Acquiring all the required quantities for each nucleus is experimentally impractical, however, certain nuclei hold greater significance than others for validating nuclear structure and reaction models. A multitude of E1 gamma transitions occur through the isovector giant dipole resonance (IVGDR), serving as a strong indicator of the reaction mechanism responsible for modifying the energy and mass composition of UHECR during their propagation. This project focuses on extracting the total photoabsorption cross section within the energy range of the IVGDR for a key nucleus in this calculation: ^{24}Mg. This extraction is accomplished through relativistic Coulomb excitation of the IVGDR in ^{24}Mg utilizing the virtual photon absorption technique.

2. Method

The K600 magnetic spectrometer, located at iThemba LABS, is one of only two facilities worldwide capable of providing high-resolution, low-background spectra specifically designed

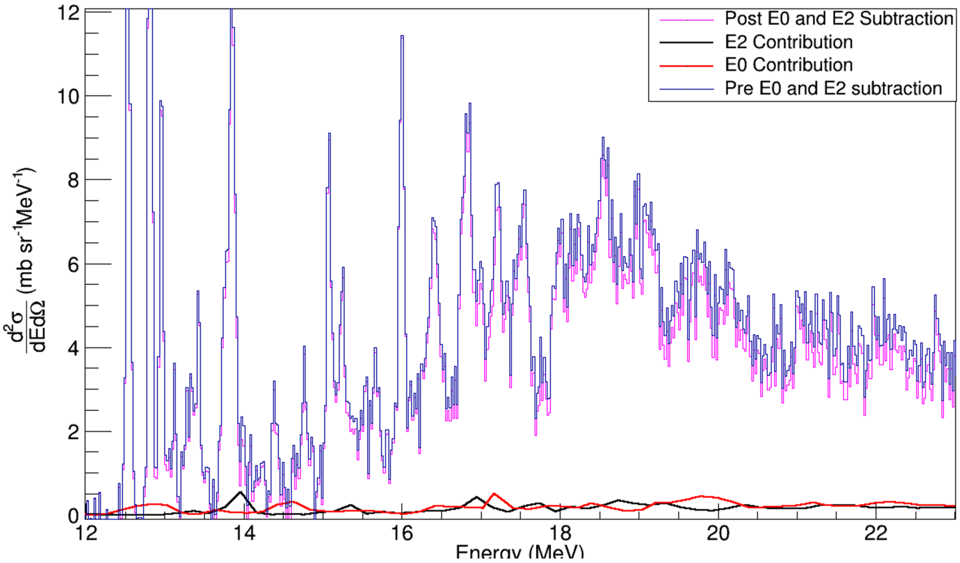

Figure 1. The experimental double differential cross section for ^{24}Mg(p,p') at 200 MeV showing the contributions of E2 and E0.

for 0° measurements at medium energies [2]. The separated sector cyclotron (SCC) is employed to accelerate protons up to 200 MeV, which are then directed towards the 24Mg target. To separate the unreacted beam from the inelastically scattered particles, the QDD magnetic spectrometer is utilized. The scattered protons are detected in the focal-plane detectors of the K600, which consist of two scintillator detectors and two multi-wire drift chambers. During the measurements, the spectrometer operated in its high-dispersion mode, and the aperture of the experiment encompassed scattering angles ranging from 0° to 2°.

3. Virtual Photons

The utilization of 200 MeV protons with a scattering angle of 0° highly favors the excitation of the IVGDR through Coulomb interaction. This choice is advantageous because it minimizes the interference between the nuclear and Coulomb interactions, thereby eliminating the task of disentangling various contributions to the spectrum. One approach employed to calculate the Coulomb excitation of the nucleus is the virtual-photon production method, which reformulates the electromagnetic interaction between the projectile and the target as a spectrum of virtual photons that are absorbed by the target. The computation of virtual photon production was carried out using a code provided by Carlos Bertulani. Tthe equivalent photoabsorption cross section can be extracted from the double-differential cross section obtained in inelastic (p,p') scattering. Protons serve as a non-selective probe in terms of parity and spin. Hence, it becomes necessary to eliminate the contributions from other multipoles present in the spectrum before applying this method. To accomplish this a DWBA calculation was employed in conjunction with the extracted strengths obtained from a ^{24}Mg(α,α')^{24}Mg* experiment. The effectiveness of this method has been demonstrated through examples studied at RCNP and iThemba.[4].

4. Results

The double differential cross section shown in Fig:1 is calculated using the following formula:

$$\frac{d^2\sigma}{d\Omega d\sigma} = \frac{10^{27} \cdot N_c}{N_0 \cdot \rho \cdot D \cdot \Delta\Omega \cdot \Delta E \cdot \epsilon_{tot}} \tag{1}$$

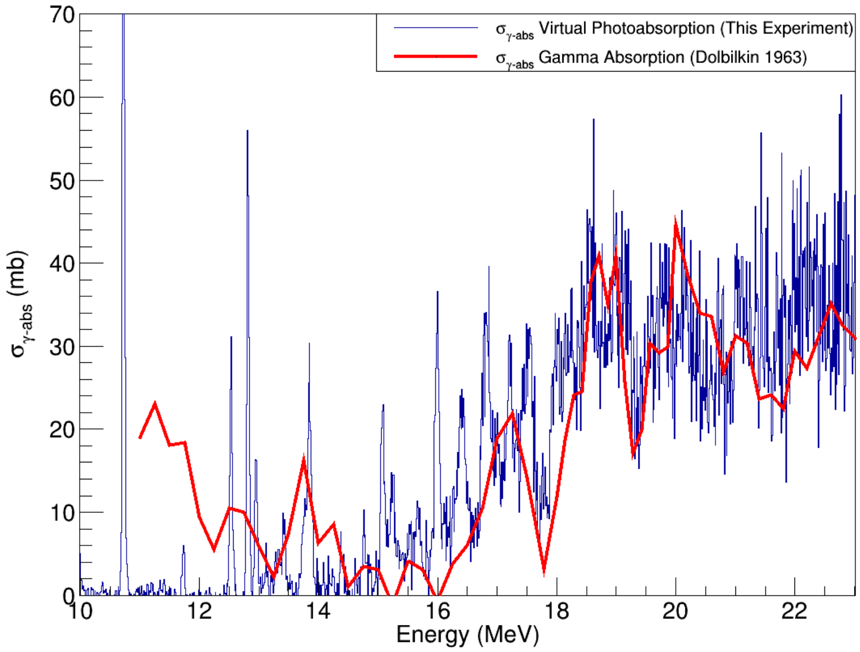

Figure 2. The virtual photon method is shown to accurately reproduce the spectrum obtained from real photon absorption.

and the total photoabsorption cross section, $\sigma_{\gamma}^{\pi\lambda}$, is calculated from the differential cross section, $\frac{d^2\sigma}{d\Omega d\sigma}$, using the number of E1 virtual photons per steradian, $\frac{dN_{E1}}{d\Omega}$:

$$\frac{d^2\sigma}{d\Omega dE_{\gamma}} = \frac{1}{E_{\gamma}} \frac{dN_{E1}\sigma_{\gamma}^{\pi\lambda}}{d\Omega}(E_{\gamma}). \tag{2}$$

The virtual photon absorption cross section from Eq. 2 reproduced the results obtained by real photon scattering quite effectively in the region of the IVGDR as seen in Fig.2 [5]. However, it is important to note that there remains a component of quasi-free background scattering as well as an unaccounted M1 contribution. Estimating these contributions accurately proves challenging without higher excitation energy and angle data..

Acknowledgments

This work is based on the research supported in part by the National Research Foundation (NRF) of South Africa grant number 118846.

References

[1] Boncioli *et al*, 2017 *Nuclear Physics Meets the Sources of the Ultra-High Energy Cosmic Rays.*Sci Rep **7**,4882.
[2] Neveling, R,*et al*, 2011 "High energy-resolution zero-degree facility for light-ion scattering and reactions at iThemba LABS."*Nuclear Instruments and Methods in Physics Research Section A* 654.1 : 29-39.
[3] Bertulani C A 2009, Theory and Applications of Coulomb Excitation. 2009, **0908.4307**, *arXiv.*
[4] von Neumann-Cosel P, Tamii, 2019 A Electric and magnetic dipole modes in high-resolution inelastic proton scattering at 0°. *Eur. Phys. J. A 55*, **110**
[5] Dolbilkin B S, 1966 "Gamma-ray absorption of ^{19}F,^{24}Mg, and ^{40}Ca in the 10-30 MeV region." *In:Izv. Akad. Nauk SSSR, Ser. Fiz.*, **30**: 349-58.