MEASUREMENTS OF ABSOLUTE γ-RAY CROSS SECTIONS FOR $^{16}O(p,p'\gamma)^{16}O$ REACTION*

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We report on the results of our measurements of γ-ray cross sections from the inelastic scattering of protons from ^{16}O in the energy range of 8–16 MeV. The absolute cross sections were measured for the γ-rays of energy 6.13, 6.92, and 7.12 MeV. Angular distribution was measured at seven angles at a proton beam energy of 9 MeV. This work reports on the first measurement of absolute cross section for 6.92 MeV γ-ray in this energy region. Such cross-section measurements provide important data for γ-ray astronomy and material analysis techniques. A phenomenological optical model potential (OMP) was set up to analyse the results of our measurements. Such OMP calculations have challenged theorists in this target mass and projectile-energy range. The challenge stems from the increased contribution of nuclear structure effects for low-mass target nuclei. We have tried to tackle this problem by including many low-energy resonances and target deformation effects. We optimised the OMP parameters by fitting a large body of available experimental data. The target deformation parameter plays a crucial role in understanding the overall dynamics of the reaction.

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1. Introduction

Study of the interaction of protons, neutrons, and α-particles with target nuclei reveals important information about the nuclear potential. Such studies are usually carried out by analysing the experimental data with Optical Model Potential (OMP) calculations. However, the low-mass target systems challenge theorists as the nuclear structure effects become dominant at projectile energy < 30 MeV. The assumption of an average potential is not accurate enough in this case. This makes the study of the interaction of low-energy protons with low-mass target nuclei such as ^{12}C, ^{16}O, *etc.*, an exciting endeavour.

Moreover, the cross-section data of production of γ-rays from such light nuclei are useful for γ-ray astronomy for the determination of the isotopic abundance of elements [1] and material surface composition analysis techniques such as Particle Induced Gamma Emission (PIGE) [2].

A thorough review of literature revealed that only three studies have been performed to measure the cross section of γ-rays from ^{16}O bombarded with protons of energy 8 to 16 MeV. Dyer *et al.* [3] reported an absolute cross section for 6.13 MeV γ-ray only. Kiener *et al.* [4] reported cross sections for 6.13, 6.92, and 7.12 MeV γ-rays. However, the cross sections were normalized to Dyer *et al.* [3], Boromiza *et al.* [5] reported absolute cross sections for 6.13 and 7.12 MeV γ-rays. However, their target thickness was large, leading to high uncertainty in beam interaction energy. This is undesirable for studying low-energy resonances.

To study the nuclear structure effects and motivated by the lack of experimental data, our group has performed $(p, p'\gamma)$ reactions with ^{12}C and ^{16}O. The results of the $^{12}\mathrm{C}(p, p'\gamma)^{12}\mathrm{C}$ reaction have been presented in the last edition of the Zakopane conference held in 2018 [6]. The present work reports on the results of $^{16}\mathrm{O}(p, p'\gamma)^{16}\mathrm{O}$ reaction in the incident proton energy range from 8 to 16 MeV. The following sections describe the details of the experimental procedure and the theoretical analysis carried out to understand the interaction of proton with ^{16}O.

2. Experimental details

The experiment was performed at the TIFR-BARC Pelletron facility in Mumbai, India. A self-supporting Mylar target of thickness of 2.2 mg cm^{-2} was bombarded with protons of energy from 8 to 16 MeV. The γ-rays thus produced were detected by a large volume $3.5'' \times 6''$ cylindrical $\mathrm{LaBr_3}$:Ce detector. The proton beam was stopped by a Faraday cup, and the total charge was measured using a beam current integrator. The timing and energy signals were processed using standard NIM electronics. The differential cross section was measured at seven angles for 9 MeV incident proton energy. The data were acquired for 15 proton energies from 8 to 16 MeV.

3. Theoretical analysis

An Optical Model Potential (OMP) analysis starts with finalising the form of the optical potential. We have used the form of OMP as described in Ref. [7]. We have included many resonances in the central potential amplitude for the low-energy region. Several low-lying states of the ^{16}O nucleus were coupled, and target deformation was incorporated to generate a realistic model of the potential. The next step is the optimisation of OMP parameters by fitting the experimental data. We have optimised the parameters by fitting the elastic scattering, analysing power and total reaction cross-section data. The corresponding fits are presented in Fig. 1. After optimising the OMP parameters, the γ-ray cross section was calculated.

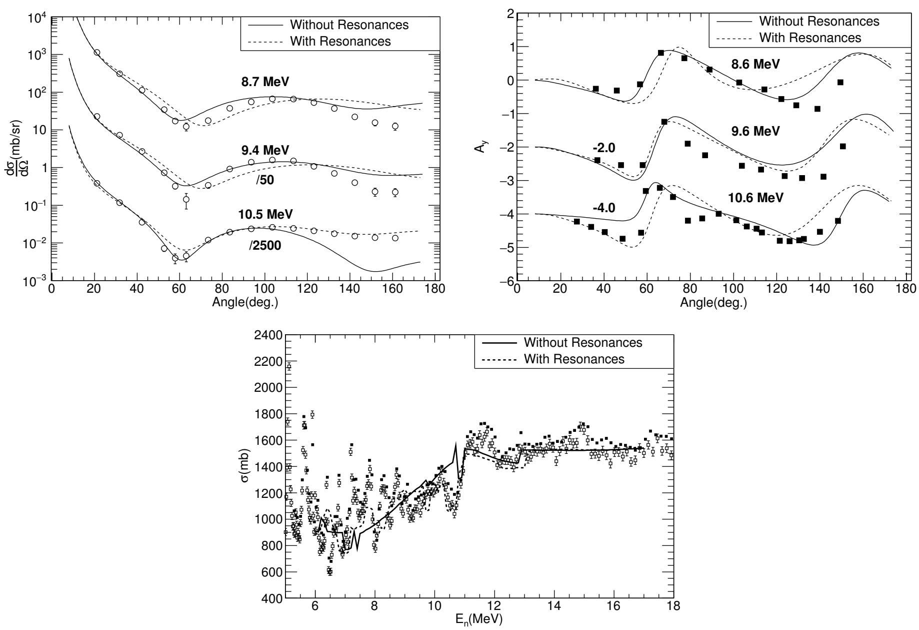

Fig. 1. Fits to proton elastic scattering, analysing power (A_y) angular distributions, and neutron total reaction data.

4. Results and discussion

Figure 2 presents the angular distribution of 6.13, 6.92, and 7.12 MeV γ-rays for 9 MeV proton energy. The distribution has been fitted with a series of Legendre polynomials to calculate the total cross section of γ-rays. Figure 3 presents the total cross section of 6.13, 6.92, and 7.12 MeV γ-rays. The measurements reveal many resonances in the low-energy region. Figure 3 also presents the results of the comprehensive OMP calculations for

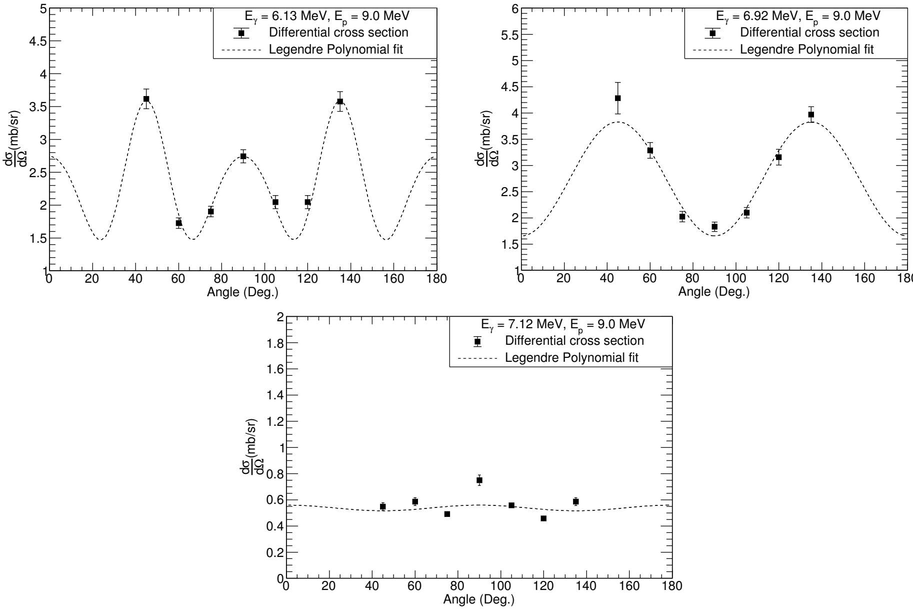

Fig. 2. Differential cross section of 6.13, 6.92, and 7.12 MeV γ-rays.

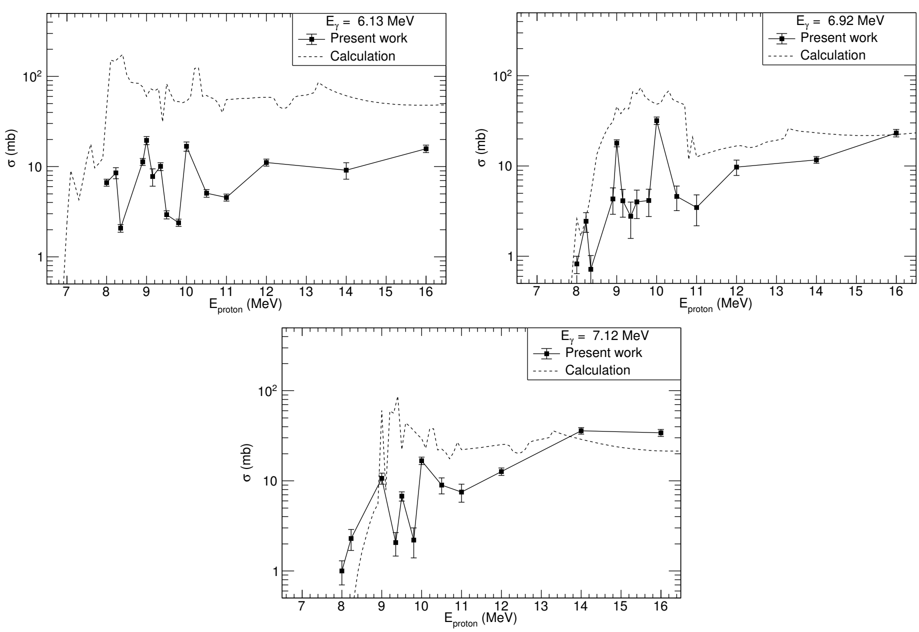

Fig. 3. Calculated $(p, p'\gamma)$ cross section of 6.13, 6.92, and 7.12 MeV γ-rays and our measured cross sections.

6.13, 6.92, and 7.12 MeV γ-rays. A reasonably good agreement exists between our calculations and our measurements for 6.92 and 7.12 MeV γ-rays. However, for 6.13 MeV γ-rays, there is a significant deviation from the calculations. Preliminary analysis shows that the deformation parameter is crucial in calculating γ-ray cross section. Further analysis is in progress to understand the role of the deformation parameter.

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REFERENCES

[1] R. Ramaty *et al.*, *Astrophys. J. Suppl.* **40**, 487 (1979).

[2] P. Dimitriou *et al.*, *Nucl. Instrum. Methods Phys. Res. B* **371**, 33 (2016).

[3] P. Dyer *et al.*, *Phys. Rev. C* **23**, 1865 (1981).

[4] J. Kiener *et al.*, *Phys. Rev. C* **58**, 2174 (1998).

[5] M. Boromiza *et al.*, *Phys. Rev. C* **101**, 024604 (2020).

[6] I. Mazumdar *et al.*, *Acta Phys. Pol. B* **50**, 377 (2019).

[7] S.P. Weppner *et al.*, *Phys. Rev. C* **80**, 034608 (2009).