EXPERIMENT PROPOSAL

Proton inelastic cross sections of $^{24}$Mg

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Scientific motivation

Magnesium has three stable isotopes: $^{24}$Mg (78.99%), $^{25}$Mg (10.00%) and $^{26}$Mg (11.01%) [1], with $^{24}$Mg being the most abundant. Magnesium represents a major ingredient of alloy steel which constitutes a common structural material in the design of nuclear reactors. Also, in the framework of the EUROTRANS project, CERCER (an alloy of a ceramic magnesia (MgO) matrix with incorporated mixed actinide dioxide fuel particles containing minor actinides – MAs) was chosen as one of the most feasible candidates for composite fuel systems used for transmutation of MAs in the European Facility for Industrial Transmutation (EFIT) [2].

In this context, a good knowledge of the neutron-induced reactions on $^{24}$Mg becomes mandatory for the design of the generation IV reactors. Our group already measured the neutron inelastic cross sections on $^{24}$Mg using the GELINA facility of EC-JRC, Geel and the GAINS spectrometer [3]. We were able to construct the excitation functions for several $\gamma$ rays [4].

Through the present proposal we aim at the measurement of the proton-induced reactions on $^{24}$Mg.

The main motivation is to compare the proton inelastic scattering cross sections with the neutron ones, already determined in Ref. [4]. The present proposal is a continuation of our previous work. We performed several previous experiments on $^{16}$O, $^{28}$Si [5,6] and $^{57}$Fe within the CHANDA project [7], using charged particle beams. In the case of the present experiment we wish to compare the $^{24}$Mg(n, n$'$$\gamma$)$^{24}$Mg and $^{24}$Mg(p, p$'$$\gamma$)$^{24}$Mg reaction cross sections in order to determine if and to which extent one can use charged particle cross sections to infer the neutron corresponding ones. By choosing an N=Z target, this investigation makes use of the isospin symmetry manifestation in the two mirror compound nuclei through which the two reactions proceed: $^{25}$Mg and $^{25}$Al, respectively. This symmetry induces very similar (low- excitation energy) level schemes for the two mirror nuclei from above. This could generate similar shapes and/or proportional inelastic cross sections in the proton and neutron
cases (see also Figure 2). For neutron-induced reactions only the nuclear interaction plays a role while for the proton ones there is also the possibility of Coulomb excitations; considering the low Coulomb barrier (i.e. 1.99 MeV) for the proposed reaction, these are expected to play a limited role.

The second goal is to provide relatively precise and reliable experimental data on the proposed reaction, which is scarce. There is a single data set of angle integrated $\gamma$ production cross sections for several $^{24}$Mg transitions [8], but only at 5, 10, 15 and 20 MeV proton beam energies (see Figure 1 for the first $^{24}$Mg transition). In the proposed experiment we intend to construct the excitations functions for all the observed $^{24}$Mg $\gamma$ rays in the entire 4-17 MeV incident proton energy range. Hence, we will start from just above the Coulomb barrier and we will use 1 MeV steps.

![Figure 1](image)

**Fig 1:** The angle integrated $\gamma$ production cross section of the first transition in $^{24}$Mg as given by Ref. [8]. The authors determined cross section points only at 5, 10, 15, 20 and 25 MeV incident proton energy (no uncertainties were reported).

**Experimental details**

The purpose of the experiment is to measure $\gamma$ production cross sections in $^{24}$Mg following the inelastic scattering of protons. For this we will employ a similar setup with the one used in the $^{16}$O(p, p$\gamma$)$^{16}$O experiment [6]. Two HPGe detectors with 100% relative efficiency will be placed at 110° and 150° relatively to the beam direction. The chosen angles will allow the extraction of angle integrated cross section values. For data normalization a Faraday cup, placed at the back of the reaction chamber, will be used.

Figure 2 displays an estimate of the cross sections for the most relevant reactions of interest, calculated using the TALYS 1.8 code [9]. The proton inelastic cross section dominates in the entire energy domain followed by (p,$\alpha$) and (p,n) contributions. A possible difficulty is related to the competing channel $^{24}$Mg(p, n)$^{24}$Al. $^{24}$Al decays into $^{24}$Mg ($T_{1/2} = 2.53$ s) and therefore the online peaks corresponding to $^{24}$Mg may be polluted through this process. However, considering that the (p,n) channel is very small we do not expect any significant parasite contribution to the $^{24}$Mg $\gamma$ production cross sections coming via the $\beta^+$ decay of $^{24}$Al. The (p,$\alpha$) channel produces $^{21}$Na which, via $\beta^+$ decay, goes with a 94.93%
intensity to the ground state of $^{21}$Ne (stable). The background generated by stopping the proton beam inside the Faraday cup will be handled by properly shielding the HPGe detectors using lead blocks. Hence, we expect a relatively clean spectra with no relevant contributions polluting the $\gamma$ peaks of interest.

The target nucleus is relatively light and its low lying excited levels have very short half-lives (in the $\text{fs}$ range). Therefore, another concern could be given by Doppler broadenings of the $^{24}\text{Mg}$ $\gamma$ peaks (especially at higher proton energies) which might complicate the $\gamma$ peaks integration procedure. Given our previous experience [6] we believe it can be properly handled by careful $\gamma$ peak integration.

![Fig. 2: Default TALYS 1.8 [9] calculations for neutron and proton induced reaction cross sections on $^{24}\text{Mg}$.](image)

**Beam time estimation**

We intend to measure the production cross section of the $^{24}\text{Mg}$ $\gamma$ rays at 1368.6, 2734.0, 4237.9, 3866.1, 4641.1 and 5063.3 keV and for proton energies in the $E_p = 4$-17 MeV range, in steps of 1 MeV (i.e. 14 points). According to TALYS 1.8 [9], the average proton inelastic $\gamma$ production cross section of the first $^{24}\text{Mg}$ transition (1368 keV) is around 350 mb. Considering an absolute HPGe detector efficiency of $\varepsilon=0.003$, a target with an areal density of $\rho_x=0.05 \text{ mg/cm}^2$, a beam intensity of 0.5-3 pnA and an acceptable amount of gathered statistics of 100,000 counts in the 1368 keV peak, the necessary beam time will be around 3-4 hours per proton energy.

Taking into account that an average measuring time of one shift is around 6-7 hours for each point (including the time required for changing the beam energy and the tuning of the beam), this adds up to 4-5 days of beam time. One or two additional shifts will be necessary for calibrations. We note that a dedicated efficiency calibration procedure will be necessary in order to extrapolate the detectors energy calibration at high gamma energies. In conclusion, we ask for 5 days of beam time.
References


