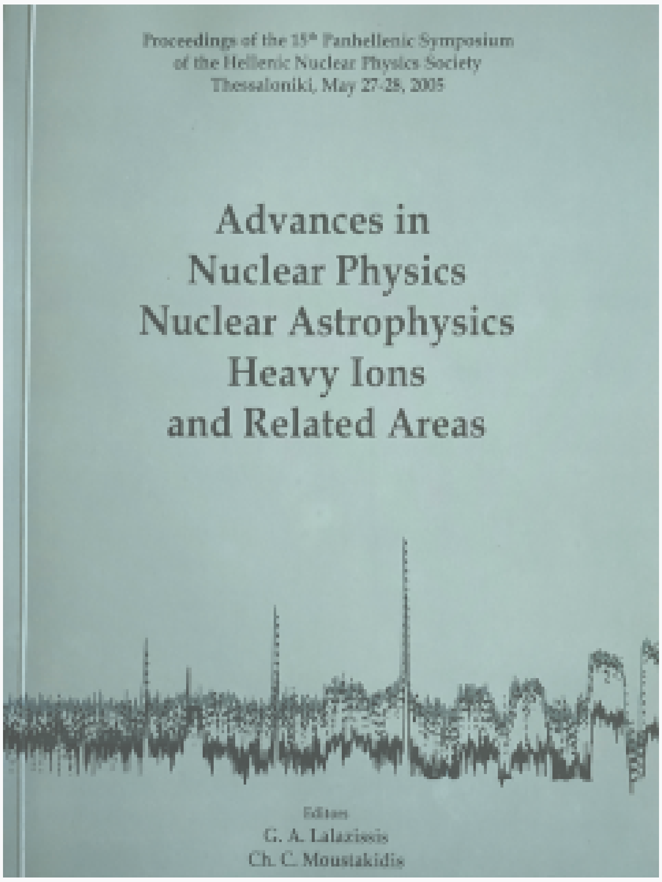
HNPS Advances in Nuclear Physics

Vol 14 (2005)

HNPS2005



Cross sections of deuteron-induced reactions on medium-mass nuclei

A. Lagoyannis, T. Konstantinopoulos, I. Yigitoglou, A. Spyrou, G. Perdikakis, Ch. Zarkadas, M. Kokkoris, P. Demetriou, S. Harissopulos

doi: [10.12681/hnps.2262](https://doi.org/10.12681/hnps.2262)

Cross sections of deuteron-induced reactions on medium-mass nuclei.

A. Lagoyannis [a], T. Konstantinopoulos [a,b], I. Yigitoglou [a,c], A. Spyrou [a], G. Perdikakis [a], Ch. Zarkadas [a], M. Kokkoris [b], P. Demetriou [a], and S. Harissopulos [a]

[a] *Tandem Accelerator Facility, Institute of Nuclear Physics, NCSR "Demokritos", 153.10 Aghia Paraskevi, Athens, Greece.*

[b] *National Technical University of Athens, Zografou Campus, 157.80 Athens, Greece.*

[c] *Faculty of Education, Istanbul University 34470, Beyazit/Istanbul, Turkey.*

Abstract

Cross section measurements of deuteron-induced reactions on Ni and Ge isotopes have been carried out at energies well below the Coulomb barrier. The preliminary results are compared with statistical model calculations.

1 Introduction

During the last five years an intense experimental effort has been devoted by the Nuclear Astrophysics of Group of "Demokritos", Athens, to the study of proton and alpha-particle capture reactions at energies well below the Coulomb barrier. These studies aim at establishing an extended cross-section database to be used for a reliability test of the models of the nuclear properties entering the Hauser-Feshbach calculations at low energies. These properties refer mainly to the nuclear level densities (NLD), the nucleon-nucleus and α-particle-nucleus optical model potentials (OMP). In continuation to the aforementioned research program, the group of "Demokritos" has recently focussed its activities on measurements of cross sections of deuteron-induced reactions. This paper reports on the first results of these measurements.

2 Experiments

The present measurements were carried out at the 5 MV TANDEM accelerator of NCSR "Demokritos", Athens, by means of the activation technique. Hereby, natural Ni and Ge targets were irradiated with deuterons with energies between 3 and 7 MeV. The beam current on target was varied between 0.2 μA at high energies and 1 μA at the lowest ones in order to keep the dead time, which was mainly due by the high flux of the produced neutrons, lower than 5%. In addition, the fluctuations of the deuteron beam was constantly monitored by means of a multiscaler. The XRF technique was employed to determine the thickness of all targets used. Hence, the Ni targets were 455 $\mu gr/cm^2$ thick, while the thickness of the Ge targets ranged from 280 to 300 $\mu gr/cm^2$. The Ni targets were self-supporting whereas the Ge targets were evaporated on thick Aluminum backings. A surface-barrier Si detector was mounted in the scattering chamber at an angle of 170° with respect to the beam direction. This way, any possible target deterioration effects could be checked by continously monitoring the yield of the Rutherford-backscattered beam particles. This check was performed during all irradiations and no significant material loss of the targets has been observed. The γ-activities induced by the deuteron reactions were measured off-line using a HPGe detector of 50% relative efficiency. Both the target and the detector were shielded with lead to reduce the background from the surrounding materials. The reactions studied in the present work together with the corresponding γ-rays observed off-line are listed in Table 1. A typical off-line spectrum measured at E_d=3 MeV for the d+^{nat}Ge reaction is shown in Fig. 1.

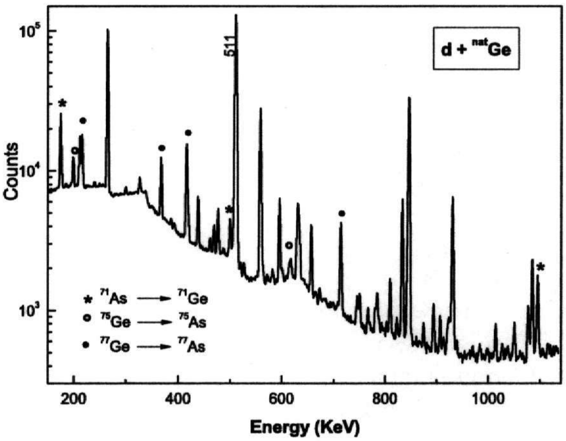


Fig. 1. Activation spectrum taken at E_d=3 MeV for the d+^{nat}Ge reaction.

Table 1
List of reactions studied in the present work.

Reaction	Half life	Abundance (%)	γ-rays (keV)
^{58}Ni(d,γ)^{60}Cu	23 min	68.08	1332
^{60}Ni(d,n)^{61}Cu	3.4 h	26.22	656, 1186
^{64}Ni(d,p)^{65}Ni	2.52 h	0.93	1482, 1115
^{70}Ge(d,n)^{71}As	65.28 h	21.23	175, 1095
^{74}Ge(d,p)^{75}Ge	83 min / 47 s	35.94	198, 618
^{76}Ge(d,p)^{77}Ge	11.3 h / 53 s	7.44	211, 416

3 Data Analysis

During the irradiation, the number of produced nuclei increases with a production rate of:

$$\frac{dN(t)}{dt} = P(t) - \lambda N(t) \tag{1}$$

where $P(t)$ is the production rate of the nuclei, while the second term $-\lambda N(t)$ corresponds to the decrease of their number. due to their subsequent decay. $P(t)$ depends on the cross section σ of the reaction, the flux $\Phi(t)$ of the incident partiles and the initial number N_0 of the target nuclei. Thus, Eq. (1) can be expressed as a function of the above mentioned parameters as:

$$\frac{dN(t)}{dt} = \sigma\Phi(t)N_0 - \lambda N(t) \tag{2}$$

The Eq. (2) can be analyticaly solved in the case of a stable beam flux. When the beam fluctuates, one has to select a properly short time interval Δt whithin which the beam flux can be considered as constant. The solution of Eq. (2) gives then the number of the nuclei produced after an irradiation time t_b:

$$N(t_b) = \sigma N_0 \frac{1 - e^{-\lambda\Delta t}}{\lambda} \sum_{i=1}^{n} \Phi_i e^{-(n-i)\lambda\Delta t} \tag{3}$$

After the irradiation, the $N(t_b)$ nuclei continue to decay with a constant rate. The number of the decaying nuclei is given by

$$N_M = N(t_b) e^{-\lambda t_w}(1 - e^{-\lambda t_m}) \tag{4}$$

where, t_w is the time intervall between the end of the irradiation and the beginning of the off-line activity measurement and t_m is the measurement time. The number of produced photons during the decay is given by

$$C_\gamma = N_M \varepsilon_\gamma I_\gamma K_\gamma \tag{5}$$

where ε_γ is the efficiency of the γ-detector used, I_γ is the branching ratio of the γ-transition of interest and K_γ is the correction factor for the self-absorption of the γ-rays into the target.

Finally, the number of decaying nuclei N_M from the latter equation is further entering Eq. (4) to derive $N(t_b)$, which is further used to obtain the cross section σ by

$$\sigma = \frac{C_\gamma \lambda}{\varepsilon_\gamma I_\gamma K_\gamma N_0 e^{-\lambda t_w}(1 - e^{-\lambda t_m})(1 - e^{-\lambda \Delta t}) \sum_{i=1}^{n} \Phi_i e^{-(n-i)\lambda \Delta t}} \tag{6}$$

More details about the analysis of the data taken in activation measurements are given in [1] and [2].

4 Results and Discussion

The preliminary data for some of the reactions studied in the present work are shown in Fig. 2 as solid circles. In addition, some previous results for the ^{58}Ni(d,γ)^{60}Cu and the ^{70}Ge(d,n)^{71}As reactions are also displayed as open circles. These have been taken from the EXFOR data library (in which ref. [4] is adopted) and from [3] respectively. The data are compared in this figure with different Hauser-Feshbach calculations (curves) performed with either the TALYS [5] or the EMPIRE [6] statistical model codes assuming various deuteron potentials. As can be seen in Fig. 2, theory and experiment agree fairly well for the (d,γ) and the (d,n) reactions. However, large deviations of the theoretical calculations from the data can be observed in the case of the (d,p) reactions. Similar findings apply also to the reactions not shown in this figure.

For the comparison of the calculations with the data, one has of course to take into account that reactions which have light complex particles in the entrance and/or exit channels have long been recognized as difficult to describe since they can involve different reaction mechanisms depending on the incident energy, such as direct nucleon transfer, knockout, inelastic processes involving cluster degrees of freedom, and projectile breakup. Although contributions from these processes are expected to become significant at incident energies

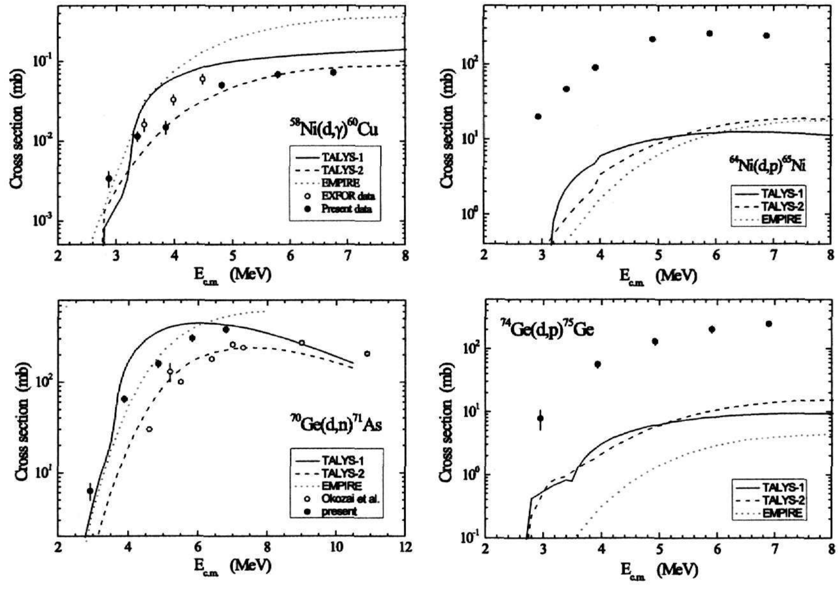


Fig. 2. Cross sections determined in the present work (solid circles) compared to statistical model calculations (curves). More details are given in the text.

above a few tens of MeV per nucleon, in the case of deuteron-induced reactions this is not so due to its small binding energy. Projectile break-up effects could therefore be important even at incident energies up to a few MeV per nucleon.

A comparison of the preliminary results for the deuteron-induced reaction cross sections measured here with model calculations based on the compound nucleus theory already indicate the possible influence of reaction mechanisms other than the well understood evaporation process. The agreement between theory and experiment observed for the (d,γ) reaction is in sharp contrast with the enormous difference, of almost one order of magnitude, obtained in the (d,p) reactions. Similar effects have also been reported in literature. In order to elucidate the origin of the observed discrepancies further measurements of (d,p) reactions are planned for the near future.

References

[1] S. Harissopulos, in *Nuclear Structure and Nuclear Astrophysics*, (Proc. 3rd Balkan School in Nuclear Physics, Sept. 18-24, 2002), edited by G. Lalazissis.

[2] T. Sauter and F. Käppler, Phys. Rev. C **55** 3127 (1997).

[3] K. Otozai et al., Nucl. Phys. A **107** 427 (1968).

[4] J. H. Carver and G. A. Jones, Nucl. Phys. **24** 607 (1961).

[5] A.J. Koning and S. Hilaire, Code TALYS, unpublished and P. Demetriou, private communication.

[6] M. Hermann, Empire-II Code, http://www-nds.iaea.org/empire/.