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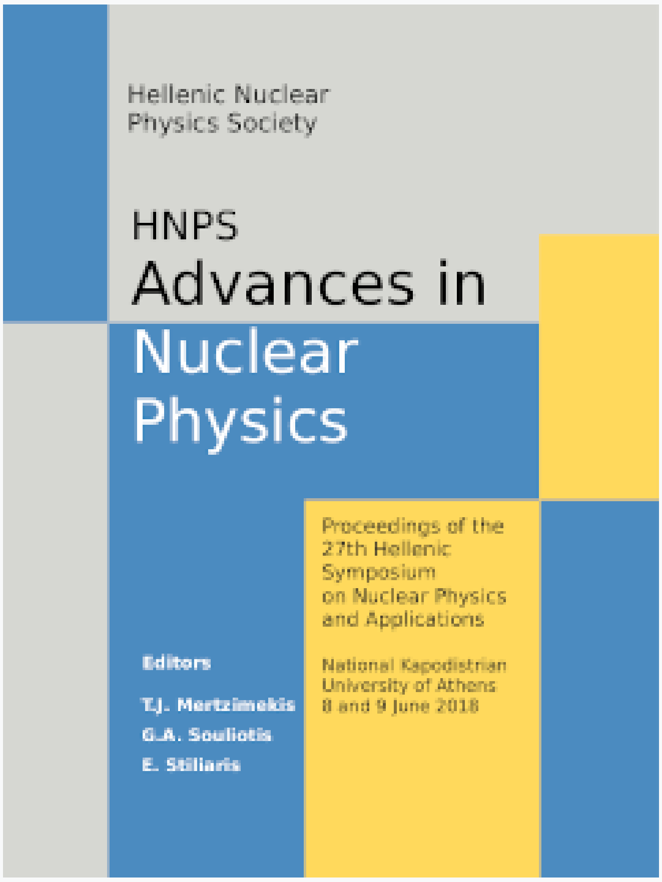

Cross section measurement of the 191Ir(n,2n)190Ir reaction

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Cross section measurement of the $^{191}Ir(n,2n)^{190}Ir$ reaction

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Abstract The cross section of the ^{191}Ir(n,2n) reaction was experimentally determined relative to the ^{27}Al(n,α)^{24}Na reference reaction one, for incident neutron beam energies ranging from 15.3 to 20.9 MeV, by means of the activation technique. The quasi-monoenergetic neutron beams were produced at the 5.5 MV Tandem Accelerator of NCSR "Demokritos" via the ^{3}H(d,n)^{4}He reaction. Following the irradiations the activity induced by the neutron beam at the targets and reference foils was measured by HPGe detectors. The cross sections for the population of the second isomeric state (m2) of ^{190}Ir and the sum of the ground and isomeric states (g+m1+0.086 m2) were independently determined. Additionally, theoretical calculations of the above cross sections were carried out using the EMPIRE code. The details of these calculations concerning the optical model parameters, are described in the present work.

Keywords neutron, Ir, cross section, EMPIRE

INTRODUCTION

Neutron induced reaction cross sections are of considerable importance for practical applications in nuclear technology, dosimetry, medicine and industry, as well as for fundamental research in Nuclear Physics and Astrophysics [1-3]. Moreover, cross section experimental data is necessary when the nuclear models need to be checked and their parameters to be accurately determined. Especially cross sections of isomeric states provide important supplementary information for the study of the compound nucleus de-excitation mechanism due to the fact that their population directly depends on the spin of the levels from which the isomeric states are fed and on the spin distribution in the continuum.

In the present work, the residual nucleus of the ^{191}Ir(n,2n) reaction, namely the ^{190}Ir one, was chosen to be studied, due to the fact that it can be formed in two levels which present large spin differences (its isomeric state m2 with $J^{\pi}=11^{-}$ and its ground state with $J^{\pi}=4^{-}$). The determination of the isomeric state cross section, regarding the theoretical study, is a powerful tool for obtaining information on the structure of the involved nuclei, while concerning experimental applications, it offers the possibility of an immediate and less time-consuming activation analysis. Therefore, the ^{191}Ir(n,2n) ^{190}Ir and ^{191}Ir(n,2n) ^{190}Ir^{m2} reaction cross sections were measured at incident neutron energies from 15.3 to 20.9 MeV, implementing the activation method and additional cross section theoretical calculations were performed by means of the EMPIRE 3.2.2 code [4,5].

EXPERIMENTAL CROSS SECTIONS

Six irradiations were performed at the 5.5 MV Tandem T11/25 Accelerator Laboratory of NCSR "Demokritos" with neutron beams produced via the $^{3}H(d, n)^{4}He$ reaction in the 15.3-20.9 MeV energy range. The total integrated neutron fluence over the irradiation time was determined by means of the $^{27}Al(n,\alpha)^{24}Na$ reference reaction. The study of the neutron energy spectra generated by deuterons on the Ti-T target was carried out using the NeuSDesc [6] and MCNP5 [7] codes.

Following the irradiations, the induced activity on both target and reference foils was measured by using HPGe detectors. The population of the second isomeric state ($J^{\pi}=11^{-}$), which decays with a half-life of 3.087 h, was measured through two γ-rays of 616.5 and 502.5 keV, while the corresponding measurements began ~1 h after the end of the irradiation and lasted for up to 15 h. Due to the fact that the first isomeric state ($J^{\pi}=1^{-}$) decays with a half-life of 1.120 h (relatively quickly), the measurements of the decay of the ground state ($J^{\pi}=4^{-}$) through the 518.6, 558.0, 569.3 keV γ-rays contains the population of both the ground (g) and the first isomeric state (m1). This measurement was carried out ~2 d after the irradiation to ensure that the second isomeric state (m2) had fully decayed to the ground state (g). More details of the experimental technique are described in the recently published article by A. Kalamara et al. [8] and in the work by Patronis et al. [9]. The former is referred to the present work (special details which have not been published will be given in the cross section theoretical calculations section), while the latter presents the measurements of the $^{190}Ir(n,2n)^{190}Ir$ reaction cross section carried out by our group in the energy range 10.0-11.3 MeV implementing the $^{2}H(d,n)$ reaction.

The experimental results of the present work are shown in Figs. 1(a) and 1(b).

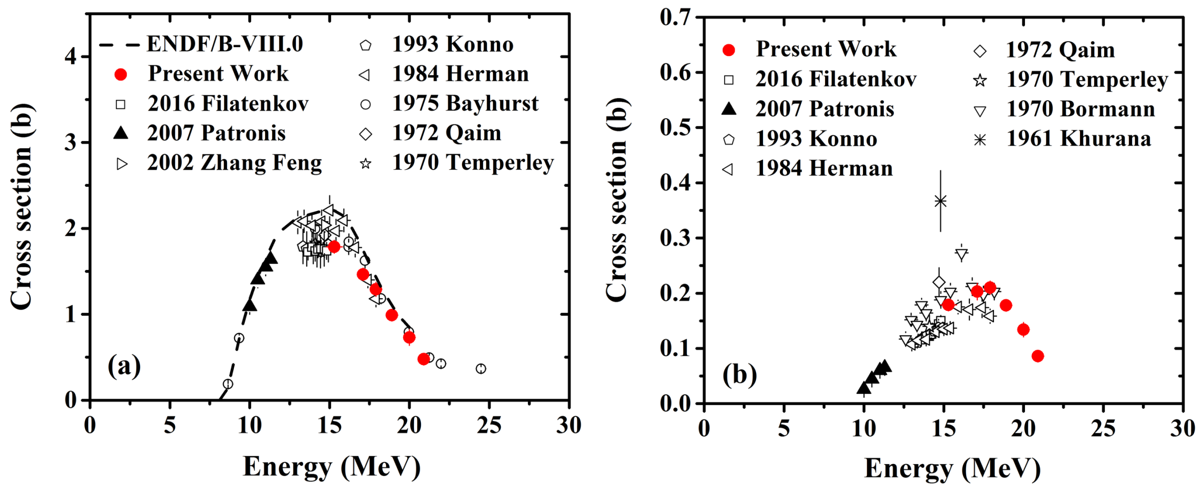

Fig. 1: Experimental results of the present work for the (a) $^{191}Ir(n,2n)190Ir^{g+m1+0.086m2}$ and (b) $^{191}Ir(n,2n)190Ir^{m2}$ reaction channels, along with previously existing data in literature [10] and ENDF/B-VIII.0 [11] evaluation (dashed curve), when is available.

CROSS SECTION THEORETICAL CALCULATIONS

Cross section theoretical calculations were performed for the two measured reaction channels, namely the $^{191}Ir(n,2n)^{190}Ir^{g+m1+0.086m2}$ and $^{191}Ir(n,2n)^{190}Ir^{m2}$ ones, by means of the EMPIRE 3.2.2 code [4,5] for incident neutron energies from threshold up to 35 MeV.

The compound nucleus reaction cross sections were calculated in the framework of the Hauser-Feshbach theory [12], while the nuclear level densities were described according to the Enhanced Generalized Superfluid Model (EGSM) [13] (LEVDEN 0). Morever, the transmission coefficients were calculated by implementing optical model routines via the ECIS06 code [14,15]. Regarding direct reaction channels, spherical optical model calculations were performed (DIRECT 0), whereas in order to account for the correlation between the incident and exit channels in elastic scattering, width fluctuation corrections were activated implementing the model of Hofmann, Richert, Tepel and Weidenmuller [16] up to an incident neutron energy of 3 MeV (HRTW 3). γ-emission was described by using modified Lorentzian (MLO1) γ-strength functions by Plujko [17], with parameters available in RIPL-3 [18]. The optical model parameters for the outgoing protons and α-particles were adopted by Koning et al. [19] and Avrigeanu et al. [20], respectively.

In order to choose from RIPL-3 the most appropriate neutron optical model potential, all the available ones were tested (see Table 1).

Table 1: The optical model potentials, available in RIPL-3 [18] that were tested in the present work.

Code in RIPL-3	Z Range	A Range	E(MeV)	Reference
100	20 - 92	40 - 238	10.0 - 50.0	[21]
101	12 - 83	24 - 209	11.0 - 11.0	[22]
401	20 - 92	40 - 238	0.0 - 25.0	[23]
430	13 - 82	27 - 208	0.1 - 24.0	[24]
2001	6 - 82	12 - 208	50.0 - 400.0	[25]
2011	77 - 77	191 - 191	0.0 - 20.0	[26]
2100	20 – 83	40 - 209	10.0 - 26.0	[27]
2101	26 - 82	54 – 208	10.0 - 80.0	[28]
2405	13 - 83	27 - 209	0.0 - 200.0	[29]
2407	27 - 83	59 - 209	0.0 - 200.0	[30]
2411	13 - 83	27 - 209	0.0 - 200.0	[31]

The EMPIRE results for each neutron optical model potential are presented in Figs. 2(a), 2(b), 3(a) and 3(b) for each reaction channel. It seems that the best reproduction of both reaction channels is achieved by using the parameters of D. Wilmore et al. (code 401 in RIPL-3) [23], theferore the optical model potential of the latter was chosen for the final results presented in Ref. [8]. The critical differences among the results of the various optical models in RIPL-3, are focused mainly in the energy region where the two reaction channels present their maximum (~15-17 MeV). In this region of the cross section plateau, the experimental data available in literature show up high discrepancies, thus most of the optical models in Table 1 produce reasonable results in comparison with the data. The new high energy measurements of the present work [8], considerably reduce the experimental uncertainties and restrict the large number of possible optical models to the one that reproduces in the most reliable way the experimental data. Furthermore, in all the aforementioned tests, the pre-equilibrium emission mechanism was described by means of the classical exciton model [24], through the PCROSS module [4] (PCROSS 2.2). This pre-equilibrium mechanism becomes very important in the high energy region, above 17 MeV, where the data of this work [8] provide significant experimental information.

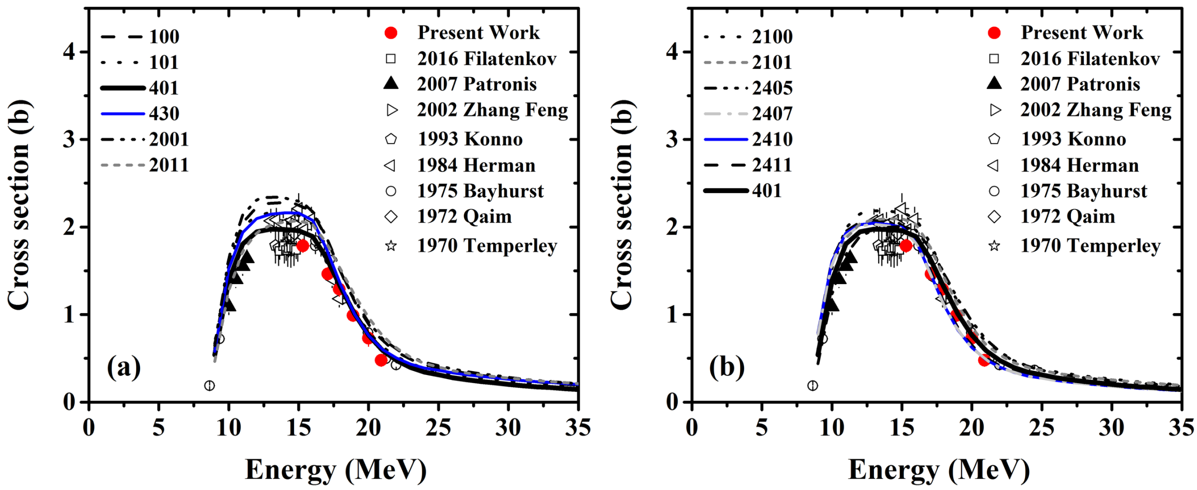

Fig. 2: Experimental results of the present work along with existing data in literature [10] and theoretical calculations results with EMPIRE 3.2.2 [4,5] for the ^{191}Ir(n,2n)190Ir$^{g+m1+0.086m2}$ reaction and for every optical model potential presented in Table 1.

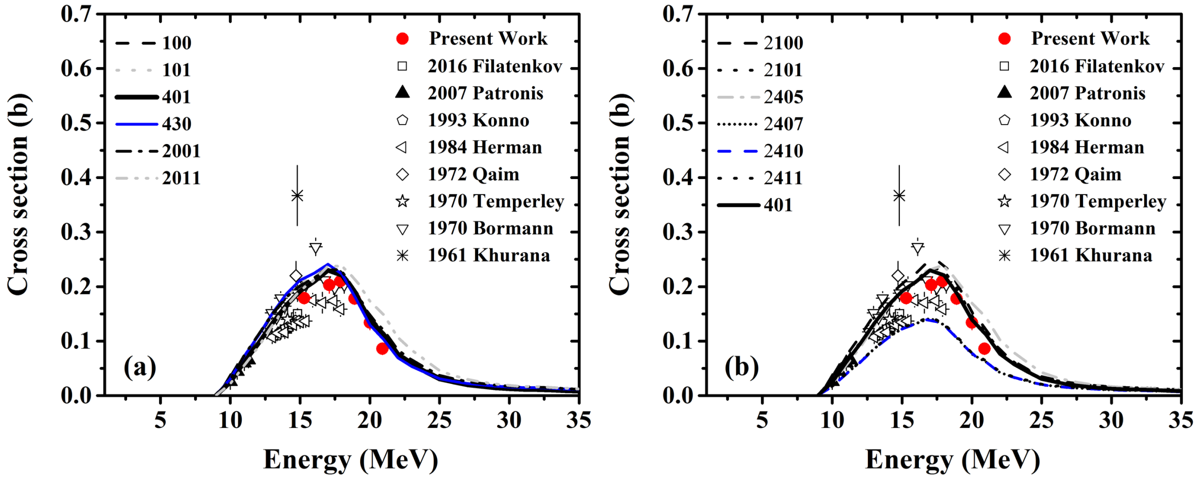

Fig. 3: Experimental results of the present work along with existing data in literature [10] and theoretical calculations results with EMPIRE 3.2.2 [4,5] for the ^{191}Ir(n,2n)190Ir^{m2} reaction and for every optical model potential presented in Table 1.

SUMMARY AND CONCLUSIONS

The ^{191}Ir(n,2n)^{190}Ir$^{g+m1+0.086m2}$ and ^{191}Ir(n,2n)^{190}Ir^{m2} reaction cross sections were measured at the 5.5 MV Tandem Accelerator of NCSR "Demokritos" for incident neutron beam energies ranging from 15.3 to 20.9 MeV. The measurements were performed by means of the activation technique, relative to the $^{27}Al(n,\alpha)^{24}Na$ reference reaction. Additionally, cross section theoretical calculations were carried out using the EMPIRE 3.2.2 code. Several tests on the input parameterization were made and the ones that gave the best simultaneous reproduction for both measured reaction channels were the optical model parameters by D. Wilmore et al. [23].

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