Indian Journal of Pure & Applied Physics
Vol. 58, April 2020, pp. 314-318

Excitation functions of (n,p) and (n,2n) reactions of tantalum, rhenium, and iridium in the neutron energy range up to 20 MeV

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Received 17 February 2020

The excitation functions for (n,p) and (n,2n) reactions up to 20 MeV on Tantalum, Rhenium, and Iridium have been calculated using the TALYS-1.9 nuclear reaction model code. Different level density models have been used to get a good agreement between the calculated and measured data. In the present work, we have carried out the TALYS-1.9 calculations to quantitatively understand the experimental data by optimizing input parameters for ^{181}Ta(n,p)^{181}Hf, ^{181}Ta(n,2n)^{180}Ta, ^{185}Re(n,p)^{185m}W, ^{185}Re(n,2n)^{184}Re, ^{191}Ir(n,p)^{191}Os and ^{191}Ir(n,2n)^{190}Ir. Theoretical results have been compared with the experimental data (taken from the EXFOR database) up to 20 MeV. Also, the results have been compared with the ENDF/B-VIII.0 and TENDL-2015 evaluated data.

Keywords: Excitation function, Nuclear reaction, TALYS-1.9, EXFOR (n,p) and (n, 2n) Cross section.

1 Introduction

Precise knowledge of neutron-induced reaction cross-section is of interest to many fields of nuclear science. The neutron cross-sections up to 20 MeV are important from the view point of fusion reactor technology and radiation damage to the materials used in the construction of the core and inner walls of the reactor. The important applications concern reactor materials, environment and space dosimetry, specimen analysis, isotope production. In the present paper, the results of nuclear reaction measurement for tantalum, rhenium, and iridium are considered. Tantalum is a high-temperature and heavy metal and it is mono-isotopic (99.988%, ^{181}Ta), ^{181}Ta is one of the important structure material nuclei in the nuclear reactor systems of fission or fusion and has a potential for application in a diversity of nuclear efforts. In these applications, the accurate nuclear data for neutron-induced reaction on ^{181}Ta are needed in the calculation of neutron and energy balance and the prediction of transmutation rates of the various radioactive species. There is also a reason to believe that useful information about their structure and property can be obtained from the systematic analysis for n+^{181}Ta reaction[1]. Elemental rhenium consists of a pair of stable isotopes, ^{185}Re (37.4%) and ^{187}Re (62.6%). The metal is a high-temperature corrosion-resistant material. Therefore, it first found applications in jet-engines for the airplane industry and special uses, such as in nuclear power sources for space applications[2]. Iridium (Ir) isotopes are used in a variety of medical and industrial applications, ranging from cancer treatment to activation detectors used to probe the energy spectrum of neutron fluence.

The aim of the present study is to investigate the cross-sections of ^{181}Ta(n,p)^{181}Hf, ^{181}Ta(n,2n)^{180}Ta, ^{185}Re(n,p)^{185m}W, ^{185}Re(n,2n)^{184}Re, ^{191}Ir(n,p)^{191}Os and ^{191}Ir(n,2n)^{190}Ir reactions induced by neutron using the TALYS-1.9 and the EXFOR database. The results of theoretical excitation function have been compared with the available experimental data taken from the EXFOR database[3], and ENDF/B-VIII.0 and TENDL-2015 evaluated nuclear data.

2 Theoretical Background

The different nuclear reaction channels occur with different probabilities. The reaction probability is expressed in terms of a quantity called nuclear cross-section. The shapes of nuclear cross-sections can be predicted using nuclear reaction model codes. These models are needed to obtain the excitation functions. One of the important inputs for reaction cross-section calculation is the nuclear level density. The level density is the number of nuclear-excited levels around the excitation energy. The nuclear-excited levels at low excitation energies are discrete, however they appear to represent a continuum with increasing excitation energy[4]. The nuclear level density models are necessary to explain the excitation function of reactions[5, 6].

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3 Nuclear Reaction Model Calculations

TALYS-1.9

TALYS-1.9[7] is a computer code system for the analysis and prediction of nuclear reactions. The main purpose of the TALYS is the simulation of nuclear reactions that involve neutrons, photons, protons, deuterons, tritons, ^{3}He- and alpha-particles as the projectile on the target nuclei for incident energies 1 keV-200 MeV. This code takes in to account difffernt reaction mechanisms like the compound, pre-equilibrium and direct reactions as the function of the incident particle energy. The code uses the Hauser-Feshbach model[8] to unified the effects of the compound nucleus reaction mechanism. The pre-equilibrium contributions has been included using exciton model, which was developed by Kalbach[9]. The optical model parameters were obtained by using a global potential, which is proposed by Koning and Delaroche[10]. The TALYS-1.9 code uses the reaction parameters from the Reference Input Parameter Library (RIPL) database[11]. The TALYS-1.9 code includes all the possible outgoing reaction channels for a chosen projectile + target system. In the present study, six-level density models (ldmodels) are included in the model code for the reproduction of the nuclear reaction cross-sections. The different level densities in the TALYS code (ldmodel 1-6) account for 1) the constant temperature Fermi gas model (CTFGM)[12]; 2)back-shifted Fermi gas model (BSFGM)[13]; 3) generalised super-fluid model (GSM)[14,15]; 4) – 5) microscopic level densities from Goriely's and Hilaire's tables[16]; and 6)microscopic level densities (temperature-dependent HFB, Gogny force)[17] respectively. Each ldmodel was used and tested for a better description of the measured results. A comparison of the TALYS-1.9 code predictions with the present calculations and the experimental data in the figures for ^{181}Ta(n,p)^{181}Hf, ^{181}Ta(n,2n)^{180}Ta, ^{185}Re(n,p)^{185m}W, ^{185}Re(n,2n)^{184}Re, ^{191}Ir(n,p)^{191}Os and ^{191}Ir(n,2n)^{190}Ir .

4 Results

In the present study, the excitation functions of (n,p) and (n,2n) reactions for ^{181}Ta (n,p) ^{181}Hf, ^{181}Ta(n,2n)^{180}Ta, ^{185}Re(n,p) ^{185m}W, ^{185}Re(n,2n)^{184}Re, ^{191}Ir(n,p)^{191}Os and ^{191}Ir(n,2n)^{190}Ir have been calculated with different level density models up to 20 MeV incident neutron energy. The results obtained by model calculations are compared with EXFOR as shown in Figs 1- 6.

4.1 Excitation functions of ^{181}Ta(n,p)^{181}Hf reaction

The cross-sections of the ^{181}Ta(n,p)^{181}Hf nuclear reaction are shown in Fig.1 for the incident neutron energies up to 20 MeV. It may be pointed out that the excitation functions calculated by ldmodel 2 and ldmodel 3 are at higher energies than those of ldmodel1,ldmodel 4, ldmodel 5, ldmodel 6, ENDF/B-VIII.0 and the data of V. Semkova[18], Junhua Luo[19], A A Filatenkov[20], S V Begun[21], Y Kasugai[22], Kong Xiang Zhong[23], Lu Han-Lin[24], R Woelfle[25], J S Brzosko[26], S K Mukherjee[27] and M Lindner[28] in the energy range 12-20 MeV. The excitation functions predicted using the ldmodel 1,ldmodel 4, ldmodel 5 and ldmodel 6, ENDF/B-VIII.0 with the data of V Semkova[18],Junhua Luo[19], A A Filatenkov[20], S V Begun[21], Y Kasugai[22], Kong Xiang Zhong[23], Lu Han-Lin[24], R Woelfle[25], J S Brzosko[26], S K Mukherjee[27] and M Lindner[28] in the energy range 12-20 MeV and also these experimental data show good agreement with the data of TENDL-2015 in the energy range 12.5-18 MeV. The excitation functions predicted using the ldmodel 1, ldmodel 4, ldmodel 5, ldmodel 6 and the data of J. S. Brzosko[26] are found to have a good agreement at the neutron energy13-15 MeV.

4.2 Excitation functions of ^{181}Ta(n,2n)^{180}Ta reaction

Figure 2 shows the theoretical and experimental data for the ^{181}Ta(n,2n)^{180}Ta nuclear reaction for the incident neutron energies up to 20 MeV. It may be noted that the excitation functions calculated from ldmodel 3 in the energy range 10-15 MeV show good agreement with the data of J. Frehaut[29] and also with

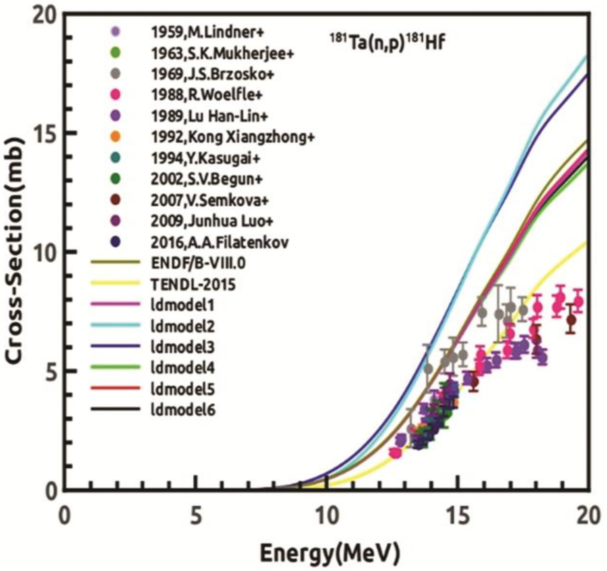

Fig. 1 — Excitation functions for ^{181}Ta(n,p)^{181}Hf nuclear reaction.

the data of L. Rosen[30] and A Takahashi[31] at the energy 14 MeV. But the data of V J Ashby[32] do not match with anyother data at 14 MeV. The excitation functions of TENDL-2015, ldmodel 1, ldmodel 2 and ldmodel 4 show good agreement with the data of L R Veeser[33] at 15 MeV and also with the excitation functions of ldmodel 5, ldmodel 6 and ENDF/B-VIII.0 in the energy range15-20 MeV.

4.3 Excitation functions of ^{185}Re(n,p)^{185m}W reaction

Figure 3 presents the theoretical excitation functions of ^{185}Re(n,p)^{185m}W nuclear reaction in comparison with experimental nuclear reaction data of Sakane[34] and ENDF/B-VIII.0 and TENDL-2015. for incident neutron energies up to 20 MeV. The excitation functions predicted using the ldmodel 1 and ldmodel 4 in the TALYS-1.9 code are found to have a good agreement with the cross-section data measured by Sakane[34] in the neutron energy range 13.5-15 MeV.

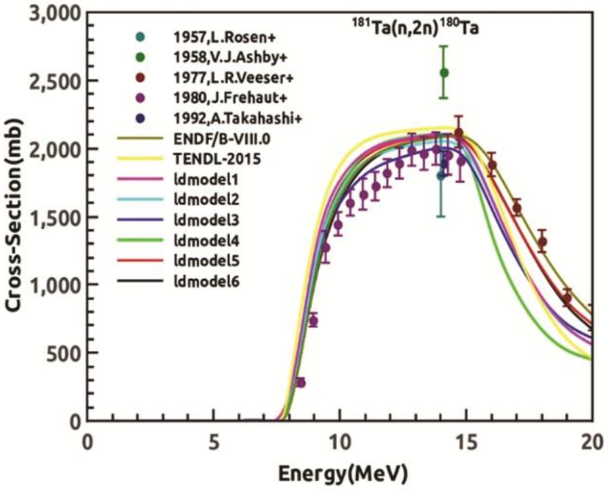

Fig. 2 — Excitation functions for ^{181}Ta(n,2n)^{180}Ta nuclear reaction.

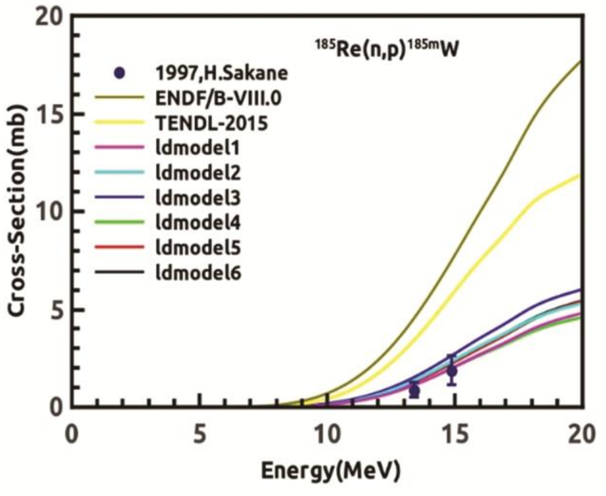

Fig. 3 — Excitation functions for ^{185}Re(n,p)^{185m}W nuclear reaction.

4.4 Excitation functions of ^{185}Re(n,2n)^{184}Re reaction

Comparison of the model-based excitation functions with the experimental data for ^{185}Re(n,2n)^{184}Re nuclear reaction is presented in Fig. 4 as a function of neutron energies up to 20 MeV. The excitation functions of ldmodel 3, ldmodel 6 and the excitation functions of ldmodel 1, ldmodel 2, ldmodel 5, ldmodel 6, ENDF/B-VIII.0 show good agreement with the data of B Kiraly[35] at the energy 11 MeV and 14.5 MeV respectively. The excitation functions of ldmodel 4 and TENDL-2015 data have better matching with the experimental data Chuanxin Zhu[36] in the energy range 13.5-15 MeV as well as the excitation functions of ldmodel 1, ldmodel 2, ldmodel 5 and ldmodel 6 show good agreement with the experimental data of Wang Xiuyuan[37]. But the acquired data from TALYS-1.9 concerning different level density models calculations are not matched the experimental data of A A Druzhinin[38] and A A Filatenkov[20].

4.5 Excitation functions of ^{191}Ir(n,p)^{191}Os reaction

The nuclear cross-sections for the ^{191}Ir(n,p)^{191}Os nuclear reaction in the present paper areshown in Fig. 5 for the incident neutron energies up to 20 MeV. It can be seen in Fig. 5 that the ENDF/B-VIII.0 excitation function shows good harmony with the experimental data of N I Molla[39] and A A Filatenkov[20].

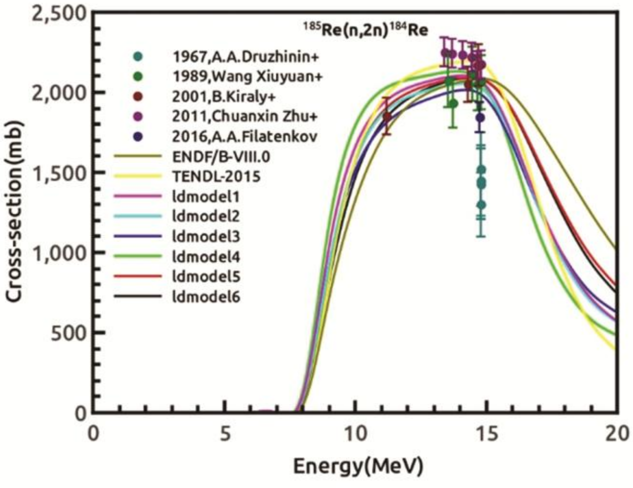

Fig. 4 — Excitation functions for ^{185}Re(n,2n)^{184}Re nuclear reaction.

The cross-sections of ldmodel 1, ldmodel 4 and ldmodel 5 are very close to the cross-sections of N I Molla[39] and A A Filatenkov[20] in the energy range 13.5-15 MeV but far from the cross-section data of ldmodel 2, ldmodel3 and ldmodel 6 and also from the data of TENDL-2015.

4.6 Excitation functions of ^{191}Ir(n,2n)^{190}Ir reaction

The calculated and measured cross-section data of the ^{191}Ir(n,2n)^{190}Ir nuclear reaction are shown in Fig.6. The excitation functions have a broad peak with a maximum value of about 2100 mb at neutron energy of 15.5 MeV. As can be seen in Fig.6, the experimental data obtained by A A Filatenkov[20] and C Konno[40] have lower cross-section values than different level density model calculations, ENDF/B-VIII.0, and TENDL-2015 database data, particularly in the incident energy range 12-15 MeV. However, the cross-section values measured by S M Qaim[41] at the incident energy 14 MeV are in good agreement with the cross-section results predicted using the ldmodel 3 and ldmodel 5 for this reaction.

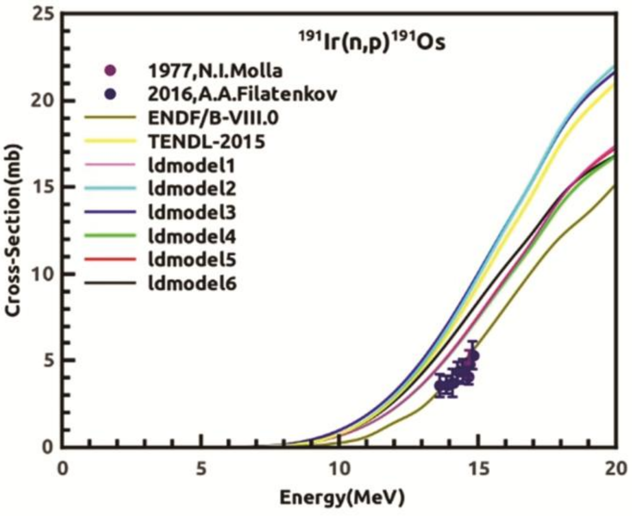

Fig. 5 — Excitation functions for ^{191}Ir(n,p)^{191}Os nuclear reaction.

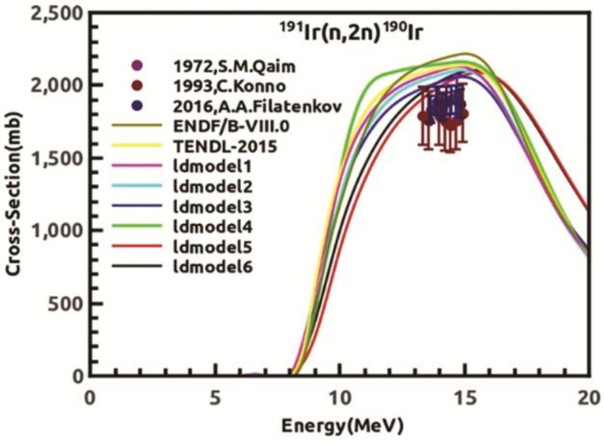

Fig. 6 — Excitation functions for ^{191}Ir(n,2n)^{190}Ir nuclear reaction.

5 Conclusions

In this work, we have calculated the excitation functions of nuclear reactions induced by neutrons on the ^{181}Ta, ^{185}Re, and ^{191}Ir nuclei in the neutron energy range up to 20 MeV using the nuclear model code TALYS-1.9. The effect of level density models on the theoretical excitation functions have been analyzed for the selected nuclear reactions. A good agreement have been obtained between the theoretical predictions and existing experimental data from EXFOR database. However, for the case of ^{185}Re(n,p$^{)185m}$Re, and ^{191}Ir(n,p)^{191}Os, there is very less number of experimental data exist to validate our theoretical results. To resolve these discrepancies, there is a need for more experimental measurement in defined energy range for these two reactions. From the obtained results, it can be concluded that the ldmodel 5and ldmodel 6 in TALYS-1.9 code are the best options for the prediction and simulation of (n,p) and (n,2n) reactions cross-section in this atomic mass region ~73-77.

Acknowledgement

One of the authors (A. Kumar) thanks to the DAE-BRNS, Government of India (Sanction No. 36(6)/14/23/2016-BRNS), SERB-DST, Government of India (Sanction No CRG/2019/000360) and UGC-DAE-CSR (Sanction No UGC-DAE-CSR-KC/CRS/19/NP03/0913) for the financial support for this work.

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