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Cascade-exciton model analysis of level density parameter dependence in proton induced fission cross sections of some sub-actinide nuclei

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Abstract: Fission cross sections strongly depend on the ratio of the level density parameter in fission to neutron emission, $a_\mathrm{f}/a_\mathrm{n}$. In this work, a cascade-exciton model implemented in the code CEM95 has been used to observe this effect for proton induced fission cross sections of tungsten, lead and bismuth. The method was employed using different level density parameter ratios for each fission cross section calculation. The calculated fission cross sections are compared with the available experimental data in the literature. It has been observed that a change of the ratio of the level density parameter, $a_\mathrm{f}/a_\mathrm{n}$, is necessary with the incident energy of the proton, to best estimate the fission cross sections in CEM95.

Key words: CEM95, fission cross sections, level density parameter

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1 Introduction

Nuclear fission is a complex and important nuclear reaction, as fission studies are used to understand the fundamentals of nuclear physics [1–4] and for current nuclear applications, like accelerator-driven systems (ADSs) [5]. Proton induced fission cross section data at intermediate and higher energies are an integral part of the design of ADSs [5], as a proton beam at higher energies will be used to derive and control the subcritical reactor in an ADS. Different models and computer codes are used to calculate the cross section data. This is necessary to compare the experimental data and to calculate the data for those nuclei for which no experimental data is available in the literature. Furthermore, because projectile beams are not common and are always weak in intensity, and the cost of experiments at accelerators is very high and beam time is limited, different models and computer codes are essential in basic and applied nuclear physics. One of the important parameters which is being used in different models and plays an important role in the calculation of fission cross sections is the ratio of the level density parameter $a_\mathrm{f}/a_\mathrm{n}$, where a_f is the level density parameter at the fission saddle point and a_n is the level density parameter after neutron emission. It is essential to select the best value of $a_\mathrm{f}/a_\mathrm{n}$, as fission cross sections are sensitive to this ratio [1, 6–8], and often problems are faced in choosing the best values for this ratio [9, 10]. The more accurate determination of this parameter, $a_\mathrm{f}/a_\mathrm{n}$, allows one to obtain more reliable fission cross sections [11].

In this work, calculations have been performed for proton induced fission cross sections of tungsten, lead and bismuth using the cascade-exciton model code CEM95 [12] and using different values of $a_\mathrm{f}/a_\mathrm{n}$. The calculations have been compared with the experimental data available in the literature. In the present model, it has been observed that different values of the ratio of level density parameter are necessary to best estimate the fission cross sections.

2 Simulation of fission cross sections

CEM95 computer code [12] has been used to com-

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[1)] E-mail: yasinzf@yahoo.com; zyasin@cern.ch pute the fission cross sections induced by protons. A cascade-exciton model of nuclear reactions [13] has been implemented in this code. We have already used this code in a new manner to compute fission cross sections induced by pions and nucleons [1–4]. In this work the same method is further elaborated. It is essential to select the proper value of a_f/a_n, as fission cross sections are sensitive to this ratio [1, 6, 8]. Iljinov et al. [14] have obtained the a_f/a_n values for zero energy pions (a_f/a_n=1.2) and energetic protons with the incident energies of 150 MeV (a_f/a_n=1.17), 660 MeV (a_f/a_n=1.06), and 1000 MeV (a_f/a_n=1.04) MeV from analysis of experimental fissilities. These values are always helpful to estimate the best value of a_f/a_n and this is done in the present study. The ratio a_f/a_n is selected semi-empirically with the help of values predicted by Iljinov et al.

3 Results and discussion

The computed proton induced fission cross sections of ^{182}W, ^{183}W, ^{184}W, ^{186}W, ^{206}Pb, ^{207}Pb, ^{208}Pb and ^{206}Pb are shown in Figs. 1, 2, 3, 4, 5, 6, 7, & 8 respectively along with the experimental data.

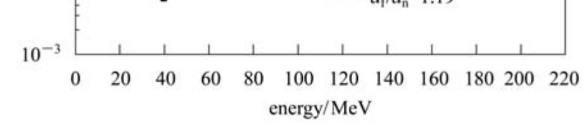

Fig. 1. Effect of the level density parameter ratio, a_f/a_n, on fission cross sections for proton induced in ^{182}W. The curves (solid, dashed, dotted and dash-dotted) represent the fission cross sections computed using CEM95 for different values of a_f/a_n. The solid squares are the experimental data from EXFOR [15]. The parameters IB and IBE are the macroscopic fission barriers and excitation energy dependence of fission barriers respectively (for details see text).

In Fig. 1 the lines (solid, dashed, dotted and dash-dotted) are the fission cross sections computed using CEM95 and the experimental data are represented by solid squares. At lower energies, up to 80 MeV, no value of a_f/a_n matches the experimental data, but above 80 MeV a value of 1.17 is in good agreement with experimental data. The curves indicate the sharply increasing trend of fission cross sections with the energy of the proton. The parameter IB in this figure is the choice of the model of macroscopic fission barriers to be used in the calculations and the value of IB equal to six represents the choice of Krape, Nix and Sierk's Yukawa-plus-exponential modified model for fission barriers. The parameter IBE in this figure is the choice of the excitation energy dependence of fission barriers to be used in the calculations, and the value of IBE equal to two represents the choice of excitation energy dependence of fission barriers proposed by Sauer Chandra and Mosel.

The computed fission cross sections of the ^{183}W (p, f) reaction are shown in Fig. 2 and compared to experimental data. At lower energies, up to 90 MeV, no value of a_f/a_n matches the experimental data, but above 90 MeV energy a value in the range 1.167–1.16 is in good agreement with experimental data.

The cross sections for fission of the ^{184}W (p, f) reaction have been shown in Fig. 3. In Fig. 3 at lower

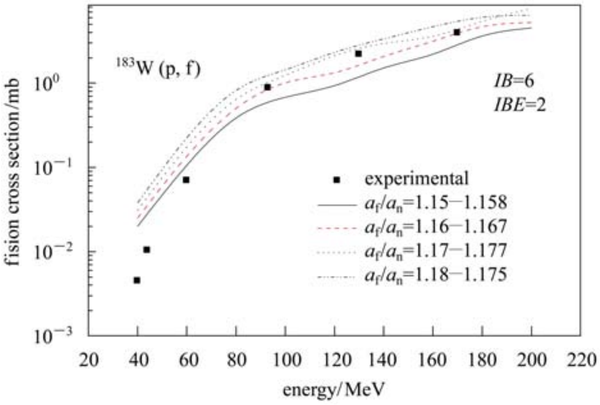

Fig. 2. Same as Fig. 1 but for ^{183}W.

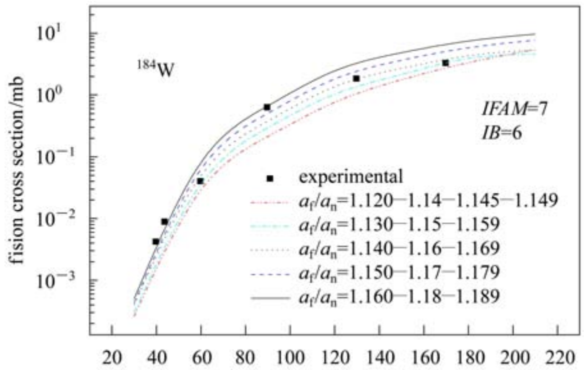

Fig. 3. Same as Fig. 1 but for ^{184}W.

energies the value of a_f/a_n that matches the experimental data starts from 1.189 and at around 200 MeV the values match at a_f/a_n of 1.140. Hence, a change of a_f/a_n in the range 1.189–1.140 is in good agreement with experimental data. The parameter IFAM in Fig. 3 is the choice of level density parameter systematics. The value of IFAM equal to seven indicates the choice of the first Iljinov, Mebel's, et al systematics.

Figure 4 shows the calculated fission cross sections of ^{186}W (p, f) along with experimental data. The trend of the computed and experimental data shows that the change of a_f/a_n in the range 1.14–1.120 yields results that are in good agreement with experimental data.

The fission cross sections for the ^{206}Pb (p, f) reaction are shown in Fig. 5. The agreement between calculation and experimental data shows the tendency to change the a_f/a_n in the range 1.165–1.138 and is in good agreement with experimental data.

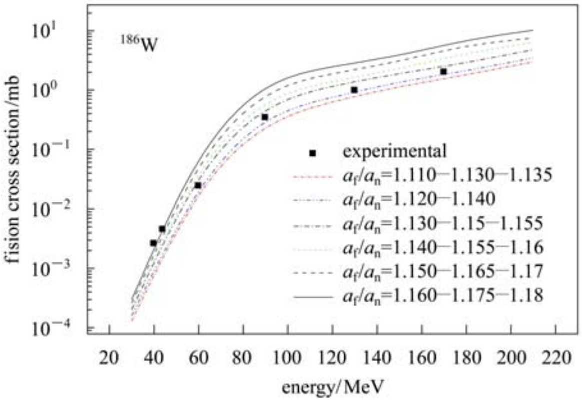

Fig. 4. Same as Fig. 1 but for ^{186}W.

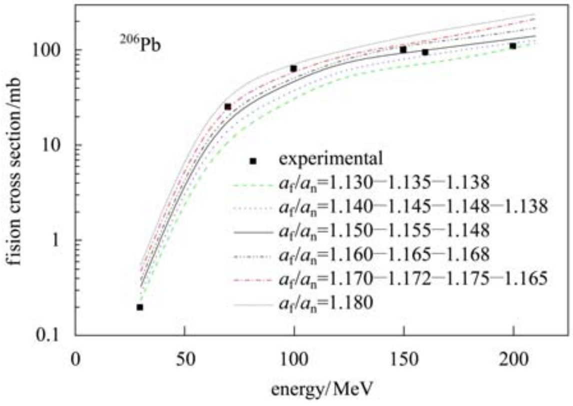

Fig. 5. Effect of the level density parameter ratio, a_f/a_n, on fission cross sections for the proton induced in ^{206}Pb. The curves (solid, dashed, dotted and dash-dotted) represent the fission cross sections computed using CEM95 for different values of a_f/a_n. The points represented by solid squares correspond to experimental data from EXFOR.

The calculated fission cross sections of the ^{207}Pb (p, f) reaction are shown in Fig. 6. The agreement between the calculation and the experimental data shows a tendency to change the a_f/a_n from 1.181–1.130 which is in good agreement with experimental data.

The calculated fission cross sections of the ^{208}Pb (p, f) reaction are shown in Fig. 7. The agreement between the calculation and experimental data show a tendency to change the a_f/a_n in the range 1.178–1.129 which is in good agreement with experimental data.

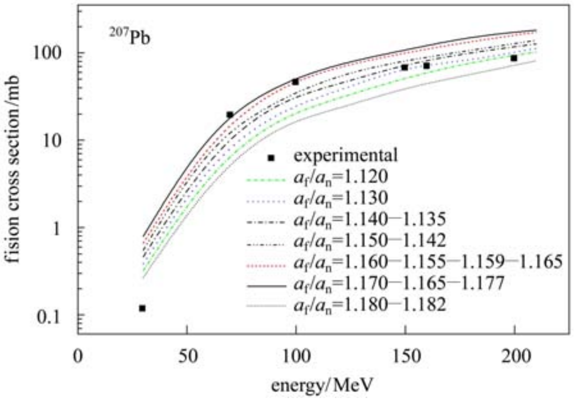

Fig. 6. Same as Fig. 5 but for ^{207}Pb.

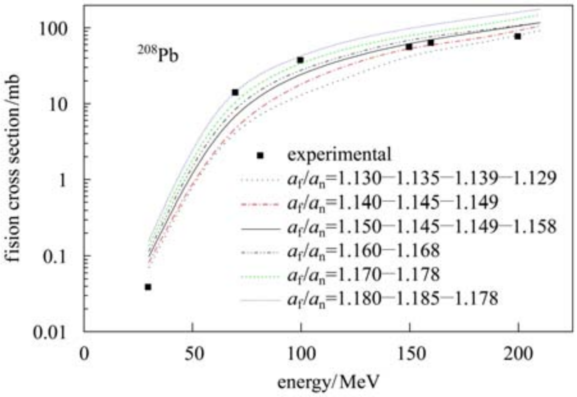

Fig. 7. Same as Fig. 5 but for ^{208}Pb.

The computed fission cross sections of ^{209}Bi (p, f) reaction are shown in Fig. 8 and compared with experimental data. The agreement between the calculation and experimental data show the tendency to change the a_f/a_n in the range 1.194–1.150 and is in good agreement with experimental data.

As it has been observed in this and in previous studies [1, 13], for CEM95, and in many other different models [6, 8, 16], that fission cross sections strongly depend on a_f/a_n. Hence, selecting the proper values of this ratio while calculating the fission cross sections by using the CEM95 computer code is strongly recommended. In this study, the excitation energy dependence of fission barriers is taken into account while calculating the cross sections.

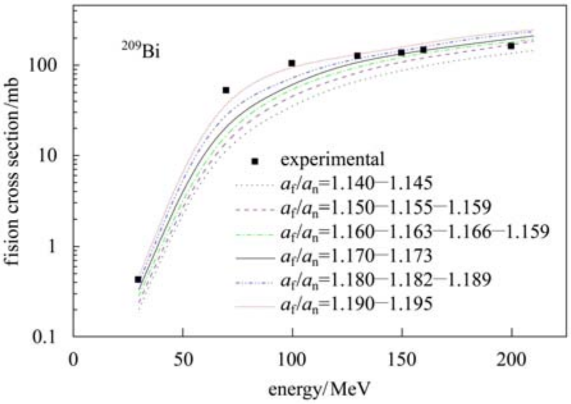

Fig. 8. Same as Fig. 5 but for ^{209}Bi.

It also should be noted that for all nuclei at all energies, the values of $a_{\rm f}/a_{\rm n}$ are greater than unity. This is due to the fact that, both in the case of near spherical and non spherical nuclei, the ground state equilibrium deformation of the residual nucleus, after neutron emission, is associated with a lower than average single particle level density, while the deformation of the fissioning nucleus is associated with a higher than average single particle level density [17, 18]. Furthermore, the fact that at the same incident energy, the values of $a_{\rm f}/a_{\rm n}$ are different for different targets is due to differences in the nuclear structure of the different targets and hence is due to the difference in the fission barriers. Also note that for the targets considered in the current analysis, the cross sections cannot be reproduced by using a single value of $a_{\rm f}/a_{\rm n}$. There are a number of other parameters such as the microscopic and macroscopic fission barriers, the ground state shell corrections, the shell and pairing corrections at the saddle point, the excitation energy dependence of fission barriers, the angular momentum dependence of fission barriers among others incorporated in CEM95 on which fission cross sections depends. But these are not considered in this work as the sensitivity of fission cross sections is not so dependent on these parameters compared with $a_{\rm f}/a_{\rm n}$.

In summary, we have studied theoretically the effect of $a_{\rm f}/a_{\rm n}$ on fission cross sections induced by protons in tungsten, lead and bismuth using the cascaded-exciton model implemented in CEM95. It seems that one cannot exactly describe the fission cross sections with a single value of level density parameter ratio ($a_{\rm f}/a_{\rm n}$), particularly for subactinide nuclei. The nuclei selected in this work may be used in accelerator-driven systems as beam windows or spallation targets and hence the cross section data for these nuclei is very useful. We conclude that our understanding of subactinide fission above the MeV range needs to be improved.

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