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EXCITON CASCADE MODEL FOR FAST NEUTRON REACTIONS

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Abstract: A more sophisticated version of the exciton cascade model, treating equilibrium and pre-equilibrium particle emissions in a unique way has been developed and applied to the description of neutron induced reactions, using realistic input data. The master equation describing the nuclear relaxation process has been solved by Monte-Carlo method. The role of Pauli's exclusion principle and different estimates of the transition matrix elements between different exciton configurations are discussed. The model is free of any adjustable parameter. Good agreement of the results of calculations with experimental data has been found for some medium and heavy nuclei.

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1. Introduction

According to the traditional conceptions of low energy ($\lesssim$2o MeV) neutron reactions most of the particles are emitted from a compound nucleus which has reached thermal equilibrium, and the emission is regarded as an evaporation process. By means of this evaporation model [1] one was able to reproduce the experimental values of the excitation functions of neutron reactions at ~14 MeV bombarding energies and also the low energy part of the secondary neutron spectra. In spite of these, the presence of high energy neutrons in the neutron energy spectra more than was predicted by the evaporation model indicates that particles are also emitted before thermal equilibrium is reached by the nuclear system. Processes involving pre-equilibrium particle emission are midway between the two extremes: the direct reaction mechanism and the reaction through compound nucleus.

Several attempts have been made to treat the whole reaction process in a unique way: those, which are based on statistical considerations are of special importance. In the statistical approach one seeks the probabilities that the nuclear system after a given time is in a given quantum state. The answer - the probabilities in question - can be found by solving a master equation written for the reaction process.

It is impossible to find the exact solution for this equation in an analytic way, because it contains negative

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source terms due to particle emission, which can take place at every step during the reaction process. Among the different ways of approximately solving the problem (e.g. closed formula, hybrid model), the solution with Monte-Carlo method seems to be the most correct and obvious one since it can take into account particle emission at every step of the simulation of the reaction process and treat the pre-equilibrium and equilibrium events on a common base.

A basic question of the model is how to characterize the different microscopic states of the nuclear system. From this point of view, two different possibilities have been proposed in the literature:

(i) In the case of the intranuclear cascade model [2, 3, 4] one considers the nucleons in the nucleus as classical objects moving along classical trajectories. This approximation can be used only for bombarding energies loo MeV, where the wavelength of the particles participating in the collisions is sufficiently small relative to their mean free path.

(ii) The exciton cascade model (ECM) [5, 6, 7] characterizes the states of the system by the number of particles and holes, i.e. by the exciton number, and follows the reaction process in the space of the quantum states. The ECM does not use the concept of the classical trajectory of nucleons, so it is suggested that low energies can also be considered.

In the present work a realistic version of ECM has been developed in order to describe the excitation functions of the fast neutron reactions and the energy spectra of the e-

mitted particles. Since the results of calculations based on the same reaction model depend on the estimation of the utilized nuclear data, they were chosen to be as realistic and correct as possible. Such input data are the inverse cross sections, nuclear level densities and the transition matrix elements between the different quantum states of the system. The aim of this work is to show that the ECM can be set free of adjustable parameters if the ideas of Toneev et al. [7, 8] are used together with realistic input data. The ability of ECM based on Monte-Carlo simulation has been examined in the case of medium and heavy target nuclei.

In Section 2 a description of the ECM based on Monte-Carlo simulation is given. The original version of the model [7, 8] is developed to include the concurrence between gamma- and particle-emission and to use more realistic input data. Estimations of the transition matrix elements are discussed in Section 3, calculations using different estimations for them are compared in the framework of the proposed model. In Section 4 the input nuclear data and the estimations connected with these are given explicitly, and finally, in Section 5 the results of the calculations are presented.

2. Description of the exciton cascade model

Let the reaction be described in the c.m.s. of the target nucleus, and let us suppose that nuclear recoil is negligible.

After collision of the nucleus with the incident neutron of kinetic energy E_n, a nuclear system with mass number A_0, charge Z_0 and excitation energy $U_0 = E_n + S_{n_0}$ is formed (S_{n_0}

is the neutron separation energy). Let us specify the nuclear states with these quantities and, in addition, with the number of excitons n , i.e. with the sum of the numbers of the excited nucleons above the Fermi sea (particles) and of the unfilled nucleon states in the Fermi sea (holes), $n = p + h$. The initial state of the excited nuclear system can be characterized by the exciton number $n_0 = 1$ ($1p-0h$ state). If highly excited neutrons do not leave the system with unchanged kinetic energy (which would be the case of elastic scattering), a nonelastic process takes place, and the system takes on the $n = 3$ ($2p-1h$) configuration. The transition rate to this state is evaluated from the optical model neutron absorption cross sections, σ_a .

During the nonelastic process starting with the $n = 3$ state the excitation energy of the nuclear system is distributed among the degrees of freedom of the system as a result of exciton-exciton collisions, accompanied by variations of the exciton number $\Delta n = 0, \pm 2$ [9]. In addition to this, from each exciton configuration particle emission including photon emission can also take place. The probability of the transition of the system to a new particle-hole configuration per unit time, $\lambda_{\Delta n}$, and the Γ_j particle emission widths depend only on the quantum numbers $\xi \equiv (A, Z, U, n)$ of the nuclear system, and do not depend on how the state ξ has been reached, i.e. we have a markovian chain. The total decay probability of the ξ state per unit time is

$$\lambda(\xi) = \sum_{\pm,0} \lambda_i(\xi) + \sum_j \Gamma_j(\xi)/\hbar \qquad (1)$$

where $\lambda_{\pm,0}$ denotes $\lambda_{\pm 1}$ and λ_0 , respectively. Then the prob-

abilities of the further events are given by $w_i = \lambda_i/\lambda$ $(i = 0, \pm)$ and $w_j = \Gamma_j/(\hbar\lambda)$. In our case j goes from 1 to 7 according to the following particles: neutron, proton, deuteron, triton, ^3He, alpha and gamma. In the framework of the model the process is governed by the probabilities $P(\xi, t)$ of finding the system in state ξ at moment t, supposing that it was initially in the state $\xi_0 = (A_0, Z_0, U_0, n_0)$ at $t = 0$. For the $P(\xi, t)$ probabilities one can write the following set of master equations [6]:

$$\frac{dP(n,t)}{dt} = P(n-2,t)\,\lambda_+(n-2) + P(n+2,t)\,\lambda_-(n+2) - \\ - P(n,t)\left[\lambda_+(n) + \lambda_-(n) + \sum_j \Gamma_j/\hbar\right] \tag{2}$$

To solve this system of equations and to calculate emission cross sections a Monte-Carlo simulation method has been used by generating N_0 Monte-Carlo experiments in the following way:

(i) The initial ξ_0 state of the system is set ($n_0 = 3$).

(ii) Depending on the exciton number, the program decides whether the nuclear system is in pre-equilibrium or in the equilibrium state, i.e. n less than the number of excitons in equilibrium states ($\bar{n}$) or not. At the beginning $\lambda_+ \gg \lambda_-$ and n increases, on average, while thermodynamic equilibrium is reached for $n = \bar{n}$, when $\lambda_+(\bar{n}) = \lambda_-(\bar{n})$. Naturally, no return from the equilibrium to the pre-equilibrium states is possible.

(iii) If the emission of the considered particles is not allowed energetically, the given experiment is broken off and a new experiment starts from (i).

(iv) If particle emission is possible, then the $\Gamma_j(\xi)$ emission widths are calculated for the given ξ state. If ξ is a pre-equilibrium state, the transition probabilities are also determined. Then the way of decay is decided by random number generation. In the case of particle emission, the energy of the emitted j type particle is determined also by random number generation, considering it as a random variable with the density function $\lambda_j(\varepsilon,\xi)/\Gamma_j(\xi)$, where $\lambda_j(\varepsilon,\xi)\,d\varepsilon$ is the emission width of the j particle with energy between ε and $\varepsilon+d\varepsilon$ in state ξ . With the quantum numbers of the new state having been determined, one returns to (ii) and the calculation is continued.

As we are only interested in quantities comparable with experimental data, there is no need to determine the time of every single event.

According to the model, the probability of the emission of a j particle in the energy interval (ε, $\varepsilon+d\varepsilon$) in a non-elastic channel k (e.g. (n,n') ,$(n,2n)$ ...) is given by

$$P_{jk}(\varepsilon)\,d\varepsilon = \frac{1}{N_0} N_{jk}(\varepsilon) \tag{3}$$

where $N_{jk}(\varepsilon)$ is the number of j particles with energy between ε and $\varepsilon+d\varepsilon$, the emission of which was observed in channel k during N_0 Monte-Carlo experiments. The spectrum of j particles summed up for all reaction channels is

$$P_j(\varepsilon)\,d\varepsilon = \sum_k P_{jk}(\varepsilon)\,d\varepsilon \tag{4}$$

The differential cross section of the j particle emission with energy between ε and $\varepsilon+d\varepsilon$ is proportional to the for-

mation cross section of the compound system, so the differential emission cross section for j particles is given by

$$\frac{d\sigma_j}{d\varepsilon} = \sum_k \frac{d\sigma_{jk}}{d\varepsilon} = \sum_k \sigma_a P_{jk}(\varepsilon) = \sigma_a P_j(\varepsilon) \tag{5}$$

One obtains the total cross section for a channel k integrating the differential cross section $d\sigma_{jk}/d\varepsilon$ by ε, and multiplying the result by a factor due to the multiple particle emission, for example in the channels $(n,2n)$ or $(n,3n)$ this factor is $1/2$ or $1/3$ respectively.

Generally a large number of Monte-Carlo experiments is performed. The energy spectra of different particles emitted from the non-equilibrated system and from the compound nucleus are stored separately. In order to accelerate the computation the weight function method has been applied [8]. Whenever a particle emission takes place, the whole energy distribution of the emitted particle is computed and these distributions are summed up at the end of a Monte-Carlo experiment, to obtain the contribution of the emitted particle to the energy spectrum. Spectra of particles emitted in different types of reactions are stored separately.

3. Estimation of the transition matrix element

The probabilities $\lambda_{\pm,0}$ for the transitions $\Delta n = 0, \pm 2$ are assumed to be defined by the average matrix element of two-particle collisions $\bar{M}$ and by the density of accessible final two-particle states $\varrho_{n'}$ in the nuclear system with n' excitons:

$$\lambda_{n \to n'} = \frac{2\pi}{\hbar} |\bar{M}|^2 \varrho_{n'}(E) \tag{6}$$

Using this expression in the case of equidistant single-particle spectrum with the level density g one obtains [9]

$$\lambda_+ = \frac{2\pi}{\hbar} |\bar{M}|^2 \frac{g^3 U^2}{n+1} \qquad (\Delta n = +2) \tag{7}$$

$$\lambda_- = \frac{2\pi}{\hbar} |\bar{M}|^2 g\, p\, h\, (n-2) \qquad (\Delta n = -2) \tag{8}$$

$$\lambda_0 = \frac{2\pi}{\hbar} |\bar{M}|^2 g^2 U \frac{3n-2}{4} \qquad (\Delta n = 0) \tag{9}$$

where U is the excitation energy of the system, p and h are the numbers of particles and holes ($n = p + h$). Here the Pauli principle is not taken into account.

The estimation of the averaged transition matrix element $\bar{M}$ proves to be one of the most crucial points in the model. Therefore different estimates of $|\bar{M}|^2$ have been examined as follows:

1) Estimates based on the mean free path of an "averaged" exciton with the kinetic energy $t = E_F + U/n$ in the nucleus:

$$\frac{2\pi}{\hbar} |\bar{M}|^2 \frac{g^3 U^2}{2} = \frac{1}{\tau_{ex}(U/n)} = v \rho \eta \sigma(v) / \kappa \tag{10}$$

where τ_{ex} is the average life time of the exciton, $v = \sqrt{2t/m}$, $E_F = (3\pi^2 \rho/2)^{2/3}/2m$ is the Fermi energy, m is the mass of the nucleon, $\rho = 0.179\ fm^{-3}$ is the density of nuclear matter. The $\sigma(v)$ is the isospin averaged nucleon-nucleon scattering cross section,

$$\sigma(v) = \frac{A-Z}{A}\left(\frac{A-Z}{A}\sigma_{nn}(v) + \frac{Z}{A}\sigma_{pn}(v)\right) + \frac{Z}{A}\left(\frac{A-Z}{A}\sigma_{np}(v) + \frac{Z}{A}\sigma_{pp}(v)\right) \tag{11}$$

where the cross sections

$$\sigma_{nn}(v) = \sigma_{pp}(v) = (10.63\,\beta^{-2} - 29.92\,\beta^{-1} + 42.9)\ mb \tag{12}$$

$$\sigma_{np}(v) = \sigma_{pn}(v) = (34.10\,\beta^{-2} - 82.2\,\beta^{-1} + 82.2)\ mb \tag{13}$$

are taken from [10], $\beta = v/c$. Blann [11] and Braga-Marcazan et al. [12] proposed $\eta = 1$ in the expression (10), while Toneev's estimate [7] $\eta = [r_0/(r_0 + \lambda\!\!\!^-)]^3$ ($r_0 = 1.2$ fm , $\lambda\!\!\!^- = \hbar/mv$) takes into account the enlargement of the effective volume of a nucleon due to quantum effects. Usually κ plays the role of a fitting parameter.

2) Kalbach's estimate [13], according to which $|\bar{M}|^2$ has the following mass number (A) and energy (U) dependence,

$$|\bar{M}|^2 = \frac{\kappa}{A^3 \cdot U} \tag{14}$$

where κ serves also as an adjustable parameter.

So far corrections due to the Pauli principle were neglected. To take the Pauli principle into account, in case 2) the only way is to modify the density of the nuclear states. In case 1), however, there are two ways of including the Pauli principle:

1a) either the free nucleon-nucleon scattering cross section should be reduced by a factor $P(E_F/t)$ [14],

$$\sigma(v) \longrightarrow \sigma(v)\, P(E_F/t) \tag{15}$$

1b) or the state density should account for the Pauli principle and no reduction of the cross section $\sigma(v)$ is needed. In the first case the $\lambda_{\Delta n}$ probabilities are given by (7), (8) and (9), while in the second case they are modified as follows [15]

$$\lambda_+ = \frac{2\pi}{\hbar} |\bar{M}|^2 \frac{g(gU - C_{p+1,h+1})}{n+1} \qquad (\Delta n = +2) \tag{16}$$

$$\lambda_- = \frac{2\pi}{\hbar} |\bar{M}|^2 g\, p h (n-2) \qquad (\Delta n = -2) \tag{17}$$

$$\lambda_0 = \frac{2\pi}{\hbar} |\bar{M}|^2 g(gU - C_{p,h})(n-1) \qquad (\Delta n = 0) \tag{18}$$

where

$$C_{p,h} = \frac{1}{2}\left(p^2 + h^2\right) \tag{19}$$

Cases 1a) and 1b) are compared in Figure 1. Calculations of the ^{181}Ta (n,2n) , (n,3n) and (n,p) excitation functions and of the spectrum of secondary neutrons at 14 MeV neutron

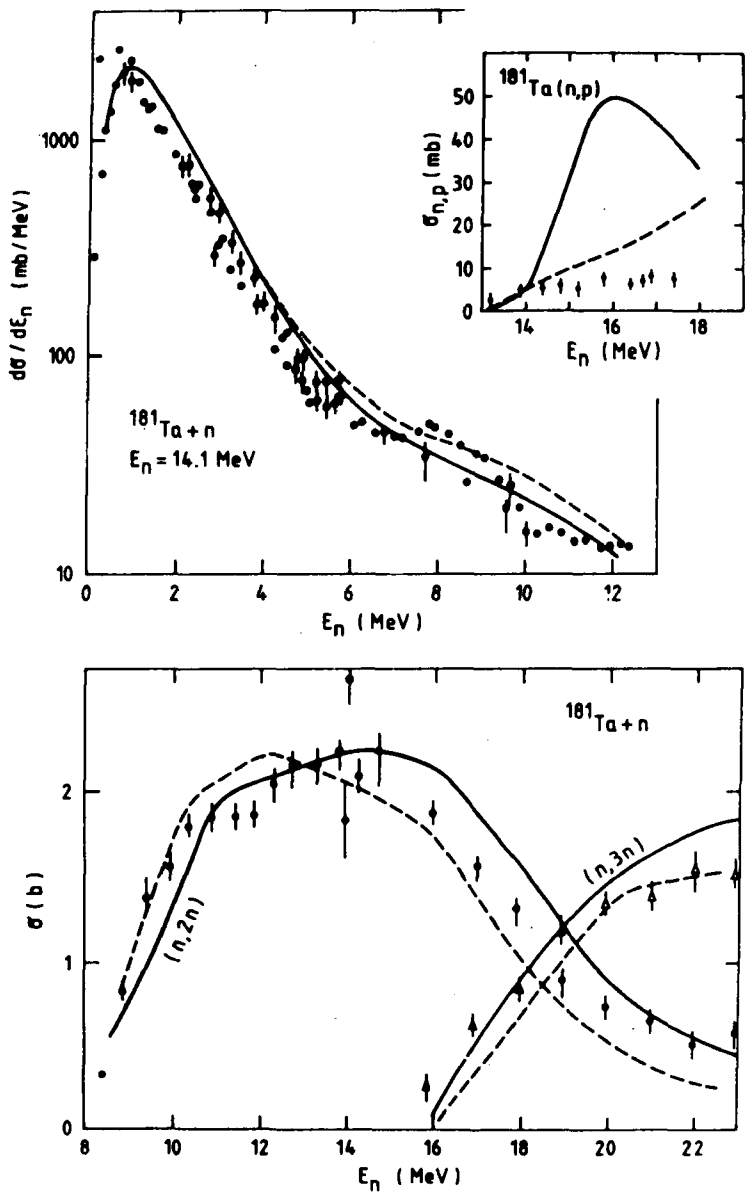

Fig. 1.:Different estimations for the inclusion of the Pauli principle. The calculated results are represented by a solid line in case 1a), $\kappa = 0.4$, and by dashed line in case 1b), $\kappa = 1.7$, (see text). Experimental data are taken from [27-31, 34]

energy ($\eta = 1$) were performed. With a significant change of the value of the fitting parameter κ almost equally good description of the neutron channel is possible in both cases, while the (n,p) excitation function in case 1b) is more acceptable. At the same time in case 1a) the pre-equilibrium particle emission is too large not only in the proton channel but also in the neutron channel: the pre-equilibrium contribution to the (n,2n) cross section at 10-15 MeV neutron energy is nearly 50%. This would contradict the fact that the evaporation model of nuclear reactions, which neglects pre-equilibrium particle emission, has given an almost correct description of integrated (n,2n) cross sections in this energy region. Correspondingly, one has to conclude that the Pauli principle in case 1) should be taken into account also in the state density of the nuclear system.

On the other hand, it has been examined how the calculated cross sections are affected by the different ways of estimating the averaged transition matrix element $\bar{M}$. Calculations were performed for the neutron and proton channels in ^{181}Ta+n and ^{56}Fe+n processes, using the different estimates of $|\bar{M}|^2$ with the following values of the fitting parameter:

$\kappa = 17$ in the case of $\eta = 1$

$\kappa = 1$ for Toneev's estimate (no fitting)

$\kappa = 700\ \mathrm{MeV}^2$ for Kalbach's estimate.

No significant difference between the calculated results can be observed. However, we preferred to use Toneev's estimate, because in this case the introduction of a fitting parameter into the exciton cascade model can be avoided.

In the model the difference between protons and neutrons has been taken into account only phenomenologically: in the first step of the Monte-Carlo experiments, e.g. in the $n_0=3$ initial state, the proton and neutron emission widths were weighted with the σ_{np} and σ_{nn} neutron-proton and neutron-neutron scattering cross section values, replacing Γ_n and Γ_p by $R\Gamma_n$ and $(1-R)\Gamma_p$, respectively, where $R=\sigma_{nn}(v)/(\sigma_{nn}(v)+\sigma_{np}(v))$.

4. Nuclear state densities, particle emission widths

The densities of states of the nuclear system with excitation energy U and with a given number of excitons $n=p+h$ is determined [16] by

$$\rho(U,p,h) = \frac{g(gU-A_{p,h})^{n-1}}{p!\,h!\,(n-1)!} \tag{20}$$

where $A_{p,h}$ is given by

$$A_{p,h} = \frac{1}{4}\left(p^2+h^2+p-3h\right) \tag{21}$$

(In case 1a) of the examination of the different estimates for the transition matrix element, $A_{p,h}=0$ was taken.)

For nuclear state density $\rho(U)$ at excitation energy U in thermodynamic equilibrium the formula for the so-called back-shifted Fermi gas model was used [17]

$$\rho(U) = \begin{cases} 0 & (U \leq \Delta) \\ \frac{\sqrt{\pi}}{12}\,\frac{\exp(2\sqrt{a\tilde{U}})}{a^{1/4}(\tilde{U}+t)^{5/4}} & (U>\Delta) \end{cases} \tag{22}$$

where $\tilde{U}=U-\Delta$, $t=(1+\sqrt{1+4a\tilde{U}})/2a$. The values of parameters a and Δ given in Table 1. were determined on the basis of [17] by interpolation. The single-particle level density

Table 1. State density parameters a and Δ used in our calculations

Nucleus	a, MeV^{-1}	Δ, MeV	Nucleus	a, MeV^{-1}	Δ, MeV
^{198}Au	16.26	-0.86	^{57}Fe	5.22	-1.04
^{197}Au	17.04	-0.25	^{56}Fe	5.45	0.69
^{196}Au	17.45	-0.90	^{55}Fe	4.87	-0.82
^{182}Ta	18.00	-0.88	^{56}Mn	5.43	-0.95
^{181}Ta	17.58	-0.42	^{54}Fe	5.23	0.70
^{180}Ta	17.85	-1.21	^{53}Fe	5.15	-0.90
^{181}Hf	17.71	0.51	^{54}Mn	4.74	-1.51

g is connected with the density parameter a by the relation $g = 6a/\pi^2$.

The basic assumption for the calculation of the particle emission widths is that the hot compound system and the "vapour" of emitted particles are in statistical equilibrium [18]. Making use of the time reversal symmetry of the matrix element of the particle emission, one can express particle emission widths in terms of the cross sections $\sigma_j^{(i)}(\varepsilon, U-\varepsilon)$ of the inverse processes. Thus if $\lambda_j(\varepsilon,\xi)d\varepsilon$ is the emission width of the j particle with energy between ε and $\varepsilon+d\varepsilon$, then one gets

$$\lambda_j(\varepsilon,\xi) = \frac{(2s_j+1)\, m_j\, \sigma_j^{(i)}(\varepsilon)\, \varepsilon}{\pi^2 \hbar^2} \cdot \frac{\rho_f(\xi')}{\rho_i(\xi)} \qquad (23)$$

where m_j and s_j are the mass and spin of the emitted particle, $\rho_f(\xi')$ and $\rho_i(\xi)$ are the state densities of the final and compound nuclei in the state ξ' and ξ , respectively.

With this expression one can obtain the total emission width of a j particle in state ξ as follows

$$\Gamma_j(\xi) = \int_0^{U-S_j} \lambda_j(\varepsilon, \xi)\, d\varepsilon \tag{24}$$

where U is the excitation energy and S_j is the separation energy of the j particle from the system. The values of S_j were determined on the basis of the exponential atomic mass formula given in [19].

Expression (23) is approximately calculated, replacing $\sigma_j^{(i)}(\varepsilon, U)$ by $\sigma_j^{(i)}(\varepsilon, U=0)$. The absorption cross sections for neutrons and protons were obtained from an optical model calculation using the optical potentials of Becchetti and Greenlees [20]. For the other particles the formula of Dostrovsky et al. [21] was used:

$$\sigma_j^{(i)}(\varepsilon) = \begin{cases} \pi r_0^2 (A-A_j)^{2/3} (1+c_j)(1-k_j V_j/\varepsilon) \; ; & (\varepsilon \geq k_j V_j) \\ 0 \; ; & (0 \leq \varepsilon < k_j V_j) \end{cases} \tag{25}$$

Here $r_0 = 1.5\,fm$, A and A_j are the mass number of the compound nuclear system and that of the particle emitted, respectively, m_j is the mass of the emitted particle, V_j is the height of the Coulomb barrier in the compound nucleus for the emitted particle and the constants c_j and k_j are taken from [21].

Photon emission widths are calculated by Brink-Axel's formula [22], which describes the experimental data [23] reasonably well, and reads as follows

$$\Gamma_\gamma = \int_0^U \lambda_\gamma(\varepsilon, \xi)\, d\varepsilon = \int_0^U \frac{\sigma_T(\varepsilon)\,\varepsilon^2}{\pi^2 \hbar^3 c^2} \cdot \frac{\rho(\xi)}{\rho(\xi)}\, d\varepsilon \tag{26}$$

where

$$\sigma_\gamma(\varepsilon) = \sigma_R \frac{\varepsilon^2 \Gamma_R^2}{(\varepsilon^2 - E_R^2)^2 + \varepsilon^2 \Gamma_R^2} \tag{27}$$

and $\varrho(\xi)$, $\varrho(\xi')$ are the state densities of the nucleus before and after photo-emission, respectively. The energy of the giant dipole resonance is given by

$$E_R = 47.9\ A^{-1/4.27} \quad \text{MeV} , \tag{28}$$

the resonance width was taken as $\Gamma_R \approx 4\,\text{MeV}$ and the resonance cross section σ_R was obtained by interpolation from experimental data [24] as

$$\sigma_R = (3.07\,A - 104.27)\ \text{mb} \qquad (50 \leq A \leq 200) \tag{29}$$

5. Results

Calculations have been performed for fast neutron induced reactions on ^{197}Au, ^{181}Ta, ^{56}Fe and ^{54}Fe target nuclei for neutron and proton channels. The resulting particle emission spectra and excitation functions are summarized and compared with experimental data in Figs. 2-14. For both channels, rather good agreement with experimental data has been found in all cases for differential and integral cross sections, despite the fact that no fitting parameter was used.

The determination of nuclear state densities, emission widths and transition matrix elements is based mainly on the Fermi gas model. The results are acceptable as much the assumptions of this model are satisfied. It was shown in the framework of the pre-equilibrium exciton model in its closed form [25, 26], that one can obtain better agreement between calculated results and experimental data if one introduces a

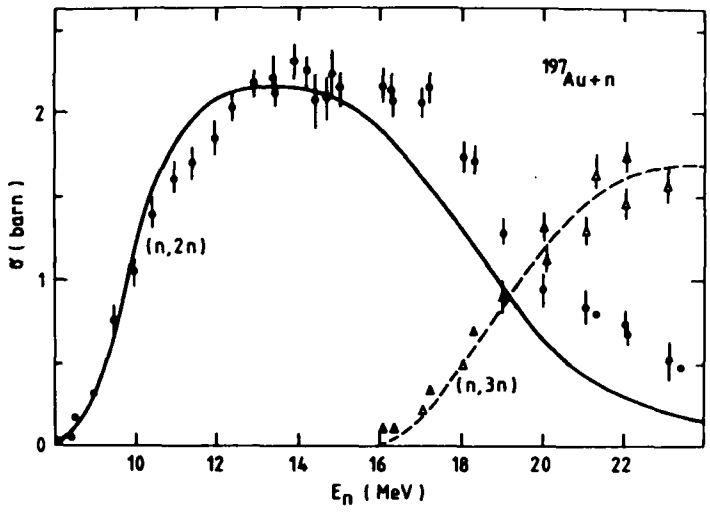

Fig. 2.: ^{197}Au (n,2n) and (n,3n) excitation functions. The solid and dashed line represent the results of the present calculation. Experimental data: [27, 28, 32]

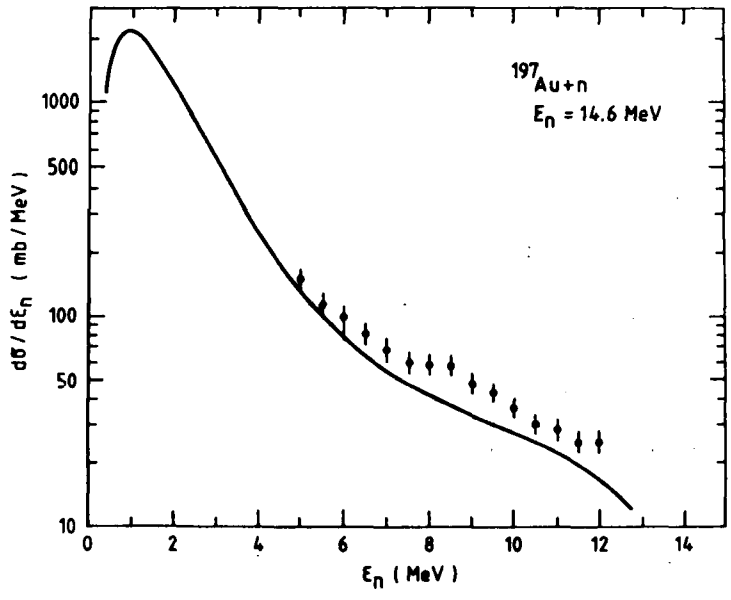

Fig. 3.: Differential neutron emission cross section for ^{197}Au+n reaction at E_n=14.6MeV bombarding neutron energy. Experimental data: [33]

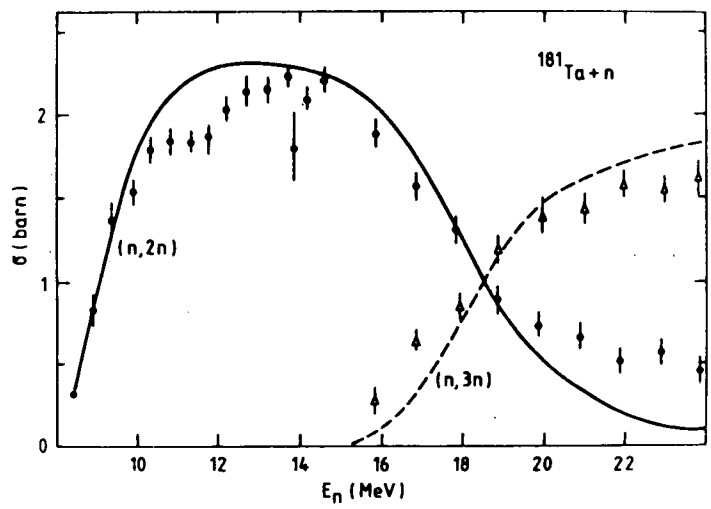

Fig. 4.:Same as Fig.2. for the target nucleus ^{181}Ta.

Experimental data: [27, 28, 34]

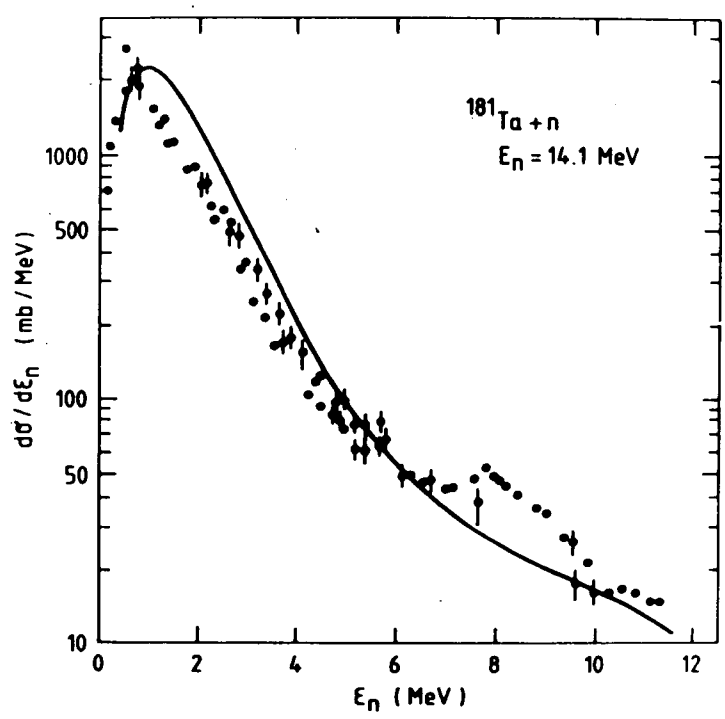

Fig. 5.:Same as Fig.3. for ^{181}Ta+n reaction at E_n=14.1MeV.

Experimental data: [29-31]

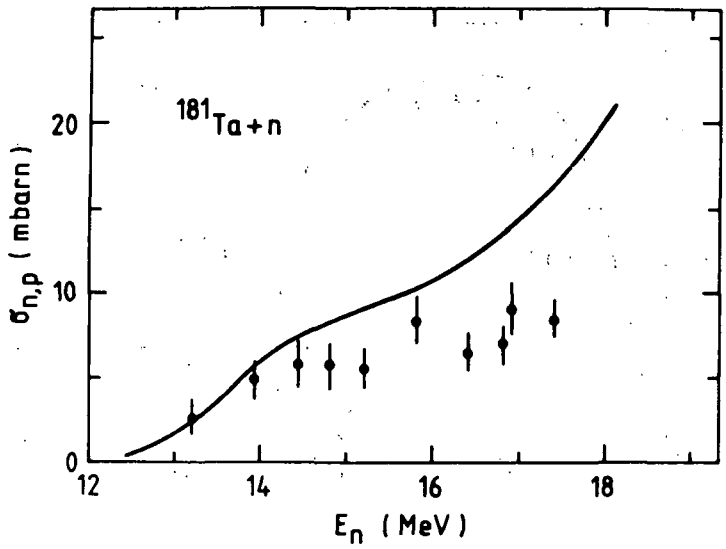

Fig. 6.:Excitation function for the reaction ^{181}Ta (n,p). Experimental values: [34]

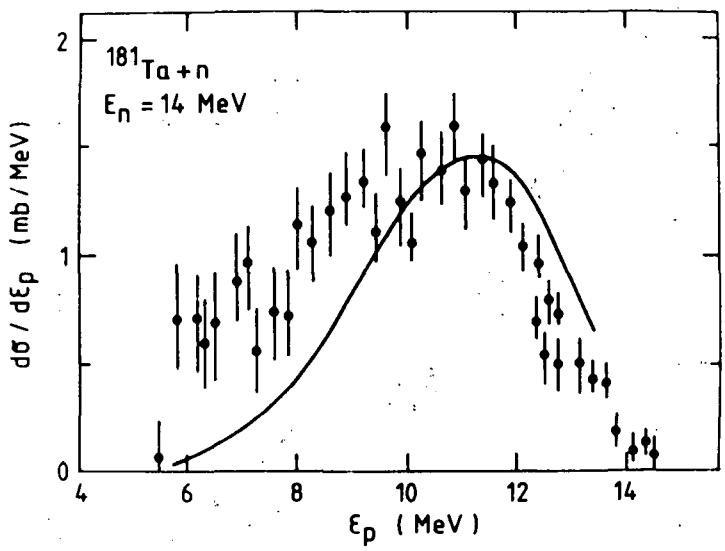

Fig. 7.:Differential proton emission cross section for ^{181}Ta+n reaction at E_n=14MeV.Experimental values are given in relative units [35]

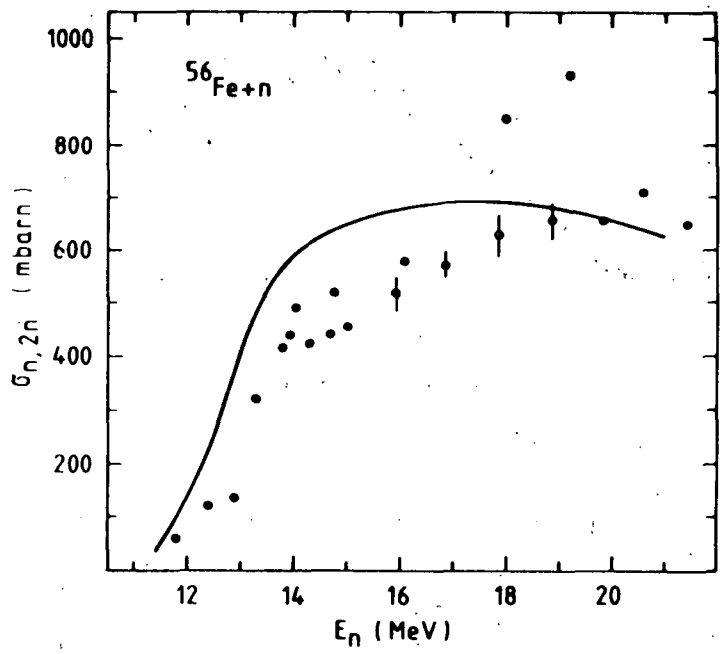

Fig. 8.: ^{56}Fe (n,2n) excitation function. Experimental data: [34]

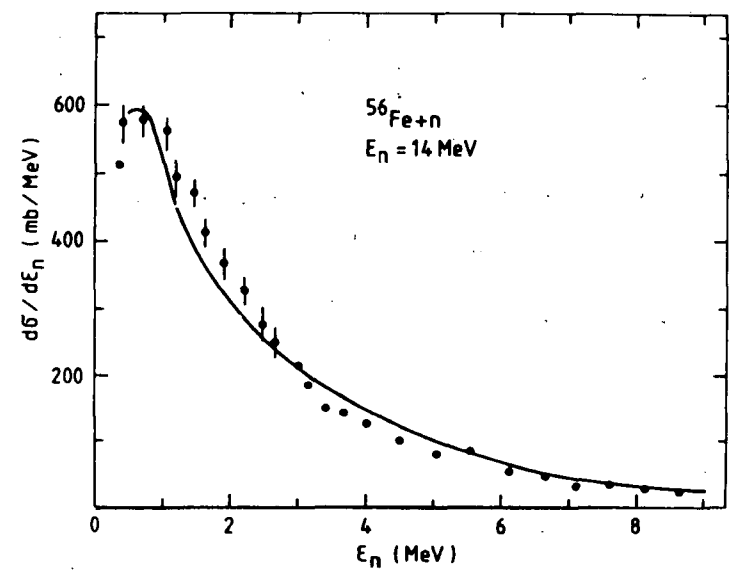

Fig. 9.:Same as Fig.3. for ^{56}Fe+n reaction at E_n=14MeV. Experimental data: [31]

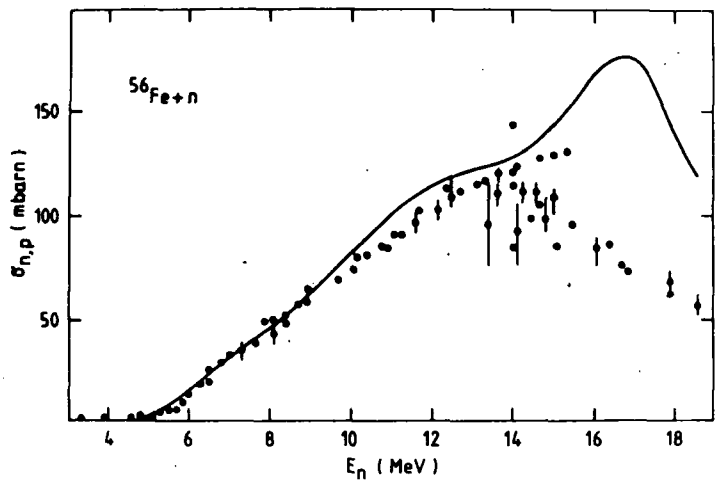

Fig.10.: ^{56}Fe (n,p) excitation function. Experimental data: [34]

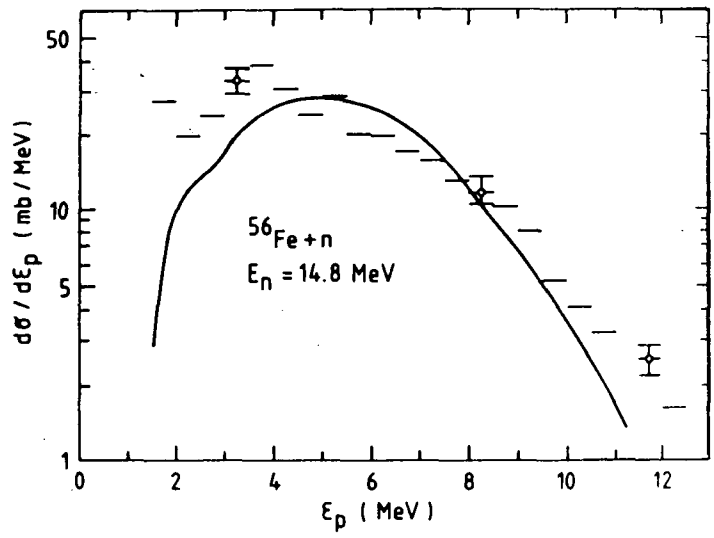

Fig.11.:Same as Fig.7. for ^{56}Fe+n reaction at E_n=14.8MeV. Experimental data: [36]

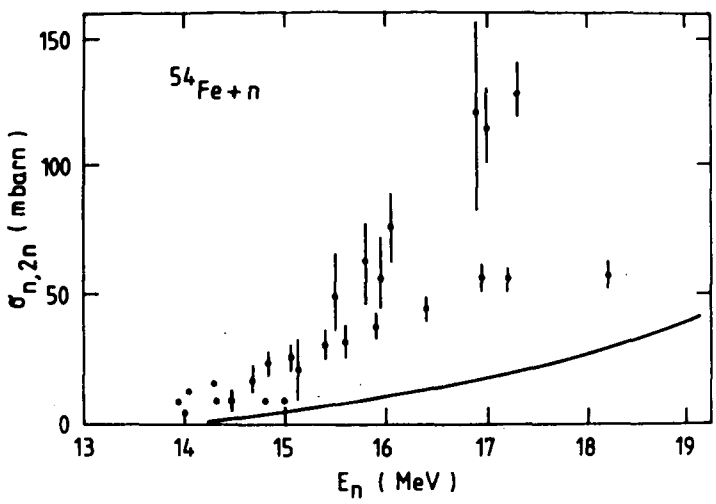

Fig.12.: ^{54}Fe (n,2n) excitation function. Experimental values: [34]

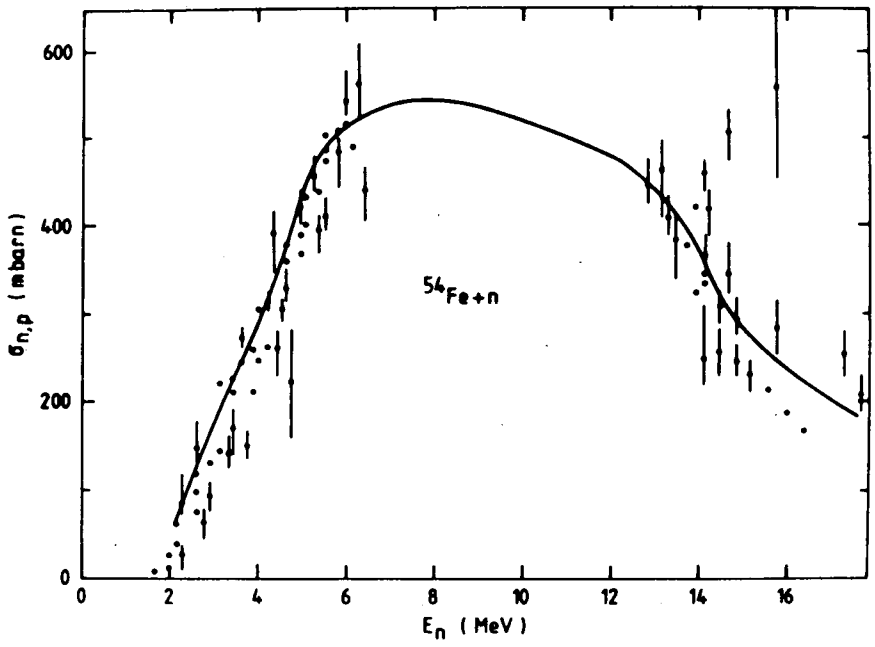

Fig.13.: ^{54}Fe (n,p) excitation function. Experimental data: [34]

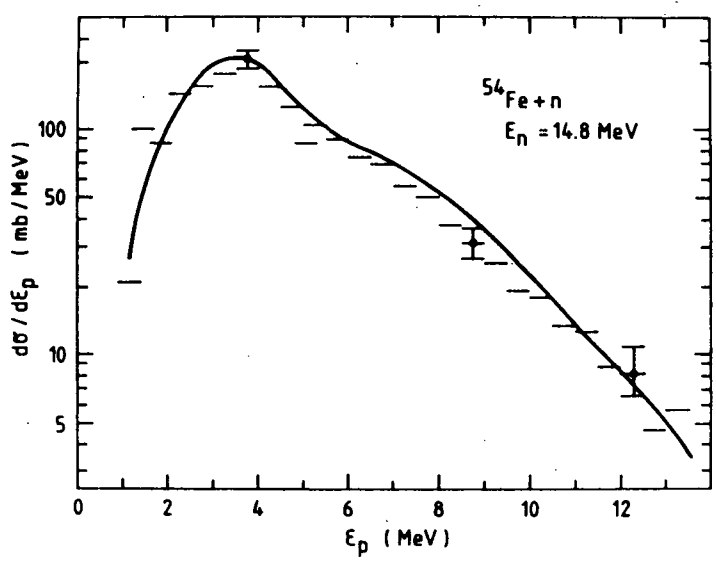

Fig.14.:Same as Fig.11. for ^{54}Fe+n reaction at E_n=14.8MeV. Experimental data: [36]

fitting parameter into the transition matrix element; the value of the fitting parameter generally varies depending on the target nucleus and on the reaction channels considered. Since the results of our calculations are equally acceptable for both the neutron and proton channels, the use of a fitting parameter is not justified. Moreover, arbitrary changes in the values of parameter κ in the transition matrix element from channel to channel are not compatible with the exciton cascade model itself.

The calculations presented here seem to prove that the ECM based on Monte-Carlo simulation is able to reproduce experimental data on fast neutron reactions in the range of medium and heavy target nuclei rather well, both in the neutron and proton channels. Further calculations are needed - including composite particle channels - to clarify the suitability of the presented model.

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