5/3

UNIVERSITY OF OXFORD

Department of Physics

PARTICLE AND NUCLEAR PHYSICS

PAULI-BLOCKING EFFECTS IN NEUTRON-ALPHA REACTIONS

M. Avrigeanu, V. Avrigeanu, A.N. Antonov,
M.B. Chadwick, P.E. Hodgson and M.V. Stoitsov

To be published in *Journal of Physics G*

Ref: OUNP–95–06

Address: Department of Physics
Particle & Nuclear Physics
Keble Road
Oxford OX1 3RH
U.K.

Pauli-Blocking Effects in Neutron-Alpha Reactions

M. Avrigeanu(1,4), V. Avrigeanu(1) A.N. Antonov(2,4),
M.B. Chadwick(3), P.E. Hodgson(4), M.V. Stoitsov(2)
(1) *Institute of Physics and Nuclear Engineering, Bucharest 76900, Romania*
(2) *Institute of Nuclear Research and Nuclear Energy, Sofia 1784, Bulgaria*
(3) *University of California, Nuclear Data Group, Lawrence Livermore National Laboratory, Livermore, California 94551, USA*
(4) *Nuclear Physics Laboratory, Department of Physics, University of Oxford, Oxford OX1-3RH, U.K.*

Abstract

A model of (n, α) knockout reactions, in which restrictions on the available phase space for the four nucleons of the alpha-particle after the knockout is imposed by a Pauli-blocking function, is developed and applied to analyze excitation functions of (n, α) reactions on ^{48}Ti, ^{51}V, ^{52}Cr , ^{54}Fe , ^{55}Mn and ^{59}Co nuclei. It is shown that Pauli-blocking effects are important for describing (n, α) processes. A sensitivity study of the results to the values of the model parameters, namely the local Fermi energy at the nuclear surface from where knockout occurs and the alpha-particle preformation factor, shows that the ranges of their variations are quite limited.

I. INTRODUCTION

The nucleon-alpha reactions provide important information on nuclear reaction mechanisms and on clustering in nuclei. There are a variety of competing mechanisms that contribute to the measured cross sections. It is well-known [1] that at low energies the (nucleon,α) reaction is dominated by the compound nucleus process and the cross sections can be described by the Weisskopf-Ewing and Hauser-Feshbach theories. At higher energies contributions from pre-equilibrium and direct processes become increasingly important and their inclusion enables the higher cross sections to be understood. In general, the pick-up process is the dominant mechanism for transitions to discrete states, though knock-out processes can also take place. This was shown by studies of (n,α) reactions on samarium- [2], on neodymium- [3] and on zirconium- [4] isotopes. As the incident energy increases, reactions to the continuum become more likely, and knock-out processes may become relatively favoured, since the density of final states increases more rapidly than that of those corresponding to pick-up process. Thus knock-out predominates in reactions to the continuum.

The exciton model (see references in [1]) has proved able to describe the cross sections of the intermediate energy multistep pre-equilibrium process. This model assumes either knockout of preformed alpha-particles or coalescence of excited and bound nucleons into an alpha-particle. The extension of the direct reaction theory to describe transitions to continuum states is the more ambitious aim of the quantum-mechanical theory of the reactions [1].

Substantial information on the mechanism of the (n,α) reaction came from studies of excitation functions at energies from about 12 to 20-22 MeV. It is known [2] that the study of reactions by neutrons with these energies is important for applied physics research, e.g. for investigations of the radiation damages caused by high fluxes of neutrons. Various problems are encountered in the description of the (n,α) reactions so that, in general, there is still no reliable way of calculating the absolute cross sections of these reactions. It is important to take proper account of the Pauli principle. In [5] it was approximately taken into account by requiring that the alpha-particles after a nucleon-alpha interaction have an energy greater than the Fermi energy ϵ_F , and in this paper we study a more detailed method.

We present a model for (n, α) reactions that has close similarities to quasi-free scattering models of nucleon and alpha-particle emission. The interaction of the incident nucleon with the (preformed) alpha particle is related to the free nucleon-alpha scattering cross section. Modifications are then applied to account for nuclear medium effects, notably the Fermi momentum of the struck alpha particle, the Pauli-blocking effects, and the influence of the residual nucleus nuclear and Coulomb barrier on the emitted alpha particle. Such an approach is also the basis of most intranuclear cascade models of nuclear reactions. In this work, however, we concentrate on the first-step "direct" part of the cascade, which is increasing with the energies considered. Our approach is also closely related to that of Chadwick *et al.* [6], who studied Pauli-blocking effects in photonuclear reactions.

In Sec. II we describe our model, and in Sec. III we present and discuss the results in connection with those from other models.

II. THE MODEL

It is assumed that the incident neutron collides with a preformed alpha-particle in the target nucleus and ejects it, leaving the neutron in a single-particle state along with some hole excitations. The emitted alpha-particle can have a range of energies and the residual nucleus is in general excited. It is possible to compare our calculated cross-sections with the available now (n, α) activation data, which refer only to alpha-emission reactions in which no other particles are emitted, but only gamma rays. In this relation we consider incident energies such that the dominant decay mechanism of the excited residual nucleus is by gamma-ray emission to its ground state.

In the present work the Pauli-blocking effects on (n, α) reactions are considered using a model of alpha knockout in which the cross-section of the process is related to the free (n, α) cross-section. In the case of the free (n,α) reaction, the nuclear medium is not present, whereas in the nuclear case the occupied states in the rest of the nucleus restrict the number of states accessible for the neutron and alpha-particle after the interaction. The effect of this restriction on the phase space can be expressed using the Pauli-blocking function, as in the analysis of quasideuteron photoabsorption [6]. We assume that if the available phase space for the four nucleons of the alpha-particle after the knockout process is reduced by Pauli-blocking, the (n, α) cross-section is also reduced by the same amount. As in [6], it is supposed that the (n, α) cross-section is proportional to the available phase space, and

Fermi-gas state densities are used. It is required that the two protons and two neutrons of the preformed alpha-particle in the nucleus (with a preformation factor ϕ_α) after leaving the nucleus will all have momenta greater than the Fermi-momentum k_F.

The direct component of the α-particle emission cross-section can then be written approximately in the form:

$$\sigma_{DC}^{\alpha} = \phi_\alpha \sigma_{(n,\alpha)}^{\text{free}}(\epsilon_{\text{inc}}) f(\epsilon_{\text{inc}}), \tag{1}$$

where $f(\epsilon_{\text{inc}})$ is the Pauli-blocking function that depends on the energy of the incident neutron ϵ_{inc}, $\sigma_{(n,\alpha)}^{\text{free}}$ is the free neutron-alpha cross-section and ϕ_α is the preformation factor. This equation is similar to Levinger's expression for the nuclear quasideuteron photoabsorption cross-section [6]. The superscript "alpha" in σ_{DC}^{α} is used to differentiate the present model by the approach developed for photoabsorption reactions [6]. The Eq.(1) uses the following simplifying approximations for the Pauli-blocking function: (1) The free (n,α) cross section is not folded in $f(\epsilon_{\text{inc}})$ and (2) The Fermi-gas momentum distribution has been used for the alpha- particles. In this case the function $f(\epsilon_{\text{inc}})$ has the form:

$$f(\epsilon_{\text{inc}}) = \int_0^{\epsilon_F^\alpha} \rho_\alpha(\epsilon_\alpha) F(\epsilon_\alpha + \epsilon_{\text{inc}}) T(\epsilon_\alpha + \epsilon_{\text{inc}}) d\epsilon_\alpha, \tag{2}$$

where ϵ_α is the energy of the preformed alpha-particle, relative to the bottom of the nuclear well, $\rho_\alpha(\epsilon_\alpha)$ is the alpha-particle state density, $F(\epsilon_\alpha + \epsilon_{\text{inc}})$ is the Pauli-blocking factor, and $T(\epsilon_\alpha + \epsilon_{\text{inc}})$ is the transmission coefficient for the excited alpha-particle to escape the nucleus. We assume that the alpha-particle state density has the form of the state density of particles in the Fermi-gas model:

$$\rho_\alpha(\epsilon_\alpha) = \frac{3}{2\epsilon_F^\alpha} \left(\frac{\epsilon_\alpha}{\epsilon_F^\alpha}\right)^{\frac{1}{2}}. \tag{3}$$

The state density (3) is normalized to unity:

$$\int_0^{\epsilon_F^\alpha} \rho_\alpha(\epsilon_\alpha) d\epsilon_\alpha = 1. \tag{4}$$

In Eqs.(3,4) ϵ_F^α is the alpha-particle effective Fermi-energy. The use of the Fermi-gas model relationships for the alpha-particles in nuclear medium can be justified by the consideration of the Pauli- blocking factor:

$$F(E) = \frac{\rho^P(4p, E)}{\rho(4p, E)} \tag{5}$$

defined as the ratio of the four-particle state densities in which the Pauli blocking is included ($\rho^P(4p, E)$) and ignored ($\rho(4p, E)$) [6],

$$\rho^P(4p, E) = \int_0^\infty \int_0^\infty \int_0^\infty \int_0^\infty \rho(1p, \epsilon_{\pi_1}) \rho(1p, \epsilon_{\pi_2}) \rho(1p, \epsilon_{\nu_1}) \rho(1p, \epsilon_{\nu_2})$$

$$\delta(E - \epsilon_{\pi_1} - \epsilon_{\pi_2} - \epsilon_{\nu_1} - \epsilon_{\nu_2}) \Theta(\epsilon_{\pi_1} - \epsilon_F) \Theta(\epsilon_{\pi_2} - \epsilon_F) \Theta(\epsilon_{\nu_1} - \epsilon_F) \Theta(\epsilon_{\nu_2} - \epsilon_F) d\epsilon_{\pi_1} d\epsilon_{\pi_2} d\epsilon_{\nu_1} d\epsilon_{\nu_2}, \tag{6}$$

$$\rho(4p,E)=\int_0^\infty\int_0^\infty\int_0^\infty\int_0^\infty \rho(1p,\epsilon_{\pi_1})\rho(1p,\epsilon_{\pi_2})\rho(1p,\epsilon_{\nu_1})\rho(1p,\epsilon_{\nu_2})$$

$$\delta(E-\epsilon_{\pi_1}-\epsilon_{\pi_2}-\epsilon_{\nu_1}-\epsilon_{\nu_2})d\epsilon_{\pi_1}d\epsilon_{\pi_2}d\epsilon_{\nu_1}d\epsilon_{\nu_2}. \qquad (7)$$

In Eqs.(6,7) $\rho(1p,\epsilon)$ is the one-particle state density. We use the Fermi-gas model for the nucleons of the nuclear system, and ϵ_F is the nucleon Fermi energy. In this case the one-particle state densities for the protons and neutrons have the following forms, respectively:

$$\rho(1p,\epsilon_\pi)=\left(\frac{3Z}{2\epsilon_F}\right)\left(\frac{\epsilon_\pi}{\epsilon_F}\right)^{\frac{1}{2}}, \qquad (8)$$

$$\rho(1p,\epsilon_\nu)=\left(\frac{3N}{2\epsilon_F}\right)\left(\frac{\epsilon_\nu}{\epsilon_F}\right)^{\frac{1}{2}}. \qquad (9)$$

Substituting Eqs.(8) and (9) in (6) and (7) gives the following expressions for the alpha-particle state densities:

$$\rho^P(4p,E)=\left(\frac{3Z}{2\epsilon_F}\right)^2\left(\frac{3N}{2\epsilon_F}\right)^2\frac{1}{\epsilon_F^2}\Theta(E-4\epsilon_F)$$

$$\times\int_{\epsilon_F}^{E-3\epsilon_F}d\epsilon_{\pi_1}\int_{\epsilon_F}^{E-2\epsilon_F-\epsilon_{\pi_1}}d\epsilon_{\pi_2}(\epsilon_{\pi_1}\epsilon_{\pi_2})^{\frac{1}{2}}\left[\frac{1}{2}(E-\epsilon_{\pi_1}-\epsilon_{\pi_2}-2\epsilon_F)\right.$$

$$\left.\times\left[(E-\epsilon_{\pi_1}-\epsilon_{\pi_2})\epsilon_F-\epsilon_F^2\right]^{\frac{1}{2}}+\frac{1}{4}(E-\epsilon_{\pi_1}-\epsilon_{\pi_2})^2\sin^{-1}\left(\frac{E-\epsilon_{\pi_1}-\epsilon_{\pi_2}-2\epsilon_F}{E-\epsilon_{\pi_1}-\epsilon_{\pi_2}}\right)\right], \qquad (10)$$

$$\rho(4p,E)=\left(\frac{3Z}{2\epsilon_F}\right)^2\left(\frac{3N}{2\epsilon_F}\right)^2\frac{\pi}{8\epsilon_F^2}\int_0^E d\epsilon_{\pi_1}\int_0^{E-\epsilon_{\pi_1}}d\epsilon_{\pi_2}(\epsilon_{\pi_1}\epsilon_{\pi_2})^{\frac{1}{2}}(E-\epsilon_{\pi_1}-\epsilon_{\pi_2})^2. \qquad (11)$$

The Pauli-blocking factor (5) does not include momentum conservation. The justification for ignoring linear-momentum restrictions in the alpha-particle emission process was given by Chadwick and Oblozinsky [7], where it was shown that if one looks at a ratio of two state densities, to a good approximation the "full" state densities which ignore the momentum conservation reproduce this ratio (to an accuracy of about 10%).

It can be seen from Eqs. (5, 10,11) that the Pauli-blocking factor can be expressed in the form:

$$F(E)=\Theta(E-4\epsilon_F)F'(E). \qquad (12)$$

In Eq. (12) the quantity $4\epsilon_F$ enters the argument of the unit step function. This quantity plays the role in some sense of the "effective Fermi energy" for the gas of alpha-particles. The Pauli-blocking factor is equal to zero below this limit and becomes finite in the region above the limit of $4\epsilon_F$, where the cluster of four fermions is assumed to be after the interaction with the neutron in the nucleus. The occupied states in the rest of the nucleus restrict the number of states accessible for the alpha-particle after the interaction. The effect of this restriction on the phase space is taken into account by means of the Pauli-blocking function $f(\epsilon_{\rm inc})$ in Eq.(2). We emphasize that the appearance of the quantity $4\epsilon_F$ as an "effective alpha-particle Fermi-energy" originates naturally from the Fermi-gas model used for the nucleons which form the alpha-cluster. This justifies the use of the concept of "the alpha-particle Fermi-gas model" in earlier works (e.g. [5] and [8]).

In Eq.(2), $T(E)$ is the transmission coefficient related to the interaction of the alpha-particle with the residual nucleus, which can be calculated from the optical model potentials for the alpha plus residual nucleus interaction. Since in our Fermi-gas model we measure the energies of the nucleons and the alpha-particles from the bottom of the potential well, the transmission coefficient in (2) contains a theta-function which enables it to "start" at an energy $4\epsilon_F + B_\alpha$, B_α being the alpha-particle binding energy (B_α= 28.3 MeV):

$$T(E) = \Theta[E - (4\epsilon_F + B_\alpha)]T'(E). \tag{13}$$

In this stage of the development of the model we use transmission coefficients averaged over a range of values of the angular momentum L. So we have in Eqs. (2,13) approximately

$$T'(E) = \frac{\sum_{L=0}^{L_{\max}}(2L+1)T_L(E)}{\sum_{L=0}^{L_{\max}}(2L+1)}. \tag{14}$$

Making the substitution $\epsilon = \epsilon_\alpha + \epsilon_{\rm inc}$ in Eq. (2) and using Eqs. (3,12,13) we obtain the following expression for the Pauli-blocking function

$$f(\epsilon_{\rm inc}) = \frac{3}{2(\epsilon_F^\alpha)^{\frac{3}{2}}} \int_{\epsilon_F^\alpha}^{\epsilon_F^\alpha+\epsilon_{\rm inc}} (\epsilon - \epsilon_{\rm inc})^{\frac{1}{2}} F'(\epsilon)T'(\epsilon)d\epsilon, \tag{15}$$

where

$$\epsilon_F^\alpha = 4\epsilon_F + B_\alpha. \tag{16}$$

The model suggested in this work is similar to the quasi-free scattering (QFS) pre-equilibrium model developed by Mignerey, Blann and Scobel [8,9], and based on the Harp-Miller-Berne approach [10,11] (which uses a Boltzmann diffusion equation to describe the evolution of the reaction). The main differences lie in the treatment of Pauli-blocking effects, and our use of transmission coefficients, rather than inverse cross sections with detailed balance, to account for the barrier penetration by the alpha-particle. The basic relations of our model, Eqs. (1,2,15) can be interpreted as the first (and at these energies, the dominant) term of a scattering series suggested in the QFS model [8,9].

III. THE CALCULATIONS OF (N,α) CROSS-SECTIONS

Since the direct and statistical emission of alpha-particles (as well as nucleons) take place together during the evaluation of the system created in a nuclear collision, one needs a cosistent way to extract reliable information for any particular process from the experimental reaction cross-section. Thus the application of the direct model suggested in this work also requires a knowlege of the statistical components of this reaction. The Hauser-Feshbach model is most suitable for this. The cross-section of (n,α) reactions is therefore calculated by means of the expression

$$\sigma(n,\alpha) = \sigma_{DC}^{em} + \sigma_{HF}^{em} - \sigma(n,\alpha n'), \tag{17}$$

where σ_{DC}^{em} and σ_{HF}^{em} are respectively the direct and compound Hauser-Feshbach components of the alpha-particle emission cross-section, the former being suggested in this work (σ_{DC}^{α} from Eq.(1)). The superscript "em" in Eq.(17) is underlying the relation of the respective cross-sections with the emitting precesses in contrast with the activation cross-sections. $\sigma(n,\alpha n')$ is the $(n,\alpha n')$-reaction cross-section. It is meaningful only for activation cross-sections.

The calculations of the alpha-emission direct component σ_{DC}^{em} were carried out using Eqs. (1-3,5,10-15). The elastic free (n,α) cross-section $\sigma_{(n,\alpha)}^{\rm free}(\epsilon_{\rm inc})$ has been taken from [12]. The transmission coefficients $T_L(E)$ in (14) were calculated using the optical model potentials from [13]. By investigating the L-dependence of the transmission coefficients, we determined that it is sufficient to include coefficients up to $L_{\rm max} = 11$ for the energies considered in this work. The parameters of the model are the preformation factor ϕ_α, and the nucleon Fermi energy ϵ_F. We set the value of the preformation factor to $\phi_\alpha = 0.30$ in the calculations. This value (found in recent analyses carried out in the framework of both exciton [14,15] and the Geometry-Dependent Hybrid (GDH) model [16]) has been determined by comparison of experimental and calculated alpha-particle emission spectra in 14 MeV neutron-induced reactions on ^{46,48}Ti,^{51}V, ^{50,52}Cr,^{55}Mn, ^{54,56}Fe and ^{59}Co.

The Hauser-Feshbach statistical calculations were made with sets of input parameters that give cross-sections in good agreement with experimental data for all competing reaction channels [16,17]. The $(n,\alpha n')$-reaction cross-section was obtained with the same formalism by taking into account the population of the residual nucleus in the alpha-particle channel given by either direct emission from the composite system or the evaporation from the compound nucleus.

The calculations of the (n,α) cross-section enable us to study the dependence of the results on the nucleon Fermi energy ϵ_F. This parameter is obtained by fitting the calculated excitation function (17) to the experimental data.

The results of the calculations of excitation functions of (n,α) reactions on the ^{54}Fe, ^{51}V, ^{55}Mn, ^{59}Co, ^{48}Ti and ^{52}Cr nuclei are given in Figs. 1-6. They are compared with the available experimental data for ^{48}Ti(n,α) ^{45}Ca from [14], for ^{51}V(n,α)^{48}Sc, ^{54}Fe(n,α)^{51}Cr, ^{59}Co(n,α)^{56} Mn and ^{55}Mn(n,α) ^{52}V from [18], and for ^{52}Cr(n,α)^{49}Ti from [19]. The data are obtained by using the activation technique and thus they refer specifically to the (n,α gamma) reaction (one chance alpha-particle emission), so that in the present analysis the (n,α n') reaction cross-section has to be subtracted from the total alpha-particle emission cross-section $\sigma_{DC}^{em} + \sigma_{HF}^{em}$, Eq. (17).

As an example we give in Fig. 7 the Pauli-blocking function $f(\epsilon_{\rm inc})$ in the case of the ^{54}Fe(n,α)^{51}Cr reaction for various values of the Fermi energy ϵ_F.

The optimum values of the nucleon Fermi energy ϵ_F with $\phi_\alpha = 0.30$ are given in Table 1. According to the local density approximation the values of ϵ_F from 9.0 to 4.0 MeV correspond to nuclear surface densities from $\rho = 0.106\rho_0$ to $\rho = 0.032\rho_0$ (when ϵ_F=40 MeV at $\rho = \rho_0$) and agree with the range (4-8 MeV) found in the QFS-model [8] when applied to (nucleon, alpha) reactions.

The sensitivity of the cross-section to variations of ϕ_α and ϵ_F was studied and it was found that the fit is essentially unaffected by correlated changes in these two parameters. Thus the parameter values (0.20, 7.0), (0.30, 9.0), and (0.40, 10.5) for $(\phi_\alpha, \epsilon_F)$ give the same cross-section for the ^{51}V (n,α)-reaction. For a particular value of ϕ_α, we estimate the uncertainty in ϵ_F to be about 0.5-1 MeV.

We should like to emphasize that the nucleon Fermi energy ϵ_F is not a new parameter suggested in this model in comparison with the original preformation model. The same two parameters, namely the preformation factor ϕ_α and the nucleon Fermi energy ϵ_F (taken to be equal to 20 MeV), have been used in the exciton model calculations of the (n,α) reaction cross-sections [5]. In this sense our model involving the assumption of ϕ_α= 0.30 and ϵ_F for alpha-particles as parameters is similar to the original preformation model and to the QFS model [8,9]. The values of ϵ_F obtained for various nuclei are indicative of surface character of the direct process.

We note that the results for the direct components of the α-emission cross-section σ_{DC}^{em} obtained in this model are in agreement with those obtained in the GDH-model [17], where the direct inelastic scattering to the continuum is described by the "direct term" of the model ([20] and references therein) for the pre-equilibrium emission. The generalized version of the GDH-model [16] includes the alpha-particle emission within the preformed cluster-exciton approach ([21] and references therein) and some additional assumptions, in particular: 1) The particle-hole state densities [22] used in the conjunction with the parameter ϕ_α [21]; 2) The exciton single-particle and alpha-particle state densities [22] are the Fermi-gas ones below the Fermi level, and depend linearly on the energy above this level; 3) The Fermi-gas model relationships for the alpha-particle in the nuclear medium are the same as that used in our direct model (Eq.(16); 4) The alpha-particle state density at the corresponding Fermi level $g_\alpha(\epsilon_F^\alpha) = A/10.36MeV^{-1}$; 5) The use of an average imaginary optical model potential for the calculations of the intranuclear transition rates of emitted particles.

In this paper the Pauli-blocking effects on the cross-section of (n,α)-reactions are considered using a phase-space analysis. The interaction of the alpha-particle with the residual nucleus is also taken into account. It is shown that the model gives a correct description of the direct components of the (n,α) cross-section (and of the total excitation function after including the statistical components) with reasonable values of the nucleon Fermi energy which indicate a nuclear surface reaction.

IV. ACKNOWLEDGMENTS

This work was funded in part by the ECC (Contract No. ERB-CIPA-CT-92-2159), by the Bulgarian National Science Foundation (Contracts No. Ph.-32, 406 (A.N.A), under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under Contract No. W-7405-ENG-48 (M.B.C.), by the Royal Society (M.A.), and by the agreement of the Royal Society with the Bulgarian Academy of Sciences (A.N.A.).

REFERENCES

[1] E. Gadioli, P.E. Hodgson, Rep. Progr. Phys. 52, 247 (1989); Pre-Equilibrium Nuclear Reactions, Clarendon Press, Oxford, 1992.

[2] E. Gadioli, S. Mattioli, W. Augustyniak, L. Glowacka, M. Jaskola, J. Turkiewicz, A. Chiadli, Phys. Rev. C43, 1932 (1991).

[3] E. Gadioli, E. Gadioli Erba, W. Augustyniak, L. Glowacka, M. Jaskola, J. Turkiewicz, Phys. Rev. C38, 1649 (1988).

[4] E. Gadioli, E. Gadioli Erba, L. Glowacka, M. Jaskola, J. Turkiewicz, L. Zemlo, J. Dalmas, A. Chiadli, Phys. Rev. C34, 2065 (1986).

[5] A. Ferrero, E. Gadioli, E. Gadioli Erba, I. Iori, N. Mohlo, L. Zetta, Z. Phys. A293, 123 (1979).

[6] M.B. Chadwick, P. Oblozinsky, P.E. Hodgson, G. Reffo, Phys. Rev. C44, 814 (1991).

[7] M.B. Chadwick, P. Oblozinsky, Phys. Rev. C46, 2028 (1992).

[8] W. Scobel, M. Blann, A. Mignerey, Nucl. Phys. A287, 301 (1977).

[9] A. Mignerey, M. Blann, W. Scobel, Nucl. Phys. A273, 125 (1976).

[10] G.D. Harp, J. M. Miller, B.J. Berne, Phys. Rev. 165, 1166 (1968).

[11] G.D. Harp, J.M. Miller, Phys. Rev. C3, 1847 (1971).

[12] JAERI-M 90-099 (JENDL-3); K. Shibata, J. of Nucl. Sci. and Technology 27[1], 81 (1990).

[13] V. Avrigeanu, P. E. Hodgson and M. Avrigeanu, Phys. Rev. C49, (1994) (in print).

[14] S.M. Qaim, M. Uhl, N.I. Molla, H. Liskien, Phys. Rev. C46, 1398 (1992).

[15] N. I. Molla, S. M. Qaim, M. Uhl, Phys. Rev. C42, 1540 (1990)

[16] M. Avrigeanu, M. Ivascu and V. Avrigeanu, Z. Phys. A235, 299 (1990).

[17] M. Avrigeanu, V. Avrigeanu and P. E. Hodgson, in Proc. of Int. Adv. Courses on Frontier Topics in Nuclear Physics, Predeal, Romania, September 1993, Eds. W. Scheid, A. Sandulescu, Plenum, N.Y. (in press).

[18] V.McLane, Ch.L. Dunford, P.E. Rose, Neutron Cross Sections, vol.2, Neutron Cross Section Curves, Academic Press, Inc., Boston, 1988.

[19] S.M. Grimes, R.C. Haight, K.R. Alvar, H.H. Barschall, R.R. Borchers, Phys. Rev. C19, 2127 (1979); A.A. Paulsen, H. Liskien, F. Arnotte, R. Widera, Nucl. Sci. Eng. 78, 377 (1981).

[20] M. Blann and H. K. Vonach, Phys. Rev. C28, 1475 (1983).

[21] E. Gadioli, E. Gadioli Erba and J. J. Hogan, Phys. Rev. C16, 1404 (1977).

[22] M. Avrigeanu and V. Avrigeanu, J. Phys. G20, 613 (1994).

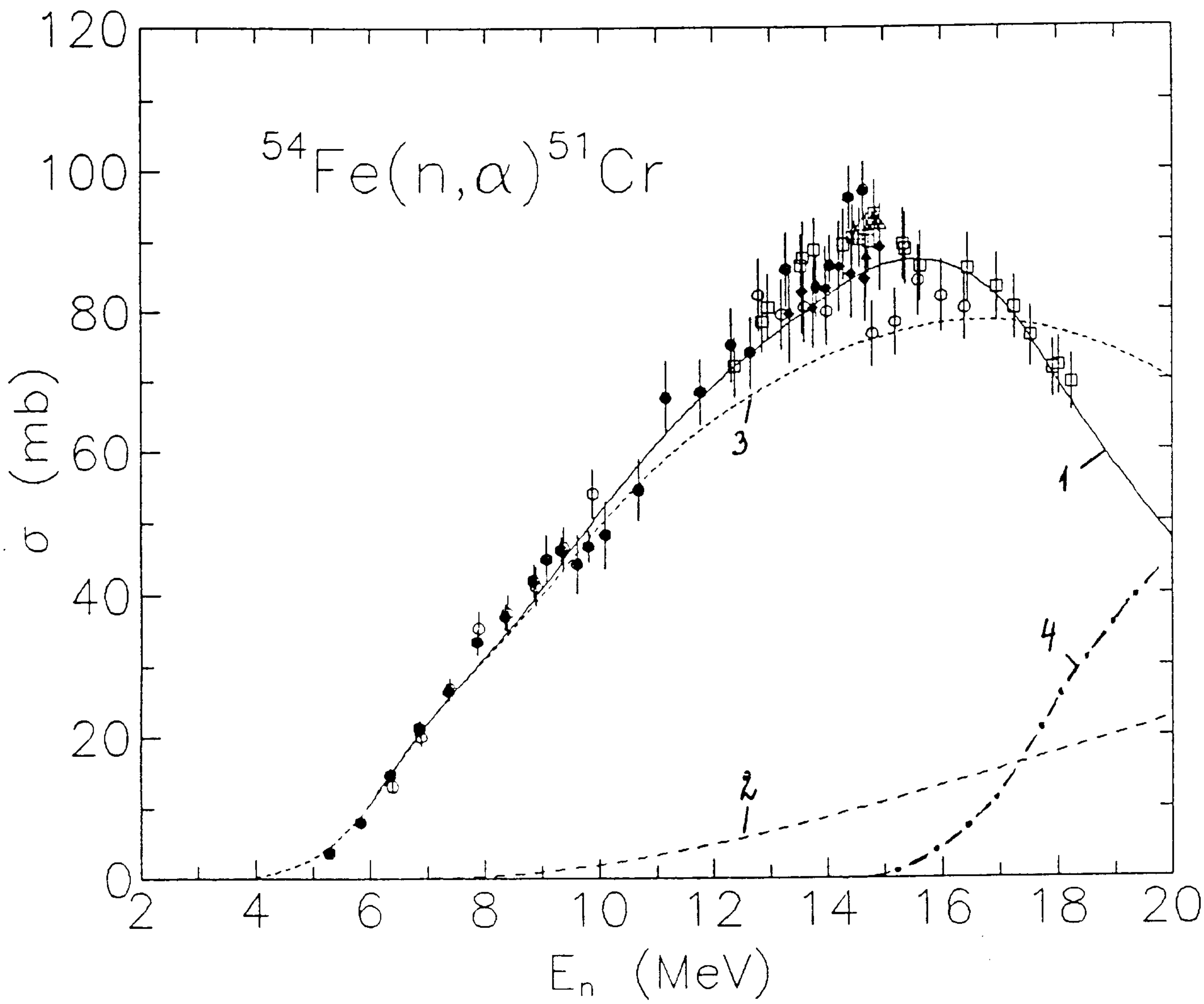

FIG. 1. The excitation function of the $^{54}Fe(n,\alpha)^{51}Cr$ reaction. Solid line (1): $\sigma(n,\alpha)$, dashed line (2): σ^{em}_{DC}, short-dashed line(3): σ^{em}_{HF}, dot-dashed line (4): $\sigma(n,\alpha n')$. References to the works from which the experimental data are taken are given in the text.

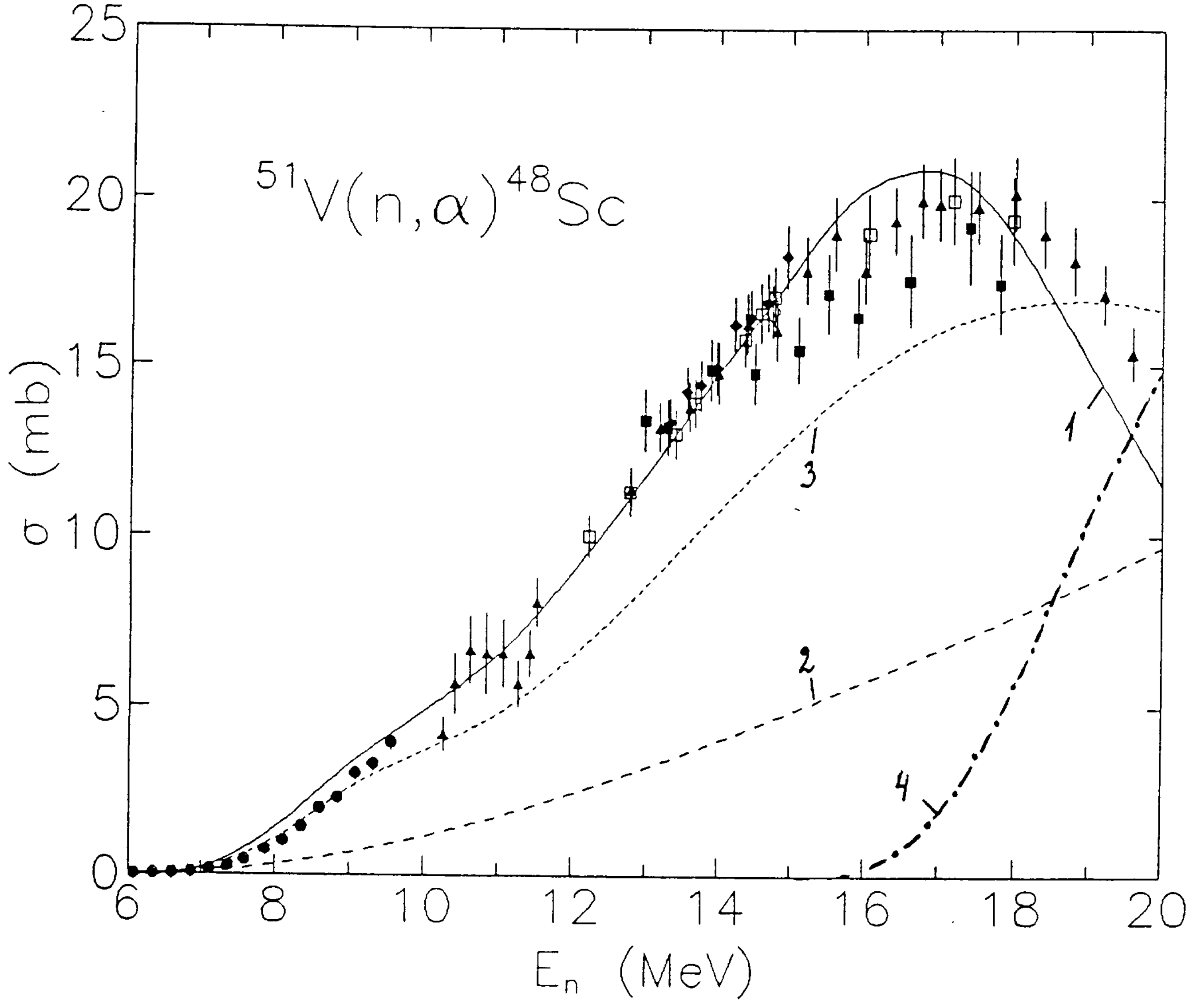

FIG. 2. The same as in Fig.1 for the $^{51}V(n,\alpha)^{48}Sc$ reaction.

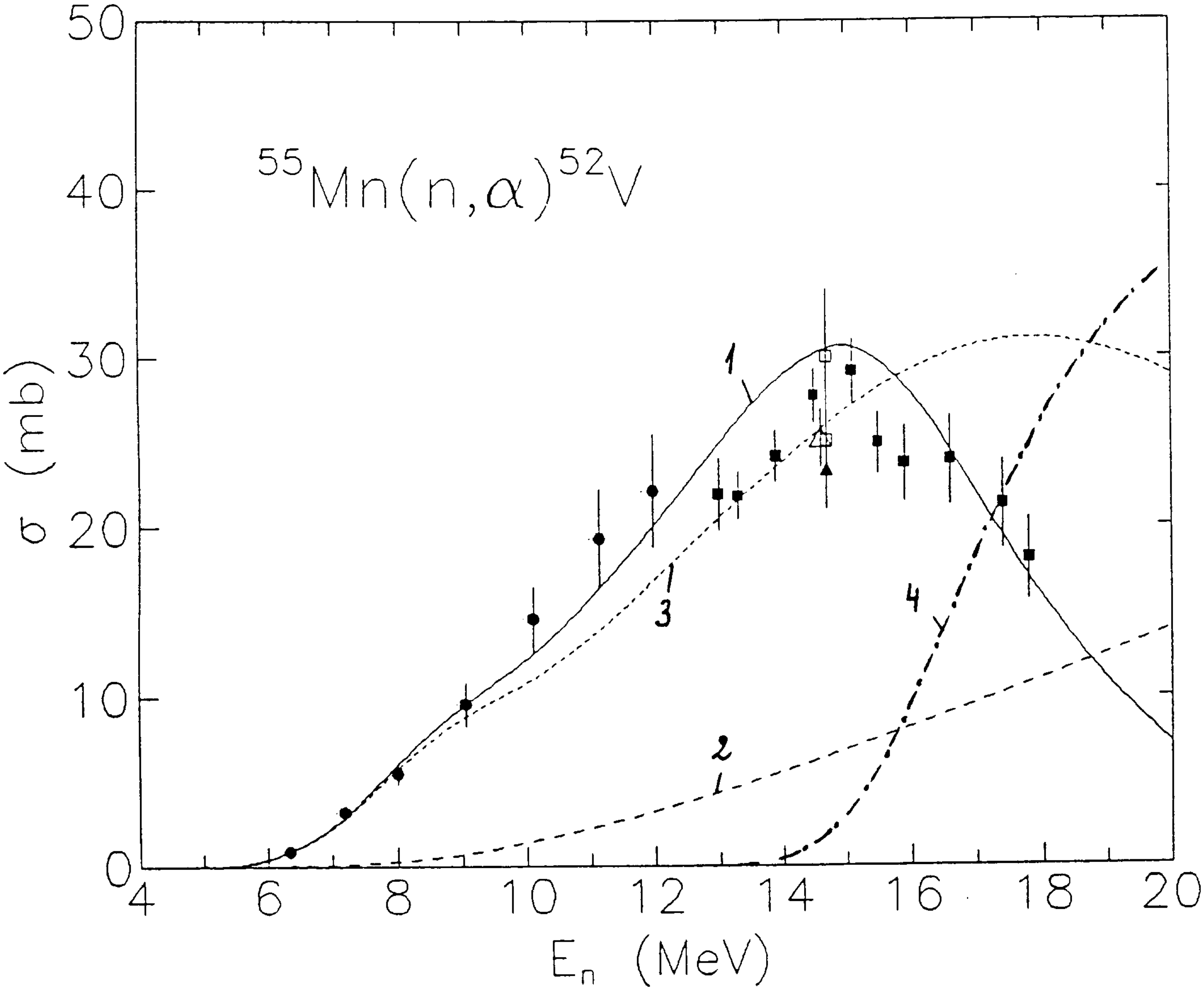

FIG. 3. The same as in Fig.1 for the $^{55}Mn(n,\alpha)^{52}V$ reaction.

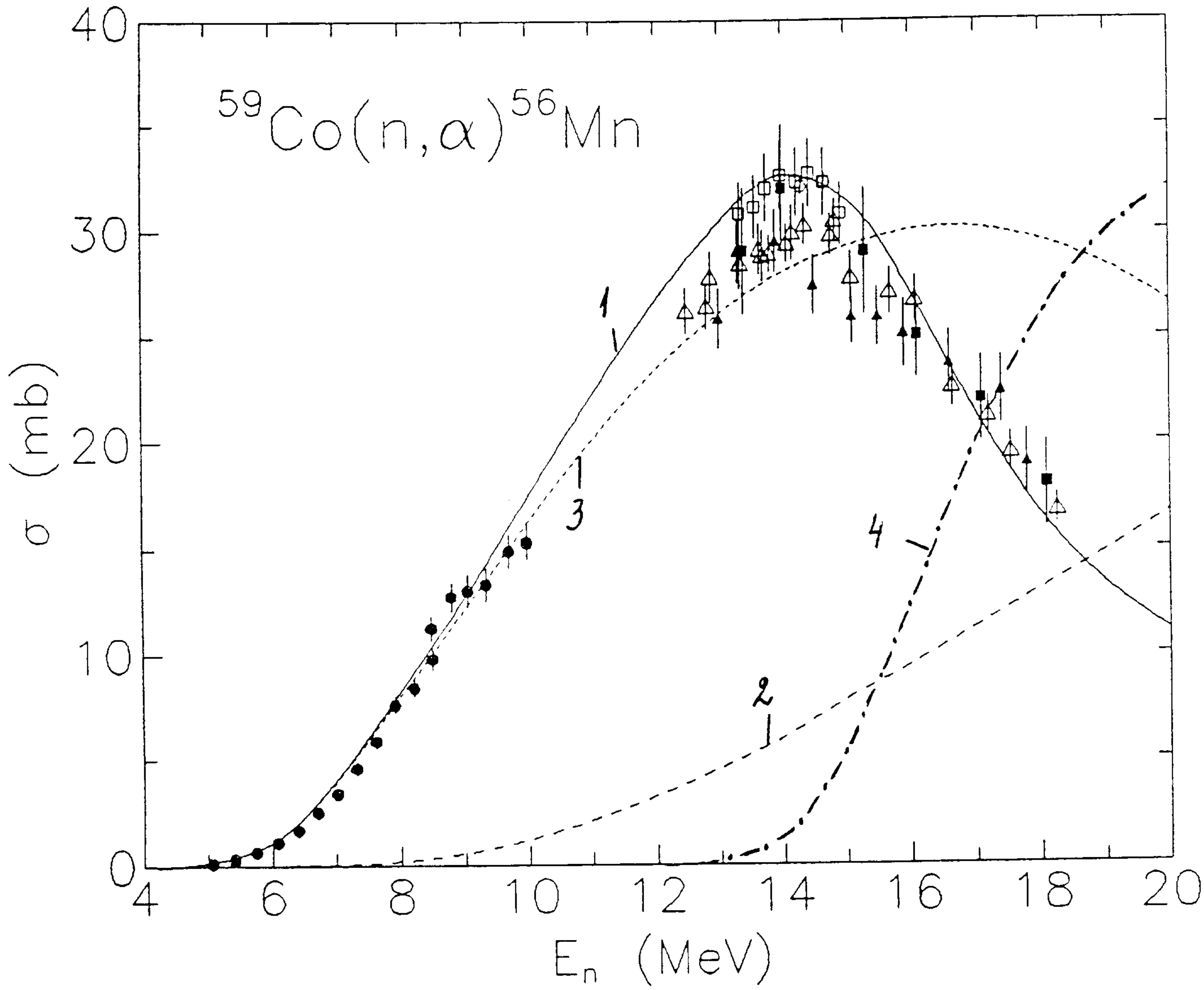

FIG. 4. The same as in Fig.1 for the $^{59}Co(n,\alpha)^{56}Mn$ reaction.

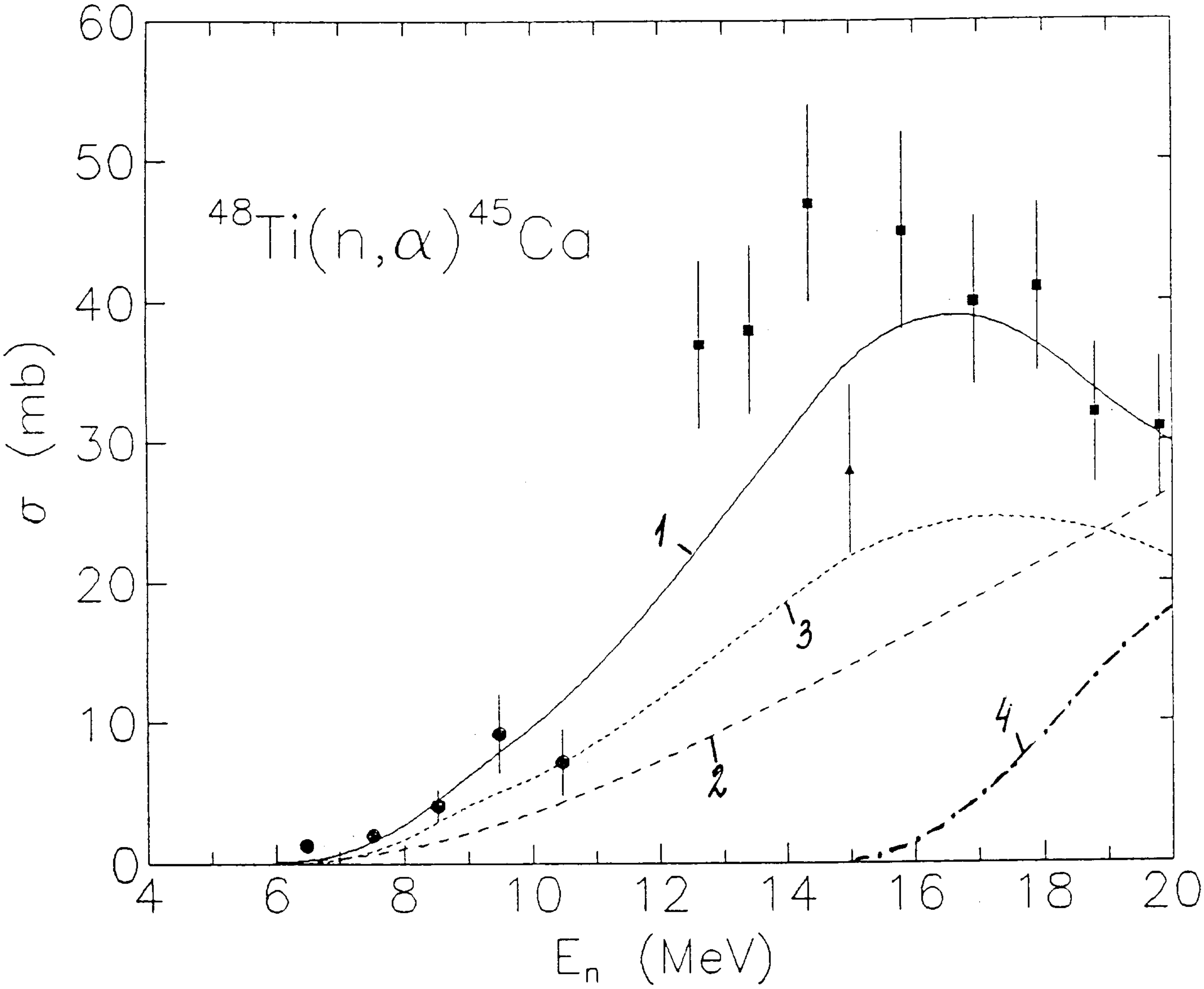

FIG. 5. The same as in Fig.1 for the $^{48}Ti(n,\alpha)^{45}Ca$ reaction.

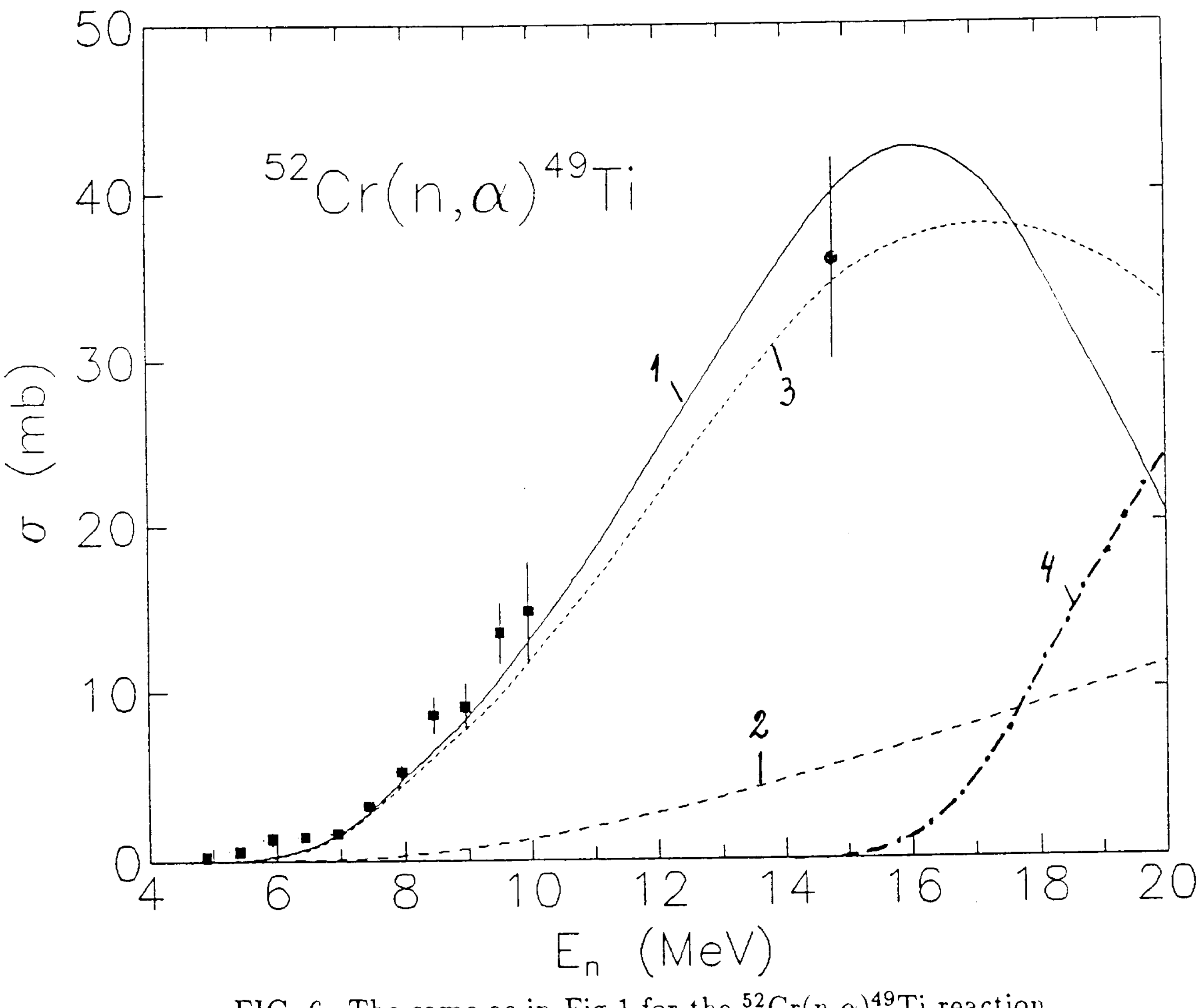

FIG. 6. The same as in Fig.1 for the $^{52}Cr(n,\alpha)^{49}Ti$ reaction.

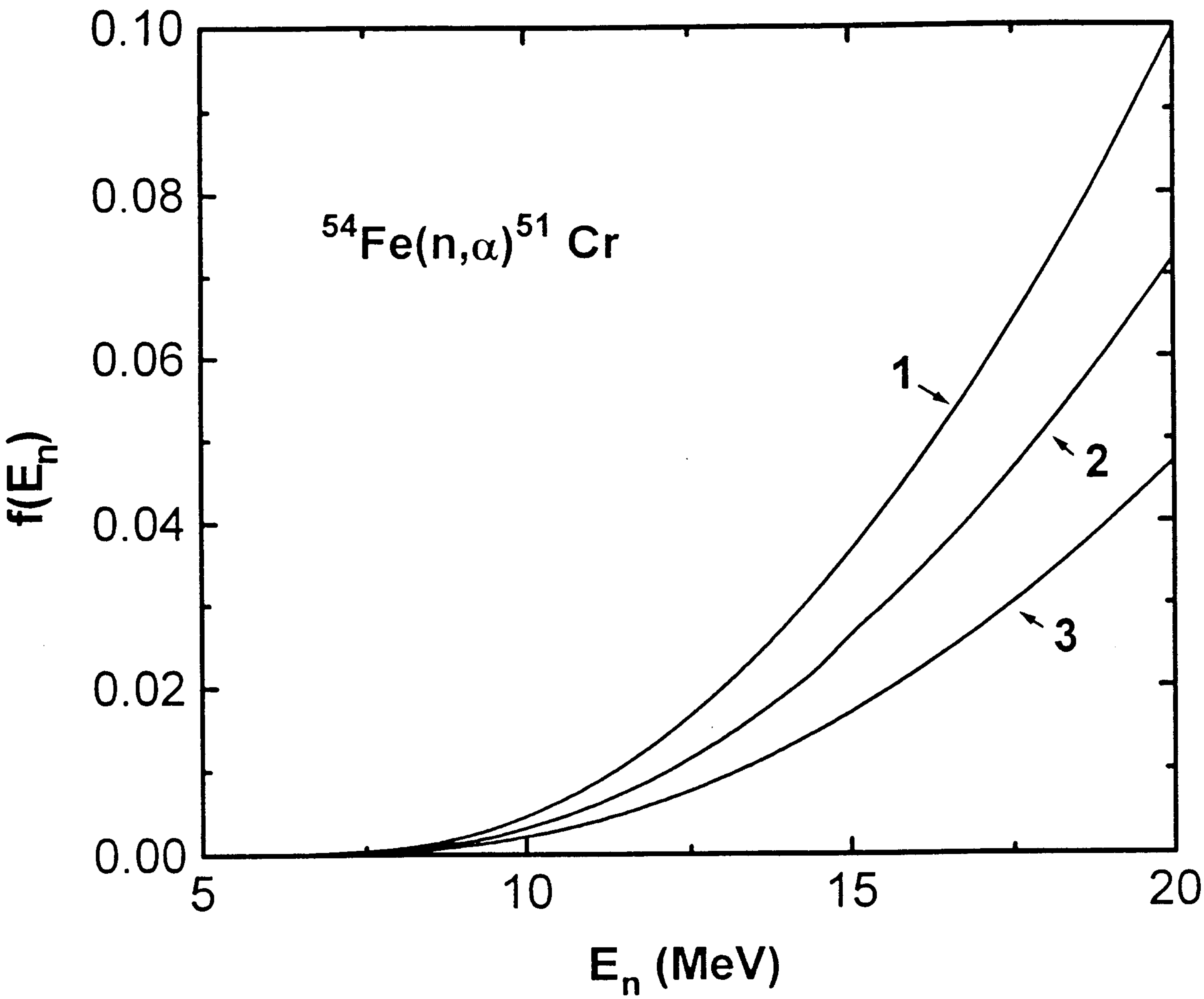

FIG. 7. The Pauli-blocking function $f(\epsilon_{inc})$ for the $^{54}Fe(n,\alpha)^{51}Cr$ calculated with the following values of ϵ_F: 4.5 MeV (curve 1), 6 MeV (curve 2) and 8 MeV (curve 3).

TABLE I. Values of the nucleon Fermi-energy using ϕ_α = 0.30. The low values of the Fermi energy indicate a nuclear surface reaction

Nuclei	^{51}V	^{55}Mn	^{59}Co	^{48}Ti	^{52}Cr	^{54}Fe
ϵ_F (MeV)	9.0	7.0	6.0	4.0	8.0	4.5