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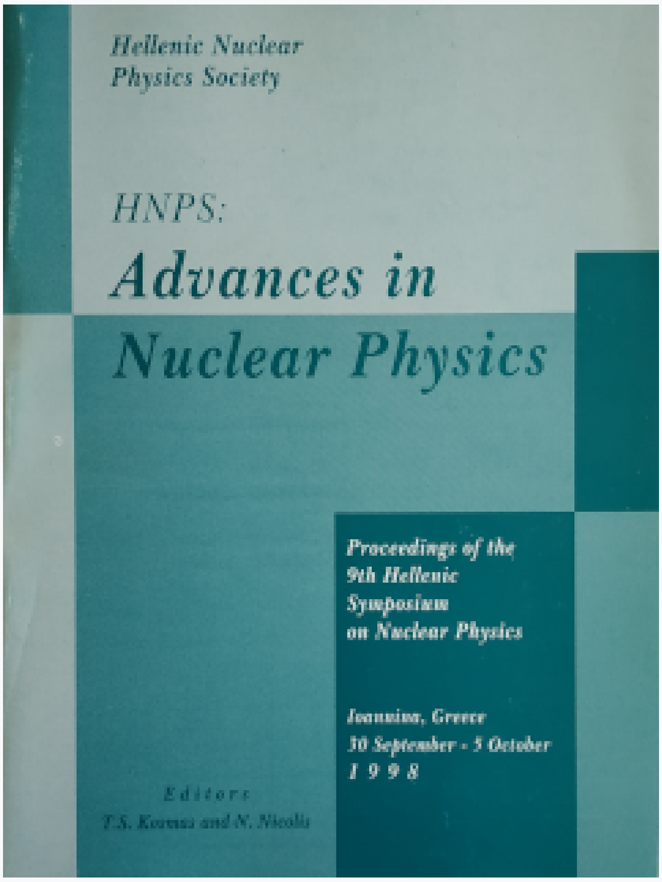

Alpha particle transmission coefficients from a global optical potential

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Alpha particle transmission coefficients from a global optical potential

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Abstract

Statistical model calculations involving a large number of emitted particles can be greatly facilitated by using transmission coefficients in a parametrized form. Thus, the execution and storage of the results of extensive optical model calculations can be avoided. Along these lines, a parametrization of optical model transmission coefficients, involving n, p, ^2H, ^3He and ^4He on many targets, was produced some years ago. In the present work, we question the validity of this technique in the description of low-energy alpha particle evaporation. We propose a new parametrization with an improved low energy behavior.

1 Introduction

The interpretation of heavy-ion fusion-evaporation reactions heavily relies on the use of the statistical model of nuclear reactions. Isotopic production yields, energy and angular distributions of the emitted particles can be investigated under the assumption of emission from an equilibrated compound nucleus [1].

One of the basic ingredients of the statistical model is the particle penetrabilities. Transmission coefficients ($T_\ell(E)$) for particle emission are usually obtained from an optical model (O.M.) calculation as an estimate of the the inverse process of particle absorption from the daughter nucleus. Particle emission cross sections are obtained in the statistical model through the principle of detailed balance, assuming equality for the transmission coefficients for particle emission with the ones corresponding to the inverse process of absorption.

Depending on the case, statistical model calculations may easily require the calculation and storage of more than a million entities due to the energy and angular momentum dependence of T_ℓ's for each particle type and emitting nuclear species[2,3]. This number may grow up enormously, if we want to refine the calculations to include emission of clusters heavier than alpha particles [3], the effect of emitting nucleus deformations [4] and/or temperature effects in particle transmission [5]

One way to overcome this problem is to use a parametrization of the O.M. transmission coefficients [6]. Such a parametrization was given some years ago, by Murthy, *et al.* [7]. It was reported that the proposed empirical forms predict the transmission coefficients and the magnitude of the scattering matrix satisfactorily for nuclei over the whole periodic table and energies up to 50 MeV. However, neither the low energy behavior nor the performance of these empirical forms was tested in actual statistical model calculations. Such a test is performed in the present work for alpha particles

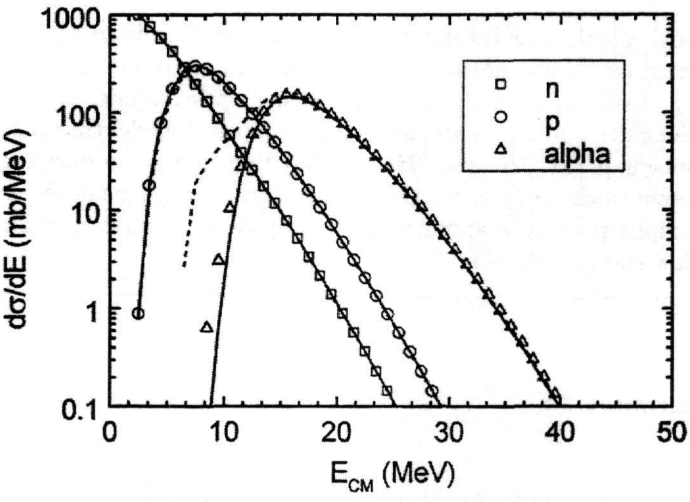

Fig. 1. Energy spectra of neutrons, protons and alpha particles emitted in the reaction $^{14}N +^{103} Rh$ at 121 MeV. The symbols show the calculated spectra with optical model transmission coefficients. The curves correspond to a calculation with the same evaporation parameters and parametrized T_ℓ's for alpha particles, according to Murthy *et al.* (dashed curves) and the present work (solid curves).

2 Parametric forms for alpha particle transmission coefficients

We performed statistical model calculations with the code CASCADE [2], involving evaporation of neutrons, protons and alpha particles. As a test case we consider the deexcitation of the compound nucleus ^{117}Te formed in the reaction $^{14}N +^{103} Rh$ at 121 MeV. The evaporation parameters were chosen in order to provide a close description of reported experimental particle spectra

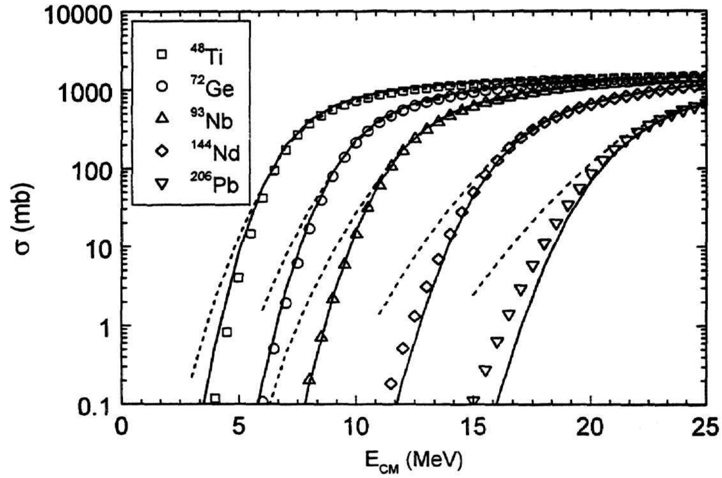

Fig. 1. Reaction cross sections of alpha particles on the indicated targets as a function of the center of mass energy. Transmission coefficients were taken from the optical model (solid curves), the parametrization of Murthy *et al.* (short dashed curves) and the present work (long dashed curves).

and multiplicities [3]; they were kept fixed in the following transmission coefficient tests. Figure 1, shows the calculated neutron, proton and alpha-particle evaporation energy spectra. The symbols correspond to the calculation with optical model transmission coefficients (T_ℓ^{OM}). The dashed curves show the results of a calculation using optical model transmission coefficients for neutrons and protons, and parametrized transmission coefficients (T_ℓ^{PAR}) for alpha particles from Ref. [7]. It is realized that the calculation with T_ℓ^{PAR} severely overestimates the low energy part of the alpha spectrum.

The same parametrization also overestimates low-energy optical model reaction cross sections of alpha particles on different targets. This is shown in Figure 2, where the symbols refer to the optical model and the dashed lines to reaction cross section calculations using T_ℓ^{PAR}.

For the alpha particle transmission coefficients, the functional form of Murthy *et al.* makes use of a Fermi combined with an exponential function

$$T_\ell = \{1 + \exp\left[\left(\ell(\ell+1) - L(L+1)\right)/D\right]\}^{-1} \text{ for } \ell \leq L \text{ and} \tag{1}$$

$$T_\ell = \frac{1}{2}\exp\left[\left(\ell(\ell+1) - L(L+1)\right)/D'\right] \text{ for } \ell > L \tag{2}$$

where L is determined by the relation

$$L(L+1) = \frac{2\mu R^2}{\hbar^2}\left(E - V_N(R) - V_C(R)\right) \tag{3}$$

The parameters D, D' and $R = R(E)$ were determined in a fitting procedure to have the following dependence on the target mass number A_T and the center of mass bombarding energy E:

$$D = d_1 A_t^{1/3} + d_2 A_T + d_3 \tag{4}$$

$$D' = \left(d'_1 A_t^{1/3} + d'_2 A_T^{2/3}\right) E + d'_3 A_T + d_4 \tag{5}$$

$$R(E) = r_1 A_T^{1/3} + r_2 E^{1/2} + r_3 \tag{6}$$

We traced the origin of the previous problems in (a) the use of the exponential function of Eq. (2), i.e. in the parametrization of the tail regions, and (b) an overestimation of $L(L+1)$ in Eq. (3), which expresses the energy where $T_\ell(E)$ attains the value of 0.5, for the highest partial waves. This is exemplified in Fig.3 which shows transmission coefficients for alpha particles emitted from ^{117}Te as a function of the center of mass energy, for $\ell = 0$ and $\ell = 10\hbar$. The symbols correspond to the optical model T_ℓ^{OM} and the dashed lines to T_ℓ^{PAR}. The upper panel emphasizes the region of T_ℓ-values greater than 0.5, whereas the lower, logarithmic plot, emphasizes the low-energy tails. Above the $T_\ell = 0.5$ level, the parametrization reproduces T_0^{OM} and underestimates, slightly T_{10}^{OM}. In both cases, the low-energy optical model tails are overestimated. We attribute the deviations discussed in connection with Figs. 1 and 2 to this tail behavior.

We realize that the problem of the low-energy parametrization can be dealt with in the following manner: For each partial wave, at the energy $E = E_{1/2}$ where $T_\ell = 0.5$, the parameter D is related with the Hill-Wheeler curvature $(\hbar\omega_\ell)$ by the relation

$$\frac{\hbar\omega_\ell}{2\pi} = \frac{\hbar^2 D}{2\mu R^2}$$

From an examination of the energy derivatives $dT_\ell(E)/dE$,, it follows that their low energy tails can be described adequately with Gaussians. The width σ of such a Gaussian is related with $\hbar\omega_\ell$ by

$$\sigma_\ell = \frac{4}{\sqrt{2\pi}}\left(\frac{\hbar\omega_\ell}{2\pi}\right)$$

For this reason we suggest an *error function* form for the parametric descrip-

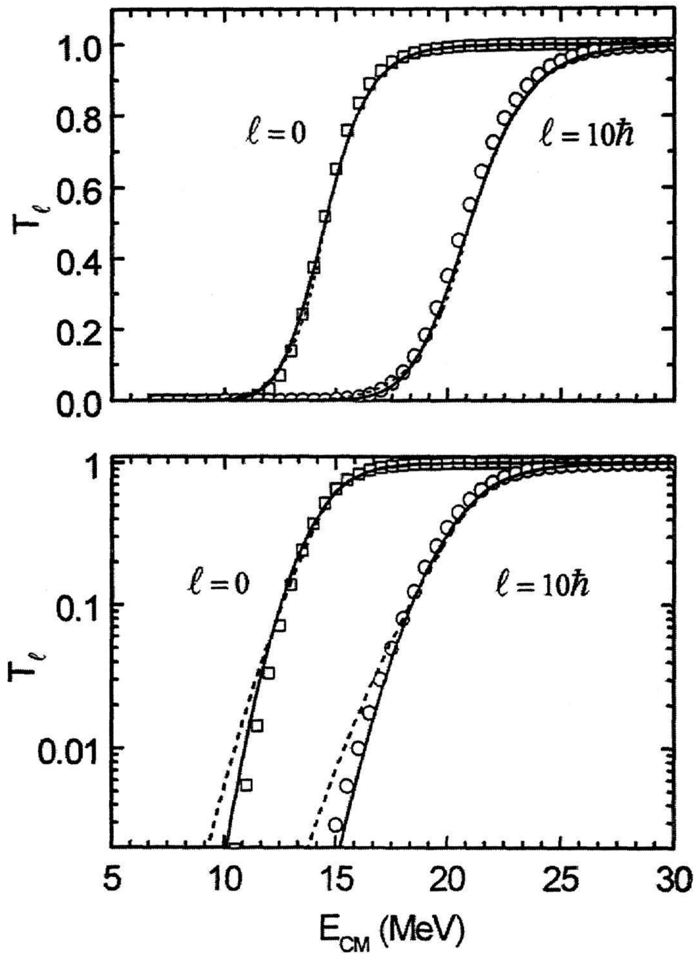

Fig. 2. The symbols show the energy dependence of T_ℓ^{OM} for alpha particles incident on ^{117}Te with $\ell = 0$ and $\ell = 10\hbar$. The dashed and solid curves show the results of the global parametrization of Murthy *et al.* and the present work, respectively.

tion of transmission coefficients below $E = E_{1/2}$

$$T_\ell^{erf}(E) = \frac{1}{2}\left\{1 + erf\left(\frac{E - V_b}{\Delta}\right)\right\} \tag{7}$$

The above modification greatly improves the agreement of the parametrization with the results of the optical model. In Fig. 3, the error function transmission coefficients with a parameter σ fixed at $E = E_{1/2}$ (solid curves) seems to be superior than the exponential function (2) which involves the energy-dependent parameter D'. A statistical model calculation for the reaction $^{14}N +^{103} Rh$ now yields the n, p and α energy spectra shown by the solid lines in Fig. 1. It is realized that the problem of low energy alpha particle emission is restored. There is only a small underestimation of the exact result by the new calculation. Furthermore, a recalculation of the reaction cross sections yields the solid lines shown in Fig. 2. There is a big improvement in the reproduction of low energy cross sections. However, there is a tendency to underestimate the low energy cross sections of the heaviest systems ($A \geq 140$).

3 Conclusion

We presented an improvement in a reported parametrization of optical model transmission coefficients for alpha particles. Remaining discrepancies with the exact results of optical model calculations are under investigation. Upon completion, such a technique can easily be extended to other types of strongly absorbing particles (^3He, ^6Li, ^{12}C, ...). Implementation of this procedure in statistical model calculations, involving a large number of emitted fragments, is expected to speed up the execution time and facilitate the study of additional effects.

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