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ON THE FORMFACTOR OF THE IMAGINARY PART AND ITS COUPLING TO THE REAL OPTICAL POTENTIAL FOR THE α-NUCLEUS SCATTERING

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The model-independent formfactor of the absorptive α-nucleus potential was calculated and compared with model dependent ones. The coupling between the shapes of the real and imaginary potential is discussed.

A number of diffraction and interference phenomena involved in the elastic scattering of α-particles results in a quite complicated pattern of angular distributions, especially at higher incident energies. The optical model description of these angular distributions, particularly in the full region of scattering angles, is difficult and several modifications to the standard optical potential recently have been proposed in order to decrease χ^2/F down to values of approximately one.

χ^2/F is the χ^2 per one degree of freedom, $F = N-K$, N is the number of experimental points in the angular distribution and K denotes the number of parameters searched for in the optical model calculations.

In the modified optical model the real part of the α-nucleus potential has a new formfactor resulting from a better understanding of the scattering phenomena [1, 2, 3, 4]. The following modified formfactors were used for the real part of the α-nucleus potential: the Woods–Saxon function squared [5], the Woods–Saxon function to the ν-th power [6] or the volume potential supplemented by a surface peak [4].

Potentials with the new formfactors of the real part usually give better fits in phenomenological calculations than the traditional Woods–Saxon potential. The most successful, however, as far as the value of χ^2/F is concerned are the model-independent calculations where the formfactor of the real part of the potential is given by the Fourier–Bessel expansion [7] or is represented by a spline function [8]. Most interesting in the model-independent

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calculations is the better insight into the detailed shape of the α–nucleus interaction and its possible connection with the matter density distribution. In all the above calculations the imaginary part of the potential is of the volume or of the surface type and no attempt has been made to represent it in a model-independent way.

The purpose of this work is to investigate the problem of the absorption of α particles in detail by comparing results obtained with different types of parametrisation of the imaginary part of the potential. So far this subject has not been treated with appropriate attention. In order to make this comparison we have taken the ^{90}Zr (α, α) ^{90}Zr comprehensive set of experimental data of Put and Paans [8]. The data consist of angular distributions measured with the same experimental accuracy in a wide region of scattering angles at incident energies of 40 MeV, 59.1 MeV, 79.5 MeV, 99.5 MeV and 118 MeV. Scattering of α particles from the ^{90}Zr nuclei is free from such "abnormal" phenomena as, e.g., the anomalous large angle scattering (ALAS) [9] and the above scattering energies are in the energy region where the conventional optical model should work properly.

TABLE I

Definitions of the optical potential terms

Formfactor of the real U or of the imaginary W part of the potential	The notation
The Woods-Saxon shape: $\left[1+\exp\frac{r-r_0\sqrt[3]{A}}{a}\right]^{-1}$	(WS)
The Woods-Saxon squared shape	$(\mathrm{WS})^2$
The folded potential supplemented by the surface term (see [4])	(Cowley)
The surface peaked formfactor given as the derivative of the volume formfactor	$\frac{d}{dr}(\mathrm{WS})$ or $\frac{d}{dr}(\mathrm{WS})^2$
The model independent formfactor given by the spline function (see text)	(Spline)

Table I defines different parametrisations of the optical potential terms, investigated in the present work and by other authors.

Three parametrisations have been tested in this work:

$$U(\mathrm{WS})^2+i\left[W_{\mathrm{v}}(\mathrm{WS})^2+W_{\mathrm{D}}\frac{d}{dr}(\mathrm{WS})^2\right], \tag{1}$$

$$U(\mathrm{Spline})+i\left[W_{\mathrm{v}}(\mathrm{WS})^2+W_{\mathrm{D}}\frac{d}{dr}(\mathrm{WS})^2\right], \tag{2}$$

$$U(\mathrm{WS})^2+iW(\mathrm{Spline}). \tag{3}$$

In the model-independent calculations the values of $U(r_i)$ or $W(r_i)$ at n specific radii r_i were treated as n independent parameters of the real potential U or the imaginary potential W. Values of the potential at intermediate radii r were interpolated by a smooth cubic curve (spline) joining the consecutive points $U(r_i)$ or $W(r_i)$. In the case of U, $n = 10$ was used similarly as in the Put and Paans calculations [8]. However, for W it was necessary to increase n up to 16 in order to get satisfactory results. The following r_i were chosen for the absorptive potential: $r_i = 0$, 3,0. 4.0, 4.3, 4.5, 4.7, 5.0, 5.5, 6.0, 6.3, 6.6, 7.0, 8.0, 9.0, 11.0 and 13.0 fm. The parameters of the real as well as of the imaginary part of the

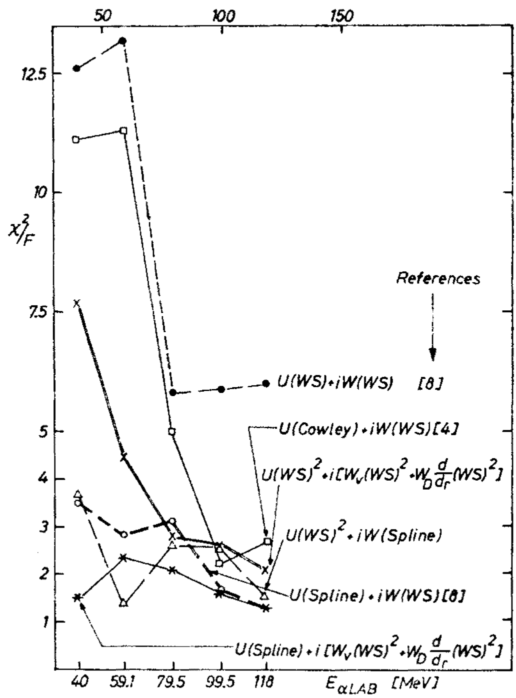

Fig. 1. Comparison of the optical model fit χ^2/F values for the potential parametrisations used by Put and Paans [8], Cowley et al. [4] and in this paper for the experimental data taken from [8]

potential were optimised by the standard fitting procedure. Potential (1) was recently used for ^{90}Zr by Majka and Srokowski [10] in a global parametrisation. The best fit parameters of potential (1) were found in this work.

Fig. 1 shows the best fit values of χ^2/F calculated in this work and by others for different versions of the optical model potential.

As can be seen the (WS) shape of the real part of the potential is definitely-inferior to other parametrisations especially for lower incident energies. The best model-dependent potential is the one given by formula (1). The derivative absorption term $W_D \dfrac{d}{dr}(WS)^2$ is important at lower scattering energies. The significance of this term can also be seen from a comparison of χ^2/F values obtained with potentials (2) and (4) with the former one being superior, where potential (4) is the one used by Put and Paans [8] and defined as:

$$U\,(\text{Spline}) + iW\,(\text{WS}). \tag{4}$$

In order to gain a better insight into the specific radial dependence of the absorption potential the model independent formfactor of the imaginary part of the potential was used in further calculations. The χ^2/F values obtained in this way are comparable with those obtained with the U(Spline) potential (Fig. 1).

Fig. 2 shows W (Spline) vs r for consecutive incident energies of α-particles obtained in the framework of potential (3). At an incident energy of 40 MeV the radial dependence

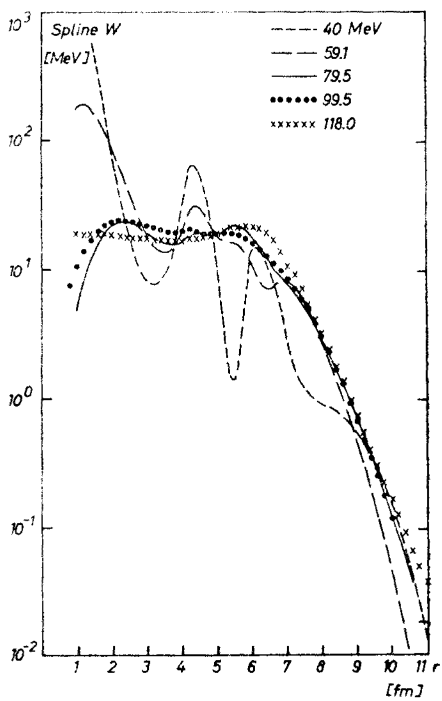

Fig. 2. Radial dependence of the model-independent formfactor W(Spline) found with potential (3) for consecutive energies of α-particles

of W(Spline) is quite complicated requiring the larger number of search points r_i ($n = 16$). This complicated form of $W(r)$ cannot be reproduced by any standard volume or derivative type of the formfactor. This fact explains why at 40 MeV no model-dependent potential could give a χ^2/F value close to one. At higher incident energies W(Spline) has a more smooth radial dependence becoming quite similar to the standard, model-dependent, imaginary potential.

Figs 3 and 4 display the radial dependence of real and imaginary parts of potentials (2), (3) and (4) for two incident energies: 40 MeV and 99.5 MeV. All these potentials con-

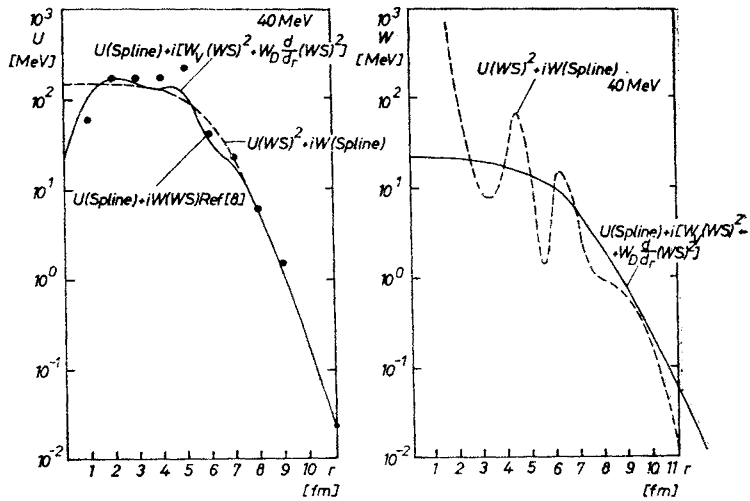

Fig. 3. Radial dependence of the real and the imaginary parts of the best fit potentials (2), (3) and (4) calculated at an incident energy of α particles of 40 MeV. The solid lines represent results for potential (2), the broken curve for potential (3), the dots were obtained according to potential (4) and were taken from Ref. [8]

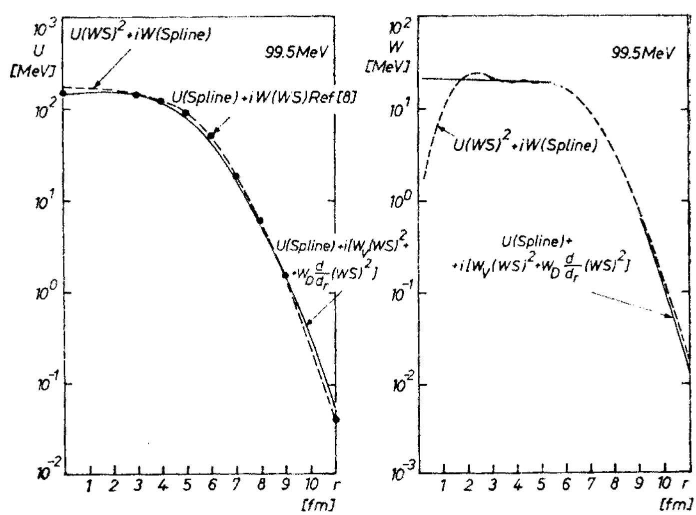

Fig. 4. Radial dependence of the real and of the imaginary parts of the best fit potentials (2), (3) and (4) calculated at an incident energy of α particles of 99.5 MeV. The solid lines represent results for potential (2), the broken curve for potential (3), the dots were obtained according to potential (4) and were taken from Ref. [8]

tain a model-independent part and provide a similar quality of fit to the experimental data. The imaginary part of the Put and Paans potential (4) is not shown in Fig. 3 since it was not given by the authors [8].

It is clear from Fig. 3 that the use of the three different parametrisations of W results at 40 MeV in three different formfactors of U. This coupling between the shapes of the real and imaginary potentials is a new type of ambiquity in the optical model for α particles. At 40 MeV incident energy the real parts of potentials (2), (3) and (4) differ significantly in the region between 3 fm and 7 fm. That is in the sensitive radial region of the potential (see the notch test presented in [8]. This difference between real parts of potentials (2), (3) and (4) diminishes at higher incident energies and becomes negligible at 99.5 MeV.

The coupling between the real and the imaginary parts of the optical potential can be important in all cases where the scattering of α particles is used to investigate the matter density distributions in atomic nuclei [11]. As one sees from Figs 3 and 4 using for that purpose 100 MeV α particles may yield reliable model-independent matter distributions while the incident energy region around 40 MeV can be misleading.

Although the results presented in this paper may indicate nothing more than a new ambiquity in the optical model, one is tempted to look for some physical interpretations of the structure in the W(Spline) formfactors.

All that can be said presently is that the fusion (compound nucleus) reactions should substantially increase the absorption for $r \lesssim R_{1/2}$ ($R_{1/2}$ — the half way radius of the matter density distribution) [12], the break-up of the α particle should be dominant in the region around 7.5 fm [13] and other direct reactions should take place at intermediate distances.

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