PHYSICAL REVIEW C VOLUME 7, NUMBER 4 APRIL 1973

Dependence of Optical-Model Parameters on Isospin*

S. Cotanch and D. Robson

Princeton University, Princeton, New Jersey 08540

and The Florida State University, Tallahassee, Florida 32301

(Received 13 April, 1972)

Global optical-model parameters describing quasielastic reactions are examined. Such potentials, particularly the absorptive components, do not in general conserve isospin. A prescription is offered in an attempt to provide a guideline for deducing optical parameters which do not violate isospin.

In a recent paper by Wong *et al.*[1] optical-model calculations of quasielastic (p, n) scattering were made using a complex isospin potential and the global parameters taken from Becchetti and Greenlees.[2] It is of interest to note that the parameters they used do not conserve isospin. This can easily be seen by transforming their potential to an isospin representation and realizing that the off-diagonal quantities describing the strong interaction do not vanish.

Isospin conservation for the strong interaction can be accomplished by obeying the following relations[3]:

$$V_0 = \frac{(T_0+1)\,V_> + T_0\,V_<}{2T_0+1}\,. \tag{1}$$

$$\frac{V_1}{A} = \frac{2(V_> - V_<)}{2T_0+1}\,. \tag{2}$$

$$V_p = V_0 - \tfrac{1}{2}\,T_0\,\frac{V_1}{A}\,. \tag{3}$$

$$V_n = V_0 + \tfrac{1}{2}(T_0-1)\,\frac{V_1}{A}\,. \tag{4}$$

$$V_{pn} = V_{np} = \tfrac{1}{2}\,(T_0)^{1/2}\,\frac{V_1}{A}\,. \tag{5}$$

Clearly, knowledge of the two quantities $V_<$ and $V_>$ (or V_0 and V_1) completely specifies the potentials V_p, V_n, and V_{pn}. It is important to recognize that in adjusting V_1 to fit quasielastic data one must also make the proper changes in V_0 (or V_p and V_n) in order to fit elastic scattering and preserve isospin. The inclusion of the isospin constraint decreases the number of adjustable parameters. The parameters used in Ref. 1 are inconsistent with the above equations.

A general guideline for determining the proper parameters which describe scattering and conserve isospin follows. For nuclei with neutron excess, the addition of another neutron can only form a $T_>$ state. We may therefore replace $V_>$ by $V_{n'}$, where $V_{n'}$ describes the scattering of a neutron by the target (not the analog). To determine $V_<$ we need simultaneously to fit proton elastic scattering and the quasielastic scattering using coupled equations. However, there are some physical restrictions on the parameters for $V_<$. Since the absorption accounts for flux into other open channels, the absorption for the $T_<$ states should be greater than the absorption for the $T_>$ states. This follows from the fact that for a given nucleus there are many more energetically available $T_<$ channels than $T_>$ channels. Therefore, the imaginary strength of $V_<$ should be greater than the imaginary strength of $V_>$ requiring in turn that the imaginary part of V_1 be positive (since Im $V_>$ and Im $V_<$ are negative). The magnitude of the real part of $V_<$ is also limited since the difference, Re$(V_> - V_<)$, is related to the symmetry energy in the system. For heavy nuclei the relation to the symmetry energy requires that Re $V_<$ be more attractive than Re $V_>$. Although this prescription may not significantly alter some of the global parameters cited above, it will in particular affect the absorptions.

As an example, we have applied the above theory to the specific case of ^{55}Mn$(p, n)^{55}$Fe at $E_p = 17.3$ MeV. Due to the lack and uncertainty of the elastic neutron scattering data, which hopefully will be remedied in the future, there is some ambiguity in deducing $V_>$. However, we were guided by the work of Cassola and Koshel[4] in making a reasonable assignment. The remaining parameters were then found by fitting both the elastic and charge exchange data. The initial choice for the $V_<$ potential was derived from Peterson.[5] The calculations were performed by the computer program TWAVE with the results given in Figs. 1 and 2. The final parameters used were:

Isospin space:

$$V_<^R = -48.93, \quad V_<^I = -9.75 \text{ (surface)};$$

$$V_>^R = -43.91, \quad V_>^I = -8.25 \text{ (surface)}.$$

Neutron-proton space:

$$V_P^R = -48.09, \quad V_P^I = -9.5 \text{ (surface)};$$

$$V_n^R = -44.75, \quad V_n^I = -8.5 \text{ (surface)}.$$

Spin orbit:

$$V_{so}^R = -8.65 \text{ (MeV)}, \quad V_{so}^I = 0.0.$$

Geometry:

$$r^R = 1.244, \quad r^I = 1.26 \text{ (surface)};$$

$$a^R = 0.57, \quad a^I = 0.54 \text{ (surface)}.$$

For simplicity the geometries were taken to be the same for $V_>$ and $V_<$ (also V_0 and V_1). In general this need not be the case. Finally, in terms of V_0 and V_1 we have:

$$V_0^R = 46.0, \quad V_0^I = -8.875 \text{ (surface)};$$

$$V_1^R = 92.0, \quad V_1^I = 27.52 \text{ (surface)},$$

where the superscripts R and I refer to the real and imaginary parts, respectively. These parameters reflect the general features of the above arguments and do conserve isospin.

It should be pointed out that the potentials used are not in the general framework of Becchetti and Greenlees. This is due to the inconsistencies mentioned earlier. In addition, when dealing with a specific nuclear system one should attempt to use the most realistic and accurate optical potential available, since due to the nature of the global parameters the cross sections can be off by as much as 10%.

The (p, n) data were roughly extracted from Ref. 1 and consequently no serious effort was made to improve the fit. These results are simply presented to show the feasibility and reasonableness of our approach.

An investigation was also made on the sensitivity of the elastic cross section to the coupling. In general the theoretical elastic cross section is decreased between 5 and 15% depending upon the strength of the coupling term. Consequently, when solving coupled equations one should use a slightly smaller over-all absorption to compensate for this effect. This decrease in the cross section is due to the presence of the additional neutron channel which provides an alternate escape for the incident flux.

As a final comment we briefly consider the connection of the isospin-dependent optical model to rearrangement collisions. In the distorted-wave Born-approximation (DWBA) formalism the cross sections depend upon the optical-model wave functions and not just their phase shifts. This places additional importance on the choice of correct optical-model parameters. In the case of transfer reactions we have extended the conventional theory by including isospin.[6] In this approach the conservation of isospin for nuclear distortions is imposed according to the ideas presented in this paper. Recent calculations[7] have revealed that such a method can account for several discrepancies existing between conventional theory[8] and experiment. Our results for transfer reactions will be presented in a separate communication.

The authors wish to acknowledge Princeton University for their hospitality and the use of their facilities.

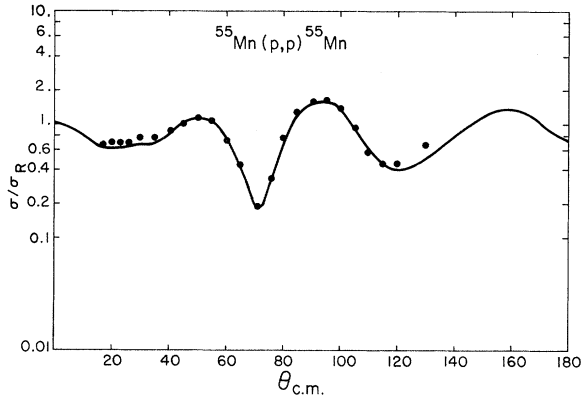

FIG. 1. Ratio of elastic differential cross section to Rutherford for 17.5-MeV protons from ^{55}Mn. Data taken from Ref. 5.

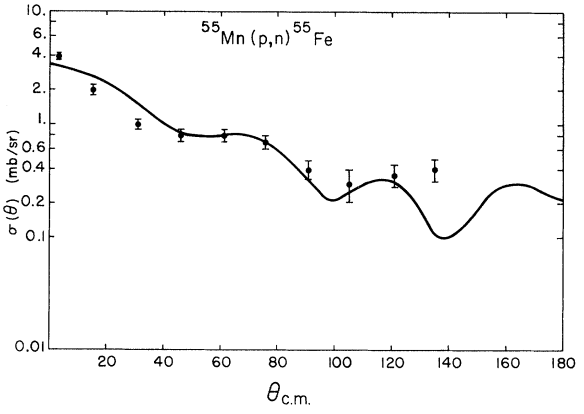

FIG. 2. Charge exchange cross section for the reaction ^{55}Mn$(p, n)^{55}$Fe at $E_p = 17.3$ MeV. Data roughly extracted from Ref. 1.

*Supported by grants Nos. NSF-GP-15855 and NSF-GJ-367 and the Alfred P. Sloan Foundation Grant No. BR-1082.

[1]C. Wong, J. D. Anderson, J. W. McClure, B. A. Pohl, and J. J. Wesolowski, Phys. Rev. C 5, 158 (1972).

[2]F. D. Becchetti, Jr., and G. W. Greenlees, Phys. Rev. 182, 1190 (1969).

[3]J. P. Bondorf, C. Ellegaard, J. Kantelle, H. Lutken, and P. Vedelsby, Nucl. Phys. A101, 338 (1967). These equations follow from the model put forth by A. M. Lane, Nucl. Phys. 35, 676 (1962).

[4]R. L. Cassola and R. D. Koshel, Nuovo Cimento 53B, 363 (1968).

[5]R. J. Peterson, Ann. Phys. (N.Y.) 53, 40 (1969).

[6]S. Cotanch and D. Robson, to be published.

[7]S. Cotanch and D. Robson, Bull. Am. Phys. Soc. 17, 510 (1972).

[8]T. Tamura, Rev. Mod. Phys. 37, 679 (1965).

PHYSICAL REVIEW C VOLUME 7, NUMBER 4 APRIL 1973

Effective Reaction Threshold for Heavy-Ion Collisions

Hartmut Holm

Institut für Theoretische Physik der Universität, Frankfurt/Main, Germany

(Received 7 June 1972)

A new interpretation of the experimental results of Gauvin, Le Beyec, Lefort, and Deprun published recently in Phys. Rev. Letters is given. The calculation of effective thresholds in a dynamical classical model for the reactions ^{40}Ar on ^{164}Dy and ^{84}Kr on ^{72}Ge and ^{116}Cd gives 139, 149.5, and 212 MeV to be compared with the experimental values of 135, 147, and 204 MeV.

In this comment another interpretation of recent experimental results of effective reaction thresholds in heavy-ion reactions[1] shall be given. The change in the radius constant from $r_0 = 1.45$ fm for ^{40}Ar on ^{164}Dy to $r_0 = 1.32$ fm for ^{84}Kr on ^{116}Cd and ^{72}Ge can be explained as follows. Hofstadter *et al.*[2] obtained a charge radius for $A \sim 40$ of $r_0 = 1.3$ fm and for $A \gtrsim 80$ of $r_0 = 1.2$ fm. If we calculate the Coulomb barrier given by

$$E_c = Z_1 Z_2 e^2 / [r_0 (A_1^{1/3} + A_2^{1/3})] \quad (1)$$

with these constants, we obtain values which are too high. This barrier $E_c = 155.5$ MeV for ^{40}Ar on ^{164}Dy is lowered by two effects: (a) the Yukawa interaction[3,4] being dominant; and (b) the static deformation of Dy[4] (see Fig. 1). These effects can be simulated using $r_0 = 1.45$ fm in Eq. (1). In the dynamical classical model[4] a new Coulomb barrier E_c' of 139 MeV ($E_{\text{exp}} = 135$ MeV) is obtained. In this calculation a sharp nuclear surface and a homogeneous nuclear-matter distribution is used. With these assumptions Coulomb barrier and reaction threshold are the same. For a Fermi-type matter distribution one could use the half-density radius to calculate the Coulomb barrier, which then would probably be a little higher than the reaction threshold.

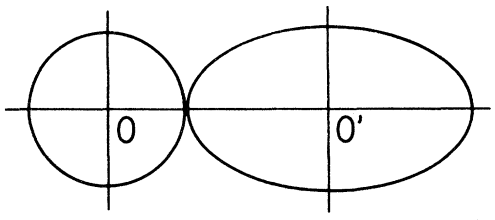

FIG. 1. The static deformation of ^{164}Dy leads to an effective increase of the nuclear radius, as shown by this orientation of the target nucleus. The corresponding energy marks the Coulomb barrier.

For ^{84}Kr on ^{72}Ge and ^{116}Cd only effect (a) holds. If we calculate the Coulomb barrier E_c' with the method given in Ref. 3 with $r_0 = 1.2$ fm and a range $\mu = 0.8$ fm for the Yukawa force we obtain for ^{84}Kr on ^{72}Ge and ^{116}Cd (in MeV):

	E_c	E_c'	E_{exp}
^{72}Ge	162.1	149.5	147
^{116}Cd	224.3	212	204

The decrease of E_c is still not sufficient in comparison with the experimental values. The calculation for Ar on Dy gives a barrier that is too high by 3%, presumably because of the unrealistic nuclear surface and higher multipoles. Let us assume that the other barriers are off by the same amount for the same reason. Then the corrected calculated barrier becomes 145 MeV for Kr on Ge and 205.8 MeV for Kr on Cd. These values are both close to the experimental values showing that the Orsay results do not indicate any unusual phenomenon. Of course the experimental barriers can be reproduced using slightly larger nuclear radii or a larger range μ.

I thank W. Greiner, W. Scheid, and V. Oberacker for encouraging discussions.