UNIVERSIDADE DE SÃO PAULO

INSTITUTO DE FÍSICA
CAIXA POSTAL 20516
01498 - SÃO PAULO - SP
BRASIL

publicações

IFUSP/P-428

CHANNEL NON-ORTHOGONALITY EFFECTS ON THE HEAVY-ION TRANSFER POLARIZATION POTENTIAL

by

M.S. Hussein
Instituto de Física, Universidade de São Paulo

and

L.F. Canto and R. Donangelo
Instituto de Física, Universidade Federal do Rio de Janeiro, Rio de Janeiro, RJ, Brasil

Setembro/1983

CHANNEL NON-ORTHOGONALITY EFFECTS ON THE HEAVY-ION TRANSFER POLARIZATION POTENTIAL[†]

M.S. Hussein

Instituto de Física, Universidade de São Paulo
C.P. 20.516, São Paulo, S.P., Brasil

and

L.F. Canto and R. Donangelo

Instituto de Física, Universidade Federal do Rio de Janeiro
Rio de Janeiro, R.J., Brasil

ABSTRACT

The channel-nonorthogonality correction to the heavy-ion transfer polarization potential is discussed.

[†]Supported in part by the CNPq.

September/1983

Owing to the complex nature of heavy-ion reactions the use of polarization potentials to represent some of the channel-coupling effects has become increasingly popular in recent years.

Considerable theoretical effort has been devoted to the derivation of these potentials for a variety of situations which include, among others, Coulomb coupling to collective excitations[1] and the nuclear coupling to inelastic and transfer channels[2-4]. In order to calculate these potentials, different procedures have been followed. Although the resulting potentials are seemingly equivalent in so far as generating the correct coupling effects asymptotically, they may behave quite differently when tested locally. Since the purpose of these potentials is most often to represent the effect of a group of channels in a pheripherical collision it is mainly their ability to reproduce the effect of these channels on the wave function in the region near the nuclear surface that has to be ascertained. A natural framework to derive these potentials is Feshbach's formalism for the optical potential[5].

In the case of reactions involving mass rearrangements this formalism presents several shortcomings which do not appear in the case of inelastic scattering. Special care must be taken to correctly consider the non-orthogonality of transfer channels. To lowest orders in the transfer coupling the polarization potential is given by[6]

$$U_{tr} = V_{ot}\, G_t^{(+)}\, V_{to} - V_{ot}\, N_{to} \qquad (1)$$

where V_{ot} and V_{to} are the transfer form factors, $G_t^{(+)}$ the Green function in the transfer channel and N_{to} is a measure of channel non-orthogonality[7].

In this letter we assess the importance of the non-orthogonality contribution to the potential in eq. (1), neglected in Refs. 2-4).

In the no recoil and zero range approximation the form factor is local. The quantities $V_{ot}(\vec{r})$, expressed in the prior form, and $N_{to}(r)$ are given by

$$V_{ot}(\vec{r}) = \int \phi_o(\vec{r}') \, v_o(\vec{r}') \, \phi_t(\vec{r}-\vec{r}') \, d^3r' \qquad (2)$$

$$N_{to}(\vec{r}) = \int \phi_t(\vec{r}-\vec{r}') \, \phi_o(\vec{r}') \, d^3r' \quad , \qquad (3)$$

where ϕ_o and ϕ_t are spherically symmetric orbitals describing the motion of the transfered particle in the initial and final nuclei respectively, and $v_o(\vec{r}')$ is the transfer coupling potential. In what follows we approximate $v_o(\vec{r}')$ by a square well and disregard the particle angular momentum in the states ϕ_o and ϕ_t. We further assume constant values for the wave functions inside the nuclei and decaying exponentials in the outside region, namely

$$\phi_o(\vec{x}) = \phi_o(x) = C_o\left[\Theta(x-R_o) + \Theta(R_o-x)\, e^{-\frac{x}{a_o}}\right] \qquad (4)$$

$$\phi_t(\vec{x}) = \phi_t(x) = C_t\left[\Theta(x-R_t) + \Theta(R_t-x)\, e^{-\frac{x}{a_t}}\right] \quad . \qquad (5)$$

In eqs. (4) and (5) R_o and R_t are the ranges of the potentials to which the particle is bound in the elastic and transfer channels, respectively. The parameters a_o and a_t are related to the initial and final binding energies ε_o and ε_t through the relation $a = \hbar / \sqrt{2m\varepsilon}$. The quantities

C_o and C_t are normalization constants, and $\Theta(x)$ is the usual step function. Using Eqs. (4) and (5) in Eqs. (2) and (3) we obtain

$$V_{ot} \simeq \frac{1}{2} \frac{v_o}{(R_o R_t)^{1/2}} \frac{a^2}{r} \exp\left[-\frac{r-R_o-R_t}{a}\right] \qquad (6)$$

$$N_{ot} \simeq \frac{1}{2} \frac{1}{(R_o R_t)^{1/2}} \left[\frac{2a^2 + a(r-R_o-R_t)}{r}\right] \exp\left[-\frac{r-R_o-R_t}{a}\right] \qquad (7)$$

In deriving Eqs. (6) and (7) we have used the same transferred particle binding energy in the initial and final channels, and ignored contributions of order $\left(\frac{a}{R}\right)$.

It is interesting to observe at this point that both V_{ot} and N_{ot} depend on r approximately through the distance between the surfaces of the two nuclei $r - R_o - R_t$, in close analogy to the proximity potential. Furthermore, the correction to the usual $V_{ot} G_t^{(+)} V_{to}$ form of the lowest-order polarizarion potential, namely, $- V_{ot} N_{to}$, comes out purely real and attractive

$$\Delta V = -\frac{\hbar^2 v_o}{2} \frac{a^4}{R_o R_t r^2} \left(1 + \frac{r-R_o-R_t}{2a}\right) \exp\left[-\frac{2(r-R_o-R_t)}{a}\right] \qquad (8)$$

This is in line with what is expected physically since non-orthogonality implies roughly that a component of the transfer channel is elastic and thus should not be counted in the calculation of the polarization potential. Being real and attractive, the correction ΔV counteracts the predominantly absorptive $V_{ot} G_t^{(+)} V_{to}$ component since the system acquires a larger local velocity as it reaches the region where $V_{ot} G_t^{(+)} V_{to}$ is active, i.e.

feels less absorption.

As an estimate of the strength of ΔV Eq. (8), we calculate the quantity $\frac{aV_o}{2}\frac{a^4}{R_o R_t (R_o+R_t)^2}$, taking for $V_o = 50$ MeV, $a = 1.2$ fm and $R = 1.2\, A^{1/3}$ fm. We find

$$\Delta V = -\Delta V_o \left(1 + \frac{S}{2.4}\right) e^{-\frac{S}{0.6}} \qquad (9)$$

where $\Delta V_o = \frac{25}{A_1^{1/3} A_2^{1/3} (A_1^{1/3}+A_2^{1/3})^2}$ [Mev]

and $S \equiv r - R_o - R_t$.

The value of "a" considered above corresponds to a neutron binding energy of about 17 MeV[3]. The for, e.g., $^{28}Si + ^{40}Ca$, we get $\Delta V_o \simeq 0.06$ MeV. This is a rather small value. We should stress, however, that in our calculation above we considered the contribution of just one one-neutron transfer channel. Depending on the shell-structure of the nuclei participating in the collision, one may have to consider a quite large number of contributing one-neutron (and one-proton) transfer channels. For example in the case of $^{28}Si + ^{40}Ca$ simple counting gives $n \simeq 96$ ground-ground one-nucleon transfer channels. Accordingly the $n \cdot \Delta V_o$ becomes about 6 MeV. We consider this estimate a lower limit as certainly other, excited, one-nucleon transfer channel may contribute.

It is important to emphasize at this point that the relevance of our "non-orthogonality potential" is strictly decided upon by the representation one chooses in the calculation of V_{ot} and V_{to}. If a prior-post form is used for the calculation of $V_{ot} G_t^{(+)} V_{to}$, which amounts to the description

of a pick-up followed by a stripping process, the non-orthogonality correction would be identically zero[7]. On the other hand a post-prior form used for a description of a stripping pick up process, would require the inclusion of our ΔV above. In calculating the heavy-ion transfer polarization potential, both pick-up-stripping and stripping-pick-up processes are considered, thus requiring the inclusion of the non-orthogonality correction term.

In particular, the potentials proposed by Frahn and Hussein[2] and by Broglia et al.[3] can not be considered as wave-function equivalent in so far as they do not take into account the non-orthogonality correction term. Granted that these potentials might be adequate for some heavy-ion systems, e.g., those involving a closed-shell projectile and or target nuclei, it would certainly over-estimate the absorption aspect of the coupling to transfer channels, in other situations, as was discussed earlier.

In conclusion, we have assessed in this letter the importance of the channel non-orthogonality correction to the heavy-ion transfer polarization potential. Though small if one-nucleon transfer channels were considered individually, it could contribute significantly in realistic situations involving a large number of transfer channels. The inclusion of the non-orthogonality correction then would guarantee that the calculated transfer polarization potential is accurate enough to describe correctly the wave function in the surface region[8].

ACKNOWLEDGEMENTS

Professor M. Kawai has read carefully the manuscript and made several useful remarks. Useful discussion with Dr. G. Pollarolo is also acknowledged.

REFERENCES

1) W.G. Love, T. Terasawa and G.R. Satchler, Phys. Rev. Lett. 39 (1977) 6; Nucl. Phys. A291 (1977) 183.
A.J. Baltz, S.K. Kaufmann, N.K. Glendenning and K. Pruess, Phys. Rev. Lett. 40 (1978) 20.
R. Donangelo, L.F. Canto and M.S. Hussein, Nucl. Phys. A320 (1979) 422.
M.S. Hussein, Phys. Lett. 88B (1979) 31.
B.V. Carlson, M.S. Hussein and A.J. Baltz, Phys. Lett. 98B (1981) 409; Ann. Phys. (NY) 138 (1982) 215.

2) W.E. Frahn and M.S. Hussein, Phys. Lett. 90B (1980) 358.

3) R.A. Broglia, G. Pollarolo and A. Winther, Nucl. Phys. A361 (1981) 307.

4) A. Bonaccorso and D.M. Brink, Nucl. Phys. A384 (1982) 161.

5) H. Feshbach, Ann. Phys. (NY) 5 (1958) 357.

6) W.E. Frahn and M.S. Hussein, Nucl. Phys. A346 (1980) 237.

7) T. Udagawa, H.H. Wolter and W.R. Coker, Phys. Rev. Lett. 31 (1973) 1507.

8) For a discussion of wave function - Vs. phase-shift-equivalent Coulomb polarization potential, see M.S. Hussein, M.P. Pato, L.F. Canto and R. Donangelo, Phys. Rev. C23 (1981) 926.