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SOLUBLE THREE-BODY MODEL OF STRIPPING

L.R. DODD

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Soluble Three-Body Model of Stripping^{*}

L. R. Dodd

Abstract

A soluble, three-body model of deuteron stripping, which is based on a new reduction of the Faddeev equations, is described. An important advantage of the model is that the separable potential approximation is used only for the proton-neutron system; the proton-core, neutron-core interactions may be central. The three-body dynamics are treated exactly.

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The application of the Faddeev equations and related methods of solution to three-body scattering problems of nuclear and atomic physics has been rather limited. In order to make practical calculations, it has been necessary to describe the two-body subsystems in a simplified way, for example, by introducing separable potentials. Recently, however, by using the distorted wave representation and certain mass conditions, a simplification of the exact equations which allows a greater freedom of choice of the two-body interactions has been developed.¹ As an illustration of this new approach, we show briefly in this paper, that if the stripping reaction is considered as a model three-body problem, simple, tractable integral equations can be formulated for the exact amplitude.

An exact equation for the stripping transition operator U_{pc} , derived in reference 1, is

$$U_{pc} = \omega_p^\dagger v_{pn} \lambda_p \lambda_n + U_{pc} G_o t_{pn} [\lambda_p \lambda_n - 1] \quad (1)$$

The operator U_{pc} describes the transition from the initial state, consisting of a bound state ϕ_i of a proton and neutron incident with momentum p on a massive core c , to a final state in which the neutron is bound to c in a state ψ_n and the proton propagates freely with momentum q . The wave operator $\omega_p^\dagger$, when acting on the final state distorts the relative motion of the proton and core. The wave operators λ_p , λ_n produce distortions in the final state associated with the p -core, n -core interactions. The operator t_{pn} gives the scattering of the proton and neutron, corresponding to the v_{pn} interaction, while G_o is the free three-body Green's operator. Eq. (1), unlike the Lippmann-Schwinger equation, has a well-behaved connected kernel.

The essential restriction used in deriving Eq. (1) is that the mass of the core must be much greater than the nucleon mass.

From Eq. (1) the amplitude for the stripping process is

$$T_{ni} = T_{ni}^0 + \langle \psi_{n,q} | U_{pc} G_o t_{pn} [\lambda_p \lambda_n^{-1}] | \phi_i, p \rangle, \quad (2)$$

with $T_{ni}^0 = \langle \psi_{n,q} | \omega_p^+ v_{pn} \lambda_p \lambda_n^{-1} | \phi_i, p \rangle$. Now $\langle p | G_o t_{pn} | p' \rangle = \langle p | p' \rangle [E - p^2 - k^2 - v_{pn}]^{-1} v_{pn}$ with k the relative momentum of the proton and neutron and E the total energy of the system. Also the states ϕ_i satisfy the eigenvalue equations $k^2 + v_{pn} | \phi_i \rangle = -E_i | \phi_i \rangle$. Thus if we consider two states ϕ_1 , the triplet deuteron state, and ϕ_2 , the singlet antibound state, of the proton-neutron system, an approximate spectral representation of the operator $G_o t_{pn}$ is

$$\sum_{j=1,2} \int d\mathbf{p}' | \mathbf{p}', \phi_j \rangle t_j(E - p'^2) \langle \mathbf{p}', \theta_j |, \quad (3)$$

where $t_j(E - p^2)$ is the propagator $[E - p^2 + E_j]^{-1}$ for the state ϕ_j and θ_j is form factor, $| \theta_j \rangle = -(E_j + k^2) | \phi_j \rangle$. In the representation (3), we have omitted the branch cut contribution for the scattering states of the p-n system. Alternatively, if v_{pn} is taken as a sum of separable potentials and the expression for the propagator modified, this representation is exact.

Inserting the expression (3) in equation (2), we have

$$T_{ni}(p) = T_{ni}^0(p) + \sum_j \int d\mathbf{p}' T_{nj}(p') t_j(E - p'^2) F_{ji}(p', p), \quad (4)$$

with $F_{ji} = \langle \theta_j, p' | \lambda_p \lambda_n^{-1} | \phi_i, p \rangle$, which are two coupled Fredholm integral equations for the stripping amplitudes T_{ni} . These equations, like those obtained by introducing separable potentials in the Faddeev equations, treat the three-body aspects of the rearrangement process exactly.

Furthermore, because of the mass condition, we need make the separable potential approximation in only the p-n subsystem. The advantages of the present formulation are apparent when the p-core and n-core systems are examined. Although the wave operators λ_p , λ_n , ω_p include the structure of the core, insofar as the optical model provides a realistic description of the p-core, n-core scattering, it is reasonable to replace λ_p , λ_n , ω_p by genuine, two-body operators evaluated off the energy shell and calculated from complex central potentials. If the core is strongly absorbing, an iterative solution of Eqs. (4) is expected to converge rapidly since the functions F_{ij} appearing in the kernel, include only the scattered waves in the p-core, n-core systems. Thus, although the structure of the core is only taken into account crudely, the composite nature of the deuteron is recognized and the three-body nature of the rearrangement process is fully apprehended.

Further simplification of the equations is possible. For example if the p-core, n-core interactions are taken to be spin-independent, Eqs. (4) uncouple due to the orthogonality of the spin parts of ϕ_1 and ϕ_2 ($F_{12} = 0$, $F_{21} = 0$). The inhomogeneous term T_1^0 of the resulting, single equation for T_1 forms the basis for an alternative model to the distorted wave Born approximation, proposed by Butler and Tanifuji,² in which the proton and neutron of the deuteron scatter independently from the core. In the case that the p-core, n-core interactions are central, a partial wave analysis shows that there is just a single, one-dimensional Fredholm equation to be solved for each partial amplitude $T_1^L(p)$, (L denotes the angular momentum of the center-of-mass of the incident deuteron with respect to the core)

$$T_1^L(p) = T_1^{0L}(p) + \int dp' p'^2 T_1^L(p') t_1(E-p'^2) F_{11}^L(p', p) \quad (5)$$

This equation has the same form as the equation considered by Aaron, Amado and ^{Yam}Lee,³ in their calculations of the three-nucleon problem, and is readily solved.

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