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Direct reactions with weakly-bound systems: a one-dimensional model

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In this contribution we develop a simple model aiming at the description of the structural and dynamical properties
of weakly-bound systems with one or more valence particles.
Even considering inert cores, the description of these systems is relatively easy in the case of one valence particle (one-particle halo),
but starts to be more complex with two particles (two-particle halo), becoming extremely complicated for systems with more active particles.
For these reasons one typically resorts to approximate schemes
(coupled-channels, first-order approximation, space truncation, effective optical potentials and form factors, continuum discretization, etc)
that need to be tested, not only against experimental data.

The main purpose of this work is precisely the comparison between approximate models and exact ones.
However, mathematical complexities and the required high computational power constitute a huge difficulty for obtaining the exact results.
Therefore, to make feasible the exact solution of the problem, particles are assumed to move just in a one dimension
and the colliding nuclei to move according to classical trajectories.
In spite of these drastic assumptions, we are confident that
the problem retains the main features and properties of the full three-dimensional case.
The model will allow us to shed some light on the reaction mechanism,
namely on the description of the process in terms of single or repeated action of the external field in a perturbative expansion.
A typical example is provided by the long-standing problem of the two-particle transfer process, which is described either as a pair transfer
in a single shot or as a correlated sequence of single-particle transfers through a number of intermediate states.

In the case of one particle, the active neutron is initially sitting on a single-particle level of a one-body Woods-Saxon potential and feels the action of a second moving potential.
The target potential is assumed to be at rest in a fixed position, whereas the projectile moves following a fixed classical trajectory.
The choice of the parameters entering in the calculation will lead to various structural and kinematical conditions,
corresponding to rather different physical situations and simulating different bombarding energy regimes, impact parameters, and Q-values for particle transfer. Essentially, one has to fix the parameters characterizing the potential wells
(energies of single-particle states in both potentials), initial condition
(selecting one of the single-particle levels in target potential), distance of closest approach, and asymptotic energy of the collision.
The “exact” result is obtained by solving numerically the time-dependent one-particle Schroedinger equation.
The probability for populating the different channels (elastic, inelastic, transfer, and breakup) after the collision is determined by projecting the asymptotic wave function (i.e.\ the solution for large values of t) onto the corresponding eigenstates of the wells.
The same problem is then solved within the first order approximation or standard coupled-channels formalism,
thus testing the validity of the necessary truncations and continuum discretization.
In particular, by this comparison, one might infer the importance of including the continuum
in the coupled-channels calculation.

We extended the model to the case of two valence neutrons.
As in previous case, the initial two-particle state is generated by the fixed well and the time evolution of the two-particle wave function is due to the action of the second moving potential along a classical trajectory.
In addition, one includes a residual zero-range pairing interaction between the two valence particles that, for simplicity, is taken to be density-dependent.

Again, the system evolution is obtained by solving numerically the time-dependent Schroedinger equation for the two-particle wave function.
At the end of the process one can project out the population of the different final channels:
elastic/inelastic (both particles still in the initial well),
one-particle transfer (one particle in the initial well and one in the moving one),
one-particle breakup (one particle in the continuum outside the wells and one in the initial or final well),
two-particle transfer (both particles in the moving well),
and two-particle breakup (both particles outside the wells).
We can study the reaction mechanism by switching on or off the pairing interaction.
In the case in which the pairing interaction is switched off (uncorrelated case),
the two-particle transfer process can only be interpreted as produced by the successive transfer of single particles
generated by the moving one-body field, and in fact the value obtained agrees with the one obtained in a perturbative two-step approach.
In the case with correlations the initial wave function is obtained by diagonalizing the residual pairing interaction
in the two-particle basis, and the effect of this initial correlation will propagate during the scattering process.
As a result, although the transfer is still induced by the moving one-body field,
we find a final probability for pair transfer larger than the uncorrelated estimate.
This increase represents therefore the enhancement factor due to the pairing correlation.

In conclusion, despite its simplicity, the model provides a framework for the clarification of different aspects of direct reactions involving one- and two-particle halo nuclei. In particular it permits to test in a simple way the role of continuum within the usual approximate approaches and to confirm the important role of pairing interaction between the valence particles of a two-body halo system.

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