DEVELOPMENT OF GLOBAL MEDIUM-ENERGY NUCLEON-NUCLEUS OPTICAL MODEL POTENTIALS

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Abstract

We report on the development of new global optical model potentials for nucleon-nucleus scattering at medium energies. Using both Schrödinger and Dirac scattering formalisms, our goal is to construct a physically realistic optical potential describing nucleon-nucleus elastic scattering observables for a projectile energy range of (perhaps) 20 MeV to (perhaps) 2 GeV and a target mass range of 16 to 209, excluding regions of strong nuclear deformation. We use a phenomenological approach guided by conclusions from recent microscopic studies. Our experimental database consists largely of proton-nucleus elastic differential cross sections, analyzing powers, spin-rotation functions, and total reaction cross sections, and neutron-nucleus total cross sections. We will use this database in a nonlinear least-squares adjustment of optical model parameters in both relativistic equivalent Schrödinger (including relativistic kinematics) and Dirac (second-order reduction) formalisms. Isospin will be introduced through the standard Lane model and a relativistic generalization of that model.

Motivation: Given the onset of a number of accelerator-based technologies at medium energies there is need for a physically realistic and user friendly medium-energy nucleon-nucleus optical model potential. The potential is required for both the design and operational phases of a medium-energy facility. It must be especially accurate in predicting the integral observables (nucleon total reaction and total cross sections) and the elastic differential cross sections, for purposes of scattering flux conservation over all open channels and nucleon transport, respectively. A phenomenological potential that is global in projectile kinetic energy $T$ and isospin $\tau$ and target mass and charge number $(A,Z)$ can, in principle, address this need. No such potential yet exists for the ranges specified above.

Experimental Database: Our present database consists of over 42000 data points from nucleon-nucleus scattering experiments ranging from 20 MeV to 2 GeV that have been reported in refereed journals. The vast majority of these points consist of proton data sets measured below 1 GeV that include one or more of the observables delineated above. Of these, the elastic differential cross sections are generally the most well measured observable. In contrast, the majority of the neutron data consist of total cross section measurements alone and include very few of the differential observables delineated above. However, the neutron total cross sections are generally well measured over wide ranges of energy. We have cross-checked and improved our database with the extensive Ohio State database. Finally, we have located a number of additional proton data sets near 200 MeV and neutron data sets below 100 MeV that have yet to be included. Figure 1 depicts the current database.
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Approach: We use a phenomenological approach in two formalisms with guidance from microscopic studies in both the bound-state and scattering-state problems:

1. Relativistic Schrödinger Formalism: A relativistic theory of a particle $m$ moving in a potential $V(r)$ is expected to be sensible provided that (a) $|V| < m$ and (b) $|\nabla V|/|V| < k$, where $k$ is the c.m. wavenumber. If these conditions hold, the Dirac equation reduces to a relativistic radial equation that is formally identical to the non-relativistic Schrödinger radial equation with

$$V(r) \rightarrow \gamma V(r)$$

$$\gamma = 1 + T_c / (T_c + 2m)$$

where $T_c$ is the total c.m. kinetic energy, and relativistic kinematics have been invoked. In this reduction $V(r)$ has been chosen as the fourth (timelike) component of a Lorentz vector potential. We apply this formalism to construct a modified (relativistic) version of the optical model code SCAT2 by Bersillon as the function call in a Levenberg-Marquardt nonlinear least-squares minimization algorithm. In using this formalism we expect to construct the “wine-bottle” radial shapes that are required in the $\sim 150 - 350$ MeV region by use of Woods-Saxon form factors and their derivatives (see, for example, the study by Satchler). A flow diagram for determining the global optical potential is shown in Fig. 2.

2. Dirac Formalism: The Dirac equation is used to describe nucleon-nucleus scattering in the mean field approximation by which the nucleon (meson) fields are replaced by their expectation values $\langle \phi \rangle$. We use an extended Walecka model in which a second-order reduction of the Dirac equation is solved for two isoscalar and two isovector mean fields simultaneously. These are:

- isoscalar-scalar nucleon field $\leftrightarrow$ $\sigma$ meson field (fictitious)
- isoscalar-vector nucleon field $\leftrightarrow$ $\omega$ meson field
- isovector-scalar nucleon field $\leftrightarrow$ $\delta$ meson field
- isovector-vector nucleon field $\leftrightarrow$ $\rho$ meson field

The two isovector fields provide naturally for a relativistic generalization of the Lane model which then allows simultaneous treatment of proton and neutron scattering. In addition, in this formalism, physically realistic spin-orbit and Coulomb correction terms appear naturally. Also, the squares and products of the potentials corresponding to these fields, in a second-order reduction, provide naturally for the “wine-bottle” radial shapes required in the $\sim 150 - 350$ MeV range. To construct the global optical potential we modify the Dirac optical model code RUNT11 by Cooper as the function call in a similar Levenberg-Marquardt algorithm; the flow diagram Fig. 2 applies here as well.

Present Status: We are ready to perform our first calculations. These will be studies of energy dependencies for fixed targets. They will be followed by studies of $(A, Z)$ dependencies for fixed energies. Initially, these calculations will be performed for fixed projectile isospin.
References:

1. B. C. Clark (private communication).


