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DOUBLE FOLDED POTENTIALS
THROUGH MOMENTUM
SPACE INTEGRATION:
RHOQ AND FINRAN METHODS
AND USERS MANUAL

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DOUBLE FOLDED POTENTIALS THROUGH MOMENTUM SPACE INTEGRATION:

RHOQ AND FINRAN METHODS AND USERS MANUAL

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ABSTRACT

We summarize the principal techniques employed in obtaining, through momentum space integrations, double folded potentials for the analysis of nucleus-nucleus interactions. The primary emphasis is on numerical accuracy and therefore no significant effort has been made to minimize computer time other than to cast the problem in momentum space. The code RHOQ obtains the density distributions in momentum space while FINRAN utilizes these results along with a nucleon-nucleon interaction in momentum space to obtain the local double folded potential in coordinate space.

I. INTRODUCTION

The double folded potential for nucleus-nucleus interaction is defined by¹⁻⁶

$$V(r) = \iint d^3r_1 d^3r_2 \rho_1(\vec{r}_1) \rho_2(\vec{r}_2) g(\vec{r}_1 - \vec{r}_2 + \vec{r}) \quad (1)$$

where ρ_1 and ρ_2 are the projectile and target total densities, respectively, and g is the nucleon-nucleon (complex) effective interaction. One ansatz for g is^{2,5,6}

$$g(r) = - \frac{2\pi\hbar^2}{M} \bar{f}(0) N e^{-r^2/r_0^2} \quad (2)$$

where M is the nucleon mass, $\bar{f}(0)$ is the complex nucleon-nucleon effective forward scattering amplitude in the nuclear medium, $N = (\pi r_0^2)^{-3/2}$. While spin and isospin dependence is possible we concentrate on the simpler situation of collisions of spin zero nuclei (spherical density distributions) where at least one has the same number of neutrons as protons. In this case g is the spin-isospin independent component of the nucleon-nucleon effective interaction and it is reasonable to take r_0 (for a Gaussian shape) to be about 1.0 to 1.4 fm.

The complex constant, $\bar{f}$, can be calculated from free nucleon-nucleon scattering data by applying corrections due to many body effects (Fermi motion, off-shell effects, and the Pauli principle) as illustrated in Ref. 2. It is also quite easy to treat it as a single adjustable complex constant in most applications. Typical values of the $\text{Re } \bar{f}$ range from 1 to 2 fm⁻¹ and $\text{Im } \bar{f}$ is usually from 10% to 30% of $\text{Re } \bar{f}$.

Now we define the Fourier transforms

$$\rho(q) = \frac{1}{(2\pi)^3} \int e^{i\vec{q} \cdot \vec{r}} \rho(\vec{r}) d^3r \quad (3)$$

$$= \frac{1}{2\pi^2 q} \int_0^\infty r \rho(r) \sin(qr) dr \quad (4)$$

and a similar transform for $g(r)$. With these we can write the nucleus-nucleus interaction as

$$V(r) = \frac{2(2\pi)^7}{r} \int_0^\infty q \sin(qr) \rho_1(q) \rho_2(q) g(q) dq \quad (5)$$

The program RHOQ performs the integration of Eq. (4) while the program FINRAN performs the integration of Eq. (5). The final result is the entirely real function $-V(r)/\bar{f}$ in units of MeV-fm.

In order to achieve maximum accuracy an exponential tail is attached to the density $\rho(r)$ and the Fourier transform for this tail is evaluated analytically.

II. DENSITIES AND THEIR CORRECTIONS

It should be clear from the functional form of $V(r)$ that the strength and rate of radial falloff at large r , in the region of the strong absorption radius for example, will be sensitive to the choice of $\rho(r)$, and to center of mass or finite proton size corrections when appropriate. In applications to peripheral heavy ion interactions it is necessary to exercise some care in these matters. We assume a Gaussian form factor for the proton charge distribution (r.m.s. radius 0.8 fm). We further assume the spurious center of mass motion correction can be treated as Negele⁷ has done i.e., as an approximate harmonic oscillator problem where the oscillator length depends on the mass. Both these corrections are options in the code FINRAN but are not available in RHOQ. The reason for this is that these corrections are most suitably handled along with the finite range effective nucleon-nucleon interaction.

III. INPUT FOR PROGRAM RHOQ

Card 1: NC, NQ, NUC, XNPTS (315, F5.2)

NC = 1 numerical $\rho(r)$ calculated by SUBROUTINE DENSITY (parameters on Cards 7a, b,...below) from a selection of popular analytic forms.

= 2 numerical $\rho(r)$ will be read in from cards (data cards 7a, b,...below).

NQ = number of q values for which $\rho(q)$ is to be calculated (≤ 300), must be even. (200 is recommended canonical choice - implies $Q_{\max} = 995$ MeV/c when recommended value of DELQ is chosen [see below]).

NUC = number of nuclei for which $\rho(q)$ is desired (≤ 20).

XNPTS = number of Simpson's rule integration mesh points per oscillation of $\sin(qr)$. At least 300 is recommended for accuracy.

Card 2: DELQ, Q0 (2F10.0)

DELQ = Δq = grid in momentum space where q is in MeV/c (5.0 recommended for accuracy).

Q0 = First value of q in MeV/c (take = 0.000001 or smaller but greater than zero to be consistent with FINRAN).

Cards 3a, b.... : array AN(I) (7F10.0) = neutron numbers for nuclei in question ($I = 1, \dots, \text{NUC}$).

Cards 4a, b,... : array AZ(I) (7F10.0) = proton numbers ($I = 1, \dots, \text{NUC}$).

Card 5: DELR (F10.0)

DELR = Δr = grid for $\rho(r)$.

Cards 6a, b,... : array NR(I) (14I5) = number of r points for each nucleus (I = 1,...,NUC).

If NC = 1

Cards 7a, b,... : RMS, CONA, CONB, CONC, COND, CONE, ICHOI (6F10.8, I1)

The available shape choices are specified by ICHOI

ICHOI = 1 modified exponential - need r.m.s. (RMS) (Root Mean Square radius in fm)

2 hollow exponential - need r.m.s. (RMS)

3 harmonic-well shell model - need r.m.s. (RMS), alpha (CONA)

4 modified harmonic-well shell model - need alpha (CONA),

RS (CONB), RP (CONC). r.m.s. (RMS) is output here.

5 Fermi three parameter - need A (CONA), R_1 (CONB), W (CONC), r.m.s. (RMS) output. Asymptotic central density output as CONE.

6 Gaussian - need r.m.s. (RMS).

Any values not specified should be set equal to 1.0. Values used are from electron scattering density measurements from:

Landolt-Börnstein, New Series Nuclear Radii, 1967. The

meanings of these parameters are more self-evident by comparing their names with the functional forms in this reference.

If NC = 2

Cards 7a,b,... : (6E13.6) array of values for $\rho(r)$ for each nucleus in succession.

IV. INPUT FOR PROGRAM FINRAN

Card 1: (315, F5.2, 415).

NQ = number of q values - must be even i.e. number of mesh points
for input momentum space projectile and target densities.

NCASE = number of foldings - number of different projectile-target
cases (≤ 10).

NR0 = number of the values of range, r_0 (≤ 10). For every projec-
tile - target case each r_0 results in a calculation of $V(r)$.

XNPTS = number of integration mesh points per oscillation of $\sin(qr)$.
About 150 should be sufficient. Note that an exponential
tail is attached to $-V_{opt}(r)/\bar{f}$ when it falls to .001. The
region beyond should not be of critical importance and that
region is difficult to calculate accurately with this method.

ICMP = 0 no center of mass correction to the projectile density(ies).
= 1 center of mass correction will be applied to projectile
density(ies). Method described in text employed.

ICHP = 0 no finite proton size correction to the projectile
density(ies).
= 1 finite proton size correction will be applied to the
total projectile density(ies).

ICMT = 0 no center of mass correction to the target density(ies).
= 1 center of mass correction will be applied to the target
density(ies).

ICHT = 0 no finite proton size correction to the target density(ies).

 = 1 finite proton size correction will be applied to the
 total target density(ies).

Cards 2a, b: R $\emptyset$ (I): (7F10.0) array of ranges r_o (I = 1,...,NR $\emptyset$).

Cards 3a,b,... : (4F10.0) for each projectile-target case:

 ANP = N of projectile

 AZP = Z of projectile

 ANT = N of target

 AZT = Z target

Card 4: (3F10.0) Note these parameters are fixed for all cases in a
 given run.

 QMAX = maximum q value of the input momentum space density distri-
 butions.

 DELQ = mesh size in MeV/c (consistent with RHOQ specifications).

 DELR = mesh size in fm for the output: $-V_{opt}/\bar{f}$.

Card 5: (10I5)

 NR(I) = array (I = 1,...,NCASE) of the number of mesh points of the
 output function(s) for each projectile-target case. Note
 that r = 0 is first output point so that if 0-14fm is
 desired and DELR is .1 then NR should be 141.

*Card 6: (8A10) Title card - projectile density

Cards 7a,b,... : [5(1PE16.8)]

$\rho(q)$ for projectile density

Card 8: (8A10) Title card - target density

**Cards 9a,b,... : [5(1PE16.8)]

$\rho(q)$ for target density

N.B. Cycle through * → ** as many times as NCASE specifies.

Note: If the option is chosen to correct the densities, a corrected density is calculated in coordinate space at the end and printed out for comparison with the original density. Note that for the purpose of this listing an exponential tail is attached to the calculated densities at $5. \times 10^{-5}$ [central density is usually 1.5×10^{-1}]. An exception to this is when the calculated density becomes unreliable and jumps to a negative value. This is discovered by looking at the printout to see the point indicated as the attaching point.

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