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Dao Tien Khoa, O.M.Knyazkov*

TOWARDS A UNIFIED DESCRIPTION OF ELASTIC AND INELASTIC SCATTERING OF NUCLEONS AND COMPOSITE PARTICLES

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* Leningrad State University

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1. Introduction

The scattering of nucleons and composite nuclear particles, such as deuterons, α-particles, heavy-ions (HI) and others, is a very important tool in extracting information on the nuclear structure /1/. Despite the existence of different microscopic and semimicroscopic nuclear models, analyses of the scattering data are mostly performed by the use of simple phenomenological models with many fitting parameters, without taking into account different effects, such as the Pauli blocking effect, the absence therein of the link with any microscopic nuclear models. Sometimes it does happen that the results of these phenomenological analyses for the same nucleus are in contradiction with each other. Therefore, different semimicroscopic approaches to the description of nucleon and composite particle scattering are of great interest.

Such an approach has been developed in /2,3/ for the description of low-energy nucleon scattering. In contrast to similar approaches /4,5/ to the nucleon-nucleus problems, in /2/ the nucleon-nucleus potentials have been obtained in a closed form with taking into account the exchange NN correlations in the density matrix formalism without using a cumbersome iterative procedure /5/. Further, this approach has been generalized to the α-nucleus case /6/ by folding the nucleon-nucleus potential, calculated within the scheme developed in /2,3/, with the nucleon density of the α-particle. However, in the α-nucleus potential obtained in this way, only a partial antisymmetrization between each nucleon in the α-particle and nucleons in a target-nucleus has been taken into account. And for the HI potentials such an approximation may not be sufficient since the exchange NN correlations result in full antisymmetrization between nucleons in the projectile-nucleus and nucleons in the target-nucleus /7/. Among other approaches to the description of composite particle scattering, the double-folding model /8/ is the most popular one. Since the exact evaluation of exchange part of the HI potential involves many calculational difficulties, in most folding calculations the exchange NN correlations in the HI potential are effectively estimated using a zero-range pseudopotential /9/. The zero-range pseudopotential is an approximation of the exchange term in the case of infinite nuclear matter with a constant density /8/ and it may be too crude for the case of collision of two finite nuclei. Moreover, an explicit and exact treatment of exchange NN correlations /2,3,5/ can lead to some effects which cannot be described in the pseudopotential approximation. Recently, a method for calculation of the exchange parts of α-nucleus and HI optical potentials with full antisymmetrization between nucleons in the colliding nuclei has been proposed in /10,11/. However, this method is based on a cumbersome iterative procedure and can be used only for the analyses of elastic scattering.

In the present work, based on a generalization of the double-folding model /8/ and the semimicroscopic approach to nucleon-nucleus problems /2,3/, unified and closed expressions of optical potentials and inelastic form factors are obtained both for nucleon-nucleus and nucleus-nucleus cases with taking into account the full antisymmetrization between nucleons in the projectile and nucleons in the target nucleus. The obtained equations can be used in the microscopic analyses of elastic and inelastic scattering of nucleons and composite nuclear particles.

2. Formalism

The nucleon-nucleus potential in general must be nonlocal in space and energy-dependent. Within the frame of a simple folding procedure /12/ this potential can be written as a sum of the local direct term and the nonlocal exchange term:

$$U(\vec{R},\vec{R}';E)=\delta(\vec{R}-\vec{R}')\sum_n\int\varphi_n^*(\vec{R}_1)v_D(\vec{R},\vec{R}_1;E)\varphi_n(\vec{R}_1)d\vec{R}_1 + \sum_n\varphi_n^*(\vec{R})v_{EX}(\vec{R},\vec{R}';E)\varphi_n(\vec{R}') \quad (1)$$

The nonlocality of the potential is due to taking account of the Pauli principle and leads to the integro-differential form of the Schrödinger equation or a system of coupled-channel equations. However, one can obtain the equivalent local potential in the manner proposed in /13/, namely:

$$U(\vec{R};E)=\int U(\vec{R},\vec{R}';E)d\vec{R}'= U^D(\vec{R};E)+U^{EX}(\vec{R};E) = \int\rho(\vec{R}')v_D(\vec{R},\vec{R}';E)d\vec{R}'+\int\rho(\vec{R},\vec{R}')v_{EX}(\vec{R},\vec{R}';E)j_0(k(\vec{R})|\vec{R}-\vec{R}'|)d\vec{R}', \quad (2)$$

where $\rho(\vec{R},\vec{R}')=\sum_n\varphi_n^*(\vec{R})\varphi_n(\vec{R}')$ is the one-body density matrix ($\varphi_n(\vec{R})$ are the single-particle wave functions of the nucleons in the target nucleus, $\rho(\vec{R})\equiv\rho(\vec{R},\vec{R})$) v_D and v_{EX} are the direct and exchange components of the chosen effective NN interaction, $j_0(k(\vec{R})s)$ - the spherical Bessel function appeared in the localization procedure. The local momentum of the relative motion of the system $k(\vec{R})$ is defined from the expression

$$k^2(\vec{R})=(2m/\hbar^2)\left[E-U(\vec{R};E)-V^C(\vec{R})\right]. \quad (3)$$

Here $U(\vec{R};E)$ is the total nuclear potential, i.e. $U(\vec{R};E) = U^D(\vec{R};E)+U^{EX}(\vec{R};E)$, $V^C(\vec{R})$ is the Coulomb potential. For the effective NN interaction one usually uses the translational invariant form, i.e. $v_{D(EX)}(\vec{R},\vec{R}';E)=v_{D(EX)}(|\vec{R}-\vec{R}'|;E)$. Further, the density matrix and potentials (2) are expanded into the multipole series:

$$\rho(\vec{R},\vec{R}+\vec{s})=\sum_{\substack{\lambda\lambda' L\\ \mu\mu' M}}C_\lambda C_{\lambda'}\rho_{LM}^{(\lambda\lambda')}(R,s)\langle\lambda\mu\lambda'\mu'|LM\rangle Y_{\lambda\mu}(\hat{\vec{R}})Y^*_{\lambda'\mu'}(\hat{\vec{s}}) , \quad (4)$$

$$U(\vec{R};E)=\sum_{LM}C_L\left[U_L^D(R;E)+U_L^{EX}(R;E)\right]Y^*_{LM}(\hat{\vec{R}}) \quad (5)$$

and

$$V^C(\vec{R})=\sum_{LM}C_L V_L^C(R)Y^*_{LM}(\hat{\vec{R}}) , \quad (5')$$

where $C_\lambda=1$ if $\lambda\neq 0$ and $C_0=\sqrt{4\pi}$. After some simple transformations one can obtains the following equation for the exchange potential:

$$C_L U_L^{EX}(R;E)=4\pi\sum_{\substack{\lambda\lambda'\\ \mu\mu'}}C_\lambda C_{\lambda'}S(L\lambda\lambda';\mu\mu')\int_0^\infty J_{\lambda'\mu'}(k(R)s)G_{\lambda\mu}(R,s)\times v_{EX}(s;E)s^2ds , \quad (6)$$

where $S(L\lambda\lambda';\mu\mu')=\frac{\hat{\lambda}\hat{\lambda}'}{\sqrt{4\pi}\hat{L}}\langle\lambda\mu\lambda'\mu'|LM\rangle\langle\lambda 0\lambda' 0|L0\rangle$, $\hat{\lambda}=\sqrt{2\lambda+1}$,

$$C_\lambda J_{\lambda\mu}(k(R)s)=\int j_0(k(\vec{R})s)Y_{\lambda\mu}(\hat{\vec{R}})d\hat{\vec{R}} , \quad \vec{s}=\vec{R}-\vec{R}'$$

and

$$C_\lambda G_{\lambda\mu}(R,s)=\frac{1}{4\pi}C_\lambda \rho^{(\lambda 0)}_{\lambda\mu}(R,s)=\frac{1}{4\pi}\int\rho(\vec{R},\vec{R}+\vec{s})Y^*_{\lambda\mu}(\hat{\vec{R}})d\hat{\vec{R}}d\hat{\vec{s}} \quad . \tag{7}$$

The density matrix in (7) can be evaluated for spherical or deformed nuclei by using single-particle wave functions calculated from some nuclear model /5/. However, instead of this exact but lengthy procedure, usually various local approximations for $\rho(\vec{R},\vec{R}+\vec{s})$ are used. The Slater approximation /14/ is the simplest one:

$$\rho(\vec{R},\vec{R}+\vec{s}) \simeq \rho(\vec{R}+\frac{\vec{s}}{2})\,\hat{j}_1(k_F(\vec{R}+\frac{\vec{s}}{2})s) \quad , \tag{8}$$

where $\hat{j}_1(x)=3(\sin x - x\cos x)/x^3$, $k_F(\vec{r})=\left[\frac{3}{2}\pi^2\rho(\vec{r})\right]^{\frac{1}{3}}$.

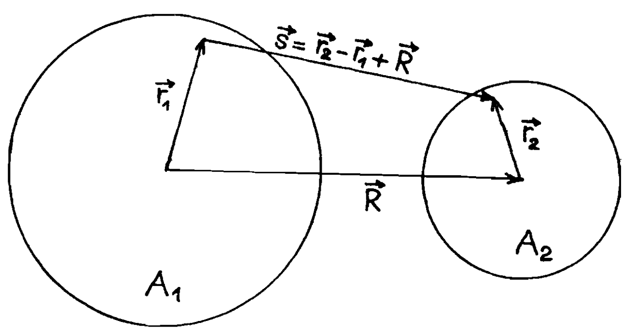

Fig. I

The direct part of the nucleus-nucleus potential can be evaluated by a simple folding formula /8/ (see Fig.1)

$$U^D(\vec{R};E)=\int\rho^{(1)}(\vec{r}_1)\rho^{(2)}(\vec{r}_2)v_D(s;E)d\vec{r}_1 d\vec{r}_2 . \tag{9}$$

Different components $U^D_L(R;E)$ of the direct parts of the nucleon-nucleus (2) and nucleus-nucleus potentials can be calculated within the standard folding model /8,15/ by using appropriate transition densities for the colliding nuclei. In this work we will concentrate mostly on our formalism developed for the exchange potentials. For simplicity we will omit the variable E in all expressions for potentials hereafter, always keeping in mind that the obtained potentials must be energy-dependent due to the energy dependence of the chosen effective NN interaction and the local momentum of relative motion of the considered system (see (3),(3')). The exchange part of the nucleus-nucleus potential is the antisymmetrized matrix element /7/:

$$U^{EX}(\vec{R})=\sum_{i\in A_1,j\in A_2}\langle ij|v_{EX}|ji\rangle ,$$

where $|i\rangle$ and $|j\rangle$ refer to the single-particle wave functions of nuclei A_1 and A_2 , respectively. Note that the localization procedure for the exchange nucleus-nucleus potential /7/ is similar to that for the nucleon-nucleus case /13/ in the plane wave représentation of the relative motion of nucleons. By writing $|i\rangle=\varphi_i\exp(i\vec{k}_1\vec{\xi}_1)$ and $|j\rangle=\varphi_j\exp(i\vec{k}_2\vec{\xi}_2)$, where φ_i and φ_j are the intrinsic single-particle wave functions of the nucleons in A_1 and A_2 with the corresponding relative coordinates $\vec{\xi}_1$, $\vec{\xi}_2$ and momenta $\vec{k}_1$, $\vec{k}_2$, one can get /7,10/:

$$U^{EX}(\vec{R})=\int\rho^{(1)}(\vec{r}_1,\vec{r}_1+\vec{s})\rho^{(2)}(\vec{r}_2,\vec{r}_2-\vec{s})v_{EX}(s)\exp\left[i\vec{k}(\vec{R})\vec{s}/\mathcal{M}\right]d\vec{r}_1 d\vec{r}_2 , \tag{10}$$

where

$$k^2(\vec{R})=\frac{2m\mathcal{M}}{\hbar^2}\left[E-U(\vec{R})-V^C(\vec{R})\right] \quad , \mathcal{M}=A_1A_2/(A_1+A_2) . \tag{3'}$$

Applying the local approximation (8) for the density matrices in (10), after some transformations one obtains:

$$U^{EX}(\vec{R})=4\pi\int_0^\infty v_{EX}(s)s^2ds\int f^{(1)}(\vec{r},s)f^{(2)}(\vec{r}-\vec{R},s)j_0(k(\vec{R})s/\mathcal{M})d\vec{r} , \tag{11}$$

where $f^{(1,2)}(\vec{r},s)=\rho^{(1,2)}(\vec{r})\hat{j}_1(k_{F_{1,2}}(\vec{r})s)$.

With the multipole expansion of the local density: $\rho(\vec{r})=\sum_{\lambda\mu}C_\lambda\langle IM\lambda\mu|I'M'\rangle\rho_\lambda(r)Y^*_{\lambda\mu}(\hat{\vec{r}})$, where I and I' are initial and final spins of the nucleus, and the folding formulae in momentum space /1,8/, one can write the second integral in (11) as:

$$\int d\vec{r}f^{(1)}(\vec{r},s)f^{(2)}(\vec{r}-\vec{R},s)=\sum_{\lambda\mu}C_\lambda G_{\lambda\mu}(R,s)Y^*_{\lambda\mu}(\hat{\vec{R}})=$$

$$
=\sum_{\substack{\lambda_1\lambda_2\lambda \\ \mu_1\mu_2\mu}} \langle \lambda_1\mu_1\lambda_2\mu_2 | \lambda\mu \rangle \langle I_1M_1\lambda_1\mu_1 | I_1'M_1' \rangle \langle I_2M_2\lambda_2\mu_2 | I_2'M_2' \rangle \times
$$

$$
\times\, C_\lambda F^{(\lambda)}_{\lambda_1\lambda_2}(R,s)\, Y^*_{\lambda\mu}(\hat{\vec{R}}), \tag{14}
$$

where $F^{(\lambda)}_{\lambda_1\lambda_2}(R,s)=\dfrac{C_{\lambda_1}C_{\lambda_2}}{\sqrt{4\pi}}\, i^{\lambda_1-\lambda_2-\lambda}\, \dfrac{\hat{\lambda}_1\hat{\lambda}_2}{\hat{\lambda}} \langle \lambda_1 0 \lambda_2 0 | \lambda 0 \rangle \times$

$$
\times \int_0^\infty \frac{1}{2\pi^2} f^{(1)}_{\lambda_1}(t,s)\, f^{(2)}_{\lambda_2}(t,s)\, j_\lambda(tR)\, t^2 dt \,, \tag{15}
$$

$$
f^{(1,2)}_{\lambda_{1,2}}(t,s) = 4\pi \int_0^\infty \rho^{(1,2)}_{\lambda_{1,2}}(r)\, \hat{j}_1(k_{F_{1,2}}(r)s)\, j_\lambda(tr)\, r^2 dr.
$$

Here $j_\lambda(tR)$ is the spherical Bessel function of λ-th order, $k_{F_{1,2}}(r)=[3/2\,\pi^2\rho_0^{(1,2)}(r)]^{1/3}$. (14) and (15) include, as special cases, mutual excitation ($I_1'\neq I_1$ and $I_2'\neq I_2$), single excitation ($I_1'\neq I_1$ or $I_2'\neq I_2$) and elastic scattering ($I_1'=I_1$ and $I_2'=I_2$). Putting (14) into (11), one can obtain:

$$
C_L U^{EX}_L(R) = 4\pi \sum_{\substack{\lambda\lambda' \\ \mu\mu'}} C_\lambda C_{\lambda'}\, S(L\lambda\lambda';\mu\mu') \int_0^\infty J_{\lambda'\mu'}(k(R)s/\mathcal{M}) \times
$$

$$
\times\, G_{\lambda\mu}(R,s)\, v_{EX}(s)\, s^2 ds \,. \tag{6'}
$$

It can be seen that this equation is the same as equation (6) for the nucleon-nucleus case if $\mathcal{M}=1$. And from (6) and (6') we will obtain unified equations both for the nucleon-nucleus and nucleus-nucleus potentials. Note that in the local approximation for the density matrix function $G_{\lambda\mu}(R,s)$ does not depend on the projection of the transferred angular momentum, i.e. $G_{\lambda\mu}(R,s)\equiv G_\lambda(R,s)$. The exchange integrals (6) and (6') in general may be evaluated by an iterative procedure. Such a procedure has been developed for the nucleon-nucleus scattering in /5/. However, with increasing number of inelastic channels under consideration, such an iterative procedure for the nucleus-nucleus case would be too tedious and needs a lot of computing time even at big computers. That's why in various semimicroscopic analyses of inelastic composite particle scattering the pseudopotential is so widely used in evaluating exchange parts of inelastic form factors. Nevertheless, it turns out that such difficulties can be avoided and one can obtain closed expressions for $U^{EX}_L(R)$ by using the multiplication theorem of the Bessel function /16/ in the case of $j_0(x)$:

$$
j_0(yz)=\sum_{n=0}^{\infty} \frac{1}{n!}\, j_n(z) \left(\frac{1-y^2}{2} z\right)^n \,, \quad |1-y|^2<1 . \tag{16}
$$

With the multipole expansions (5) and (5'), one can define y and z as

$$
y=\left[k_0^2(R)-k_1^2(\vec{R})\right]^{1/2} / |k_0(R)| \,, \quad z=|k_0(R)|\,s/\mathcal{M} \,, \tag{17}
$$

where

$$
k_0^2(R)=\frac{2m\mathcal{M}}{\hbar^2}\left[E-U_0^D(R)-V_0^C(R)\right] \tag{18}
$$

and

$$
k_1^2(\vec{R})=\frac{2m\mathcal{M}}{\hbar^2}\left\{U_0^{EX}(R)+{\sum_{LM}}'\left[U_L^{EX}(R)+U_L^D(R)+V_L^C(R)\right]Y^*_{LM}(\hat{\vec{R}})\right\}. \tag{19}
$$

Here the primed sum means that the sum runs only over $L\neq 0$. One can see that $k_0(R)$ is the momentum of relative motion in the centre-of-mass frame in the case of elastic scattering without any exchange interaction. The results of our calculations have shown that $k_0^2(R)>0$ for all considered cases of nucleon- and α-scattering. However, in some cases of HI scattering at energies below the Coulomb barrier $k_0^2(R)<0$ and the scattering here appears to be due to the nondirect effects (exchange, tunnel effects...) in the colliding nuclei. We think that in such cases it is important to take into account properly the Pauli principle. By using (17)-(19) expansion (16) can be written as:

$$
j_0(k(\vec{R})s/\mathcal{M})=\sum_{n=0}^{\infty}\frac{1}{n!}\, j_n(|k_0(R)|s/\mathcal{M}) \times
$$

$$
\times \begin{cases} \left[(k_1^2(\vec{R})-2k_0^2(R))\,s/(2\mathcal{M}|k_0(R)|)\right]^n & \text{if } k_0^2(R)<0 \\ \left[k_1^2(\vec{R})\,s/(2\mathcal{M}k_0(R))\right]^n & \text{if } k_0^2(R)\geq 0 . \end{cases} \tag{20}
$$

It is easy to see that an n-th term in (20) is proportional to $\varkappa^n(R)\, j_n(|k_0(R)|s/\mathcal{M})/n!$, where $\varkappa(R)=m/(|k_0(R)|\hbar^2)$. For the projectile energies of about some tens MeV per nucleon, from a simple evaluation one can find out that $\varkappa(R) \backsim 10^{-4}$ (MeV fm)$^{-1}$ for nucleons, $\varkappa(R) \backsim 10^{-3}$ (MeV fm)$^{-1}$ for α-particles, and $10^{-3} \lesssim \varkappa(R) \lesssim 10^{-2}$ (MeV fm)$^{-1}$ for HI cases. Moreover, the Bessel function $j_n(x)$ rapidly decreases with increasing order n. Therefore expansion (20) converges very rapidly, and it is sufficient to take into calculations the first three terms in (20) (results of our calculations show that the 4-th term in (20) can lead to a difference in the calculated potential of about $1\div2\%$, much less than the uncertainties in the effective NN forces or the nuclear transition densities themselves /1,8/. Putting (20) into (6), (6') and neglecting all terms proportional to $\varkappa^n(R)$ with $n\geqslant3$, we obtain the potential in the following closed form:

$$U_L(R)=U_L^D(R)+U_L^{EX}(R)=U_L^D(R)+I_{L0}(R)+\varkappa(R)I_{L1}(R)\times$$
$$\times\left[1+\varkappa(R)I_{01}(R)\right]\left[I_{00}(R)-f_{k_0}(R)\right]+\varkappa^2(R)I_{L2}(R)\left[I_{00}(R)-f_{k_0}(R)\right]^2+$$
$$+\frac{\varkappa^2(R)}{4\pi}I_{L1}(R)\sum_{\lambda}{}'(2\lambda+1)\left[I_{\lambda 0}(R)+V_\lambda(R)\right]I_{\lambda 1}(R)+\varkappa(R)\sum_{\lambda\mu}\sum_{\lambda'\mu'}{}'\frac{C_\lambda}{C_L}\times$$
$$\times S(L\lambda\lambda';\mu\mu')\Big\{\left[I_{\lambda'0}(R)+V_{\lambda'}(R)\right]\Big[I_{\lambda 1}(R)+2\varkappa(R)I_{\lambda 2}(R)\times$$
$$\times\left(I_{00}(R)-f_{k_0}(R)\right)\Big]+\varkappa(R)I_{\lambda'1}(R)\left[I_{00}(R)-f_{k_0}(R)\right]I_{\lambda 1}(R)\Big\},\tag{21}$$

where $V_\lambda(R)=U_\lambda^D(R)+V_\lambda^C(R)$ and the exchange integrals are

$$I_{\lambda n}(R)=\frac{4\pi}{n!}\int_0^\infty v_{EX}(s)\,j_n(|k_0(R)|s/\mathcal{M})\,G_\lambda(R,s)\,s^{n+2}ds,\tag{22}$$

where

$$f_{k_0}(R)=\begin{cases}0 & \text{if } k_0^2(R)\geqslant0\\ \hbar^2k_0^2(R)/(m\mathcal{M}) & \text{if } k_0^2(R)<0.\end{cases}\tag{23}$$

The direct and exchange parts of the optical potential correspond to the term with $L=0$ from (21), i.e. $U_0(R)$. For the low-energy nucleons or nonrelativistic HI (with energies of about some tens MeV per nucleon), the effective NN interaction is usually taken as the effective G-matrix for bound nucleons (see, for example /17/) which is real. In such cases, equation (21) can be used for evaluating the real parts of the optical potential $U_0(R)$ and inelastic form factors $U_L(R)$ $(L\neq0)$. The imaginary part may be added from the usual optical model to the $U_0(R)$ and from the collective model to the $U_L(R)$ /1/. And that is the reason why we call our

approach a semimicroscopic one. Equations (21)-(23) are obtained in a unified form for both nucleon-nucleus (by putting $\mathcal{M}=1$) and nucleus-nucleus potentials with the difference only in the calculation of $G_\lambda(R,s)$ for these cases using (7),(8) and (14),(15).

Since the exchange potential is obtained from first principles with full antisymmetrization between nucleons in the projectile and nucleons in the target-nucleus, our model can be used first to study single-nucleon exchange effects in elastic and inelastic scattering of nucleons and composite nuclear particles. This is one of the objects of our further study within this model. We here show only as an example the results of our calculations for the real optical potential of the system $\alpha+{}^{58}$Ni at energies E_α= 139 and 172.5 MeV (see the table). It can be seen from the table that our microscopic calculations using the so-called /8,17/ M3Y interaction with a finite-range exchange term (M3Y/FRE) give the results very closed to the phenomenologically adjusted potentials /18,19/ (especially for the case of E_α =139 MeV, where the potential can be unambiguously determined as the squared Woods-Saxon potential /18/ $(WS)^2$). The potentials calculated using the pseudopotential approximation (M3Y) are in poor agreement with the realistic potentials both in the interiour and surface regions.

Table. Real optical potentials for system $\alpha+{}^{58}$Ni

R (fm)	E_α= 139 MeV			E_α= 172.5 MeV		
	$U_0(R)$ M3Y (MeV)	$U_0(R)$ M3Y/FRE (MeV)	$U_0(R)$ $(WS)^2$/18/ (MeV)	$U_0(R)$ M3Y (MeV)	$U_0(R)$ M3Y/FRE (MeV)	$U_0(R)$ Model Ind.Anal./19/ (MeV)
0	146.7	137.9	140.5	137.1	131.0	50+200
4	76.7	81.1	82.3	71.4	76.2	81.5
6	16.1	20.1	20.3	15.2	19.1	20.9
8	1.0	1.2	1.6	0.9	1.2	1.3

3. Conclusion

We have obtained for the first time, without using any iterative procedure, unified and closed expressions for the nucleon-nucleus and nucleus-nucleus potentials with taking into account full antisymmetrization between nucleons in the projectile and nucleons in the target. By using microscopic nuclear transition densities calculated from some nuclear model (see, for example, /20/) with taking into account the Pauli principle, this approach may be used for a detailed study of exchange NN correlations in the elastic and inelastic scattering of nucleons and composite particles.

By expressing in an explicit form the dependence of potentials on the deformation parameters as in /2,3/, the obtained equations may be used in the elastic and inelastic data analyses in the distorted wave Born approximation or in the coupled channel method for extracting the deformation parameters of the nuclear states excited in the considered processes.

Along with the energy dependence of the obtained potentials,from (21) one can extract the so-called multiple-mixing effect /2,5/ which is absent in the pseudopotential approximation.This effect leads to the fact that the L-component of the potential is determined both by the L-component and λ-components with $\lambda = L$ of the nuclear transition densities of colliding nuclei. In the framework of coupled channel analyses, the multipole mixing effect involves an additional coupling scheme for the considered channels. And it is believed that this effect would be substantial in the excitation of nuclear states with complicated structure.

This approach may be used in the description of intermediate energy particle scattering, when the umpulse approximation is valid, and one can choose for $v_{D(EX)}(s;E)$ the realistic t-matrix for free nucleons (see, for example, /21/). Our approach can also be generalized to study many-body NN correlations in the nucleon and HI potentials by introducing into $v_D(s;E)$ a realistic density dependence /3,22/.

And finally we note that this approach is developed for systems of spherical nuclei, but it is straightforward to obtain analogous equations for a system of strongly deformed nuclei by using the multipole expansions from /5/ for the densities and potentials.

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References

1. Satchler G.R. Direct Nuclear Reactions, Oxford University Press, Oxford, 1983.
2. Knyazkov O.M., Nekrasov A.A. Yad.Fiz., 1983, vol.38, p.36.

3. Knyazkov O.M. Fiz.Elem.Chast.At.Yad., 1986, vol.17, p.318.
4. Microscopic Optical Potential, Lecture Notes in Physics, vol.89, ed. by H.V. von Geramb, Springer-Verlag, 1979.
5. Mackintosh R.S. Nucl. Phys., 1978, A307, p.365; Georgiev B.Z., Mackintosh R.S. Nucl.Phys., 1978, A307, p.377.
6. Knyazkov O.M., Kuchtina I.N., Feofilov G.A. Preprint JINR, P4-85-908, Dubna, 1985.
7. Sinha B., Moszkowski S.A. Phys.Lett., 1979, 81B, p.289.
8. Satchler G.R., Love W.G. Phys. Reports, 1979, vol.55, p.183.
9. Golin M., Petrovich F., Robson D. Phys.Lett., 1976, 64B, p.253.
10. Gupta S.K., Sinha B. Phys.Rev., 1984, C30, p.1093;
Chaudhuri A.K., Basu D.N., Sinha B. Nucl. Phys., 1985, A439, p.415.
11. Chaudhuri A.K., Sinha B. Nucl. Phys., 1986, A455, p.169.
12. Owen L.W., Satchler G.R. Phys.Rev.Lett., 1970, vol.25, p.1720.
13. Sinha B. Phys.Reports, 1975, vol.20, p.1.
14. Negele J.W., Vautherin D. Phys.Rev., 1972, C5, p.1472.
15. Dao Tien Khoa, Kuchtina I.N., Ponomarev V.Yu. Yad.Fiz., 1986, vol.44, p.906;
Dao Tien Khoa, Shitikova K.V. Yad.Fiz., 1985, vol.41. p.1166.
16. Gradstein I.S., Ryzhik I.M. Tables of Integrals, Sums, Series and Products, Fizmatgiz, Moscow, 1963.
17. Bertsch G. et al. Nucl. Phys., 1977, A284, p.399.
18. Goldberg D.A. et al. Phys.Rev., 1973, C7, p.1938.
19. Dabrowski H., Budzanowski A., Mayer-Böricke C. Institut für Kernforschungsanlage Jülich, Annual Report, 1979, p.3.
20. Voronov V.V., Soloviev V.G. Fiz.Elem. Chast. At.Yad., 1983, vol.14, p.1380.
21. Franey M.A., Love W.G. Phys.Rev., 1985, C31, p.488.
22. Jeukenne J.P., Mahaux C. Z.Phys. 1981, A302, p.233.

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16.	Health physics. Shieldings
17.	Theory of condenced matter
18.	Applied researches
19.	Biophysics

Дао Тиен Кхоа, О.М.Князьков Е4-86-755

К единому описанию упругого и неупругого рассеяния нуклонов и сложных частиц

Предлагается единый полумикроскопический подход к описанию рассеяния нуклонов и сложных ядерных частиц, в котором оптические потенциалы и формфакторы неупругих переходов получены в замкнутой форме с учетом принципа Паули в локальном приближении формализма матрицы плотности.

Работа выполнена в Лаборатории теоретической физики ОИЯИ.

Препринт Объединенного института ядерных исследований. Дубна 1986

Dao Tien Khoa, O.M.Knyazkov E4-86-755

Towards a Unified Description of Elastic and Inelastic Scattering of Nucleons and Composite Particles

A unified semimicroscopic approach to the description of nucleon- and composite nuclear particle scattering has been proposed. The optical potentials and inelastic form factors are obtained in a closed form with taking into account the Pauli principle in the local density approximation.

The investigation has been performed at the Laboratory of Theoretical Physics, JINR.

Preprint of the Joint Institute for Nuclear Research. Dubna 1986