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SECTION 2 — METHODS OF NUCLEAR PHYSICS

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2.3. The measurement of penetration profiles of Argon ions in Tantalum using (p, gamma) reaction

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2.4. The unitary operator method in theory of slow neutron scattering by bound centers system

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Abstract: An operator suitable for treating slow neutron scattering by a system of bound centers has been derived by starting from one general expression of the unitary operator in the scattering theory. A conection of the obtained operator with the Heisenberg number density operator has been shown. The expression of slow neutron scattering cross section expressed by the correlation function has been obtained for the first Born approximation. However, this method is useful for studing the number density function or the two-body potential. The proposed method has been applied to potential and resonance neutron scattering.

The intention of this work is to introduce the number density operator in the theory of nuclear reactions, whenever the interaction of incoming particle-bound center of the system may be described as a two body potential. Some informations about the number density, correlation function or the two body potential may be obtained by the interpretation of the experimental results. The use of this operator has been illustrated in the case of slow neutron scattering treating the potential and the resonance scattering.

Let the Hamiltonian of the whole system be

$$H = H_0 + V, \tag{1}$$

then the solution of the wave equation may be expressed using the unitary operator $U(t, t_0)$

$$| \alpha, t\rangle = U(t, t_0) | \alpha, t_0 \rangle \tag{2}$$

$$i\hbar \frac{\partial U(t, t_0)}{\partial t} = H(t)\, U(t, t_0) \tag{3}$$

$$U^+(t, t_0)\, U(t, t_0) = 1, \tag{4}$$

where $H(t)$ is the evolution operator:

$$H(t) = \exp(iH_0\, t/\hbar) V \cdot \exp(-iH_0 t/\hbar). \tag{5}$$

In the case of potential scattering the bound centers system is actually the system of atoms and the two-body potential takes the form of the Fermi potential[1,2,3])

$$V_1(\vec{r} - \vec{r}_l) = 2\pi a\hbar^2/m\delta(\vec{r} - \vec{r}_l), \tag{6}$$

or for the whole system

$$V(\vec{r}) = \sum_i V_1(\vec{r} - \vec{r}_l) = a_1 \sum_i \delta(\vec{r} - \vec{r}_l), \tag{7}$$

where m is the neutron mass and a-the scattering length. The evolution operator reduces into

$$H(t) = a_1 \varrho(\vec{r}_t, t), \tag{8}$$

where

$$\varrho(\vec{r}_t, t) = \sum_i \delta(\vec{r}_t - \vec{r}_i(t)) \tag{9}$$

is the number density operator. However, in the case of the resonance scattering the potential reduces to

$$V(\vec{r}) = \int d^3r' V_1(\vec{r}) \varrho(\vec{r} - \vec{r}', 0), \tag{10}$$

and the evolution operator (5) becomes

$$H(t) = \int d^3r' V_1(\vec{r}) \varrho(\vec{r}_t - \vec{r}', t). \tag{11}$$

By using the perturbation expansion of the operator $U(t, t_0)$ the transition matrix element in the first Born approximation becomes

$$\langle i | U_1(\infty) | f\rangle = -\frac{ia_1}{\hbar} \int d^3r dt \exp\left[i(\omega t - \vec{K} \cdot \vec{r})\right] \varrho(\vec{r}, t), \tag{12}$$

for the potential scattering. With the help of (12) the potential cross section takes the form of Van Hove's results. In the case of resonance scattering the matrix element

$$\langle i \mid U_1(\infty) \mid f \rangle \approx -\frac{i}{\hbar} \int \mathrm{d}^3 r' V_1(\vec{r}') \int_0^\infty \mathrm{d}t \exp\left[-i(\hbar\lambda_K - E_i)\, t/\hbar \cdot \right.$$

$$\left. \cdot \langle i \mid \Phi_K \rangle \langle \Phi_K \mid \varrho(\vec{r} - \vec{r}', 0) \mid f \rangle \sim \frac{\text{const}}{\hbar\lambda_K - E_i} \right. \tag{13}$$

is the usual Breit-Wigner expression[4,5,6].

The used number density function in (13) has been obtained by solving the Louville type equation

$$\frac{\partial \varrho}{\partial t} = \frac{i}{\hbar} \left[\varrho, H_0 \right] = -iL\varrho,$$

where $\hbar\lambda_K = E_0 - i\Gamma/2$ and Φ_K are the eigenvalue and eigenfunction of the non-hermitian operator L.

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2.5. Gamma-ray planar Si(Li) polarimeter

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Linear polarization is defined by the ratio

$$P = \frac{N_1 - N_2}{N_1 + N_2},$$

where N_1 and N_2 are the numbers of photons polarized in two mutually perpendicular directions.

Following the measurements of Honzatko and Kajfosz[1] and of Ewan et al.[2], a planar Si(Li) detector was applied as a polarimeter and its sensitivity determined. The beam of linearly polarized gamma rays was achieved by Compton scattering of 122 keV gamma rays from a 2 mCi source of ^{57}Co in graphite at 90°. Linearly polarized gamma rays undergo a second Compton scattering in the detector, preferentially in the plane perpendicular to the direction of polarization[3]. The number of pulses in the total energy peak for the two orientations of the detector (parallel and perpendicular to the polarization plane) were determined. From these results an asymmetry ratio $A = (3.0 \pm 0.6)\%$ was obtained[4].