POLARIZATION OF NUCLEONS SCATTERED FROM NUCLEI WITH NON-ZERO SPIN

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The optical model is used for an analysis of the polarization of nucleons scattered from nuclei with non-zero spin. It is shown that, in general, such nuclei lead to an additional polarization as compared to nuclei with the same optical parameters and zero spin.

THE introduction of a spin-orbit interaction in the optical model of nuclear reactions allows us to compute the polarization of the nucleon as a result of the interaction with the nucleus.

The polarization P, as all quantities predicted by this model, is the result of an averaging over many resonances. The transition from the unaveraged quantities to the averaged quantities is conveniently made by averaging the phases of the scattered waves.[1] The relative amplitudes $\tilde{\eta}$ of the divergent waves are averaged.

Eder at al.[2] also considered the polarization in the scattering of nucleons from nuclei with zero spin. The polarization was found here to be completely determined by the elastic potential scattering. The expression for the polarization has the form

$$\mathbf{P} = (A^* \sigma A) / (d\sigma / d\Omega), \tag{1}$$

where A is the amplitude of the elastic potential scattering. The resonance part of the scattering does not give a contribution to the polarization; the corresponding terms drop out after the averaging.[2]

This is the situation in the case of spherical even-even nuclei.

It is of interest to generalize these considerations to the nuclei with spin $I \neq 0$. The corresponding phase analysis shows that for an unpolarized incident beam and unpolarized target the final state is described by the function

$$\psi_f = \frac{1}{\sqrt{2(2I+1)}} \times \sum \varepsilon_{m_s} \varepsilon_{m_I} f(m_s m_I l0 \mid m_{s'} m_{I'} l' m)\, \chi_{I'}^{m_{I'}} \chi_{s'}^{m_{s'}} Y_{l'}^{m}(\theta, \varphi), \tag{2}$$

where $\chi_s^{m_s}$ is the spin function, $f(\ldots \mid \ldots)$ is the amplitude for scattering from a state characterized by the first set of quantum numbers to a state defined by the second set; the summation goes over all quantum numbers. The ϵ are analogous to those introduced by Blin-Stoyle.[3] The polarization of the particles after the scattering is defined by

$$\mathbf{P} = (\psi_f^* \sigma \psi_f) / (\psi_f^* \psi_f), \tag{3}$$

where σ is a vector whose components are the Pauli matrices for the particles s (nucleons). Substituting (2) in (3), we obtain

$$\frac{d\sigma}{d\Omega}(P_x + iP\ ) = \frac{e^{i\varphi}}{2I+1} \sum_{m_s m_I m_{I'}} \Big\{ \sum_{LL'} f\Big(m_s m_I\, L0 \Big| \tfrac{1}{2} m_{I'} l' m\Big)^* \times f\Big(m_s m_I L'0 \Big| -\tfrac{1}{2} m_{I'} l'' m'\Big)\Big\} P_{l'}^{m}(\cos\theta)\, P_{l''}^{m'}(\cos\theta). \tag{4}$$

If the expression (4) written in terms of the unaveraged quantities $\tilde{\eta}$, is then averaged over the resonances, we obtain an expression different from (1). This procedure was used in the specific case $I = I' = 1/2$. We restrict ourselves to the consideration of the s and p phases ($l \leq 1$) and obtain after averaging (η, as opposed to $\tilde{\eta}$, is averaged over the resonances)

$$\begin{aligned} \frac{d\sigma}{d\Omega} P = {} & \text{const}\, e^{i\varphi}\, \text{Im} \Big\{ \frac{\sqrt{2}}{3} (\eta_{22} - \eta_{11})^* (1 - \eta_{00})\, P_0 P_1^1 \\ & + \frac{2\sqrt{2}}{3} [2|\eta_{11}|^2 - |\eta_{22}|^2 - \eta_{11}\eta_{22}^* + 3(\eta_{22} - \eta_{11})]\, P_1^0 P_1^1 \Big\} \\ & - \text{const}\, e^{i\varphi}\, \text{Im}\, \{ \overline{4\tilde{\eta}_{11}^1 \eta_{12}^{1*}} - 3\eta_{11}\eta_{12}^* + 3\sqrt{2}|\eta_{21}|^2 \\ & - 6\sqrt{2}|\eta_{12}|^2 - 2\sqrt{2}\eta_{12}\eta_{21}^* \} \frac{P_1^0 P_1^1}{36} = P_{\text{pot}} + P_{\text{add}}, \end{aligned} \tag{5}$$

where $\eta_{jj'}^{J}$ is the coefficient of the outgoing wave with angular momentum j′ generated by the incoming wave with angular momentum j, both waves corresponding to an intermediate state of the system with total angular momentum J. The systems of levels corresponding to different J are assumed to be uncorrelated. The index 1 of the phases corresponds to the state $p_{3/2}$, the index 2 to the state $p_{1/2}$, and the index 0 to the s state.

Expression (5) is made up of two terms. The first term is the polarization of the particles corresponding to a nucleus with zero spin, and coincides with (1). The second term corresponds to the additional effect due to the fact that the nucleus has nonvanishing spin. In a transition to $I = 0$ P_{add} vanishes, since in this case all η_{12} and η_{21} vanish. We also note that in (5) the terms that correspond to transitions with $\Delta l = 2$ are neglected; they also enter in the quantity P_{add}. This may be regarded as the result of the correlation of the systems of resonance levels over which the phases are averaged. In the case of non-overlapping levels these correlations can be quite important, since they receive a contribution of the same sign in the averaging over the levels from all resonances.

Thus, of the two nuclei with approximately the same optical properties (lying close to each other in the periodic table), one even-even (spin $I = 0$) and the other odd ($I \neq 0$), the latter will lead to an additional polarization. This difference should be observable in experiment. The nuclei Pb^{207} and Pb^{208} are convenient for this purpose. These nuclei are spherical, and the term P_{pot} will be very nearly the same for both of them, since it is determined mainly by the nuclear radius. The additional term appears in the case of Pb^{207}, where the polarization should differ by P_{add} from the polarization caused by the neighboring even-even nuclei. This type of experiment would be helpful in estimating this quantity, which cannot be calculated from the optical model.

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[3] R. J. Blin-Stoyle, Proc. Phys. Soc. **A64**, 700 (1951).

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356