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Relationships between Tensor Analyzing Powers in Elastic Scattering of Deuterons and ^{7}Li

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Tensor analyzing powers A_{xx} and A_{yy} for deuteron elastic scattering have been measured for many 0^+ targets at E_{lab}=56 MeV[1]. The data show a general feature

$$A_{yy} \simeq -2A_{xx}, \tag{1}$$

in a middle angular region. Examples are shown in Fig. 1. In the following, this relation and more refined ones are derived by the invariant-amplitude method[2] in a way free from theoretical parameters, for example those of optical potentials. The derivation is typically shown for elastic scattering of spin 1 particle by a 0^+ target. The transition amplitude $\langle \nu_f,\vec{k}_f|M|\nu_i,\vec{k}_i\rangle$, where $\vec{k}_i(\vec{k}_f)$ is the momentum and $\nu_i(\nu_f)$ the z-component of the spin in the initial(final) state, is given by the invariant amplitude $F_{K r}$,

$$\langle \nu_f,\vec{k}_f|M|\nu_i,\vec{k}_i\rangle = \sum_K (-)^{1-\nu_f}(11\nu_i -\nu_f|K\kappa)\sum_{r=\bar{K}-K}^{K}\left[C_r(\Omega_i)\times C_{\bar{K}-r}(\Omega_f)\right]^K_\kappa F_{Kr}, \tag{2}$$

where $\bar{K}$=K for K=even and $\bar{K}$=K+1 for K=odd and $\Omega_i(\Omega_f)$ is the solid angle of $\vec{k}_i(\vec{k}_f)$. Let us define the scalar amplitude U, the vector one S and the tensor ones T and T',

$$U=\sqrt{3}\,F_{00},\quad S=F_{11}\sin\theta/\sqrt{2},$$
$$T=(\sqrt{6}\,F_{20}\cos\theta+F_{21})\sin\theta/\sqrt{2},\quad T'=\sqrt{3/8}F_{20}\sin^2\theta, \tag{3}$$

where θ is the angle between $\vec{k}_i$ and $\vec{k}_f$. The amplitudes U, S and T(T') are related to the central, spin-orbit and tensor interactions, respectively, in their first order and thus U is dominant and others are relatively small. Polarization observables are described by these amplitudes. Neglecting U-independent terms,

$$A_{xx}=2\sqrt{2}Re(\sqrt{2}UT'^* - UT^*\cot\theta)/9\sigma,\quad A_{yy}=2\sqrt{2}Re(-2\sqrt{2}UT'^* - UT^*\cot\theta)/9\sigma,$$
$$A_{xz}=\sqrt{2}Re(UT^*)/3\sigma, \tag{4}$$

where σ is the cross section. Using these equations, we obtain

$$A_{yy}\sin\theta=-2A_{xx}\sin\theta-2A_{xz}\cos\theta, \tag{5}$$

which leads to eq.(1) for $\theta\simeq 90°$. In the spherical representation, eq.(5) becomes

$$\sqrt{3/2}\;T_{20}\sin\theta=T_{22}\sin\theta -2T_{21}\cos\theta. \tag{6}$$

These formulae can be derived for spin 3/2 particle in the same approximation. Exact relationships which correspond to (6) are rather complicated and are discussed in Ref. 3. In the following, we will investigate the validity of the approximate formulae derived above in scattering of deuterons and ^{7}Li and emphasize that they provide a simple method to obtain informations about spin-dependent interactions directly from experimental data.

The deuteron data approximately satisfy eq.(5) in heavy targets but not at large scattering angles in light targets, examples of which are shown in Fig. 2. This means that effects of higher-order terms of spin-dependent interactions are important at large angles in light targets. The difference between the left-hand side(LHS) and the right-hand side(RHS) in eq.(5) is $3Re(S^*T)/\sigma\sin\theta$ and thus will strongly be affected by the presence of tensor interactions. In Fig. 2, two kinds of optical-model[1] calculations are shown for Ca target; (a) one includes central and spin-orbit potentials and (b) the other includes central, spin-orbit and tensor potentials. They give almost the same values for the LHS which is shown by the solid line but quite different ones for the RHS at large angles, where the dash-dotted line and the dashed line are for cases (a) and (b), respectively. The latter calculation reproduces the data very well.

In the $^7Li+^{58}Ni$ scattering at low energies, experimental data of tensor analyzing powers can be described by the following formulae in good approximations[4),

$$T_{20}=(1-3\sin^2\frac{\theta}{2})\,{}^{T}T_{20},\qquad T_{21}=-\sqrt{\frac{3}{2}}\sin\theta\,{}^{T}T_{20},\qquad (7)$$

$$T_{22}=-\sqrt{\frac{3}{2}}\cos^2\frac{\theta}{2}\,{}^{T}T_{20},\ \text{where}\ {}^{T}T_{20}=-(T_{20}+\sqrt{6}T_{22})/2.$$

It is easily seen that eqs.(7) satisfy eq.(6) and thus the higher-order effects of spin-dependent interactions are quite small. In fact, the coupled-channel calculations[4] which include virtual excitations of ^7Li make only very small differences between the LHS and RHS of eq.(6).

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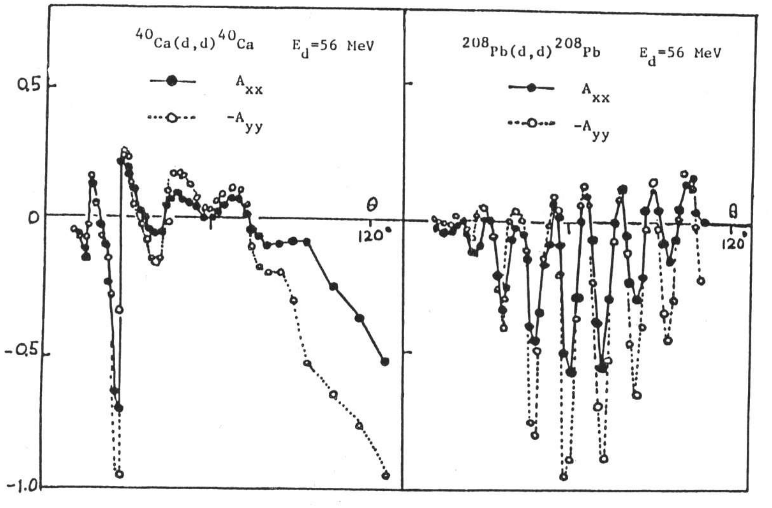

Fig. 1.
Measured tensor analyzing powers, A_{xx} and $-A_{yy}$ at E_{lab}=56 MeV for Ca and Pb targets.

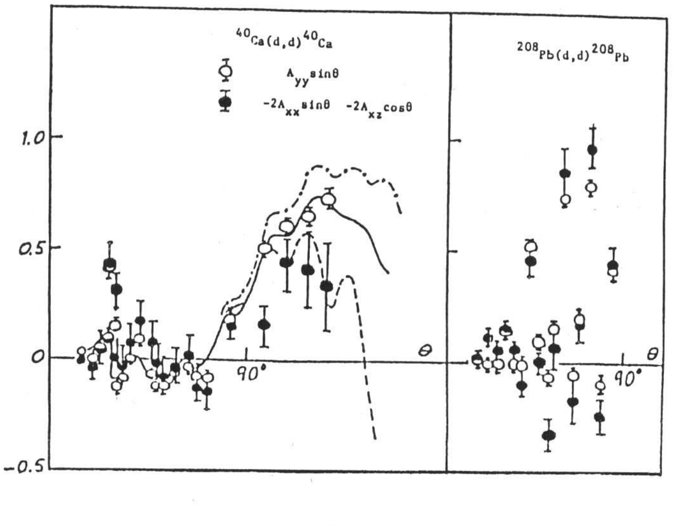

Fig. 2
Comparison between $A_{yy}\sin\theta$ and $-2A_{xx}\sin\theta-2A_{xz}\cos\theta$ for experimental data and optical-model calculations. The dashed line includes a tensor potential and the dash-dotted line does not. The targets are ^{40}Ca and ^{208}Pb.