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The Spin Correlation Parameter C_{yy} for Reactions of the Type $\vec{1/2} + \vec{1/2} \to 1 + 0$

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Spin correlation parameters for a reaction $\vec{a} + \vec{b} \to c + d$ are hardly to be measured because of experimental difficulties. Still worse is the case if the spin correlation in the exit channel is of interest. We will show for reactions of the spin structure $\vec{1/2} + \vec{1/2} \to 1 + 0$ that the correlation parameter C_{yy} is equal to $(1/3 + 2/3\ A_{yy})$ where A_{yy} is the tensor analyzing power of the inverse reaction $\vec{1} + 0 \to 1/2 + 1/2$ which is much easier to be determined.

With cartesian polarisation tensors one has for $\vec{1/2} + \vec{1/2} \to 1 + 0$ (I) the relation

$$\left(\frac{d\sigma}{d\Omega_f}\right)^{I}_{\uparrow\uparrow} + \left(\frac{d\sigma}{d\Omega_f}\right)^{I}_{\downarrow\downarrow} = 2\cdot\left(\frac{d\sigma}{d\Omega_f}\right)^{I}_{0} (1+P^b_y P^t_y C_{yy}) \tag{1}$$

where $(d\sigma/d\Omega_f)_{\uparrow\uparrow}$ is the differential cross section when both the beam (b) and target (t) are polarised along the y-direction $\vec{k}_{in} \times \vec{k}_{fin}$. The symbols $\downarrow\downarrow$ denote the opposite polarisation direction and $(d\sigma/d\Omega_f)_0$ is the unpolarised cross section. The corresponding relation for $\vec{1} + 0 \to 1/2 + 1/2$ (II) is

$$\left(\frac{d\sigma}{d\Omega_f}\right)^{II}_{\uparrow} + \left(\frac{d\sigma}{d\Omega_f}\right)^{II}_{\downarrow} = 2\cdot\left(\frac{d\sigma}{d\Omega_f}\right)^{II}_{0} (1+\tfrac{1}{2} P_{yy}A_{yy}) \tag{2}$$

where again $\vec{k}_{in} \times \vec{k}_{fin}$ is the quantization axis and $\uparrow$, $\downarrow$ mean m = +1, -1.

The cross section for $\vec{a} + \vec{b} \to c + d$ can be written[1]

$$\frac{d\sigma}{d\Omega_f} = \sum_{\substack{m_a m_b m_i m_f m \\ s_f s s'}} R^{s_f\ s}_{((m_a m_b)m_i m_f)m}(\Omega_i,\Omega_f) \times R^{*\,s_f\ s}_{((m_a m_b)m_i m_f)m}(\Omega_i,\Omega_f) N_{m_a} N_{m_b}$$

with

$$R^{s_f\ s}_{((m_a m_b)m_i m_f)m}(\Omega_i,\Omega_f) \equiv \frac{\pi}{k_i} \sum_{\ell_i s_i J \ell_f} (-)^{\ell_i+s_i+J+\ell_f+s} \hat{\ell}_i \hat{\ell}_f \hat{J}^2 \left(\begin{matrix} s_a & s_b \\ m_a & m_b \end{matrix}\middle|\begin{matrix} s_i \\ m_i \end{matrix}\right)$$

$$\times \left(\begin{matrix} s_i & s_f \\ m_i & m_f \end{matrix}\middle|\begin{matrix} s \\ m \end{matrix}\right) \begin{Bmatrix} \ell_i & s_i & J \\ s_f & \ell_f & s \end{Bmatrix} \langle E_f(\ell_f(s_c s_d)s_f)J|T|E_i(\ell_i(s_a s_b)s_i)J\rangle$$

$$\times \left[C^{(\ell_i)}(\Omega_i) \times C^{(\ell_f)}(\Omega_f)\right]^{(s)}_m \quad \text{if } \Omega_a = \Omega_b = \Omega_z .$$

Especially for $\vec{1/2} + \vec{1/2} \to 1 + 0$ (I) one gets with $\Omega_z \perp \Omega_i$, Ω_f and $m_a = m_b = -1/2$ $(s_i = s_f = 1)$

$$R^{1\ s}_{(-1,m_f)m}(\Omega_i,\Omega_f) = \frac{\pi}{k_i} \sum_{\ell_i J \ell_f} (-)^{\ell_i+\ell_f+J+s+1} \hat{\ell}_i \hat{\ell}_f \hat{J}^2 \times \left(\begin{matrix} 1 & 1 \\ -1 & m_f \end{matrix}\middle|\begin{matrix} s \\ m \end{matrix}\right) \left\{\begin{matrix} \ell_i & \ell_f \\ 1 & 1 \end{matrix}\middle|\begin{matrix} s \\ J \end{matrix}\right\}$$

$$\times <(\ell_f\ 1)J|T|(\ell_i\ (\tfrac{1}{2}\ \tfrac{1}{2})1)J> \left[C^{(\ell_i)}(\Omega_i) \times C^{(\ell_f)}(\Omega_f)\right]^{(s)}_m$$

If the inner parities of the reacting particles don't change, $(\ell_i+\ell_f)$ has to be even. The Bohr theorem[1] then requires an even m.

Evaluating the corresponding R for the reaction $\vec{1} + 0 \rightarrow 1/2 + 1/2$ (II) with $m_a = +1$ $(s_i=s_f=1)$, going over to the time reversed reaction $1/2 + 1/2 \rightarrow \vec{1} + 0$ $(\bar{R})$ by taking into account the time reversal invariance and replacing $\ell_i \Leftrightarrow \ell_f$, $\Omega_i \Leftrightarrow -\Omega_f$, $k_i \Leftrightarrow k_f$ finally delivers

$$k_f \bar{R}^{\,s}_{(1,\pm1)\frac{1}{2}0}(-\Omega_f,-\Omega_i) = k_i R^{\,s}_{(-1,\mp1)\frac{1}{2}0}(\Omega_i,\Omega_f) \quad \text{and}$$

consequently

$$\left(\frac{d\sigma}{d\Omega_f}\right)^{I}_{\downarrow\downarrow} = \left(\frac{d\sigma}{d\Omega_f}\right)^{II}_{\uparrow} \quad \text{and} \quad \left(\frac{d\sigma}{d\Omega_f}\right)^{I}_{\uparrow\uparrow} = \left(\frac{d\sigma}{d\Omega_f}\right)^{II}_{\downarrow} .$$

With equations (1) and (2) and the ratio of the unpolarized cross sections

$$\left(\frac{d\sigma}{d\Omega_f}\right)^{I} \Big/ \left(\frac{d\sigma}{d\Omega_f}\right)^{II}_{0} = \frac{(2s_c+1)(2s_d+1)}{(2s_a+1)(2s_b+1)} = \frac{3}{4}$$

one has the equality

$$C_{yy} = \frac{1}{3} + \frac{2}{3} A_{yy}$$

which is valid for the same total energy and same scattering angle in the center of mass system.

The derived relation is especially interesting for reactions like

$$^{12}C + d \rightarrow {}^{13}C^*(3.09\ \text{MeV}) + p$$

which lead to an excited state, because no spin correlation measurements in the exit channel are possible. Fig. 1 shows C_{yy} for $^{13}\vec{C}^* + \vec{p} \rightarrow {}^{12}C + d$ derived from the tensor analyzing powers of $^{12}C + \vec{d} \rightarrow {}^{13}C^* + p$ measured by Johnson et al.[2] C_{yy} is positive for all angles which could be due to the fact that the reaction proceeds mainly via one channel spin.

The reaction $^3He(t,d)^4He$, which has the some spin structure $1/2 + 1/2 \rightarrow 1 + 0$, also seems to prefer one channel spin[4] because the vector analyzing power A_y is nearly antisymmetrical to 90° c.m.[3]. The deviations of A_y from antisymmetry are different for $^3He(\vec{t},d)^4He$ and $^4He(\vec{d},t)^3He$[5] so that there has to be another effect besides the violation of the Barshay-Temmer theorem which destroys the antisymmetry. The measurement of C_{yy} for $^3\vec{He} + {}^3\vec{H} \rightarrow {}^4He + d$ or A_{yy} for $^4He + \vec{d} \rightarrow {}^3He + {}^3H$ could show whether this effect is caused by non-conservation of the channel spin.

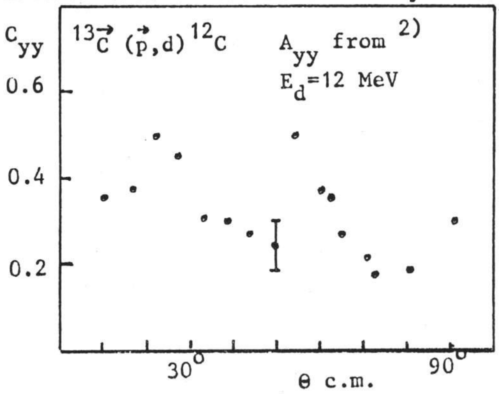

Fig.1

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