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1.37 Analyzing Power for the $^{12}C(\vec{p},p'\gamma)^{12}C_{1+}$ Reaction

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The analyzing power and angular distribution for the γ-ray following the $^{12}C(\vec{p},p')^{12}C_{1+}$ (15.1 MeV) reaction at E_p = 40 MeV were measured using a large NaI(Tl) crystal named HERMES[1]. The polarized proton beam was provided by the Osaka University RCNP cyclotron. The average beam polarization was about 70 %. The results are shown in Fig.1. The measured analyzing power and the angular distribution were fitted by curves of $A_\gamma(\theta) = -0.08\sin2\theta$, and $W_\gamma(\theta) = C(1-0.129\sin^2\theta)$, where $A_\gamma(\theta)$ and $W_\gamma(\theta)$ are defined by

$$A_\gamma(\theta) = \frac{W_\gamma^\uparrow(\theta) - W_\gamma^\downarrow(\theta)}{W_\gamma^\uparrow(\theta) + W_\gamma^\downarrow(\theta)} \quad \text{, and } W_\gamma(\theta) = W_\gamma^\uparrow(\theta) + W_\gamma^\downarrow(\theta).$$

These fits can be obtained by the following simple model. The intensity of the scattered proton of the $^{12}C(\vec{p},p')^{12}C_{1+}$ reaction is given by $\sigma = \sigma_0(1 + \vec{P}\vec{n}A)$, where $\vec{P}$ is the beam polarization, $\vec{n} = \vec{k}_i \times \vec{k}_f$, and A the analyzing power of the reaction. For simplicity we assume the particle is scattered in the average angle $\bar{\theta}$ and $|\vec{P}| = 1$.

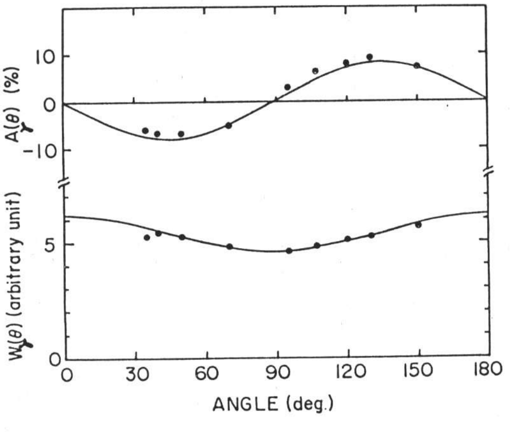

Fig.1. The analyzing power and the angular distribution of the 15.1 MeV γ-ray following the $^{12}C(\vec{p},p'\gamma)^{12}C_{1+}$ reaction at E_p = 40 MeV. Solid lines are $A_\gamma(\theta) = -0.08\sin2\theta$ and $W_\gamma(\theta) = C(1 - 0.129\sin^2\theta)$.

First, we argue the case where the particle is scattered in the plane perpendicular to the spin of the incident proton. The spin of the excited state may align in the plane which is perpendicular to the transferred momentum. The angular distribution of dipole γ-ray transition from the states with a plane alignment is given by $\sin^2\phi$, where ϕ is the angle between the emitted γ-ray and the normal of the alignment plane which is the direction of the transferred momentum. Therefore the angular distribution of the γ-ray for the spin up incident proton is given by

$$W_\gamma^\uparrow(\theta) = \sigma_0(1 - A)\sin^2(\theta + \alpha) + \sigma_0(1 + A)\sin^2(\theta - \alpha) \tag{1}$$

and for spin down

$$W_\gamma^\downarrow(\theta) = \sigma_0(1 + A)\sin^2(\theta + \alpha) + \sigma_0(1 - A)\sin^2(\theta - \alpha) \tag{2}$$

for the inelastic scattering with $|\vec{P}| = 1$. The α is the angle between the direction of the momentum transfer $\vec{q}$ and the beam axis (thus $\phi = \theta + \alpha$) as shown in Fig.2. Second, in the case that the particle is scattered in the plane which is parallel to the spin of the incident proton, the alignment of the residual nuclear spin is perpendicular to the beam direction. Thus the γ-ray angular distribution is given by

$\sigma_0 \sin^2\theta$. Since this is a simple minded argument, there may be the nuclear states whose spins do not align in a plane. Thus we may have γ-rays emitted isotropically. Therefore the γ-ray angular distribution can generally be expressed by

$$W_\gamma^\uparrow(\theta) = \sigma_0' + \sigma_0\{\sin^2\theta + (1-A)\sin^2(\theta + \alpha) + (1+A)\sin^2(\theta - \alpha)\} \tag{3}$$

$$W_\gamma^\downarrow(\theta) = \sigma_0' + \sigma_0\{\sin^2\theta + (1+A)\sin^2(\theta + \alpha) + (1-A)\sin^2(\theta - \alpha)\} \tag{4}$$

$$W_\gamma(\theta) = W_\gamma^\uparrow(\theta) + W_\gamma^\downarrow(\theta) \tag{5}$$

$$A_\gamma(\theta) = \frac{W_\gamma^\uparrow(\theta) - W_\gamma^\downarrow(\theta)}{W_\gamma^\uparrow(\theta) + W_\gamma^\downarrow(\theta)} \tag{6}$$

If $\sigma_0' \gg \sigma_0$, $W_\gamma(\theta)$ and $A_\gamma(\theta)$ are given by

$$W_\gamma(\theta) = 2\sigma_0'\{ 1 + \frac{\sigma_0}{\sigma_0'}(1 + 2\cos2\alpha)\sin^2\theta \} \tag{7}$$

$$A_\gamma(\theta) = - \frac{\sigma_0}{\sigma_0'} A \sin2\alpha \sin2\theta . \tag{8}$$

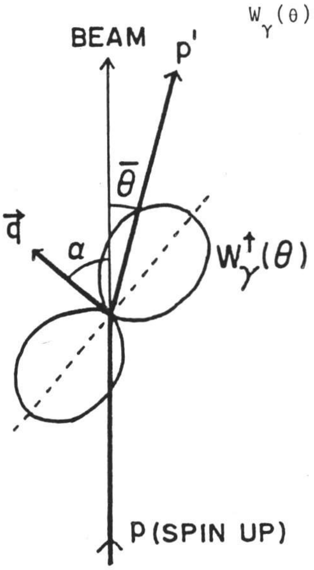

Fig.2. Angular distribution of the dipole transition from the states with a plane alignment produced by the $(\vec{p},p')$ reaction. $W_\gamma(\theta)$ shows an angular distribution given by eq.(1) with A = -1.

Since the angle α has to be smaller than 90°, the sign of the analyzing power for the γ-ray following the $(\vec{p},p'\gamma)$ reaction is opposite to the one for the proton of the $(\vec{p},p')$ inelastic scattering. The obtained values of $(\sigma_0/\sigma_0')A\sin2\alpha = -0.08$ and $(\sigma_0/\sigma_0')(1 + 2\cos2\alpha) = -0.129$ are consistent, if the analyzing power A of the inelastic scattering $^{12}C(\vec{p},p')^{12}C_{1+}$ has negative value (A < -0.08) at the average scattering angle θ and if the angle α of the momentum transfer has a value between 60° and 90°. Since the γ-ray was measured at negative angle in the present experiment (the left side in the Fig.2), the angle θ in the eq (8) is negative. Note that the present measurement of the analyzing power for the γ-ray was carried out without coincidence with scattered particles. The analyzing power of the γ-ray following the inelastic scattering gives some information about the analyzing power of the inelastic scattering leading to the excited state which emits the γ-ray. Since this method does not need to measure the scattered particle, it may have an advantage when the energy resolution is not good enough to separate the excited levels, because the energy resolution for the γ-ray measurement may be good enough to separate the levels.

Reference

1) T.Kishimoto, T.Shibata, M.Sasao, M.Noumachi, and H.Ejiri: Nucl. Instr. Meth. 198(1982)269.