ОБЪЕДИНЕННЫЙ
ИНСТИТУТ
ЯДЕРНЫХ
ИССЛЕДОВАНИЙ
ДУБНА

E2-93-397

V.L.Lyuboshitz

THE PROCESS $^3He + p \rightarrow {}^4He + \pi^+$ ON THE POLARIZED HYDROGEN TARGET AS AN ANALYZER OF THE ^3He POLARIZATION

Report at International Symposium «Dubna, Deuteron-93»,
14—18 September, 1993

1993

In connection with the interest in experiments with polarized beams of ^3He nuclei the problem of measuring the ^3He polarization appears. It seems that the reaction $p(^3He, {}^4He)\pi^+$ on the polarized hydrogen target is appropriate for this purpose.

1. It follows from the conservation of the angular momentum and the space parity that in the case of reactions of the type $1/2 + 1/2 \to 0 + 0$, when two fermions with spins of 1/2 transform into two spinless bosons, the transitions from fermion singlet state are forbidden on condition that the internal parity products of the initial fermions and the final bosons are opposite [1,2,3]. Therefore, in view of the fact that π^+ is the pseudoscalar meson, the process $^3He + p \to {}^4He + \pi^+$ is possible only when the total spin of the ^3He nucleus and the proton equals unity (the triplet state).

Let $\vec{P}_1$ and $\vec{P}_2$ be the independent polarization vectors of the ^3He nucleus and the proton, respectively. It is easy to show that the probabilities of detecting the $(^3He, p)$-system in the triplet states with the total spin projections $\mu = \pm 1, 0$ to the ^3He momentum are the following:

$$W_{\pm 1}^{(t)} = \frac{1}{4}\left(1 \pm \vec{P}_1\vec{\ell}\right)\left(1 \pm \vec{P}_2\vec{\ell}\right), \tag{1}$$

$$W_0^{(t)} = \frac{1}{4}\left[1 + \vec{P}_1\vec{P}_2 - 2\left(\vec{P}_1\vec{\ell}\right)\left(\vec{P}_2\vec{\ell}\right)\right], \tag{2}$$

where $\vec{\ell}$ is the unity vector in the direction of the ^3He momentum.

The total probability of detecting the triplet states is equal to

$$W^{(t)} = \frac{1}{4}\left(3 + \vec{P}_1\vec{P}_2\right), \tag{3}$$

and the probability of detecting the singlet state

$$W^{(s)} = \frac{1}{4}\left(1 - \vec{P}_1\vec{P}_2\right). \tag{4}$$

2. Let us consider the case of the flight of the final ^4He nucleus, produced in the reaction $^3He + p \to {^4He} + \pi^+$, in the forward direction. Then, in consequence of the conservation of the projection of the total angular momentum, this process is possible only at the zero value of the total spin projection of $(^3He, p)$-system to the reaction axis, and it is forbidden for projections equalling (+1) and (-1). As a result, in accordance with formula (2) the differential cross-section of the process $^3He + p \to {^4He} + \pi^+$ at the zero angle depends simply on polarizations of the ^3He beam and the proton target:

$$\frac{d\sigma}{d\Omega}(0) = \left(\frac{d\sigma}{d\Omega}(0)\right)_{unpol}\left[1 + \vec{P}_1\vec{P}_2 - 2(\vec{P}_1\vec{\ell})(\vec{P}_2\vec{\ell})\right], \tag{5}$$

where $\left(d\sigma/d\Omega(0)\right)_{unpol}$ is the differential cross-section of the same reaction in the case when both the beam and the target are unpolarized.

Under standard methods of the beam polarization the vector $\vec{P}_1$ is perpendicular to the momentum $(\vec{P}_1\vec{\ell} = 0)$. Then the relation (5) gives

$$\frac{d\sigma}{d\Omega}(0) = \left(\frac{d\sigma}{d\Omega}(0)\right)_{unpol}\left(1 + |\vec{P}_1||\vec{P}_2|\cos\alpha\right), \tag{6}$$

where α is the angle between the polarization directions of the ^3He nucleus and the proton. The relative change of the cross-section with the ^3He polarization reversal (or the proton polarization one) equals

$$\eta = \left(\frac{d\sigma^{(+)}}{d\Omega}(0) - \frac{d\sigma^{(-)}}{d\Omega}(0)\right)\Big/\left(\frac{d\sigma^{(+)}}{d\Omega}(0) + \frac{d\sigma^{(-)}}{d\Omega}(0)\right) = |\vec{P}_1||\vec{P}_2|\cos\alpha. \tag{7}$$

Thus, it is possible to determine the degree of the ^3He beam polarization, knowing the asymmetry η, the degree of the proton target polarization and the angle between the ^3He and proton polarization vectors.

3. At non-zero angles of the flight of the ^4He nucleus, taking into account the parity conservation, the cross-section of the reaction $^3He + p \to {^4He} + \pi^+$, integrated over azimuth angles (as well as the total cross-section of the reaction), has the following structure:

$$\sigma(\theta) = \frac{1}{4}\sigma_{t,0}(\theta)\left[1 + \vec{P}_1\vec{P}_2 - 2(\vec{P}_1\vec{\ell})(\vec{P}_2\vec{\ell})\right] + \frac{1}{2}\sigma_{t,1}(\theta)\left[1 + (\vec{P}_1\vec{\ell})(\vec{P}_2\vec{\ell})\right], \tag{8}$$

where $\sigma_{t,\mu}(\theta)$ is the cross-section corresponding to the triplet state of the $(^3He, p)$-system with the projection μ to the direction of the ^3He momentum. Here we have taken into account that the interference between states with different projections of the total spin disappears after the integration over azimuth angles, and, besides, in consequence of the parity conservation the equality

$$\sigma_{t,+1}(\theta) = \sigma_{t,-1}(\theta) \tag{9}$$

is satisfied. At very small angles the triplet cross-section corresponding to projections (± 1) tends to zero being proportional to the square of the angle $(\sigma_{t,1} \sim \theta^2)$.

The formula (8) can be rewritten in the form

$$\sigma(\theta) = \sigma_1(\theta) + \sigma_2(\theta)(\vec{P}_1\vec{P}_2) + \sigma_3(\theta)(\vec{P}_1\vec{l})(\vec{P}_2\vec{l}), \tag{10}$$

where

$$\sigma_1(\theta) = \frac{1}{4}\sigma_{t,0}(\theta) + \frac{1}{2}\sigma_{t,1}(\theta), \quad \sigma_2(\theta) = \frac{1}{4}\sigma_{t,0}(\theta),$$

$$\sigma_3(\theta) = \frac{1}{2}\left(\sigma_{t,1}(\theta) - \sigma_{t,0}(\theta)\right). \tag{11}$$

It is evident that values $\sigma_1(\theta)$ and $\sigma_2(\theta)$ are positive, and $\sigma_1(\theta) \geqslant \sigma_2(\theta)$. When the polarization vector of a ^3He nucleus is perpendicular to its momentum the asymmetry at the polarization reversal is expressed as

$$\eta = A|\vec{P}_1||\vec{P}_2|\cos\alpha, \quad A = \frac{\sigma_2}{\sigma_1} \leqslant 1. \tag{12}$$

In accordance with the relations (11) the following equality is valid:

$$\sigma_1 = 3\sigma_2 + \sigma_3. \tag{13}$$

The same result takes place for the annihilation processes $\bar{p}p \to \pi^+\pi^-, K^+K^-, K^0\bar{K}^0$ [3].

4. The process $^3He(p,\pi^+)^4He$ on the helium target, as well as the time-reversal reactions $\pi^+ + {}^4He \to p + {}^3He$, $\pi^- + {}^4He \to n + {}^3H$, were studied experimentally in a number of works (see, for example, [4-8]).

In accordance with experimental data, when both the beam and the target are unpolarized, at ^3He laboratory kinetic energies in the range of (1÷2) GeV the small-angle differential cross-section of the process $^3He + p \to {}^4He + \pi^+$ is of $\sim 10\ \mu b/sr$ in the center-of-mass system. The cross-section maximum of about $15\ \mu b/sr$ at the ^3He laboratory kinetic energy $T \simeq 1.25$ GeV and $\theta_{c.m} = 0$ corresponds, apparently, to the formation of $\Delta(33)$-resonance on a bound nucleon [5] (in the proton rest frame $d\sigma/d\Omega^{(max)}(0) \simeq 250\ \mu b/sr$).

Author would like to thank N.M.Piskunov, I.M.Sitnik and E.A.Strokovsky for their interest in this work and valuable discussions.

References

1. Bylenky S.M., Ryndin R.M. Phys.Lett., 1963, v.6, p.217.
2. Bylenky S.M., Ryndin R.M. Zh.Teor.Exp.Fiz., 1963, v.45, p. 1192.

3. Lyuboshitz V.L. Yad.Fiz., 1970, v.12, p.199
(Sov. J.Nucl.Phys., 1970, v.12, p.107).

4. Cabathuler K. et al. Nucl.Phys., 1972, v. B40, p. 32.

5. Tatischeff B. et al. Phys.Lett., 1976, v.B63, p. 158.

6. Höistad B. et al. Phys.Rev., 1984, v. C29, p.553.

7. Källne J. et al. Phys.Rev., 1981, v. C24, p. 1102.

8. Källne J. et al. Phys.Rev., 1983, v. C28, p.304

Received by Publishing Department
on November 2, 1993.