PHOTO-MESONS FROM POLARIZED NUCLEONS

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1. INTRODUCTION

PHOTO PRODUCTION of pions by nucleons is fairly well understood for energies up to above three or four hundred MEV. The resonance predicted by theory of Chew and Low at about 300 MEV has been experimentally confirmed. However the behaviour of photo production cross-section at higher energies say above 700 MEV is still an open question. The calculations for energies higher than 500 MEV are done on the understanding that only low energy intermediate states are important for low energy processes and hence are not successful in explaining the important features of the phenomena. In such calculations, an improved solution of the Chew-Low amplitude is sought by including the corrections from two and possibly three meson states and these corrections are much smaller than what has been actually observed. Thus it would be worthwhile investigating other features of Chew-Low cross-section at low energy and their agreement with photo production experiments. One such feature relates to the polarisation phenomena. In this note, we shall examine the angular distribution of mesons produced by polarised photons taking into account the spin states of the nucleon.

2. ANGULAR DISTRIBUTION OF NEUTRAL MESONS RESULTING FROM A POLARIZED PHOTON BEAM

We shall first consider the production of neutral mesons and the charged ones will be dealt with in the next section. The amplitude for π° photo production by a nucleon is given by (Chew and Low, 1956)

$$F(\pi^\circ) = \frac{ef}{\sqrt{4\omega k}}\left(\frac{\mu_p + \mu_n}{2M}\right)\frac{i\vec{\sigma}\cdot\left[\vec{q}\times\left(\vec{k}\times\vec{\epsilon}\right)\right]}{\omega}$$

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$$-\frac{e}{f}\left(\frac{\mu_p-\mu_n}{4M}\right)\frac{1}{2\sqrt{\omega k}}\left[\vec{q}\cdot\left(\vec{k}\times\vec{\epsilon}\right)\left(\frac{a_1+4a_2+4a_3}{3q^2}\right)\right.$$

$$\left.+\,i\vec{\sigma}\cdot\left\{\vec{q}\times\left(\vec{k}\times\vec{\epsilon}\right)\right\}\left(\frac{a_1+a_2-2a_3}{3q^2}\right)\right] \qquad (1)^*$$

where μ_p, μ_n are the magnetic moments of the proton and the neutron respectively. $\vec{k}$ is the momentum of the photon, $\vec{\epsilon}$ its direction of polarization while $\vec{q}$ is the pion momentum. a's are the pion nucleon scattering amplitudes. The term proportional to $(\mu_p+\mu_n)$ can be neglected in comparison with the second term though its inclusion does not in any way affect the results of the paper.

Let us choose a co-ordinate system with z-axis in the direction of the photon propagation. (1) gives the following amplitudes for right and left circularly polarized photons:

$$F_{r.c.}(\pi^\circ)=-\frac{ie}{f}\left(\frac{\mu_p-\mu_n}{8Mq}\right)\sqrt{\frac{k}{\omega}}\left[-\frac{a_1+4a_2+4a_3}{3\sqrt{2}}e^{i\phi}\sin\theta\right.$$

$$\left.+\frac{a_1+a_2-2a_3}{3}\left(\frac{\sigma_z}{\sqrt{2}}e^{i\phi}\sin\theta-\sigma_+\cos\theta\right)\right] \qquad (2)$$

$$F_{l.c.}(\pi^\circ)=-\frac{ie}{f}\left(\frac{\mu_p-\mu_n}{8Mq}\right)\sqrt{\frac{k}{\omega}}\left[\frac{a_1+4a_2+4a_3}{3\sqrt{2}}e^{-i\phi}\sin\theta\right.$$

$$\left.+\frac{a_1+a_2-2a_3}{3}\left(\frac{\sigma_z}{\sqrt{2}}e^{-i\phi}\sin\theta-\sigma-\cos\theta\right)\right] \qquad (3)$$

θ is the angle between the vectors $\vec{k}$ and $\vec{q}$ while ϕ is the angle which the projection of $\vec{q}$ makes with the x-axis. $F_{r.c.}$ and $F_{l.c.}$ matrices in the spin space of the nucleon. Since (2) and (3) are derived in the assumption that the nucleon has no motion, it has a definite spin orientation. Let us assume that the direction coincides with that of photon propagation. It follows from (2) that spin flip cross-section is zero for a right circularly polarized photon beam and that the non-spin flip cross-section is given by

$$\frac{d\sigma_{r.c.}(\pi^\circ)}{d\Omega}=\frac{e^2(\mu_p-\mu_n)^2}{(16\pi Mqf)^2}\left(\frac{kq}{2}\right)|a_2+2a_3|^2\sin^2\theta \qquad (4)$$

* Throughout this paper we use natural units, *i.e.*, $h=c=1$. The energy of the charged pion (139·6 MEV) will serve as the energy unit and its compton wavelength as the unit of length. In these units M the rest of the nucleon is 6·72.

On the other hand, a left circularly polarized beam yields both spin flip and non-spin flip cross-sections:

$$\frac{d\sigma_{l.c.}^{(1)}(\pi^\circ)}{d\Omega} = \frac{e^2(\mu_p - \mu_n)^2}{(16\pi\, Mfq)^2}\left(\frac{kq}{18}\right) | 2a_1 + 5a_2 + 2a_3 |^2 \sin^2\theta \tag{5}$$

$$\frac{d\sigma_{l.c.}^{(2)}(\pi^\circ)}{d\Omega} = \frac{e^2(\mu_p - \mu_n)^2}{(16\pi\, Mqf)^2}\left(\frac{kq}{9}\right) | a_1 + a_2 + 2a_3 |^2 \cos^2\theta \tag{6}$$

We have used superscripts (1) and (2) to denote non-spin flip and spin flip cross-sections.

We note that if we have the nucleon polarized opposite to the direction of propagation of photon, it is the right circular photon that will yield non-zero spin flip amplitude while the spin flip amplitude arising from a left circular photon is zero. The above results also bring out the need for polarizing the target nucleon.

3. Charged Pions

The complete amplitude for photo production of a positively charged meson is given by

$$\begin{aligned} F(\pi^+) = \frac{ef}{\omega}\Bigg[& i\vec{\sigma}\cdot\vec{\epsilon} + 2i\frac{\vec{\sigma}\cdot\left(\vec{k}-\vec{q}\right)\left(\vec{\epsilon}\cdot\vec{q}\right)}{1+\left(\vec{k}-\vec{q}\right)^2} \\ & + \frac{\mu_p - \mu_n}{4Mf^2}\left\{\left(\vec{q}\cdot(\vec{k}\times\vec{\epsilon})\right)\left(\frac{a_1+a_2-2a_3}{3q^2}\right)\right. \\ & \left. + i\sigma\cdot\left(\vec{q}\times(\vec{k}\times\vec{\epsilon})\right)\left(\frac{a_1-2a_2+a_3}{3q^2}\right)\right\} \\ & - \left(\frac{\mu_p+\mu_n}{2M}\right)\frac{i\vec{\sigma}\cdot\left(\vec{q}\times(\vec{k}\times\vec{\epsilon})\right)}{\omega}\Bigg] \end{aligned} \tag{7}$$

where the first two terms in the bracket are respectively the s-wave "guage" contribution and the "pion current" contribution. We can proceed in exactly the same way as in the previous section and calculate the amplitudes for a positively charged pion production by left and right circular photons. However, we note that due to the presence of the pion current term, spin flip and non-spin-flip amplitudes occur for both the cases. The pion current term is important only for small angles and we can neglect it since it is proportional to $\sin^2\theta$. Thus we find that even in the case of charged pions the cross-sections for right and left circular photons are of the same form as for neutral mesons. We give below for completeness the various cross-sections for the production of a positive pion:

$$\frac{d\sigma_{r.c.}(\pi^+)}{d\Omega} = \left(\frac{\mu_p - \mu_n}{8\pi M f}\right)^2 \frac{e^2}{4}\frac{k}{q} \mid a_3 - a_2 \mid^2 \sin^2\theta \tag{8}$$

$$\frac{d\sigma_{l.c.}^{(1)}(\pi^+)}{d\Omega} = \left(\frac{\mu_p - \mu_n}{8M\pi f}\right)^2 \frac{e^2}{36}\frac{k}{q} \mid 2a_1 - a_2 - a_3 \mid^2 \sin^2\theta \tag{9}$$

$$\frac{d\sigma_{l.c.}^{(2)}(\pi^+)}{d\Omega} = \frac{qe^2f^2}{4\pi^2}\left| 1 - \frac{(\mu_p - \mu_n)\,k}{12Mf^2q}(a_1 + a_3 - 2a_2)\cos\theta \right|^2 \tag{10}$$

We note from equations (4), (5) and (6) that the cross-section for a right circular photon is proportional to $\sin^2\theta$ while that for a left circular photon is proportional to $\cos^2\theta$. In the case of positive pion production, the difference in angular distribution is more pronounced. The positive pions arising from left circular photons is distributed according to the law $A + B\cos\theta + C\cos^2\theta$. These features can be checked against experiments by using a polarized beam on a polarized nucleon target.

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Summary

It is shown that the angular distribution of photo-mesons obtained from polarized nucleons behaves differently for left and right circularly polarized beams.

Reference

1. Chew, G. F. and Low, F. E. .. *Phys. Rev.*, 1956, **101**, 1579.