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To Jens Vigen <Jens.Vigen@cern.ch>

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Dear Jens Vigen,

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Kindest regards

Carmen Vasini

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Chew 57:41 -

On the Nucleons Magnetic Moments Contribution to the Radiative Pion-Nucleon Scattering

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(ricevuto l'11 Marzo 1957)

With the aim to get more and more information on the pion nucleon interaction many efforts have been devoted until now, both experimentally and theoretically, to investigate phenomena involving pion nucleon scattering with and without the presence of an electromagnetic field

It is well known that the most successful theory in explaining such a type of phenomena is the so called cut off form of the Yukawa theory, first proposed by CHEW ⁽¹⁾

Recently the results of this theory have been very much improved by using the CHEW, LOW ⁽²⁾ and WICK ⁽³⁾ technics

It seems then interesting to apply this theory to the radiative pion nucleon scattering

Of course the experimentally observed γ rays spectrum is composed of both nuclear and bremsstrahlung spectra

We wish in this letter only to outline the treatment of the nuclear current while the complete results including the bremsstrahlung spectrum will appear in the near future

Following the Chew Low idea of the photoproduction theory ⁽⁴⁾ we can write down the matrix element

$$\mathcal{H}'_k(q, q'),$$

due to the current j for the radiative scattering from a meson q' in a meson q

(*) On leave from Istituto di Fisica dell'Università Torino (Italy)

⁽¹⁾ G. CHEW: *Phys. Rev.* **89** 591 (1953) and **95** 1669 (1954)

⁽²⁾ G. CHEW and F. LOW: *Phys. Rev.* **101** 1570 (1956) and *Phys. Rev.* **101** 1579 (1956); this paper will be denoted in the following as CL

⁽³⁾ G. C. WICK: *Rev. Mod. Phys.* **27** 339 (1955)

⁽⁴⁾ See foot note ⁽²⁾

with emission of a photon k in the form:

$$(1) \quad \mathcal{H}_k^j(q, q') = \left(\psi_q^{(-)} \int dv (-\mathbf{j} \cdot \mathbf{A}_k) \psi_{q'}^{(+)} \right)$$

Here the indexes q, k, q' stand for all the variable of the particles to which they refer; $\mathbf{A}_k = (1/\sqrt{2k})\mathbf{e} \exp[-i\mathbf{k} \cdot \mathbf{r}]$ is the electromagnetic vector potential associated with the emission of photon k and $\psi_q^{(-)}(\psi_{q'}^{(+)})$ is the exact eigenvector of the Schrödinger equation for the meson nucleon system which asymptotically contains no incoming (no outgoing) particles

If then we assume $\mathbf{j}'$ as nucleonic density current operator and make the Chew Low decomposition $\mathbf{j}' = \mathbf{j}_v + \mathbf{j}_s$ we can write immediately

$$(2) \quad \mathcal{H}_k^{j_v}(q, q') = \frac{1}{(4\pi)^{\frac{1}{2}}(f/\mu)} \frac{g_P - g_N}{2} \frac{e}{2M} E(k) \left(\frac{\omega_P}{k} \right)^{\frac{1}{2}} \frac{1}{v(p)} (\psi_q^{(-)}, V_P^0 \psi_{q'}^{(+)})$$

Where all the symbols all the same as in CL Work

The analogous term for $\mathbf{j}_s$ can be neglected for the same reason for which it is omitted in CL, i.e. for the smallness of the ratio $(g_P + g_N)/(g_P - g_N)$

Unfortunately here, also working only with eq (2) there does not exist a simple connection between the matrix element

$$(\psi_q^{(-)}, V_P^0 \psi_{q'}^{(+)})$$

and the scattering matrix

However, this expression can be cast into a form consisting in a sum of terms of the type

$$\left(\psi_0 V \frac{1}{H +} V \frac{1}{H +} V \psi_0 \right),$$

and then evaluated first introducing the one meson approximation and then retaining only the terms which can be expressed by means of the scattering matrix

This calculation is not difficult but rather cumbersome and we will give details in the more complete paper; the results for the reaction

$$\pi^+ + p \rightarrow \pi^+ + p + \gamma,$$

read:

$$(3) \quad (\psi_q^{(-)}, V_P^0 \psi_{q'}^{(+)}) = \text{Born term} + \langle \alpha | [h_1(q, q', p) \boldsymbol{\sigma} \cdot \mathbf{p} \mathbf{q} \cdot \mathbf{q}' + h_2(q, q', p) \boldsymbol{\sigma} \cdot \mathbf{q} \mathbf{p} \cdot \mathbf{q}' + h_3(q, q', p) \boldsymbol{\sigma} \cdot \mathbf{q}' \mathbf{p} \cdot \mathbf{q} + h_4(q, q', p) \mathbf{p} \cdot \mathbf{q} \times \mathbf{q}'] | \alpha' \rangle,$$

where h_i are quite complicate functions of the phase shifts and

$$|\alpha'\rangle = (|\alpha\rangle),$$

are the spin function of the proton in the initial (final) state and the Born term is:

$$(4) \quad \text{Born term} = 4i(4\pi)^{\frac{3}{2}} \left(\frac{f}{\mu}\right)^{\frac{3}{2}} \frac{v(q)v(p)v(q')}{\sqrt{2\omega_q}\sqrt{2\omega_p}\sqrt{2\omega_q}} \left\langle \alpha \left| \left[\frac{1}{\omega_q k} \boldsymbol{\sigma} \cdot \mathbf{q} \mathbf{p} \cdot \mathbf{q} - \frac{1}{\omega_q k} \boldsymbol{\sigma} \cdot \mathbf{q} \mathbf{p} \cdot \mathbf{q}' \right] \right| \alpha' \right\rangle$$

Since all the h_i are such that they vanish if all the phase shifts are put equal to zero the approximation expressed by (3) means that we have decomposed the process in Born approximation plus scattering corrections

We give here the cross section in Born approximation: by substitution of (4) in (2) and using the usual formula for the cross section one finds:

$$(5) \quad \frac{d\sigma}{d\Omega_k}(k, q') = \frac{1}{12\pi^2} \left(\frac{f}{\mu}\right)^4 (g_P - g_N)^2 \frac{e^2}{M^2} \frac{v^2(q')v^2([(\omega_q - k)^2 - \mu^2]^{\frac{1}{2}})}{(\omega_q - k)^3 \omega_q^2} \lambda_q^2 g_1^2 [(\omega_q - k)^2 - \mu^2]^2 \{2(\omega_q - k)^2 + [3\omega_q^2 - 2\omega_q(\omega_q - k)] \cos \Theta\} k dk$$

where Θ is the angle between $\mathbf{q}'$ and $\mathbf{p} = \mathbf{k} \wedge \boldsymbol{\epsilon}$ $\cos \Theta$ can be expressed in terms of the angle θ between $\mathbf{k}$ and $\mathbf{q}$ and the angle α between $\boldsymbol{\epsilon}$ and the $(\mathbf{q}, \mathbf{k})$ plane by the relation:

$$\cos \Theta = \sin \theta \sin \alpha$$

If we are not interested in the polarization of the emitted radiation we have to perform the sum over the polarizations; then we get:

$$(6) \quad \frac{d\sigma}{d\Omega_k}(q', k) = \frac{1}{12\pi^2} \left(\frac{f}{\mu}\right)^4 (g_P - g_N)^2 \frac{e^2}{M^2} \frac{v^2(q')v^2([(\omega_q - k)^2 - \mu^2]^{\frac{1}{2}})}{(\omega_q - k)^3 \omega_q^2} \lambda_q^2 [(\omega_q - k)^2 - \mu^2]^2 q'^2 \{4(\omega_q - k)^2 + [3\omega_q^2 - 2\omega_q(\omega_q - k)] \sin^2 \theta\} k dk$$

In Fig 1 we give the graphical representation of (6) for incident 220 MeV energy of π^+ in the laboratory system and for $\theta = 45^\circ$ and 90°

Since this cross section is very small if the scattering corrections will not turn out to change very much the order of magnitude of the Born approximation, we can conclude that the contribution of the nucleons magnetic moment to the radiative scattering is very small and that significant contributions to the complete spectrum only can derive from interference terms

Fig 1

* * *

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