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THE PRODUCTION OF NEUTRAL MESONS BY PHOTONS

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A number of recent experiments at Berkeley have given independent and strong support for the hypothesis that there exists a neutral meson which is strongly coupled to nucleons. Of particular interest are the experiments of Steinberger, Panofsky, and Steller[1] which seem to indicate that neutral mesons can be produced by photons with a cross section which is not less than that for charged mesons.

Photo-meson production is among the simplest of phenomena involving mesons; and it might therefore be hoped that some of its general features can be understood on the basis of our admittedly very incomplete theoretical knowledge of the properties of mesons. In particular, we are interested in seeing whether a photo-production cross section for neutral mesons as large as that for charged mesons can be understood theoretically.

For the photo-production of charged mesons Brueckner[2] found that of the four types of meson fields only the pseudoscalar theory gave satisfactory agreement with experiment. For such a theory as the scalar theory with charged meson currents extending about the nucleon over a region of the order of the meson Compton wave-length, the angular (dipole) distribution of the ejected photo-mesons arising from the coupling of the electromagnetic field to the meson currents is incompatible with the observed,[3] flat angular distribution

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[1] J. Steinberger, W. Panofsky, and J. Steller, Phys. Rev., in press.

[2] K. Brueckner, Phys. Rev., in press. His calculations of radiative corrections did not include effects from virtual neutral mesons, but it does not seem that this would change his results in a qualitative manner.

[3] J. Steinberger and A. S. Bishop, Phys. Rev., in press.

for charged mesons. Such a coupling of the charged meson field to the electromagnetic field would also lead one to expect the ratio of cross sections for neutral to charged mesons to be of the order of $(\mu/M)^2$ (where μ is the meson mass and M is the nucleon mass), since for neutral meson production the electromagnetic field coupling is to the nucleon. This is in contradiction to the observed largeness of the neutral meson cross section.

Assuming that neutral meson production takes place through the interaction of the electromagnetic field with the magnetic moment of the nucleon, both classical and lowest order perturbation calculations for scalar mesons and pseudoscalar mesons with pseudovector coupling lead to a ratio of the neutral to charged meson cross section (near threshold) of the order of $(\mu/M)^2$, in agreement with the above qualitative arguments.

Such semiclassical arguments are not necessarily applicable in the case of the pseudoscalar field, however, where relativistic quantum-mechanical effects are likely to be important. Here the matrix element for neutral meson production for a γ-ray striking a proton is proportional to

$$(F|H|I) \simeq \underset{\sim}{\mu} \cdot \underset{\sim}{\hat{\xi}}(\rho) \left\{ \left[\frac{1}{\underset{\sim}{P}_I \cdot \underset{\sim}{\rho}} - \frac{1}{\underset{\sim}{P}_F \cdot \underset{\sim}{\rho}} \right] M\rho_0 \right\} \qquad (1)$$

$\underset{\sim}{\mu}$ is the Dirac magnetic moment of the proton, $\underset{\sim}{P}_I$ and $\underset{\sim}{P}_F$ are its four-momenta in the initial and final states, respectively, $\underset{\sim}{\rho}$ is the four-momentum of the incident protons, and $\underset{\sim}{\hat{\xi}}$ is the electric field strength. Equation (1) differs from that for charged meson emission by the factor in brackets, which is nonvanishing only because of retardation effects and is of order (μ/M) near threshold. This is because the magnetic moment is relatively undisturbed by the process of neutral meson emission, causing phase cancellation between initial and final states. Thus, again the ratio of neutral to charged meson cross sections

is of order $(\mu/M)^2$. Similar results are obtained for vector and pseudovector theories. (The experimental evidence is against the neutral mesons having spin one, because of their apparent annihilation into two photons.[4])

It is seen, therefore, that neither classical considerations nor lowest order perturbation theory provide a clue to the largeness of the cross section for neutral photo-mesons. We note, however, that the factor in the brackets in Equation (1) is small only when the nucleon recoil is small. Due to the very close binding of the meson field to the nucleon for pseudoscalar theory, high energy virtual recoils are expected and it might be thought that these will remove the near cancellation of the two terms in the brackets. To investigate this possibility, we have calculated the first order radiative corrections to Equation (1). The corresponding radiative corrections for charged meson production have been calculated by Brueckner.[2] Combining lowest order and first order radiative corrections for both charged and neutral meson production and choosing the coupling constant as $\frac{g^2}{4\pi} \simeq 10$ (a reasonable value obtained from other considerations), we obtain about equal cross sections for the two processes--in reasonable agreement with experiment. With this choice of coupling constant, the radiative corrections to charged meson production are not qualitatively important, while for neutral meson production the lowest order terms are small.

Since the validity of large radiative corrections is open to considerable doubt, we feel justified in concluding only that the large observed cross section for neutral meson production is not necessarily incompatible with conclusions that can be drawn from pseudoscalar meson theory.

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[4] C. N. Yang, Phys. Rev. 77, 242 (1950)

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