Radiative Pion-Nucleon Scattering.

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Summary. — We use current algebra in the off-mass-shell limit \( q^2 \rightarrow 0 \) to study radiative pion-nucleon scattering. We disperse both the pions and the photon thus treating the pions symmetrically. The difficulty connected with gauge invariance arising because of our limiting procedure is discussed. Our calculations, which are valid in the low-energy region, give results which are comparable to that of the static-model predictions.

1. — Introduction.

Recent successes of current algebra have motivated us to study the radiative pion-nucleon scattering process \( \pi^+ p \rightarrow \pi^+ p \gamma \) using the hypothesis of the partial conservation of the axial-vector current (PCAC) and current-commutation relations. Most of the earlier current-algebra calculations \(^1\) were performed in the soft-pion limit \( q_\pi \rightarrow 0 \). It has recently been shown that \(^2\) if one works in the much weaker off-mass-shell limit \( q^2 \rightarrow 0 \), one gets additional contributions to the current-algebra amplitude which, in general, are not negligible. Hence in the present calculation we work in the off-mass-shell limit and treat both the pions on an equal footing and thus disperse them simul-


taneously. In this way we assure Bose symmetry for the two pions. Here, we would like to point out that recently techniques (3) have been developed to do away even with the limit $q_\pi^2 \rightarrow 0$. However, these have been developed largely for meson-meson processes. In case of pion-baryon processes the off-mass shell corrections that arise because of the $q_\pi^2 \rightarrow 0$ limit are expected to be of the order $(m_\pi/2m_B)^2$ and hence not large (4). In the present formulation, the additional terms, which will otherwise vanish in the soft-pion limit, are either of first order in the pion four-momenta or quadratic in it (eq. (6) of the text). We note that the term which is quadratic in pion momenta is the only one which survives in the on-shell limit and hence some of the dynamical details are present in it.

We will evaluate these additional matrix elements in the pole model including octet ($N$) and decuplet ($N^*(1238)$) poles only. Certain difficulties connected with gauge invariance arise which are common in such off-mass-shell current-algebra calculations involving a photon. To resolve these difficulties, we assume the validity of the PCAC and a smooth extrapolation from off-mass-shell to the on-shell limit and demand the gauge invariance of the off-mass-shell amplitude (5). The total cross-section for the process $\pi^+p \rightarrow \pi^+p\gamma$ is evaluated numerically. The phase-space integration is done exactly and in a covariant manner (6).

We note here that earlier calculations of radiative meson-nucleon scattering by Cutkosky (7) and by Carruthers (8) were performed within the framework of the static model. They used a meson current and an interaction current to describe the above process. The interaction current dominates the high-energy end of the $\gamma$-ray spectrum, the meson current the spectrum at long wavelengths. Carruthers (8) considered different diagrams in which i) the meson shakes off the photon before or after scattering in the $3-3$ resonance state, ii) an $s$-wave meson is converted into an electric-dipole photon along with the $\pi$-resonance, and iii) de-excitation of $N^*$ via decay into an $s$-wave pion and an electric-dipole

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