Electroproduction of \( \pi \)-Mesons (*)

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(ricettuto l'11 Giugno 1960)

**Summary.** — An approximate evaluation is made of the dispersion relations for the production of pions in electron-nucleon collisions. The results are applicable at low energies in the final pion-nucleon barycentric system where the assumption that the \((3, 3)\) state dominates the dispersion integrals is expected to be valid. Effects due to nuclear recoil and crossing symmetry are treated exactly to all orders.

1. — Introduction.

By use of the method of dispersion-relations, Fubini, Nambu and Wataghin \(^{(1)}\) have shown that experiments on the production of \( \pi \)-mesons in electron-nucleon collisions may be used as a tool for further study of the electromagnetic-structure of the nucleon. Unlike the case of elastic electron-nucleon scattering \(^{(2)}\), for which the scattering amplitude is very simply related to the


\(^{(2)}\) G. Hofstadter: Rev. Mod. Phys., 28, 214 (1956). See also other papers quoted in this article.
form factors, in the meson-production problem, the amplitude depends on the nucleon structure in a fairly complicated way. This dependence can only be obtained by an evaluation of the dispersion-relations together with the unitarity condition. In the present note we present the results of such an approximate evaluation.

We shall need to assume only that the $(3, 3)$ pion-nucleon state dominates the dispersion integrals and further that states of more than one meson play no role. This means that the results obtained here are confined to experiments in which the center-of-mass energies in the final pion-nucleon state are near and below the resonance. No assumptions concerning the effects of nuclear recoils need be made. Now, for the case of photo-meson production at low energies (3) an expansion of the amplitude in inverse powers of the nucleon mass may be presumed to converge rapidly since only the photon and meson energies, $k$ and $\omega$ respectively, are available for constructing a dimensionless expansion parameter (4). On the other hand, for the case of electro-pion production, there is an additional quantity available, namely the square of the invariant momentum transfer given up by the electron $\lambda^2$, and this allows the construction of other dimensionless ratios; for example, $\lambda^2/M\omega$. Even though one is at reasonably low energies in the pion-nucleon system, in order to map out the form factors, one would like to have the freedom to allow values of $(\lambda^2)^{\frac{1}{2}}$ comparable to and even greater than a nucleon mass. Thus, since quantities such as $\lambda^2/M\omega$ make expansions in powers of $1/M$ very inconvenient, it is of importance to be able to evaluate the dispersion relations without making this expansion.

Following the methods given in a previous paper (5), we shall write down an approximate solution for the dispersion relations. Since the underlying philosophy and methods on electro-pion production already exist (1,4), and since the evaluational techniques have also been discussed (5), we shall give essentially only the final results with a minimum of subsidiary discussion.

2. – Solution of the dispersion relations.

We now proceed to write down the lowest order solution to the dispersion-relation as derived in reference (4). More precisely, it will be assumed that

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(4) However, the arguments of Charap and Fubini (Nuovo Cimento, 14, 540 (1959)) even cast doubts on the validity of this expansion in this case.
