their excitation by the (^{3}He,d) reaction.

Concluding, one might say that the study of gross structure in the final nucleus could throw a new light on the problem of intermediate phenomena. Here the gross structure occurs at lower energies than in the compound system, and it might be easier to identify the simple configurations associated with it.[4]

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APPLICATION OF CURRENT ALGEBRA TO PION EMISSION

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We show that some calculations of pion emission based on current algebra need model-dependent corrections even in the limit of zero four-momenta. The corrections are ambiguous and depend on the way in which the limit is reached. We obtain by means of Fubini's method general rules to know when to expect the corrections.

Current algebra (CA) combined with the hypothesis of partially conserved axial-vector current (PCAC) was recently applied to the calculation of many processes involving the emission of pions.[1] The results obtained follow directly from the algebra and are apparently model independent.

In this note we show that in many cases CA does not determine the problem completely and some terms require evaluation by means of a model. Even in the soft-pion limit these terms are important, depending on the process. They change some calculations[2,3] by factors that cannot be unambiguously calculated. However, we find it impossible to reach over-all agreement with experiment by any choice of model or extrapolation procedure. We first consider CA predictions for ratios of the form $r_{DB} = \Gamma(D\to B+\pi+\pi)/\Gamma(D\to B+\gamma)$, in particular,

$$r_{\omega\pi} = \Gamma(\omega\to\pi+\pi+\pi)/\Gamma(\omega\to\pi+\gamma), \quad (1)$$

$$r_{\eta\gamma} = \Gamma(\eta\to\pi^++\pi^-+\gamma)/\Gamma(\eta\to\gamma+\gamma), \quad (2)$$

$$r_{X^0\gamma} = \Gamma(X^0\to\pi^++\pi^-+\gamma)/\Gamma(X^0\to\gamma+\gamma). \quad (3)$$

$r_{\omega\pi}$ and $r_{\eta\gamma}$ have been calculated recently[2,3] and agreement was found with experiment as well as consistency with the pole model.[4] We have performed the analogous calculation for $r_{X^0\gamma}$ and obtained 1.7. This is in clear contradiction to the present lower limit of 4.1 for this ratio[5] and is also inconsistent with the pole model.[4] η-X^0 mixing cannot change this result significantly.[6] The calculation reads as follows: We start from the causal amplitude

$$T_{\mu\nu}^{ij} = -i\int d^4x \exp(-iq_i x) \times\langle B|T[A_\mu^i(x)A_\nu^j(0)]|D\rangle, \qquad (4)$$

where i and j run from 1 to 3 and are isospin indices of the axial current (see Figs. 1 and 2). By use of partial integration and PCAC we find a relation of the form

$$q_\mu^i q_\nu^j T_{\mu\nu}^{ij} = W^{ij} + E^{ij}, \qquad (5)$$

where W^{ij} is related to the amplitude $D \to B + \pi^i + \pi^j$ and E^{ij} is the contribution of the equal-time commutator (ETC) which is related by U(2) $\otimes$ U(2) algebra to the amplitude $D \to B + \gamma$. The left-hand side of Eq. (5) is not directly related to any observable experimental quantity and can be evaluated only with the aid of a model, except in the soft-pion limit $q^i = q^j = 0$, where it vanishes. Thus the characteristic model-independent results are obtained from CA in this limit.

We wish to point out that in many cases, including (1)-(3) above, the quantities W^{ij} and E^{ij} also vanish in the soft-pion limit as rapidly as $q^i q^j T^{ij}$, and the only model-independent result obtainable from Eq. (5) is the trivial $0 = 0$. Nontrivial relations can be obtained by canceling powers of momentum from both sides of Eq. (5) before going to the limit, but these are no longer model independent as they require evaluation of T^{ij}.

The vanishing of W^{ij} for the processes (1)-(3) which involve the coupling of one vector and three pseudoscalar particles is seen by noting that covariance requires the behavior

$$W = \epsilon_{\mu\nu\delta\varphi} p_\mu^D e_\nu q_\delta^i q_\varphi^j \overline{W}, \qquad (6)$$

where e_ν is the polarization of the external particle, and $\overline{W}$ is a function of the scalar invariants. The E amplitude must have a similar form. Thus relations between W and E are obtainable only if some model is assumed for the evaluation of $q^i q^j T^{ij}$. We assume the pole model,[4] for which the relevant diagrams are shown in Figs. 1 and 2. All these processes have corrections coming from diagram 1 and not from diagram 2. By explicit calculations of the diagrams in Fig. 1 for the ω decay, one finds the left-hand side of (5) to be

$$\{[(p^D - q^i)^2 - m_\rho^2]^{-1} + [(p^D - q^j)^2 - m_\rho^2]^{-1}\} \times \overline{N} p_\mu^D e_\nu q_\delta^i q_\varphi^j \epsilon_{\mu\nu\delta\varphi}, \qquad (7)$$

where $\overline{N}$ is a scalar function. The correction is very sensitive to the mass of the off-shell meson. It is zero if all particles are extrapolated to zero four-momentum.[7] However, if the ω is kept on the mass shell, the correction can amount to several orders of magnitude because of the small denominators in Eq. (7). Notice that there is no a priori dynamical reason to prefer one extrapolation procedure or the other.

For the η and X^0 decays G parity forbids the ρ intermediate state and the first contributing particle to diagram 1 is the A_2.[8] The results of Ref. 3 seem unchanged because the A_2 is not coupled[9] to $\eta\pi$.

To get agreement with experiment for $r_{\omega\pi}$ one has to assume that the correct prescription is to let all particles go to zero four-momentum.[10] Since the X^0 mass is not that much different from the ω, one is led to believe that the approximation should be valid in this case, too. However, we find strong disagreement with experiment.[5] If one is to blame the extrap-

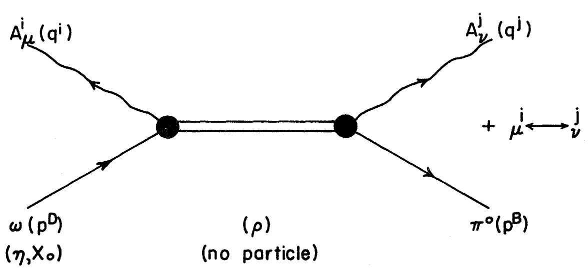

FIG. 1. Diagrams providing for corrections when q^i, q^j go to zero.

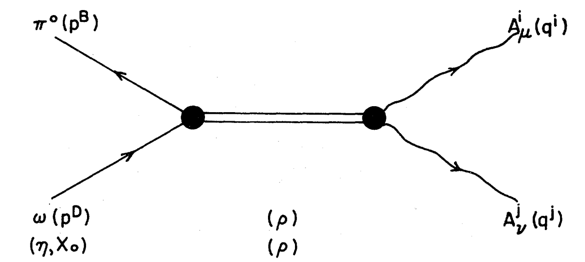

FIG. 2. Diagrams whose contributions can be neglected in the limit $q^i q^j \to 0$.

olation for the disagreement, then one must admit that the success of the ω-decay calculation is an accident.

We now examine this point in a study of processes of the type $\pi^i + D \to \pi^j + B$ with the use of the Fubini method.[11] If D and B are nucleons, the Adler-Weisberger relation is obtained[11] by applying the method to the amplitude of Eq. (4). The case where D and B are pions is also free from difficulties. However, when B and D are the states involved in the Reactions (1)-(3), the situation is similar to the corresponding decays. Even in the limit $q^{i2} = q^{j2} = q^i \cdot q^j = 0$ the sum rule obtained is not expressible in terms of the physical amplitudes W only, but contains a piece of $T_{\mu\nu}$. This piece is just the part of the amplitude that has the Lorentz structure $\epsilon_{\mu\nu\theta\sigma} p_\theta^D e_\sigma$. This is the amplitude found before and it provides the corrections we described. It is interesting to analyze the results in terms of the contributions from intermediate states in all channels. The CA relation has the general form given by Eq. (5). If one considers any diagram of the form depicted in Fig. 3, one can show that (5) reads

$$q_\mu^i q_\nu^j T_{\mu\nu}^{ij} = W^{ij}. \tag{8}$$

In other words these diagrams do not contribute to the ETC. This comes about because for these diagrams there is only one axial current in each vertex and so there is no T product of currents that could give rise to any difference between both members of Eq. (8). This result explains in all generality our previous conclusions.

It is also interesting to notice that the nonleptonic weak decays calculated by CA are different for parity-nonconserving and parity-conserving processes.[12] The former case has the same structure as the Adler-Weisberger one, while the second has corrections of the type described in this note, which a priori cannot be considered small.

We conclude that soft-pion-emission processes are not always model-independent, strict CA calculations. In the cases studied here no simple consistent picture can be obtained by means of CA plus "reasonable" corrections. It seems to us that straightforward use of the pole model is in these cases a simpler and perhaps better approximation.[13]

We are both happy to acknowledge interesting discussions with J. Dothan and H. J. Lipkin. One of us (G.V.) thanks R. Gatto and M. Ademollo for useful discussions.

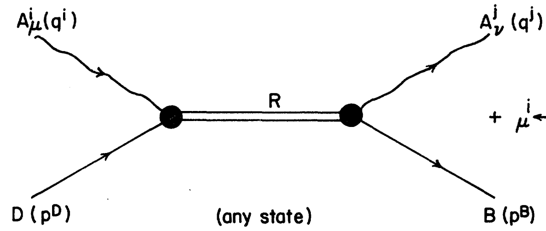

FIG. 3. General type of diagram leading to Eq. (8) (see text).

Note added in proof.—After completion of our work, we noticed a preprint by H. C. Kellet from Imperial College, London, where some of the difficulties of the epsilon tensor are also discussed.

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[1]See, for instance, the Rapporteur talks of N. Cabibbo and R. Dashen, in Proceedings of the Thirteenth International Conference on High Energy Physics, Berkeley, California, 1966 (to be published).

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[6]We have used the mixing angle quoted in Ademollo and Gatto, Ref. 3. We have assumed that the photon is a U-spin scalar (to relate isovector γ's to physical ones) and that the X^0 is the 36th member of the $(6, \underline{6})$. If the first assumption is not correct, we then have a free parameter and no prediction is possible; however, it is hard to see that this effect could produce an order-of-magnitude suppression.

[7]Though not explicitly stated, this is what we believe is meant by K. Kawarabayashi and M. Suzuki in their Erratum, Phys. Rev. Letters 16, 384(E) (1966). We find the same rate but a change in sign for the ratio of the amplitudes.

[8]The A_1 could contribute if it is a 2^+. However, it is also weakly coupled to $\eta\pi$.

[9]G. Goldhaber, in Proceedings of the Thirteenth International Conference on High Energy Physics, Berkeley, California, 1966 (to be published). For the X^0 the coupling to $A_2\pi$ is not known. However, we cannot calculate consistently high-spin contributions in the linear four-momentum approximation. This is true for both cases.

[10]In fact, it is enough to let $m_\omega = m_\pi$ to make the correction very small.

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[12]The situation concerning these problems is discussed by N. Cabibbo in his report (see Ref. 1).

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PHOTOPRODUCTION OF CHARGED PIONS BY 2- TO 5-GeV TAGGED γ RAYS*

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A pion photoproduction experiment[1] has been carried out at the Cambridge Electron Accelerator (CEA) in which, for the first time, data could be obtained simultaneously at different unique photon energies. The vector momenta of the photon incident on the proton and that of the outgoing pion were measured so that the four-momentum transfer of the photon to the pion and the mass of the recoiling baryon system could be determined. Thus, it was possible to gather information on inelastic π^+ and π^- production, as well as elastic π^+ production. Only the latter is reported here, and the results are compared with predictions of various models, particularly pion exchange altered by final-state absorption or by Reggeization. While no "shrinkage" is observed, it is possible to obtain a pion trajectory because of the unusually strong α (Reggeized angular momentum) dependence for the particular reaction $\gamma+p\to\pi^++n$. The most striking feature of the inelastic data is the large excess of positive over negative pions, which may perhaps be evidence for an important ρ^+ current in the proton, but these data will be presented separately, as will information on the reactions $\gamma+p\to\pi^-+N_{33}^*$ and $\gamma+p\to K^++\Lambda^0$ or Σ^0.

The photon energy-tagging system[2] started with a bremsstrahlung beam produced in the CEA and striking an external target, yielding electron pairs. Monoenergetic (to $\pm1\%$) positrons were selected and allowed to strike a thin radiator, producing photons and recoil positrons, which were momentum analyzed and detected in a 19-counter hodoscope. The difference between the energies of an incident and a recoil positron is the photon energy, and this was determined to $\pm2.5\%$. The tagged-photon beam interacted in a liquid-hydrogen target, giving π^+ or π^-, the production angles (between 3° and 17°) and momenta (between 1.2, and 5 GeV/c)[3] of which were accurately measured by thin-plate spark-chamber pairs before and after a bending magnet. These pions were identified by means of a Cherenkov and a shower counter behind the spark-chamber spectrometer. Most of the spark-chamber photographs were measured automatically by the "spark-chamber automatic scanning system" (SPASS) developed by Deutsch at the Laboratory for Nuclear Science, Massachusetts Institute of Technology.

The flux of γ rays of a particular energy incident on the hydrogen target is the same as the counting rate in the corresponding tagging counter, aside from background corrections, and therefore absolute cross sections are determined directly. By comparison of these