calculation at the Σ decay vertex. We examined the K^-d data with this method and found that the net effect is to smear the mass distributions. As an example, the $Y_0^*(1520)$ was found to have a width of about 60 MeV compared to an accepted width of 16 ± 2 MeV. (The K^-d production-origin constraint gave a width of 20 ± 5 MeV). Nevertheless $Y_0^*(1520)$ production was quite pronounced in the $K^- + d \rightarrow \Sigma^- + \pi^+ + \pi^- + p$ events. Another asymmetric aspect of the carbon data is the fact that the $\Sigma^-\pi^+\pi^-$ events had a much lower average K^-n center-of-mass energy than did the $\Sigma^+\pi^-\pi^-$ events. Most of the events in the $Y_2^*(1415)$ peak came from these lower K^-n c.m. energies. In contrast to these asymmetries, the K^-n c.m. energies available and the mass plots for the $\Sigma^-\pi^+\pi^-$ and $\Sigma^+\pi^-\pi^-$ events produced from K^-d were found to be identical.

In the previous experiment the peak interpreted as possible Y_2^* resonance corresponded to a cross section of 0.07 ± 0.015 mb. From Fig. 2 we estimate that there are less than seven events above background in a comparable energy bin, implying a cross section of less than 0.02 mb for Y_2^* production in the present data.

In conclusion, we find no evidence for a $T = 2$ resonance in this experiment and set an upper limit for its production of 0.02 mb averaged over the K^-n c.m. energy interval from 1660 to 1900 MeV. The previous experiment reported the enhancement to exist down to a K^-n c.m. energy of 1615 MeV but was not confined to energies below 1660 MeV. We feel that the negative result of our experiment makes it unlikely that the enhancement of Ref. 1 should be interpreted as a resonance.

We would like to express our appreciation to the members of the Powell-Birge group for their interest and assistance during the course of the analysis of this data. In particular thanks go to Dr. R. W. Birge for his constant interest and encouragement.

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PARTIAL SYMMETRY*

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Partial symmetry is proposed as the general basis for a phenomenological method that replaces current algebra. Its practical merit is displayed through a reinterpretation of combined internal and spin transformations. Among various results referring to coupling constants, magnetic moments, and electromagnetic decays, the following is noted:

$$-G_A/G_V = 2^{-1/2} \times 5/3 = 1.18.$$

I have suggested[1] that the operator techniques of current algebra[2] are not the most effective way to explore the utility of kinematical transformation groups as a means of conveying dynamical information. The phenomenological description of the low-energy πN system by a numerical effective Lagrange function was the context used to introduce its replacement. The chiral group $SU(2) \otimes SU(2)$ appears in this example as a partial-symmetry group—that is, a set of transformations under which a significant portion of an effective Lagrange function, referring to specific physical circumstances, remains invariant. The notion of partial symmetry includes the current-algebraic approach, in a much simpler form. Equal-time commutation relations of group generators (currents), a purely kinematical concept, are implicit[3] in a dynamical framework that supplies equations of motion for the generators (current conservation or nonconservation equations). The search for approximate realizations of the commutators among a small set of particle states can be viewed as the quest for an artificial but relevant dynamical situation in which the group would have dynamical significance. The partial-symmetry attitude emphasizes that one is revealing, not "explaining," particle relationships that ultimately must be assertions about the self-consistency of the dynamical mechanisms that govern the subparticle world.

In order to stress the practical advantages of the partial-symmetry method, we shall use it to reinterpret the much discussed group of transformations involving internal and spin degrees of freedom [usually SU(6) or U(6) ⊗ U(6), but we shall only consider a U(4) factor of U(4) ⊗ U(4)]. The particles principally involved are π, ρ, ω, and N, N^*, although we shall later add Φ and the other members of the baryon octuplet and decuplet.

It is important to recognize that no change in the earlier chiral-group discussion is required by the inclusion of N^*. An elementary approach to the baryon chiral transformation is based on the π-ρ coupling term

$$g\rho^{\mu}\cdot\partial_{\mu}\pi\times\pi.$$

Consider the chiral transformation $\pi\rightarrow\pi+\delta\pi+\cdots$, where $\delta\pi$ is a constant. If we retain only the latter, and not higher powers in the π field, the change in the π-ρ coupling induces a simple gauge transformation on the ρ field,

$$\delta\rho_{\mu}=\partial_{\mu}[(g/m_{\rho}^{2})\pi\times\delta\pi].$$

The corresponding response of any isospin-bearing field is the appropriate chiral transformation. For a nucleon field,

$$\delta N=ig\times\tfrac{1}{2}\tau\cdot(g/m_{\rho}^{2})\pi\times\delta\pi N,$$

and comparison with the form of the s-wave πN coupling, $(f_0/m_\pi)^2\bar{N}\gamma^{\mu}\tau N\cdot\partial_{\mu}\pi\times\pi$, gives the relation

$$\tfrac{1}{2}(g/m_{\rho})^2=(f_0/m_{\pi})^2.$$

No mixing of the N and N^* fields appears, since the chiral transformations depend only upon isospin. This is in sharp distinction to the more usual γ_5 representation of chiral transformations, in which such mixing does occur.[4]

We shall describe the mesons by appropriate (pseudo)scalars, vectors, and antisymmetrical tensors, with the Lagrange function supplying the first-order differential connections, as in the following π and ρ contributions:

$$\mathcal{L}_{\pi}=-\pi^{\mu}\cdot\partial_{\mu}\pi+\tfrac{1}{2}\pi^{\mu}\cdot\pi_{\mu}-\tfrac{1}{2}m_{\pi}^{2}\pi^{2},$$

$$\mathcal{L}_{\rho}=-\tfrac{1}{2}\rho^{\mu\nu}\cdot(\partial_{\mu}\rho_{\nu}-\partial_{\nu}\rho_{\mu})+\tfrac{1}{4}\rho^{\mu\nu}\cdot\rho_{\mu\nu}-\tfrac{1}{2}m_{\rho}^{2}\rho^{\mu}\cdot\rho_{\mu}.$$

The single meson interactions with the baryons involve the field components π^{μ}, ρ^{μ}, ω^{μ}, $\rho^{\mu\nu}$, and $\omega^{\mu\nu}$. Suppose we restrict our attention to arbitrarily small momentum exchanges between the mesons and baryons. This introduces two types of simplifications: When viewed in the rest frame of the baryons, only positive-parity meson-field components contribute to the interaction; the positive- and negative-parity meson components are uncoupled, in the absence of the coordinate derivative terms. The positive-parity field components can be assembled in the 4×4 Hermitian matrix $[H_{\rho3}=\rho_{12}$, etc.]

$$M=(\vec{\pi}+\vec{\mathrm{H}}_{\rho}):\vec{\sigma}\tau+\vec{\mathrm{H}}_{\omega}\cdot\vec{\sigma}-m_{\rho}\rho^{0}\cdot\tau-m_{\omega}\omega^{0}1,$$

with appropriate scalar products in the three-dimensional isotopic and coordinate spaces. The quadratic terms in $\mathcal{L}$ that refer to these components are reproduced by $\mathrm{tr}(\tfrac{1}{4}M)^2$, together with a similar structure that contains $\vec{\pi}-\vec{\mathrm{H}}_{\rho}$. The trace is invariant under the group U(4) of transformations[5] on the $\vec{\sigma}$ and τ matrices in M.

Let us test a hypothesis of partial symmetry —that the meson-baryon coupling also possesses U(4) symmetry when the baryon rest-frame fields N and N^* are united in $\Psi_{A_1A_2A_3}$. The latter is totally symmetrical in the four-valued indices $A=\sigma,\ \tau$. Such a coupling is

$$(g/2m_{\rho})\Psi^{\dagger}\Big(\sum_{\alpha=1}^{3}M_{\alpha}\Big)\Psi,$$

where each M_{α} acts only on the corresponding indices. The scale factor

$$g/2m_{\rho}=2^{-1/2}f_0/m_{\pi}$$

is established by the general relationship between $-g\rho^0$ and the density of isospin. The nucleon part of this interaction is[6]

$$2^{-1/2}(f_0/m_\pi)N^\dagger[(5/3)(\vec{\pi}+\vec{\mathrm{H}}_\rho):\vec{\sigma}\tau + \vec{\mathrm{H}}_\omega\cdot\vec{\sigma}-m_\rho\rho^0\cdot\tau-3m_\omega\omega^0]N.$$

The implied πN coupling constant f is given by

$$f=2^{-1/2}(5/3)f_0=1.18f_0=0.95.$$

This is in striking agreement[7] with the indirect β-decay measurement

$$f/f_0=-G_A/G_V=1.18\pm0.02,$$

and quite close to the πN scattering determination

$$f=1.01\pm0.01.$$

Unlike the SU(6) treatment, so-called central masses of meson and baryon multiplets play no role in this discussion. Concerning πNN^* coupling we shall only remark that, if the width of N^* is compared with a rough calculation that neglects recoil effects, the corresponding value of $f\simeq1.1$.

Electromagnetic properties are introduced by the following substitutions, which are designed to reproduce the charges of the baryons[8]:

$$\rho_\mu^{(0)}\rightarrow(e/g)A_\mu,\quad \omega_\mu\rightarrow\tfrac{1}{3}(e/g)(m_\rho/m_\omega)A_\mu.$$

The implied magnetic field coupling predicts the total moments

$$\mu_p=\frac{5}{3}\frac{e}{2m_\rho}+\frac{1}{3}\frac{e}{2m_\omega},\quad \mu_n=-\frac{5}{3}\frac{e}{2m_\rho}+\frac{1}{3}\frac{e}{2m_\omega}.$$

If the mass difference between ω and ρ^0 is ignored, we recover the famous ratio $-\mu_p/\mu_n=\frac{3}{2}$. An assumed mass difference of 25 MeV gives the ratio 1.48. The experimental value is 1.46. The absolute moment predictions are about 15% too small.

The extension of the internal unitary space to three dimensions introduces the other members of the baryon multiplets. We keep our U(4) notation and write successively, $\Psi_{A_1A_2,\sigma3}$, $\Psi_{A,\sigma3,\sigma'3}$, and $\Psi_{\sigma3,\sigma'3,\sigma''3}$. SU(3) dynamical symmetry is not assumed. Nevertheless, the coupling of M to the various U(4) indices must be universal to reproduce the isospin dependence of electric charge. Consequently, the π-baryon couplings are just those that appear in the literature parametrized as $d/f=\alpha/(1-\alpha)=\frac{3}{2}$.

The even-parity Φ field components are assembled in the 2×2 matrix

$$M_\Phi=\vec{\mathrm{H}}_\Phi\cdot\vec{\sigma}-m_\Phi\Phi^0 1.$$

A corresponding U(2) partial-symmetry hypothesis gives the typical meson-baryon coupling term

$$(g/2m_\rho)\Psi^\dagger\Big(\sum_{\alpha=1}M_\alpha\Big)\Psi+(g_\Phi/2m_\Phi)\Psi^\dagger M_{\Phi3}\Psi,$$

which here refers to a Ψ with a single 3 index, representing the particles with $Y=0$. The hypercharge component of electric charge is reproduced with the substitution

$$\Phi_\mu\rightarrow-\tfrac{2}{3}(e/g_\Phi)A_\mu.$$

Some magnetic moments obtained in this way are

$$\mu_\Lambda=-\frac{2}{3}\frac{e}{2m_\Phi},$$

$$\mu_{\Sigma^\pm}=\pm\frac{4}{3}\frac{e}{2m_\rho}+\mu_{\Sigma^0},\quad \mu_{\Sigma^0}=\frac{4}{9}\frac{e}{2m_\omega}+\frac{2}{9}\frac{e}{2m_\Phi}.$$

The ratios

$$\frac{\mu_\Lambda}{\mu_n}=\frac{(2/m_\Phi)}{(5/m_\rho)-(1/m_\omega)},$$

$$\frac{\mu_{\Sigma^+}}{\mu_p}=\frac{(4/m_\rho)+\frac{4}{3}(1/m_\omega)+\frac{2}{3}(1/m_\Phi)}{(5/m_\rho)+(1/m_\omega)}$$

predict $\mu_\Lambda=-0.706$ and $\mu_{\Sigma^+}=2.71$, in nucleon magnetons. The current experimental values are -0.73 ± 0.16 and 2.3 ± 0.6, respectively.

Finally, here are some remarks about the pion coupling of the unit-spin mesons. Without attempting to fully implement an invariant structure, we recognize in $\mathcal{L}_\rho+\mathcal{L}_\omega$, $m_\omega\cong m_\rho$, the odd-parity field combinations that are arranged in the matrices

$$\rho_k\cdot\sigma_k\tau+\omega_k\sigma_k,\quad \rho_k^0\cdot\sigma_k\tau+\omega_k^0\sigma_k.$$

Now consider the ρ^0 and $\vec{\pi}$ coupling terms in

$$(g/2m_\rho)\tfrac{1}{4}i\mathrm{tr}\{(\rho_k^0\cdot\sigma_k\tau+\omega_k^0\sigma_k)[M,\rho_l\cdot\sigma_l\tau+\omega_l\sigma_l]\}=g\rho_k^0\cdot\rho^0\times\rho_k+(g/m_\rho)\epsilon_{klm}(\omega_k^0\rho_l+\rho_k^0\omega_l)\cdot\pi_m.$$

The relativistic form of the latter is [$*\omega_{12} = \omega_{03}$, etc]

$$\mathcal{L}_{\omega\rho\pi} = (g/m_\rho)(*\omega^{\mu\nu}\rho_\nu + *\rho^{\mu\nu}\omega_\nu)\cdot\pi_\mu.$$

We present two electromagnetic tests of this prediction. The substitution $\rho_\nu^{(0)} \rightarrow (e/g)A_\nu$ gives, effectively,

$$\mathcal{L}_{\omega\gamma\pi} = -(e/m_\rho)*\omega^{\mu\nu}F_{\mu\nu}\pi^{(0)},$$

and the width anticipated for the decay $\omega \rightarrow \gamma + \pi$ is 0.96 MeV. The present experimental value is 1.2 ± 0.2 MeV. The further electromagnetic substitution, $*\omega^{\mu\nu} \rightarrow \frac{1}{3}(e/g)(m_\rho/m_\omega)*F^{\mu\nu}$, produces

$$\mathcal{L}_{\gamma\gamma\pi} = -\tfrac{1}{3}(e^2/g)(1/m_\omega)*F^{\mu\nu}F_{\mu\nu}\pi^{(0)}.$$

The width predicted for $\pi^0 \rightarrow \gamma + \gamma$ is 7.4 eV. The measured value is 7.4 ± 1.5 eV.

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[4]Except in a rest frame of the particles. But such a rest frame is useless for the discussion of γ_5 transformations.

[5]To completely realize $U(4) \otimes U(4)$ transformations, other field components are required which would make asertions about η and η^* couplings, for example, but we shall not write them out.

[6]It suffices to consider the proton state with $S_z = \frac{1}{2}$ and to represent it unsymmetrically by $\Psi_{\sigma_1+,\sigma_2+,\sigma_3-}$, where the first two spins are in a triplet state. Then $\langle\sum_\alpha \sigma_\alpha^z \tau_\alpha^3\rangle = (\vec{S}_{12} - \vec{S}_3)\cdot\vec{S}/\frac{3}{4} = 5/3$, since $\vec{S}_{12}\cdot\vec{S} = 1$ and $\vec{S}_3\cdot\vec{S} = -\frac{1}{4}$.

[7]The classic SU(6) value for $-G_A/G_V$ is 5/3. The same result is obtained from current-commutator matrix elements that are restricted to the baryon octuplet and decuplet. This has produced much discussion of more elaborate mixing schemes. The new situation seems to reflect the different physical interpretation given to chiral transformations. Such a transformation on N generates $N+\pi$, not N and N^* with orbital motion.

[8]Whenever confusion of indices may occur, (0) is used to designate neutral particles.

MEASUREMENTS OF π^0 PHOTOPRODUCTION CROSS SECTIONS FOR INCIDENT GAMMA-RAY ENERGIES OF 2.0 TO 5.0 GeV*

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Cross sections for the reaction $\gamma + p \rightarrow \pi^0 + p$ for incident gamma-ray energies of 2.0 to 5.0 GeV and for baryon four-momentum transfers squared of 0.5 to 4.0 $(\mathrm{GeV}/c)^2$ are presented. The results are compared with theoretical predictions based on Reggeized vector-meson exchange.

We report here measurements of the differential cross section for the reaction $\gamma + p \rightarrow \pi^0 + p$ over a wide range of incident photon energies (2.0 to 5.0 GeV) and of baryon four-momentum transfers squared [0.5 to 4.0 $(\mathrm{GeV}/c)^2$]. Since the experimental method, along with earlier cross-section results, are reported in detail elsewhere,[1-3] we give below only a brief description of the experimental technique.

The experiment was performed using the bremsstrahlung beam from the Cambridge Electron Accelerator. The momenta and angles of the recoil protons were measured with a magnetic-spectrometer system that used scintillation counters and scintillation-counter hodoscopes as detectors. The π^0-decay gammas were detected in a 6×8 array of lead-glass shower counters that measured both the laboratory angles and the energies of the detected gammas. Background events due to reactions such as $\gamma + p \rightarrow \pi^0 + \pi^0 + p$ were separated from $\pi^0 p$ events by requiring that the energies and angles of