energy π-N scattering.[5] The sensitivity of $A_{(L)}'$ to the cutoff position z_0 depends on the value of L, since each partial wave subtracted from A' is, in effect, a subtraction in the integral in Eq. (2). In practice $L \geq 1$, so there are always at least two effective subtractions in the integral, and consequently the dependence of $A_{(L)}'$ on z_0 is weak. We have used $z_0 = 2.27$.

[5] T. D. Spearman, Phys. Rev. 129, 1847 (1963).

[6] For details of the notation and kinematics see, for example, J. Bowcock, W. N. Cottingham, and D. Lurie, Nuovo Cimento 16, 918 (1960).

[7] In the actual calculation, corrections for the Coulomb interaction were included, but for simplicity they have been omitted from the discussion. No account was taken of the inelastic effects.

[8] That we obtain a good *SPD* fit when, in effect, the f waves are pinned to the calculated values, means that the calculated f waves are certainly satisfactory.

[9] There has recently been experimental evidence for a resonant $T = 0$, $J = 2^+$ state which can decay into pions: (a) the f^0 resonance of W. Selove, V. Hagopian, H. Brody, A. Baker, and E. Leboy, Phys. Rev. Letters 9, 272 (1962); (b) the fact that preliminary data indicate a significant difference between the cross sections for electron-proton and positron-proton scattering (private communication from A. Browman and J. Pine, Stanford University, Stanford, California) may be understandable in terms of a resonant $J = 2^+$ enhancement of the two-photon exchange contribution [see D. Flamm and W. Kummer, Nuovo Cimento 28, 33 (1963)]. If we introduce such an interaction by writing, in analogy with the usual treatment of the ρ, $\mathrm{Im} f_\pm^{\,2} = b_\pm \delta(t - t_R)$, and we use values such as $t_R = 80$, $b_\pm \simeq 1.2$, our calculated value for δ_{2-} becomes very much like its value in the *SPD* fit, the agreement for δ_{2+} is improved, and the f-wave phase shifts are hardly affected.

$\varphi\omega$ MIXING*

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(Received 10 May 1963)

We consider the possibility that the nine known strongly interacting vector mesons comprise a unitary octet and a unitary singlet. Symmetry breakdown is assumed to result from a mixing of the singlet with the $T = Y = 0$ member of the octet.[1,2] We assume that the couplings of the vector mesons are otherwise invariant under the transformations of the eightfold way.[3,4] Because of the mixing, the particle eigenstates, ω and φ, are linear combinations of ω_1 (the unitary singlet) and ω_8 (the $T = Y = 0$ member of the octet):

$$\omega_1 = \omega\cos\theta - \varphi\sin\theta,$$
$$\omega_8 = \varphi\cos\theta + \omega\sin\theta. \qquad (1)$$

In this note, we relate the mixing angle θ to more experimentally accessible parameters.

The SU_3-invariant vecton-vecton-meson couplings (we use the word "vecton" to mean "vector meson") are[5]

$$g\epsilon^{\mu\nu\lambda\sigma}\omega_1{}^{\mu\nu}\,\mathrm{Tr}(V^{\lambda\sigma}P) = g\omega_1(\rho^+\pi^- + K^{*+}K^-) + \cdots,$$
$$f\epsilon^{\mu\nu\lambda\sigma}\,\mathrm{Tr}(V^{\mu\nu}V^{\lambda\sigma}P) = f\omega_8(\rho^+\pi^- - \tfrac{1}{2}K^{*+}K^-) + \cdots, \qquad (2)$$

where V and P are 3×3 matrices representing the vector and pseudoscalar meson octets, and space-time indices are omitted from the right-hand sides. The first interaction couples the singlet vecton and the octet vectons, the second interaction involves only the octet vectons and is D type. The octet of vectons, but not the singlet, also participates in vecton-meson-meson couplings of the F type,

$$h\,\mathrm{Tr}(V^\mu P\partial_\mu P) = h\omega_8K^+K^- + \cdots. \qquad (3)$$

For the couplings of the particles, ω and φ, we obtain

$$G_{\rho\omega\pi} = g\cos\theta + f\sin\theta,$$
$$G_{\omega K^*\bar{K}} = g\cos\theta - \tfrac{1}{2}f\sin\theta,$$
$$G_{\omega\bar{K}K} = h\sin\theta, \qquad (4)$$

and

$$G_{\rho\varphi\pi} = -g\sin\theta + f\cos\theta,$$
$$G_{\varphi K^*\bar{K}} = -g\sin\theta - \tfrac{1}{2}f\cos\theta,$$
$$G_{\varphi\bar{K}K} = h\cos\theta. \qquad (5)$$

One method of determining the mixing angle θ is to measure the one-K-exchange (OKE) contribution to $K^-p \to \Lambda$ (ω or ϕ). The ratio of the OKE cross sections is proportional to $\cot^2\theta$ and certain kinematical factors. Unfortunately, these factors involve unknown meson-baryon and meson-meson form factors. Comparison must be made at identical momentum transfer, and even then the $\bar{K}K\phi$ and $\bar{K}K\omega$ form factors may be different. Far less sensitive to these form factors would be the comparison of one-K^* exchange with one-K exchange in both ϕ production and ω production. This determines the coupling constant ratio

$$R=(G_{\phi K^*\bar{K}}/G_{\phi\bar{K}K})(G_{\omega K^*\bar{K}}/G_{\omega\bar{K}K})^{-1},$$

or, in terms of θ and $\epsilon=G_{\rho\phi\pi}/G_{\rho\omega\pi}$, we obtain

$$R=-\left[\frac{\frac{3}{2}\sin\theta\cos\theta-\epsilon(1-\frac{3}{2}\cos^2\theta)}{1-\frac{3}{2}\sin^2\theta-\frac{3}{2}\epsilon\sin\theta\cos\theta}\right]\tan\theta.$$

Experimentally, $|\epsilon|$ seems to be small because the partial decay width for $\phi\to\rho\pi$ is less than 1 MeV,[6,7] an order of magnitude smaller than Sakurai[2] and others have anticipated.[8] Assuming $\epsilon\sim 0$, we find that $|R|\leq 1$ requires $\sin^2\theta\leq\frac{1}{3}$. With the weaker assumption that $|\epsilon|\leq 1$, we find that $|R|\leq 1$ requires $\sin^2\theta\leq\frac{1}{2}$.

There are preliminary indications that (i) $K^-p\to\Lambda\omega$ occurs peripherally with contributions from both one-K exchange and one-K^* exchange,[9] and (ii) $K^-p\to\Lambda\phi$ is consistent with pure K exchange.[10] No stronger conclusion than $|R|\leq 1$ may be made at present, but this fact is already sufficient to require that the $\phi\omega$ mixing is such that ω is mostly singlet and ϕ is mostly octet.[11]

The hypothesis of eightfold symmetry broken principally by $\omega\phi$ mixing is compatible with the present experimental situation. In particular, the theory can accomodate any value of ϵ, so that a great disparity between ω and ϕ production in pion experiments is possible.

Also interesting from the point of view of $\omega\varphi$ mixing are the various electromagnetic decay modes of ρ, ω, and φ. These depend upon the couplings of the photon to the vector mesons: $G_{\rho\gamma}$, $G_{\omega_1\gamma}$, $G_{\omega_8\gamma}$. In the eightfold-way limit, we have $G_{\rho\gamma}=\sqrt{3}G_{\omega_8\gamma}$ and $G_{\omega_1\gamma}=0$, and for the matrix elements of the electromagnetic decay modes we obtain

$$M(\omega\to\pi^0\gamma)\sim\sqrt{3}(g\cos\theta+f\sin\theta),$$

$$M(\varphi\to\pi^0\gamma)\sim\sqrt{3}(-g\sin\theta+f\cos\theta),$$

$$M(\rho\to\pi^0\gamma)\sim f,$$

$$M(\omega\to\eta\gamma)\sim g\cos\theta-f\sin\theta,$$

$$M(\varphi\to\eta\gamma)\sim-(g\sin\theta+f\cos\theta),$$

$$M(\rho\to\eta\gamma)\sim\sqrt{3}f.$$

Comparison of these results to experiment can give an independent determination of f, g, and θ. The decay mode $\varphi\to\pi^0\gamma$ is suppressed because $G_{\rho\varphi\pi}\sim 0$, but we anticipate $\Gamma(\varphi\to\eta\gamma)\cong\Gamma(\omega\to\pi^0\gamma)$ [the available momenta are nearly equal, and $M^2(\omega\to\pi^0\gamma)\cong M^2(\varphi\to\eta\gamma)$ for $\sin^2\theta\cong\frac{1}{3}$].

We gratefully acknowledge helpful conversations with Professor G. Goldhaber, Professor S. Goldhaber, Professor L. Stevenson, and Professor H. Ticho. We thank Professor C. Levinson, Professor H. Lipkin, and Professor S. Meshkov for a copy of their work prior to publication.

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*This research was supported in part by the U. S. Air Force Office of Scientific Research Grant USAF-OSR-62-373.

†Alfred P. Sloan Foundation Fellow.

[1] M. Gell-Mann, Phys. Rev. 125, 1067 (1962); see also S. L. Glashow, in Istanbul Summer School in Theoretical Physics, 1962 (Gordon and Breach, to be published).

[2] J. J. Sakurai, Phys. Rev. Letters 9, 472 (1962).

[3] M. Gell-Mann, California Institute of Technology Synchrotron Report No. 20, 1961 (unpublished).

[4] Y. Ne'eman, Nucl. Phys. 26, 222 (1961).

[5] Related considerations of C. Levinson, H. Lipkin, and S. Meshkov (unpublished) omit the possibility of vecton-vecton-meson couplings involving ω_1.

[6] P. L. Connolly et al., Phys. Rev. Letters 10, 371 (1963).

[7] P. Schlein, W. E. Slater, L. T. Smith, D. H. Stork, and H. K. Ticho, Phys. Rev. Letters 10, 368 (1963).

[8] Moreover, in π^+p collisions from 2.3-2.9 BeV/c, ω production is copious and forward peaked [C. Alff et al., Phys. Rev. Letters 9, 322 (1962)], while ϕ production is rare [as reported by N. Gelfand and D. Berley, American Physical Society Washington Meeting, 1963, postdeadline paper (unpublished)].

[9] L. Stevenson (private communication).

[10] H. Ticho, Proceedings of the Athens Conference on Resonant Particles, Ohio University, 1963 (to be published). It should be kept in mind that this result is based on a small number of observed ϕ's.

[11] This result agrees with Sakurai's estimate of $\phi\omega$ mixing obtained in his attempt to understand the vector mass spectrum with the hypothesis that all breaking of eightfold symmetry is due to $\phi\omega$ mixing [J. Sakurai (to be published)].