# SOME REMARKS ON THE NINTH PSEUDOSCALAR MESON

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The purpose of this note is to draw attention to the fact that the present experimental evidence for the absence of a ninth pseudoscalar meson is not very strong when one keeps in mind that such a meson could reasonably have certain peculiar properties; precisely this ninth PS meson could reasonably behave in a way similar to that of the $\varphi$ vector meson. Now the available experimental evidence indicates that the $\varphi$ meson has a preference for interacting strongly with $K$ mesons rather than with pions; or, in other words, that the strong interactions of the $\varphi$ meson with the pions are considerably inhibited. In fact, (a) the three-pion decay of the $\varphi$ has a width[1] less than 0.7 MeV, while a value of 54 MeV should be expected[2] on the basis of the $3\pi$ width of 8.5 MeV and available phase space; (b) a large inhibition is operating in the production by pions on nucleons,[3] this fact perhaps being related to the previous one through the peripheral mechanism.

If a ninth neutral pseudoscalar meson (let us call it $X$, a name perhaps preferable to $\pi_0^0$, in view of the too many meanings which this latter name has had in the past) exists, it is reasonable to presume that it could have strong-interaction properties similar to those of the $\varphi$, since the lack of inhibitions in the $\eta$ production by pions indicate that it is the $\eta$ that is to be in correspondence with the $\omega$. As far as the decay of the $X$ is concerned, this should depend of course on its mass; if $M_X > 2M_K + m_\pi$, $X$ should probably decay into two kaons plus a pion, while if[4] $M_X < 2M_K + m_\pi$, it should decay into pions at a rate inhibited by at least the factor mentioned above; the pionic decay width of the $X$ should therefore be not much larger, or smaller, than that of the $\eta$. The $X$ might also have, like the $\eta$, decays into pion plus photon modes or into purely photonic modes.

In any case, if our analogy is correct, the $X$ meson should not be strongly produced in $\pi$-$N$ reactions; therefore the reactions in which, so far, one should have had the largest chance of detecting it are the $K^-N$ reactions, or, perhaps, $p\bar{p}$ annihilation; but it is easy to convince oneself that, on account of statistics and resolution a particle with a mass between, say, 350 and 1000 MeV produced with a cross section of, say, $\frac{1}{3}$ of that of the $\eta$ would have had a large change of escaping detection in such reactions.[5,6] It seems therefore important to improve the statistical accuracy in these reactions by at least a factor of 10.

All that has been said so far should be true independent of the particular theory; we have only assumed that if the nine vector mesons are interpreted as $^3S_1$ structures of the kind $\bar{\psi}_a\psi_b$, where $\psi_a$ $(a=0,1,2)$ are particles of some unitary triplet, there should also be nine corresponding $^1S_0$ states, that is nine PS mesons; and that the peculiar properties of the $\varphi$ meson mentioned above are consequences of the conservation of some kind of kaonic quantum number and are, therefore, also shared by the $X$.

To attribute a mass to the $X$ is a much less secure step which needs more specific assumptions; indeed in three recent papers[2,7,8] three different mass formulas have been proposed for the vector mesons which all agree with the experimental masses within the experimental errors. Our feeling is that there are not sufficient grounds, in the present situation, to make a case in favor of one or another of these formulas or underlying theories. Nevertheless we do not consider natural the assumption made by Gürsey, Lee, and Nauenberg[8] that the pseudoscalar mesons are built with entirely different objects than of the vector mesons; we therefore consider it reasonable to extend Formula (22) of reference 8 to the pseudoscalar mesons,[9] in the same way as this extension is proposed in reference 2 (obtaining for the $X$ a mass ~1.3 BeV) and in reference 7 (obtaining a mass of ~1.5 GeV). One has in this way

$$2M_X + M_\eta + M_\pi = 4M_K \tag{1}$$

leading to the value[10]

$$M_X \cong 645 \text{ MeV}. \tag{2}$$

Using a formula similar to (1) but quadratic in the masses, one gets instead

$$M_X \cong 580 \text{ MeV}. \tag{3}$$

If the $X$ has a mass given by (2) or (3), all the remarks of the first part of this note apply. In particular, the only experiments which possibly could have detected this particle are those of Button-Shafer et al., of Murray et al., and of Bertanza et al.,[5] using the reactions $K^- + p \to \Lambda$ + neutrals and $K^- + p \to \Lambda + \pi^+ + \pi^- + \pi^0$ at $K^-$ momenta, respectively, of 1.22, 1.51, and 2.24 BeV/$c$. As stated before, more generally such experiments cannot exclude, as far as we can see, the production of $X$ particles of mass 645 or 580 MeV with a cross section smaller than or equal to three times that of $\eta$ particles.

To conclude, the following remark is appropriate: Our idea is not that necessarily a ninth PS meson must exist, but that if the present explanation of the vector "nonet" in terms of $\varphi$-$\omega$ mixing is correct, then also a ninth pseudoscalar meson might be conjectured to exist with the properties described previously.[11] An alternative possibility is that a new neutral vector meson be discovered with the mass predicted by the original Okubo mass formula or near to it; this meson should be produced strongly in all reactions and not preferentially in the $K^-N$ ones. In this case the deviation of the mass of the $\eta$ from the value given by the original Okubo mass formula should be explained as a "second-order correction" in the semistrong interactions.

Appendix.– It may be of interest to rederive Formula (22) of reference 8 in a simple way which shows very clearly the assumptions which underlie the derivation. On writing $\psi_a \psi_b = D_b{}^a$, the unperturbed octet mesons are

$$(\rho^-, \rho^0, \rho^+) = (D_2{}^1, (1/\sqrt{2})(D_1{}^1 - D_2{}^2), D_1{}^2),$$

$$(K^{*0}, K^{*+}, K^{*-}, \bar{K}^{*0}) = (D_2{}^3, D_1{}^3, D_3{}^1, D_3{}^2),$$

$$\omega_8 = (1/\sqrt{6})(D_1{}^1 + D_2{}^2 - 2D_3{}^3),$$

and the singlet meson is

$$\omega_0 = (1/\sqrt{3})(D_1{}^1 + D_2{}^2 + D_3{}^3).$$

We assume that the very strong forces which bind the $\psi_a$ and $\psi_b$ are such that all the $D_b{}^a$ have the same mass. The mass differences are produced by a semistrong Hamiltonian $h$. We now call $2a$, $b$, and $2c$ the expectation values of this Hamiltonian in the states $D_1{}^1 + D_2{}^2$, $D_3{}^3$, and $D_1{}^1 - D_2{}^2$:

$$\langle D_1{}^1 + D_2{}^2 | h | D_1{}^1 + D_2{}^2 \rangle = 2a,$$

$$\langle D_3{}^3 | h | D_3{}^3 \rangle = b,$$

$$\langle D_1{}^1 - D_2{}^2 | h | D_1{}^1 - D_2{}^2 \rangle = 2c.$$

To proceed, we now introduce two additional assumptions: (1) The matrix elements of $h$ between $D_3{}^3$ and $D_1{}^1$ or $D_2{}^2$ are zero. (2) The Hamiltonian $h$ behaves, under SU(3), as the $T_3{}^3$ component of a unitary tensor. The assumption (1) allows us to calculate the expectation value of $h$ in the $\omega_0$ and $\omega_8$ states:

$$\langle \omega_0 | h | \omega_0 \rangle = \tfrac{1}{3}(2a + b), \quad \langle \omega_8 | h | \omega_8 \rangle = \tfrac{1}{3}(a + 2b),$$

and the matrix element

$$\langle \omega_0 | h | \omega_8 \rangle = (1/3\sqrt{2})(a - b).$$

One can therefore diagonalize the matrix $\langle \omega_k | h | \omega_i \rangle$ $(k, i = 1, 8)$ obtaining, as could be easily anticipated,

$$M_\omega = a, \quad M_\varphi = b.$$

The assumption (2) leads easily to the relation

$$\langle D_3{}^2 | h | D_3{}^2 \rangle = \tfrac{1}{2}\langle D_3{}^3 - D_2{}^2 | h | D_3{}^3 - D_2{}^2 \rangle$$
$$= \tfrac{1}{2}(\langle D_2{}^2 | h | D_2{}^2 \rangle + \langle D_3{}^3 | h | D_3{}^3 \rangle),$$

where the last step implies the use of assumption (1). Noting that, on account of invariance under isospin rotation there holds $\langle D_1{}^1 | h | D_1{}^1 \rangle = \langle D_2{}^2 | h | D_2{}^2 \rangle$ and that

$$\langle D_1{}^1 | h | D_1{}^1 \rangle + \langle D_2{}^2 | h | D_2{}^2 \rangle = a + c,$$

we get

$$\langle D_3{}^2 | h | D_3{}^2 \rangle = \tfrac{1}{2}[b + \tfrac{1}{2}(a + c)];$$

that is,

$$M_{K^*} = \tfrac{1}{2}[M_\varphi + \tfrac{1}{2}(M_\omega + M_\rho)],$$

which is the mass relation, in the vector nonet, of reference 8.

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[1] N. Gelfand et al., Phys. Rev. Letters 11, 436 (1963); P. L. Connolly et al., Phys. Rev. Letters 10, 371 (1963); R. H. Dalitz, Ann. Rev. Nucl. Sci. 13, 378 (1963).

[2] G. Zweig, to be published.

[3] Y. Y. Lee, W. D. C. Moebs, Jr., B. P. Roe, D. Sinclair, and J. C. Vander Velde, Phys. Rev. Letters 11, 508 (1963).

[4] $XK\bar{K}$ strong interactions are forbidden by parity (thanks are due to Dr. J. Prentki for correcting an oversight on this point). The existing evidence from $K$ decay probably excludes $M_X < M_K - M_\pi$.

[5] $K^-N$ reactions: J. Button-Shafer et al., Proceedings of the International Conference on High-Energy Nuclear Physics, Geneva, 1962 (CERN Scientific Information Service, Geneva, Switzerland, 1962), p. 307; L. Bertanza et al., ibid., pp. 279, 284. P. L. Bastien et al., Phys. Rev. Letters 8, 114 (1962); J. J. Murray, Jr., et al., Phys. Letters 7, 358 (1963).

[6] $p$-$\bar{p}$ reactions: R. Armenteros et al., Proceedings of the International Conference on High-Energy Nuclear

Physics, Geneva, 1962 (CERN Scientific Information Service, Geneva, Switzerland, 1962), p. 90.

[7]J. Schwinger, Phys. Rev. Letters 12, 235 (1964).

[8]F. Gürsey, T. D. Lee, and M. Nauenberg, Phys. Rev. (to be published).

[9]A point in favor of this formula is that the assumptions which underlie its derivation (compare the Appendix) lead to an identical structure, from the point of view of unitary symmetry, of the $X$ and $\omega$ particles, in agreement with the analogy on which this paper is based. It has to be noted, however, that the treatment of reference 8 is not crossing invariant and it may be difficult in such a model to reconcile crossing invariance with a nontrivial interaction satisfying the assumption (1) of the Appendix.

[10]It must be noted that if $M_X$ should turn out to be 645 MeV in agreement with the linear mass formula, the fair agreement of the pseudoscalar meson masses with the quadratic Okubo octet mass formula should be regarded as an accident.

[11]This is, of course, a conjecture; nobody can exclude, at the moment, that the forces in the pseudoscalar states are very different from those in the vector states, leading, for instance, to a mass degeneracy of the vector but not of the pseudoscalar states.

# POLARIZED ELECTRONS AND POSITRONS BY TAGGING TECHNIQUE*

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Considerable effort has been made recently in order to obtain polarized high-energy electrons. We should like to point out here that a coincidence technique somewhat similar to the tagging technique which has recently been proposed for application to the bremsstrahlung process to obtain monochromatic photons[1] may be applied to the pair-production process in order to create polarized high-energy electrons or positrons from unpolarized photons. The method utilizes the correlation between the electron, positron, and photon momenta, $\vec{p}_-$, $\vec{p}_+$, and $\vec{k}$, respectively, and the electron or positron polarization, $\vec{P}_-$ or $\vec{P}_+$. One must indeed observe the momenta of both the electron and positron. For example, in the case of electron polarization, if the electron is detected, but not the positron, then the electron has a very small transverse polarization (of order $mc/|\vec{k}|$) at high energies. If, however, the positron is detected in coincidence with the electron at suitable angles and energies, then the electron polarization, $\vec{P}_-$, is found to be large at high energies. By varying the coincidence angles and energy partition of the pair, strongly transversely or longitudinally polarized electrons may be selected. Polarized positrons may be obtained in the same manner.

It should be pointed out that the pair-production process is the only electromagnetic process which produces strongly polarized particles from initially unpolarized particles at high energies. Thus, for example, in Coulomb scattering of initially unpolarized high-energy ($E_1 \gg mc^2$) electrons, the transverse polarization of the scattered electron is small[2] (of order $mc^2/E_1$). Similarly, for bremsstrahlung from unpolarized electrons, a process closely related to pair production, the polarization of the final electron as well as the circular polarization of the photon are small at high energies even if the final electron and photon are detected in coincidence.[3] It should also be pointed out that correlation effects such as the one considered here occur only in the second and higher Born approximations, as has been discussed in detail in earlier work.[4]

A schematic representation of the process considered here is given in Fig. 1. The positron created in target 1 by the unpolarized photon is identified by the magnetic field $\vec{H}$ and detected in detector $D$. The polarized electron hits target 2, where the desired process initiated by the polarized electron occurs. The products of this latter process are detected in coincidence by means of detector $D$.

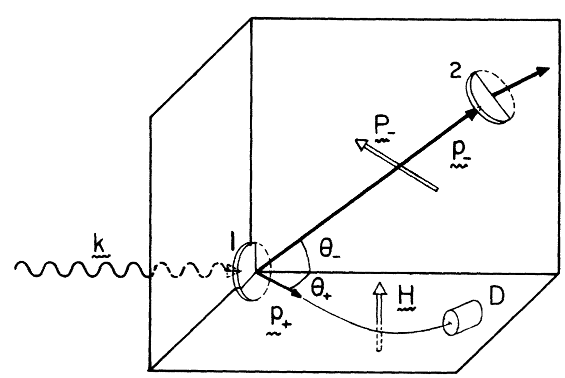


FIG. 1. Schematic representation of the process.