SOVIET PHYSICS JETP VOLUME 21, NUMBER 1 JULY, 1965

Letters to the Editor

SEVERAL CONSEQUENCES OF UNITARY SYMMETRY FOR PROCESSES INVOLVING ω, φ and f^0 MESONS

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Submitted to JETP editor November 5, 1964

J. Exptl. Theoret. Phys. (U.S.S.R.) 48, 375-378 (January, 1965)

1. In the unitary symmetry scheme it is usually assumed (see for example[1,2]) that the ω and φ meson states are mixtures of two states: the unitary singlet ψ_1 and the state with T = 0 and Y = 0, belonging to the unitary octet ψ_8, i.e.,

$$\omega = \alpha\psi_8 + (1-\alpha^2)^{1/2}\psi_1, \qquad \varphi = (1-\alpha^2)^{1/2}\psi_8 - \alpha\psi_1. \quad (1)$$

The mixing parameter α, defined by Okubo[1] and derived from the experimentally observable ω and φ masses and from the theoretical value of the mass of the T = Y = 0 state given by the Gell-Mann—Okubo mass formula, is $\alpha \approx 0.64$.

We examine in the scheme of unitary symmetry the decays of certain resonance states $A \to C + \varphi$ and $A \to C + \omega$. We assume that these decays are allowed in the SU_3 scheme and that the states A and C are related to representations of SU_3 of different dimension. Then it is evident that only the unitary octet contributes to the matrix element arising from (1), and therefore, upon considering only SU_3-invariant interactions, the ratio of the squares of the matrix elements for the transitions $A \to C + \varphi$ and $A \to C + \omega$ will be equal to

$$|M_{A\to C+\varphi}|^2 / |M_{A\to C+\omega}|^2 = (1-\alpha^2)/\alpha^2. \quad (2)$$

If the kinetic energy of decay in the processes $A \to C + \varphi$ is small, then it is necessary to take into account the $\omega - \varphi$ mass difference. This can be done by writing the matrix element in the form $M_{\varphi\omega} = a(k_{\varphi\omega})^l$, where l is the orbital angular momentum of the system $C + \omega$ or $C + \varphi$, and k_φ and k_ω are the momenta of the φ and ω mesons in the rest system of the particle A. The relative probability of the processes $A \to C + \varphi$ and $A \to C + \omega$ will then be equal to

$$\frac{w(A\to C+\varphi)}{w(A\to C+\omega)} = \frac{1-\alpha^2}{\alpha^2}\left(\frac{k_\varphi}{k_\omega}\right)^{2l+1}. \quad (3)$$

If A and C are related to representations of the unitary group of the same dimension, then, clearly, no conclusions can be drawn concerning this relation.

Relation (3) makes it possible to investigate the unitary symmetry scheme in different aspects. If the dimensions of the representations which are related to particles A and C are known, we can test with the help of (3) the hypothesis that φ and ω are mixtures of a unitary singlet and an octet. If the dimensions of the representations are not known, then on the basis of the experimentally observed ratio $w(A \to C + \varphi)/w(A \to C + \omega)$ and (3) it may be possible to get definite information about these dimensions.

An example of an observed reaction of the above type is the decay of the B meson of mass 1220 Mev: $B \to \pi + \omega$ (see[3]). In agreement with the experimental results given in[3] we have[1)]

$$w(B\to\pi+\varphi)/w(B\to\pi+\omega) < 0.2 \pm 0.1,$$

and at the same time from (3) for $l = 0$ it follows that $[(1-\alpha^2)/\alpha^2](k_\varphi/k_\omega) = 0.58$. Combining these two numbers we find that if the B meson has spin and parity 1^+, then it must belong to an octet. This would, however, be at variance with the scheme assumed by Vladimirskiĭ[4], in which the B meson with $J^P = 1^+$ belongs to a 27-supermultiplet. If the spin and parity of the B meson are $J^P = 1^-$ (or 2^-), (which is supported by[5]) then $l = 1$ and from (3),

$$w(B\to\pi+\varphi)/w(B\to\pi+\omega) \approx 0.1.$$

This number is in agreement with experiments within the existing errors and it follows that the B meson may belong to any of the representations occurring in the product $\{8\}\times\{8\}$, which contains the 27-supermultiplet[4].

2. At the present time there are indications[6-10] that the f^0 meson with mass 1250 MeV is an isoscalar. If the f^0 meson lies on the vacuum trajectory, as was proposed by Chew, Gell-Mann, Frautschi and Zachariasen[11,12], then it must be a unitary singlet. Then the amplitude for the reactions

$$\text{meson}\,(1.1) + \text{baryon}\,(1.1) \to \text{baryons}\,(3.0) + f^0 \quad (4)$$

must be expressed in terms of one unitary amplitude. The relations between the amplitudes of different charge channels can be easily derived with the help of the U2 transformations[13] and isotopic invariance, so that the corresponding amplitudes are

$$\text{I. } \pi^- + p \to \Delta^0 + f^0: a, \qquad \text{II. } \pi^+ + p \to \Delta^{++} + f^0: \sqrt{3}\cdot a,$$
$$\text{III. } K^- + p \to \Sigma_\delta{}^0 + f^0: a/\sqrt{2}, \qquad \text{IV. } \bar{K}^0 + p \to \Sigma_\delta{}^+ + f^0: a. \quad (5)$$

A check on the relations between the cross sections of the pairs of reactions I, II and III, IV in (5) could give information about the unitary spin of the f^0 meson. These relations are best tested at energies not close to the threshold for the production of an f^0 meson in reaction IV and for large momentum transfer. We note that the relations I—IV are valid also in the case of the production of n f^0 mesons.

3. The probabilities of different modes of decay of the f^0 meson, if it is a unitary singlet, are related in the following way:

$$w(f^0 \to \pi^+ + \pi^-) : w(f^0 \to K^+ + K^-) : w(f^0 \to \eta^0 + \eta^0) : w(f^0 \to \pi^0 + \pi^0) : w(f^0 \to K^0 + \bar{K}^0) = k_\pi^{2l+1} : k_K^{2l+1} : {}^1\!/_2 k_\eta^{2l+1} : {}^1\!/_2 k_\pi^{2l+1} : k_K^{2l+1}, \tag{6}$$

where l is the spin of the f^0 meson, which, it is assumed, is equal to 2.

The possibility that the f^0 meson does not lie on the vacuum trajectory can not be excluded at the present time. In this case the f^0 meson may be not a unitary singlet, but may belong, say, to a unitary octet. The relations between cross sections of different processes in reaction IV, if the meson is taken as a member of a unitary octet with T = 0, is derived in[13]. The probabilities for the various decay modes of the f^0 meson, if it belongs to a unitary octet, must be related as

$$w(f^0 \to \pi^+ + \pi^-) : w(f^0 \to K^+ + \bar{K}^-) : w(f^0 \to \eta^0 + \eta^0) : w(f^0 \to \pi^0 + \pi^0) : w(f^0 \to K^0 + \bar{K}^0) = k_\pi^{2l+1} : {}^1\!/_4 k_K^{2l+1} : {}^1\!/_2 k_\eta^{2l+1} : {}^1\!/_2 k_\pi^{2l+1} : {}^1\!/_4 k_K^{2l+1}. \tag{7}$$

It follows from (7) and (6) in the case of the f^0 meson belonging to a unitary octet, that the probability of decay into K^0 mesons must be one-fourth that of a unitary-singlet f^0 meson. Substituting in (6) and (7) the experimentally observed quantity

$$R = w(f^0 \to K_1^0 + K_1^0) \,/\, w(f^0 \to \pi^+ + \pi^-)$$

we find, for an f^0 mass equal to 1260 MeV

$$f^0 \text{ — unitary singlet:} \qquad R = 0.048,$$

$$f^0 \text{ — belonging to an octet:} \quad R = 0.012. \tag{8}$$

Relations (6)—(8) were derived on the assumption of a vanishing radius of interaction for the particles produced through f^0 decay. The inclusion of a finite radius of interaction will change the quantity (8). The error in the quantity R in (8), considered as a lower bound, depends on the unitary symmetry breaking, and it can be assumed that, as in other cases[14], it is not worse than 30—50%. From the experimental data[6], R = 0.022 ± 0.01. This possibly indicates that the f^0 is not a unitary singlet. Of course, we can not exclude an even larger breaking of unitary symmetry in this case. Besides this, some of the decays observed in[6] may be due to the A_2 meson[15].

If the f^0 belongs to a unitary octet, then this octet should also include a triplet π_2^+ and two doublets K_2^+ and $\bar{K}_2^+$. The partial widths of the decays of these mesons, which are unitary analogues of the f^0 decays, are related in the following manner to the widths of the f^0 decaying into $\pi^+\pi^-$ and $\pi^0\pi^0$, and are practically equal to its full width Γ:

$$\Gamma(\pi^+_{2+} \to \eta\pi^+) = \Gamma(\pi^0_{2+} \to \eta\pi^0) = {}^2\!/_3 (q_1 / k_\pi)^5 \Gamma,$$
$$\Gamma(\pi^+_{2+} \to K^+\bar{K}^0) = (q_2 / k_\pi)^5 \Gamma,$$
$$\Gamma(\pi^0_{2+} \to K^+K^-) = {}^1\!/_2 (q_2 / k_\pi)^5 \Gamma,$$
$$\Gamma(\pi_2{}^{+0} \to K_1{}^0 K_1{}^0) = \Gamma(\pi_2{}^{+0} \to K_2{}^0 K_2{}^0) = {}^1\!/_4 (q_2 / k_\pi)^5 \Gamma \tag{9}$$

and correspondingly

$$\Gamma(K^+_{2+} \to \eta K^+) = \Gamma(K^0_{2+} \to \eta K^0) = {}^1\!/_6 (q_3 / k_\pi)^5 \Gamma,$$
$$\Gamma(K^+_{2+} \to K^+\pi^0) = \Gamma(K^0_{2+} \to K^0\pi^0) = {}^1\!/_2 (q_4 / k_\pi)^5 \Gamma,$$
$$\Gamma(K^+_{2+} \to K^0\pi^+) = \Gamma(K^0_{2+} \to K^+\pi^-) = (q_4 / k_\pi)^5 \Gamma, \tag{10}$$

where q_i are the momenta of the mesons produced in the given decay. The measurement of these partial widths and their comparison with formulae (9) and (10) might prove useful in an attempt to identify resonances of particles belonging to members of the above-mentioned octet. For example, the meson π_2^+ may turn out to be the A_2 resonance with mass 1310 MeV and $J^P = 2^+$. Then from the Gell-Mann—Okubo mass formula the mass of the K_2^+ resonance must be equal to 1270 MeV. A K resonance with strangeness s = ±1/2 and I_z = ±1/2 has apparently been observed[16] with mass 1215 MeV. Its quantum numbers are presently unknown.

The authors thank A. G. Meshkovskiĭ and V. A. Shebanov for reporting the results of[6] prior to publication and L. B. Okun' for useful discussions.

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1)The upper bound for th ratio $w(B \to \pi + \varphi) / w(B \to \pi + \omega)$ is found from the experimental data[3] under the assumption that in the given experiment all of the observed φ mesons arose from the decay of B mesons.

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[1] S. Okubo. Phys. Lett. 5, 165 (1963).

[2] C. L. Glashow. Phys. Rev. Lett. 11, 48 (1963).

[3] Abolins, Lander, Mehlhop, Xuong, and Yager, Phys. Rev. Lett. 11, 381 (1963).

[4] V. V. Vladimirskiĭ, Preprint ITEP, No. 240 (1964).

[5] Carmony, Lander, Rindfleisch, Xuong, and Yager, Phys. Rev. Lett. 12, 254 (1964).

[6] Barmin, Dolgolenko, Erofeev, Krestnikov, Meshkovskiĭ, Tekomerov, Trebukovskiĭ, and Shebanov. Preprint ITEP, No. 233 (1964); Yadernaya fizika 1, No. 2 (1965), Sov. J. Nucl. Phys. 1, in press.

[7] Benson, Lovell, Marquit, Roe, Sinclair, Van der

Velde, and Van Rookhuyzen, Phys. Rev. Lett. **12**, 600 (1964).

[8]Gelfand, Lütjens, Nussbaum, Steinberger, Cohn, Bugg, and Condo, Phys. Rev. Lett. **12**, 567 (1964).

[9]Sodickson, Wahlig, Mandli, Frisch, and Fackler, Phys. Rev. Lett. **12**, 485 (1964).

[10]Lee, Roe, Sinclair, and Van der Velde. Phys. Rev. Lett. **12**, 342 (1964).

[11]G. F. Chew and S. C. Frautschi, Phys. Rev. Lett. **5**, 580 (1961).

[12]Frautschi, Gell-Mann, and Zachariasen, Phys. Rev. **126**, 2204 (1964).

[13]Meshkov, Levinson, and Lipkin, Phys. Rev. Lett. **10**, 361 (1964).

[14]S. L. Glashow and A. H. Rosenfeld, Phys. Rev. Lett. **10**, 192 (1963).

[15]Chung, Dahl, Hardy, Hess, Kalbfleisch, Kirz, Miller, and Smith. Phys. Rev. Lett. **12**, 621 (1964).

[16]R. Armenteros. Intern. Conf. on High Energy Physics at Dubna (1964), preprint JINR E-1804 (1964).

Translated by R. White
50

INVESTIGATIONS OF INDUCED RAMAN SCATTERING IN MIXTURES

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Submitted to JETP editor November 10, 1964

J. Exptl. Theoret. Phys. (U.S.S.R.) 48, 378-380 (January, 1965)

WE present in this report the results of an experimental investigation of the excitation threshold and line intensity of induced Raman scattering. We studied the dependence of these quantities on the concentration of the investigated medium in the mixture, and also the dependence of the intensity of the Raman lines on the intensity of the exciting light.

1. The excitation threshold was measured by means of the method described in[1]. Mixtures of carbon disulfide and benzene were investigated.

The results of the measurements of the excitation threshold of the CS_2 lines with frequency 656 cm^{-1} are shown in Fig. 1. Excitation of this line in our installation could be realized at a volume concentration of CS_2 in the mixture ranging from 100 to 50%. At a 40% concentration, the excitation of the 992 cm^{-1} of benzene started.

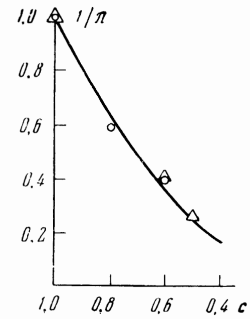

FIG. 1. Dependence of the excitation threshold of the 656 cm^{-1} carbon disulfide line on the concentration. Continuous line – $1/\pi = c^2$, the points correspond to two series of experiments.

As shown by the results, the reciprocal of the excitation threshold π is proportional, within the limits of experimental error, to the square of the concentration c of the carbon disulfide in the mixture. Thus, by combining this result with the previously obtained[1] dependence of the threshold on the intensity of the line in the spectrum of ordinary Raman scattering I_{ord}, we can write

$$1/\pi = AI_{ord}c^2, \tag{1}$$

where A—factor depending on the employed installation and on the experimental conditions.

2. In the study of the dependence of the intensity of the lines in the induced Raman scattering spectrum on the intensity of the exciting light, we used the method of photographic photometry. The blackening marks were produced with the aid of an optical step wedge, and the source of the light in this case was a flash from a ruby laser (to avoid the influence of the Schwarzschild factor). During the processing and measurement of the spectrograms, the usual methods were employed with all the necessary precautions.

To broaden the range of the measured intensities, neutral optical filters were used, the transmission of which was measured with the same installation [1)]. To measure the intensity of the exciting light we used, as in the measurement of the threshold[1], a stack of glass plates.

The measurements have shown that the intensity of the induced Raman scattering lines, I, is determined by the excess of intensity of the exciting light I_{exc} over threshold, that is, by the quantity $x = I_{exc} - \pi$. In the mixtures, the quantity I turned