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E-η MIXING AND SOME RADIATIVE DECAY PROCESSES

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E–η -смешивание и радиационные распады мезонов

Обсуждаются следствия $E-\eta$ -смешивания в предположении, что девятое место в псевдоскалярном нонете занимает E(1420) -мезон. Приведены значения ширин распада $E\to 2\gamma$, $E\to\rho\gamma$, $E\to\omega\gamma$ и др., вычисленные в различных моделях. Наиболее предпочтительное значение $\Gamma(E\to 2\gamma)\sim$ (200 ÷ 300) кэв оказывается довольно большим, а ширина распада $E\to\rho\gamma\approx$ ÷ 10 Мэв. Обнаружение распада $E\to 2\gamma$ окончательно доказало бы псевдоскалярность E -мезона, а исследование ширин радиационных распадов E -мезона помогло бы в выборе правильной модели.

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E – η Mixing and Some Radiative Decay Processes

The consequences of $E-\eta$ mixing under the assumption that the E(1420) meson takes the ninth place in a pseudoscalar nonet are discussed. The width values of $E\to 2\gamma$, $E\to\rho\gamma$, $E\to\omega\gamma$, etc. found in various models are presented. A value $\Gamma(E\to 2\gamma)\sim$ ~ (200 ÷ 300) KeV turns out to be rather large, the decay width $E\to\rho\gamma$ being ~ 10 MeV. The determination of the decay $E\to 2\gamma$ would prove the pseudoscalarity of the E -meson, the investigation of the E -meson radiative decay width would help to select reasonable models.

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1. At present there are two main candidates for the ninth pseudoscalar meson: X^0 (960) and E(1420) mesons.

In the literature, especially in theoretical papers the X^0(960) meson is taken as the ninth pseudoscalar one. As is seen now, this tendency may be irregular, since the conclusion about the pseudoscalarity X^0(960) in previous papers was not final. The spin-parity 2^- for the X^0-meson is possible as well as the spin-parity 0^- [1,2]. Available experimental data do not exclude it.

Let us consider the properties of the E(1420)-meson under the condition that this meson is just the 9th pseudoscalar one.

The effects connected with $X^0-\eta$ mixing were considered in detail in a current algebra[3,4], in various models[5,6] by many authors beginning from Dalitz and Sutherland[7].

The consequences of $E-\eta$ mixing for the radiative decays $E\to 2\gamma$, $E\to\rho\gamma$, $E\to\omega\gamma$, etc. obtained by the method of ref.[7] are discussed in this paper.

The mass formulas (presented in detail in[8]) which unambiguously select the particle with a mass of $\approx$ 1.4 GeV as the ninth pseudoscalar meson are considered in § 2.

$E - \eta$ mixing for decays amplitudes is considered in § 3. The probabilities of the radiative decays $E(1420) \to 2\gamma$, $E \to \rho\gamma$, $E \to \omega\gamma$, etc. obtained in various models are given here in. The result of our calculations, as in the case of $X^0 - \eta$ mixing, depend on the models. The most preferable value $\Gamma(E \to 2\gamma) \sim (200 \div 300)$ KeV is rather great, and owing to a large phase volume the decay width $E \to \rho\gamma$ is equal to ≈ 10 MeV according to our estimations. These conditions favour the experimental investigations of the radiative decays of the E(1420) meson.

The searches for the radiative decays are of great importance since the determination of the decay $E \to \gamma\gamma$ would definitely prove the pseudoscalarity of the E(1420) meson and would completely exclude another possible value of the spin-parity 1^+.

2. Under general assumptions on the type of $SU_W(6)$ symmetry breaking the mass formula

$$m_\pi^2 + m_\eta^2 + m_\chi^2 = m_\rho^2 + m_\phi^2 + m_\omega^2 \tag{1}$$

was obtaines in ref.[8], i.e. the sum of the nonstrange meson squared masses in pseudoscalar and vector nonets is identical.

The formula (1) unambiguously selects the E(1420) meson (not the X^0 -meson) as the ninth pseudoscalar one. As far as in this case, as mentioned above in § 1 there is no experimental proof of the pseudoscalarity of the X^0 (960) [1,2], let us consider the E(1420) meson as the 9th member of a pseudoscalar nonet with $E - \eta$ mixing angle equal to -6.5°. Under this condition we now discuss the radiative decays of the E -meson.

3. Taking into account SU(3) with octet breaking the matrix elements of the radiative decay of π^0, η and E(1420) mesons are written as follows:

$$T(E \to 2\gamma) = M_1 \cos\theta_p + M_8 (1+\beta) \sin\theta_p$$
$$T(\eta \to 2\gamma) = -M_1 \sin\theta_p + M_8 (1+\beta) \cos\theta_p \qquad (2)$$
$$T(\pi^0 \to 2\gamma) = \sqrt{3}\, M_8 \,,$$

where M_8 and M_1 are octet and singlet amplitudes; β - is the SU(3) breaking contribution, $\theta_p = -6.5^0$. As is easily seen, there is no relation between matrix elements $T(\pi^0)$, $T(\eta)$ and $T(E)$ since the number of independent amplitudes is equal to three. In order to restrict the number of amplitudes, different assumptions are made, and the results of the calculation depend strongly on them. For example, under different assumptions /3-5/ for $\Gamma(X^0 \to 2\gamma)$ the values, varying in a wide range of (1-50) KeV have been obtained. A similar unambiguity of the result and its dependence on the model obviously remain under the assumption of $E-\eta$ mixing.

a) In the framework of current algebra and technique of hard pions Riazuddin and Sarker have obtained the following expression for β /3/:

$$\frac{T(\eta_8 \to 2\gamma)}{T(\pi^0 \to 2\gamma)} \equiv 1+\beta = \frac{f_\pi}{f_{\eta_8}} \frac{m^2_{\omega_8}}{m^2_\pi} \frac{g_\rho}{g_{\omega_8}} \frac{2f_\pi^2 - f_{\eta_8}^2}{f_\pi^2} \,,$$

where f_π, f_{η_8} are the decay constants of the corresponding particles. The values of the constants in this formula are not well determined, and the authors use two different values of g_{ω_8}. We follow their choice and obtain for the breaking parameter β depending on g_{ω_8} :

$$\beta = \begin{cases} 0{,}57 \\ 0{,}3 \,. \end{cases}$$

Using the experimental data[1] for $\Gamma(\pi^0 \to 2\gamma)$ and $\Gamma(\eta \to 2\gamma)$ we obtain from the formula (2)

$$\Gamma(E \to 2\gamma) = \begin{cases} (155 \pm 80)\ \text{keV}. \\ (260 \pm 100)\ \text{keV}. \end{cases} \tag{3}$$

Large errors in the determination of $\Gamma(E \to 2\gamma)$ results from the errors in the measurement of the width of the radiative decays of π^0 and η -mesons.

Following Dalitz and Sutherland[7], knowing $\Gamma(E \to 2\gamma)$ it is easy to calculate $\Gamma(E \to \rho\gamma)$ and $\Gamma(E \to \omega\gamma)$:

$$\frac{\Gamma(E \to 2\gamma)}{\Gamma(E \to \rho\gamma)} = \frac{a\, m_E^5}{9\left(\frac{g_\rho^2}{4\pi}\right)} \left(\frac{2m_E}{m_E^2 + m_\rho^2}\right)^2 \left(\frac{2m_E}{m_E^2 - m_\rho^2}\right)^3 \left[\frac{1 + \frac{M_8(1+\beta)}{M_1} \operatorname{tg} \theta_p}{1 + \frac{2M_8(1+\beta)}{M_1} \operatorname{tg} \theta_p}\right]^2 \cong$$

$$\cong 0{,}0228 \left[\frac{1 + \frac{M_8(1+\beta)}{M_1} \operatorname{tg} \theta_p}{1 + \frac{2M_8(1+\beta)}{M_1} \operatorname{tg} \theta_p}\right]^2, \tag{4}$$

$$\Gamma(E \to \rho\gamma) = \begin{cases} (6{,}9 \pm 3{,}5)\ \text{MeV} \\ (11{,}4 \pm 4{,}4)\ \text{MeV} \end{cases} \tag{5}$$

$$\frac{\Gamma(E\to\omega\gamma)}{\Gamma(E\to\rho\gamma)}=\frac{1}{9}\left(\frac{m_E^2-m_\omega^2}{m_E^2-m_\rho^2}\right)^3;\quad \Gamma(E\to\omega\gamma)=\begin{cases}(0,72\pm0,36)\,\mathrm{MeV}\\ (1,2\pm0,45)\,\mathrm{MeV}\end{cases} \qquad (6)$$

The $E-\eta$ mixing angle, being equal to -6.5° differs from the mixing angle $X^0-\eta$. Due to this fact the $\phi\to\eta\gamma$ and $\omega\to\eta\gamma$ decay rates are different from those in[3,4,7] calculated under the assumption of $X^0-\eta$ mixing and are within the limits of experimental estimates:

$$\Gamma(\phi\to\eta\gamma)=\begin{cases}(210\pm20)\,\mathrm{keV}.\\ (175\pm15)\,\mathrm{keV}.\end{cases}\qquad \Gamma(\omega\to\eta\gamma)=\begin{cases}(3,14\pm0,27)\,\mathrm{keV}\\ (1,90\pm0,16)\,\mathrm{keV}.\end{cases} \qquad (7)$$

The exact SU(3) symmetry taking into account $E-\eta$ mixing ($\beta=0$) predicts a somewhat greater value[9] of $\Gamma(E\to2\gamma)$

$\Gamma(E\to2\gamma)=(425\pm140)$ keV.

and, consequently, $\Gamma(E\to\rho\gamma)$, $\Gamma(E\to\omega\gamma)$, etc. are also shifted:

$\Gamma(E\to\rho\gamma)=(18,5\pm6,5)$ MeV. $\quad\Gamma(\phi\to\eta\gamma)=(120\pm10)$ keV.

$\Gamma(E\to\omega\gamma)=(1,92\pm0,68)$ MeV. $\quad\Gamma(\omega\to\eta\gamma)=(0,42\pm0,04)$ keV.

b) S. Matsuda and S. Oneda have recently obtained the following relations for the amplitudes $T(\eta')$ and $T(\eta)$ in their model of SU(3) breaking[5]

$$\frac{T(\eta\to2\gamma)}{T(\pi^0\to2\gamma)}=\frac{1}{\sqrt{3}\cos\theta_p}\left(\frac{m_{\eta'}^2-m_\pi^2}{m_{\eta'}^2-m_\eta^2}\right);\quad \frac{T(\eta'\to2\gamma)}{T(\pi^0\to2\gamma)}=-\frac{1}{\sqrt{3}\sin\theta_p}\left(\frac{m_\eta^2-m_\pi^2}{m_{\eta'}^2-m_\eta^2}\right), \qquad (8)$$

Assuming that $\eta' \equiv X^0(960)$ and $\theta_p = -10.5^\circ$, the authors have obtained

$$T(\eta \to 2\gamma) = \frac{1}{\sqrt{3}} T(\pi^0 \to 2\gamma)\ (1,5 - 1,7)\ .$$

In this case $\Gamma(\eta \to 2\gamma)$ is larger by a factor of (2.5÷3) than the value predicted by exact SU(3) i.e. $\Gamma(\eta \to 2\gamma) \approx (400 - 600)$ eV. This is not far from the experimental value $\Gamma(\eta \to 2\gamma) = (1{,}00 \pm 0{,}22)$ keV. and this is the main result of the work/5/. As mentioned in §1, our assumption consists in that the E(1420) meson is the ninth pseudoscalar one. In this case the formulas (8) give

$$T(\eta \to 2\gamma) = \frac{1}{\sqrt{3}} T(\pi^0 \to 2\gamma) \times (1{,}16 - 1.18)$$

$$T(E \to 2\gamma) = 0{,}82\ T(\pi^0 \to 2\gamma).$$

We obtain that $\Gamma(\eta \to 2\gamma) = (225 \pm 55)$ eV. This is in a sharp disagreement with experiment. Thus, if $\eta' \equiv E(1420)$, the model involved in/5/ does not improve the SU(3) result for $\Gamma(\eta \to 2\gamma)$. Taking into account the violation ($X = 0.1$/5/) does not change this statement. In this case a small value of $\Gamma(E \to 2\gamma) = (5{,}2 \pm 1{,}1)$ keV is predicted for the decay width $E \to 2\gamma$. This value significantly differs from the result given by the formula (3).

c) In ref./9/ the width of the decay $E \to 2\gamma$ is calculated by us in the model of broken $SU_W(6)$ -symmetry with a special type of breaking. An anomalously great value ($\sim$ 1 MeV) for $\Gamma(E \to 2\gamma)$ is obtained, the application of the formula (4) gives $\sim$ 40 MeV for $\Gamma(E \to \rho\gamma)$. The vector dominance does not give predictions with a high accuracy; nevertheless, these results turn out to be overestimated.

4. We have discussed some model for the calculation of $E \to 2\gamma$ and $E \to \rho\gamma$ under the assumption of $E-\eta$ mixing with the mixing angle $\theta_p = -6.5^{\circ}$. The width values obtained in various models are presented in Table. As is seen, the results strongly depend on the model. The most preferable values are $\Gamma(E\to 2\gamma) \sim (200 - 300)\,\mathrm{keV}$ and $\Gamma(E\to\rho\gamma) \sim 10\,\mathrm{MeV}$ calculated in the Riazuddin and Sarker's model/3/.

In conclusion we stress that the exprimental determination of the decays $E\to 2\gamma$, $E\to\rho\gamma$ and the measurement of their widths are an important task. The solution of this problem would make clear the matter of $E(1420)$ meson spin-parity, would be critical for the considered models and would permit to select between them.

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Table

Model	$\Gamma(\eta \to 2\gamma)$	$\Gamma(E \to 2\gamma)$	$\Gamma(E \to \rho\gamma)$	$\Gamma(E \to \omega\gamma)$
Model [3] $\left\{\begin{array}{l}0{,}57\\0{,}3\end{array}\right.$	(1.0+0.22) keV input	$\left\{\begin{array}{l}(155 \pm 80)\ \text{keV}\\(260 \pm 100)\ \text{keV}\end{array}\right.$	$\left\{\begin{array}{l}(6{,}9 \pm 3{,}5)\ \text{MeV}\\(11{,}4 \pm 4{,}4)\ \text{MeV}\end{array}\right.$	$\left\{\begin{array}{l}(0{,}72 \pm 0{,}36)\ \text{MeV}\\(1{,}20 \pm 0{,}45)\ \text{MeV}\end{array}\right.$
Exact SU(3) with $E-\eta$ mixing [9]	(1.0±0,22) keV input	(425 ± 140) keV	(18,5 ±6,5) MeV	(1,92 ± 0,68) MeV
Model [5] with $E-\eta$ mixing	(225 ± 55) eV	(5.1 ±1.1) keV	(225 ± 50) keV	(24 ± 5) keV
Model [9] broken $SU_W(6)$	(880± 190) eV input	(940 ± 380) keV	(41 ± 16) MeV	(4.3 ± 1.7) MeV