CM-P00057396

ARCHIVES

ON THE LIFETIME OF THE η -MESON

F.A. Berends^{*)} and P. Singer^{**)}

CERN - Geneva

^{*)} On leave from Instituut - Lorentz, Leiden, The Netherlands.

^{**)} Permanent address: Department of Physics, Israel Institute of Technology, Haifa. Research supported in part by the Aerospace Research Laboratories, OAR, under grant AF-EOAR-65-80, through the European Office of Aerospace Research, USAF.

In this note we present an estimate for the lifetime of the η -meson, based on a theoretical calculation for the partial decay width of $\eta \rightarrow \pi^+ \pi^- \gamma$ and the known experimental percentage of this partial rate.

Our calculation gives a total decay width for the η -meson of about 8 keV which is a factor of about 40 larger than the previous theoretical estimates. This discrepancy is somewhat surprising as both the previous ones and the present calculation use currently accepted theoretical models.

The outline of the calculation is as follows. We assume the $\eta \rightarrow \pi^+ \pi^- \gamma$ decay to proceed via the $\eta \rightarrow \rho + \gamma \rightarrow \pi^+ \pi^- \gamma$ chain (the so-called " ρ -dominance" model^{1,2}). Then we relate the $\langle \eta | \rho \gamma \rangle$ amplitude to the $\langle \omega | \pi \gamma \rangle$ amplitude by using SU_3 , $\omega - \varphi$ mixing and the presumed knowledge of a very small $\varphi \rightarrow \pi \gamma$ decay, which is inferred from the small rate of the observed $\varphi \rightarrow \rho \pi$ transition. As a result, the $\langle \eta | \rho \gamma \rangle$ amplitude is related to the measured $\omega \rightarrow \pi \gamma$ width.

The vector-pseudoscalar meson-photon coupling is written in the form:

$$\frac{f_{\nu\rho\gamma}}{m_\pi} \epsilon^{\mu\nu\sigma\tau} \rho_\mu^V \epsilon_\nu^V \rho_\sigma^\gamma \epsilon_\tau^\gamma \quad (1)$$

Then the partial decay width for $\eta \rightarrow \pi^+ \pi^- \gamma$ is given by²⁾

$$\Gamma_\eta(\pi^+ \pi^- \gamma) = 1.6 \frac{f_{\eta\pi\gamma}^2}{4\pi} \frac{(f_{\rho\pi\pi}/4\pi)^2 m_\pi^3 m_\eta^2}{3\pi m_\rho^4} \quad (2)$$

2.

while the decay width for $\omega \rightarrow \pi \gamma$ transition is

$$\Gamma_{\omega}(\pi^0 \gamma) = \frac{f_{\omega \pi \gamma}^2}{4\pi} \frac{(m_{\omega}^2 - m_{\pi}^2)^3}{24 m_{\pi}^2 m_{\omega}^3} \quad (3)$$

Using the experimental knowledge that $\Gamma_{\omega}(\pi^0 \gamma) = 1.3 \text{ MeV}$, one obtains

$$\frac{f_{\omega \pi \gamma}^2}{4\pi} = 0.18 \alpha, \quad (4)$$

where α is the fine-structure constant.

In order to relate $f_{\eta \rho \gamma}$ to $f_{\omega \pi \gamma}$ we assume ω to be a mixture of a singlet and a $T = Y = 0$ component of an octet⁴⁾. For the mixing angle the value $\sin \Theta = 1/\sqrt{3}$ is taken⁵⁾, which gives in the vector meson nonet description zero rates for $\phi \rightarrow \rho \pi$, $\phi \rightarrow \pi \gamma$. Actually the mixing angle as calculated from the ω , ϕ masses or the $\phi \rightarrow \pi \rho$ decay⁶⁾ in the nonet model is slightly different from the above value. This, however, has no practical influence on the calculation. So we obtain⁷⁾

$$f_{\eta \rho \gamma} = \frac{1}{\sqrt{3}} f_{\omega \pi \gamma} \quad (5)$$

This gives, using (2), (4) and $f_{\rho \pi \pi}^2 / 4\pi = 2.4$ which corresponds to a ρ width of 124 MeV:

$$\Gamma_{\eta}(\pi^+\pi^-\gamma) = 426 \text{ eV} \quad (6)$$

By using the experimental value³⁾

$$\frac{\Gamma_{\eta}(\pi^+\pi^-\gamma)}{\Gamma_{\eta}(\text{all})} = 5.5\%$$

one obtains

$$\Gamma_{\eta}(\text{total}) = 7.7 \text{ keV} \quad (7)$$

or

$$\tau_{\eta} = 8.5 \cdot 10^{-20} \text{ sec.}$$

We have not included $\eta - X^0$ mixing in the above calculation. If a mixing angle⁸⁾ of $10^0(-10^0)$ is used then Glashow and Socolow⁶⁾ obtain $f_{\eta\gamma}^2/4\pi = 3(9) \times 10^{-2}\alpha$, which, if used in (2) gives $\Gamma_{\eta}(\text{total}) \simeq 4(12) \text{ keV}$. Thus the result (7) is not significantly changed.

One could classify the previous estimates of the η width into two categories: those considering the $\eta \rightarrow 3\pi$ width⁹⁻¹¹⁾ and the estimates of the $\eta \rightarrow 2\gamma$ decay^{2), 11), 12)}. The first type of calculations, which gave $\Gamma_{\eta}(3\pi)$ of the order of 100-300 eV, do generally involve not well verified assumptions. On the other side, the calculation of the $\eta \rightarrow 2\gamma$ decay width uses the experimentally known $\pi^0 \rightarrow 2\gamma$ decay width and the SU_3 ratio of $\langle \eta | 2\gamma \rangle = 1/\sqrt{3} \langle \pi | 2\gamma \rangle$ ¹³⁾. With an experimental π^0 lifetime of $1.8 \cdot 10^{-16} \text{ sec}$ ³⁾ one obtains

$$\Gamma_{\eta}(2\gamma) = 1/3 \left(\frac{m_{\eta}}{m_{\pi}} \right)^3 \Gamma_{\pi}(2\gamma) \simeq 80 \text{ eV}.$$

From the known $(\eta \rightarrow 2\gamma)/(\eta \rightarrow \text{total})$ ratio one would have then

$$\int_{\eta} (\text{total}) \simeq 200 \text{ eV.}$$

In our calculation SU_3 relations for the VP γ amplitude are used in conjunction with $\omega - \phi$ mixing and also the dominance of the $\pi\pi$ state in the $\eta \rightarrow \pi^+\pi^-\gamma$ decay by the ρ meson. The strong disagreement between the result given in Eq. (7) and the previous estimates implies that either one of our assumptions is not reliable or that the SU_3 relation between $\langle \eta | 2\gamma \rangle$ and $\langle \pi | 2\gamma \rangle$ is badly broken. Although our calculation involves more assumptions than the previous $\eta \rightarrow 2\gamma$ SU_3 calculation, one may remark firstly that the ρ dominance model gives good agreement with the experimental $\eta \rightarrow 2\gamma / \eta \rightarrow \pi^+\pi^-\gamma$ ratio and secondly that we use SU_3 relations for VP γ vertices, which may be less affected by the large $\pi - \eta$ mass difference. One should stress that the large η width is directly related in our calculation to the large experimental $\omega \rightarrow \pi\gamma$ rate.

In conclusion, we remark that the new value obtained for the η -meson width is of significance for the planning of experiments designed to measure it¹⁴⁾.

Furthermore, this value would lower^{*)} the estimates¹⁵⁾ of the branching ratio for the possible C violating $\eta \rightarrow \pi^0 e^+ e^-$ decay by a factor of about 40 such that the existing experimental upper limits¹⁶⁾ for this process do not rule out C violation in electromagnetic interactions¹⁵⁾.

We thank Prof. J.J. Sakurai for a discussion and we gratefully acknowledge Prof. L. van Hove for the hospitality of the CERN Theoretical Division.

*) We are indebted to Prof. J. Prentki for this remark.

REFERENCES

- 1) M. Gell-Mann, D. Sharp and W.G. Wagner, Phys.Rev.Letters 8, 261 (1962).
- 2) L.M. Brown and P. Singer, Phys.Rev.Letters 8, 460 (1962).
- 3) A.H. Rosenfeld, A. Barbaro-Galtieri, W.H. Barkas, P.L. Bastien, J. Kirz and M. Roos, UCRL 8030 - Part I (August 1965).
- 4) M. Gell-Mann, Phys.Rev. 125, 1067 (1962);
J.J. Sakurai, Phys.Rev.Letters 9, 472 (1962);
- 5) S. Okubo, Phys.Letters 5, 165 (1963);
F. Gürsey, T.D. Lee and M. Nauenberg, Phys.Rev. 135, B 467 (1964).
- 6) $\Gamma_{\rho}(\rho\pi) = 0.56 \pm 0.25$ MeV is given by J. Lindsey, quoted by S.L. Glashow and R.H. Socolow, Phys.Rev.Letters 15, 329 (1965).
- 7) The same value is obtained in SU_6 models; see V.V. Anisovich, A.A. Anselm, Ya.I. Azimov, G.S. Danilov and I.T. Dyatlov, Phys.Letters 16, 194 (1965);
L.D. Soloviev, Phys.Letters 16, 345 (1965).
- 8) R.H. Dalitz and D.G. Sutherland, Nuovo Cimento 37, 1777 (1965); 1945.
- 9) B. Barrett and G. Barton, Phys.Rev. 133, B 466 (1964).
- 10) L.M. Brown and P. Singer, Phys.Rev. 133, B 812 (1964).
- 11) S. Okubo and B. Sakita, Phys.Rev.Letters 11, 50 (1963).
- 12) B. Barrett and G. Barton, Phys.Letters 4, 16 (1963).
- 13) N. Cabibbo and R. Gatto, Nuovo Cimento 21, 872 (1961).

6.

- 14) See e.g. G. Belletini, Proc. Cambridge Conf. on Photon Interactions in the GeV Energy Range, Cambridge, Mass., Jan. 26-30, (1963) IV, p.17;
C.M. Andersen, A. Halprin and H. Primakoff, Phys.Rev.Letters 9, 512 (1962).
- 15) J. Bernstein, G. Feinberg and T.D. Lee, Phys.Rev. (to be published);
G. Feinberg (Columbia University preprint).
- 16) L.R. Price and F.S. Crawford, Jr., Phys.Rev.Letters 15, 123 (1965);
A. Rittenberg and G.R. Kalbfleisch (UCRL - 16297).