Temperature Dependence of η and η' Masses*

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Temperature dependence of η and η' masses is a very interesting subject and has been a hot topic lately. The η', being heavier than the other pseudoscalar mesons, naturally begs the question why it is so heavy. Besides being of academic interest, this also has important experimental consequences: for instance, in dilepton spectra which may help with identifying signals of a possible quark-gluon plasma. Any appreciable drop in η and η' masses will lead to significant enhancement of their production rates which would in turn cause an enhancement in the corresponding decay channels of these particles.

There are a number of works which address the temperature dependence of η and η' at and near the chiral phase transition temperature. Since the precise temperature dependence of the coefficient of the $U(1)$ anamoly term is not known, all these models assume a Gaussian form for its temperature dependence motivated by the belief that at high enough temperatures $U(1)$ symmetry should be restored. At best, this is a working ansatz which enables one to make semi-quantitative predictions about η and η' masses. Since this Gaussian ansatz is designed mainly to address the phase transition region, it is not expected to be very accurate at temperatures much lower than the chiral phase transition temperature.

We propose to use the non-linear sigma model, with symmetry breaking and an anomaly term added, to investigate the temperature dependence of η and η' masses for temperatures much less than T_c, the chiral phase transition temperature. We consider the change in masses of η and η' due to scatterings from a heat bath consisting mainly of pions. By evaluating the relevant one loop diagrams at finite temperature, one can calculate the temperature dependence of this change in masses.

We then consider the one loop diagrams with pions in the loop arising from the following Lagrangian

$$\begin{aligned} L &= \frac{1}{8}F_\pi^2 \mathrm{tr}\partial_\mu U \partial^\mu U^\dagger + \frac{1}{8}F_\pi^2 \mathrm{tr} M(U + U^\dagger - 2) \\ &+ a(\det U + \det U^\dagger - 2) \end{aligned}$$

where $U = \exp\left(\frac{2i\phi}{F_\pi}\right)$ and $F_\pi = \sqrt{2} f_\pi = 132$ MeV is the pion decay constant. These diagrams, evaluated at finite T, correspond to scattering of η or η' from thermal pions in the heat bath and lead to the following expressions for temperature dependence of the η and η' masses

$$\Delta m^2_{\eta,\eta'} \sim \frac{m_\pi^2}{F_\pi^2} I$$

where $I_{max} = .035 m_\pi^2$. Numerically, these changes are of the order of a few MeV and are therefore negligible. We also show that the change in the mixing angle is very small. We then consider the possibility that η or η' can fluctuate into a vector or axial vector meson, scatter from thermal pions in the bath and then go back to its original state. Using an effective action in a gauge where all axial vectors are zero, leads to the following interaction term

$$\mathrm{tr} V_\mu \phi \overleftrightarrow{\partial}_\mu \phi = V_\mu^a \phi^b \partial_\mu \phi^c \mathrm{tr} \lambda^a [\lambda^b, \lambda^c]$$

from which one can show that these processes are absent and do not contribute to mass shifts of η and η'.

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