The hadron properties in the massless sigma model at finite temperature

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We have constructed the massless linear sigma model in the Coleman-Weinberg (CW) mechanism, which has the stable effective potential including the one-boson and one-nucleon loop corrections for the first time [1]. We would like to see the hadron properties of the massless linear sigma model at finite temperature. Here we consider the Gibbs free energy similar to the optimized perturbation theory [2]. The Gibbs free energy of massless linear sigma model including one-loop corrections is given by,

$$\begin{aligned} V^{\rm total}(\phi, \boldsymbol{\pi}, T) &= \frac{\lambda}{4}\left(\phi^2+\boldsymbol{\pi}^2\right)^2 - \varepsilon\phi + \frac{\gamma-1}{8\pi^2} g_\sigma^4 \left(\phi^2+\boldsymbol{\pi}^2\right)^2 \left[\ln\left(\frac{\phi^2+\boldsymbol{\pi}^2}{m^2}\right) - \frac{25}{6}\right] \\ &+ T\int \frac{d^3k}{(2\pi)^3}\left[\ln\left(1-e^{-\beta\mathcal{E}_\sigma}\right) + 3\ln\left(1-e^{-\beta\mathcal{E}_\pi}\right) - 8\ln\left(1+e^{-\beta\mathcal{E}_N}\right)\right], \end{aligned}$$

where $\mathcal{E}_i = \sqrt{k^2+m_i^2}$. The left-hand side of Fig. 1 shows the masses of mesons and nucleon and the condensation as function of temperature through the stationary condition. The critical temperature about the restoration of the chiral symmetry is almost same as the results of the linear sigma model [2, 3]. The linear sigma model needs the self-consistent approach [3] or optimized perturbation approach [2] to avoid the tachyonic problem of scalar meson since the negative-mass term is constant at any temperature. In the massless linear sigma model the negative-mass term does not exist, and the loop corrections replace its role. The loop corrections from boson and fermion are dependent on the condensation f_π. As the condensation decreases, the loop corrections also decrease. Therefore, the tachyonic problem does not appear in the massless linear sigma model. This is a good feature of the massless linear sigma model. In the massless linear sigma model the "mass parameters" for σ and π meson are defined as

$$\mu_\sigma^2 = (\gamma-1)\frac{3g_\sigma^4 f_\pi^2}{2\pi^2}\left[\ln\left(\frac{f_\pi^2}{m^2}\right) - 3\right], \quad \mu_\pi^2 = (\gamma-1)\frac{g_\sigma^4 f_\pi^2}{2\pi^2}\left[\ln\left(\frac{f_\pi^2}{m^2}\right) - \frac{11}{3}\right]$$

This mass parameters have the dependence on the temperature through the condensation f_π as shown in the right-hand side of Fig. 1. The linear sigma model has the same "mass parameter" for σ and π mesons which is negative constant. However the massless linear sigma model does not provide the same "mass parameter" in the broken phase. We construct this model by introducing the loop corrections consistent with the chiral symmetry in the Wigner phase. After the spontaneous chiral symmetry breaking, the "mass parameter" appears for the σ and π mesons independently.

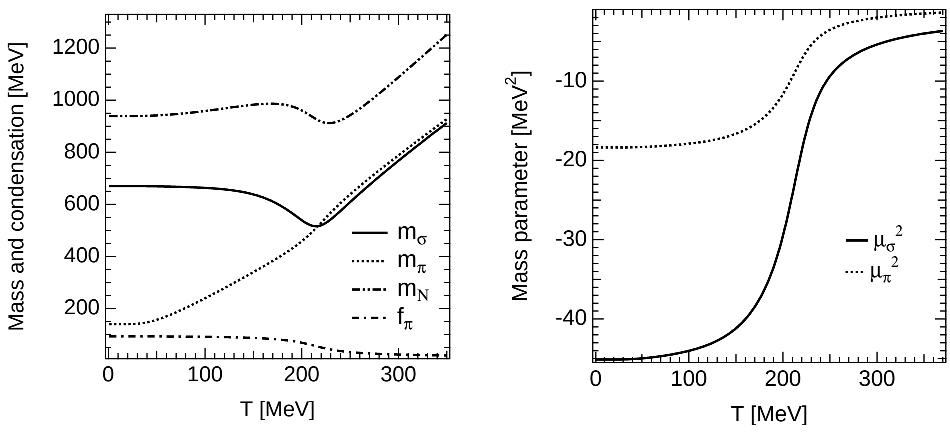

Figure 1: **The behaviors of mass, condensation, and mass parameters dependent on temperature with the CW scheme in the case of broken chiral symmetry $\varepsilon \neq 0$.**

References

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