Partial $U(1)_A$ Restoration and η Enhancement in High-Energy Heavy-Ion Collisions *

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It is well known that the $U(1)_A$ symmetry in QCD is violated by the axial anomaly present at the quantum level and thus cannot give rise to the Goldstone boson which would occur when $U(N_f) \times U(N_f)$ chiral symmetry is spontaneously broken. The $U(1)_A$ particle, known as $\eta'(958)$ in the $N_f = 3$ case, acquires an additional mass through the quantum tunneling effects mediated by instantons, breaking up the mass degeneracy with pions, kaons and η's. The $\eta(547)$ particle also acquires an additional mass through the mixing with the η'. It is believed that at high temperatures the instanton effects are suppressed due to the Debye-type screening. Then one expects a practical restoration of $U(1)_A$ at high temperatures.

One of the consequences of $U(1)_A$ restoration is the enhancement of η particle production at small and intermediate transverse momenta due to the softening of its mass at high temperatures. However, the final yield of the η particles and their p_t distributions both depend crucially on the chemical and thermal equilibrating processes involving the η.

In this paper, we examine the rates of various processes relevant for the thermal η particle production, in particular, whether or not the η can decouple early enough from the thermal system expected to be produced in relativistic heavy-ion collisions. We present a theoretical calculation of thermal cross sections for the processes $\eta\eta \leftrightarrow \eta\eta$, $\pi\eta \leftrightarrow \pi\eta$ and $\eta\eta \leftrightarrow \pi\pi$, essential to the thermal and chemical equilibration. Our calculations are based on models which explicitly incorporate the $U(1)_A$ anomaly. We also assume an exponential suppression of the $U(1)_A$ anomaly due to the Debye-type screening of the instanton effect, which leads to the temperature dependence of the η and η' masses. Our results, as shown in Fig. 1 and 2, suggest that the η particles are out of chemical equilibrium long before the thermal freeze-out.

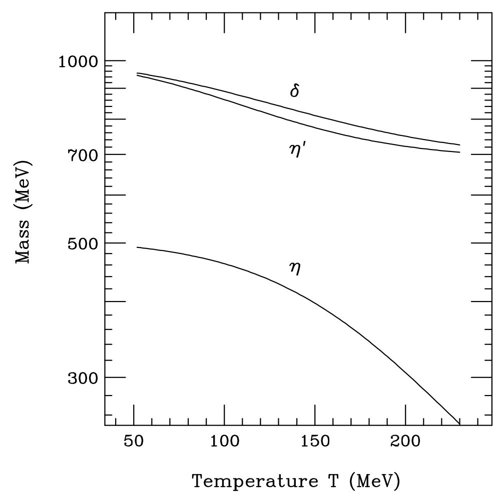

Figure 1: The temperature dependence of m_η, $m_{\eta'}$, m_δ.

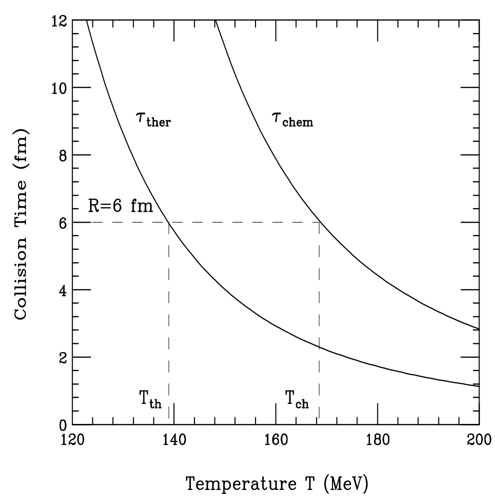

Figure 2: The characteristic time scales of the thermal and chemical equilibration for the η particle.

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