Chemical + Kinetic eqn.

1. What is thermal equilibrium? What are the conditions to be met to achieve this? Explain with example. [4]

2. What is decoupling and what is freeze-out? Explain how the freezeout and decoupling of photons took place in the early universe. [5]

3. The number density of relativistic bosons and relativistic fermions are given

$$
\begin{aligned}
n &= \frac{\zeta(3)}{\pi^2} g T^3, \quad \text{for bosons}, \\
&= \frac{3}{4}\frac{\zeta(3)}{\pi^2} g T^3, \quad \text{for fermions},
\end{aligned}
$$

where $\zeta(3) = 1.20205$. Assuming the room temperature to be 27^{o}C, calculate the number density of photons in the room. *You are given* $\hbar c = 1.973269804 \times 10^{-7} eV.m$ *and* $k_B = 8.617333262 \times 10^{-5} eV/K$ [6]

4. Write down the reactions that kept the neutrino in thermal equilibrium with the photons. Suppose $T_{\nu 0}$ and $T_{\gamma 0}$ are the temperature of cosmic neutrino background and cosmic microwave background, respectively. Which of the following is true and explain why [5]

$$T_{\nu 0} = T_{\gamma 0}, \qquad T_{\nu 0} > T_{\gamma 0}, \qquad \boxed{T_{\nu 0} < T_{\gamma 0}}.$$