B09 (HW 2009 6.1) (old!, newer version on another page)

Universe, black body radiation:

a) Adiabatic expansion because

Universe → close system → $\Delta Q = 0 = T\Delta S \rightarrow \underline{\Delta S = 0}$

b) Upon $V \rightarrow 2V$

$$S = \frac{U+PV}{T} = \frac{4}{3}\frac{U}{T} \propto VT^3 = \text{const}$$

$$\rightarrow V \rightarrow 2V \longrightarrow T \rightarrow \frac{T}{2^{1/3}}$$

c) $\frac{U}{V} = \frac{\pi^2 k^4}{15\hbar^3 c^3} T^4 \approx 5\times10^{-13}\ \frac{\text{erg}}{\text{cm}^3}$, $\frac{U(T_f)/2V}{U(T_i)/V} = \frac{1}{2}, \frac{1}{2^{1/3}} = \frac{1}{2^{3/3}}$

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$$v_s^2 = \frac{B}{\rho} \qquad B = -V\frac{dP}{dV} \overset{\text{adiabat}}{=} \frac{5}{3}P \qquad \rho = N\frac{m}{V}$$

$$v_g^2 = \frac{P_F^2}{m^2} \qquad \text{at } T=0 \quad P = P_0 \text{ (pressure)}$$

$$\rightarrow \frac{v_s^2}{v_g^2} = \frac{5PVm}{NP_F^2} = \sim \frac{1}{3}$$