Physics 1215
Group Problem

a) Your friend is not convinced that entropy must increase in every situation. To prove to you that he is right, he pours 240 g of water at 100°C into an insulated 150-g aluminum cup at 20°C. The water cools down somewhat and your friend insists that the entropy has decreased. He says that the rapid molecular motion of the hot water has decreased as the water cooled so that in the final situation the molecules must be more ordered. Is your friend correct in saying that entropy has decreased? If not, why not? Calculate the entropy change involved in this process?

b) Your friend is still not convinced. He injects 2.0 g of steam at 100°C into a sealed insulated aluminum container with a mass of 150 g at a temperature of 20°C. The steam condenses on the inside of the aluminum and your friend is sure that entropy has decreased. After all the very rapid motion of the steam molecules has practically ceased, as the steam has become water. Calculate the total entropy of this process (from the time the water starts to condense at 100°C until the time it has just completely condensed, still at 100°C) and comment on whether or not your friend is correct.

c) Your friend would like to compare the answers you got in part (a) and (b) with something he can relate to, so he asks you how the entropy of the universe will change if he drops a 450 gram ball from a height of 1.5 meters and it hits the ground and stops when the temperature of the ball and the surroundings are 20°C.

a) The friend has neglected the change in entropy of the cup. Final temperature of cup + water must be found

$$Q_w + Q_c = 0$$

$$m_w c_w (T_f - T_w) + m_A c_A (T_f - T_A) = 0$$

$$T_f = \frac{T_w m_w c_w + T_A m_A c_A}{m_w c_w + m_A c_A}$$

$$= \frac{(100\,°C)(.240\,kg)(4186\,J/kg\,°C) + (20\,°C)(.150\,kg)(900\,J/kg\,°C)}{(.240\,kg)(4186\,J/kg\,°C) + (.150\,kg)(900\,J/kg\,°C)}$$

$$= 90.5\,°C$$

$$\Delta S = \Delta S_w + \Delta S_A$$

$$= \int \frac{dQ_w}{T_w} + \int \frac{dQ_A}{T_A} = m_w c_w \int \frac{dT_w}{T_w} + m_A c_A \int \frac{dT_A}{T_A}$$

$$= m_w c_w \ln \frac{T_f}{T_w} + m_A c_A \ln \frac{T_f}{T_A}$$

$$= (.240\,kg)(4186\,J/kg\,°C) \ln\left(\frac{363.5}{373}\right) + (.150\,kg)(900\,J/kg\,°C) \ln\left(\frac{363.5}{293}\right)$$

$$= -25.9\,J/K + 29.1\,J/K = \boxed{3.2\,J/K}$$

b)

$$Q_w + Q_{AL} = 0$$

$$m_w L_f + m_A c_A (T_f - T_A) = 0$$

$$T_f = \frac{m_w L_f + m_A c_A T_A}{m_A c_A} = \frac{(.002\,kg)(22.6 \cdot 10^5\,J/kg) + (.150\,kg)(900\,J/kg\,K)(293\,K)}{(.150\,kg)(900\,J/kg\cdot K)}$$

$$= 327\,K$$

$$\Delta S = \Delta S_w + \Delta S_A$$

$$= \int \frac{dQ_w}{T_w} + \int \frac{dQ_A}{T_A} = \frac{m L_f}{T_w} + m_A c_A \ln \frac{T_f}{T_A}$$

$$= -\frac{(.002\,kg)(22.6 \times 10^5\,J/kg)}{373\,K} + (.150\,kg)(900\,J/kg\,K) \ln\left(\frac{327}{293}\right)$$

$$= -12.12 + 14.82 = \boxed{2.7\,J/K}$$

The entropy of the water does decrease, but the container increases, so that the total entropy increases.

c)

$$\Delta S_{\text{System}} = \int \frac{dQ}{T} = \frac{1}{T}\int dQ = \frac{Q_{\text{System}}}{T} = \frac{W_{\text{by}} + \Delta U + \Delta K + \Delta PE + \Delta E_{\text{other}}}{T} = \frac{\Delta PE}{T}$$

$$= \frac{-mgh}{T} = \frac{-(0.450\,\text{kg})(9.80\,\text{m/s}^2)(1.5\,\text{m})}{293\,\text{K}} = -0.23\,\frac{\text{J}}{\text{K}}$$

$$\Delta S_{\text{Universe}} = -\Delta S_{\text{System}} = 0.23\,\frac{\text{J}}{\text{K}}$$