Physics 108 Test 1 Spring 2015

1. (a)(17) Following a heat wave two years ago, in Prof. Sher's subdivision, the swimming pool, which has a size of 1.2 meters x 10 meters x 5 meters, was 95 degrees F (35 C). The density of water is 1000 kg/m^3. It was suggested that ice be added to cool it down to 86 F (30 C). How much ice (initially at -20 C) would have to be added?
(b)(5) When the amount of ice in your answer to part (a) melts, what is the change in its entropy?
(c)(3) When you freeze water in your freezer, the entropy of the water decreases. Does this violate the 2nd Law of Thermodynamics? Explain why or why not.

a) $m_w = \rho V = \left(1000 \frac{Kg}{m^3}\right)(10 \times 1.2 \times 5\ m^3) = 6 \times 10^4\ Kg$

ignore cooling of air/ground around pool: treat as isolated system

$Q_{hot} + Q_{cold} = 0$

$Q_{hot} = m_w c_w \Delta T = (6 \times 10^4\ Kg)\left(\frac{10^3\ cal}{Kg\ ^\circ C}\right)(30^\circ C - 35^\circ C) = -3 \times 10^8\ cal$

Q_{cold} : 3 steps → Q_1 = warm ice to 0°C
Q_2 = melt ice
Q_3 = warm melted ice to 30°C

m = mass of ice required

$Q_{cold} = Q_1 + Q_2 + Q_3 = m c_{ice}(0^\circ C - (-20^\circ C)) + m L_f + m c_w (30^\circ C - 0^\circ C)$

(Note: c_w, c_{ice}, L_f were given on the equation sheet in 2015)

$= m\left[c_{ice}(20^\circ C) + L_f + c_w(30^\circ C)\right]$

$= m\left[\left(\frac{500\ cal}{Kg \cdot ^\circ C}\right)(20^\circ C) + \frac{80 \times 10^3\ cal}{Kg} + \left(\frac{10^3\ cal}{Kg \cdot ^\circ C}\right)(30^\circ C)\right]$

$= m\left(1.2 \times 10^5 \frac{cal}{Kg}\right)$

$\therefore\ Q_{hot} + Q_{cold} = 0$

$-3 \times 10^8\ cal + m\left(1.2 \times 10^5 \frac{cal}{Kg}\right) = 0$

$m = \frac{3 \times 10^8\ cal}{1.2 \times 10^5\ cal/Kg} = \boxed{2500\ Kg}$

2.5 metric tons!

b) $\Delta S = \frac{Q}{T} = \frac{m L_f}{T} = \frac{(2500\ Kg)\left(80 \times 10^3 \frac{cal}{Kg}\right)}{(273\ K)}$

$= 7.33 \times 10^5\ cal/K = \boxed{3.07 \times 10^6 \frac{J}{K}}$

(note: phase change is a reversible process)

c) This does not violate the 2nd Law, because the water in the freezer is not an isolated system (neither is the freezer).

2.(a)(15) A person eats a dessert that contains 260 kcal. Her skin temperature is 36 C and the environment is 21 C. Her skin has a surface area of 1.3 m^2 and an emissivity of 0.75. How much time would it take her to emit a net radiant energy from her body that is equal to the energy contained in the dessert?

(b)(10) Your professor eats the same dessert. When he drinks cold water, his body must expend metabolic energy in order to maintain normal body temperature (37 C) by warming up the water in his stomach. How many liters of ice water (initially water at 0 C) would he have to drink in order to use up these calories? The density of water is 1 kg per liter. For comparison, the stomach can hold about one liter.

a) $$\frac{Q}{t} = \sigma \varepsilon A\left(T_{hot}^4 - T_{cold}^4\right) = \left(5.69\times10^{-8}\ \frac{J}{s\cdot m^2\cdot K^4}\right)(0.75)(1.3\,m^2)\left[(309\,K)^4-(294\,K)^4\right]$$

$$= 91.3\ J/s$$

$$Q = 2.6\times10^2\ Kcal \times \frac{4186\,J}{Kcal} = 1.09\times10^6\ J$$

$$t = \frac{Q}{Q/t} = \frac{1.09\times10^6\,J}{91.3\ J/s} = \boxed{1.19\times10^4\,s}$$

($\approx$ 200 min)

b) $$Q = 2.6\times10^2\ Kcal = m_{icewater}\, C_w\, \Delta T$$

$$= m_{icewater}\left(\frac{1\ Kcal}{Kg\,^\circ C}\right)(37^\circ C - 0^\circ C)$$

$$\therefore\ m_{icewater} = \frac{2.6\times10^2\ Kcal}{\left(\frac{1\,Kcal}{Kg\cdot ^\circ C}\right)(37^\circ C)} = 7.0\ Kg$$

$$V = m/\rho = \frac{7\,Kg}{1\,Kg/l} = \boxed{7\ \text{litres}}$$

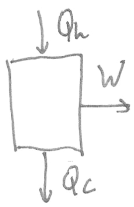
3. Two unrelated problems

(a)(15) The Surry nuclear power plant puts out 1000 Megawatts of power to the electrical grid. Its high temperature reservoir (the uranium core) is at 900 K, the cold temperature reservoir (the James River) is at 300K. The plant operates at 50% of the maximum possible efficiency. What is the efficiency at which the plant operates, and what is the waste heat dumped into the James River every second?

Max. $\mathcal{E}$ is $\mathcal{E}^{carnot} = 1 - \frac{T_c}{T_h} = 1 - \frac{300K}{900K} = 2/3 = 0.667 = \mathcal{E}^c$

$\therefore \mathcal{E} = 0.50\,\mathcal{E}^{carnot} = (0.5)(2/3) = 1/3$ $\boxed{\mathcal{E} = 0.333}$

$\mathcal{E} = \frac{W}{Q_H}$ $\therefore Q_H = \frac{W}{\mathcal{E}}$ $\therefore \frac{Q_H}{t} = \frac{(W/t)}{\mathcal{E}}$ $\frac{W}{t} = \text{power} = 10^3\ \text{MWatt} = 10^9\ \text{Watts}$



$\therefore \frac{Q_H}{t} = \frac{10^9\ \text{Watts}}{0.333} = 3\times10^9\ \text{Watts}$

$Q_c = Q_H - W$

$\frac{Q_c}{t} = \frac{Q_H}{t} - \frac{W}{t} = (3\times10^9 W) - (10^9 W) = 2\times10^9 W = 2\times10^9\ J/s$

$\therefore \boxed{2\times10^9\ J}$ waste energy (heat) per second

(b)(10) The chain used to measure yardage in football is 9.5 meters long at room temperature (20 C) and is made of steel. During a game, it is found to be 3 millimeters shorter. What is the temperature?

Note: $\alpha_{steel} = 12\times10^{-6}/{}^\circ C$ was given on Equation sheet

$\Delta L = \alpha L \Delta T$

$\Delta T = \frac{\Delta L}{L\alpha} = \frac{-3\times10^{-3} m}{(9.5m)\left(\frac{12\times10^{-6}}{{}^\circ C}\right)} = -26.3^\circ C$

$\therefore T_{game} = 20^\circ C - 26.3^\circ C = \boxed{-6.3^\circ C}$

4. (a)(10) Which of the following are **NOT** expressions of the 2nd Law of Thermodynamics? There may be more than one answer. Circle your answer or answers.

(a) The energy of a closed system is conserved. – 1st Law

(b) The entropy of a closed system never decreases with time.

(c) A heat engine operating in a closed cycle cannot turn heat completely into work.

(d) Heat can never flow spontaneously from a colder body to a hotter body.

(e) The efficiency of an engine operated between T_c and T_H cannot exceed $1 - T_c/T_H$

(f) The change in the internal energy of a system is given by the heat flow into the system minus the work done by the system. – 1st Law

(b)(5) A gas is at 27 C and a pressure of 2 atmospheres and at constant volume. It is heated until its pressure is 4 atmospheres. What is the new temperature?

b) Assume ideal gas: $P_1V_1 = nRT_1$ $P_2V_2 = nRT_2$ (n = constant)

$V_1 = V_2$ $\therefore$ $\frac{P_2}{P_1} = \frac{T_2}{T_1} = \frac{(4\,atm)}{(2\,atm)} = 2$ $\therefore$ $T_2 = 2T_1$

$T_1 = 27°C = 300K$ ↑ remember to convert!

$= 2(300K) = \boxed{600K}$

or $= 327°C$