PHYSICS-2
Elementary Physics of Energy
Midterm Examination
28 APRIL 2011
100 Total Points

1. (a) A coal burning power plant burns coal at 1100^0C and exhausts heat into a river with average temperature 10^0C. The rate of thermal pollution (i.e. heat exhausted into the river) is given to be 80 MW. Assuming that it is a perfect plant with no second law losses, calculate the power output of the plant. [20]

Solution: Since $T_H = 1100 + 273 = 1373$K and $T_L = 10 + 273 = 283$K, the Carnot efficiency is given by $\eta = 1090/1373 = .794$. We can also express the Carnot efficiency in terms of the power as

$$\eta = \frac{(P_H - P_L)}{P_H} = .794,$$

where P_H and P_L are the power input (from coal burning) and power rejected into the river respectively, and hence

$$P_L = P_H \times (1 - \eta) = P_H \times .206.$$

We are given $P_L = 80$MW, and hence solving above equation for P_H, we obtain

$$P_H = 388MW.$$

The power output $P_{Output} = P_H - P_L = 308MW$.

(b) If the plant works with 65% second law efficiency, calculate the first law efficiency, and from that calculate the power output. [10]

Since the second law efficiency is 65% the first law efficieny is given from

$$\eta_{SecondLaw} = \frac{\eta_{FirstLaw}}{\eta_{Carnot}} = .65.$$

We know $\eta_{Carnot} = .794$ from Part (a) and hence infer that $\eta_{FirstLaw} = .794 \times .65 = .516$.

Now we use the fact that the second law efficiency is also related to the actual work available to the ideal work, and hence to the respective powers. Therefore we write

$$\eta_{SecondLaw} = \frac{W_{actual}}{W_{ideal}} = \frac{P_{actual}}{P_{ideal}},$$

therefore

$$P_{actual} = P_{ideal} \times \eta_{SecondLaw} = .65 \times 308 = 200MW.$$

The question as framed could have been sharper, since you need not use the first law efficiency - as shown above. In order to compensate, all fair attempts were given full points while grading.

2. A jeweller melts a block of silver at 10^0C, using 312kJ heat from a furnace. Find the mass of the silver block.[30]

   Solution: This problem requires us to use the formula for heat

   $$Q = m \times (L + c \times (T_B - T_{Room}),$$

   where m, c, L are the mass, specific heat and latent heat of melting of silver, and T_B, T_{Room} are the temperatures of melting of silver and the room temperature. In this problem we are given the values of Q, c, L, T_B, T_{Room} from the data items, and the only unknown is the mass m. Thus

   $$m = \frac{312kJ}{[88.3 + .235 \times (961 - 10)]kJ/kG} = 1\ kG$$

   .

3. Solar energy is incident on a parking lot of unknown area with intensity 1000 W/m^2, and 50 % of it is absorbed. After 2 hours of exposure, the heat absorbed is enough to warm up 20 kg water from 10^0C to steam at 110^0C. What is the area of the parking lot?[40]

   Solution: We set up an equation with the unknown area of the parking lot A as a variable in units of m^2 where $m = meter$. First consider the heat absorbed by the lot

   $$Q_{Absorbed} = A\ m^2 \times 1000\ W/m^2\ \times .5 \times\ 120 \times 60\,\mathrm{sec} = A \times 3.6 \times 10^6 J.$$

   On the other hand the heat needed to warm up 20kG water to steam at 110C can be viewed as a three step process (a) heating water to 100C (b) boiling water at 100C into steam and (c) heating steam from 100C to 110C. Adding the three contributions to the heat the total is expressed as

   $$Q_{Water} = 20kg \times \{c_{water} \times (100 - 10) + L_{boiling} + c_{steam} \times (110 - 100)\},$$

where the specific heats are given in Joules per kG per degree and and latent heat in Joules per kG. Working this out we get

$$Q_{Water} = 5.29 \times 10^7 \ J,$$

and equating $Q_{Absorbed} = Q_{Water}$ we get

$$A = 14.7 \ m^2.$$

DATA

- (Heat capacity and specific heat are used interchangeably here).
- Heat capacity of water $=4.2kJ/(kg^0C)$. Density of water $=1gm/cc$. Heat capacity of steam $= 1.99kJ/(kg^0C)$. Latent heat of boiling$=2.25MJ/(kg)$. Boiling point of water $=100^0C$.
- Heat capacity of silver $=.235kJ/(kg^0C)$.
- Melting temp of silver $=960.8^0C$.
- Latent heat of fusion for silver $= 88.3kJ/kg$.
- 1 BTu = 1055 J. 1 calorie = 4.2 J.