PHYSICS-2
Elementary Physics of Energy

Homework 4 Solutions
Adam Chan

1. Suppose the power plant burns the equivalent of 100 Joules of natural gas. At 40% efficiency, this generates 40 Joules of electrical energy. With a 10% transmission line loss, 4 Joules would be lost and the net electrical energy delivered to the house would be 36 Joules. The water heater will convert 60 Joules of the initial 100 Joules in the natural gas into heat energy in the water. Or, to get 36 Joules of heating, one would need to start with 60 Joules equivalent of natural gas. Thus, the electrical heating scheme uses 100 Joules for every 60 Joules that the natural gas-fueled water heater uses. The electrical heating method costs more gas, even though it has less air pollution; there is a trade-off.

2. A heat engine in each cycle extracts 50,000 Btu of thermal energy and rejects (or releases) 20,000 Btu of thermal energy.
a) How many Btu of work are done each cycle?

Solution: In a heat engine, the extracted energy comes from the hot reservoir, and is labeled Q_h, while the rejected energy is the waste energy dumped into the cold reservoir, labeled Q_c. For a heat engine, we have $Q_h = W + Q_c$, so $W = Q_h - Qc = \boxed{30,000\ Btu}$.

b) What is the efficiency of this engine?

Solution: The efficiency is defined as $\eta = \dfrac{W}{Q_h} = \dfrac{3}{5} = \boxed{60\%}$.

3. Suppose the power plant consumes 100 J of energy. With an efficiency of 40%, the plant delivers 40 J of Work to the heat pump. With a C.O.P. of 4 (which is $\frac{Q_h}{W}$), the heat pump can then deliver as much heat energy Q_h as 4 times the amount of Work input. This is delivering $4 \times 40J = 160J$ to the home, which is 60 J more than would be generated in the home if all 100 J of the fuel were combusted with 100% efficiency! The improvement is 60 100 = 60%

4. From page 80, the EER is dened as the rate at which heat energy is removed in Btu/hr divided by the rate at which energy is consumed by the appliance in watts. An EER of ten indicates that for each unit of energy consumed by the refrigerator, ten times as much energy is removed from the inside and delivered to the room.

5. When considering a heat pump, the energy delivered to a house corresponds to Q_h, and the energy drawn from the low temperature reservoir corresponds to Q_c. Since $Q_h = W + Q_c$, $W = 8Btu - 6Btu = 2Btu$. The coefficient of performance is defined as $C.O.P. = \frac{Q_h}{W} = \frac{8}{2} = \boxed{4}$

Multiple Choice

1. From the inside cover, one ton (not tonne) of bituminous coal is the energy equivalent of $2.81 \times 10^{10}J$. The energy delivered in one day from a $500MW_e$ plant is:

$$500 \times 10^6 \frac{J}{sec} \times \frac{3600sec}{hr} \times \frac{24hr}{day} = 4.32 \times 10^{13}J$$

If the efficiency is just 30%, then the required energy equivalent of coal is $\frac{4.32 \times 10^{13}J}{0.30} = 1.44 \times 10^{14}J$. Converting to coal, we then have:

$$1.44 \times 10^{14}J(\frac{1ton\ coal}{2.81 \times 10^{10}J}) = 5125tons$$

But, according to the footnote at the bottom of the inside cover page, 1 ton is equivalent to .907 *tonnes*, which is the unit we want. This gives us:

$$5125tons(\frac{.907tonnes}{1ton}) = \boxed{4648\ tonnes}$$ which is answer $\boxed{\textbf{b}}$

2. $\boxed{\textbf{a}}$. The refrigerator will run continuously, as it tries to cool the box, which is open to the room. The room wont cool because it is insulated and every Joule of energy that is pumped out of the box will be rejected at the heat exchanger, owing back into the room. In fact, the heat pump is not

ideal and friction causes the motor to heat up, provided a source of energy which accumulates in the room and causes the temperature to rise.

3. The Carnot efficiency is defined at $\eta = 1 - \frac{T_c}{T_h}$. But, we must do this in the Absolute Temperature scale, which means we must convert the temperatures to their Absolute Temperature in Kelvin by adding 273.
The efficiency then becomes $\eta = 1 - \frac{723K}{1273K}$, which is approximately 43%.
This is answer $\boxed{\textbf{d}}$

4. The $COP = \frac{T_h}{T_h - Tc}$, and the higher temperature is the same in both cases. So, we just need to compare the ratio of the second temperature difference t the first - note that the temperature difference term is in the denominator. Also, since we have a ratio of temperature differences we can use Fahrenheit degrees or Kelvin, so we get: $ratio = \frac{100^\circ F}{55^\circ} = \boxed{1.8}$, or the answer $\boxed{\textbf{b}}$

5. $\frac{7200 tonnes}{day}(\frac{2 \times 10^4 Btu}{kg})(\frac{1000kg}{tonne})(.3)(\frac{1kWh}{3413Btu})(\frac{1day}{24hours}) = \boxed{5.27 \times 5^5 kW}$, which is answer $\boxed{\textbf{d}}$