PHYSICS-2

Elementary Physics of Energy

Homework 4 Solutions

Problems from Chapter 3 of Ristinen and Kraushaar:

Questions & Problems (pg. 85):

3. a) From the Principle of Energy Conservation, we know that the sum of the work done and the heat delivered to the lower temperature reservoir must be equal to the heat derived from the higher temperature reservoir, i.e.

$$W + Q_c = Q_h$$

$$W = Q_h - Q_c$$

The efficiency is the ratio of the work done to the energy taken from the hot reservoir:

$$\eta = \frac{W}{Q_h} = \frac{Q_h - Q_c}{Q_h} = 1 - \frac{Q_c}{Q_h} = 1 - \frac{T_c}{T_h}$$

b) A heat engine is a device that transfers energy from a warmer body to a cooler body, while simultaneously doing work. Ideally, the work done is exactly equal to the difference between the energy taken from the warmer body and the energy delivered to the cooler body.

8. a) Millions of years ago, solar energy combined with water and carbon dioxide to grow the plants that eventually decayed, became compressed and converted chemically into coal. The original solar energy, plus the chemical energy of the pre-coal constituents, plus the energy of the other transforming processes, e.g. high pressure, are thus contained in the chemical bonds of the coal. When combusted, the carbon in coal is converted largely into carbon dioxide and the hydrogen into water, releasing chemical energy as heat. The heat is absorbed by water to produce hot water vapor, i.e., steam. The steam expands against a turbine and its energy is converted into mechanical energy as the turbine rotates. In an electrical generator, some of this mechanical energy is converted into electrical energy, which is then transmitted to the home, with some energy loss along the way due to resistive heating.

b) The electrical energy in the heater flows through an element that gets hot and warms the surrounding air due to direct physical contact (a form of mechanical energy transfer) while also radiating electromagnetic waves into the air to warm surrounding objects, which absorb the infrared electromagnetic radiation. Ultimately the heaters energy is dissipated into random motions of its surroundings.

15. From page 80, the EER is defined 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.

Multiple Choice Questions:

4. d. Molecular Weight $= 8 \times 12 + 18 \times 1 = 96 + 18 = 114$ grams per mole.

6. 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, flowing back into the room. In fact, the heat pump is not ideal and friction causes the motor to heat up, providing a source of energy which accumulates in the room and causes the temperature to rise.

7. h. $(98.632) \times \frac{5}{9} = 37°\text{C}$; $37 + 273 = 310\ K$

13. b. The COP $= \frac{T_h}{T_h - T_c}$, and the higher temperature is the same in both cases. So, we just need to compare the ratio of the second temperature difference to 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 $= \frac{100°\text{F}}{55°} = 1.8$

14. d. One mole of a substance has a mass that is one gram molecular weight.

16. a. Each molecule of methane contains 1 carbon atom, and therefore produces 1 molecule of carbon dioxide when burned. The answer lies in the relative molecular weights of the two; carbon dioxide has a MW of 44 $\frac{grams}{mol}$ while methanes MW is 16 $\frac{grams}{mol}$. The number of tons of CO_2 produced in the combustion of one ton of methane is: $\frac{44}{16} = 2.75$ tons.

Other problems:

1. $T_h = 120°\text{C} = 393$ K, and $T_c = 15°\text{C} = 288$ K.

Heat Engine:

$$\eta_C = \frac{T_h - T_c}{T_h} = 0.27$$

Heat Pump:

$$\eta_C = \frac{T_h}{T_h - T_c} = 3.74$$

Refrigerator:

$$\eta_C = \frac{T_c}{T_h - T_c} = 2.74$$

2. So w is 10% less than W, or $w = 0.9$ W. Hence $c = 0.9$ in the equation $w = cW$. Using Carnot's relation ($\frac{T_c}{T_h} = \frac{Q_c}{Q_h}$) rewrite the above

$$\eta_C = \frac{T_h - T_c}{T_h} = \frac{Q_h - Q_c}{Q_h} = \frac{W}{Q_h}.$$

And by definition

$$\eta_{1^{st}} = \frac{w}{Q_h}.$$

Then,

$$\eta_{2^{nd}} = \frac{\eta_{1^{st}}}{\eta_C} = \frac{\frac{w}{Q_h}}{\frac{W}{Q_h}} = \frac{w}{W} = c = 0.9$$

Now, using this

$$\eta_{1^{st}} = c\eta_C = 0.9 \times 0.27 = 0.24$$

For a heat pump $\eta_C = \frac{Q_h}{W}$ and $\eta_{1^{st}} = \frac{Q_h}{w}$, so

$$\eta_{2^{nd}} = \frac{\eta_{1^{st}}}{\eta_C} = \frac{\frac{Q_h}{w}}{\frac{Q_h}{W}} = \frac{W}{w} = \frac{1}{c} = 1.1$$

and

$$\eta_{1^{st}} = \frac{\eta_C}{c} = \frac{3.74}{0.9} = 4.2$$

3. Now w is 10% more than W, so $w = 1.1$ W, and $c = 1.1$. Here $\eta_C = \frac{Q_c}{W}$ and $\eta_{1^{st}} = \frac{Q_c}{w}$. By the same method as in the previous problem

$$\eta_{2^{nd}} = \frac{1}{c} = 0.91$$

and

$$\eta_{1^{st}} = 2.49$$