PHYSICS-2

Elementary Physics of Energy

Homework 3 Solutions

Problems from Chapter 3 of Ristinen and Kraushaar:

1. First convert this temperature to Celsius:

$$(68 - 32) \times \frac{5}{9} = 20°\text{C}$$

To obtain the corresponding temperature in Kelvin, add 273.15, i.e. 293.15 K.

4. Convert temperatures to Kelvin. The maximum efficiency is:

$$1 - \frac{T_c}{T_h} = -\frac{293\ K}{423\ K} = 1 - 0.69 = 0.31$$

The maximum efficiency is thus 31%, and the inventors claim is bogus.

9. The electrically-powered heat pump is drawing heat from a hot reservoir and delivering it to a cold reservoir. As long as the difference between the energy drawn from the hot reservoir and the work done by the pump (the electrical work) is equal to the energy delivered to the cold reservoir, the Principle of Energy Conservation is not violated. The Principle does not require that the electrical work be greater than the energy delivered to the cold reservoir.

More problems:

1. The process of water evaporating is endothermic.

2. A high specific heat means that water can absorb a relatively large amount of energy while only changing temperature by a small amount. This causes coastal climates to have more moderate temperature variability, in contrast to inland regions which are more prone to hot summers and cold winters.

3. Use the formula

$$T_f = \frac{M_1 c_1 T_1 + M_2 c_2 T_2}{M_1 c_1 + M_2 c_2}$$

with $M_1 = 5\ kg,\ c_1 = 4.2\ \frac{kJ}{kg\cdot°\mathrm{C}},\ T_1 = 20°\mathrm{C}$ and $M_2 = 10\ kg,\ c_2 = 0.358\ \frac{kJ}{kg\cdot°\mathrm{C}},\ T_2 = 60°\mathrm{C}$, then $T_f = 25.8°\mathrm{C}$.

4. To find the specific heat of the mixture in problem 3, take a mass weighted average:

$$c_{mix} = \frac{5\ kg \times 4.2\ \frac{kJ}{kg\cdot°\mathrm{C}} + 10\ kg \times 0.358\ \frac{kJ}{kg\cdot°\mathrm{C}}}{15\ kg} = 1.64\ \frac{kJ}{kg\cdot°\ \mathrm{C}}$$

Convert gallons of water to kg:

$$2\ gal \times \frac{3.78\ liters}{1\ gal} \times \frac{1000\ cm^3}{1\ liter} \times \frac{1\ gram}{1\ cm^3} = 7560\ grams = 7.56\ kg$$

Now use the same formula as in the previous problem, but with $M_1 = 15\ kg,\ c_1 = 1.64\ \frac{kJ}{kg\cdot°\mathrm{C}},\ T_1 = 25.8°\mathrm{C}$ and $M_2 = 7.56\ kg,\ c_2 = 4.2\ \frac{kJ}{kg\cdot°\mathrm{C}},\ T_2 = 50°\mathrm{C}$, then $T_f = 39.4°\mathrm{C}$.

5. $30\ g \times 6 = 180\ g$. The latent heat of melting is 333 J/g, so the energy required to melt the ice cubes is $\Delta Q = M \times \mathrm{L} = 59.9\ kJ$. The energy required to raise the 180 g of water from 0°C to 5°C is then $\Delta Q = M \times \mathrm{c} \times \Delta T = 180\ g \times 4.2\ \frac{J}{g\cdot°\mathrm{C}} \times 5°\mathrm{C} = 3.78\ kJ$. To find the mass of water originally at 20°C use conservation of energy, i.e. the energy that melted the ice and raised its temperature by 5°C is the amount of energy that was lost by the unkown amount of water, which underwent a change in temperature from 20°C to 5°C. Using the last formula, and rearranging to solve for the mass, we have

$$M = \frac{\Delta Q_{total}}{c \times \Delta T} = \frac{59.9\ kJ + 3.78\ kJ}{4.2\ \frac{kJ}{kg\cdot°\mathrm{C}} \times 15°\mathrm{C}} = 1.01\ kg.$$

6. Convert temperature to Celsius: $(40 - 32) \times \frac{5}{9} = 4.4°\mathrm{C}$, and 1 tonne water is 1000 kg. Energy to raise water to 100°C:

$$\Delta Q = M \times \mathrm{c} \times \Delta T = 1000\ kg \times 4.2\ \frac{kJ}{kg\cdot°\ \mathrm{C}} \times 95.6°\mathrm{C} = 4.02 \times 10^5\ kJ = 402\ MJ$$

Energy to turn water to steam:

$$\Delta Q = M \times \mathrm{L} = 1000\ kg \times 2.25\ MJ/kg = 2250\ MJ$$

Energy to heat steam from 100°C to 120°C:

$$\Delta Q = M \times \mathrm{c} \times \Delta T = 1000\ kg \times 4.2\ \frac{kJ}{kg \cdot^{\circ} \mathrm{C}} \times 20^{\circ}\mathrm{C} = 84\ MJ$$

Total energy is the sum of these, so 2736 MJ or 2.7 GJ. Convert to BTU:

$$2.7 \times 10^{9}\ J \times \frac{1\ BTU}{1055\ J} = 2.6 \times 10^{6}\ BTU$$

7. The process for this problem is the same as the previous one, except here energy is being liberated instead of consumed and the phase transition is freezing. Energy released as water cools to 0°C:

$$\Delta Q = M \times \mathrm{c} \times \Delta T = 1000\ kg \times 4.2\ \frac{kJ}{kg \cdot^{\circ} \mathrm{C}} \times 5^{\circ}\mathrm{C} = 21\ MJ$$

Energy released in freezing:

$$\Delta Q = M \times \mathrm{L} = 1000\ kg \times 333\ kJ/kg = 333\ MJ$$

Energy released in cooling to −15°C:

$$\Delta Q = M \times \mathrm{c} \times \Delta T = 1000\ kg \times 4.2\ \frac{kJ}{kg \cdot^{\circ} \mathrm{C}} \times 15^{\circ}\mathrm{C} = 63\ MJ$$

The total of these is 417 MJ.

8.

$$1\ liter \times \frac{1000\ cm^{3}}{1\ liter} \times \frac{1\ gram}{1\ cm^{3}} = 1\ kg$$

Energy to heat 1 kg water from 30°C to 100°C:

$$\Delta Q = M \times \mathrm{c} \times \Delta T = 1\ kg \times 4.2\ \frac{kJ}{kg \cdot^{\circ} \mathrm{C}} \times 70^{\circ}\mathrm{C} = 294\ kJ$$

Energy required to convert it to steam:

$$\Delta Q = M \times \mathrm{L} = 1\ kg \times 2.25\ MJ/kg = 2.25\ MJ$$

Energy to heat the steam to 120°C:

$$\Delta Q = M \times \mathrm{c} \times \Delta T = 1\ kg \times 4.2\ \frac{kJ}{kg \cdot^{\circ} \mathrm{C}} \times 20^{\circ}\mathrm{C} = 84\ kJ$$

As in problem 5, the total energy gained by the 1 kg water (2.63 MJ) is what was lost by the lead as it cooled from 190°C to 120°C.

$$M = \frac{\Delta Q_{total}}{c \times \Delta T} = \frac{2630\ kJ}{4.2\ \frac{kJ}{kg \cdot^{\circ}\mathrm{C}} \times 70^{\circ}\mathrm{C}} = 8.94\ kg.$$