CHAPTER 19: Heat and the First Law of Thermodynamics

Responses to Questions

26. At night, the Earth cools primarily through radiation of heat back into space. Clouds reflect energy back to the Earth and so the surface cools less on a cloudy night than on a clear one.

30. A thermos bottle is designed to minimize heat transfer between the liquid contents and the outside air, even when the temperature difference is large. Heat transfer by radiation is minimized by the silvered lining. Shiny surfaces have very low emissivity, \( e \), and thus the net rate of energy flow by radiation between the contents of the thermos and the outside air will be small. Heat transfer by conduction and convection will be minimized by the vacuum between the inner and outer walls of the thermos, since both these methods require a medium to transport heat.

Solutions to Problems

58. The heat conduction rate is given by Eq. 19-16a.

\[
\frac{Q}{t} = kA \frac{T_1 - T_2}{l} = (380 \text{J/s/m°C}) \pi \left(0.010 \text{ m}\right)^2 \frac{(460°C - 22°C)}{0.45 \text{ m}} = 116 \text{ W} \approx 120 \text{ W}
\]

61. (a) The rate of heat transfer due to radiation is given by Eq. 19-17. We assume that each teapot is a sphere that holds 0.55 L. The radius and then the surface area can be found from that.

\[
V = \frac{4}{3} \pi r^3 \quad \rightarrow \quad r = \left(\frac{3V}{4\pi}\right)^{1/3} \quad \rightarrow \quad S.A. = 4\pi r^2 = 4\pi \left(\frac{3V}{4\pi}\right)^{2/3}
\]

\[
\frac{\Delta Q}{\Delta t} = e\sigma A (T_1^4 - T_2^4) = 4\pi \sigma \left(\frac{3V}{4\pi}\right)^{2/3} (T_1^4 - T_2^4)
\]

\[
\left(\frac{\Delta Q}{\Delta t}\right)_{\text{ceramic}} = 4\pi (0.70) \left(5.67 \times 10^{-8} \frac{\text{W}}{\text{m}^2 \text{K}^4}\right) \left[\frac{3(0.55 \times 10^{-3} \text{ m}^3)}{4\pi}\right]^{2/3} \left[(368 \text{ K})^4 - (293 \text{ K})^4\right] = 14.13 \text{ W} \approx 14 \text{ W}
\]

\[
\left(\frac{\Delta Q}{\Delta t}\right)_{\text{shiny}} = \left(\frac{\Delta Q}{\Delta t}\right)_{\text{ceramic}} \left(\frac{0.10}{0.70}\right) = 2.019 \text{ W} \approx 2.0 \text{ W}
\]
(b) We assume that the heat capacity comes primarily from the water in the teapots, and ignore the heat capacity of the teapots themselves. We apply Eq. 19-2, along with the results from part (a). The mass is that of 0.55 L of water, which would be 0.55 kg.

\[
\Delta Q = mc\Delta T \quad \rightarrow \quad \Delta T = \frac{1}{mc} \left( \Delta \frac{Q}{\Delta t} \right)_{\text{elapsed}}
\]

\[
(\Delta T)_{\text{ceramic}} = \frac{14.13 \text{ W}}{(0.55 \text{ kg}) \left( 4186 \frac{\text{J}}{\text{kg}\cdot\text{C}} \right)} (1800 \text{ s}) = 11 \text{ C}^\circ
\]

\[
(\Delta T)_{\text{shiny}} = \frac{1}{7} (\Delta T)_{\text{ceramic}} = 1.6 \text{ C}^\circ
\]

62. For the temperature at the joint to remain constant, the heat flow in both rods must be the same. Note that the cross-sectional areas and lengths are the same. Use Eq. 19-16a for heat conduction.

\[
\left( \frac{Q}{t} \right)_{\text{Cu}} = \left( \frac{Q}{t} \right)_{\text{Al}} \quad \rightarrow \quad k_{\text{Cu}} A \frac{T_{\text{hot}} - T_{\text{middle}}}{l} = k_{\text{Al}} A \frac{T_{\text{middle}} - T_{\text{cool}}}{l} \quad \rightarrow
\]

\[
T_{\text{middle}} = \frac{k_{\text{Cu}} T_{\text{hot}} + k_{\text{Al}} T_{\text{cool}}}{k_{\text{Cu}} + k_{\text{Al}}} = \frac{(380 \text{ J/gmol} \text{ C}) (225 \text{ C}) + (200 \text{ J/gmol} \text{ C}) (0.0 \text{ C})}{380 \text{ J/gmol} \text{ C} + 200 \text{ J/gmol} \text{ C}} = 147 \text{ C}
\]

63. (a) The cross-sectional area of the Earth, perpendicular to the Sun, is a circle of radius \( R_{\text{Earth}} \), and so has an area of \( \pi R_{\text{Earth}}^2 \). Multiply this area times the solar constant to get the rate at which the Earth is receiving solar energy.

\[
\frac{Q}{t} = \pi R_{\text{Earth}}^2 \left( \text{solar constant} \right) = \pi \left( 6.38 \times 10^6 \text{ m} \right)^2 \left( 1350 \text{ W/m}^2 \right) = 1.73 \times 10^{17} \text{ W}
\]

(b) Use Eq. 19-18 to calculate the rate of heat output by radiation, and assume that the temperature of space is 0 K. The whole sphere is radiating heat back into space, and so we use the full surface area of the Earth, \( 4\pi R_{\text{Earth}}^2 \).
64. This is an example of heat conduction. The temperature difference can be calculated by Eq. 19-16a.

\[
\frac{Q}{t} = e\sigma AT^4 \quad \rightarrow \quad T = \left( \frac{Q}{t e\sigma A} \right)^{1/4}
\]

\[
= \left( \frac{1.73 \times 10^{17} \text{ J/s}}{(1.0)\left(5.67 \times 10^{-8} \text{ W/m}^2 \text{K}^4\right)4\pi \left(6.38 \times 10^8 \text{ m}\right)} \right)^{1/4} = 278 \text{ K} = 5^\circ\text{C}
\]

CHAPTER 20: Second Law of Thermodynamics

Responses to Questions

1. Yes, mechanical energy can be transformed completely into heat or internal energy, as when an object moving over a surface is brought to rest by friction. All of the original mechanical energy is converted into heat. No, the reverse cannot happen (second law of thermodynamics) except in very special cases (reversible adiabatic expansion of an ideal gas). For example, in an explosion, a large amount of internal energy is converted into mechanical energy, but some internal energy is lost to heat or remains as internal energy of the explosion fragments.

2. Yes, you can warm a kitchen in winter by leaving the oven door open. The oven converts electrical energy to heat and leaving the door open will allow this heat to enter the kitchen. However, you cannot cool a kitchen in the summer by leaving the refrigerator door open. The refrigerator is a heat engine which (with an input of work) takes heat from the low-temperature reservoir (inside the refrigerator) and exhausts heat to the high-temperature reservoir (the room). As shown by the second law of thermodynamics, there is no “perfect refrigerator,” so more heat will be exhausted into the room than removed from the inside of the refrigerator. Thus, leaving the refrigerator door open will actually warm the kitchen.

5. A 10ºC decrease in the low-temperature reservoir will give a greater improvement in the efficiency of a Carnot engine. By definition, \(T_i\) is less than \(T_{hi}\), so a 10ºC change will be a larger percentage change in \(T_i\) than in \(T_{hi}\) yielding a greater improvement in efficiency.