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.

$$\frac{Q}{t} = kA\frac{T_1 - T_2}{l} = \left(380\,\mathrm{J/s\cdot m\cdot C^\circ}\right)\pi\left(0.010\,\mathrm{m}\right)^2\frac{\left(460^\circ\mathrm{C} - 22^\circ\mathrm{C}\right)}{0.45\,\mathrm{m}} = 116\,\mathrm{W} \approx \boxed{120\,\mathrm{W}}$$

$\boxed{61.}$ (*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.

$$V = \tfrac{4}{3}\pi r^3 \;\rightarrow\; r = \left(\frac{3V}{4\pi}\right)^{1/3} \;\rightarrow\; S.A. = 4\pi r^2 = 4\pi\left(\frac{3V}{4\pi}\right)^{2/3}$$

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

$$\left(\frac{\Delta Q}{\Delta t}\right)_{\text{ceramic}} = 4\pi\left(0.70\right)\left(5.67\times10^{-8}\,\frac{\mathrm{W}}{\mathrm{m^2\cdot K^4}}\right)\left(\frac{3\left(0.55\times10^{-3}\,\mathrm{m^2}\right)}{4\pi}\right)^{2/3}\left[\left(368\,\mathrm{K}\right)^4 - \left(293\,\mathrm{K}\right)^4\right]$$

$$= 14.13\mathrm{W} \approx \boxed{14\,\mathrm{W}}$$

$$\left(\frac{\Delta Q}{\Delta t}\right)_{\text{shiny}} = \left(\frac{\Delta Q}{\Delta t}\right)_{\text{ceramic}}\left(\frac{0.10}{0.70}\right) = 2.019\,\mathrm{W} \approx \boxed{2.0\,\mathrm{W}}$$

(*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.

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

$$(\Delta T)_{\text{ceramic}} = \frac{14.13\,\text{W}}{(0.55\,\text{kg})\left(4186\,\dfrac{\text{J}}{\text{kggC}^\circ}\right)}(1800\,\text{s}) = \boxed{11\text{C}^\circ}$$

$$(\Delta T)_{\text{shiny}} = \frac{1}{7}(\Delta T)_{\text{ceramic}} = \boxed{1.6\,\text{C}^\circ}$$

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.

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

$$T_{\text{middle}} = \frac{k_{\text{Cu}}T_{\text{hot}} + k_{\text{Al}}T_{\text{cool}}}{k_{\text{Cu}} + k_{\text{Al}}} = \frac{(380\,\text{J/sgmgC}^\circ)(225^\circ\text{C}) + (200\,\text{J/sgmgC}^\circ)(0.0^\circ\text{C})}{380\,\text{J/sgmgC}^\circ + 200\,\text{J/sgmgC}^\circ} = \boxed{147^\circ\text{C}}$$

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

$$\frac{Q}{t} = \pi R_{\text{Earth}}^2(\text{solar constant}) = \pi\left(6.38\times10^6\,\text{m}\right)^2\left(1350\,\text{W/m}^2\right) = \boxed{1.73\times10^{17}\,\text{W}}$$

(*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, $4\pi R_{\text{Earth}}^2$.

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

$$= \left[\left(1.73 \times 10^{17}\ \mathrm{J/s}\right) \frac{1}{(1.0)\left(5.67 \times 10^{-8}\ \mathrm{W/m^2 \cdot K^4}\right) 4\pi \left(6.38 \times 10^6\ \mathrm{m}\right)^2} \right]^{1/4} = \boxed{278\ \mathrm{K} = 5^\circ\mathrm{C}}$$

64. This is an example of heat conduction. The temperature difference can be calculated by Eq. 19-16a.

$$\frac{Q}{t} = P = kA \frac{T_1 - T_2}{l} \quad \rightarrow \quad \Delta T = \frac{Pl}{kA} = \frac{(95\ \mathrm{W})\left(5.0 \times 10^{-4}\ \mathrm{m}\right)}{\left(0.84\ \mathrm{J/s \cdot m \cdot C^\circ}\right) 4\pi \left(3.0 \times 10^{-2}\ \mathrm{m}\right)^2} = \boxed{5.0\ \mathrm{C^\circ}}$$