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Heat and the First Law of Thermodynamics

CHAPTER OUTLINE

ANSWERS TO QUESTIONS

Q20.1 Temperature is a measure of molecular motion. Heat is energy in the process of being transferred between objects by random molecular collisions. Internal energy is an object's energy of random molecular motion and molecular interaction.

***Q20.2** With a specific heat half as large, the ΔT is twice as great in the ethyl alcohol. Answer (c).

Q20.3 Heat is energy being transferred, not energy contained in an object. Further, a low-temperature object with large mass, or an object made of a material with high specific heat, can contain more internal energy than a higher-temperature object.

***Q20.4** We think of the product $mc\Delta T$ in each case, with $c = 1$ for water and about 0.5 for beryllium. For (a) we have $1 \cdot 1 \cdot 6 = 6$. For (b), $2 \cdot 1 \cdot 3 = 6$. For (c), $2 \cdot 1 \cdot 3 = 6$. For (d), $2(0.5)3 = 3$. For (e), a large quantity of energy input is required to melt the ice. Then we have $e > a = b = c > d$.

Q20.5 There are three properties to consider here: thermal conductivity, specific heat, and mass. With dry aluminum, the thermal conductivity of aluminum is much greater than that of (dry) skin. This means that the internal energy in the aluminum can more readily be transferred to the atmosphere than to your fingers. In essence, your skin acts as a thermal insulator to some degree (pun intended). If the aluminum is wet, it can wet the outer layer of your skin to make it into a good conductor of heat; then more internal energy from the aluminum can get into you. Further, the water itself, with additional mass and with a relatively large specific heat compared to aluminum, can be a significant source of extra energy to burn you. In practical terms, when you let go of a hot, dry piece of aluminum foil, the heat transfer immediately ends. When you let go of a hot *and* wet piece of aluminum foil, the hot water sticks to your skin, continuing the heat transfer, and resulting in more energy transfer to you!

Q20.6 Write $1\,000\text{ kg}(4\,186\text{ J/kg}\cdot{}^\circ\text{C})(1^\circ\text{C}) = V\left(1.3\text{ kg/m}^3\right)(1\,000\text{ J/kg}\cdot{}^\circ\text{C})(1^\circ\text{C})$ to find $V = 3.2\times10^3\text{ m}^3$.

***Q20.7** Answer (a). Do a few trials with water at different original temperatures and choose the one where room temperature is halfway between the original and the final temperature of the water. Then you can reasonably assume that the contents of the calorimeter gained and lost equal quantities of heat to the surroundings, for net transfer zero. James Joule did it like this in his basement in London.

Q20.8 If the system is isolated, no energy enters or leaves the system by heat, work, or other transfer processes. Within the system energy can change from one form to another, but since energy is conserved these transformations cannot affect the total amount of energy. The total energy is constant.

***Q20.9** (i) Answer (d). (ii) Answer (d). Internal energy and temperature both increase by minuscule amounts due to the work input.

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Q20.10 The steam locomotive engine is one perfect example of turning internal energy into mechanical energy. Liquid water is heated past the point of vaporization. Through a controlled mechanical process, the expanding water vapor is allowed to push a piston. The translational kinetic energy of the piston is usually turned into rotational kinetic energy of the drive wheel.

Q20.11 The tile is a better thermal conductor than carpet. Thus, energy is conducted away from your feet more rapidly by the tile than by the carpeted floor.

***Q20.12** Yes, wrap the blanket around the ice chest. The insulation will slow the transfer of heat from the exterior to the interior. Explain to your little sister that her winter coat helps to keep the outdoors cold to the same extent that it helps to keep her warm. If that is too advanced, promise her a *really cold* can of Dr. Pepper at the picnic.

Q20.13 The sunlight hitting the peaks warms the air immediately around them. This air, which is slightly warmer and less dense than the surrounding air, rises, as it is buoyed up by cooler air from the valley below. The air from the valley flows up toward the sunny peaks, creating the morning breeze.

***Q20.14** Answer (d). The high specific heat will keep the end in the fire from warming up very fast. The low conductivity will make your end warm up only very slowly.

***Q20.15** Twice the radius means four times the surface area. Twice the absolute temperature makes T^4 sixteen times larger in Stefan's law. We multiply 4 times 16 to get answer (e).

Q20.16 The bit of water immediately over the flame warms up and expands. It is buoyed up and rises through the rest of the water. Colder, more dense water flows in to take its place. Convection currents are set up. They effectively warm the bulk of the water all at once, much more rapidly than it would be warmed by heat being conducted through the water from the flame.

Q20.17 Keep them dry. The air pockets in the pad conduct energy by heat, but only slowly. Wet pads would absorb some energy in warming up themselves, but the pot would still be hot and the water would quickly conduct and convect a lot of energy right into you.

Q20.18 The person should add the cream immediately when the coffee is poured. Then the smaller temperature difference between coffee and environment will reduce the rate of energy loss during the several minutes.

***Q20.19** Convection: answer (b). The bridge deck loses energy rapidly to the air both above it and below it.

Q20.20 The marshmallow has very small mass compared to the saliva in the teacher's mouth and the surrounding tissues. Mostly air and sugar, the marshmallow also has a low specific heat compared to living matter. Then the marshmallow can zoom up through a large temperature change while causing only a small temperature drop of the teacher's mouth. The marshmallow is a foam with closed cells and it carries very little liquid nitrogen into the mouth. (Note that microwaving the marshmallow beforehand might change it into an open-cell sponge, with disasterous effects.) The liquid nitrogen still on the undamaged marshmallow comes in contact with the much hotter saliva and immediately boils into cold gaseous nitrogen. This nitrogen gas has very low thermal conductivity. It creates an insulating thermal barrier between the marshmallow and the teacher's mouth (the Leydenfrost effect). A similar effect can be seen when water droplets are put on a hot skillet. Each one dances around as it slowly shrinks, because it is levitated on a thin film of steam. Upon application to the author of this manual, a teacher who does this demonstration for a class using the Serway-Jewett textbook may have a button reading "I am a professional. Do not try this at home."

The most extreme demonstration of this effect is pouring liquid nitrogen into one's mouth and blowing out a plume of nitrogen gas. We strongly recommended that you read of Jearl Walker's adventures with this demonstration rather than trying it.

Q20.21 (a) Warm a pot of coffee on a hot stove.

(b) Place an ice cube at 0°C in warm water—the ice will absorb energy while melting, but not increase in temperature.

(c) Let a high-pressure gas at room temperature slowly expand by pushing on a piston. Work comes out of the gas in a constant-temperature expansion as the same quantity of heat flows in from the surroundings.

(d) Warm your hands by rubbing them together. Heat your tepid coffee in a microwave oven. Energy input by work, by electromagnetic radiation, or by other means, can all alike produce a temperature increase.

(e) Davy's experiment is an example of this process.

(f) This is not necessarily true. Consider some supercooled liquid water, unstable but with temperature below 0°C. Drop in a snowflake or a grain of dust to trigger its freezing into ice, and the loss of internal energy measured by its latent heat of fusion can actually push its temperature up.

Q20.22 Heat is conducted from the warm oil to the pipe that carries it. That heat is then conducted to the cooling fins and up through the solid material of the fins. The energy then radiates off in all directions and is efficiently carried away by convection into the air. The ground below is left frozen.

SOLUTIONS TO PROBLEMS

Section 20.1 **Heat and Internal Energy**

P20.1 Taking $m = 1.00$ kg, we have

$$\Delta U_g = mgh = (1.00\text{ kg})(9.80\text{ m/s}^2)(50.0\text{ m}) = 490\text{ J}$$

But $\Delta U_g = Q = mc\Delta T = (1.00\text{ kg})(4\,186\text{ J/kg}\cdot{}^\circ\text{C})\Delta T = 490\text{ J}$ so $\Delta T = 0.117^\circ\text{C}$

$$T_f = T_i + \Delta T = \boxed{(10.0 + 0.117)^\circ\text{C}}$$

P20.2 The container is thermally insulated, so no energy flows by heat:

$$Q = 0 \quad \text{and} \quad \Delta E_{\text{int}} = Q + W_{\text{input}} = 0 + W_{\text{input}} = 2mgh$$

The work on the falling weights is equal to the work done on the water in the container by the rotating blades. This work results in an increase in internal energy of the water:

$$2mgh = \Delta E_{\text{int}} = m_{\text{water}} c \Delta T$$

$$\Delta T = \frac{2mgh}{m_{\text{water}} c} = \frac{2 \times 1.50\text{ kg}(9.80\text{ m/s}^2)(3.00\text{ m})}{0.200\text{ kg}(4\,186\text{ J/kg}\cdot{}^\circ\text{C})} = \frac{88.2\text{ J}}{837\text{ J/}^\circ\text{C}}$$

$$= \boxed{0.105^\circ\text{C}}$$

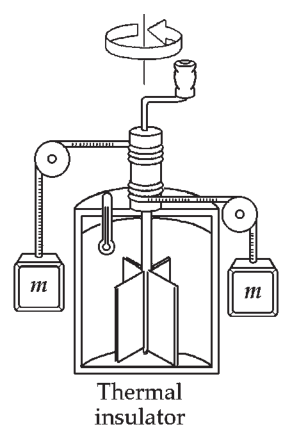

FIG. P20.2

Section 20.2 **Specific Heat and Calorimetry**

P20.3 $\Delta Q = mc_{\text{silver}}\Delta T$

$$1.23\ \text{kJ} = (0.525\ \text{kg})c_{\text{silver}}(10.0°\text{C})$$

$$c_{\text{silver}} = \boxed{0.234\ \text{kJ/kg}\cdot°\text{C}}$$

P20.4 The laser energy output:

$$\mathcal{P}\Delta t = (1.60\times10^{13}\ \text{J/s})2.50\times10^{-9}\ \text{s} = 4.00\times10^{4}\ \text{J}$$

The teakettle input:

$$Q = mc\Delta T = 0.800\ \text{kg}(4\ 186\ \text{J/kg}\cdot°\text{C})80°\text{C} = 2.68\times10^{5}\ \text{J}$$

$\boxed{\text{The energy input to the water is 6.70 times larger than the laser output of 40 kJ.}}$

P20.5 We imagine the stone energy reservoir has a large area in contact with air and is always at nearly the same temperature as the air. Its overnight loss of energy is described by

$$\mathcal{P} = \frac{Q}{\Delta t} = \frac{mc\Delta T}{\Delta t}$$

$$m = \frac{\mathcal{P}\Delta t}{c\Delta T} = \frac{(-6\ 000\ \text{J/s})(14\ \text{h})(3\ 600\ \text{s/h})}{(850\ \text{J/kg}\cdot°\text{C})(18°\text{C}-38°\text{C})} = \frac{3.02\times10^{8}\ \text{J}\cdot\text{kg}\cdot°\text{C}}{850\ \text{J}(20°\text{C})} = \boxed{1.78\times10^{4}\ \text{kg}}$$

P20.6 Let us find the energy transferred in one minute.

$$Q = \left[m_{\text{cup}}c_{\text{cup}} + m_{\text{water}}c_{\text{water}}\right]\Delta T$$

$$Q = \left[(0.200\ \text{kg})(900\ \text{J/kg}\cdot°\text{C}) + (0.800\ \text{kg})(4\,186\ \text{J/kg}\cdot°\text{C})\right](-1.50°\text{C}) = -5\ 290\ \text{J}$$

If this much energy is removed from the system each minute, the rate of removal is

$$\mathcal{P} = \frac{|Q|}{\Delta t} = \frac{5\ 290\ \text{J}}{60.0\ \text{s}} = 88.2\ \text{J/s} = \boxed{88.2\ \text{W}}$$

P20.7 $Q_{\text{cold}} = -Q_{\text{hot}}$

$$(mc\Delta T)_{\text{water}} = -(mc\Delta T)_{\text{iron}}$$

$$20.0\ \text{kg}(4\ 186\ \text{J/kg}\cdot°\text{C})(T_f - 25.0°\text{C}) = -(1.50\ \text{kg})(448\ \text{J/kg}\cdot°\text{C})(T_f - 600°\text{C})$$

$$T_f = \boxed{29.6°\text{C}}$$

***P20.8** (a) Work that the bit does in deforming the block, breaking chips off, and giving them kinetic energy is not a final destination for energy. All of this work turns entirely into internal energy as soon as the chips stop their macroscopic motion. The amount of energy input to the steel is the work done by the bit:

$$W = \vec{\mathbf{F}} \cdot \Delta\vec{\mathbf{r}} = (3.2\text{ N})(40\ \text{m/s})(15\text{ s})\cos 0° = 1\,920\text{ J}$$

To evaluate the temperature change produced by this energy we imagine injecting the same quantity of energy as heat from a stove. The bit, chips, and block all undergo the same temperature change. Any difference in temperature between one bit of steel and another would erase itself by causing a heat transfer from the temporarily hotter to the colder region.

$$Q = mc\Delta T$$

$$\Delta T = \frac{Q}{mc} = \frac{1\,920\text{ J}\cdot\text{kg}\cdot°\text{C}}{(0.267\text{ kg})(448\text{ J})} = \boxed{16.1°\text{C}}$$

(b) See part (a). $\boxed{16.1°\text{C}}$

(c) It makes no difference whether the drill bit is dull or sharp, how far into the block it cuts, or what its diameter is. The answers to (a) and (b) are the same because work (or 'work to produce deformation') cannot be a final form of energy: all of the work done by the bit constitutes energy being transferred into the internal energy of the steel.

***P20.9** (a) $Q_{\text{cold}} = -Q_{\text{hot}}$

$$(m_w c_w + m_c c_c)(T_f - T_c) = -m_{\text{Cu}} c_{\text{Cu}}(T_f - T_{\text{Cu}}) - m_{unk} c_{unk}(T_f - T_{unk})$$

where *w* is for water, *c* the calorimeter, Cu the copper sample, and *unk* the unknown.

$$\left[250\text{ g}(1.00\ \text{cal/g}\cdot°\text{C}) + 100\text{ g}(0.215\ \text{cal/g}\cdot°\text{C})\right](20.0 - 10.0)°\text{C}$$
$$= -(50.0\text{ g})(0.092\,4\ \text{cal/g}\cdot°\text{C})(20.0 - 80.0)°\text{C} - (70.0\text{ g})c_{unk}(20.0 - 100)°\text{C}$$
$$2.44\times 10^3\ \text{cal} = (5.60\times 10^3\ \text{g}\cdot°\text{C})c_{unk}$$

or

$$c_{unk} = \boxed{0.435\ \text{cal/g}\cdot°\text{C}}$$

(b) We cannot make a definite identification. The material might be beryllium. It might be some alloy or a material not listed in the table.

P20.10 (a) $(f)(mgh) = mc\Delta T$

$$\frac{(0.600)(3.00\times 10^{-3}\ \text{kg})(9.80\ \text{m/s}^2)(50.0\text{ m})}{4.186\ \text{J/cal}} = (3.00\text{ g})(0.092\,4\ \text{cal/g}\cdot°\text{C})(\Delta T)$$

$\Delta T = 0.760°\text{C}$; $\boxed{T = 25.8°\text{C}}$

(b) The final temperature does not depend on the mass. Both the change in potential energy, and the heat that would be required from a stove to produce the temperature change, are proportional to the mass; hence, the mass divides out in the energy relation.

P20.11 We do not know whether the aluminum will rise or drop in temperature. The energy the water can absorb in rising to 26°C is $mc\Delta T = 0.25\text{ kg}\ 4\,186\dfrac{\text{J}}{\text{kg °C}}6\text{°C} = 6\,279\text{ J}$. The energy the copper can put out in dropping to 26°C is $mc\Delta T = 0.1\text{ kg}\ 387\dfrac{\text{J}}{\text{kg °C}}74\text{°C} = 2\,864\text{ J}$. Since 6 279 J > 2 864 J, the final temperature is less than 26°C. We can write $Q_h = -Q_c$ as

$$Q_{\text{water}} + Q_{\text{Al}} + Q_{\text{Cu}} = 0$$

$$0.25\text{ kg}\ 4\,186\frac{\text{J}}{\text{kg °C}}\left(T_f - 20\text{°C}\right) + 0.4\text{ kg}\ 900\frac{\text{J}}{\text{kg °C}}\left(T_f - 26\text{°C}\right)$$

$$+\,0.1\text{ kg}\ 387\frac{\text{J}}{\text{kg °C}}\left(T_f - 100\text{°C}\right) = 0$$

$$1\,046.5T_f - 20\,930\text{°C} + 360T_f - 9\,360\text{°C} + 38.7T_f - 3\,870\text{°C} = 0$$

$$1\,445.2T_f = 34\,160\text{°C}$$

$$T_f = \boxed{23.6\text{°C}}$$

P20.12 Vessel one contains oxygen described by $PV = nRT$:

$$n_c = \frac{PV}{RT} = \frac{1.75\left(1.013\times10^5\text{ Pa}\right)16.8\times10^{-3}\text{ m}^3}{8.314\ \text{ Nm/mol}\cdot\text{K}\ \ 300\text{ K}} = 1.194\text{ mol}$$

Vessel two contains this much oxygen:

$$n_h = \frac{2.25\left(1.013\times10^5\right)22.4\times10^{-3}}{8.314(450)}\text{ mol} = 1.365\text{ mol}$$

(a) The gas comes to an equilibrium temperature according to

$$(mc\Delta T)_{\text{cold}} = -(mc\Delta T)_{\text{hot}}$$

$$n_cMc\left(T_f - 300\text{ K}\right) + n_hMc\left(T_f - 450\text{ K}\right) = 0$$

The molar mass M and specific heat divide out:

$$1.194T_f - 358.2\text{ K} + 1.365T_f - 614.1\text{ K} = 0$$

$$T_f = \frac{972.3\text{ K}}{2.559} = \boxed{380\text{ K}}$$

(b) The pressure of the whole sample in its final state is

$$P = \frac{nRT}{V} = \frac{2.559\text{ mol}\ 8.314\text{ J}\ 380\text{ K}}{\text{mol K}\,(22.4+16.8)\times10^{-3}\text{ m}^3} = \boxed{2.06\times10^5\text{ Pa}} = 2.04\text{ atm}$$

Section 20.3 **Latent Heat**

P20.13 The energy input needed is the sum of the following terms:

$$Q_{\text{needed}} = (\text{heat to reach melting point}) + (\text{heat to melt})$$
$$+ (\text{heat to reach boiling point}) + (\text{heat to vaporize}) + (\text{heat to reach } 110^\circ\text{C})$$

Thus, we have

$$Q_{\text{needed}} = 0.040\,0\text{ kg}\big[(2\,090\text{ J/kg}\cdot{}^\circ\text{C})(10.0^\circ\text{C}) + (3.33\times10^5\text{ J/kg})$$
$$+(4\,186\text{ J/kg}\cdot{}^\circ\text{C})(100^\circ\text{C}) + (2.26\times10^6\text{ J/kg}) + (2\,010\text{ J/kg}\cdot{}^\circ\text{C})(10.0^\circ\text{C})\big]$$

$$Q_{\text{needed}} = \boxed{1.22\times10^5\text{ J}}$$

P20.14 $Q_{\text{cold}} = -Q_{\text{hot}}$

$$(m_w c_w + m_c c_c)(T_f - T_i) = -m_s\left[-L_v + c_w(T_f - 100)\right]$$

$$\left[0.250\text{ kg}(4\,186\text{ J/kg}\cdot{}^\circ\text{C}) + 0.050\,0\text{ kg}(387\text{ J/kg}\cdot{}^\circ\text{C})\right](50.0^\circ\text{C} - 20.0^\circ\text{C})$$
$$= -m_s\left[-2.26\times10^6\text{ J/kg} + (4\,186\text{ J/kg}\cdot{}^\circ\text{C})(50.0^\circ\text{C} - 100^\circ\text{C})\right]$$

$$m_s = \frac{3.20\times10^4\text{ J}}{2.47\times10^6\text{ J/kg}} = 0.012\,9\text{ kg} = \boxed{12.9\text{ g steam}}$$

P20.15 The bullet will not melt all the ice, so its final temperature is 0°C.

Then $\left(\frac{1}{2}mv^2 + mc|\Delta T|\right)_{\text{bullet}} = m_w L_f$

where m_w is the melt water mass

$$m_w = \frac{0.500(3.00\times10^{-3}\text{ kg})(240\text{ m/s})^2 + 3.00\times10^{-3}\text{ kg}(128\text{ J/kg}\cdot{}^\circ\text{C})(30.0^\circ\text{C})}{3.33\times10^5\text{ J/kg}}$$

$$m_w = \frac{86.4\text{ J} + 11.5\text{ J}}{333\,000\text{ J/kg}} = \boxed{0.294\text{ g}}$$

P20.16 (a) Q_1 = heat to melt all the ice

$$= (50.0\times10^{-3}\text{ kg})(3.33\times10^5\text{ J/kg}) = 1.67\times10^4\text{ J}$$

Q_2 = (heat to raise temp of ice to 100°C)

$$= (50.0\times10^{-3}\text{ kg})(4\,186\text{ J/kg}\cdot{}^\circ\text{C})(100^\circ\text{C}) = 2.09\times10^4\text{ J}$$

Thus, the total heat to melt ice and raise temp to 100°C $= 3.76\times10^4$ J

$$Q_3 = \begin{matrix}\text{heat available}\\ \text{as steam condenses}\end{matrix} = (10.0\times10^{-3}\text{ kg})(2.26\times10^6\text{ J/kg}) = 2.26\times10^4\text{ J}$$

Thus, we see that $Q_3 > Q_1$, but $Q_3 < Q_1 + Q_2$.

Therefore, $\boxed{\text{all the ice melts}}$ but $T_f < 100^\circ\text{C}$. Let us now find T_f

$Q_{\text{cold}} = -Q_{\text{hot}}$

$$(50.0\times10^{-3}\text{ kg})(3.33\times10^5\text{ J/kg}) + (50.0\times10^{-3}\text{ kg})(4\,186\text{ J/kg}\cdot{}^\circ\text{C})(T_f - 0^\circ\text{C})$$
$$= -(10.0\times10^{-3}\text{ kg})(-2.26\times10^6\text{ J/kg}) - (10.0\times10^{-3}\text{ kg})(4\,186\text{ J/kg}\cdot{}^\circ\text{C})(T_f - 100^\circ\text{C})$$

From which,

$$\boxed{T_f = 40.4^\circ\text{C}}$$

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(b) Q_1 = heat to melt all ice = 1.67×10^4 J [See part (a)]

$$Q_2 = \begin{matrix}\text{heat given up} \\ \text{as steam condenses}\end{matrix} = \left(10^{-3}\ \text{kg}\right)\left(2.26\times 10^6\ \text{J/kg}\right) = 2.26\times 10^3\ \text{J}$$

$$Q_3 = \begin{matrix}\text{heat given up as condensed} \\ \text{steam cools to 0°C}\end{matrix} = \left(10^{-3}\ \text{kg}\right)\left(4\,186\ \text{J/kg}\cdot\text{°C}\right)(100\text{°C}) = 419\ \text{J}$$

Note that $Q_2 + Q_3 < Q_1$. Therefore, $\boxed{\text{the final temperature will be 0°C}}$ with some ice remaining. Let us find the mass of ice which must melt to condense the steam and cool the condensate to 0°C.

$$mL_f = Q_2 + Q_3 = 2.68\times 10^3\ \text{J}$$

Thus,

$$m = \frac{2.68\times 10^3\ \text{J}}{3.33\times 10^5\ \text{J/kg}} = 8.04\times 10^{-3}\ \text{kg} = \boxed{8.04\ \text{g of ice melts}}$$

Therefore, there is 42.0 g of ice left over, also at 0°C.

P20.17 $Q = m_{\text{Cu}} c_{\text{Cu}} \Delta T = m_{\text{N}_2}\left(L_{\text{vap}}\right)_{\text{N}_2}$

$$1.00\ \text{kg}\left(0.092\,0\ \text{cal/g}\cdot\text{°C}\right)(293 - 77.3)\text{°C} = m\left(48.0\ \text{cal/g}\right)$$

$$m = \boxed{0.414\ \text{kg}}$$

***P20.18** (a) Let n represent the number of stops. Follow the energy:

$$n\tfrac{1}{2}(1500\ \text{kg})(25\ \text{m/s})^2 = 6\ \text{kg}(900\ \text{J/kg}\cdot\text{°C})(660 - 20)\text{°}C$$

$$n = \frac{3.46\times 10^6\ \text{J}}{4.69\times 10^5\ \text{J}} = 7.37$$

Thus $\boxed{\text{seven}}$ stops can happen before melting begins.

(b) As the car is moving or stopping it transfers part of its kinetic energy into the air and into its rubber tires. As soon as the brakes rise above the air temperature they lose energy by heat, and lost it very fast if they attain a high temperature.

P20.19 (a) Since the heat required to melt 250 g of ice at 0°C *exceeds* the heat required to cool 600 g of water from 18°C to 0°C, the final temperature of the system (water + ice) must be $\boxed{0\text{°C}}$.

(b) Let m represent the mass of ice that melts before the system reaches equilibrium at 0°C.

$$Q_{\text{cold}} = -Q_{\text{hot}}$$

$$mL_f = -m_w c_w\left(0\text{°C} - T_i\right)$$

$$m\left(3.33\times 10^5\ \text{J/kg}\right) = -\left(0.600\ \text{kg}\right)\left(4\,186\ \text{J/kg}\cdot\text{°C}\right)(0\text{°C} - 18.0\text{°C})$$

$m = 136$ g, so the ice remaining $= 250\ \text{g} - 136\ \text{g} = \boxed{114\ \text{g}}$

***P20.20** The left-hand side of the equation is the kinetic energy of a 12-g object moving at 300 m/s together with an 8-g object moving at 400 m/s. If they are moving in opposite directions, collide head-on, and stick together, momentum conservation implies that we have a 20-g object moving with speed given by $8(400) - 12(300) = 20v \quad |v| = 20$ m/s, and the kinetic energy of a 20-g object moving at 20 m/s appears on the right-hand side. Thus we state

(a) Two speeding lead bullets, one of mass 12.0 g moving to the right at 300 m/s and one of mass 8.00 g moving to the left at 400 m/s, collide head-on and all of the material sticks together. Both bullets are originally at temperature 30.0°C. Describe the state of the system immediately thereafter.

(b) We find $\quad 540\text{ J} + 640\text{ J} = 4\text{ J} + 761\text{ J} + m_\ell(24500\text{ J/kg})$

So the mass of lead melted is $\quad m_\ell = 415\text{ J}/(24500\text{ J/kg}) = 0.0169$ kg.

After the completely inelastic collision, a glob comprising 3.10 g of solid lead and 16.9 g of liquid lead is moving to the right at 20.0 m/s. Its temperature is 327.3°C.

Section 20.4 Work and Heat in Thermodynamic Processes

P20.21 $W_{if} = -\int_i^f P\,dV$

The work done on the gas is the negative of the area under the curve $P = \alpha V^2$ between V_i and V_f.

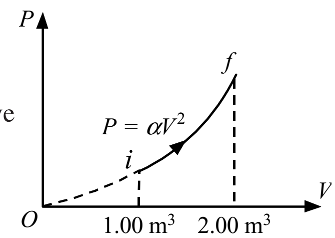

FIG. P20.21

$$W_{if} = -\int_i^f \alpha V^2 dV = -\frac{1}{3}\alpha\left(V_f^3 - V_i^3\right)$$

$$V_f = 2V_i = 2\left(1.00\text{ m}^3\right) = 2.00\text{ m}^3$$

$$W_{if} = -\frac{1}{3}\left[\left(5.00\text{ atm/m}^6\right)\left(1.013\times10^5\text{ Pa/atm}\right)\right]\left[\left(2.00\text{ m}^3\right)^3 - \left(1.00\text{ m}^3\right)^3\right] = \boxed{-1.18\text{ MJ}}$$

P20.22 (a) $W = -\int P\,dV$

$$W = -\left(6.00\times10^6\text{ Pa}\right)(2.00-1.00)\text{ m}^3 + -\left(4.00\times10^6\text{ Pa}\right)(3.00-2.00)\text{ m}^3 + -\left(2.00\times10^6\text{ Pa}\right)(4.00-3.00)\text{ m}^3$$

$$W_{i\to f} = \boxed{-12.0\text{ MJ}}$$

(b) $W_{f\to i} = \boxed{+12.0\text{ MJ}}$

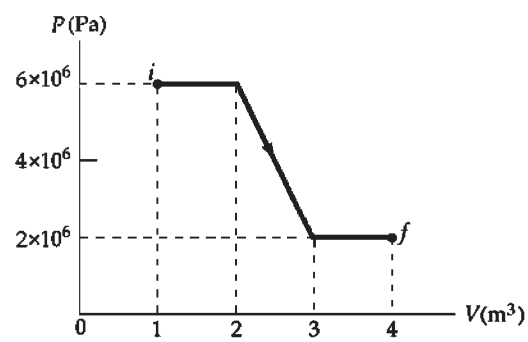

FIG. P20.22

P20.23 $W = -P\Delta V = -P\left(\frac{nR}{P}\right)\left(T_f - T_i\right) = -nR\Delta T = -(0.200)(8.314)(280) = \boxed{-466\text{ J}}$

P20.24 $W = -\int_i^f P\,dV = -P\int_i^f dV = -P\Delta V = -nR\Delta T = \boxed{-nR(T_2 - T_1)}$ The negative sign for work *on* the sample indicates that the expanding gas *does* positive work. The quantity of work is directly proportional to the quantity of gas and to the temperature change.

P20.25 During the heating process $P = \left(\frac{P_i}{V_i}\right)V$

(a) $W = -\int_i^f P\,dV = -\int_{V_i}^{3V_i} \left(\frac{P_i}{V_i}\right)V\,dV$

$$W = -\left(\frac{P_i}{V_i}\right)\frac{V^2}{2}\Bigg|_{V_i}^{3V_i} = -\frac{P_i}{2V_i}\left(9V_i^2 - V_i^2\right) = \boxed{-4P_iV_i}$$

(b) $PV = nRT$

$$\left[\left(\frac{P_i}{V_i}\right)V\right]V = nRT$$

$$\boxed{T = \left(\frac{P_i}{nRV_i}\right)V^2}$$

Temperature must be proportional to the square of volume, rising to nine times its original value.

Section 20.5 The First Law of Thermodynamics

P20.26 (a) $Q = -W =$ Area of triangle

$$Q = \frac{1}{2}\left(4.00\text{ m}^3\right)(6.00\text{ kPa}) = \boxed{12.0\text{ kJ}}$$

(b) $Q = -W = \boxed{-12.0\text{ kJ}}$

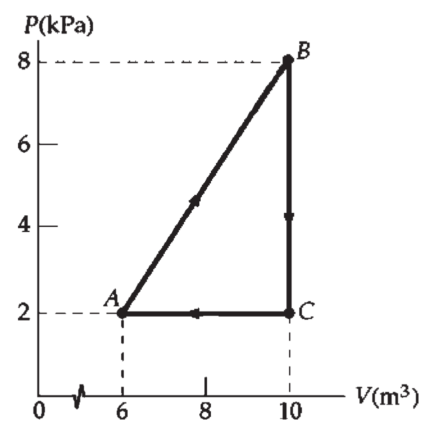

FIG. P20.26

P20.27 $\Delta E_{\text{int}} = Q + W$

$$Q = \Delta E_{\text{int}} - W = -500\text{ J} - 220\text{ J} = \boxed{-720\text{ J}}$$

The negative sign indicates that positive energy is transferred *from* the system by heat.

P20.28 $W_{BC} = -P_B(V_C - V_B)$

$= -3.00 \text{ atm}(0.400 - 0.090\,0) \text{ m}^3$

$= -94.2 \text{ kJ}$

$\Delta E_{\text{int}} = Q + W$

$E_{\text{int, C}} - E_{\text{int, B}} = (100 - 94.2) \text{ kJ}$

$E_{\text{int, C}} - E_{\text{int, B}} = 5.79 \text{ kJ}$

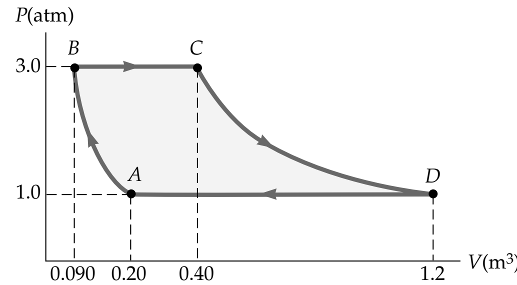

FIG. P20.28

Since T is constant,

$$E_{\text{int, D}} - E_{\text{int, C}} = 0$$

$$W_{DA} = -P_D(V_A - V_D) = -1.00 \text{ atm}(0.200 - 1.20) \text{ m}^3$$

$$= +101 \text{ kJ}$$

$$E_{\text{int, A}} - E_{\text{int, D}} = -150 \text{ kJ} + (+101 \text{ kJ}) = -48.7 \text{ kJ}$$

Now, $E_{\text{int, B}} - E_{\text{int, A}} = -\left[\left(E_{\text{int, C}} - E_{\text{int, B}}\right) + \left(E_{\text{int, D}} - E_{\text{int, C}}\right) + \left(E_{\text{int, A}} - E_{\text{int, D}}\right)\right]$

$$E_{\text{int, B}} - E_{\text{int, A}} = -[5.79 \text{ kJ} + 0 - 48.7 \text{ kJ}] = \boxed{42.9 \text{ kJ}}$$

P20.29

	Q	W	ΔE_{int}	
BC	−	0	−	$(Q = \Delta E_{\text{int}}$ since $W_{BC} = 0)$
CA	−	+	−	$(\Delta E_{\text{int}} < 0$ and $W > 0$, so $Q < 0)$
AB	+	−	+	$(W < 0$, $\Delta E_{\text{int}} > 0$ since $\Delta E_{\text{int}} < 0$ for $B \to C \to A$; so $Q > 0)$

Section 20.6 **Some Applications of the First Law of Thermodynamics**

P20.30 (a) $W = -nRT \ln\left(\dfrac{V_f}{V_i}\right) = -P_f V_f \ln\left(\dfrac{V_f}{V_i}\right)$

so

$$V_i = V_f \exp\left(+\frac{W}{P_f V_f}\right) = (0.025\,0)\exp\left[\frac{-3\,000}{0.025\,0(1.013 \times 10^5)}\right] = \boxed{0.007\,65 \text{ m}^3}$$

(b) $T_f = \dfrac{P_f V_f}{nR} = \dfrac{1.013 \times 10^5 \text{ Pa}(0.025\,0 \text{ m}^3)}{1.00 \text{ mol}(8.314 \text{ J/K} \cdot \text{mol})} = \boxed{305 \text{ K}}$

P20.31 (a) $\Delta E_{\text{int}} = Q - P\Delta V = 12.5 \text{ kJ} - 2.50 \text{ kPa}(3.00 - 1.00) \text{ m}^3 = \boxed{7.50 \text{ kJ}}$

(b) $\dfrac{V_1}{T_1} = \dfrac{V_2}{T_2}$

$T_2 = \dfrac{V_2}{V_1} T_1 = \dfrac{3.00}{1.00}(300 \text{ K}) = \boxed{900 \text{ K}}$

P20.32 (a) $W = -P\Delta V = -P[3\alpha V \Delta T]$

$$= -\left(1.013\times10^{5}\ \text{N/m}^2\right)\left[3\left(24.0\times10^{-6}\,^{\circ}\text{C}^{-1}\right)\left(\frac{1.00\ \text{kg}}{2.70\times10^{3}\ \text{kg/m}^3}\right)(18.0^{\circ}\text{C})\right]$$

$W = \boxed{-48.6\ \text{mJ}}$

(b) $Q = cm\Delta T = \left(900\ \text{J/kg}\cdot{}^{\circ}\text{C}\right)(1.00\ \text{kg})(18.0^{\circ}\text{C}) = \boxed{16.2\ \text{kJ}}$

(c) $\Delta E_{\text{int}} = Q + W = 16.2\ \text{kJ} - 48.6\ \text{mJ} = \boxed{16.2\ \text{kJ}}$

P20.33 $W = -P\Delta V = -P\left(V_s - V_w\right) = -\dfrac{P(nRT)}{P} + P\left[\dfrac{18.0\ \text{g}}{\left(1.00\ \text{g/cm}^3\right)\left(10^{6}\ \text{cm}^3/\text{m}^3\right)}\right]$

$W = -(1.00\ \text{mol})(8.314\ \text{J/K}\cdot\text{mol})(373\ \text{K}) + \left(1.013\times10^{5}\ \text{N/m}^2\right)\left(\dfrac{18.0\ \text{g}}{10^{6}\ \text{g/m}^3}\right) = \boxed{-3.10\ \text{kJ}}$

$Q = mL_v = 0.018\,0\ \text{kg}\left(2.26\times10^{6}\ \text{J/kg}\right) = 40.7\ \text{kJ}$

$\Delta E_{\text{int}} = Q + W = \boxed{37.6\ \text{kJ}}$

P20.34 (a) The work done during each step of the cycle equals the negative of the area under that segment of the *PV* curve.

$W = W_{DA} + W_{AB} + W_{BC} + W_{CD}$

$W = -P_i\left(V_i - 3V_i\right) + 0 - 3P_i\left(3V_i - V_i\right) + 0 = \boxed{-4P_iV_i}$

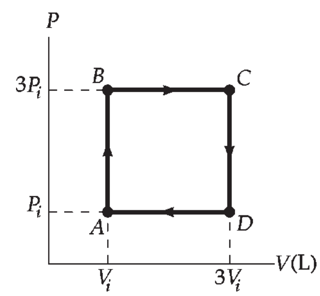

FIG. P20.34

(b) The initial and final values of *T* for the system are equal. Therefore,

$\Delta E_{\text{int}} = 0$ and $Q = -W = \boxed{4P_iV_i}$

(c) $W = -4P_iV_i = -4nRT_i = -4(1.00)(8.314)(273) = \boxed{-9.08\ \text{kJ}}$

P20.35 (a) $P_iV_i = P_fV_f = nRT = 2.00\ \text{mol}\left(8.314\ \text{J/K}\cdot\text{mol}\right)(300\ \text{K}) = 4.99\times10^{3}\ \text{J}$

$V_i = \dfrac{nRT}{P_i} = \dfrac{4.99\times10^{3}\ \text{J}}{0.400\ \text{atm}}$

$V_f = \dfrac{nRT}{P_f} = \dfrac{4.99\times10^{3}\ \text{J}}{1.20\ \text{atm}} = \dfrac{1}{3}V_i = \boxed{0.041\,0\ \text{m}^3}$

(b) $W = -\int PdV = -nRT\ln\left(\dfrac{V_f}{V_i}\right) = -\left(4.99\times10^{3}\right)\ln\left(\dfrac{1}{3}\right) = \boxed{+5.48\ \text{kJ}}$

(c) $\Delta E_{\text{int}} = 0 = Q + W$

$Q = \boxed{-5.48\ \text{kJ}}$

P20.36 $\Delta E_{\text{int},\,ABC} = \Delta E_{\text{int},\,AC}$ (conservation of energy)

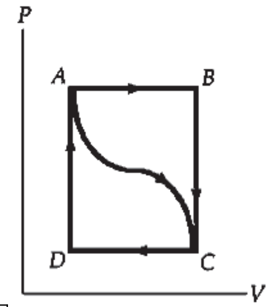

FIG. P20.36

(a) $\Delta E_{\text{int},\,ABC} = Q_{ABC} + W_{ABC}$ (First Law)

$Q_{ABC} = 800\text{ J} + 500\text{ J} = \boxed{1\,300\text{ J}}$

(b) $W_{CD} = -P_C \Delta V_{CD}$, $\Delta V_{AB} = -\Delta V_{CD}$, and $P_A = 5P_C$

Then, $W_{CD} = \frac{1}{5} P_A \Delta V_{AB} = -\frac{1}{5} W_{AB} = \boxed{100\text{ J}}$

(+ means that work is done on the system)

(c) $W_{CDA} = W_{CD}$ so that $Q_{CA} = \Delta E_{\text{int},\,CA} - W_{CDA} = -800\text{ J} - 100\text{ J} = \boxed{-900\text{ J}}$

(− means that energy must be removed from the system by heat)

(d) $\Delta E_{\text{int},\,CD} = \Delta E_{\text{int},\,CDA} - \Delta E_{\text{int},\,DA} = -800\text{ J} - 500\text{ J} = -1\,300\text{ J}$

and $Q_{CD} = \Delta E_{\text{int},\,CD} - W_{CD} = -1\,300\text{ J} - 100\text{ J} = \boxed{-1\,400\text{ J}}$

Section 20.7 **Energy Transfer Mechanisms**

P20.37 $\mathcal{P} = \dfrac{kA\Delta T}{L} = \dfrac{(0.800\text{ W/m}\cdot{}^\circ\text{C})(3.00\text{ m}^2)(25.0^\circ\text{C})}{6.00\times 10^{-3}\text{ m}} = 1.00\times 10^4\text{ W} = \boxed{10.0\text{ kW}}$

P20.38 $\mathcal{P} = \dfrac{A\Delta T}{\sum_i L_i/k_i} = \dfrac{(6.00\text{ m}^2)(50.0^\circ\text{C})}{2(4.00\times 10^{-3}\text{ m})/[0.800\text{ W/m}\cdot{}^\circ\text{C}] + [5.00\times 10^{-3}\text{ m}]/[0.023\,4\text{ W/m}\cdot{}^\circ\text{C}]}$

$= \boxed{1.34\text{ kW}}$

P20.39 In the steady state condition, $\mathcal{P}_{\text{Au}} = \mathcal{P}_{\text{Ag}}$

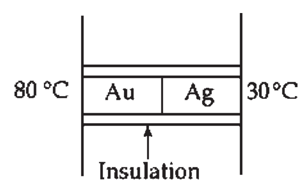

FIG. P20.39

so that $k_{\text{Au}} A_{\text{Au}} \left(\dfrac{\Delta T}{\Delta x}\right)_{\text{Au}} = k_{\text{Ag}} A_{\text{Ag}} \left(\dfrac{\Delta T}{\Delta x}\right)_{\text{Ag}}$

In this case $A_{\text{Au}} = A_{\text{Ag}}$

$\Delta x_{\text{Au}} = \Delta x_{\text{Ag}}$

$\Delta T_{\text{Au}} = (80.0 - T)$

and $\Delta T_{\text{Ag}} = (T - 30.0)$

where T is the temperature of the junction.

Therefore, $k_{\text{Au}}(80.0 - T) = k_{\text{Ag}}(T - 30.0)$

And $\boxed{T = 51.2^\circ\text{C}}$

P20.40 From the table of thermal resistances in the chapter text,

(a) $R = \boxed{0.890\ \text{ft}^2 \cdot {}^\circ\text{F} \cdot \text{h/Btu}}$

(b) The insulating glass in the table must have sheets of glass less than $\frac{1}{8}$ inch thick. So we estimate the R-value of a 0.250-inch air space as $\frac{0.250}{3.50}$ times that of the thicker air space. Then for the double glazing

$$R_b = \left[0.890 + \left(\frac{0.250}{3.50}\right)1.01 + 0.890\right]\frac{\text{ft}^2 \cdot {}^\circ\text{F} \cdot \text{h}}{\text{Btu}} = \boxed{1.85\frac{\text{ft}^2 \cdot {}^\circ\text{F} \cdot \text{h}}{\text{Btu}}}$$

(c) Since A and $(T_2 - T_1)$ are constants, heat flow is reduced by a factor of $\frac{1.85}{0.890} = \boxed{2.08}$.

***P20.41** The net rate of energy loss from his skin is

$$\mathcal{P}_{\text{net}} = \sigma Ae\left(T^4 - T_0^4\right) = \left(5.67 \times 10^{-8}\ \text{W/m}^2 \cdot \text{K}^4\right)\left(1.50\ \text{m}^2\right)(0.900)\left[(308\ \text{K})^4 - (293\ \text{K})^4\right]$$
$$= 125\ \text{W}$$

Note that the temperatures must be in kelvins. The energy loss in ten minutes is

$$Q = \mathcal{P}_{\text{net}}\Delta t = (125\ \text{J/s})(600\ \text{s}) = \boxed{7.48 \times 10^4\ \text{J}}$$

In the infrared, the person shines brighter than a hundred-watt light bulb.

P20.42 $\mathcal{P} = \sigma AeT^4 = \left(5.669\,6 \times 10^{-8}\ \text{W/m}^2 \cdot \text{K}^4\right)\left[4\pi\left(6.96 \times 10^8\ \text{m}\right)^2\right](0.986)(5\,800\ \text{K})^4$

$\mathcal{P} = \boxed{3.85 \times 10^{26}\ \text{W}}$

***P20.43** (a) The heat leaving the box during the day is given by $\mathcal{P} = kA\frac{(T_H - T_c)}{L} = \frac{Q}{\Delta t}$

$$Q = 0.012\frac{\text{W}}{\text{m}^\circ\text{C}}0.49\ \text{m}^2\frac{37^\circ\text{C} - 23^\circ\text{C}}{0.045\ \text{m}}12\ \text{h}\left(\frac{3\,600\ \text{s}}{1\ \text{h}}\right) = 7.90 \times 10^4\ \text{J}$$

The heat lost at night is

$$Q = 0.012\frac{\text{W}}{\text{m}^\circ\text{C}}0.49\ \text{m}^2\frac{37^\circ\text{C} - 16^\circ\text{C}}{0.045\ \text{m}}12\ \text{h}\left(\frac{3\,600\ \text{s}}{1\ \text{h}}\right) = 1.19 \times 10^5\ \text{J}$$

The total heat is $1.19 \times 10^5\ \text{J} + 7.90 \times 10^4\ \text{J} = 1.98 \times 10^5\ \text{J}$. It must be supplied by the solidifying wax: $Q = mL$

$$m = \frac{Q}{L} = \frac{1.98 \times 10^5\ \text{J}}{205 \times 10^3\ \text{J/kg}} = \boxed{0.964\ \text{kg or more}}$$

(b) The test samples and the inner surface of the insulation can be prewarmed to 37°C as the box is assembled. If this is done, nothing changes in temperature during the test period. Then the masses of the test samples and the insulation make no difference.

P20.44 Suppose the pizza is 70 cm in diameter and $\ell = 2.0$ cm thick, sizzling at 100°C. It cannot lose heat by conduction or convection. It radiates according to $\mathcal{P} = \sigma A e T^4$. Here, A is its surface area,

$$A = 2\pi r^2 + 2\pi r\ell = 2\pi(0.35\text{ m})^2 + 2\pi(0.35\text{ m})(0.02\text{ m}) = 0.81\text{ m}^2$$

Suppose it is dark in the infrared, with emissivity about 0.8. Then

$$\mathcal{P} = \left(5.67\times10^{-8}\ \text{W/m}^2\cdot\text{K}^4\right)\left(0.81\text{ m}^2\right)(0.80)(373\text{ K})^4 = 710\text{ W}\ \boxed{\sim10^3\text{ W}}$$

If the density of the pizza is half that of water, its mass is

$$m = \rho V = \rho\pi r^2\ell = \left(500\ \text{kg/m}^3\right)\pi(0.35\text{ m})^2(0.02\text{ m}) = 4\text{ kg}$$

Suppose its specific heat is $c = 0.6\ \text{cal/g}\cdot°\text{C}$. The drop in temperature of the pizza is described by

$$Q = mc\left(T_f - T_i\right)$$

$$\mathcal{P} = \frac{dQ}{dt} = mc\frac{dT_f}{dt} - 0$$

$$\frac{dT_f}{dt} = \frac{\mathcal{P}}{mc} = \frac{710\ \text{J/s}}{(4\text{ kg})(0.6\cdot4\,186\ \text{J/kg}\cdot°\text{C})} = 0.07\ °\text{C/s}\ \boxed{\sim10^{-1}\ \text{K/s}}$$

P20.45 $\mathcal{P} = \sigma A e T^4$

$$2.00\text{ W} = \left(5.67\times10^{-8}\ \text{W/m}^2\cdot\text{K}^4\right)\left(0.250\times10^{-6}\ \text{m}^2\right)(0.950)T^4$$

$$T = \left(1.49\times10^{14}\ \text{K}^4\right)^{1/4} = \boxed{3.49\times10^3\ \text{K}}$$

P20.46 We suppose the earth below is an insulator. The square meter must radiate in the infrared as much energy as it absorbs, $\mathcal{P} = \sigma A e T^4$. Assuming that $e = 1.00$ for blackbody blacktop:

$$1\,000\text{ W} = \left(5.67\times10^{-8}\ \text{W/m}^2\cdot\text{K}^4\right)\left(1.00\text{ m}^2\right)(1.00)T^4$$

$$T = \left(1.76\times10^{10}\ \text{K}^4\right)^{1/4} = \boxed{364\text{ K}}$$ (You can cook an egg on it.)

***P20.47** Intensity is defined as power per area perpendicular to the direction of energy flow. The direction of sunlight is along the line from the sun to the object. The perpendicular area is the projected flat circular area enclosed by the *terminator*—the line that separates day from night on the object. The object radiates infrared light outward in all directions. The area perpendicular to this energy flow is its spherical surface area.

The sphere of radius R absorbs sunlight over area πR^2. It radiates over area $4\pi R^2$. Then, in steady state,

$$\mathcal{P}_{\text{in}} = \mathcal{P}_{\text{out}}$$

$$e\left(1\,370\ \text{W/m}^2\right)\pi R^2 = e\sigma\left(4\pi R^2\right)T^4$$

The emissivity e, the radius R, and π all cancel.

Therefore,

$$T = \left[\frac{1\,370\ \text{W/m}^2}{4\left(5.67\times10^{-8}\ \text{W/m}^2\cdot\text{K}^4\right)}\right]^{1/4} = \boxed{279\text{ K}} = 6°\text{C}$$

$\boxed{\text{It is chilly, well below room temperatures we find comfortable.}}$

***P20.48** (a) Because the bulb is evacuated, the filament loses energy by radiation but not by convection; we ignore energy loss by conduction. From Stefan's law, the power ratio is

$$e\sigma A T_h^4 / e\sigma A T_c^4 = (2373/2273)^4 = \boxed{1.19}$$

(b) The radiating area is the lateral surface area of the cylindrical filament, $2\pi r\ell$. Now we want

$$e\sigma 2\pi r_h \ell T_h^4 = e\sigma 2\pi r_c \ell T_c^4 \qquad \text{so} \qquad r_c/r_h = \boxed{1.19}$$

Additional Problems

P20.49 The increase in internal energy required to melt 1.00 kg of snow is

$$\Delta E_{\text{int}} = (1.00 \text{ kg})(3.33\times 10^5 \text{ J/kg}) = 3.33\times 10^5 \text{ J}$$

The force of friction is

$$f = \mu n = \mu m g = 0.200(75.0 \text{ kg})(9.80 \text{ m/s}^2) = 147 \text{ N}$$

According to the problem statement, the loss of mechanical energy of the skier is assumed to be equal to the increase in internal energy of the snow. This increase in internal energy is

$$\Delta E_{\text{int}} = f\Delta r = (147 \text{ N})\Delta r = 3.33\times 10^5 \text{ J}$$

and

$$\Delta r = \boxed{2.27\times 10^3 \text{ m}}$$

P20.50 (a) The energy thus far gained by the copper equals the energy loss by the silver. Your down parka is an excellent insulator.

$$Q_{\text{cold}} = -Q_{\text{hot}}$$

or $$m_{\text{Cu}} c_{\text{Cu}} (T_f - T_i)_{\text{Cu}} = -m_{\text{Ag}} c_{\text{Ag}} (T_f - T_i)_{\text{Ag}}$$

$$(9.00 \text{ g})(387 \text{ J/kg}\cdot{}^\circ\text{C})(16.0^\circ\text{C}) = -(14.0 \text{ g})(234 \text{ J/kg}\cdot{}^\circ\text{C})(T_f - 30.0^\circ\text{C})_{\text{Ag}}$$

$$(T_f - 30.0^\circ\text{C})_{\text{Ag}} = -17.0^\circ\text{C}$$

so $$T_{f,\text{Ag}} = \boxed{13.0^\circ\text{C}}$$

(b) Differentiating the energy gain-and-loss equation gives: $m_{\text{Ag}} c_{\text{Ag}} \left(\dfrac{dT}{dt}\right)_{\text{Ag}} = -m_{\text{Cu}} c_{\text{Cu}} \left(\dfrac{dT}{dt}\right)_{\text{Cu}}$

$$\left(\frac{dT}{dt}\right)_{\text{Ag}} = -\frac{m_{\text{Cu}} c_{\text{Cu}}}{m_{\text{Ag}} c_{\text{Ag}}} \left(\frac{dT}{dt}\right)_{\text{Cu}} = -\frac{9.00 \text{ g}(387 \text{ J/kg}\cdot{}^\circ\text{C})}{14.0 \text{ g}(234 \text{ J/kg}\cdot{}^\circ\text{C})}(+0.500\,^\circ\text{C/s})$$

$$\left(\frac{dT}{dt}\right)_{\text{Ag}} = \boxed{-0.532\,^\circ\text{C/s}} \quad (\text{negative sign} \Rightarrow \text{decreasing temperature})$$

P20.51 (a) Before conduction has time to become important, the energy lost by the rod equals the energy gained by the helium. Therefore,

$$(mL_v)_{\text{He}} = (mc|\Delta T|)_{\text{Al}}$$

or $(\rho V L_v)_{\text{He}} = (\rho V c|\Delta T|)_{\text{Al}}$

so $V_{\text{He}} = \dfrac{(\rho V c|\Delta T|)_{\text{Al}}}{(\rho L_v)_{\text{He}}}$

$$V_{\text{He}} = \frac{(2.70\ \text{g/cm}^3)(62.5\ \text{cm}^3)(0.210\ \text{cal/g}\cdot{}^\circ\text{C})(295.8^\circ\text{C})}{(0.125\ \text{g/cm}^3)(2.09\times10^4\ \text{J/kg})(1.00\ \text{cal/4.186 J})(1.00\ \text{kg/1 000 g})}$$

$$V_{\text{He}} = 1.68\times10^4\ \text{cm}^3 = \boxed{16.8\ \text{liters}}$$

(b) The rate at which energy is supplied to the rod in order to maintain constant temperatures is given by

$$\mathcal{P} = kA\left(\frac{dT}{dx}\right) = (31.0\ \text{J/s}\cdot\text{cm}\cdot\text{K})(2.50\ \text{cm}^2)\left(\frac{295.8\ \text{K}}{25.0\ \text{cm}}\right) = 917\ \text{W}$$

This power supplied to the helium will produce a "boil-off" rate of

$$\frac{\mathcal{P}}{\rho L_v} = \frac{(917\ \text{W})(10^3\ \text{g/kg})}{(0.125\ \text{g/cm}^3)(2.09\times10^4\ \text{J/kg})} = 351\ \text{cm}^3/\text{s} = \boxed{0.351\ \text{L/s}}$$

***P20.52** (a) Work done by the gas is the negative of the area under the PV curve $W = -P_i\left(\dfrac{V_i}{2} - V_i\right) = \boxed{+\dfrac{P_iV_i}{2}}$

Put the cylinder into a refrigerator at absolute temperature $T_i/2$. Let the piston move freely as the gas cools.

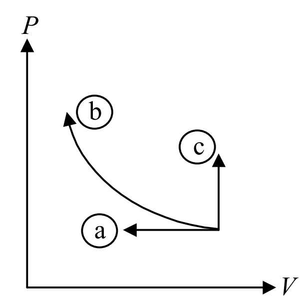

FIG. P20.52

(b) In this case the area under the curve is $W = -\int P\,dV$. Since the process is isothermal,

$$PV = P_iV_i = 4P_i\left(\frac{V_i}{4}\right) = nRT_i$$

and

$$W = -\int_{V_i}^{V_i/4}\left(\frac{dV}{V}\right)(P_iV_i) = -P_iV_i\ln\left(\frac{V_i/4}{V_i}\right) = P_iV_i\ln 4$$

$$= \boxed{+1.39P_iV_i}$$

With the gas in a constant-temperature bath at T_i, slowly push the piston in.

(c) The area under the curve is 0 and $\boxed{W = 0}$.

Lock the piston in place and hold the cylinder over a hotplate at $3T_i$.

The student may be confused that the integral in part (c) is not explicitly covered in calculus class. Mathematicians ordinarily study integrals of functions, but the pressure is not a single-valued function of volume in a isovolumetric process. Our physics idea of an integral is more general. It still corresponds to the idea of area under the graph line.

P20.53 $Q = mc\Delta T = (\rho V)c\Delta T$ so that when a constant temperature difference ΔT is maintained, the rate of adding energy to the liquid is $\mathcal{P} = \frac{dQ}{dt} = \rho\left(\frac{dV}{dt}\right)c\Delta T = \rho Rc\Delta T$ and the specific heat of the liquid is $c = \boxed{\frac{\mathcal{P}}{\rho R\Delta T}}$

P20.54 The initial moment of inertia of the disk is

$$\frac{1}{2}MR^2 = \frac{1}{2}\rho VR^2 = \frac{1}{2}\rho\pi R^2 tR^2 = \frac{1}{2}(8\,920\ \text{kg/m}^3)\pi(28\ \text{m})^4\ 1.2\ \text{m} = 1.033\times10^{10}\ \text{kg}\cdot\text{m}^2$$

The rotation speeds up as the disk cools off, according to

$$I_i\omega_i = I_f\omega_f$$

$$\frac{1}{2}MR_i^2\omega_i = \frac{1}{2}MR_f^2\omega_f = \frac{1}{2}MR_i^2(1-\alpha|\Delta T|)^2\omega_f$$

$$\omega_f = \omega_i\frac{1}{(1-\alpha|\Delta T|)^2} = 25\ \text{rad/s}\frac{1}{\left[1-(17\times10^{-6}\ 1/^\circ\text{C})830^\circ\text{C}\right]^2} = 25.720\ 7\ \text{rad/s}$$

(a) The kinetic energy increases by

$$\frac{1}{2}I_f\omega_f^2 - \frac{1}{2}I_i\omega_i^2 = \frac{1}{2}I_i\omega_i\omega_f - \frac{1}{2}I_i\omega_i^2 = \frac{1}{2}I_i\omega_i(\omega_f-\omega_i)$$

$$= \frac{1}{2}1.033\times10^{10}\ \text{kg}\cdot\text{m}^2(25\ \text{rad/s})0.720\ 7\ \text{rad/s} = \boxed{9.31\times10^{10}\ \text{J}}$$

(b) $\Delta E_{\text{int}} = mc\Delta T = 2.64\times10^7\ \text{kg}(387\ \text{J/kg}\cdot{}^\circ\text{C})(20^\circ\text{C}-850^\circ\text{C}) = \boxed{-8.47\times10^{12}\ \text{J}}$

(c) As 8.47×10^{12} J leaves the fund of internal energy, 9.31×10^{10} J changes into extra kinetic energy, and the rest, $\boxed{8.38\times10^{12}\ \text{J}}$ is radiated.

P20.55 The loss of mechanical energy is

$$\frac{1}{2}mv_i^2 + \frac{GM_Em}{R_E} = \frac{1}{2}670\ \text{kg}(1.4\times10^4\ \text{m/s})^2 + \frac{6.67\times10^{-11}\ \text{Nm}^2\ 5.98\times10^{24}\ \text{kg}\ 670\ \text{kg}}{\text{kg}^2\ 6.37\times10^6\ \text{m}}$$

$$= 6.57\times10^{10}\ \text{J} + 4.20\times10^{10}\ \text{J} = 1.08\times10^{11}\ \text{J}$$

One half becomes extra internal energy in the aluminum: $\Delta E_{\text{int}} = 5.38\times10^{10}$ J. To raise its temperature to the melting point requires energy

$$mc\Delta T = 670\ \text{kg}\ 900\frac{\text{J}}{\text{kg}^\circ\text{C}}(660-(-15^\circ\text{C})) = 4.07\times10^8\ \text{J}$$

To melt it, $mL = 670\ \text{kg}\ 3.97\times10^5\ \text{J/kg} = 2.66\times10^8\ \text{J}$

To raise it to the boiling point, $mc\Delta T = 670(1\,170)(2\,450-660)\,\text{J} = 1.40\times10^9\,\text{J}$

To boil it, $mL = 670\ \text{kg}\ 1.14\times10^7\ \text{J/kg} = 7.64\times10^9\,\text{J}$

Then

$$5.38\times10^{10}\ \text{J} = 9.71\times10^9\ \text{J} + 670(1\,170)(T_f - 2\,450^\circ\text{C})\text{J}/^\circ\text{C}$$

$$T_f = \boxed{5.87\times10^4\,^\circ\text{C}}$$

P20.56 From $Q = mL_V$ the rate of boiling is described by

$$\mathcal{P} = \frac{Q}{\Delta t} = \frac{L_V m}{\Delta t} \qquad \therefore \frac{m}{\Delta t} = \frac{\mathcal{P}}{L_V}$$

Model the water vapor as an ideal gas

$$P_0 V_0 = nRT = \left(\frac{m}{M}\right)RT$$

$$\frac{P_0 V}{\Delta t} = \frac{m}{\Delta t}\left(\frac{RT}{M}\right)$$

$$P_0 A v = \frac{\mathcal{P}}{L_V}\left(\frac{RT}{M}\right)$$

$$v = \frac{\mathcal{P}RT}{ML_V P_0 A} = \frac{1\,000\text{ W}(8.314\text{ J/mol}\cdot\text{K})(373\text{ K})}{(0.018\,0\text{ kg/mol})(2.26\times10^{6}\text{ J/kg})(1.013\times10^{5}\text{ N/m}^2)(2.00\times10^{-4}\text{ m}^2)}$$

$$v = \boxed{3.76\text{ m/s}}$$

P20.57 The power incident on the solar collector is

$$\mathcal{P}_i = IA = (600\text{ W/m}^2)\left[\pi(0.300\text{ m})^2\right] = 170\text{ W}$$

For a 40.0% reflector, the collected power is $\mathcal{P}_c = 67.9$ W. The total energy required to increase the temperature of the water to the boiling point and to evaporate it is $Q = cm\Delta T + mL_V$:

$$Q = 0.500\text{ kg}\left[(4\,186\text{ J/kg}\cdot{}^\circ\text{C})(80.0^\circ\text{C}) + 2.26\times10^{6}\text{ J/kg}\right]$$
$$= 1.30\times10^{6}\text{ J}$$

The time interval required is

$$\Delta t = \frac{Q}{\mathcal{P}_c} = \frac{1.30\times10^{6}\text{ J}}{67.9\text{ W}} = \boxed{5.31\text{ h}}$$

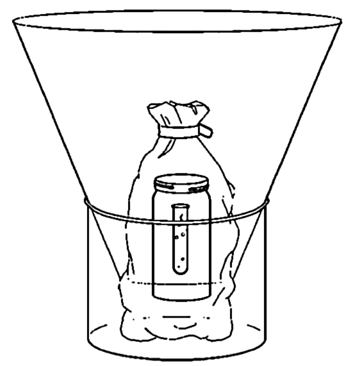

FIG. P20.57

P20.58 (a) The block starts with $K_i = \frac{1}{2}mv_i^2 = \frac{1}{2}(1.60\text{ kg})(2.50\text{ m/s})^2 = 5.00\text{ J}$

All this becomes extra internal energy in ice, melting some according to "Q" $= m_{\text{ice}}L_f$

Thus, the mass of ice that melts is

$$m_{\text{ice}} = \frac{\text{“}Q\text{”}}{L_f} = \frac{K_i}{L_f} = \frac{5.00\text{ J}}{3.33\times10^{5}\text{ J/kg}} = 1.50\times10^{-5}\text{ kg} = \boxed{15.0\text{ mg}}$$

For the block:	$Q = 0$ (no energy flows by heat since there is no temperature difference)
	$W = -5.00$ J
	$\Delta E_{\text{int}} = 0$ (no temperature change)
and	$\Delta K = -5.00$ J
For the ice,	$Q = 0$
	$W = +5.00$ J
	$\Delta E_{\text{int}} = +5.00$ J
and	$\Delta K = 0$

continued on next page

(b) Again, $K_i = 5.00$ J and $m_{\text{ice}} = \boxed{15.0 \text{ mg}}$

For the block of ice:	$Q = 0$; $\Delta E_{\text{int}} = +5.00$ J; $\Delta K = -5.00$ J
so	$W = 0$
For the copper, nothing happens:	$Q = \Delta E_{\text{int}} = \Delta K = W = 0$

(c) Again, $K_i = 5.00$ J. Both blocks must rise equally in temperature.

$$\text{“}Q\text{”} = mc\Delta T: \qquad \Delta T = \frac{\text{“}Q\text{”}}{mc} = \frac{5.00 \text{ J}}{2(1.60 \text{ kg})(387 \text{ J/kg}\cdot\text{°C})} = \boxed{4.04\times10^{-3}\text{°C}}$$

At any instant, the two blocks are at the same temperature, so for both $Q = 0$.

For the moving block:	$\Delta K = -5.00$ J
and	$\Delta E_{\text{int}} = +2.50$ J
so	$W = -2.50$ J
For the stationary block:	$\Delta K = 0$
and	$\Delta E_{\text{int}} = +2.50$ J
so	$W = +2.50$ J

For each object in each situation, the general continuity equation for energy, in the form $\Delta K + \Delta E_{\text{int}} = W + Q$, correctly describes the relationship between energy transfers and changes in the object's energy content.

P20.59 Energy goes in at a constant rate $\mathcal{P}$. For the period from

50.0 min to 60.0 min, $Q = mc\Delta T$

$$\mathcal{P}(10.0 \text{ min}) = (10 \text{ kg} + m_i)(4\,186 \text{ J/kg}\cdot\text{°C})(2.00\text{°C} - 0\text{°C})$$

$$\mathcal{P}(10.0 \text{ min}) = 83.7 \text{ kJ} + (8.37 \text{ kJ/kg})m_i \qquad (1)$$

For the period from 0 to 50.0 min, $Q = m_i L_f$

$$\mathcal{P}(50.0 \text{ min}) = m_i(3.33\times10^5 \text{ J/kg})$$

Substitute $\mathcal{P} = \dfrac{m_i(3.33\times10^5 \text{ J/kg})}{50.0 \text{ min}}$ into Equation (1) to find

$$\frac{m_i(3.33\times10^5 \text{ J/kg})}{5.00} = 83.7 \text{ kJ} + (8.37 \text{ kJ/kg})m_i$$

$$m_i = \frac{83.7 \text{ kJ}}{(66.6 - 8.37) \text{ kJ/kg}} = \boxed{1.44 \text{ kg}}$$

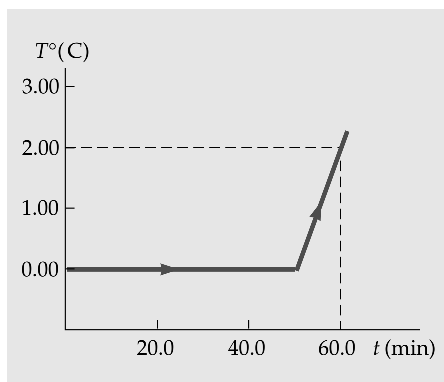

FIG. P20.59

P20.60 $\dfrac{L\rho A dx}{dt} = kA\left(\dfrac{\Delta T}{x}\right)$

$$L\rho \int_{4.00}^{8.00} x dx = k\Delta T \int_0^{\Delta t} dt$$

$$L\rho \left.\frac{x^2}{2}\right|_{4.00}^{8.00} = k\Delta T\,\Delta t$$

$$\left(3.33\times 10^5 \text{ J/kg}\right)\left(917 \text{ kg/m}^3\right)\left(\frac{(0.080\,0 \text{ m})^2 - (0.040\,0 \text{ m})^2}{2}\right) = (2.00 \text{ W/m}\cdot{}^\circ\text{C})(10.0^\circ\text{C})\Delta t$$

$$\Delta t = 3.66\times 10^4 \text{ s} = \boxed{10.2 \text{ h}}$$

P20.61 $A = A_{\text{end walls}} + A_{\text{ends of attic}} + A_{\text{side walls}} + A_{\text{roof}}$

$$A = 2(8.00 \text{ m}\times 5.00 \text{ m}) + 2\left[2\times\frac{1}{2}\times 4.00 \text{ m}\times(4.00 \text{ m})\tan 37.0^\circ\right]$$

$$+\,2(10.0 \text{ m}\times 5.00 \text{ m}) + 2(10.0 \text{ m})\left(\frac{4.00 \text{ m}}{\cos 37.0^\circ}\right)$$

$$A = 304 \text{ m}^2$$

$$\mathcal{P} = \frac{kA\Delta T}{L} = \frac{\left(4.80\times 10^{-4} \text{ kW/m}\cdot{}^\circ\text{C}\right)\left(304 \text{ m}^2\right)(25.0^\circ\text{C})}{0.210 \text{ m}} = 17.4 \text{ kW} = 4.15 \text{ kcal/s}$$

Thus, the energy lost per day by heat is $(4.15 \text{ kcal/s})(86\,400 \text{ s}) = 3.59\times 10^5 \text{ kcal/day}$.

The gas needed to replace this loss is $\dfrac{3.59\times 10^5 \text{ kcal/day}}{9\,300 \text{ kcal/m}^3} = \boxed{38.6 \text{ m}^3\text{/day}}$.

P20.62 See the diagram appearing with the next problem. For a cylindrical shell of radius r, height L, and thickness dr, the equation for thermal conduction,

$$\frac{dQ}{dt} = -kA\frac{dT}{dx} \qquad \text{becomes} \qquad \frac{dQ}{dt} = -k(2\pi rL)\frac{dT}{dr}$$

Under equilibrium conditions, $\dfrac{dQ}{dt}$ is constant; therefore,

$$dT = -\frac{dQ}{dt}\left(\frac{1}{2\pi kL}\right)\left(\frac{dr}{r}\right) \qquad \text{and} \qquad \int_{T_a}^{T_b} dT = -\frac{dQ}{dt}\left(\frac{1}{2\pi kL}\right)\int_a^b \frac{dr}{r}$$

$$T_b - T_a = -\frac{dQ}{dt}\left(\frac{1}{2\pi kL}\right)\ln\left(\frac{b}{a}\right)$$

But $T_a > T_b$, so $\boxed{\dfrac{dQ}{dt} = \dfrac{2\pi kL(T_a - T_b)}{\ln(b/a)}}$

P20.63 From the previous problem, the rate of energy flow through the wall is

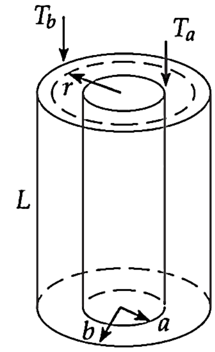

FIG. P20.63

$$\frac{dQ}{dt} = \frac{2\pi kL(T_a - T_b)}{\ln(b/a)}$$

$$\frac{dQ}{dt} = \frac{2\pi(4.00\times10^{-5}\ \text{cal/s}\cdot\text{cm}\cdot{}^\circ\text{C})(3\,500\ \text{cm})(60.0^\circ\text{C})}{\ln(256\ \text{cm}/250\ \text{cm})}$$

$$\frac{dQ}{dt} = 2.23\times10^3\ \text{cal/s} = \boxed{9.32\ \text{kW}}$$

This is the rate of energy loss from the plane by heat, and consequently is the rate at which energy must be supplied in order to maintain a constant temperature.

***P20.64** $Q_{\text{cold}} = -Q_{\text{hot}}$

or $Q_{\text{Al}} = -(Q_{\text{water}} + Q_{\text{calo}})$

$$m_{\text{Al}}c_{\text{Al}}(T_f - T_i)_{\text{Al}} = -(m_w c_w + m_c c_c)(T_f - T_i)_w$$

$$(0.200\ \text{kg})c_{\text{Al}}(+39.3^\circ\text{C}) = -[0.400\ \text{kg}(4\,186\ \text{J/kg}\cdot{}^\circ\text{C}) + 0.040\,0\ \text{kg}(630\ \text{J/kg}\cdot{}^\circ\text{C})]\ (-3.70^\circ\text{C})$$

$$c_{\text{Al}} = \frac{6.29\times10^3\ \text{J}}{7.86\ \text{kg}\cdot{}^\circ\text{C}} = \boxed{800\ \text{J/kg}\cdot{}^\circ\text{C}}$$

This differs from the tabulated value by (900–800)/900 =11%, so the values agree within 15%.

***P20.65**
(a) If the energy flowing by heat through one spherical surface within the shell were different from the energy flowing through another sphere, the temperature would be changing at a radius between the layers, so the steady state would not yet be established.

For a spherical shell of radius r and thickness dr, the equation for thermal conduction,

$$\frac{dQ}{dt} = -kA\frac{dT}{dx}, \quad \text{becomes} \quad \left|\frac{dQ}{dt}\right| = \mathcal{P} = k(4\pi r^2)\frac{dT}{dr} \quad \text{so} \quad \frac{dT}{dr} = \frac{\mathcal{P}}{k4\pi r^2}$$

(b) We separate the variables T and r and integrate from the interior to the exterior of the shell:

$$\int_{5^\circ\text{C}}^{40^\circ\text{C}} dT = \frac{\mathcal{P}}{4\pi k}\int_{3\text{cm}}^{7\text{cm}} \frac{dr}{r^2}$$

(c) $$T\Big|_{5^\circ\text{C}}^{40^\circ\text{C}} = \frac{\mathcal{P}}{4\pi k}\frac{r^{-1}}{-1}\Bigg|_{3\text{cm}}^{7\text{cm}} \qquad 40^\circ\text{C} - 5^\circ\text{C} = \frac{\mathcal{P}}{4\pi(0.8\ \text{W/m}^\circ\text{C})}\left(-\frac{1}{7\ \text{cm}} + \frac{1}{3\ \text{cm}}\right)$$

$\mathcal{P}$ = 35°C(4π)(0.8 W/100 cm·°C)/(0.190/cm) = $\boxed{18.5\ \text{W}}$

(d) With $\mathcal{P}$ now known, we take the equation from part (a), separate the variables again and integrate between a point on the interior surface and any point within the shell.

$$\int_{5^\circ\text{C}}^{T} dT = \frac{\mathcal{P}}{4\pi k}\int_{3\text{cm}}^{r} \frac{dr}{r^2}$$

(e) $$T\Big|_{5^\circ\text{C}}^{T} = \frac{\mathcal{P}}{4\pi k}\frac{r^{-1}}{-1}\Bigg|_{3\text{cm}}^{r} \qquad T - 5^\circ\text{C} = \frac{18.5\ \text{W}}{4\pi(0.8\ \text{W/m}^\circ\text{C})}\left(-\frac{1}{r} + \frac{1}{3\ \text{cm}}\right)$$

$\boxed{T = 5^\circ\text{C} + 184\ \text{cm}\cdot{}^\circ\text{C}\ (1/3\ \text{cm} - 1/r)}$

(f) $T = 5^\circ\text{C} + 184\ \text{cm}\cdot{}^\circ\text{C}\ (1/3\ \text{cm} - 1/5\ \text{cm}) = \boxed{29.5^\circ\text{C}}$

***P20.66** (a) $\mathcal{P} = \sigma AeT^4 = \left(5.67\times10^{-8}\ \text{W/m}^2\text{K}^4\right)5.1\times10^{14}\ \text{m}^2\ (0.965)\left(5\,800\ \text{K}\right)^4 = \boxed{3.16\times10^{22}\ \text{W}}$

(b) $T_{\text{avg}} = 0.1\left(4\,800\ \text{K}\right) + 0.9\left(5\,890\ \text{K}\right) = \boxed{5.78\times10^3\ \text{K}}$

$\boxed{\text{This is cooler than 5 800 K by } \dfrac{5\,800-5\,781}{5\,800} = 0.328\%}$

(c) $\mathcal{P} = \left(5.67\times10^{-8}\ \text{W/m}^2\text{K}^4\right)0.1\left(5.1\times10^{14}\ \text{m}^2\right)0.965\left(4\,800\ \text{K}\right)^4$

$+\ 5.67\times10^{-8}\ \text{W}\ 0.9\left(5.1\times10^{14}\right)0.965\left(5\,890\right)^4 = \boxed{3.17\times10^{22}\ \text{W}}$

$\boxed{\text{This is larger than } 3.158\times10^{22}\ \text{W by } \dfrac{1.29\times10^{20}\ \text{W}}{3.16\times10^{22}\ \text{W}} = 0.408\%}$

ANSWERS TO EVEN PROBLEMS

P20.2 0.105°C

P20.4 The energy input to the water is 6.70 times larger than the laser output of 40.0 kJ.

P20.6 88.2 W

P20.8 (a) 16.1°C (b) 16.1°C (c) It makes no difference whether the drill bit is dull or sharp, or how far into the block it cuts. The answers to (a) and (b) are the same because work cannot be a final form of energy: all of the work done by the bit constitutes energy being transferred into the internal energy of the steel.

P20.10 (a) 25.8°C (b) The final temperature does not depend on the mass. Both the change in potential energy and the heat that would be required (from a stove to produce the change in temperature) are proportional to the mass; hence, the mass cancels in the energy relation.

P20.12 (a) 380 K (b) 2.04 atm

P20.14 12.9 g

P20.16 (a) all the ice melts; 40.4°C (b) 8.04 g melts; 0°C

P20.18 (a) 7 (b) As the car stops it transfers part of its kinetic energy into the air. As soon as the brakes rise above the air temperature they lose energy by heat, and lose it very fast if they attain a high temperature.

P20.20 (a) Two speeding lead bullets, one of mass 12.0 g moving to the right at 300 m/s and one of mass 8.00 g moving to the left at 400 m/s, collide head-on and all of the material sticks together. Both bullets are originally at temperature 30.0°C. Describe the state of the system immediately thereafter. (b) After the completely inelastic collision, a glob comprising 3.10 g of solid lead and 16.9 g is liquid lead is moving to the right at 20.0 m/s. Its temperature is 327.3°C.

P20.22 (a) −12.0 MJ (b) +12.0 MJ

P20.24 $-nR\left(T_2 - T_1\right)$

P20.26 (a) 12.0 kJ (b) −12.0 kJ

P20.28 42.9 kJ

P20.30 (a) 7.65 L (b) 305 K

P20.32 (a) –48.6 mJ (b) 16.2 kJ (c) 16.2 kJ

P20.34 (a) $-4P_iV_i$ (b) $+4P_iV_i$ (c) –9.08 kJ

P20.36 (a) 1 300 J (b) 100 J (c) –900 J (d) –1 400 J

P20.38 1.34 kW

P20.40 (a) $0.890 \text{ ft}^2 \cdot °\text{F} \cdot \text{h/Btu}$ (b) $1.85 \frac{\text{ft}^2 \cdot °\text{F} \cdot \text{h}}{\text{Btu}}$ (c) 2.08

P20.42 3.85×10^{26} W

P20.44 (a) $\sim 10^3$ W (b) decreasing at $\sim 10^{-1}$ K/s

P20.46 364 K

P20.48 (a) 1.19 (b) 1.19

P20.50 (a) 13.0°C (b) –0.532°C/s

P20.52 (a) $P_iV_i/2$. Put the cylinder into a refrigerator at absolute temperature $T_i/2$. Let the piston move freely as the gas cools. (b) $1.39P_iV_i$. With the gas in a constant-temperature bath at T_i, slowly push the piston in. (c) 0. Lock the piston in place and hold the cylinder over a hotplate at $3T_i$. See the solution.

P20.54 (a) 9.31×10^{10} J (b) -8.47×10^{12} J (c) 8.38×10^{12} J

P20.56 3.76 m/s

P20.58 (a) 15.0 mg. Block: $Q = 0$, $W = -5.00$ J, $\Delta E_{\text{int}} = 0$, $\Delta K = -5.00$ J. Ice: $Q = 0$, $W = 5.00$ J, $\Delta E_{\text{int}} = 5.00$ J, $\Delta K = 0$. (b) 15.0 mg. Block: $Q = 0$, $W = 0$, $\Delta E_{\text{int}} = 5.00$ J, $\Delta K = -5.00$ J. Metal: $Q = 0$, $W = 0$, $\Delta E_{\text{int}} = 0$, $\Delta K = 0$. (c) 0.004 04°C. Moving block: $Q = 0$, $W = -2.50$ J, $\Delta E_{\text{int}} = 2.50$ J, $\Delta K = -5.00$ J. Stationary block: $Q = 0$, $W = 2.50$ J, $\Delta E_{\text{int}} = 2.50$ J, $\Delta K = 0$.

P20.60 10.2 h

P20.62 see the solution

P20.64 800 J/kg·°C. This differs from the tabulated value by 11%, so they agree within 15%.

P20.66 (a) 3.16×10^{22} W (b) 5.78×10^3 K, 0.328% less than 5 800 K (c) 3.17×10^{22} W, 0.408% larger