

Heat and the First Law of Thermodynamics

CHAPTER OUTLINE

- 20.1 Heat and Internal Energy
- 20.2 Specific Heat and Calorimetry
- 20.3 Latent Heat
- 20.4 Work and Heat in Thermodynamic Processes
- 20.5 The First Law of Thermodynamics
- 20.6 Some Applications of the First Law of Thermodynamics
- 20.7 Energy Transfer Mechanisms

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** The ΔT is twice as great in the ethyl alcohol.
- Q20.3** The final equilibrium temperature will show no significant increase over the initial temperature of the water.
- Q20.4** Some water may boil away. You would have to very precisely measure how much, and very quickly measure the temperature of the steam; it is not necessarily 100°C .
- Q20.5** The fingers are wetted to create a layer of steam between the fingers and the molten lead. The steam acts as an insulator and can prevent or delay serious burns. The molten lead demonstration is dangerous, and we do not recommend it.
- Q20.6** Heat is energy being transferred, not energy contained in an object. Further, a large-mass object, or an object made of a material with high specific heat, can contain more internal energy than a higher-temperature object.
- Q20.7** 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!
- Q20.8** Write $1\,000\text{ kg}(4\,186\text{ J/kg}\cdot^\circ\text{C})(1^\circ\text{C}) = V(1.3\text{ kg/m}^3)(1\,000\text{ J/kg}\cdot^\circ\text{C})(1^\circ\text{C})$ to find $V = 3.2 \times 10^3\text{ m}^3$.

- Q20.9** The large amount of energy stored in concrete during the day as the sun falls on it is released at night, resulting in an higher average evening temperature than the countryside. The cool air in the surrounding countryside exerts a buoyant force on the warmer air in the city, pushing it upward and moving into the city in the process. Thus, evening breezes tend to blow from country to city.
- Q20.10** 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.
- Q20.11** (a) and (b) both increase by minuscule amounts.
- Q20.12** The steam locomotive engine is a 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.
- Q20.13** Yes. If you know the different specific heats of zinc and copper, you can determine the fraction of each by heating a known mass of pennies to a specific initial temperature, say 100°C , and dumping them into a known quantity of water, at say 20°C . The final temperature T will reveal the metal content:

$$m_{\text{pennies}}[xc_{\text{Cu}} + (1-x)c_{\text{Zn}}](100^{\circ}\text{C} - T) = m_{\text{H}_2\text{O}}c_{\text{H}_2\text{O}}(T - 20^{\circ}\text{C}).$$

Since all quantities are known, except x , the fraction of the penny that is copper will be found by putting in the experimental numbers m_{pennies} , $m_{\text{H}_2\text{O}}$, $T(\text{final})$, c_{Zn} , and c_{Cu} .

- Q20.14** The materials used to make the support structure of the roof have a higher thermal conductivity than the insulated spaces in between. The heat from the barn conducts through the rafters and melts the snow.
- Q20.15** 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.
- Q20.16** The question refers to baking in a conventional oven, not to microwaving. The metal has much higher thermal conductivity than the potato. The metal quickly conducts energy from the hot oven into the center of potato.
- Q20.17** Copper has a higher thermal conductivity than the wood. Heat from the flame is conducted through the copper away from the paper, so that the paper need not reach its kindling temperature. The wood does not conduct the heat away from the paper as readily as the copper, so the energy in the paper can increase enough to make it ignite.
- Q20.18** In winter the interior of the house is warmer than the air outside. On a summer day we want the interior to stay cooler than the exterior. Heavy draperies over the windows can slow down energy transfer by conduction, by convection, and by radiation, to make it easier to maintain the desired difference in temperature.
- Q20.19** You must allow time for the flow of energy into the center of the piece of meat. To avoid burning the outside, the meat should be relatively far from the flame. If the outer layer does char, the carbon will slow subsequent energy flow to the interior.

- Q20.20** At night, the Styrofoam beads would decrease the overall thermal conductivity of the windows, and thus decrease the amount of heat conducted from inside to outside. The air pockets in the Styrofoam are an efficient insulator. During the winter day, the influx of sunlight coming through the window warms the living space.
- An interesting aside—the majority of the energy that goes into warming a home from sunlight through a window is *not* the infrared light given off by the sun. Glass is a relatively good insulator of infrared. If not, the window on your cooking oven might as well be just an open hole! Glass is opaque to a large portion of the ultraviolet range. The glass molecules absorb ultraviolet light from the sun and re-emit the energy in the infrared region. It is this re-emitted infrared radiation that contributes to warming your home, along with visible light.
- Q20.21** In winter the produce is protected from freezing. The heat capacity of the earth is so high that soil freezes only to a depth of a few decimeters in temperate regions. Throughout the year the temperature will stay nearly constant all day and night. Factors to be considered are the insulating properties of soil, the absence of a path for energy to be radiated away from or to the vegetables, and the hindrance to the formation of convection currents in the small, enclosed space.
- Q20.22** The high mass and specific heat of the barrel of water and its high heat of fusion mean that a large amount of energy would have to leak out of the cellar before the water and the produce froze solid. Evaporation of the water keeps the relative humidity high to protect foodstuffs from drying out.
- Q20.23** 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.
- Q20.24** Sunlight hits the earth and warms the air immediately above it. This warm, less-dense air rises, creating an up-draft. Many raptors, like eagles, hawks and falcons use updrafts to aid in hunting. These birds can often be seen flying without flapping their wings—just sitting in an updraft with wings extended.
- Q20.25** 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. This effectively warms the bulk of the water all at once, much more rapidly than it would be by heat being conducted through the water from the flame.
- Q20.26** The porcelain of the teacup is a thermal insulator. That is, it is a thermal conductor of relatively low conductivity. When you wrap your hands around a cup of hot tea, you make A large and L small in the equation $\mathcal{P} = kA \frac{T_h - T_c}{L}$ for the rate of energy transfer by heat from tea into you. When you hold the cup by the handle, you make the rate of energy transfer much smaller by reducing A and increasing L . The air around the cup handle will also reduce the temperature where you are touching it. A paper cup can be fitted into a tubular jacket of corrugated cardboard, with the channels running vertically, for remarkably effective insulation, according to the same principles.
- Q20.27** As described in the answer to question 20.25, convection currents in the water serve to bring more of the heat into the water from the paper cup than the specific heats and thermal conductivities of paper and water would suggest. Since the boiling point of water is far lower than the kindling temperature of the cup, the extra energy goes into boiling the water.
- Q20.28** 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.

578 *Heat and the First Law of Thermodynamics*

- Q20.29** 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.
- Q20.30** The cup without the spoon will be warmer. Heat is conducted from the coffee up through the metal. The energy then radiates and convects into the atmosphere.
- Q20.31** Convection. The bridge deck loses energy rapidly to the air both above it and below it.
- Q20.32** 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. The liquid nitrogen still on the 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. 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.
- Q20.33**
- (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.
- Q20.34** 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 $\Delta U_g = Q = mc\Delta T = (1.00 \text{ kg})(4186 \text{ J/kg}\cdot^\circ\text{C})\Delta T = 490 \text{ J}$ 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:

$$Q = 0$$

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

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:

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

$$\begin{aligned} \Delta T &= \frac{2mgh}{m_{\text{water}}c} = \frac{2 \times 1.50 \text{ kg}(9.80 \text{ m/s}^2)(3.00 \text{ m})}{0.200 \text{ kg}(4186 \text{ J/kg}\cdot^\circ\text{C})} = \frac{88.2 \text{ J}}{837 \text{ J/}^\circ\text{C}} \\ &= \boxed{0.105^\circ\text{C}} \end{aligned}$$

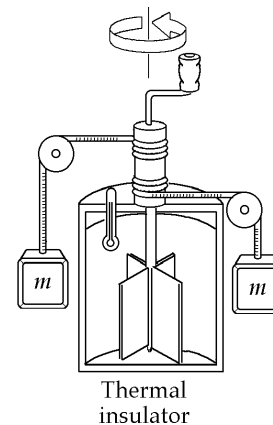


FIG. P20.2

Section 20.2 Specific Heat and Calorimetry

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

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

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

P20.4 From $Q = mc\Delta T$

$$\text{we find } \Delta T = \frac{Q}{mc} = \frac{1200 \text{ J}}{0.0500 \text{ kg}(387 \text{ J/kg}\cdot^\circ\text{C})} = 62.0^\circ\text{C}$$

Thus, the final temperature is $\boxed{87.0^\circ\text{C}}$.

***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

$$\begin{aligned} \mathcal{P} &= \frac{Q}{\Delta t} = \frac{mc\Delta T}{\Delta t} \\ m &= \frac{\mathcal{P}\Delta t}{c\Delta T} = \frac{(-6000 \text{ J/s})(14 \text{ h})(3600 \text{ s/h})}{(850 \text{ J/kg}\cdot^\circ\text{C})(18^\circ\text{C} - 38^\circ\text{C})} = \frac{3.02 \times 10^8 \text{ J}\cdot\text{kg}\cdot^\circ\text{C}}{850 \text{ J}(20^\circ\text{C})} = \boxed{1.78 \times 10^4 \text{ kg}} \end{aligned}$$

*P20.6 The laser energy output:

$$\mathcal{P}\Delta t = (1.60 \times 10^{13} \text{ J/s}) 2.50 \times 10^{-9} \text{ s} = 4.00 \times 10^4 \text{ J}.$$

The teakettle input:

$$Q = mc\Delta T = 0.800 \text{ kg}(4186 \text{ J/kg}\cdot^\circ\text{C})80^\circ\text{C} = 2.68 \times 10^5 \text{ J}.$$

This is larger by 6.70 times.

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

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

$$20.0 \text{ kg}(4186 \text{ J/kg}\cdot^\circ\text{C})(T_f - 25.0^\circ\text{C}) = -(1.50 \text{ kg})(448 \text{ J/kg}\cdot^\circ\text{C})(T_f - 600^\circ\text{C})$$

$$T_f = \boxed{29.6^\circ\text{C}}$$

P20.8 Let us find the energy transferred in one minute.

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

$$Q = [(0.200 \text{ kg})(900 \text{ J/kg}\cdot^\circ\text{C}) + (0.800 \text{ kg})(4186 \text{ J/kg}\cdot^\circ\text{C})](-1.50^\circ\text{C}) = -5290 \text{ J}$$

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

$$\mathcal{P} = \frac{|Q|}{\Delta t} = \frac{5290 \text{ J}}{60.0 \text{ s}} = 88.2 \text{ J/s} = \boxed{88.2 \text{ W}}.$$

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

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

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

$$\begin{aligned} & [250 \text{ g}(1.00 \text{ cal/g}\cdot^\circ\text{C}) + 100 \text{ g}(0.215 \text{ cal/g}\cdot^\circ\text{C})](20.0 - 10.0)^\circ\text{C} \\ & = -(50.0 \text{ g})(0.0924 \text{ cal/g}\cdot^\circ\text{C})(20.0 - 80.0)^\circ\text{C} - (70.0 \text{ g})c_{\text{unk}}(20.0 - 100)^\circ\text{C} \\ & 2.44 \times 10^3 \text{ cal} = (5.60 \times 10^3 \text{ g}\cdot^\circ\text{C})c_{\text{unk}} \end{aligned}$$

$$\text{or } c_{\text{unk}} = \boxed{0.435 \text{ cal/g}\cdot^\circ\text{C}}.$$

(b) The material of the sample is beryllium.

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

$$\frac{(0.600)(3.00 \times 10^{-3} \text{ kg})(9.80 \text{ m/s}^2)(50.0 \text{ m})}{4.186 \text{ J/cal}} = (3.00 \text{ g})(0.0924 \text{ cal/g}\cdot^\circ\text{C})(\Delta T)$$

$$\Delta T = 0.760^\circ\text{C}; \quad T = 25.8^\circ\text{C}$$

(b) No. Both the change in potential energy and the heat absorbed are proportional to the mass; hence, the mass cancels 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 $mc\Delta T = 0.25 \text{ kg} \cdot 4186 \frac{\text{J}}{\text{kg}\cdot^\circ\text{C}} \cdot 6^\circ\text{C} = 6279 \text{ J}$. The energy the copper can put out in dropping to 26°C is $mc\Delta T = 0.1 \text{ kg} \cdot 387 \frac{\text{J}}{\text{kg}\cdot^\circ\text{C}} \cdot 74^\circ\text{C} = 2864 \text{ J}$. Since $6279 \text{ J} > 2864 \text{ J}$, the final temperature is less than 26°C . We can write $Q_h = -Q_c$ as

$$\begin{aligned} Q_{\text{water}} + Q_{\text{Al}} + Q_{\text{Cu}} &= 0 \\ 0.25 \text{ kg} \cdot 4186 \frac{\text{J}}{\text{kg}\cdot^\circ\text{C}} (T_f - 20^\circ\text{C}) + 0.4 \text{ kg} \cdot 900 \frac{\text{J}}{\text{kg}\cdot^\circ\text{C}} (T_f - 26^\circ\text{C}) \\ &\quad + 0.1 \text{ kg} \cdot 387 \frac{\text{J}}{\text{kg}\cdot^\circ\text{C}} (T_f - 100^\circ\text{C}) = 0 \\ 1046.5T_f - 20930^\circ\text{C} + 360T_f - 9360^\circ\text{C} + 38.7T_f - 3870^\circ\text{C} &= 0 \\ 1445.2T_f &= 34160^\circ\text{C} \\ T_f &= \boxed{23.6^\circ\text{C}} \end{aligned}$$

P20.12 $Q_{\text{cold}} = -Q_{\text{hot}}$

$$\begin{aligned} m_{\text{Al}}c_{\text{Al}}(T_f - T_c) + m_c c_w (T_f - T_c) &= -m_h c_w (T_f - T_h) \\ (m_{\text{Al}}c_{\text{Al}} + m_c c_w)T_f - (m_{\text{Al}}c_{\text{Al}} + m_c c_w)T_c &= -m_h c_w T_f + m_h c_w T_h \\ (m_{\text{Al}}c_{\text{Al}} + m_c c_w + m_h c_w)T_f &= (m_{\text{Al}}c_{\text{Al}} + m_c c_w)T_c + m_h c_w T_h \\ T_f &= \boxed{\frac{(m_{\text{Al}}c_{\text{Al}} + m_c c_w)T_c + m_h c_w T_h}{m_{\text{Al}}c_{\text{Al}} + m_c c_w + m_h c_w}} \end{aligned}$$

P20.13 The rate of collection of energy is $\mathcal{P} = 550 \text{ W/m}^2 (6.00 \text{ m}^2) = 3300 \text{ W}$. The amount of energy required to raise the temperature of 1000 kg of water by 40.0°C is:

$$Q = mc\Delta T = 1000 \text{ kg}(4186 \text{ J/kg}\cdot^\circ\text{C})(40.0^\circ\text{C}) = 1.67 \times 10^8 \text{ J}$$

Thus, $\mathcal{P}\Delta t = 1.67 \times 10^8 \text{ J}$

or $\Delta t = \frac{1.67 \times 10^8 \text{ J}}{3300 \text{ W}} = \boxed{50.7 \text{ ks}} = 14.1 \text{ h}.$

***P20.14** Vessel one contains oxygen according to $PV = nRT$:

$$n_c = \frac{PV}{RT} = \frac{1.75(1.013 \times 10^5 \text{ Pa})16.8 \times 10^{-3} \text{ m}^3}{8.314 \text{ Nm/mol} \cdot \text{K} \cdot 300 \text{ K}} = 1.194 \text{ mol}.$$

Vessel two contains this much oxygen:

$$n_h = \frac{2.25(1.013 \times 10^5)22.4 \times 10^{-3}}{8.314(450)} \text{ mol} = 1.365 \text{ mol}.$$

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

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

$$n_c Mc(T_f - 300 \text{ K}) + n_h Mc(T_f - 450 \text{ K}) = 0$$

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

$$P = \frac{nRT}{V} = \frac{2.559 \text{ mol} \cdot 8.314 \text{ J} \cdot 380 \text{ K}}{\text{mol K}(22.4 + 16.8) \times 10^{-3} \text{ m}^3} = \boxed{2.06 \times 10^5 \text{ Pa}} = 2.04 \text{ atm}.$$

Section 20.3 Latent Heat

P20.15 The heat needed is the sum of the following terms:

$$Q_{\text{needed}} = (\text{heat to reach melting point}) + (\text{heat to melt})$$

$$+ (\text{heat to reach melting point}) + (\text{heat to vaporize}) + (\text{heat to reach } 110^\circ\text{C})$$

Thus, we have

$$Q_{\text{needed}} = 0.0400 \text{ kg} \left[(2090 \text{ J/kg} \cdot ^\circ\text{C})(10.0^\circ\text{C}) + (3.33 \times 10^5 \text{ J/kg}) \right]$$

$$+ (4186 \text{ J/kg} \cdot ^\circ\text{C})(100^\circ\text{C}) + (2.26 \times 10^6 \text{ J/kg}) + (2010 \text{ J/kg} \cdot ^\circ\text{C})(10.0^\circ\text{C})$$

$$Q_{\text{needed}} = \boxed{1.22 \times 10^5 \text{ J}}$$

P20.16 $Q_{\text{cold}} = -Q_{\text{hot}}$

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

$$[0.250 \text{ kg}(4186 \text{ J/kg} \cdot ^\circ\text{C}) + 0.0500 \text{ kg}(387 \text{ J/kg} \cdot ^\circ\text{C})](50.0^\circ\text{C} - 20.0^\circ\text{C})$$

$$= -m_s [-2.26 \times 10^6 \text{ J/kg} + (4186 \text{ J/kg} \cdot ^\circ\text{C})(50.0^\circ\text{C} - 100^\circ\text{C})]$$

$$m_s = \frac{3.20 \times 10^4 \text{ J}}{2.47 \times 10^6 \text{ J/kg}} = 0.0129 \text{ kg} = \boxed{12.9 \text{ g steam}}$$

P20.17 The bullet will not melt all the ice, so its final temperature is 0°C .

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

where m_w is the melt water mass

$$m_w = \frac{0.500(3.00 \times 10^{-3} \text{ kg})(240 \text{ m/s})^2 + 3.00 \times 10^{-3} \text{ kg}(128 \text{ J/kg}\cdot^\circ\text{C})(30.0^\circ\text{C})}{3.33 \times 10^5 \text{ J/kg}}$$

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

P20.18 (a) $Q_1 = \text{heat to melt all the ice} = (50.0 \times 10^{-3} \text{ kg})(3.33 \times 10^5 \text{ J/kg}) = 1.67 \times 10^4 \text{ J}$

$Q_2 = (\text{heat to raise temp of ice to } 100^\circ\text{C})$

$$= (50.0 \times 10^{-3} \text{ kg})(4186 \text{ J/kg}\cdot^\circ\text{C})(100^\circ\text{C}) = 2.09 \times 10^4 \text{ J}$$

Thus, the total heat to melt ice and raise temp to $100^\circ\text{C} = 3.76 \times 10^4 \text{ J}$

$$Q_3 = \frac{\text{heat available}}{\text{as steam condenses}} = (10.0 \times 10^{-3} \text{ kg})(2.26 \times 10^6 \text{ J/kg}) = 2.26 \times 10^4 \text{ J}$$

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

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

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

$$(50.0 \times 10^{-3} \text{ kg})(3.33 \times 10^5 \text{ J/kg}) + (50.0 \times 10^{-3} \text{ kg})(4186 \text{ J/kg}\cdot^\circ\text{C})(T_f - 0^\circ\text{C})$$

$$= -(10.0 \times 10^{-3} \text{ kg})(-2.26 \times 10^6 \text{ J/kg}) - (10.0 \times 10^{-3} \text{ kg})(4186 \text{ J/kg}\cdot^\circ\text{C})(T_f - 100^\circ\text{C})$$

From which, $\boxed{T_f = 40.4^\circ\text{C}}$.

(b) $Q_1 = \text{heat to melt all ice} = 1.67 \times 10^4 \text{ J}$ [See part (a)]

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

$$Q_3 = \frac{\text{heat given up as condensed}}{\text{steam cools to } 0^\circ\text{C}} = (10^{-3} \text{ kg})(4186 \text{ J/kg}\cdot^\circ\text{C})(100^\circ\text{C}) = 419 \text{ J}$$

Note that $Q_2 + Q_3 < Q_1$. Therefore, 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 .

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

$$\text{Thus, } m = \frac{2.68 \times 10^3 \text{ J}}{3.33 \times 10^5 \text{ J/kg}} = 8.04 \times 10^{-3} \text{ kg} = 8.04 \text{ g}.$$

Therefore, there is $\boxed{42.0 \text{ g of ice left over}}$.

584 Heat and the First Law of Thermodynamics

P20.19 $Q = m_{\text{Cu}} c_{\text{Cu}} \Delta T = m_{\text{N}_2} (L_{\text{vap}})_{\text{N}_2}$
 $1.00 \text{ kg}(0.0920 \text{ cal/g} \cdot ^\circ\text{C})(293 - 77.3)^\circ\text{C} = m(48.0 \text{ cal/g})$
 $m = \boxed{0.414 \text{ kg}}$

- *P20.20** The original gravitational energy of the hailstone-Earth system changes entirely into additional internal energy in the hailstone, to produce its phase change. No temperature change occurs, either in the hailstone, in the air, or in sidewalk. Then

$$mgy = mL$$

$$y = \frac{L}{g} = \frac{3.33 \times 10^5 \text{ J/kg}}{9.8 \text{ m/s}^2} \left(\frac{1 \text{ kg} \cdot \text{m}^2/\text{s}^2}{1 \text{ J}} \right) = \boxed{3.40 \times 10^4 \text{ m}}$$

- P20.21** (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 $\boxed{0^\circ\text{C}}$.
- (b) Let m represent the mass of ice that melts before the system reaches equilibrium at 0°C .

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

$$mL_f = -m_w c_w (0^\circ\text{C} - T_i)$$

$$m(3.33 \times 10^5 \text{ J/kg}) = -(0.600 \text{ kg})(4186 \text{ J/kg} \cdot ^\circ\text{C})(0^\circ\text{C} - 18.0^\circ\text{C})$$

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

- P20.22** The original kinetic energy all becomes thermal energy:

$$\frac{1}{2}mv^2 + \frac{1}{2}mv^2 = 2\left(\frac{1}{2}\right)(5.00 \times 10^{-3} \text{ kg})(500 \text{ m/s})^2 = 1.25 \text{ kJ.}$$

Raising the temperature to the melting point requires

$$Q = mc\Delta T = 10.0 \times 10^{-3} \text{ kg}(128 \text{ J/kg} \cdot ^\circ\text{C})(327^\circ\text{C} - 20.0^\circ\text{C}) = 393 \text{ J.}$$

Since $1250 \text{ J} > 393 \text{ J}$, the lead starts to melt. Melting it all requires

$$Q = mL = (10.0 \times 10^{-3} \text{ kg})(2.45 \times 10^4 \text{ J/kg}) = 245 \text{ J.}$$

Since $1250 \text{ J} > 393 + 245 \text{ J}$, it all melts. If we assume $\boxed{\text{liquid lead}}$ has the same specific heat as solid lead, the final temperature is given by

$$1.25 \times 10^3 \text{ J} = 393 \text{ J} + 245 \text{ J} + 10.0 \times 10^{-3} \text{ kg}(128 \text{ J/kg} \cdot ^\circ\text{C})(T_f - 327^\circ\text{C})$$

$$\boxed{T_f = 805^\circ\text{C}}$$

Section 20.4 Work and Heat in Thermodynamic Processes

P20.23 $W_{if} = -\int_i^f P dV$

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 .

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

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

$$W_{if} = -\frac{1}{3} \left[(5.00 \text{ atm/m}^6) (1.013 \times 10^5 \text{ Pa/atm}) \right] \left[(2.00 \text{ m}^3)^3 - (1.00 \text{ m}^3)^3 \right] = \boxed{-1.18 \text{ MJ}}$$

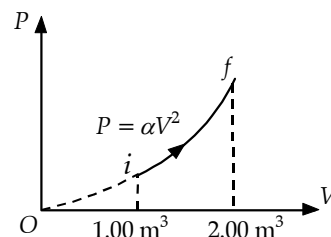


FIG. P20.23

P20.24 (a) $W = -\int P dV$

$$W = -(6.00 \times 10^6 \text{ Pa})(2.00 - 1.00) \text{ m}^3 + \\ -(4.00 \times 10^6 \text{ Pa})(3.00 - 2.00) \text{ m}^3 + \\ -(2.00 \times 10^6 \text{ Pa})(4.00 - 3.00) \text{ m}^3$$

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

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

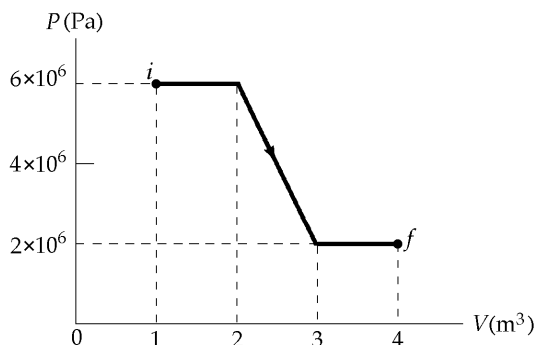


FIG. P20.24

P20.25 $W = -P \Delta V = -P \left(\frac{nR}{P} \right) (T_f - T_i) = -nR \Delta T = -(0.200)(8.314)(280) = \boxed{-466 \text{ J}}$

P20.26 $W = -\int_i^f P dV = -P \int_i^f dV = -P \Delta V = -nR \Delta T = \boxed{-nR(T_2 - T_1)}$

P20.27 During the heating process $P = \left(\frac{P_i}{V_i} \right) V$.

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

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

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

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

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

Section 20.5 The First Law of Thermodynamics

P20.28 (a) $W = -P\Delta V = -(0.800 \text{ atm})(-7.00 \text{ L})(1.013 \times 10^5 \text{ Pa/atm})(10^{-3} \text{ m}^3/\text{L}) = \boxed{+567 \text{ J}}$

(b) $\Delta E_{\text{int}} = Q + W = -400 \text{ J} + 567 \text{ J} = \boxed{167 \text{ J}}$

P20.29 $\Delta E_{\text{int}} = Q + W$

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

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

P20.30 (a) $Q = -W = \text{Area of triangle}$

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

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

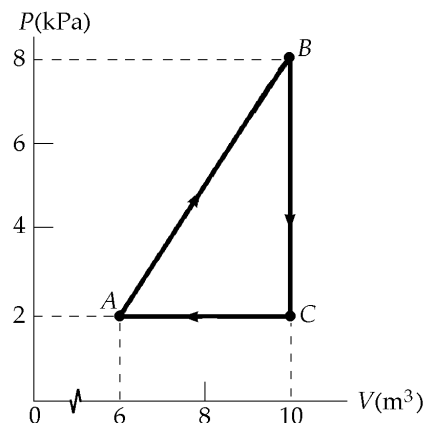


FIG. P20.30

P20.31

	Q	W	ΔE_{int}
BC	-	0	-
CA	-	+	-
AB	+	-	+

($Q = \Delta E_{\text{int}}$ since $W_{BC} = 0$)

($\Delta E_{\text{int}} < 0$ and $W > 0$, so $Q < 0$)

($W < 0$, $\Delta E_{\text{int}} > 0$ since $\Delta E_{\text{int}} < 0$ for $B \rightarrow C \rightarrow A$; so $Q > 0$)

P20.32

$W_{BC} = -P_B(V_C - V_B) = -3.00 \text{ atm}(0.400 - 0.0900) \text{ m}^3$
 $= -94.2 \text{ kJ}$

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

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

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

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

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

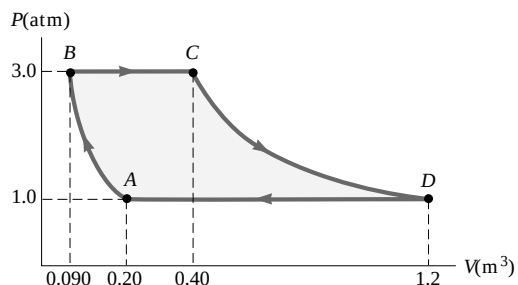


FIG. P20.32

***P20.33** The area of a true semicircle is $\frac{1}{2}\pi r^2$. The arrow in Figure P20.33 looks like a semicircle when the scale makes 1.2 L fill the same space as 100 kPa. Its area is

$$\frac{1}{2}\pi(2.4 \text{ L})(200 \text{ kPa}) = \frac{1}{2}\pi(2.4 \times 10^{-3} \text{ m}^3)(2 \times 10^5 \text{ N/m}^2).$$

The work on the gas is

$$\begin{aligned} W &= -\int_A^B P dV = -\text{area under the arch shown in the graph} \\ &= -\left(\frac{1}{2}\pi(2.4)(200) \text{ J} + 3 \times 10^5 \text{ N/m}^2 (4.8 \times 10^{-3} \text{ m}^3)\right) \\ &= -(754 \text{ J} + 1440 \text{ J}) = -2190 \text{ J} \\ \Delta E_{\text{int}} &= Q + W = 5790 \text{ J} - 2190 \text{ J} = \boxed{3.60 \text{ kJ}} \end{aligned}$$

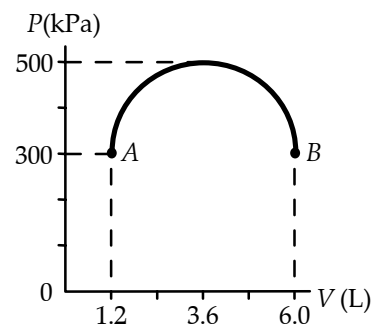


FIG. P20.33

Section 20.6 Some Applications of the First Law of Thermodynamics

P20.34 (a) $W = -nRT \ln\left(\frac{V_f}{V_i}\right) = -P_f V_f \ln\left(\frac{V_f}{V_i}\right)$

so $V_i = V_f \exp\left(+\frac{W}{P_f V_f}\right) = (0.0250) \exp\left[\frac{-3000}{0.0250(1.013 \times 10^5)}\right] = \boxed{0.00765 \text{ m}^3}$

(b) $T_f = \frac{P_f V_f}{nR} = \frac{1.013 \times 10^5 \text{ Pa}(0.0250 \text{ m}^3)}{1.00 \text{ mol}(8.314 \text{ J/K} \cdot \text{mol})} = \boxed{305 \text{ K}}$

P20.35 (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) $\frac{V_1}{T_1} = \frac{V_2}{T_2}$

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

P20.36 (a) $W = -P\Delta V = -P[3\alpha V\Delta T]$

$$= -(1.013 \times 10^5 \text{ N/m}^2) \left[3(24.0 \times 10^{-6} \text{ }^\circ\text{C}^{-1}) \left(\frac{1.00 \text{ kg}}{2.70 \times 10^3 \text{ kg/m}^3} \right) (18.0^\circ\text{C}) \right]$$

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

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

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

$$\text{P20.37} \quad W = -P\Delta V = -P(V_s - V_w) = -\frac{P(nRT)}{P} + P\left[\frac{18.0 \text{ g}}{(1.00 \text{ g/cm}^3)(10^6 \text{ cm}^3/\text{m}^3)}\right]$$

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

$$Q = mL_v = 0.0180 \text{ kg}(2.26 \times 10^6 \text{ J/kg}) = 40.7 \text{ kJ}$$

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

- P20.38** (a) The work done during each step of the cycle equals the negative of the area under that segment of the PV curve.

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

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

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

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

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

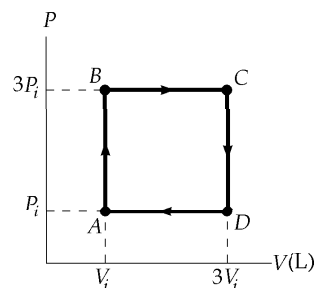


FIG. P20.38

P20.39 (a) $P_iV_i = P_fV_f = nRT = 2.00 \text{ mol}(8.314 \text{ J/K}\cdot\text{mol})(300 \text{ K}) = 4.99 \times 10^3 \text{ J}$

$$V_i = \frac{nRT}{P_i} = \frac{4.99 \times 10^3 \text{ J}}{0.400 \text{ atm}}$$

$$V_f = \frac{nRT}{P_f} = \frac{4.99 \times 10^3 \text{ J}}{1.20 \text{ atm}} = \frac{1}{3}V_i = \boxed{0.0410 \text{ m}^3}$$

(b) $W = -\int P dV = -nRT \ln\left(\frac{V_f}{V_i}\right) = -(4.99 \times 10^3) \ln\left(\frac{1}{3}\right) = \boxed{+5.48 \text{ kJ}}$

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

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

P20.40 $\Delta E_{\text{int}, ABC} = \Delta E_{\text{int}, AC}$ (conservation of energy)

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

$$Q_{ABC} = 800 \text{ J} + 500 \text{ J} = \boxed{1300 \text{ J}}$$

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

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

(+ 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) $\Delta E_{\text{int}, CD} = \Delta E_{\text{int}, CDA} - \Delta E_{\text{int}, DA} = -800 \text{ J} - 500 \text{ J} = -1300 \text{ J}$

$$\text{and } Q_{CD} = \Delta E_{\text{int}, CD} - W_{CD} = -1300 \text{ J} - 100 \text{ J} = \boxed{-1400 \text{ J}}$$

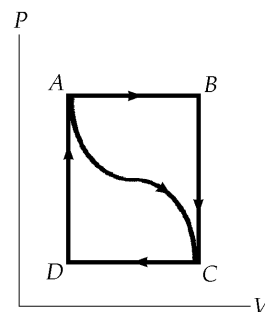


FIG. P20.40

Section 20.7 Energy Transfer Mechanisms

P20.41 $\mathcal{P} = kA \frac{\Delta T}{L}$

$$k = \frac{\mathcal{P}L}{A\Delta T} = \frac{10.0 \text{ W}(0.0400 \text{ m})}{1.20 \text{ m}^2(15.0^\circ\text{C})} = \boxed{2.22 \times 10^{-2} \text{ W/m}\cdot^\circ\text{C}}$$

P20.42 $\mathcal{P} = \frac{kA\Delta T}{L} = \frac{(0.800 \text{ W/m}\cdot^\circ\text{C})(3.00 \text{ m}^2)(25.0^\circ\text{C})}{6.00 \times 10^{-3} \text{ m}} = 1.00 \times 10^4 \text{ W} = \boxed{10.0 \text{ kW}}$

P20.43 In the steady state condition, $\mathcal{P}_{\text{Au}} = \mathcal{P}_{\text{Ag}}$
so that $k_{\text{Au}}A_{\text{Au}}\left(\frac{\Delta T}{\Delta x}\right)_{\text{Au}} = k_{\text{Ag}}A_{\text{Ag}}\left(\frac{\Delta T}{\Delta x}\right)_{\text{Ag}}$

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

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

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

and

where T is the temperature of the junction.

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

And

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

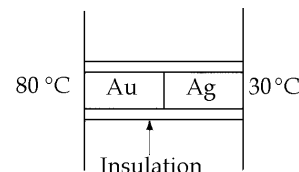


FIG. P20.43

P20.44 $\mathcal{P} = \frac{A\Delta T}{\sum_i \frac{L_i}{k_i}} = \frac{(6.00 \text{ m}^2)(50.0^\circ\text{C})}{\left[2(4.00 \times 10^{-3} \text{ m})\right]/[0.800 \text{ W/m}\cdot^\circ\text{C}] + [5.00 \times 10^{-3} \text{ m}]/[0.0234 \text{ W/m}\cdot^\circ\text{C}]} = \boxed{1.34 \text{ kW}}$

***P20.45** We suppose that the area of the transistor is so small that energy flow by heat from the transistor directly to the air is negligible compared to energy conduction through the mica.

$$\mathcal{P} = kA \frac{(T_h - T_c)}{L}$$

$$T_h = T_c + \frac{\mathcal{P}L}{kA} = 35.0^\circ\text{C} + \frac{1.50 \text{ W}(0.0852 \times 10^{-3} \text{ m})}{(0.0753 \text{ W/m}\cdot^\circ\text{C})(8.25 \times 6.25)10^{-6} \text{ m}^2} = \boxed{67.9^\circ\text{C}}$$

P20.46 From Table 20.4,

(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 $\frac{1.85}{0.890} = \boxed{2.08}$.

$$\begin{aligned} \text{P20.47} \quad \mathcal{P} &= \sigma A e T^4 = \left(5.669 \times 10^{-8} \text{ W/m}^2 \cdot \text{K}^4 \right) \left[4\pi (6.96 \times 10^8 \text{ m})^2 \right] (0.965) (5800 \text{ K})^4 \\ \mathcal{P} &= \boxed{3.77 \times 10^{26} \text{ W}} \end{aligned}$$

P20.48 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

$$\mathcal{P} = \left(5.67 \times 10^{-8} \text{ W/m}^2 \cdot \text{K}^4 \right) (0.81 \text{ m}^2) (0.80) (373 \text{ K})^4 = 710 \text{ W} \quad \boxed{\sim 10^3 \text{ W}}.$$

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

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

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

$$\begin{aligned} Q &= mc(T_f - T_i) \\ \mathcal{P} &= \frac{dQ}{dt} = mc \frac{dT_f}{dt} - 0 \\ \frac{dT_f}{dt} &= \frac{\mathcal{P}}{mc} = \frac{710 \text{ J/s}}{(4 \text{ kg})(0.6 \cdot 4186 \text{ J/kg} \cdot ^\circ\text{C})} = 0.07 \text{ } ^\circ\text{C/s} \quad \boxed{\sim 10^{-1} \text{ K/s}} \end{aligned}$$

$$\begin{aligned} \text{P20.49} \quad \mathcal{P} &= \sigma A e T^4 \\ 2.00 \text{ W} &= \left(5.67 \times 10^{-8} \text{ W/m}^2 \cdot \text{K}^4 \right) (0.250 \times 10^{-6} \text{ m}^2) (0.950) T^4 \\ T &= \left(1.49 \times 10^{14} \text{ K}^4 \right)^{1/4} = \boxed{3.49 \times 10^3 \text{ K}} \end{aligned}$$

P20.50 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:

$$\begin{aligned} 1000 \text{ W} &= \left(5.67 \times 10^{-8} \text{ W/m}^2 \cdot \text{K}^4 \right) (1.00 \text{ m}^2) (1.00) T^4 \\ T &= \left(1.76 \times 10^{10} \text{ K}^4 \right)^{1/4} = \boxed{364 \text{ K}} \quad (\text{You can cook an egg on it.}) \end{aligned}$$

P20.51 The sphere of radius R absorbs sunlight over the area of its day hemisphere, projected as a flat circle perpendicular to the light: πR^2 . It radiates in all directions, over area $4\pi R^2$. Then, in steady state,

$$\begin{aligned} \mathcal{P}_{\text{in}} &= \mathcal{P}_{\text{out}} \\ e(1340 \text{ W/m}^2) \pi R^2 &= e\sigma(4\pi R^2) T^4 \end{aligned}$$

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

$$\text{Therefore, } T = \left[\frac{1340 \text{ W/m}^2}{4(5.67 \times 10^{-8} \text{ W/m}^2 \cdot \text{K}^4)} \right]^{1/4} = \boxed{277 \text{ K}} = 4^\circ\text{C}.$$

Additional Problems

- P20.52** 77.3 K = -195.8°C is the boiling point of nitrogen. It gains no heat to warm as a liquid, but gains heat to vaporize:

$$Q = mL_v = (0.100 \text{ kg})(2.01 \times 10^5 \text{ J/kg}) = 2.01 \times 10^4 \text{ J}.$$

The water first loses heat by cooling. Before it starts to freeze, it can lose

$$Q = mc\Delta T = (0.200 \text{ kg})(4186 \text{ J/kg}\cdot^\circ\text{C})(5.00^\circ\text{C}) = 4.19 \times 10^3 \text{ J}.$$

The remaining $(2.01 \times 10^4 - 4.19 \times 10^3) \text{ J} = 1.59 \times 10^4 \text{ J}$ that is removed from the water can freeze a mass x of water:

$$\begin{aligned} Q &= mL_f \\ 1.59 \times 10^4 \text{ J} &= x(3.33 \times 10^5 \text{ J/kg}) \\ x &= 0.0477 \text{ kg} = \boxed{47.7 \text{ g}} \text{ of water can be frozen} \end{aligned}$$

- P20.53** 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 $f = \mu n = \mu mg = 0.200(75.0 \text{ kg})(9.80 \text{ m/s}^2) = 147 \text{ N}$

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

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

- P20.54** (a) The energy thus far gained by the copper equals the energy loss by the silver. Your down parka is an excellent insulator.

$$\begin{aligned} Q_{\text{cold}} &= -Q_{\text{hot}} \\ \text{or } m_{\text{Cu}}c_{\text{Cu}}(T_f - T_i)_{\text{Cu}} &= -m_{\text{Ag}}c_{\text{Ag}}(T_f - T_i)_{\text{Ag}} \\ (9.00 \text{ g})(387 \text{ J/kg}\cdot^\circ\text{C})(16.0^\circ\text{C}) &= -(14.0 \text{ g})(234 \text{ J/kg}\cdot^\circ\text{C})(T_f - 30.0^\circ\text{C})_{\text{Ag}} \\ (T_f - 30.0^\circ\text{C})_{\text{Ag}} &= -17.0^\circ\text{C} \\ \text{so } T_{f, \text{Ag}} &= \boxed{13.0^\circ\text{C}}. \end{aligned}$$

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

$$\begin{aligned} \left(\frac{dT}{dt}\right)_{\text{Ag}} &= -\frac{m_{\text{Cu}}c_{\text{Cu}}}{m_{\text{Ag}}c_{\text{Ag}}}\left(\frac{dT}{dt}\right)_{\text{Cu}} = -\frac{9.00 \text{ g}(387 \text{ J/kg}\cdot^\circ\text{C})}{14.0 \text{ g}(234 \text{ J/kg}\cdot^\circ\text{C})}(+0.500^\circ\text{C/s}) \\ \left(\frac{dT}{dt}\right)_{\text{Ag}} &= \boxed{-0.532^\circ\text{C/s}} \text{ (negative sign } \Rightarrow \text{ decreasing temperature)} \end{aligned}$$

- P20.55** (a) Before conduction has time to become important, the energy lost by the rod equals the energy gained by the helium. Therefore,

$$\begin{aligned} (mL_v)_{\text{He}} &= (mc|\Delta T|)_{\text{Al}} \\ \text{or } (\rho VL_v)_{\text{He}} &= (\rho Vc|\Delta T|)_{\text{Al}} \\ \text{so } V_{\text{He}} &= \frac{(\rho Vc|\Delta T|)_{\text{Al}}}{(\rho L_v)_{\text{He}}} \\ V_{\text{He}} &= \frac{(2.70 \text{ g/cm}^3)(62.5 \text{ cm}^3)(0.210 \text{ cal/g}\cdot^\circ\text{C})(295.8^\circ\text{C})}{(0.125 \text{ g/cm}^3)(2.09 \times 10^4 \text{ J/kg})(1.00 \text{ cal/4.186 J})(1.00 \text{ kg/1000 g})} \\ V_{\text{He}} &= 1.68 \times 10^4 \text{ cm}^3 = \boxed{16.8 \text{ liters}} \end{aligned}$$

- (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

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

- *P20.56** At the equilibrium temperature T_{eq} the diameters of the sphere and ring are equal:

$$\begin{aligned} d_s + d_s \alpha_{\text{Al}}(T_{\text{eq}} - T_i) &= d_r + d_r \alpha_{\text{Cu}}(T_{\text{eq}} - 15^\circ\text{C}) \\ 5.01 \text{ cm} + 5.01 \text{ cm}(2.40 \times 10^{-5} \text{ } 1/^\circ\text{C})(T_{\text{eq}} - T_i) &= 5.00 \text{ cm} + 5.00 \text{ cm}(1.70 \times 10^{-5} \text{ } 1/^\circ\text{C})(T_{\text{eq}} - 15^\circ\text{C}) \\ 0.01^\circ\text{C} + 1.2024 \times 10^{-4} T_{\text{eq}} - 1.2024 \times 10^{-4} T_i &= 8.5 \times 10^{-5} T_{\text{eq}} - 1.275 \times 10^{-3}^\circ\text{C} \\ 1.1275 \times 10^{-2}^\circ\text{C} + 3.524 \times 10^{-5} T_{\text{eq}} &= 1.2024 \times 10^{-4} T_i \\ 319.95^\circ\text{C} + T_{\text{eq}} &= 3.4120 T_i \end{aligned}$$

At the equilibrium temperature, the energy lost is equal to the energy gained:

$$\begin{aligned} m_s c_{\text{Al}}(T_{\text{eq}} - T_i) &= -m_r c_{\text{Cu}}(T_{\text{eq}} - 15^\circ\text{C}) \\ 10.9 \text{ g } 0.215 \text{ cal/g}\cdot^\circ\text{C}(T_{\text{eq}} - T_i) &= -25 \text{ g } 0.0924 \text{ cal/g}\cdot^\circ\text{C}(T_{\text{eq}} - 15^\circ\text{C}) \\ 2.3435 T_{\text{eq}} - 2.3435 T_i &= 34.65^\circ\text{C} - 2.31 T_{\text{eq}} \\ 4.6535 T_{\text{eq}} &= 34.65^\circ\text{C} + 2.3435 T_i \end{aligned}$$

Solving by substitution,

$$\begin{aligned} 4.6535(3.4120 T_i - 319.95^\circ\text{C}) &= 34.65^\circ\text{C} + 2.3435 T_i \\ 15.8777 T_i - 1488.89^\circ\text{C} &= 34.65^\circ\text{C} + 2.3435 T_i \end{aligned}$$

$$(b) \quad T_i = \frac{1523.54^\circ\text{C}}{13.534} = \boxed{113^\circ\text{C}}$$

$$(a) \quad T_{\text{eq}} = -319.95 + 3.4120(112.57) = \boxed{64.1^\circ\text{C}}$$

P20.57 $Q = mc\Delta T = (\rho V)c\Delta T$ so that when a constant temperature difference ΔT is maintained,

the rate of adding energy to the liquid is $\mathcal{P} = \frac{dQ}{dt} = \rho \left(\frac{dV}{dt} \right) c\Delta T = \rho R c \Delta T$

and the specific heat of the liquid is $c = \boxed{\frac{\mathcal{P}}{\rho R \Delta T}}$.

P20.58 (a) Work done by the gas is the negative of the area under the PV curve

$$W = -P_i \left(\frac{V_i}{2} - V_i \right) = \boxed{+\frac{P_i V_i}{2}}.$$

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

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

$$\begin{aligned} \text{and } W &= - \int_{V_i}^{V_i/4} \left(\frac{dV}{V} \right) (P_i V_i) = -P_i V_i \ln \left(\frac{V_i/4}{V_i} \right) = P_i V_i \ln 4 \\ &= \boxed{+1.39 P_i V_i} \end{aligned}$$

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

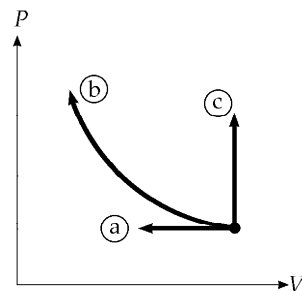


FIG. P20.58

P20.59 Call the initial pressure P_1 . In the constant volume process $1 \rightarrow 2$ the work is zero.

$$\begin{aligned} P_1 V_1 &= nRT_1 \\ P_2 V_2 &= nRT_2 \end{aligned}$$

$$\text{so } \frac{P_2 V_2}{P_1 V_1} = \frac{T_2}{T_1}; T_2 = 300 \text{ K} \left(\frac{1}{4} \right) = 75.0 \text{ K}$$

Now in $2 \rightarrow 3$

$$W = - \int_2^3 P dV = -P_2 (V_3 - V_2) = -P_3 V_3 + P_2 V_2$$

$$W = -nRT_3 + nRT_2 = -(1.00 \text{ mol})(8.314 \text{ J/mol} \cdot \text{K})(300 \text{ K} - 75.0 \text{ K})$$

$$W = \boxed{-1.87 \text{ kJ}}$$

***P20.60** The initial moment of inertia of the disk is

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

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

$$\begin{aligned} I_i\omega_i &= I_f\omega_f \\ \frac{1}{2}MR_i^2\omega_i &= \frac{1}{2}MR_f^2\omega_f = \frac{1}{2}MR_i^2(1-\alpha|\Delta T|)^2\omega_f \\ \omega_f &= \omega_i \frac{1}{(1-\alpha|\Delta T|)^2} = 25\text{ rad/s} \frac{1}{[1-(17 \times 10^{-6}\text{ 1/}^\circ\text{C})830^\circ\text{C}]^2} = 25.7207\text{ rad/s} \end{aligned}$$

(a) The kinetic energy increases by

$$\begin{aligned} \frac{1}{2}I_f\omega_f^2 - \frac{1}{2}I_i\omega_i^2 &= \frac{1}{2}I_i\omega_i\omega_f - \frac{1}{2}I_i\omega_i^2 = \frac{1}{2}I_i\omega_i(\omega_f - \omega_i) \\ &= \frac{1}{2}1.033 \times 10^{10}\text{ kg}\cdot\text{m}^2(25\text{ rad/s})0.7207\text{ rad/s} = \boxed{9.31 \times 10^{10}\text{ J}} \end{aligned}$$

(b) $\Delta E_{\text{int}} = mc\Delta T = 2.64 \times 10^7\text{ kg}(387\text{ J/kg}\cdot^\circ\text{C})(20^\circ\text{C} - 850^\circ\text{C}) = \boxed{-8.47 \times 10^{12}\text{ J}}$

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

***P20.61** The loss of mechanical energy is

$$\begin{aligned} \frac{1}{2}mv_i^2 + \frac{GM_E m}{R_E} &= \frac{1}{2}670\text{ kg}(1.4 \times 10^4\text{ m/s})^2 + \frac{6.67 \times 10^{-11}\text{ Nm}^2}{\text{kg}^2} \frac{5.98 \times 10^{24}\text{ kg}}{6.37 \times 10^6\text{ m}} \\ &= 6.57 \times 10^{10}\text{ J} + 4.20 \times 10^{10}\text{ J} = 1.08 \times 10^{11}\text{ J} \end{aligned}$$

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

$$mc\Delta T = 670\text{ kg} 900 \frac{\text{J}}{\text{kg}\cdot^\circ\text{C}} (660 - (-15^\circ\text{C})) = 4.07 \times 10^8\text{ J}.$$

To melt it, $mL = 670\text{ kg} 3.97 \times 10^5\text{ J/kg} = 2.66 \times 10^8\text{ J}$. To raise it to the boiling point, $mc\Delta T = 670(1\,170)(2\,450 - 600)\text{J} = 1.40 \times 10^9\text{ J}$. To boil it, $mL = 670\text{ kg} 1.14 \times 10^7\text{ J/kg} = 7.64 \times 10^9\text{ J}$. Then

$$\begin{aligned} 5.38 \times 10^{10}\text{ J} &= 9.71 \times 10^9\text{ J} + 670(1\,170)(T_f - 2\,450^\circ\text{C})\text{J}/^\circ\text{C} \\ T_f &= \boxed{5.87 \times 10^4^\circ\text{C}} \end{aligned}$$

P20.62 (a) $Fv = (50.0 \text{ N})(40.0 \text{ m/s}) = \boxed{2\,000 \text{ W}}$

- (b) Energy received by each object is $(1\,000 \text{ W})(10 \text{ s}) = 10^4 \text{ J} = 2\,389 \text{ cal}$. The specific heat of iron is $0.107 \text{ cal/g}\cdot^\circ\text{C}$, so the heat capacity of each object is $5.00 \times 10^3 \times 0.107 = 535.0 \text{ cal/}^\circ\text{C}$.

$$\Delta T = \frac{2\,389 \text{ cal}}{535.0 \text{ cal/}^\circ\text{C}} = \boxed{4.47^\circ\text{C}}$$

P20.63 The power incident on the solar collector is

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

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

$$Q = 0.500 \text{ kg} [(4\,186 \text{ J/kg}\cdot^\circ\text{C})(80.0^\circ\text{C}) + 2.26 \times 10^6 \text{ J/kg}] = 1.30 \times 10^6 \text{ J}.$$

The time interval required is $\Delta t = \frac{Q}{\mathcal{P}_c} = \frac{1.30 \times 10^6 \text{ J}}{67.9 \text{ W}} = \boxed{5.31 \text{ h}}$.

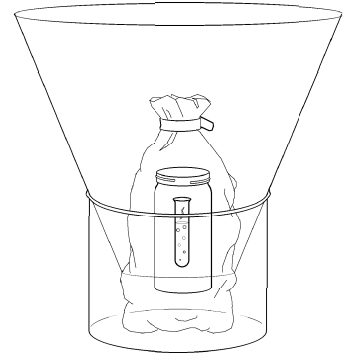


FIG. P20.63

P20.64 From $Q = mL_V$ the rate of boiling is described by

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

Model the water vapor as an ideal gas

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

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

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

$$v = \frac{\mathcal{P} RT}{ML_V P_0 A} = \frac{1\,000 \text{ W}(8.314 \text{ J/mol}\cdot\text{K})(373 \text{ K})}{(0.0180 \text{ kg/mol})(2.26 \times 10^6 \text{ J/kg})(1.013 \times 10^5 \text{ N/m}^2)(2.00 \times 10^{-4} \text{ m}^2)}$$

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

P20.65 Energy goes in at a constant rate $\mathcal{P}$. For the period from

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

$$\mathcal{P}(10.0 \text{ min}) = (10 \text{ kg} + m_i)(4186 \text{ J/kg}\cdot^\circ\text{C})(2.00^\circ\text{C} - 0^\circ\text{C})$$

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

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

$$\mathcal{P}(50.0 \text{ min}) = m_i(3.33 \times 10^5 \text{ J/kg})$$

Substitute $\mathcal{P} = \frac{m_i(3.33 \times 10^5 \text{ J/kg})}{50.0 \text{ min}}$ into Equation (1) to find

$$\frac{m_i(3.33 \times 10^5 \text{ J/kg})}{50.0} = 83.7 \text{ kJ} + (8.37 \text{ kJ/kg})m_i$$

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

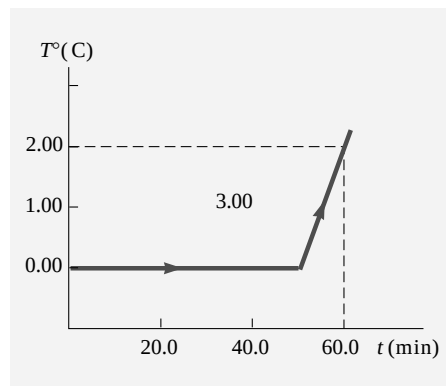


FIG. P20.65

P20.66 (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

$$m_{\text{ice}} = \frac{Q}{L_f} = \frac{K_i}{L_f} = \frac{5.00 \text{ J}}{3.33 \times 10^5 \text{ J/kg}} = 1.50 \times 10^{-5} \text{ kg} = \boxed{15.0 \text{ mg}}.$$

For the block: $Q = 0$ (no energy flows by heat since there is no temperature difference)

$$W = -5.00 \text{ J}$$

$$\Delta E_{\text{int}} = 0 \text{ (no temperature change)}$$

and

$$\Delta K = -5.00 \text{ J}$$

For the ice,

$$Q = 0$$

$$W = +5.00 \text{ J}$$

$$\Delta E_{\text{int}} = +5.00 \text{ J}$$

and

$$\Delta K = 0$$

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

For the block of ice: $Q = 0$; $\Delta E_{\text{int}} = +5.00 \text{ J}$; $\Delta K = -5.00 \text{ J}$

so $W = 0$.

For the copper, nothing happens: $Q = \Delta E_{\text{int}} = \Delta K = W = 0$.

continued on next page

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

$${}^{\text{“}}Q^{\text{”}} = mc\Delta T: \quad \Delta T = \frac{{}^{\text{“}}Q^{\text{”}}}{mc} = \frac{5.00 \text{ J}}{2(1.60 \text{ kg})(387 \text{ J/kg}\cdot^{\circ}\text{C})} = \boxed{4.04 \times 10^{-3} {}^{\circ}\text{C}}$$

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.

P20.67 $A = A_{\text{end walls}} + A_{\text{ends of attic}} + A_{\text{side walls}} + A_{\text{roof}}$

$$\begin{aligned} A &= 2(8.00 \text{ m} \times 5.00 \text{ m}) + 2\left[2 \times \frac{1}{2} \times 4.00 \text{ m} \times (4.00 \text{ m}) \tan 37.0^{\circ}\right] \\ &\quad + 2(10.0 \text{ m} \times 5.00 \text{ m}) + 2(10.0 \text{ m})\left(\frac{4.00 \text{ m}}{\cos 37.0^{\circ}}\right) \\ A &= 304 \text{ m}^2 \\ \mathcal{P} &= \frac{kA\Delta T}{L} = \frac{(4.80 \times 10^{-4} \text{ kW/m}\cdot^{\circ}\text{C})(304 \text{ m}^2)(25.0^{\circ}\text{C})}{0.210 \text{ m}} = 17.4 \text{ kW} = 4.15 \text{ kcal/s} \end{aligned}$$

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 $\frac{3.59 \times 10^5 \text{ kcal/day}}{9\,300 \text{ kcal/m}^3} = \boxed{38.6 \text{ m}^3/\text{day}}$.

P20.68 $\frac{L\rho A dx}{dt} = kA\left(\frac{\Delta T}{x}\right)$

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

$$L\rho \frac{x^2}{2} \Big|_{4.00}^{8.00} = k\Delta T \Delta t$$

$$(3.33 \times 10^5 \text{ J/kg})(917 \text{ kg/m}^3) \left(\frac{(0.0800 \text{ m})^2 - (0.0400 \text{ m})^2}{2} \right) = (2.00 \text{ W/m}\cdot^{\circ}\text{C})(10.0^{\circ}\text{C})\Delta t$$

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

P20.69 $W = W_{AB} + W_{BC} + W_{CD} + W_{DA}$

$$W = -\int_A^B P dV - \int_B^C P dV - \int_C^D P dV - \int_D^A P dV$$

$$W = -nRT_1 \int_A^B \frac{dV}{V} - P_2 \int_B^C dV - nRT_2 \int_C^D \frac{dV}{V} - P_1 \int_D^A dV$$

$$W = -nRT_1 \ln\left(\frac{V_B}{V_1}\right) - P_2(V_C - V_B) - nRT_2 \ln\left(\frac{V_2}{V_C}\right) - P_1(V_A - V_D)$$

Now $P_1 V_A = P_2 V_B$ and $P_2 V_C = P_1 V_D$, so only the logarithmic terms do not cancel out.

Also, $\frac{V_B}{V_1} = \frac{P_1}{P_2}$ and $\frac{V_2}{V_C} = \frac{P_2}{P_1}$

$$\sum W = -nRT_1 \ln\left(\frac{P_1}{P_2}\right) - nRT_2 \ln\left(\frac{P_2}{P_1}\right) = +nRT_1 \ln\left(\frac{P_2}{P_1}\right) - nRT_2 \ln\left(\frac{P_2}{P_1}\right) = -nR(T_2 - T_1) \ln\left(\frac{P_2}{P_1}\right)$$

Moreover $P_1 V_2 = nRT_2$ and $P_1 V_1 = nRT_1$

$$\sum W = \left[-P_1(V_2 - V_1) \ln\left(\frac{P_2}{P_1}\right) \right]$$

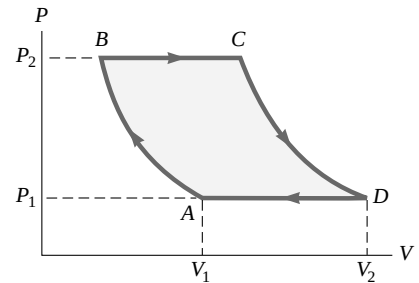


FIG. P20.69

P20.70 For a cylindrical shell of radius r , height L , and thickness dr , the equation for thermal conduction,

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

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

$$dT = -\frac{dQ}{dt} \left(\frac{1}{2\pi kL} \right) \left(\frac{dr}{r} \right) \quad \text{and} \quad T_b - T_a = -\frac{dQ}{dt} \left(\frac{1}{2\pi kL} \right) \ln\left(\frac{b}{a}\right)$$

But $T_a > T_b$, so

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

P20.71 From problem 70, the rate of energy flow through the wall is

$$\begin{aligned} \frac{dQ}{dt} &= \frac{2\pi kL(T_a - T_b)}{\ln(b/a)} \\ \frac{dQ}{dt} &= \frac{2\pi(4.00 \times 10^{-5} \text{ cal/s} \cdot \text{cm} \cdot ^\circ\text{C})(3500 \text{ cm})(60.0^\circ\text{C})}{\ln(256 \text{ cm}/250 \text{ cm})} \\ \frac{dQ}{dt} &= 2.23 \times 10^3 \text{ cal/s} = \boxed{9.32 \text{ kW}} \end{aligned}$$

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.

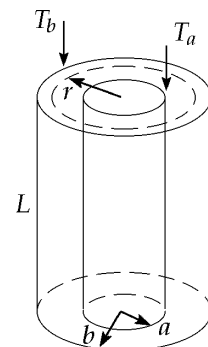


FIG. P20.71

P20.72 $Q_{\text{cold}} = -Q_{\text{hot}}$

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

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

$$(0.200 \text{ kg})c_{\text{Al}}(+39.3^\circ\text{C}) = -[0.400 \text{ kg}(4186 \text{ J/kg}\cdot^\circ\text{C}) + 0.0400 \text{ kg}(630 \text{ J/kg}\cdot^\circ\text{C})](-3.70^\circ\text{C})$$

$$c_{\text{Al}} = \frac{6.29 \times 10^3 \text{ J}}{7.86 \text{ kg}\cdot^\circ\text{C}} = \boxed{800 \text{ J/kg}\cdot^\circ\text{C}}$$

***P20.73** (a) $\mathcal{P} = \sigma A e T^4 = (5.67 \times 10^{-8} \text{ W/m}^2\text{K}^4) 5.1 \times 10^{14} \text{ m}^2 (0.965)(5800 \text{ K})^4 = \boxed{3.16 \times 10^{22} \text{ W}}$

(b) $T_{\text{avg}} = 0.1(4800 \text{ K}) + 0.9(5890 \text{ K}) = \boxed{5.78 \times 10^3 \text{ K}}$

This is cooler than 5800 K by $\frac{5800 - 5781}{5800} = 0.327\%$.

(c) $\mathcal{P} = (5.67 \times 10^{-8} \text{ W/m}^2\text{K}^4) 0.1(5.1 \times 10^{14} \text{ m}^2) 0.965(4800 \text{ K})^4$
 $+ 5.67 \times 10^{-8} \text{ W} 0.9(5.1 \times 10^{14}) 0.965(5890)^4 = \boxed{3.17 \times 10^{22} \text{ W}}$

This is larger than $3.158 \times 10^{22} \text{ W}$ by $\frac{1.29 \times 10^{20} \text{ W}}{3.16 \times 10^{22} \text{ W}} = 0.408\%$.

ANSWERS TO EVEN PROBLEMS

P20.2 0.105°C

P20.22 liquid lead at 805°C

P20.4 87.0°C

P20.24 (a) -12.0 MJ ; (b) $+12.0 \text{ MJ}$

P20.6 The energy input to the water is 6.70 times larger than the laser output of 40.0 kJ .

P20.26 $-nR(T_2 - T_1)$

P20.8 88.2 W

P20.28 (a) 567 J ; (b) 167 J

P20.10 (a) 25.8°C ; (b) no

P20.30 (a) 12.0 kJ ; (b) -12.0 kJ

P20.12 $T_f = \frac{(m_{\text{Al}}c_{\text{Al}} + m_c c_w)T_c + m_h c_w T_h}{m_{\text{Al}}c_{\text{Al}} + m_c c_w + m_h c_w}$

P20.32 42.9 kJ

P20.34 (a) 7.65 L ; (b) 305 K

P20.14 (a) 380 K ; (b) 206 kPa

P20.36 (a) -48.6 mJ ; (b) 16.2 kJ ; (c) 16.2 kJ

P20.16 12.9 g

P20.38 (a) $-4P_i V_i$; (b) $+4P_i V_i$; (c) -9.08 kJ

P20.18 (a) all the ice melts; 40.4°C ;
(b) 8.04 g melts; 0°C

P20.40 (a) 1300 J ; (b) 100 J ; (c) -900 J ; (d) -1400 J

P20.20 34.0 km

P20.42 10.0 kW

600 *Heat and the First Law of Thermodynamics***P20.44** 1.34 kW**P20.46** (a) $0.890 \text{ ft}^2 \cdot ^\circ\text{F} \cdot \text{h/Btu}$; (b) $1.85 \frac{\text{ft}^2 \cdot ^\circ\text{F} \cdot \text{h}}{\text{Btu}}$;
(c) 2.08**P20.48** (a) $\sim 10^3 \text{ W}$; (b) $\sim -10^{-1} \text{ K/s}$ **P20.50** 364 K**P20.52** 47.7 g**P20.54** (a) 13.0°C ; (b) -0.532°C/s **P20.56** (a) 64.1°C ; (b) 113°C **P20.58** see the solution (a) $\frac{1}{2}P_iV_i$; (b) $1.39P_iV_i$; (c) 0**P20.60** (a) $9.31 \times 10^{10} \text{ J}$; (b) $-8.47 \times 10^{12} \text{ J}$;
(c) $8.38 \times 10^{12} \text{ J}$ **P20.62** (a) 2 000 W; (b) 4.47°C **P20.64** 3.76 m/s**P20.66** (a) 15.0 mg; block: $Q = 0$; $W = -5.00 \text{ J}$;
 $\Delta E_{\text{int}} = 0$; $\Delta K = -5.00 \text{ J}$;
ice: $Q = 0$; $W = 5.00 \text{ J}$; $\Delta E_{\text{int}} = 5.00 \text{ J}$; $\Delta K = 0$;
(b) 15.0 mg; block: $Q = 0$; $W = 0$;
 $\Delta E_{\text{int}} = 5.00 \text{ J}$; $\Delta K = -5.00 \text{ J}$;
metal: $Q = 0$; $W = 0$; $\Delta E_{\text{int}} = 0$; $\Delta K = 0$;
(c) 0.00404°C ; moving block: $Q = 0$;
 $W = -2.50 \text{ J}$; $\Delta E_{\text{int}} = 2.50 \text{ J}$; $\Delta K = -5.00 \text{ J}$;
stationary block: $Q = 0$; $W = 2.50 \text{ J}$;
 $\Delta E_{\text{int}} = 2.50 \text{ J}$; $\Delta K = 0$ **P20.68** 10.2 h**P20.70** see the solution**P20.72** 800 J/kg $\cdot^\circ\text{C}$