(E) The answer depends on the thermal conductivity, k, of the cylinders.

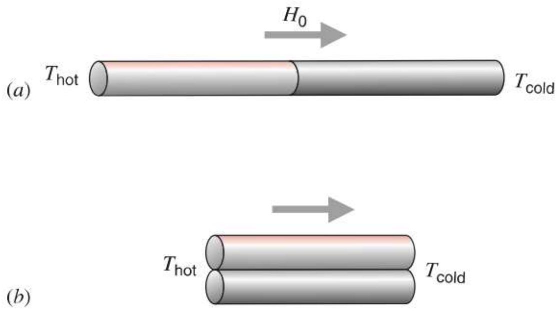

FIGURE 23-24. Multiple-choice question 1.

2. Two long, thin, solid cylinders are identical in size, but they are made of different substances with two different thermal conductivities. The two cylinders are connected in series between a reservoir at temperature T_{hot} and a reservoir at temperature T_{cold}. The temperature at the boundary between the two cylinders is T_b. One can conclude that
   (A) T_b is exactly half way between T_{hot} and T_{cold}.
   (B) T_b is closer to T_{hot} than it is to T_{cold}.
   (C) T_b is closer to T_{cold} than it is to T_{hot}.
   (D) T_b is closer to the temperature of the reservoir that is in contact with the cylinder with the lower thermal conductivity.
   (E) T_b is closer to the temperature of the reservoir that is in contact with the cylinder with the higher thermal conductivity.

3. A spherical constant temperature heat source of radius r_1 is at the center of a uniform solid sphere of radius r_2. The rate at which heat is transferred through the surface of the sphere is proportional to
   (A) $r_2^2 - r_1^2$. (B) $r_2 - r_1$.
   (C) $\ln r_1 - \ln r_2$. (D) $1/r_2 - 1/r_1$.
   (E) $(1/r_2 - 1/r_1)^{-1}$.

23-3 The First Law of Thermodynamics

4. Which of the following processes must violate the first law of thermodynamics? (There may be more than one answer!)
   (A) $W > 0, Q < 0$, and $\Delta E_{int} = 0$
   (B) $W > 0, Q < 0$, and $\Delta E_{int} > 0$
   (C) $W > 0, Q < 0$, and $\Delta E_{int} < 0$
   (D) $W < 0, Q > 0$, and $\Delta E_{int} < 0$
   (E) $W > 0, Q > 0$, and $\Delta E_{int} < 0$

23-4 Heat Capacity and Specific Heat

5. A 100-g cube of aluminum originally at 120°C is placed into an insulated container of water originally at 18°C. After some time the system reaches equilibrium, and the final temperature of the water is 22°C. What is the final temperature of the aluminum cube?
   (A) It is greater than 22°C.
   (B) It is equal to 22°C.
   (C) It is less than 22°C.
   (D) It could be more or less than 22°C, depending on the mass of water present.

6. Block A is a 50-g aluminum block originally at 90°C. Block B is a 100-g aluminum block originally at 45°C. The blocks are placed in two separate 1.0 liter containers of water that were originally at 20°C. When the systems reach thermal equilibrium, which aluminum block will have the higher final temperature?
   (A) Block A (B) Block B
   (C) The blocks will have the same final temperature.
   (D) The answer depends on the specific heat of water.

7. A 1-kg block of ice at 0°C is placed into a perfectly insulated, sealed container that has 2 kg of water also at 0°C. The water and ice completely fill the container, but the container is flexible. After some time one can expect that
   (A) the water will freeze so that the mass of the ice will increase.
   (B) the ice will melt so that the mass of the ice will decrease.
   (C) both the amount of water and the amount of ice will remain constant.
   (D) both the amount of water and the amount of ice will decrease.

23-5 Work Done on or by an Ideal Gas

8. In which of the paths between initial state i and final state f in Fig. 23-25 is the work done on the gas the greatest?

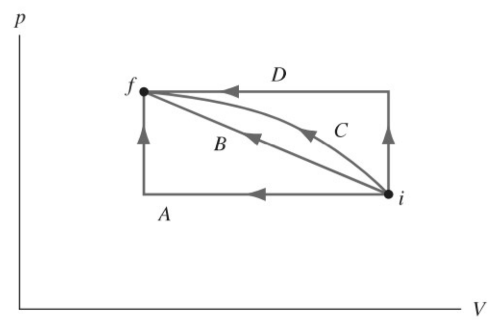

FIGURE 23-25. Multiple-choice question 8.

9. Which of the following is *not* a necessary condition for a process involving an ideal gas to do work? (There may be more than one correct answer!)
   (A) $\Delta T \neq 0$ (B) $\Delta p \neq 0$
   (C) $\Delta V \neq 0$ (D) $Q \neq 0$

23-6 The Internal Energy of an Ideal Gas

10. Consider the following processes that can be done on an ideal gas: constant volume, $\Delta V = 0$; constant pressure, $\Delta p = 0$; and constant temperature, $\Delta T = 0$. (*a*) For which process does $W = 0$? (*b*) For which process does $Q = 0$? (*c*) For which of these processes does $W + Q = 0$? (*d*) For which of these processes does $\Delta E_{int} = Q$? (*e*) For which of these processes does $\Delta E_{int} = W$?
    (A) $\Delta V = 0$ (B) $\Delta p = 0$ (C) $\Delta T = 0$
    (D) None of these

23-7 Heat Capacities of an Ideal Gas

11. Which type of ideal gas will have the largest value for $C_p - C_V$?
    (A) Monatomic (B) Diatomic (C) Polyatomic
    (D) The value will be the same for all.

12. What would be the most likely value for C_T, the molar heat capacity at constant temperature?
    (A) 0 (B) $0 < C_T < C_V$
    (C) $C_V < C_T < C_p$ (D) $C_T = \infty$

23-8 Applications of the First Law of Thermodynamics

13. Which of the following processes is forbidden by the first law of thermodynamics? (There may be more than one correct answer!)
    (A) An ice cube is placed in hot coffee; the ice gets colder and the coffee gets hotter.
    (B) Solid wax is placed in a hot metal pan; the wax melts and the metal pan cools.
    (C) Cold water is placed in a cold glass; the glass gets colder and the water gets colder.
    (D) A student builds an automobile engine that converts into work the heat energy released when water changes to ice.
    (E) Dry ice can be made by allowing carbon dioxide gas to expand in a bag.

QUESTIONS

1. Temperature and heat are often confused, as in "the heat is really severe today." By example, distinguish between these two concepts as carefully as you can.
2. Give an example of a process in which no heat is transferred to or from the system but the temperature of the system changes.
3. Can heat be considered a form of stored (or potential) energy? Would such an interpretation contradict the concept of heat as energy in the process of transfer because of a temperature difference?
4. Can heat be added to a substance without causing the temperature of the substance to rise? If so, does this contradict the concept of heat as energy in the process of transfer because of a temperature difference?
5. Why must heat energy be supplied to melt ice? After all, the temperature does not change.
6. Explain the fact that the presence of a large body of water nearby, such as a sea or ocean, tends to moderate the temperature extremes of the climate on adjacent land.
7. As ice is heated it melts, forming a liquid, and then it boils. However, as solid carbon dioxide is heated it goes directly to the vapor state—we say it sublimes—without passing through a liquid state. How could liquid carbon dioxide be produced?
8. Pails of hot and cold water are set out in freezing weather. Explain how (*a*) if the pails have lids, the cold water will freeze first, but (*b*) if the pails do not have lids, it is possible for the hot water to freeze first.
9. Why does the boiling temperature of a liquid increase with pressure?
10. A block of wood and a block of metal are at the same temperature. When the blocks feel cold, the metal feels colder than the wood; when the blocks feel hot, the metal feels hotter than the wood. Explain. At what temperature will the blocks feel equally hot or cold?
11. How can you best use a spoon to cool a cup of coffee? Stirring—which involves doing work—would seem to heat the coffee rather than cool it.
12. How does a layer of snow protect plants during cold weather? During freezing spells, citrus growers in Florida often spray their fruit with water, hoping it will freeze. How does that help?
13. Explain the wind-chill effect.
14. You put your hand in a hot oven to remove a casserole and burn your fingers on the hot dish. However, the air in the oven is at the same temperature as the casserole dish but it does not burn your fingers. Why not?
15. Metal workers have observed that they can dip a hand very briefly into hot molten metal without ill effects. Explain.
16. Why is thicker insulation used in an attic than in the walls of a house?
17. Is ice always at 0°C? Can it be colder? Can it be warmer? What about an ice–water mixture?
18. (*a*) Can ice be heated to a temperature above 0°C without its melting? Explain. (*b*) Can water be cooled to a temperature below 0°C without its freezing? Explain. (See "The Undercooling of Liquids," by David Turnbull, *Scientific American*, January 1965, p. 38.)
19. Explain why your finger sticks to a metal ice tray just taken from your refrigerator.
20. It is difficult to "boil" eggs in water at the top of a high mountain because water boils there at a relatively low temperature. What is a simple, practical way of overcoming this difficulty?
21. Will a 3-minute egg cook any faster if the water is boiling furiously than if it is simmering quietly?
22. Water is a much better coolant than most liquids. Why? Would there be instances in which another liquid might be preferred?
23. Explain why the latent heat of vaporization of a substance might be expected to be considerably greater than its latent heat of fusion.
24. Explain why the specific heat at constant pressure is greater than the specific heat at constant volume.
25. Why is the difference between C_p and C_V often neglected for solids?
26. Can C_p ever be less than C_V? If so, give an example.
27. Real gases always cool when making a free expansion, whereas an ideal gas does not. Explain.
28. Discuss the similarities and especially the distinctions between heat, work, and internal energy.
29. Discuss the process of the freezing of water from the point of view of the first law of thermodynamics. Remember that ice occupies a greater volume than an equal mass of water.
30. A thermos bottle contains coffee. The thermos bottle is vigorously shaken. Consider the coffee as the system. (*a*) Does its temperature rise? (*b*) Has heat been added to it? (*c*) Has work been done on it? (*d*) Has its internal energy changed?

31. Is the temperature of an isolated system (no interaction with the environment) conserved? Explain.

32. Is heat the same as internal energy? If not, give an example in which a system's internal energy changes without a flow of heat across the system's boundary.

33. Can you tell whether the internal energy of a body was acquired by heat transfer or by the performance of work?

34. If the pressure and volume of a system are given, is the temperature always uniquely determined?

35. Keeping in mind that the internal energy of a body consists of kinetic energy and potential energy of its particles, how would you distinguish between the internal energy of a body and its temperature?

36. Explain how we might keep a gas at a constant temperature during a thermodynamic process.

37. On a winter day the temperature on the inside surface of a wall is much lower than room temperature and that of the outside surface is much higher than the outdoor temperature. Explain.

38. Can heat energy be transferred through matter by radiation? If so, give an example. If not, explain why.

39. Why does stainless steel cookware often have a layer of copper or aluminum on the bottom?

40. Consider that heat can be transferred by convection and radiation, as well as by conduction, and explain why a thermos bottle is doubled-walled, evacuated, and silvered.

41. A lake freezes first at its upper surface. Is convection involved? What about conduction and radiation?

42. Explain why the temperature of a gas drops in an adiabatic expansion.

43. Comment on this statement: "There are two ways to carry out an adiabatic process. One is to do it quickly and the other is to do it in an insulated box."

EXERCISES

23-1 Heat: Energy in Transit

23-2 The Transfer of Heat

1. The average rate at which heat flows out through the surface of the Earth in North America is 54 mW/m^2 and the average thermal conductivity of the near surface rocks is 2.5 W/m·K. Assuming a surface temperature of 10°C, what should be the temperature at a depth of 33 km (near the base of the crust)? Ignore the heat generated by radioactive elements; the curvature of the Earth can also be ignored.

2. Calculate the rate at which heat would be lost on a very cold winter day through a 6.2 m × 3.8 m brick wall 32 cm thick. The inside temperature is 26°C and the outside temperature is −18°C; assume that the thermal conductivity of the brick is 0.74 W/m·K.

3. Consider the slab shown in Fig. 23-2. Suppose that $\Delta x = 24.9$ cm, $A = 1.80$ m^2, and the material is copper. If $T = -12.0$°C, $\Delta T = 136$ C°, and a steady state is reached, find (*a*) the temperature gradient, (*b*) the rate of heat transfer, and (*c*) the temperature at a point in the rod 11.0 cm from the high-temperature end.

4. (*a*) Calculate the rate at which body heat flows out through the clothing of a skier, given the following data: the body surface area is 1.8 m^2 and the clothing is 1.2 cm thick; skin surface temperature is 33°C, whereas the outer surface of the clothing is at 1.0°C; the thermal conductivity of the clothing is 0.040 W/m·K. (*b*) How would the answer change if, after a fall, the skier's clothes become soaked with water? Assume that the thermal conductivity of water is 0.60 W/m·K.

5. Four square pieces of insulation of two different materials, all with the same thickness and area A, are available to cover an opening of area $2A$. This can be done in either of the two ways shown in Fig. 23-26. Which arrangement, (*a*) or (*b*), would give the lower heat flow if $k_2 \neq k_1$?

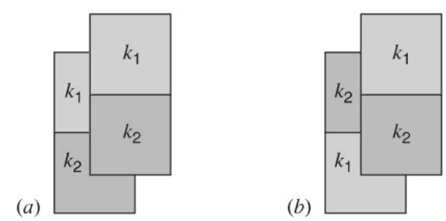

FIGURE 23-26. Exercise 5.

6. Show that the temperature T_x at the interface of a compound slab (see Sample Problem 23-1) is given by

$$T_x = \frac{R_1T_1 + R_2T_2}{R_1 + R_2}.$$

7. Ice has formed on a shallow pond and a steady state has been reached with the air above the ice at −5.20°C and the bottom of the pond at 3.98°C. If the total depth of ice + water is 1.42 m, how thick is the ice? (Assume that the thermal conductivities of ice and water are 1.67 and 0.502 W/m·K, respectively.)

8. Two identical rectangular rods of metal are welded end to end as shown in Fig. 23-27*a*, and 10 J of heat flows through the rods in 2.0 min. How long would it take for 30 J to flow through the rods if they are welded as shown in Fig. 23-27*b*?

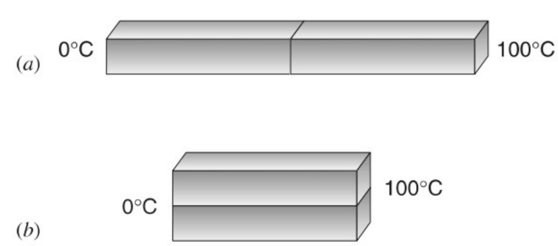

FIGURE 23-27. Exercise 8.

9. An idealized representation of the air temperature as a function of distance from a single-pane window on a calm, winter day is shown in Fig. 23-28. The window dimensions are 60 cm × 60 cm × 0.50 cm. (*a*) At what rate does heat flow out through the window? (Hint: The temperature drop across the glass is very small.) (*b*) Estimate the difference in temperature between the inner and outer glass surfaces.

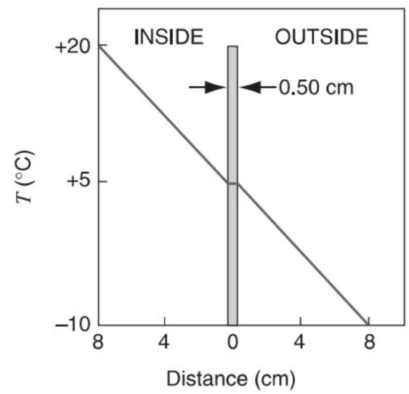

FIGURE 23-28. Exercise 9.

23-3 The First Law of Thermodynamics

10. Consider that 214 J of work are done on a system, and 293 J of heat are extracted from the system. In the sense of the first law of thermodynamics, what are the values (including algebraic signs) of (*a*) W, (*b*) Q, and (*c*) ΔE_{int}?

11. When a system is taken from state i to state f along the path iaf in Fig. 23-29, it is found that $Q = 50$ J and $W = -20$ J. Along the path ibf, $Q = 36$ J. (*a*) What is W along the path ibf? (*b*) If $W = +13$ J for the curved return path fi, what is Q for this path? (*c*) Take $E_{\text{int},\,i} = 10$ J. What is $E_{\text{int},\,f}$? (*d*) If $E_{\text{int},\,b} = 22$ J, find Q for process ib and process bf.

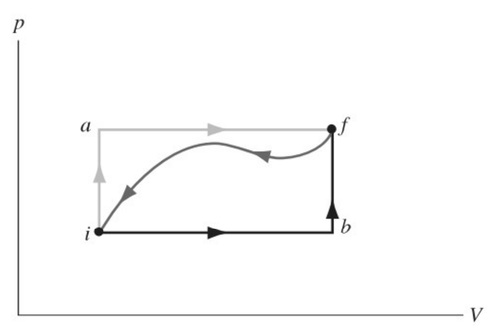

FIGURE 23-29. Exercise 11.

23-4 Heat Capacity and Specific Heat

12. Icebergs in the North Atlantic present hazards to shipping (see Fig. 23-30), causing the length of shipping routes to increase by about 30% during the iceberg season. Strategies for destroying icebergs include planting explosives, bombing, torpedoing, shelling, ramming, and painting with lampblack. Suppose that direct melting of the iceberg, by placing heat sources in the ice, is tried. How much heat is required to melt 10% of a 210,000-metric-ton iceberg? (One metric ton = 1000 kg.)

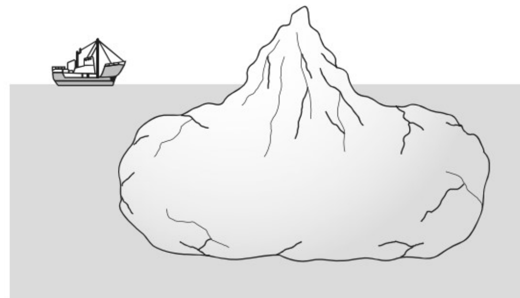

FIGURE 23-30. Exercise 12.

13. In a certain solar house, energy from the Sun is stored in barrels filled with water. In a particular winter stretch of five cloudy days, 5.22 GJ are needed to maintain the inside of the house at 22.0°C. Assuming that the water in the barrels is at 50.0°C, what volume of water is required?

14. A small electric immersion heater is used to boil 136 g of water for a cup of instant coffee. The heater is labeled 220 watts. Calculate the time required to bring this water from 23.5°C to the boiling point, ignoring any heat losses.

15. How much water remains unfrozen after 50.4 kJ of heat have been extracted from 258 g of liquid water initially at 0°C?

16. (*a*) Compute the possible increase in temperature for water going over Niagara Falls, 49.4 m high. (*b*) What factors would tend to prevent this possible rise?

17. A 146-g copper bowl contains 223 g of water; both bowl and water are at 21.0°C. A very hot 314-g copper cylinder is dropped into the water. This causes the water to boil, with 4.70 g being converted to steam, and the final temperature of the entire system is 100°C. (*a*) How much heat was transferred to the water? (*b*) How much to the bowl? (*c*) What was the original temperature of the cylinder?

18. Calculate the minimum amount of heat required to completely melt 130 g of silver initially at 16.0°C. Assume that the specific heat does not change with temperature. See Tables 23-2 and 23-3.

19. An aluminum electric kettle of mass 0.560 kg contains a 2.40-kW heating element. It is filled with 0.640 L of water at 12.0°C. How long will it take (*a*) for boiling to begin and (*b*) for the kettle to boil dry? (Assume that the temperature of the kettle does not exceed 100°C at any time.)

20. What mass of steam at 100°C must be mixed with 150 g of ice at 0°C, in a thermally insulated container, to produce liquid water at 50°C?

21. A 21.6-g copper ring has a diameter of 2.54000 cm at its temperature of 0°C. An aluminum sphere has a diameter of 2.54533 cm at its temperature of 100°C. The sphere is placed on top of the ring (Fig. 23-31), and the two are allowed to come to thermal equilibrium, no heat being lost to the surroundings. The sphere just passes through the ring at the equilibrium temperature. Find the mass of the sphere.

22. (*a*) Two 50-g ice cubes are dropped into 200 g of water in a glass. If the water were initially at a temperature of 25°C, and if the ice came directly from a freezer at −15°C, what is the final temperature of the drink? (*b*) If only one ice cube had been used in (*a*), what would be the final temperature of the drink? Neglect the heat capacity of the glass.

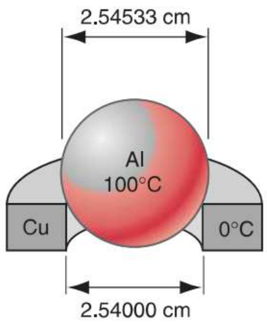

FIGURE 23-31. Exercise 21.

23. A certain substance has a molar mass of 51.4 g/mol. When 320 J of heat are added to a 37.1-g sample of this material, its temperature rises from 26.1 to 42.0°C. (*a*) Find the specific heat of the substance. (*b*) How many moles of the substance are present? (*c*) Calculate the molar heat capacity of the substance.

23-5 The Work Done on or by an Ideal Gas

24. A sample of gas expands from 1.0 to 5.0 m^3 while its pressure decreases from 15 to 5.0 Pa. How much work is done on the gas if its pressure changes with volume according to each of the three processes shown in the pV diagram in Fig. 23-32?

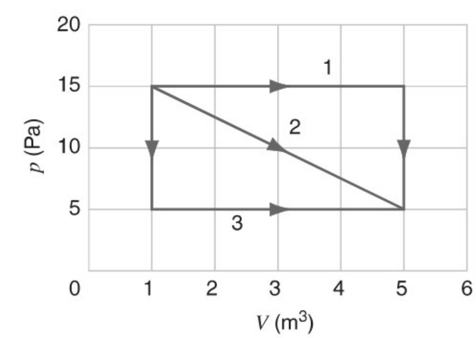

FIGURE 23-32. Exercise 24.

25. Suppose that a sample of gas expands from 2.0 to 8.0 m^3 along the diagonal path in the pV diagram shown in Fig. 23-33. It is then compressed back to 2.0 m^3 along either path 1 or path 2. Compute the net work done on the gas for the complete cycle in each case.

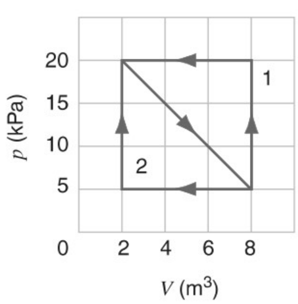

FIGURE 23-33. Exercise 25.

26. Air that occupies 0.142 m^3 at 103 kPa gauge pressure is expanded isothermally to zero gauge pressure and then cooled at constant pressure until it reaches its initial volume. Compute the work done on the gas.

27. Calculate the work done by an external agent in compressing 1.12 mol of oxygen from a volume of 22.4 L and 1.32 atm pressure to 15.3 L at the same temperature.

28. (*a*) One liter of gas with $\gamma = 1.32$ is at 273 K and 1.00 atm pressure. It is suddenly (adiabatically) compressed to half its original volume. Find its final pressure and temperature. (*b*) The gas is now cooled back to 273 K at constant pressure. Find the final volume. (*c*) Find the total work done on the gas.

29. Gas occupies a volume of 4.33 L at a pressure of 1.17 atm and a temperature of 310 K. It is compressed adiabatically to a volume of 1.06 L. Determine (*a*) the final pressure and (*b*) the final temperature, assuming the gas to be an ideal gas for which $\gamma = 1.40$. (*c*) How much work was done on the gas?

30. An air compressor takes air at 18.0°C and 1.00 atm pressure and delivers compressed air at 2.30 atm pressure. The compressor operates at 230 W of useful power. Assume that the compressor operates adiabatically. (*a*) Find the temperature of the compressed air. (*b*) How much compressed air, in liters, is delivered each second?

23-6 The Internal Energy of an Ideal Gas

31. Calculate the total rotational kinetic energy of all the molecules in 1 mole of air at 25.0°C.

32. Calculate the internal energy of 1 mole of an ideal gas at 250°C.

33. An ideal gas experiences an adiabatic compression from $p = 122$ kPa, $V = 10.7$ m^3, $T = -23.0$°C to $p = 1450$ kPa, $V = 1.36$ m^3. (*a*) Calculate the value of γ. (*b*) Find the final temperature. (*c*) How many moles of gas are present? (*d*) What is the total translational kinetic energy per mole before and after the compression? (*e*) Calculate the ratio of the rms speed before to that after the compression.

34. A cosmic-ray particle with energy 1.34 TeV is stopped in a detecting tube that contains 0.120 mol of neon gas. Once this energy is distributed among all the atoms, by how much is the temperature of the neon increased?

23-7 Heat Capacities of an Ideal Gas

35. In an experiment, 1.35 mol of oxygen (O_2) are heated at constant pressure starting at 11.0°C. How much heat must be added to the gas to double its volume?

36. Twelve grams of nitrogen (N_2) in a steel tank are heated from 25.0 to 125°C. (*a*) How many moles of nitrogen are present? (*b*) How much heat is transferred to the nitrogen?

37. A 4.34-mol sample of an ideal diatomic gas experiences a temperature increase of 62.4 K under constant-pressure conditions. (*a*) How much heat was added to the gas? (*b*) By how much did the internal energy of the gas increase? (*c*) By how much did the internal translational kinetic energy of the gas increase?

38. The mass of a helium atom is 6.66×10^{-27} kg. Compute the specific heat at constant volume for helium gas (in J/kg · K) from the molar heat capacity at constant volume.

39. A container holds a mixture of three nonreacting gases: n_1 moles of the first gas with molar specific heat at constant volume C_1, and so on. Find the molar specific heat at constant volume of the mixture, in terms of the molar specific heats and quantities of the three separate gases.

23-8 Applications of the First Law of Thermodynamics

40. Gas within a chamber passes through the cycle shown in Fig. 23-34. Determine the net heat added to the gas during process *CA* if $Q_{AB} = 20$ J, $Q_{BC} = 0$, and $W_{BCA} = -15$ J.

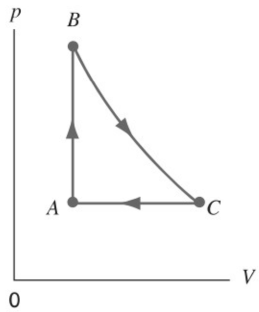

FIGURE 23-34. Exercise 40.

41. A sample of *n* moles of an ideal gas undergoes an isothermal expansion. Find the heat flow into the gas in terms of the initial and final volumes and the temperature.

42. A quantity of ideal gas occupies an initial volume V_0 at a pressure p_0 and a temperature T_0. It expands to volume V_1 (*a*) at constant pressure, (*b*) at constant temperature, and (*c*) adiabatically. Graph each case on a pV diagram. In which case is Q greatest? Least? In which case is W greatest? Least? In which case is ΔE_{int} greatest? Least?

43. (*a*) A monatomic ideal gas initially at 19.0°C is suddenly compressed to one-tenth its original volume. What is its temperature after compression? (*b*) Make the same calculation for a diatomic gas.

44. In Fig. 23-35, assume the following values:

$$p_i = 2.20 \times 10^5 \text{ Pa}, \quad V_i = 0.0120 \text{ m}^3,$$

$$p_f = 1.60 \times 10^5 \text{ Pa}, \quad V_f = 0.0270 \text{ m}^3.$$

For each of the three paths shown, find the value of Q, W, and $Q + W$. (Hint: Find P, V, T at points A, B, C. Assume an ideal monatomic gas.)

45. A quantity of ideal monatomic gas consists of *n* moles initially at temperature T_1. The pressure and volume are then slowly doubled in such a manner as to trace out a straight line on the pV diagram. In terms of n, R, and T_1, find (*a*) W, (*b*) ΔE_{int}, and (*c*) Q. (*d*) If one were to define an equivalent specific heat for this process, what would be its value?

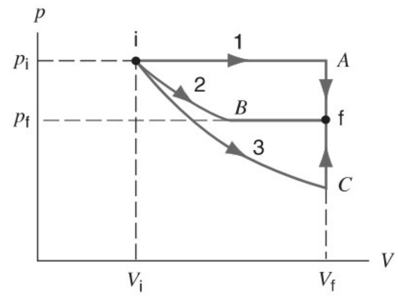

FIGURE 23-35. Exercise 44.

46. Gas within a chamber undergoes the processes shown in the pV diagram of Fig. 23-36. Calculate the net heat added to the system during one complete cycle.

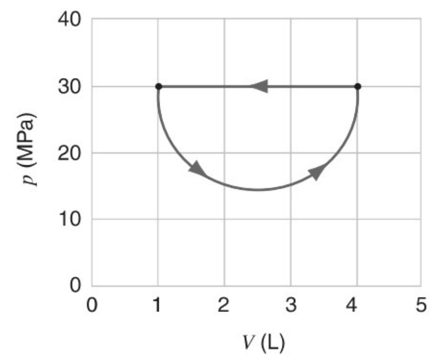

FIGURE 23-36. Exercise 46.

47. Let 20.9 J of heat be added to a particular ideal gas. As a result, its volume changes from 63.0 to 113 cm^3 while the pressure remains constant at 1.00 atm. (*a*) By how much does the internal energy of the gas change? (*b*) If the quantity of gas present is 2.00×10^{-3} mol, find the molar heat capacity at constant pressure. (*c*) Find the molar heat capacity at constant volume.

48. The temperature of 3.15 mol of an ideal polyatomic gas is raised 52.0 K by each of three different processes: at constant volume, at constant pressure, and by an adiabatic compression. Complete a table, showing for each process the heat added, the work done on the gas, the change in internal energy of the gas, and the change in total translational kinetic energy of the gas molecules.

PROBLEMS

1. (*a*) Calculate the rate of heat loss through a glass window of area 1.4 m^2 and thickness 3.0 mm if the outside temperature is −20°F and the inside temperature is +72°F. (*b*) A storm window is installed having the same thickness of glass but with an air gap of 7.5 cm between the two windows. What will be the corresponding rate of heat loss presuming that conduction is the only important heat-loss mechanism?

2. A cylindrical silver rod of length 1.17 m and cross-sectional area 4.76 cm^2 is insulated to prevent heat loss through its surface. The ends are maintained at a temperature difference of 100 C° by having one end in a water–ice mixture and the other in boiling water and steam. (*a*) Find the rate at which heat is transferred along the rod. (*b*) Calculate the rate at which ice melts at the cold end.

3. Assuming k is constant, show that the radial rate of flow of heat in a substance between two concentric spheres is given by

$$H = \frac{(T_1 - T_2)4\pi k r_1 r_2}{r_2 - r_1},$$

where the inner sphere has a radius r_1 and temperature T_1, and the outer sphere has a radius r_2 and temperature T_2.

4. (*a*) Use the data in Exercise 1 to calculate the rate at which heat flows out through the surface of the Earth. (*b*) Suppose that this heat flux is due to the presence of a hot core in the Earth and that this core has a radius of 3470 km. Assume also that the material lying between the core and the surface of the Earth contains no sources of heat and has an average thermal conductivity of 4.2 W/m · K. Use the result of Problem 3 to calculate the temperature of the core. (Assume that the Earth's surface is at 0°C.) The answer obtained is too high by a factor of about 10. Why?

5. At low temperatures (below about 50 K), the thermal conductivity of a metal is proportional to the absolute temperature; that is, $k = aT$, where a is a constant with a numerical value that depends on the particular metal. Show that the rate of heat flow through a rod of length L and cross-sectional area A whose ends are at temperatures T_1 and T_2 is given by

$$H = \frac{aA}{2L}(T_1^2 - T_2^2).$$

(Ignore heat loss from the surface.)

6. A container of water has been outdoors in cold weather until a 5.0-cm-thick slab of ice has formed on its surface (Fig. 23-37). The air above the ice is at −10°C. Calculate the rate of formation of ice (in centimeters per hour) on the bottom surface of the ice slab. Take the thermal conductivity and density of ice to be 1.7 W/m · K and 0.92 g/cm^3. Assume that no heat flows through the walls of the container.

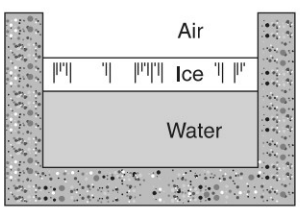

FIGURE 23-37. Problem 6.

7. A person makes a quantity of iced tea by mixing 520 g of the hot tea (essentially water) with an equal mass of ice at 0°C. What are the final temperature and mass of ice remaining if the initial hot tea is at a temperature of (*a*) 90.0°C and (*b*) 70.0°C?

8. A *flow calorimeter* is used to measure the specific heat of a liquid. Heat is added at a known rate to a stream of the liquid as it passes through the calorimeter at a known rate. Then a measurement of the resulting temperature difference between the inflow and the outflow points of the liquid stream enables us to compute the specific heat of the liquid. A liquid of density 0.85 g/cm^3 flows through a calorimeter at the rate of 8.2 cm^3/s. Heat is added by means of a 250-W electric heating coil, and a temperature difference of 15 C° is established in steady-state conditions between the inflow and the outflow points. Find the specific heat of the liquid.

9. Water standing in the open at 32°C evaporates because of the escape of some of the surface molecules. The heat of vaporization is approximately equal to ϵn, where ϵ is the average energy of the escaping molecules and n is the number of molecules per kilogram. (*a*) Find ϵ. (*b*) What is the ratio of ϵ to the average kinetic energy of H_2O molecules, assuming that the kinetic energy is related to temperature in the same way as it is for gases?

10. A thermometer of mass 0.055 kg and heat capacity 46.1 J/K reads 15.0°C. It is then completely immersed in 0.300 kg of water and it comes to the same final temperature as the water. If the thermometer reads 44.4°C, what was the temperature of the water before insertion of the thermometer, neglecting other heat losses?

11. From Fig. 23-11, estimate the amount of heat needed to raise the temperature of 0.45 mol of carbon from 200 to 500 K. (Hint: Approximate the actual curve in this region with a straight-line segment).

12. The molar heat capacity of silver, measured at atmospheric pressure, is found to vary with temperature between 50 and 100 K by the empirical equation

$$C = 0.318T - 0.00109T^2 - 0.628,$$

where C is in J/mol · K and T is in K. Calculate the quantity of heat required to raise 316 g of silver from 50.0 to 90.0 K. The molar mass of silver is 107.87 g/mol.

13. The gas in a cloud chamber at a temperature of 292 K undergoes a rapid expansion. Assuming the process is adiabatic, calculate the final temperature if $\gamma = 1.40$ and the volume expansion ratio is 1.28.

14. Calculate the work done on n moles of a van der Waals gas in an isothermal expansion from volume V_i to V_f.

15. A thin tube, sealed at both ends, is 1.00 m long. It lies horizontally, the middle 10.0 cm containing mercury and the two equal ends containing air at standard atmospheric pressure. If the tube is now turned to a vertical position, by what amount will the mercury be displaced? Assume that the process is (*a*) isothermal and (*b*) adiabatic. (For air, $\gamma = 1.40$.) Which assumption is more reasonable?

16. A room of volume V is filled with diatomic ideal gas (air) at temperature T_1 and pressure p_0. The air is heated to a higher temperature T_2, the pressure remaining constant at p_0 because the walls of the room are not airtight. Show that the internal energy content of the air remaining in the room is the same at T_1 and T_2 and that the energy supplied by the furnace to heat the air has all gone to heat the air outside the room. If we add no energy to the air, why bother to light the furnace? (Ignore the furnace energy used to raise the temperature of the walls, and consider only the energy used to raise the air temperature.)

17. The molar atomic mass of iodine is 127 g. A standing wave in a tube filled with iodine gas at 400 K has nodes that are 6.77 cm apart when the frequency is 1000 Hz. Determine from these data whether iodine gas is monatomic or diatomic.

18. Figure 23-38*a* shows a cylinder containing gas and closed by a movable piston. The cylinder is submerged in an ice–water mixture. The piston is quickly pushed down from position 1 to position 2. The piston is held at position 2 until the gas is again at 0°C and then is slowly raised back to position 1. Figure 23-38*b* is a *pV* diagram for the process. If 122 g of ice are melted during the cycle, how much work has been done on the gas?

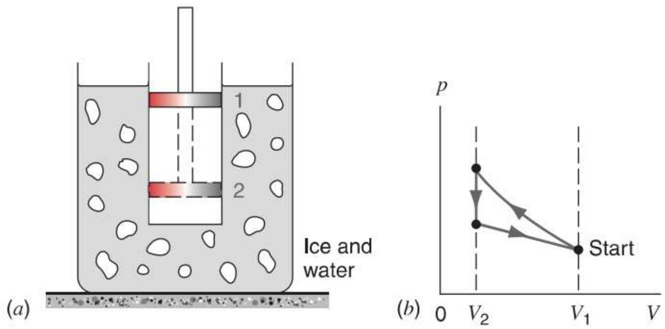

FIGURE 23-38. Problem 18.

19. An engine carries 1.00 mol of an ideal monatomic gas around the cycle shown in Fig. 23-39. Process *AB* takes place at constant volume, process *BC* is adiabatic, and process *CA* takes place at a constant pressure. (*a*) Compute the heat *Q*, the change in internal energy E_{int}, and the work *W* for each of the three processes and for the cycle as a whole. (*b*) If the initial pressure at point *A* is 1.00 atm, find the pressure and the volume at points *B* and *C*. Use 1 atm $= 1.013 \times 10^5$ Pa and R = 8.314 J/mol · K.

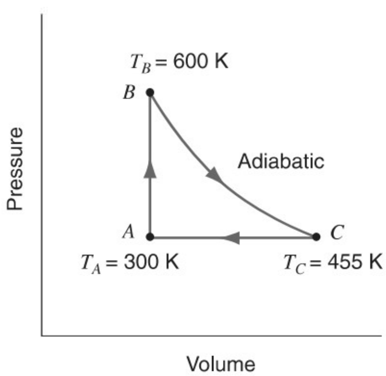

FIGURE 23-39. Problem 19.

20. A cylinder has a well-fitted, 2.0-kg metal piston whose cross-sectional area is 2.0 cm³ (Fig. 23-40). The cylinder contains water and steam at constant temperature. The piston is observed to fall slowly at a rate of 0.30 cm/s because heat flows out of the cylinder through the cylinder walls. As this happens, some steam condenses in the chamber. The density of the steam inside the chamber is 6.0×10^{-4} g/cm³ and the atmospheric pressure is 1.0 atm. (*a*) Calculate the rate of condensation of steam. (*b*) At what rate is heat leaving the chamber? (*c*) What is the rate of change of internal energy of the steam and water inside the chamber?

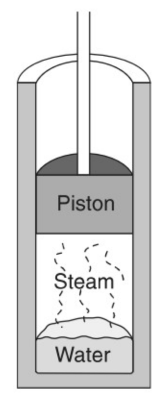

FIGURE 23-40. Problem 20.

21. In a motorcycle engine, after combustion occurs in the top of the cylinder, the piston is forced down as the mixture of gaseous products undergoes an adiabatic expansion. Find the average power involved in this expansion when the engine is running at 4000 rpm, assuming that the gauge pressure immediately after combustion is 15.0 atm, the initial volume is 50.0 cm³, and the volume of the mixture at the bottom of the stroke is 250 cm³. Assume that the gases are diatomic and that the time involved in the expansion is one-half that of the total cycle.

COMPUTER PROBLEMS

1. The theoretical specific heat capacity of a solid at temperature *T* is given by the Debye formula

$$c_V = 9\left[4\left(\frac{T}{\Theta}\right)^3 \int_0^{\Theta} \frac{x}{T^2} \frac{dx}{e^{x/T} - 1} - \frac{\Theta/T}{e^{\Theta/T} - 1}\right],$$

where Θ is a constant, called the Debye temperature, that depends on the substance. (*a*) Numerically integrate this expression to find the specific heat capacity of aluminum at room temperature, using $\Theta_{\text{aluminum}} = 420$ K. Compare your result to the measured value. (*b*) Generate a graph of the specific heat capacity of aluminum for the range $T = 0$ to $T = 500$ K.

2. The specific heat capacity of aluminum at low temperatures is given by

$$c_V = \frac{12\pi^4}{5} R \left(\frac{T}{420\text{ K}}\right)^3.$$

A 1.0-kg block of aluminum originally at 20 K is placed into a device (left in Roswell, New Mexico by aliens) that can extract 1000 J of heat energy from the aluminum every minute. (*a*) How long before the temperature of the aluminum is 1 K? (*b*) What is the temperature of the aluminum after 12 hours? (*c*) Can the aluminum ever be cooled to absolute zero with this device?