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

41. Why is it more common to excite radiation from gaseous atoms by use of electrical discharge than by thermal methods?

42. We have seen that "energy conservation" is a universal law of nature. At the same time national leaders urge "energy conservation" upon us (for example, driving slower). Explain the two quite different meanings of these words.

43. 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.

44. The physiological mechanisms that maintain a person's internal temperature operate in a limited range of external temperature. Explain how this range can be extended at each extreme by the use of clothes. (See "Heat, Cold, and Clothing," by James B. Kelley, *Scientific American*, February 1956, p. 109.)

45. What requirements for thermal conductivity, specific heat capacity, and coefficient of expansion would you want a material to be used in a cooking utensil to satisfy?

46. Both heat conduction and wave propagation involve the transfer of energy. Is there any difference in principle between these two phenomena?

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

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

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

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

PROBLEMS

Section 25-2 Heat Capacity and Specific Heat

1. 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?

2. Icebergs in the North Atlantic present hazards to shipping (see Fig. 22), causing the length of shipping routes to increase by about 30% during the iceberg season. Attempts to destroy 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.)

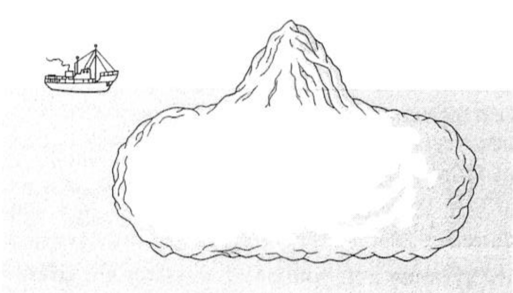

Figure 22 Problem 2.

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

4. An object of mass 6.50 kg falls through a height of 50.0 m and, by means of a mechanical linkage, rotates a paddle wheel that stirs 520 g of water. The water is initially at 15°C. What is the maximum possible temperature rise?

5. (*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?

6. 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.

7. 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?

8. An athlete needs to lose weight and decides to do it by "pumping iron." (*a*) How many times must an 80.0-kg weight be lifted a distance of 1.30 m in order to burn off 1 lb of fat, assuming that it takes 3500 Cal to do this? (*b*) If the weight is lifted once every 4 s, how long does it take?

9. 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 1 and 2.

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. A chef, awaking one morning to find the stove out of order, decides to boil water for coffee by shaking it in a thermos flask. Suppose the chef uses 560 cm^3 of tap water at 59°F, and the water falls 35 cm each shake, the chef making 30 shakes each minute. Neglecting any loss of energy, how long must the flask be shaken before the water boils?

12. In a solar water heater, energy from the Sun is gathered by rooftop collectors, which circulate water through tubes in the collector. The solar radiation enters the collector through a transparent cover and warms the water in the tubes; this water is pumped into a holding tank. Assuming that the efficiency of the overall system is 20% (that is, 80% of the incident solar energy is lost from the system), what

collector area is necessary to take water from a 200-L tank and raise its temperature from 20 to 40°C in 1.0 h? The intensity of incident sunlight is 700 W/m^2.

13. 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.)

14. 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.

15. 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?

16. 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?

17. 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?

18. (*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.

19. 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), 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.

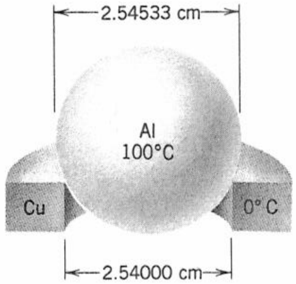

Figure 23 Problem 19.

Section 25-3 Heat Capacities of Solids

20. 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.

21. Near absolute zero, the molar heat capacity of aluminum varies with the absolute temperature T and is given by $C = (3.16 \times 10^{-5})T^3$, in J/mol·K. How much heat is needed to raise the temperature of 1.2 g of aluminum from 6.6 to 15 K?

22. 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.

23. From Fig. 3, 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.)

Section 25-4 Heat Capacities of an Ideal Gas

24. 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.

25. 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?

26. 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?

27. 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? See Eq. 36 of Chapter 23. (*c*) By how much did the internal translational kinetic energy of the gas increase?

28. 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.

29. 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.

30. 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 temper-

ature of the walls, and consider only the energy used to raise the air temperature.)

Section 25-6 Applications of the First Law

31. 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.

32. Gas within a chamber passes through the cycle shown in Fig. 24. Determine the net heat added to the gas during process CA if $Q_{AB} = 20$ J, $Q_{BC} = 0$, and $W_{BCA} = -15$ J.

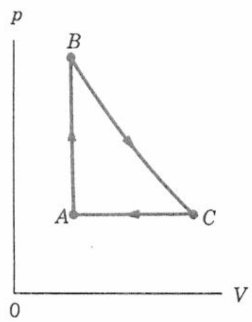

Figure 24 Problem 32.

33. 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}?

34. Figure 25*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 25*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?

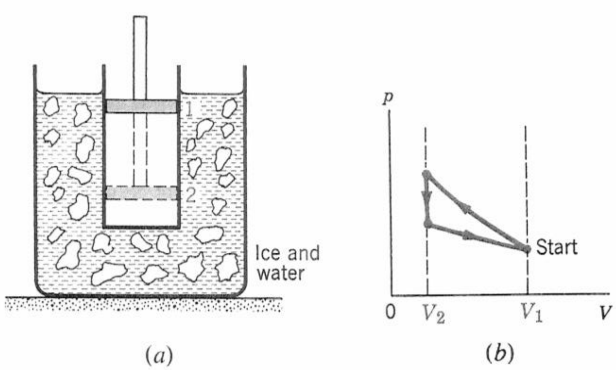

Figure 25 Problem 34.

35. (*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.

36. 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, (*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?

37. 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?

38. In Fig. 11, assume the following values: $p_i = 2.20 \times 10^5$ Pa, $V_i = 0.0120$ m^3, $p_f = 1.60 \times 10^5$ Pa, $V_f = 0.0270$ 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.)

39. When a system is taken from state i to state f along the path iaf in Fig. 26, 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.

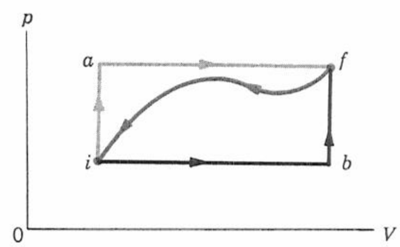

Figure 26 Problem 39.

40. Gas within a chamber undergoes the processes shown in the pV diagram of Fig. 27. Calculate the net heat added to the system during one complete cycle.

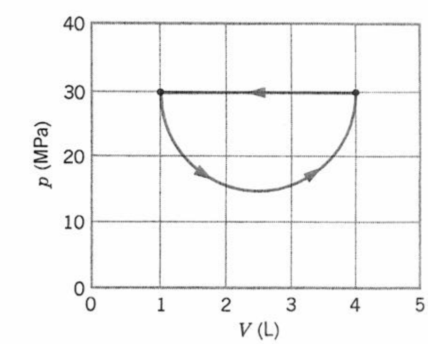

Figure 27 Problem 40.

41. 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 did 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.

42. 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.

43. An engine carries 1.00 mol of an ideal monatomic gas around the cycle shown in Fig. 28. 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 ΔE_{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.

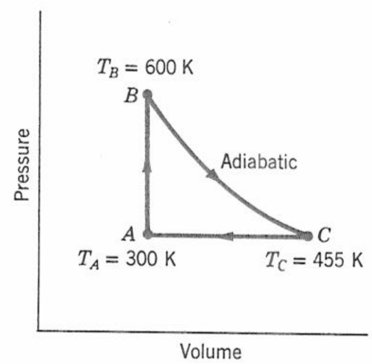

Figure 28 Problem 43.

44. A cylinder has a well-fitted 2.0-kg metal piston whose cross-sectional area is 2.0 cm^2 (Fig. 29). 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/cm^3 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?

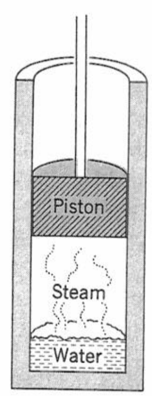

Figure 29 Problem 44.

45. 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 cm^3, and the volume of the mixture at the bottom of the stroke is 250 cm^3. Assume that the gases are diatomic and that the time involved in the expansion is one-half that of the total cycle.

Section 25-7 The Transfer of Heat

46. Calculate the rate at which heat would be lost on a very cold winter day through a 6.2 m $\times$ 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.

47. 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.

48. (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.

49. Consider the slab shown in Fig. 16. 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.

50. 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.

51. 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. 30. Which arrangement, (a) or (b), would give the lower heat flow if $k_2 \neq k_1$?

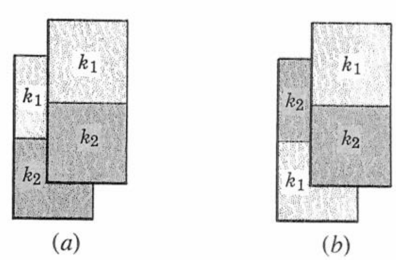

Figure 30 Problem 51.

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

$$T_x = \frac{R_1 T_1 + R_2 T_2}{R_1 + R_2}.$$

53. A long tungsten heater wire is rated at 3.08 kW/m and is 0.520 mm in diameter. It is embedded along the axis of a ceramic cylinder of diameter 12.4 cm. When operating at the rated power, the wire is at 1480°C; the outside of the cylinder is at 22.0°C. Calculate the thermal conductivity of the ceramic.

54. Two identical rectangular rods of metal are welded end to end as shown in Fig. 31*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. 31*b*?

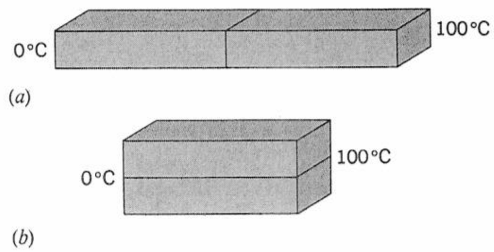

Figure 31 Problem 54.

55. (*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?

56. Compute the rate of heat flow through two storm doors 1.96 m high and 0.770 m wide. (*a*) One door is made with aluminum panels 1.50 mm thick and a 3.10-mm glass pane that covers 75.0% of its surface (the structural frame is considered to have negligible area). (*b*) The second door is made entirely of white pine averaging 2.55 cm in thickness. Take the temperature drop through the doors to be 33.0 C° (=59.4 F°). See Table 5.

57. 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. 32. 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.

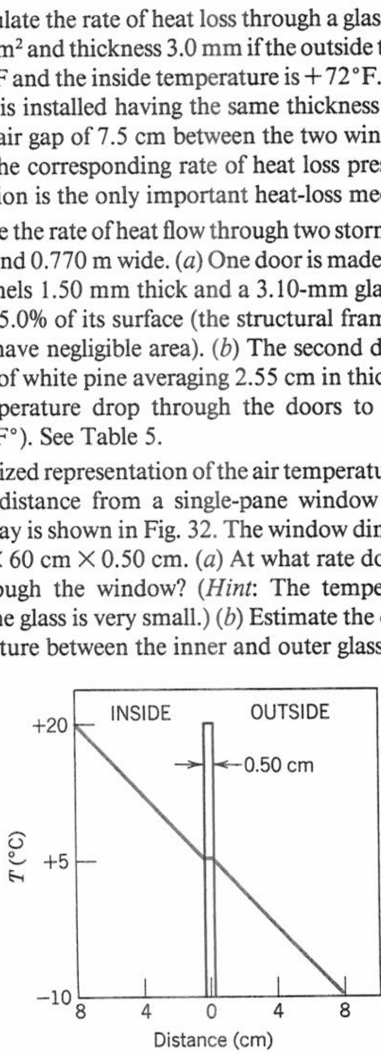

Figure 32 Problem 57.

58. 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. 33). 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 tank.

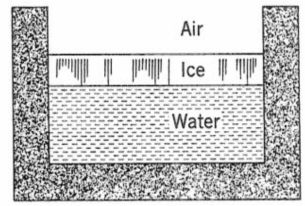

Figure 33 Problem 58.

59. 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.)

60. A wall assembly consists of a 20 ft × 12 ft frame made of 16 two-by-four vertical studs, each 12 ft long and set with their center lines 16 in. apart. The outside of the wall is faced with $\frac{1}{4}$-in. plywood sheet ($R = 0.30$) and $\frac{3}{4}$-in. white pine siding ($R = 0.98$). The inside is faced with $\frac{1}{4}$-in. plasterboard ($R = 0.47$), and the space between the studs is filled with polyurethane foam ($R = 5.9$ for a 1-in. layer). A "two-by-four" is actually 1.75 in. × 3.75 in. in size. Assume that they are made of wood for which $R = 1.3$ for a 1-in. slab. (*a*) At what rate does heat flow through this wall for a 30 F° temperature difference? (*b*) What is the *R*-value for the assembled wall? (*c*) What fraction of the wall area contains studs, as opposed to foam? (*d*) What fraction of the heat flow is through the studs, as opposed to the foam?

61. 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.

62. (*a*) Use data in Problem 47 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 61 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?

63. 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.)