sec. 18-4 Measuring Temperature

*1 Suppose the temperature of a gas is 373.15 K when it is at the boiling point of water. What then is the limiting value of the ratio of the pressure of the gas at that boiling point to its pressure at the triple point of water? (Assume the volume of the gas is the same at both temperatures.)

*2 Two constant-volume gas thermometers are assembled, one with nitrogen and the other with hydrogen. Both contain enough gas so that $p_1 = 80$ kPa. (a) What is the difference between the pressures in the two thermometers if both bulbs are in boiling water? (Hint: See Fig. 18-6.) (b) Which gas is at higher pressure?

*3 A gas thermometer is constructed of two gas-containing bulbs, each in a water bath, as shown in Fig. 18-29. The pressure difference between the two bulbs is measured by a mercury manometer as shown. Appropriate reservoirs, not shown in the diagram, maintain constant gas volume in the two bulbs. There is no difference in pressure when both baths are at the triple point of water. The pressure difference is 120 torr when one bath is at the triple point and the other is at the boiling point of water. It is 90.0 torr when one bath is at the triple point and the other is at an unknown temperature to be measured. What is the unknown temperature?

Fig. 18-29 Problem 3.

sec. 18-5 The Celsius and Fahrenheit Scales

*4 (a) In 1964, the temperature in the Siberian village of Oymyakon reached −71°C. What temperature is this on the Fahrenheit scale? (b) The highest officially recorded temperature in the continental United States was 134°F in Death Valley, California. What is this temperature on the Celsius scale?

*5 At what temperature is the Fahrenheit scale reading equal to (a) twice that of the Celsius scale and (b) half that of the Celsius scale?

*6 On a linear X temperature scale, water freezes at $-125.0^\circ$X and boils at $375.0^\circ$X. On a linear Y temperature scale, water freezes at $-70.00^\circ$Y and boils at $-30.00^\circ$Y. A temperature of $50.00^\circ$Y corresponds to what temperature on the X scale?

*7 ILW Suppose that on a linear temperature scale X, water boils at $-53.5^\circ$X and freezes at $-170^\circ$X. What is a temperature of 340 K on the X scale? (Approximate water’s boiling point as 373 K.)

sec. 18-6 Thermal Expansion

*8 At 20°C, a brass cube has an edge length of 30 cm. What is the increase in the cube’s surface area when it is heated from 20°C to 75°C?

*9 ILW A circular hole in an aluminum plate is 2.725 cm in diameter at 0.000°C. What is its diameter when the temperature of the plate is raised to 100.0°C?

*10 An aluminum flagpole is 33 m high. By how much does its length increase as the temperature increases by 15°C?

*11 What is the volume of a lead ball at 30.00°C if the ball’s volume at 60.00°C is 50.00 cm³?

*12 An aluminum-alloy rod has a length of 10.00 cm at 20.00°C and a length of 10.015 cm at the boiling point of water. (a) What is the length of the rod at the freezing point of water? (b) What is the temperature if the length of the rod is 10.009 cm?

*13 SSM Find the change in volume of an aluminum sphere with an initial radius of 10 cm when the sphere is heated from 0.0°C to 100°C.

*14 When the temperature of a copper coin is raised by 100°C, its diameter increases by 0.18%. To two significant figures, give the percent increase in (a) the area of a face, (b) the thickness, (c) the volume, and (d) the mass of the coin. (e) Calculate the coefficient of linear expansion of the coin.

*15 ILW A steel rod is 3.000 cm in diameter at 25.00°C. A brass ring has an interior diameter of 2.992 cm at 25.00°C. At what common temperature will the ring just slide onto the rod?

*16 When the temperature of a metal cylinder is raised from 0.0°C to 100°C, its length increases by 0.23%. (a) Find the percent change in density. (b) What is the metal? Use Table 18-2.

*17 SSM WWW An aluminum cup of 100 cm³ capacity is completely filled with glycerin at 22°C. How much glycerin, if any, will spill out of the cup if the temperature of both the cup and the glycerin is increased to 28°C? (The coefficient of volume expansion of glycerin is $5.1 \times 10^{-4}^\circ$C.)

*18 At 20°C, a rod is exactly 20.05 cm long on a steel ruler. Both the rod and the ruler are placed in an oven at 270°C, where the rod now measures 20.11 cm on the same ruler. What is the coefficient of linear expansion for the material of which the rod is made?

*19 SSM A vertical glass tube of length $L = 1.280 \times 10^3$ m is half filled with a liquid at 20.000°C. How much will the height of the liquid column change when the tube and liquid are heated to 30.000°C? Use coefficients $\alpha_{\text{glass}} = 1.000 \times 10^{-5}^\circ$K and $\beta_{\text{liquid}} = 4.000 \times 10^{-4}^\circ$K.

*20 In a certain experiment, a small radioactive source must move at selected, extremely slow speeds. This motion is accomplished by fastening the source to one end of an aluminum rod and heating the central section of the rod in a controlled way. If the effective heated section of the rod in Fig. 18-30 has length $d = 2.00$ cm, at what constant rate must the temperature of the rod be changed if the source is to move at a constant speed of 100 mm/s?

Fig. 18-30 Problem 20.
**21 SSM ILW** As a result of a temperature rise of 32 °C, a bar with a crack at its center buckles upward (Fig. 18-31). If the fixed distance \( L_0 \) is 3.77 m and the coefficient of linear expansion of the bar is \( 25 \times 10^{-6} \text{°C}^{-1} \), find the rise \( x \) of the center.

![Fig. 18-31 Problem 21.](image)

**sec. 18-8 The Absorption of Heat by Solids and Liquids**

**22** One way to keep the contents of a garage from becoming too cold on a night when a severe subfreezing temperature is forecast is to put a tub of water in the garage. If the mass of the water is 125 kg and its initial temperature is 20°C, (a) how much energy must the water transfer to its surroundings in order to freeze completely and (b) what is the lowest possible temperature of the water and its surroundings until that happens?

**23 SSM** A small electric immersion heater is used to heat 100 g of water for a cup of instant coffee. The heater is labeled “200 watts” (it converts electrical energy to thermal energy at this rate). Calculate the time required to bring all this water from 23.0°C to 100°C, ignoring any heat losses.

**24** A certain substance has a mass per mole of 50.0 g/mol. When 314 J is added as heat to a 30.0 g sample, the sample’s temperature rises from 25.0°C to 45.0°C. What are the (a) specific heat and (b) molar specific heat of this substance? (c) How many moles are in the sample?

**25** A certain diet doctor encourages people to diet by drinking ice water. His theory is that the body must burn off enough fat to raise the temperature of the water from 0.00°C to the body temperature of 37.0°C. How many liters of ice water would have to be consumed to burn off 454 g (about 1 lb) of fat, assuming that burning this much fat requires 3500 Cal be transferred to the ice water? Why is it not advisable to follow this diet? (One liter = 10³ cm³. The density of water is 1.00 g/cm³.)

**26** What mass of butter, which has a usable energy content of 6.0 Cal/g (= 6000 cal/g), would be equivalent to the change in gravitational potential energy of a 73.0 kg man who ascends from sea level to the top of Mt. Everest, at elevation 8.84 km? Assume that the average g for the ascent is 9.80 m/s².

**27 SSM** Calculate the minimum amount of energy, in joules, required to completely melt 130 g of silver initially at 15.0°C.

**28** How much water remains unfrozen after 50.2 kJ is transferred as heat from 260 g of liquid water initially at its freezing point?

**29** In a solar water heater, energy from the Sun is gathered by water that circulates through tubes in a rooftop 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. Assume 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 raise the temperature of 200 L of water in the tank from 20°C to 40°C in 1.0 h when the intensity of incident sunlight is 700 W/m²?

**30** A 0.400 kg sample is placed in a cooling apparatus that removes energy as heat at a constant rate. Figure 18-32 gives the temperature \( T \) of the sample versus time \( t \); the horizontal scale is set by \( t_i = 80.0 \) min. The sample freezes during the energy removal. The specific heat of the sample in its initial liquid phase is 3000 J/kg·K. What are (a) the sample’s heat of fusion and (b) its specific heat in the frozen phase?

![Fig. 18-32 Problem 30.](image)

**31 ILW** What mass of steam at 100°C must be mixed with 150 g of ice at its melting point, in a thermally insulated container, to produce liquid water at 50°C?

**32** The specific heat of a substance varies with temperature according to the function \( c = 0.20 + 0.14T + 0.023T^2 \), with \( T \) in °C and \( c \) in cal/g·K. Find the energy required to raise the temperature of 2.0 g of this substance from 5.0°C to 15°C.

**33 Nonmetric version:** (a) How long does a 2.0 \( \times 10^3 \) Btu/h water heater take to raise the temperature of 40 gal of water from 70°F to 100°F? **Metric version:** (b) How long does a 59 kW water heater take to raise the temperature of 150 L of water from 21°C to 38°C?

**34** Samples A and B are at different initial temperatures when they are placed in a thermally insulated container and allowed to come to thermal equilibrium. Figure 18-33a gives their temperatures \( T \) versus time \( t \). Sample A has a mass of 5.0 kg; sample B has a mass of 1.5 kg. Figure 18-33b is a general plot for the material of sample B. It shows the temperature change \( \Delta T \) that the material undergoes when energy is transferred to it as heat \( Q \). The change \( \Delta T \) is plotted versus the energy \( Q \) per unit mass of the material, and the scale of the vertical axis is set by \( \Delta T_i = 4.0 \) °C. What is the specific heat of sample A?

![Fig. 18-33 Problem 34.](image)

**35** An insulated Thermos contains 130 cm³ of hot coffee at 80.0°C. You put in a 12.0 g ice cube at its melting point to cool the coffee. By how many degrees has your coffee cooled once the ice has melted and equilibrium is reached? Treat the coffee as though it were pure water and neglect energy exchanges with the environment.

**36** A 150 g copper bowl contains 220 g of water, both at 20.0°C. A very hot 300 g copper cylinder is dropped into the water, causing the
water to boil, with 5.00 g being converted to steam. The final temperature of the system is 100°C. Neglect energy transfers with the environment. (a) How much energy (in calories) is transferred to the water as heat? (b) How much to the bowl? (c) What is the original temperature of the cylinder?

•37 A person makes a quantity of iced tea by mixing 500 g of hot tea (essentially water) with an equal mass of ice at its melting point. Assume the mixture has negligible energy exchanges with its environment. If the tea’s initial temperature is \( T_I = 90^\circ \text{C} \), when thermal equilibrium is reached what are (a) the mixture’s temperature \( T_f \) and (b) the remaining mass \( m_f \) of ice? If \( T_I = 70^\circ \text{C} \), when thermal equilibrium is reached what are (c) \( T_f \) and (d) \( m_f \)?

•38 A 0.530 kg sample of liquid water and a sample of ice are placed in a thermally insulated container. The container also contains a device that transfers energy as heat from the liquid water to the ice at a constant rate \( P \), until thermal equilibrium is reached. The temperatures \( T \) of the liquid water and the ice are given in Fig. 18-34 as functions of time \( t \); the horizontal scale is set by \( t_s = 80.0 \) min. (a) What is rate \( P \)? (b) What is the initial mass of the ice in the container? (c) When thermal equilibrium is reached, what is the mass of the ice produced in this process?

![Figure 18-34](image)

**Fig. 18-34** Problem 38.

•39 Ethyl alcohol has a boiling point of 78.0°C, a freezing point of \(-114^\circ \text{C}\), a heat of vaporization of 879 kJ/kg, a heat of fusion of 109 kJ/kg, and a specific heat of 2.43 kJ/kg·K. How much energy must be removed from 0.510 kg of ethyl alcohol that is initially a gas at 78.0°C so that it becomes a solid at \(-114^\circ \text{C}\)?

•40 Calculate the specific heat of a metal from the following data. A container made of the metal has a mass of 3.6 kg and contains 14 kg of water. A 1.8 kg piece of the metal initially at a temperature of 180°C is dropped into the water. The container and water initially have a temperature of 16.0°C, and the final temperature of the entire (insulated) system is 18.0°C.

•41 **SSM WWW** (a) Two 50 g ice cubes are dropped into 200 g of water in a thermally insulated container. If the water is initially at 25°C, and the ice comes directly from a freezer at \(-15^\circ \text{C}\), what is the final temperature at thermal equilibrium? (b) What is the final temperature if only one ice cube is used?

•42 A 20.0 g copper ring at 0.000°C has an inner diameter of \( D = 2.5400 \) cm. An aluminum sphere at 100.0°C has a diameter of \( d = 2.545 \) 0.08 cm. The sphere is put on top of the ring (Fig. 18-35), and the two are allowed to come to thermal equilibrium, with no heat lost to the surroundings. The sphere just passes through the ring at the equilibrium temperature. What is the mass of the sphere?

**sec. 18-11 Some Special Cases of the First Law of Thermodynamics**

•43 In Fig. 18-36, a gas sample expands from \( V_0 \) to \( 4.0 V_0 \) while its pressure decreases from \( p_0 \) to \( p_0/4.0 \). If \( V_0 = 1.0 \) m³ and \( p_0 = 40 \) Pa, how much work is done by the gas if its pressure changes with volume via (a) path A, (b) path B, and (c) path C?

![Figure 18-36](image)

**Fig. 18-36** Problem 43.

•44 A thermodynamic system is taken from state A to state B to state C, and then back to A, as shown in the \( p-V \) diagram of Fig. 18-37a. The vertical scale is set by \( p_1 = 40 \) Pa, and the horizontal scale is set by \( V_1 = 4.0 \) m³. (a)–(g) Complete the table in Fig. 18-37b by inserting a plus sign, a minus sign, or a zero in each indicated cell. (h) What is the net work done by the system as it moves once through the cycle ABCBA?

![Figure 18-37](image)

**Fig. 18-37** Problem 44.

•45 **SSM WWW** A gas within a closed chamber undergoes the cycle shown in the \( p-V \) diagram of Fig. 18-38. The horizontal scale is set by \( V_f = 4.0 \) m³. Calculate the net energy added to the system as heat during one complete cycle.

![Figure 18-38](image)

**Fig. 18-38** Problem 45.

•46 Suppose 200 J of work is done on a system and 70.0 cal is extracted from the system as heat. In the sense of the first law of thermodynamics, what are the values (including algebraic signs) of (a) \( W \), (b) \( Q \), and (c) \( \Delta E_{\text{melt}} \)?
47. When a system is taken from state $i$ to state $f$ along path $iaf$ in Fig. 18-39, $Q = 50$ cal and $W = 20$ cal. Along path $ibf$, $Q = 36$ cal. (a) What is $W$ along path $ibf$? (b) If $W = -13$ cal for the return path $fbi$, what is $Q$ for this path? (c) If $E_{int,i} = 10$ cal, what is $E_{int,f}$? If $E_{int,b} = 22$ cal, what is $Q$ for (d) path $ib$ and (e) path $bf$?

![Fig. 18-39 Problem 47.](image)

48. Gas held within a chamber passes through the cycle shown in Fig. 18-40. Determine the energy transferred by the system as heat during process $CA$ if the energy added as heat $Q_{AB}$ during process $AB$ is 20 J, no energy is transferred as heat during process $BC$, and the net work done during the cycle is 15.0 J.

![Fig. 18-40 Problem 48.](image)

49. Figure 18-41 represents a closed cycle for a gas (the figure is not drawn to scale). The change in the internal energy of the gas as it moves from $a$ to $c$ along the path $abc$ is $-200$ J. As it moves from $c$ to $d$, 180 J must be transferred to it as heat. An additional transfer of 80 J to it as heat is needed as it moves from $d$ to $a$. How much work is done on the gas as it moves from $c$ to $d$?

![Fig. 18-41 Problem 49.](image)

50. A lab sample of gas is taken through cycle $abc$ shown in the $p-V$ diagram of Fig. 18-42. The net work done is +1.2 J. Along path $ab$, the change in the internal energy is $+3.0$ J and the magnitude of the work done is 5.0 J. Along path $ca$, the energy transferred to the gas as heat is $+2.5$ J. How much energy is transferred as heat along (a) path $ab$ and (b) path $bc$?

![Fig. 18-42 Problem 50.](image)

51. A sphere of radius $0.500$ m, temperature $27.0^\circ$C, and emissivity 0.850 is located in an environment of temperature $77.0^\circ$C. At what rate does the sphere (a) emit and (b) absorb thermal radiation? (c) What is the sphere's net rate of energy exchange?

52. The ceiling of a single-family dwelling in a cold climate should have an $R$-value of 30. To give such insulation, how thick would a layer of (a) polyurethane foam and (b) silver have to be?

53. Consider the slab shown in Fig. 18-18. Suppose that $L = 25.0$ cm, $A = 90.0$ cm$^2$, and the material is copper. If $T_H = 125^\circ$C, $T_C = 10.0^\circ$C, and a steady state is reached, find the conduction rate through the slab.

54. If you were to walk briefly in space without a spacesuit while far from the Sun (as an astronaut does in the movie 2001, A Space Odyssey), you would feel the cold of space—while you radiated energy, you would absorb almost none from your environment. (a) At what rate would you lose energy? (b) How much energy would you lose in 30 s? Assume that your emissivity is 0.90, and estimate other data needed in the calculations.

55. A cylindrical copper rod of length 1.2 m and cross-sectional area 4.8 cm$^2$ is insulated to prevent heat loss through its surface. The ends are maintained at a temperature difference of 100$^\circ$C by having one end in a water–ice mixture and the other in a mixture of boiling water and steam. (a) At what rate is energy conducted along the rod? (b) At what rate does ice melt at the cold end?

56. The giant hornet Vespa mandarinia japonica preys on Japanese bees. However, if one of the hornets attempts to invade a beehive, several hundred of the bees quickly form a compact ball around the hornet to stop it. They don't sting, bite, crush, or suffocate it. Rather they overheat it by quickly raising their body temperatures from the normal $35^\circ$C to $47^\circ$C or $48^\circ$C, which is lethal to the hornet but not to the bees (Fig. 18-43). Assume the following: 500 bees form a ball of radius $R = 2.0$ cm for a time $t = 20$ min, the primary loss of energy by the ball is by thermal radiation, the ball's surface has emissivity $e = 0.80$, and the ball has a uniform temperature. On average, how much additional energy must each bee produce during the 20 min to maintain $47^\circ$C?

57. (a) What is the rate of energy loss in watts per square meter through a glass window 3.0 mm thick if the outside temperature is $-20^\circ$F and the inside temperature is $72^\circ$F? (b) A storm window having the same thickness of glass is installed parallel to the first window, with an air gap of 7.5 cm between the two windows. What now is the rate of energy loss if conduction is the only important energy-loss mechanism?

58. A solid cylinder of radius $r_1 = 2.5$ cm, length $h_1 = 5.0$ cm, emissivity 0.85, and temperature $30^\circ$C is suspended in an environment of temperature $50^\circ$C. (a) What is the cylinder's net thermal radiation transfer rate $P_2$? (b) If the cylinder is stretched until its radius is $r_2 = 0.50$ cm, its net thermal radiation transfer rate becomes $P_3$. What is the ratio $P_3/P_2$?

59. In Fig. 18-44a, two identical rectangular rods of metal are welded end to end, with a temperature of $T_1 = 0^\circ$C on the left side and a temperature of $T_2 = 100^\circ$C on
the right side. In 2.0 min, 10 J is conducted at a constant rate from the right side to the left side. How much time would be required to conduct 10 J if the rods were welded side to side as in Fig. 18-44b?

**60** Figure 18-45 shows the cross section of a wall made of three layers. The layer thicknesses are \( L_1 = 0.700 L_2 \), and \( L_3 = 0.350 L_2 \). The thermal conductivities are \( k_1 = 0.900k_1 \), and \( k_3 = 0.800k_1 \). The temperatures at the top and the sides of the wall are \( T_{H} = 30.0^\circ \text{C} \) and \( T_{C} = -15.0^\circ \text{C} \), respectively. Thermal conduction is steady. (a) What is the temperature difference \( \Delta T_2 \) across layer 2 (between the left and right sides of the layer)? If \( k_2 \) were, instead, equal to 1.1\( k_1 \), (b) would the rate at which energy is conducted through the wall be greater than, less than, or the same as previously, and (c) what would be the value of \( \Delta T_2 \)?

**61** SSM: A tank of water has been outdoors in cold weather, and a slab of ice 5.0 cm thick has formed on its surface (Fig. 18-46). The air above the ice is at \(-10^\circ \text{C}\). Calculate the rate of ice formation (in centimeters per hour) on the ice slab. Take the thermal conductivity of ice to be 0.0040 cal/s · cm · °C and its density to be 0.92 g/cm³. Assume no energy transfer through the tank walls or bottom.

**62** Leidenfrost effect. A water drop that is slung onto a skillet with a temperature between 100°C and about 200°C will last about 1 s. However, if the skillet is much hotter, the drop can last several minutes, an effect named after an early investigator. The longer lifetime is due to the support of a thin layer of air and water vapor that separates the drop from the metal (by distance \( L \) in Fig. 18-47). Let \( L = 0.100 \) mm, and assume that the drop is flat with height \( h = 1.50 \) mm and bottom face area \( A = 4.00 \times 10^{-4} \) m². Also assume that the skillet has a constant temperature \( T_s = 300^\circ \text{C} \) and the drop has a temperature of 100°C. Water has density \( \rho = 1000 \) kg/m³, and the supporting layer has thermal conductivity \( k = 0.026 \) W/m · K. (a) At what rate is energy conducted from the skillet to the drop through the drop’s bottom surface? (b) If conduction is the primary way energy moves from the skillet to the drop, how long will the drop last?

**63** Figure 18-48 shows (in cross section) a wall consisting of four layers, with thermal conductivities \( k_1 = 0.060 \) W/m · K, \( k_3 = 0.040 \) W/m · K, and \( k_4 = 0.12 \) W/m · K (\( k_2 \) is not known). The layer thicknesses are \( L_1 = 1.5 \) cm, \( L_2 = 2.8 \) cm, and \( L_4 = 3.5 \) cm (\( L_2 \) is not known). The known temperatures are \( T_1 = 30^\circ \text{C} \), \( T_2 = 25^\circ \text{C} \), and \( T_4 = -10^\circ \text{C} \). Energy transfer through the wall is steady. What is interface temperature \( T_3 \)?

**64** Penguin huddling. To withstand the harsh weather of the Antarctic, emperor penguins huddle in groups (Fig. 18-49). Assume that a penguin is a circular cylinder with a top surface area \( a = 0.34 \) m² and height \( h = 1.1 \) m. Let \( P \) be the rate at which an individual penguin radiates energy to the environment (through the top and the sides); thus \( NP \), is the rate at which \( N \) identical, well-separated penguins radiate. If the penguins huddle closely to form a huddled cylinder with top surface area \( Na \) and height \( h \), the cylinder radiates at the rate \( P_\mu \). If \( N = 1000 \), (a) what is the value of the fraction \( P_\mu/\, NP \), and (b) by what percentage does huddling reduce the total radiation loss?

**65** Ice has formed on a shallow pond, and a steady state has been reached, with the air above the ice at \(-5.0^\circ \text{C}\) and the bottom of the pond at 4.0°C. If the total depth of ice + water is 1.4 m, how thick is the ice? (Assume that the thermal conductivities of ice and water are 0.40 and 0.12 cal/m · °C · s, respectively.)

**66** Evaporative cooling of beverages. A cold beverage can be kept cold even on a warm day if it is slipped into a porous ceramic container that has been soaked in water. Assume that energy lost to evaporation matches the net energy gained via the radiation exchange through the top and side surfaces. The container and beverage have temperature \( T = 15^\circ \text{C} \), the environment has temperature \( T_{env} = 32^\circ \text{C} \), and the container is a cylinder with radius \( r = 2.2 \) cm and height 10 cm. Approximate the emissivity as \( \varepsilon = 1 \), and neglect other energy exchanges. At what rate \( dW/dt \) is the container losing water mass?

**Additional Problems**

67 In the extrusion of cold chocolate from a tube, work is done on the chocolate by the pressure applied by a ram forcing the chocolate through the tube. The work per unit mass of extruded chocolate is equal to \( p/p \), where \( p \) is the difference between the applied pressure and the pressure where the chocolate emerges from the tube, and \( \rho \) is the density of the chocolate.
Rather than increasing the temperature of the chocolate, this work melts cocoa fats in the chocolate. These fats have a heat of fusion of 150 kJ/kg. Assume that all of the work goes into that melting and that these fats make up 30% of the chocolate's mass. What percentage of the fats melt during the extrusion if \( p = 5.5 \) MPa and \( \rho = 1200 \) kg/m³?

68 Icebergs in the North Atlantic present hazards to shipping, causing the lengths of shipping routes to be increased by about 30% during the iceberg season. Attempts to destroy icebergs include planting explosives, bombing, torpédoining, shelling, ramming, and coating with black soot. Suppose that direct melting of the iceberg, by placing heat sources in the ice, is tried. How much energy as heat is required to melt 10% of an iceberg that has a mass of 200 000 metric tons? (Use 1 metric ton = 1000 kg.)

69 Figure 18-50 displays a closed cycle for a gas. The change in internal energy along path \( ab \) is \(-160 \) J and the energy transferred to the gas as heat is \( 200 \) J along path \( ab \), and \( 40 \) J along path \( bc \). How much work is done by the gas along (a) path \( abc \) and (b) path \( ab \)?

Fig. 18-50

Problem 69.

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, \( 1.00 \times 10^9 \) kcal is needed to maintain the inside of the house at 22.0°C. Assuming that the water in the barrels is at 50.0°C and that the water has a density of \( 1.00 \times 10^3 \) kg/m³, what volume of water is required?

71 A 0.300 kg sample is placed in a cooling apparatus that removes energy as heat at a constant rate of 2.81 W. Figure 18-51 gives the temperature \( T \) of the sample versus time \( t \). The temperature scale is set by \( T_s = 30°C \) and the time scale is set by \( t_s = 20 \) min. What is the specific heat of the sample?

Fig. 18-51

Problem 71.

The average rate at which energy is conducted outward through the ground surface in North America is 54.0 mW/m², and the average thermal conductivity of the near-surface rocks is 2.50 W/m·K. Assuming a surface temperature of 10.0°C, find the temperature at a depth of 35.0 km (near the base of the crust). Ignore the heat generated by the presence of radioactive elements.

73 What is the volume increase of an aluminum cube 5.00 cm on an edge when heated from 10.0°C to 60.0°C?

74 In a series of experiments, block \( B \) is to be placed in a thermally insulated container with block \( A \), which has the same mass as block \( B \). In each experiment, block \( B \) is initially at a certain temperature \( T_B \), but temperature \( T_A \) of block \( A \) is changed from experiment to experiment. Let \( T_f \) represent the final temperature of the two blocks when they reach thermal equilibrium in any of the experiments. Figure 18-52 gives temperature \( T_f \) versus the initial temperature \( T_A \) for a range of possible values of \( T_A \).

Fig. 18-52

Problem 74.

\( T_A \), from \( T_{A1} = 0 \) K to \( T_{A2} = 500 \) K. The vertical axis scale is set by \( T_B = 400 \) K. What are (a) temperature \( T_B \) and (b) the ratio \( c_B/c_A \) of the specific heats of the blocks?

75 Figure 18-53 displays a closed cycle for a gas. From \( c \) to \( b \), 40 J is transferred from the gas as heat. From \( b \) to \( a \), 130 J is transferred from the gas as heat, and the magnitude of the work done by the gas is 80 J. From \( a \) to \( c \), 40 J is transferred to the gas as heat. What is the work done by the gas from \( a \) to \( c \)? (Hint: You need to supply the plus and minus signs for the given data.)

Fig. 18-53

Problem 75.

Three equal-length straight rods, of aluminum, Invar, and steel, all at 20.0°C, form an equilateral triangle with hinge pins at the vertices. At what temperature will the angle opposite the Invar rod be 59.95°? See Appendix E for needed trigonometric formulas and Table 18-2 for needed data.

77 SSM The temperature of a 0.700 kg cube of ice is decreased to \(-150°C\). Then energy is gradually transferred to the cube as heat while it is otherwise thermally isolated from its environment. The total transfer is 0.6993 MJ. Assume the value of \( c_{Ice} \) given in Table 18-3 is valid for temperatures from \(-150°C\) to 0°C. What is the final temperature of the water?

78 Ice. Liquid water coats an active (growing) icicle and extends up a short, narrow tube along the central axis (Fig. 18-54). Because the water–ice interface must have a temperature of 0°C, the water in the tube cannot lose energy through the sides of the icicle or down through the tip because there is no temperature change in those directions. It can lose energy and freeze only by sending energy up (through distance \( L \)) to the top of the icicle, where the temperature \( T_i \) can be below 0°C. Take \( L = 0.12 \) m and \( T_i = -5°C \). Assume that the central tube and the upward conduction path both have cross-sectional area \( A \). In terms of \( A \), what rate is (a) energy conducted upward and (b) mass converted from liquid to ice at the top of the central tube? (c) At what rate does the top of the tube move downward because of water freezing there? The thermal conductivity of ice is 0.400 W/m·K, and the density of liquid water is 1000 kg/m³.

Fig. 18-54

Problem 78.

79 SSM A sample of gas expands from an initial pressure and volume of 10 Pa and 1.0 m³ to a final volume of 2.0 m³. During the expansion, the pressure and volume are related by the equation \( p = aV^2 \), where \( a = 10 \) N/m³. Determine the work done by the gas during this expansion.
80 Figure 18-55a shows a cylinder containing gas and closed by a movable piston. The cylinder is kept submerged in an ice-water mixture. The piston is quickly pushed down from position 1 to position 2 and then held at position 2 until the gas is again at the temperature of the ice-water mixture; it then is slowly raised back to position 1. Figure 18-55b is a p-V diagram for the process. If 100 g of ice is melted during the cycle, how much work has been done on the gas?

![Diagram of a cylinder with ice and water](image)

**Fig. 18-55** Problem 80.

81 SSM A sample of gas undergoes a transition from an initial state a to a final state b by three different paths (processes), as shown in the p-V diagram in Fig. 18-56, where \( V_b = 5.00 V_a \). The energy transferred to the gas as heat in process 1 is \( 10pV_a \). In terms of \( p_1V_a \), what are (a) the energy transferred to the gas as heat in process 2 and (b) the change in internal energy that the gas undergoes in process 3?

![Diagram of a p-V graph](image)

**Fig. 18-56** Problem 81.

82 A copper rod, an aluminum rod, and a brass rod, each of 6.00 m length and 1.00 cm diameter, are placed end to end with the aluminum rod between the other two. The free end of the copper rod is maintained at water's boiling point, and the free end of the brass rod is maintained at water’s freezing point. What is the steady-state temperature of (a) the copper-aluminum junction and (b) the aluminum-brass junction?

83 SSM The temperature of a Pyrex disk is changed from 10.0°C to 60.0°C. Its initial radius is 8.00 cm; its initial thickness is 0.500 cm. Take these data as being exact. What is the change in the volume of the disk? (See Table 18-2.)

84 (a) Calculate the rate at which body heat is conducted through the clothing of a skier in a steady-state process, given the following data: the body surface area is 1.8 m², and the clothing is 1.0 cm thick; the skin surface temperature is 33°C and the outer surface of the clothing is at 1.0°C; the thermal conductivity of the clothing is 0.040 W/m·K. (b) If, after a fall, the skier’s clothes became soaked with water of thermal conductivity 0.60 W/m·K, by how much is the rate of conduction multiplied?

85 SSM A 2.50 kg lump of aluminum is heated to 92.0°C and then dropped into 8.00 kg of water at 5.00°C. Assuming that the lump-water system is thermally isolated, what is the system’s equilibrium temperature?

86 A glass window pane is exactly 20 cm by 30 cm at 10°C. By how much has its area increased when its temperature is 40°C, assuming that it can expand freely?

87 A recruit can join the semi-secret "300 F" club at the Amundsen–Scott South Pole Station only when the outside temperature is below –70°C. On such a day, the recruit first basks in a hot sauna and then runs outside wearing only shoes. (This is, of course, extremely dangerous, but the rite is effectively a protest against the constant danger of the cold.)

Assume that upon stepping out of the sauna, the recruit’s skin temperature is 102°F and the walls, ceiling, and floor of the sauna room have a temperature of 30°C. Estimate the recruit’s surface area, and take the skin emissivity to be 0.80. (a) What is the approximate net rate \( P_{\text{net}} \) at which the recruit loses energy via thermal radiation exchanges with the room? Next, assume that when outdoors, half the recruit’s surface area exchanges thermal radiation with the sky at a temperature of –25°C and the other half exchanges thermal radiation with the snow and ground at a temperature of –80°C. What is the approximate net rate at which the recruit loses energy via thermal radiation exchanges with (b) the sky and (c) the snow and ground?

88 A steel rod at 25.0°C is bolted at both ends and then cooled. At what temperature will it rupture? Use Table 12-1.

89 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 1.00 m in order to burn off 1.00 lb of fat, assuming that that much fat is equivalent to 3500 Cal? (b) If the weight is lifted once every 2.00 s, how long does the task take?

90 Soon after Earth was formed, heat released by the decay of radioactive elements raised the average internal temperature from 300 to 3000 K, at about which value it remains today. Assuming an average coefficient of volume expansion of \( 3.0 \times 10^{-3} \) K⁻¹, by how much has the radius of Earth increased since the planet was formed?

91 It is possible to melt ice by rubbing one block of it against another. How much work, in joules, would you have to do to get 1.00 g of ice to melt?

92 A rectangular plate of glass initially has the dimensions 0.200 m by 0.300 m. The coefficient of linear expansion for the glass is 9.00 \( \times 10^{-6} \) K⁻¹. What is the change in the plate’s area if its temperature is increased by 20.0 K?

93 Suppose that you intercept \( 5.0 \times 10^{-3} \) of the energy radiated by a hot sphere that has a radius of 0.020 m, an emissivity of 0.80, and a surface temperature of 500 K. How much energy do you intercept in 2.0 min?

94 A thermometer of mass 0.055 kg and of specific heat 0.837 kJ/kg·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 then reads 44.4°C, what was the temperature of the water before insertion of the thermometer?

95 A sample of gas expands from \( V_1 = 1.0 \) m³ and \( p_1 = 40 \) Pa to \( V_3 = 4.0 \) m³ and \( p_2 = 10 \) Pa along path B in the p-V diagram in Fig. 18-57. It is then compressed back to \( V_1 \) along either path A or path C. Compute the net work done by the gas for the complete cycle along (a) path BA and (b) path BC.

![Diagram of a p-V graph](image)

**Fig. 18-57** Problem 95.