Temperature and Heat (Answer)

Check Your Understanding

1.1. The actual amount (mass) of gasoline left in the tank when the gauge hits "empty" is less in the summer than in the winter. The gasoline has the same volume as it does in the winter when the "add fuel" light goes on, but because the gasoline has expanded, there is less mass.

1.2. Not necessarily, as the thermal stress is also proportional to Young's modulus.

1.3. To a good approximation, the heat transfer depends only on the temperature difference. Since the temperature differences are the same in both cases, the same 25 kJ is necessary in the second case. (As we will see in the next section, the answer would have been different if the object had been made of some substance that changes phase anywhere between **30°C** and **50°C**.)

1.4. The ice and liquid water are in thermal equilibrium, so that the temperature stays at the freezing temperature as long as ice remains in the liquid. (Once all of the ice melts, the water temperature will start to rise.)

1.5. Snow is formed from ice crystals and thus is the solid phase of water. Because enormous heat is necessary for phase changes, it takes a certain amount of time for this heat to be transferred from the air, even if the air is above **0°C**.

1.6. Conduction: Heat transfers into your hands as you hold a hot cup of coffee. Convection: Heat transfers as the barista "steams" cold milk to make hot cocoa. Radiation: Heat transfers from the Sun to a jar of water with tea leaves in it to make "Sun tea." A great many other answers are possible.

1.7. Because area is the product of two spatial dimensions, it increases by a factor of four when each dimension is doubled ($A_{final} = (2d)^2 = 4d^2 = 4A_{initial}$). The distance, however, simply doubles. Because the temperature difference and the coefficient of thermal conductivity are independent of the spatial dimensions, the rate of heat transfer by conduction increases by a factor of four divided by two, or two: $P_{final} = \frac{kA_{final}(T_h - T_c)}{d_{final}} = \frac{k(4A_{final}(T_h - T_c))}{2d_{initial}} = 2\frac{kA_{final}(T_h - T_c)}{d_{initial}} = 2P_{initial}$.

1.8. Using a fan increases the flow of air: Warm air near your body is replaced by cooler air from elsewhere. Convection increases the rate of heat transfer so that moving air "feels" cooler than still air.

1.9. The radiated heat is proportional to the fourth power of the absolute temperature. Because $T_1 = 293K$ and $T_2 = 313K$, the rate of heat transfer increases by about 30% of the original rate.

Conceptual Questions

1. They are at the same temperature, and if they are placed in contact, no net heat flows between them.

3. The reading will change.

5. The cold water cools part of the inner surface, making it contract, while the rest remains expanded. The strain is too great for the strength of the material. Pyrex contracts less, so it experiences less strain.

7. In principle, the lid expands more than the jar because metals have higher coefficients of expansion than glass. That should make unscrewing the lid easier. (In practice, getting the lid and jar wet may make gripping them more difficult.)

9. After being heated, the length is $(1 + 300\alpha)(1m)$. After being cooled, the length is $(1 - 300\alpha)(1 + 300\alpha)(1m)$. That answer is not 1 m, but it should be. The explanation is that even if α is exactly constant, the relation $\Delta L = \alpha L \Delta T$ is strictly true only in the limit of small ΔT. Since α values are small, the discrepancy is unimportant in practice.

11. Temperature differences cause heat transfer.

13. No, it is stored as thermal energy. A thermodynamic system does not have a well-defined quantity of heat.

15. It raises the boiling point, so the water, which the food gains heat from, is at a higher temperature.

17. Yes, by raising the pressure above 56 atm.

19. work

21. **0°C** (at or near atmospheric pressure)

23. Condensation releases heat, so it speeds up the melting.

25. Because of water's high specific heat, it changes temperature less than land. Also, evaporation reduces temperature rises. The air tends to stay close to equilibrium with the water, so its temperature does not change much where there's a lot of water around, as in San Francisco but not Sacramento.

27. The liquid is oxygen, whose boiling point is above that of nitrogen but whose melting point is below the boiling point of liquid nitrogen. The crystals that sublime are carbon dioxide, which has no liquid phase at atmospheric pressure. The crystals that melt are water, whose melting point is above carbon dioxide's sublimation point. The water came from the instructor's breath.

29. Increasing circulation to the surface will warm the person, as the temperature of the water is warmer than human body temperature. Sweating will cause no evaporative cooling under water or in the humid air immediately above the tub.

31. It spread the heat over the area above the heating elements, evening the temperature there, but does not spread the heat much beyond the heating elements.

33. Heat is conducted from the fire through the fire box to the circulating air and then convected by the air into the room (forced convection).

35. The tent is heated by the Sun and transfers heat to you by all three processes, especially radiation.

37. If shielded, it measures the air temperature. If not, it measures the combined effect of air temperature and net radiative heat gain from the Sun.

39. Turn the thermostat down. To have the house at the normal temperature, the heating system must replace all the heat that was lost. For all three mechanisms of heat transfer, the greater the temperature difference between inside and outside, the more heat is lost and must be replaced. So the house should be at the lowest temperature that does not allow freezing damage.

41. Air is a good insulator, so there is little conduction, and the heated air rises, so there is little convection downward.

Problems

43. That must be Celsius. Your Fahrenheit temperature is **102°F**. Yes, it is time to get treatment.

45. a. $\Delta T_C = 22.2^\circ C$;

b. We know that $\Delta T_F = T_{F2} - T_{F1}$. We also know that $T_{F2} = \frac{9}{5}T_{C2} + 32$ and $T_{F1} = \frac{9}{5}T_{C1} + 32$. So, substituting, we have $\Delta T_F = (\frac{9}{5}T_{C2} + 32) - (\frac{9}{5}T_{C1} + 32)$. Partially solving and rearranging the equation, we have $\Delta T_F = \frac{9}{5}(T_{C2} - T_{C1})$. Therefore, $\Delta T_F = \frac{9}{5}\Delta T_C$ ΔTF=95ΔTC.

47. a. **−40°**; b. 575 K

49. Using Table 1.2 to find the coefficient of thermal expansion of marble:

$$L = L_0 + \Delta L = L_0(1 + \alpha\Delta T) = 170m[1 + (2.5 \times 10^{-6}/^\circ C)(-45.0^\circ C)] = 169.98m$$

(Answer rounded to five significant figures to show the slight difference in height.)

51. We use β instead of α since this is a volume expansion with constant surface area. Therefore:

$$\Delta L = \alpha L\Delta T = (6.0 \times 10^{-5}/^\circ C)(0.0300m)(3.00^\circ C) = 5.4 \times 10^{-6}m.$$

53. On the warmer day, our tape measure will expand linearly. Therefore, each measured dimension will be smaller than the actual dimension of the land. Calling these measured dimensions l'l' and w'w', we will find a new area, A. Let's calculate these measured dimensions:

$$l' = l_0 - \Delta l = (20m) - (20^\circ C)(20m)(\frac{1.2 \times 10^{-5}}{^\circ C}) = 19.9952m$$

$$A' = l \times w' = (29.9928m)(19.9952m) = 599.71m^2$$

Cost change = $(A - A')(\frac{\$60,000}{m^2}) = ((600 - 599.71)m^2)(\frac{\$60,000}{m^2}) = \$17,000$

Because the area gets smaller, the price of the land **decreases** by about $17,000.

55. a. Use Table 1.2 to find the coefficients of thermal expansion of steel and aluminum. Then $\Delta L_{Al} - \Delta L_{steel} = (\alpha_{Al} - \alpha_{steel})L_0\Delta T = (\frac{2.5 \times 10^{-5}}{^\circ C} - \frac{1.2 \times 10^{-5}}{^\circ C})(1.00m)(22^\circ C) = 2.9 \times 10^{-4}m$

b. By the same method with $L_0 = 30.0m$, we have $\Delta L = 8.6 \times 10^{-3}m$.

57. $\Delta V = 0.475L$

59. If we start with the freezing of water, then it would expand to $(1m^3)(\frac{1000kg/m^3}{917kg/m^3}) = 1.09m^3 = 1.98 \times 10^8 N/m^2$ of ice.

61. $m = 5.20 \times 10^8 J$

63. $Q = mc\Delta T \Rightarrow \Delta T = \frac{Q}{mc}$; a. **21.0°C**; b. **25.0°C**; c. **29.3°C**; d. **50.0°C**

65. $Q = mc\Delta T \Rightarrow c = \frac{Q}{m\Delta T} = \frac{1.04kcal}{(0.250kg)(45.0^\circ C)} = 0.0924kcal/kg\cdot{}^\circ C$. It is copper.

67. a. $Q = m_w c_w \Delta T + m_{A1}c_{A1}\Delta T = (m_w c_w + m_{A1}c_{A1})\Delta T$;
\($Q = [(0.500kg)(1.00kcal/kg\cdot{}^\circ C) + (0.100kg)(0.215kcal/kg\cdot{}^\circ C)](54.9^\circ C) = 28.63kcal$; $\frac{Q}{m_p} = \frac{28.63kcal}{5.00g} = 5.73kcal/g$;

b. $\frac{Q}{m_p} = \frac{200kcal}{33g} = 6kcal/g$, which is consistent with our results to part (a), to one significant figure.

69. 0.139°C

71. It should be lower. The beaker will not make much difference: **16.3°C**

73. a. $1.00 \times 10^5 J$;

b. $3.68 \times 10^5 J$;

c. The ice is much more effective in absorbing heat because it first must be melted, which requires a lot of energy, and then it gains the same amount of heat as the bag that started with water. The first $2.67 \times 10^5 J$ of heat is used to melt the ice, then it absorbs the $1.00 \times 10^5 J$ of heat as water.

75. 58.1 g

77. Let **M** be the mass of pool water and m be the mass of pool water that evaporates.

$$Mc\Delta T = mLV_{(37^\circ C)} \Rightarrow \frac{m}{M} = \frac{c\Delta T}{L_{V(37^\circ C)}} = \frac{(1.00kcal/kg\cdot{}^\circ C)(1.50^\circ C)}{580kcal/kg} = 2.59 \times 10^{-3} \quad ;$$

(Note that L_V for water at **37°C** is used here as a better approximation than L_V for **100°C** water.)

79. a. $1.47 \times 10^{15} kg$;

b. $4.90 \times 10^{20} J$;

c. $48.5y$

81. a. 9.35 L;

b. Crude oil is less dense than water, so it floats on top of the water, thereby exposing it to the oxygen in the air, which it uses to burn. Also, if the water is under the oil, it is less able to absorb the heat generated by the oil.

83. a. 319 kcal; b. **2.00°C**

85. First bring the ice up to **0°C** and melt it with heat Q_1: 4.74 kcal. This lowers the temperature of water by $\Delta T_2 : 23.15^\circ C$. Now, the heat lost by the hot water equals that gained by the cold water (T_f is the final temperature): **20.6°C**

87. Let the subscripts r, e, v, and w represent rock, equilibrium, vapor, and water, respectively.

$$m_r c_r (T_1 - T_e) = m_V L_V + m_W c_W (T_e - T_2) \quad ;$$

$$m_r = \frac{m_V L_V + m_W c_W (T_e - T_2)}{c_r (T_1 - T_e)} = \frac{(0.0250kg)(2256 \times 10^3 J/kg) + (3.975kg)(4186 \times 10^3 J/kg\cdot{}^\circ C)(100^\circ C - 15^\circ C)}{(840J/kg\cdot{}^\circ C)(500^\circ C - 100^\circ C)} = 4.38kg$$

89. a. $1.01 \times 10^3 W$;

b. One 1-kilowatt room heater is needed.

91. 84.0 W

93. 2.59 kg

95. a. 39.7 W; b. 820 kcal

97. $\frac{Q}{t} = \frac{kA(T_2 - T_1)}{d}, so that \frac{(Q/t)_{wall}}{(Q/t)_{window}} = \frac{k_{wall} A_{wall} d_{window}}{k_{window} A_{window} d_{wall}} = \frac{(2 \times 0.042 J/s \cdot m \cdot {}^\circ C)(10.0m^2)(0.750 \times 10^{-2} m)}{(0.84 J/s \cdot m \cdot {}^\circ C)(2.00m^2)(13.0 \times 10^{-2} m)}$

This gives 0.0288 wall: window, or 35:1 window: wall

99. $\frac{Q}{t} = \frac{kA(T_2 - T_1)}{d} = \frac{kA\Delta T}{d} \Rightarrow \Delta T = \frac{d(Q/t)}{kA} = \frac{(6.00 \times 10^{-3} m)(2256W)}{(0.84 J/s \cdot m \cdot {}^\circ C)(1.54 \times 10^{-2} m^2)} = 1046^\circ C = 1.05 \times 10^3 K$

101. We found in the preceding problem that $P = 126\Delta TW \cdot {}^\circ C$ as baseline energy use. So the total heat loss during this period is $Q = (126J/s \cdot {}^\circ C)(15.0^\circ C)(120days)(86.4 \times 10^3 s/day) = 1960 \times 10^6 J$. At the cost of \$1/MJ, the cost is \$1960. From an earlier problem, the savings is 12% or \$235/y. We need $150m^2$ of insulation in the attic. At $\$4/m^2$, this is a \$500 cost. So the payback period is $\$600/(\$235/y) = 2.6 years$(excluding labor costs).

Additional Problems

103. 7.39%

105. $\frac{F}{A} = (210 \times 10^9 Pa)(12 \times 10^{-6}/{}^\circ C)(40^\circ C - (-15^\circ C)) = 1.4 \times 10^8 N/m^2$

107. a. 1.06 cm;

b. 1.11 cm

109. $1.7kJ/(kg \cdot {}^{\circ}C)$

111. a. $1.57 \times 10^4 kcal$;

b. $18.3kW \cdot h$;

c. 1.29×10^4 kcal

113. 6.3°C. All of the ice melted.

115. 63.9°C, all the ice melted

117. a. 83 W;

b. $1.97 \times 10^3 W$; The single-pane window has a rate of heat conduction equal to 1969/83, or 24 times that of a double-pane window.

119. The rate of heat transfer by conduction is 20.0 W. On a daily basis, this is 1,728 kJ/day. Daily food intake is **2400kcal/d×4186J/kcal=10,050kJ/day**. So only 17.2% of energy intake goes as heat transfer by conduction to the environment at this ΔT.

121. 620 K

Challenge Problems

123. Denoting the period by **P**, we know $P = 2\pi\sqrt{L/g}$. When the temperature increases by dT, the length increases by αLdT. Then the new length is a. $P = 2\pi\sqrt{L + \alpha LdT}\, g = 2\pi\sqrt{\frac{L}{g}(1 + \alpha dT)} = 2\pi\sqrt{\frac{L}{g}}(1 + \frac{1}{2}\alpha dT) = P(1 + \frac{1}{2}\alpha dT)$ by the binomial expansion. b. The clock runs slower, as its new period is 1.00019 s. It loses 16.4 s per day.

125. The amount of heat to melt the ice and raise it to **100°C** is not enough to condense the steam, but it is more than enough to lower the steam's temperature by **50°C**, so the final state will consist of steam and liquid water in equilibrium, and the final temperature is **100°C**; 9.5 g of steam condenses, so the final state contains 49.5 g of steam and 40.5 g of liquid water.

127. a. $dL/dT = kT/\rho L$;

b. $L = \sqrt{2kTt/\rho L_f}$;

c. yes

129. a. $\sigma(\pi R^2)T_s^4$;

b. $e\sigma\pi R^2 T_s^4$;

c. $2e\sigma\pi R^2 T_e^4$;

d. $T_s^4 = 2T_e^4 T_s^4 = 2T_e^4$;

e. $e\sigma T_s^4 + \frac{1}{4}(1 - A)S = \sigma T_s^4$;

f. 288 K