Answers to selected problems from Essential Physics, Chapter 13

1. (a) In England, temperatures are measured in Celsius. Bill, coming from the United States, is used to hearing temperatures stated in Fahrenheit. (b) 77°F

3. The disk expands when heated, increasing the radius of the disk, and increasing the disk's rotational inertia. Because the disk's angular momentum should be conserved, the angular velocity of the disk decreases when the rotational inertia increases.

5. (a) Brass has a larger thermal expansion coefficient than iron. When the temperature increases from 20°C, the brass will expand more than the iron, so the brass strip will be longer than the iron strip. This causes the bimetallic strip to curve, with the longer strip on the outside (the longer side) of the curve. Thus, in the picture, the brass is the upper strip and the iron is the lower strip.

(b) One way to do this is to have the strip bend when it cools, so the strip makes electrical contact with a switch, turning on the heating system. When the room warms up, so does the strip, straightening the strip out so that it no longer makes contact with the switch, turning the heating system off again.

7. $m_B > m_C > m_A$

9. $m_B > m_C > m_A$

11. (a) The temperature of the black one increases more quickly, because the black object absorbs energy more efficiently from the Sun. (b) The temperature of the black one also decreases more quickly. Black objects also emit energy more quickly than do shiny objects.

13. (a) $T_K = \left(\frac{5°\text{K}}{9°\text{F}}\right)(T_F + 459.4°\text{F})$ (b) $T_F = \left(\frac{9°\text{F}}{5°\text{K}}\right)T_K - 459.4°\text{F}$

15. (a) Canada uses the metric system, so the temperature given on the box would be in Celsius, instead of in Fahrenheit as James is used to. James set the temperature on his stove to 250°F, but the cake should have been baked at a temperature of 250°C. (b) The cake was underdone, because 250°F is a lower temperature than 250°C. (c) 482°F.

17. 1.0007 cm

19. (a) Water will spill out of the pot as the temperature increases. This is because the thermal expansion coefficient for water is larger than the thermal expansion coefficient for aluminum, so the water will expand to a larger volume than the volume of the pot. (b) 0.84% of the water has spilled out by the time the temperature reaches 80°C.

21. 19.98 rad/s

23. (a) There are three heat terms here. Two of these terms are positive, representing the heat gained by the water (Q_w) and the container (Q_c) as their temperatures increase. The third term is negative, as it represents the heat lost by the block (Q_b) as it cools down.

(b) $Q_w + Q_c + Q_b = 0$

(c) $m_w c_w (T_F - 10°\text{C}) + m_c c_c (T_F - 10°\text{C}) + m_b c_b (T_F - 80°\text{C}) = 0$

(d) $(m_w c_w + m_c c_c + m_b c_b) T_F = m_w c_w \times 10°\text{C} + m_c c_c \times 10°\text{C} + m_b c_b \times 80°\text{C}$

$$T_F = \frac{m_w c_w \times 10°\text{C} + m_c c_c \times 10°\text{C} + m_b c_b \times 80°\text{C}}{m_w c_w + m_c c_c + m_b c_b}$$

$$T_F = \frac{(500\text{ g}) \times [4186\text{ J/(kg °C)}] \times 10°\text{C} + (200\text{ g}) \times [900\text{ J/(kg °C)}] \times 10°\text{C} + (300\text{ g}) \times [900\text{ J/(kg °C)}] \times 80°\text{C}}{(500\text{ g}) \times [4186\text{ J/(kg °C)}] + (200\text{ g}) \times [900\text{ J/(kg °C)}] + (300\text{ g}) \times [900\text{ J/(kg °C)}]}$$

$$T_F = 17.4°\text{C}$$

25. (a) There are four heat terms here. One of these terms is positive, representing the heat gained by the block (Q_b) as its temperature increases. The other three terms are negative, representing the heat lost by the water (Q_{w1}) as it cools down as a liquid from +50°C to 0°C; the heat lost by the water (Q_{w2}) as it changes phase from liquid to solid at 0°C; and the heat lost by the water (Q_{w3}) as it cools down as a solid from 0°C to –20°C.

(b) $Q_b + Q_{w1} + Q_{w2} + Q_{w3} = 0$

(c)

$$m_b c_b [-20°\text{C} - (-196°\text{C})] + m_w c_{w,liquid} (0°\text{C} - 50°\text{C}) - m_w L_f + m_w c_{w,solid} (-20°\text{C} - 0°\text{C}) = 0$$

(d)

$$m_w = \frac{-m_b c_b [-20°\text{C} - (-196°\text{C})]}{c_{w,liquid} (0°\text{C} - 50°\text{C}) - L_f + c_{w,solid} (-20°\text{C} - 0°\text{C})}$$

$$m_w = \frac{-(500\text{ g}) \times [385\text{ J/(kg °C)}] \times (+176°\text{C})}{[4186\text{ J/(kg °C)}] \times (-50°\text{C}) - (335000\text{ J/kg}) + [2060\text{ J/(kg °C)}](-20°\text{C})}$$

$$m_w = 57.9\text{ g}$$

27. (a) There are three heat terms here. One of these terms is positive, representing the heat gained by the block (Q_b) as its temperature increases. The other two terms are negative, representing the heat lost by the water (Q_w) as it cools down as a liquid from +50°C to +20°C, and the heat lost by the cup (Q_c) as it cools down from +50°C to +20°C

(b) $Q_b + Q_w + Q_c = 0$

(c) $m_b c_b [+20°\text{C} - (-196°\text{C})] + m_w c_w (+20°\text{C} - 50°\text{C}) + m_c c_c (+20°\text{C} - 50°\text{C}) = 0$

(d)

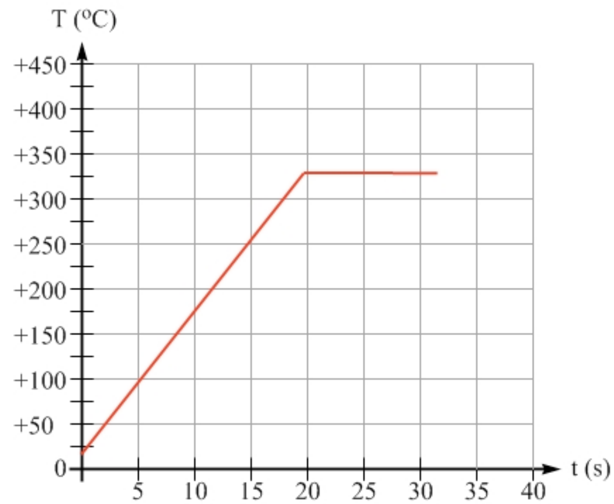
$$m_w = \frac{-m_b c_b [+20°\text{C} - (-196°\text{C})] - m_c c_c (+20°\text{C} - 50°\text{C})}{c_w (+20°\text{C} - 50°\text{C})}$$

$$m_w = \frac{-(500\text{ g})\times[385\text{ J/(kg °C)}]\times(+216°\text{C}) - (300\text{ g})\times[900\text{ J/(kg °C)}]\times(-30°\text{C})}{[4186\text{ J/(kg °C)}]\times(-30°\text{C})}$$

$$m_w = 267\text{ g}$$

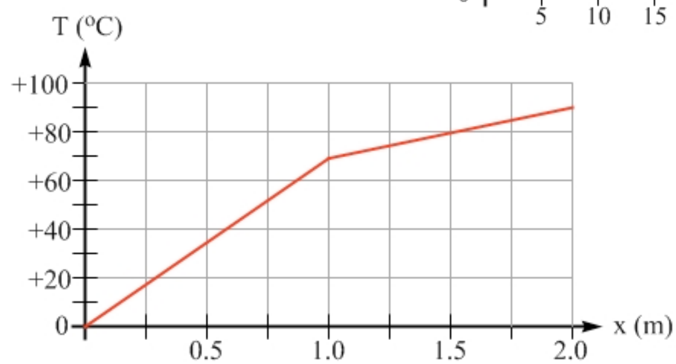
29. 17.1 minutes

31. (a) 19.8 s (b) 11.5 s (c)



33. 250 W

35.



37. The property of the liquid that is being exploited here is the fact that the density of the liquid depends on temperature. To be specific, the density of the liquid decreases as the temperature of the liquid increases. The balls in the thermometer all have slightly different densities from one another, and their densities are close to that of the liquid. Take, for example, a Galileo thermometer with 5 balls in it, marked 18°C, 19°C, 20°C, 21°C, and 22°C, and imagine that the thermometer starts off at a temperature of 17°C. At this temperature, the density of the liquid would be higher than that of the balls, and the balls would all float. If the thermometer's temperature was raised above 18°C, however, the density of the liquid would decrease below that of the 18°C ball, and that ball would sink to the bottom. Raising the temperature further, if the liquid's temperature rises above 19°C, the 19°C ball sinks, etc. This thermometer gives the temperature within 1°C – if the 19°C ball sinks while the 20°C ball floats, all we know is that the temperature is somewhere between 19°C and 20°C.

39. 250000 J

41. (a) The final temperature should be quite a bit lower than 60°C. The masses of the lead and water are the same, so the final temperature would be halfway between 100°C and 20°C only if the specific heats of water and lead were the same. In a case like this, $mc\Delta T$ for the lead has the same magnitude as $mc\Delta T$ for the water. However, the specific heat of water is significantly larger than the specific heat of lead, so the temperature change for the lead must be significantly larger than the temperature change for the water. The final temperature will be a lot closer to the initial temperature of the water than it is to the initial temperature of the lead. (b) 22.4°C.

43. 325 g

45. (a) 0.447 kg represents the smallest amount of ice that can be added to the punch to produce a final temperature of 0°C. In this case, all the ice melts, so the punch transfers the maximum amount of heat possible to the ice. (b) The other extreme is to use a large amount of ice, so large that the punch cools down to 0°C and then all the punch freezes, with the situation at equilibrium being that everything is solid at 0°C. The mass of ice required to do this is 27.1 kg of ice.

47. 24.6°C

49. 26.1°C

51. There is not quite enough information given here to state the ranking by final temperature. In general, we can say that the temperature of the cup with the gold ball will be greater than or equal to the temperature of the cup with the copper ball, which will be greater than or equal to the temperature of the cup with the aluminum ball. However, we would need to know how the mass of the balls compares to the mass of the water in the cup to determine the exact ranking by final temperature. The difficulty arises because the water could experience a phase change, so there are wide ranges of ball masses that can result in a final temperature of 0°C for the three cases, and these ranges overlap.

55. Inverting the 1.2 m tube 100 times is like dropping the balls from a height of 120 m. If we assume that all the gravitational potential energy is converted into heat, and all the heat is transferred to the lead balls, we have $mgh = mc\Delta T$. The mass cancels, so we don't even need the mass that is given. This gives a temperature difference of:

$$\Delta T = \frac{gh}{c} = \frac{(9.8 \text{ m/s}^2)\times(120 \text{ m})}{129 \text{ J/(kg °C)}} \approx 9\text{°C}$$

57. (a) 3.65×10^{26} W (b) 1360 W

59. (a) It takes longer than T to heat the water with the aluminum pot. Aluminum has a smaller thermal conductivity than copper, so the rate at which energy is transferred through the base of the aluminum pot to the water is less than the rate at which energy is transferred through the base of the copper pot. (b) 1.7 T

61. (a) 6.84×10^{10} J (b) 6.22×10^{10} J (c) 1 kW h = 3.6×10^{6} , which means you would save about $350. (Note that the house in this example has an especially low R-value – with a higher R value, the amount of energy lost through the walls is reduced, as is the cost and the savings from reducing the temperature.)

63. 359 m of aluminum