11

Energy in Thermal Processes

ANSWERS TO MULTIPLE CHOICE QUESTIONS

1. From the mechanical equivalent of heat, $1\ \text{cal} = 4.186\ \text{J}$. Therefore,

$$3.50\times10^{3}\ \text{cal} = \left(3.50\times10^{3}\ \text{cal}\right)\left(\frac{4.186\ \text{J}}{1\ \text{cal}}\right) = 1.47\times10^{4}\ \text{J}$$

and (b) is the correct choice for this question.

2. From $Q = mc(\Delta T)$, we see that when equal-mass samples have equal amounts of energy transferred to them by heat, the expected temperature rise is inversely proportional to the specific heat:

$$\Delta T = \frac{(Q/m)}{c}$$

Thus, the alcohol sample, with a specific heat that is about one-half that of water, should experience a temperature rise that is approximately twice that of the water sample. The correct choice is (c).

3. The rate of energy transfer by conduction through a wall of area A and thickness L is $P = kA\left(T_h - T_c\right)/L$, where k is the thermal conductivity of the material making up the wall, while T_h and T_c are the temperatures on the hotter and cooler sides of the wall, respectively. For the case given, the transfer rate will be

$$P = \left(0.08\ \frac{\text{J}}{\text{s}\cdot\text{m}\cdot{}^\circ\text{C}}\right)\left(48.0\ \text{m}^2\right)\frac{\left(25^\circ\text{C} - 14^\circ\text{C}\right)}{\left(4.00\times10^{-2}\ \text{m}\right)} = 1.1\times10^{3}\ \text{J/s} = 1.1\times10^{3}\ \text{W}$$

and (d) is the correct answer.

4. The energy which must be added to the 0°C ice to melt it, leaving liquid at 0°C, is

$$Q_1 = mL_f = (2.00\text{ kg})(3.33\times10^5\text{ J/kg}) = 6.66\times10^5\text{ J}$$

Once this is done, there is $Q_2 = Q_{\text{total}} - Q_1 = 9.30\times10^5\text{ J} - 6.66\times10^5\text{ J} = 2.64\times10^5\text{ J}$ of energy still available to raise the temperature of the liquid. The change in temperature this produces is

$$\Delta T = T_f - 0°\text{C} = \frac{Q_2}{mc_{\text{water}}} = \frac{2.64\times10^5\text{ J}}{(2.00\text{ kg})(4\,186\text{ J/kg}\cdot°\text{C})} = 31.5°\text{C}$$

so the final temperature is $T_f = 0°\text{C} + 31.5°\text{C} = 31.5°\text{C}$ and the correct choice is (c).

5. The required energy input is

$$Q = mc(\Delta T) = (5.00\text{ kg})(128\text{ J/kg}\cdot°\text{C})(327°\text{C} - 20.0°\text{C}) = 1.96\times10^5\text{ J}$$

and the correct response is (e).

6. The power radiated by an object with emissivity *e*, surface area *A*, and absolute temperature *T*, in a location with absolute ambient temperature T_0, is given by $P = \sigma Ae\left(T^4 - T_0^4\right)$, where $\sigma = 5.669\,6\times10^{-8}\text{ W/m}^2\cdot\text{K}^4$ is a constant. Thus, for the given spherical object $\left(A = 4\pi r^2\right)$ with $T = 273 + 135 = 408\text{ K}$ and $T_0 = 273 + 25 = 298\text{ K}$, we have

$$P = \left(5.669\,6 \times 10^{-8}\ \text{W/m}^2 \cdot \text{K}^4\right) 4\pi\,(2.00\ \text{m})^2\,(0.450)\left[(408\ \text{K})^4 - (298\ \text{K})^4\right]$$

yielding $P = 2.54 \times 10^4\ \text{W},$ so (e) is the correct choice.

7. The temperature of the ice must be raised to the melting point, $\Delta T = +20.0°\text{C}$, before it will start to melt. The total energy input required to melt the 2.00-kg of ice is

$$Q = mc(\Delta T) + mL_f = (2.00\ \text{kg})\left[(2\,090\ \text{J/kg}\cdot°\text{C})(20.0°\text{C}) + 3.33\times10^5\ \text{J/kg}\right] = 7.50\times10^5\ \text{J}$$

The time the heating element will need to supply this quantity of energy is

$$\Delta t = \frac{Q}{P} = \frac{7.50\times10^5\ \text{J}}{1.00\times10^3\ \text{J/s}} = 750\ \text{s}\left(\frac{1\ \text{min}}{60\ \text{s}}\right) = 12.5\ \text{min}$$

making (d) the correct choice.

8. If energy transfer between the environment and the contents of the calorimeter cannot be avoided, one would like the initial temperature to be such that the contents of the calorimeter would gain as much energy from the environment in one part of the process as it loses to the environment in another part of the process. Thus, we would like (after a few trial runs) to choose an initial temperature such that room temperature will be about halfway between the initial and final temperatures of the calorimeter contents. The best response is therefore choice (a).

ANSWERS TO EVEN NUMBERED CONCEPTUAL QUESTIONS

2. The high thermal capacity of the barrel of water and its high heat of fusion mean that a large amount of energy would have to leak out of the cellar before the water and produce froze solid. Also, evaporation of the water keeps the relative humidity high to protect foodstuffs from drying out.

4. (a) Yes, wrap the blanket around the ice chest. The environment is warmer than the ice, so the low thermal conductivity of the blanket slows energy transfer by heat from the environment to the ice.

(b) Explain to your little sister that her body is warmer than the environment and requires energy transfer by heat into the air to remain at a fixed temperature. The blanket will slow this conduction and cause her to feel warmer, not cool like the ice.

PROBLEM SOLUTIONS

11.2 $$c = \frac{Q}{m(\Delta T)} = \frac{1.23 \times 10^3 \text{ J}}{(0.525 \text{ kg})(10.0°\text{C})} = 234 \text{ J/kg} \cdot °\text{C} = \boxed{0.234 \text{ kJ/kg} \cdot °\text{C}}$$

11.3 The mass of water involved is

$$m = \rho V = \left(10^3 \ \frac{\text{kg}}{\text{m}^3}\right)\left(4.00 \times 10^{11} \text{ m}^3\right) = 4.00 \times 10^{14} \text{ kg}$$

(a) $Q = mc(\Delta T) = \left(4.00 \times 10^{14} \text{ kg}\right)\left(4\,186 \text{ J/kg} \cdot °\text{C}\right)(1.00°\text{C}) = \boxed{1.67 \times 10^{18} \text{ J}}$

(b) The power input is $P = 1\,000 \text{ MW} = 1.00 \times 10^9 \text{ J/s}$,

so $$t = \frac{Q}{P} = \frac{1.67 \times 10^{18} \text{ J}}{1.00 \times 10^9 \text{ J/s}}\left(\frac{1 \text{ yr}}{3.156 \times 10^7 \text{ s}}\right) = \boxed{52.9 \text{ yr}}$$

11.5 (a) $Q = 0.600\left|\Delta PE_g\right| = 0.600\left(mg|h|\right) = 0.600 \cdot m\left(9.80\ \text{m/s}^2\right)(50.0\ \text{m})$

or $Q = \left(294\ \text{m}^2/\text{s}^2\right) \cdot m$

From $Q = mc(\Delta T) = mc(T_f - T_i)$, we find the final temperature as

$$T_f = T_i + \frac{Q}{mc} = 25.0°\text{C} + \frac{\left(294\ \text{m}^2/\text{s}^2\right)\cdot \cancel{m}}{\cancel{m}\left(387\ \text{J/kg}\cdot°\text{C}\right)} = \boxed{25.8°\text{C}}$$

(b) Observe that the mass of the coin cancels out in the calculation of part (a). Hence, the $\boxed{\text{result is independent of the mass of the coin}}$.

11.9 The mechanical energy transformed into internal energy of the bullet is $Q = \frac{1}{2}\left(KE_i\right) = \frac{1}{2}\left(\frac{1}{2}mv_i^2\right) = \frac{1}{4}mv_i^2$.

Thus, the change in temperature of the bullet is

$$\Delta T = \frac{Q}{mc} = \frac{\frac{1}{4}\cancel{m}v_i^2}{\cancel{m}c_{\text{lead}}} = \frac{\left(300\ \text{m/s}\right)^2}{4\left(128\ \text{J/kg}\cdot°\text{C}\right)} = \boxed{176\,°\text{C}}$$

11.25 Remember that energy must be supplied to melt the ice before its temperature will begin to rise. Then, assuming a thermally isolated system, $Q_{\text{cold}} = -Q_{\text{hot}}$, or

$$m_{\text{ice}}L_f + m_{\text{ice}}c_{\text{water}}\left(T_f - 0°\text{C}\right) = -m_{\text{water}}c_{\text{water}}\left(T_f - 25°\text{C}\right)$$

and

$$T_f = \frac{m_{\text{water}}c_{\text{water}}(25°\text{C}) - m_{\text{ice}}L_f}{\left(m_{\text{ice}} + m_{\text{water}}\right)c_{\text{water}}} = \frac{\left(825\ \cancel{\text{g}}\right)\left(4\,186\ \text{J/kg}\cdot°\text{C}\right)(25°\text{C}) - \left(75\ \cancel{\text{g}}\right)\left(3.33\times10^5\ \text{J/kg}\right)}{\left(75\ \cancel{\text{g}} + 825\ \cancel{\text{g}}\right)\left(4\,186\ \text{J/kg}\cdot°\text{C}\right)}$$

yielding $\boxed{T_f = 16°\text{C}}$

11.26 The total energy input required is

$$\begin{aligned} Q &= (\text{energy to melt 50 g of ice}) \\ &\quad + (\text{energy to warm 50 g of water to 100°C}) \\ &\quad + (\text{energy to vaporize 5.0 g water}) \\ &= (50\text{ g})L_f + (50\text{ g})c_{\text{water}}(100°\text{C} - 0°\text{C}) + (5.0\text{ g})L_v \end{aligned}$$

Thus, $Q = (0.050\text{ kg})\left(3.33\times10^5\ \frac{\text{J}}{\text{kg}}\right)$

$$+ (0.050\text{ kg})\left(4\,186\ \frac{\text{J}}{\text{kg}\cdot°\text{C}}\right)(100°\text{C} - 0°\text{C})$$

$$+ (5.0\times10^{-3}\text{ kg})\left(2.26\times10^6\ \frac{\text{J}}{\text{kg}}\right)$$

which gives $Q = 4.9\times10^4\text{ J} = \boxed{49\text{ kJ}}$

11.28 The energy required is the following sum of terms:

$$\begin{aligned} Q &= (\text{energy to reach melting point}) \\ &\quad + (\text{energy to melt}) + (\text{energy to reach boiling point}) \\ &\quad + (\text{energy to vaporize}) + (\text{energy to reach 110°C}) \end{aligned}$$

Mathematically,

$$Q = m\Big[c_{\text{ice}}\left[0°\text{C} - (-10°\text{C})\right] + L_f + c_{\text{water}}(100°\text{C} - 0°\text{C}) + L_v + c_{\text{steam}}(110°\text{C} - 100°\text{C})\Big]$$

This yields

$$Q = \left(40\times10^{-3}\ \text{kg}\right)\left[\left(2\ 090\ \frac{\text{J}}{\text{kg}\cdot{}^\circ\text{C}}\right)(10^\circ\text{C}) + \left(3.33\times10^{5}\ \frac{\text{J}}{\text{kg}}\right)\right.$$

$$\left. + \left(4\ 186\ \frac{\text{J}}{\text{kg}\cdot{}^\circ\text{C}}\right)(100^\circ\text{C}) + \left(2.26\times10^{6}\ \frac{\text{J}}{\text{kg}}\right) + \left(2\ 010\ \frac{\text{J}}{\text{kg}\cdot{}^\circ\text{C}}\right)(10^\circ\text{C})\right]$$

or $Q = 1.2\times10^{5}\ \text{J} = \boxed{0.12\ \text{MJ}}$