Section 6.4: States of Matter and Changes of State

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1. Since a change of state is occurring, use $Q = mL_i$ to solve the problem.

Given: $V_w = 2.0$ L = 2000 mL; $L_f = 3.4 \times 10^5$ J/kg

Required: Q, latent heat of fusion

Analysis: $Q = mL_i$

Solution: Since the latent heat equation is based on the mass of a substance, first calculate the mass of water, m_w, in kilograms, using the volume of water, V_w, provided and the density of water.

$$m_w = 2000\ \cancel{\text{mL}} \times \frac{1\ \cancel{\text{g}}}{1\ \cancel{\text{mL}}} \times \frac{1\ \text{kg}}{1000\ \cancel{\text{g}}}$$

$$m_w = 2.0\ \text{kg}$$

$$Q = mL_f$$

$$= (2.0\ \cancel{\text{kg}})(3.4\times10^5\ \text{J}/\cancel{\text{kg}})$$

$\cancel{Q = 6.8\times10^5\ \text{J}}$ $Q = -6.8\times10^5$ J (releases energy)

Statement: The liquid water releases 6.8×10^5 J of thermal energy when it freezes.

2. Since a change of state is occurring, use $Q = mL_i$ to solve the problem.

Given: $m_m = 350$ g = 0.35 kg; $L_f = 1.1 \times 10^6$ J/kg

Required: Q, latent heat of fusion

Analysis: $Q = mL_i$

Solution:

$$Q = mL_f$$

$$= (0.35\ \cancel{\text{kg}})(1.1\times10^6\ \text{J}/\cancel{\text{kg}})$$

$$Q = 3.9\times10^5\ \text{J}$$

Statement: When the gold melts, 3.9×10^5 J of thermal energy is absorbed.

3. Given: $m_w = 500$ g = 0.5 kg; $L_v = 2.3 \times 10^6$ J/kg; $c = 4.18 \times 10^3$ J/(kg•°C); $T_1 = 100$ °C; $T_2 = 50$ °C

Required: Q_{total}, total amount of thermal energy released

Analysis: $Q_1 = mL_v$; $Q_2 = mc\Delta T$; $Q_{total} = Q_1 + Q_2$

Solution:

$$Q_1 = mL_v$$

$$= (0.5\ \cancel{\text{kg}})(2.3\times10^6\ \text{J}/\cancel{\text{kg}})$$

$\cancel{Q_1 = 1.15\times10^6\ \text{J}}$ (one extra digit carried)

$Q_1 = -1.15\times10^6$ J (releases energy)

$$Q_2 = mc\Delta T$$

$$= (0.5\ \cancel{\text{kg}})\left(4.18\times10^3\ \frac{\text{J}}{\cancel{\text{kg}}\bullet\cancel{^\circ\text{C}}}\right)(50\ \cancel{^\circ\text{C}} - 100\ \cancel{^\circ\text{C}})$$

$Q_2 = -1.05\times10^5$ J (one extra digit carried)

$$Q_{total} = Q_1 + Q_2$$

$$= -1.15\times10^6\ \text{J} + (-1.05\times10^5\ \text{J})$$

$$= -11.5\times10^5\ \text{J} - 1.05\times10^5\ \text{J}$$

$= \cancel{10.45\times10^5\ \text{J}}$ -1.255×10^6 J

$\cancel{Q_{total} = 1.0\times10^6\ \text{J}}$ $Q_{total} = -1.3\times10^6$ J (releases energy)

Statement: The total amount of thermal energy released is 1.0×10^6 J.

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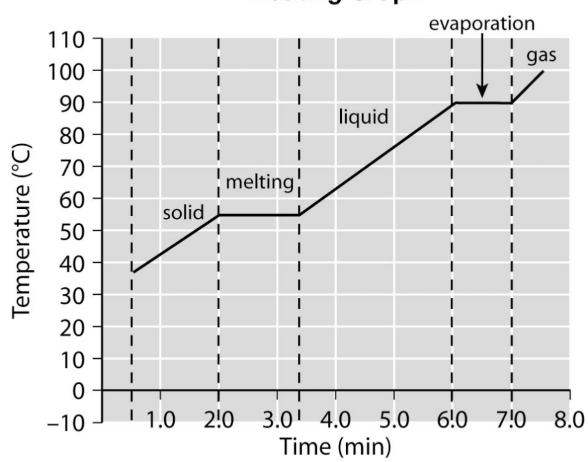
1. (a) The first section of the graph, where the line is going down, shows a single-state substance cooling down. The second section of the graph, where the line is horizontal and the temperature is stable, shows a substance changing states, either from a gas to a liquid or from a liquid to a solid. The third section of the graph, where the line is again going down, shows the substance, in its new state, cooling down again.

(b) This is a cooling graph. It is a cooling graph because the temperature is decreasing.

2. (a), (b)

Heating Graph



(c) The melting point of the substance occurs at 55 °C. The boiling point of the substance occurs at 90 °C.

3. Liquid water cannot reach a temperature of 110 °C. At 100 °C, liquid water begins to change state into its gas state: water vapour. It remains at 100 °C until all the water has evaporated, at which point the gas can heat up to 110 °C.

4. Latent heat of fusion is the amount of thermal energy required to change a solid into a liquid or a liquid into a solid. Latent heat of vaporization is the amount of thermal energy required to change a liquid into a gas or a gas into a liquid.

5. Frost can damage fruit because it forms ice crystals on the outside of the fruit. This causes moisture to be drawn out of the fruit, dehydrating it. Fruit growers can prevent fruit from freezing by spraying the fruit with water because, as the water freezes and evaporation starts, the fruit releases its thermal energy to the fruit. The theory of latent heat says that the water will remain at 0 °C until all of it has frozen, so it protects the fruit from dropping below 0 °C and freezing, even if the outside air drops below zero.

6. Since a change of state is occurring, use $Q = mL_f$ to solve the problem.

Given: $m_m = 2.40$ kg; $L_f = 1.1 \times 10^6$ J/kg

Required: Q, latent heat of fusion

Analysis: $Q = mL_f$

Solution:

$$Q = mL_f$$
$$= (2.40\ \cancel{\text{kg}})(1.1 \times 10^6\ \text{J}/\cancel{\text{kg}})$$
$$\cancel{Q = 2.6 \times 10^5\ \text{J}}$$

$Q = -2.6 \times 10^5$ J (releases energy)

Statement: The latent heat of fusion is 2.6×10^6 J.

7. Given: $m = 100$ g $= 0.1$ kg; $c_w = 4.18 \times 10^3$ J/(kg • °C); $T_1 = -20$ °C; $T_2 = 0$ °C; $L_f = 3.4 \times 10^5$ J/kg; $T_3 = 0$ °C; $T_4 = 100$ °C; $L_v = 2.3 \times 10^6$ J/kg; $T_5 = 100$ °C; $T_6 = 110$ °C

Required: Q, thermal energy required

Analysis: $Q = mL_f$; $Q = mL_v$; $Q = mc\Delta T$

Solution: To find the total thermal energy required, break the problem down into six steps.

Step 1: Calculate the energy required to bring the ice from –20 °C to its melting point at 0 °C.

$$Q_1 = mc\Delta T$$
$$= (0.1\ \cancel{\text{kg}})\left(4.18 \times 10^3\ \frac{\text{J}}{\cancel{\text{kg}} \bullet \cancel{°\text{C}}}\right)(20\ \cancel{°\text{C}})$$
$$Q_1 = 8.36 \times 10^3\ \text{J (one extra digit carried)}$$

Step 2: Calculate the energy required to change the state of the water from ice to liquid water.

$$Q_2 = mL_f$$
$$= (0.1\ \cancel{\text{kg}})(3.4 \times 10^5\ \text{J}/\cancel{\text{kg}})$$
$$Q_2 = 3.4 \times 10^4\ \text{J}$$

Step 3: Calculate the energy required to bring the water from 0 °C to its vaporizing point at 100 °C.

$$Q_3 = mc\Delta T$$
$$= (0.1\ \cancel{\text{kg}})\left(4.18 \times 10^3\ \frac{\text{J}}{\cancel{\text{kg}} \bullet \cancel{°\text{C}}}\right)(100\ \cancel{°\text{C}})$$
$$Q_3 = 4.18 \times 10^4\ \text{J (one extra digit carried)}$$

Step 4: Calculate the energy required to change the state of the water from liquid to gas.

$$Q_4 = mL_v$$
$$= (0.1\ \cancel{\text{kg}})(2.3 \times 10^6\ \text{J}/\cancel{\text{kg}})$$
$$Q_4 = 2.3 \times 10^5\ \text{J}$$

Step 5: Calculate the energy required to bring the water from its vaporizing point of 100 °C to 110 °C.

$$Q_5 = mc\Delta T$$
$$= (0.1\ \cancel{\text{kg}})\left(4.18 \times 10^3\ \frac{\text{J}}{\cancel{\text{kg}} \bullet \cancel{°\text{C}}}\right)(10\ \cancel{°\text{C}})$$
$$Q_5 = 4.18 \times 10^3\ \text{J (one extra digit carried)}$$

Step 6: Calculate the total thermal energy.

$$Q_{\text{total}} = Q_1 + Q_2 + Q_3 + Q_4 + Q_5$$
$$= 8.36 \times 10^3\ \text{J} + 3.4 \times 10^4\ \text{J} + 4.18 \times 10^4\ \text{J}$$
$$+\ 2.3 \times 10^5\ \text{J} + 4.18 \times 10^3\ \text{J}$$
$$Q_{\text{total}} = 3.2 \times 10^5\ \text{J}$$

Statement: The thermal energy required to change the ice into steam is 3.2×10^5 J.

8. Given: $m = 1.50$ kg; $c_a = 9.2 \times 10^2$ J/(kg • °C); $T_1 = 2700$ °C; $T_2 = 2519$ °C; $L_f = 6.6 \times 10^5$ J/kg; $T_3 = 2519$ °C; $T_4 = 23.0$ °C

Required: Q, thermal energy released

Analysis: $Q = mL_f$; $Q = mc\Delta T$

Solution: To calculate the total thermal energy released, break the problem down into four steps.

Step 1: Calculate the energy released when the aluminum cools from 2700 °C to its freezing (melting) point at 2519 °C.

$$Q_1 = mc\Delta T$$
$$= (1.5\ \cancel{\text{kg}})\left(9.2 \times 10^2\ \frac{\text{J}}{\cancel{\text{kg}} \bullet °\text{C}}\right)(2519\ °\text{C} - 2700\ °\text{C})$$
$$= \left(13.8 \times 10^2\ \frac{\text{J}}{\cancel{°\text{C}}}\right)(-181\ \cancel{°\text{C}})$$
$$Q_1 = -2.498 \times 10^5\ \text{J (two extra digits carried)}$$

Step 2: Calculate the energy released when the aluminum changes state from a liquid to a solid.

$$Q_2 = mL_f$$
$$= (1.5\ \cancel{\text{kg}})(6.6 \times 10^5\ \text{J}/\cancel{\text{kg}})$$
$$\cancel{Q_2 = 9.9 \times 10^5\ \text{J}}$$

$Q_2 = -9.9 \times 10^5\,\text{J}$ (releases energy)

Step 3: Calculate the energy released in cooling the solid aluminum from its freezing point at 2519 °C to 23 °C.

$$Q_3 = mc\Delta T$$
$$= (1.5\ \cancel{\text{kg}})\left(9.2 \times 10^2\ \frac{\text{J}}{\cancel{\text{kg}} \bullet {}^\circ\text{C}}\right)(23\ {}^\circ\text{C} - 2519\ {}^\circ\text{C})$$
$$= \left(13.8 \times 10^2\ \frac{\text{J}}{\cancel{{}^\circ\text{C}}}\right)(-2496\ \cancel{{}^\circ\text{C}})$$
$$Q_3 = -3.444 \times 10^6\ \text{J}\ \text{(two extra digits carried)}$$

Step 4: Calculate the total thermal energy released.

$$Q_{\text{total}} = Q_1 + Q_2 + Q_3$$
$$= -2.498 \times 10^5\ \text{J} - 9.9 \times 10^5\ \text{J} + (-3.444 \times 10^6\ \text{J})$$
$$\cancel{Q_{\text{total}} = 2.7 \times 10^6\ \text{J}}$$

$Q_{total} \doteq -4.6838 \times 10^6\,\text{J}$ (releases energy)

Statement: The thermal energy released during the process was 2.7×10^6 J.

9. In most substances, the solid form sinks within the liquid form because the solid form is denser than the liquid. However, the solid state of water, ice, is less dense than liquid water, so it floats on top. This is because of the structure of the water molecule. The hydrogen atoms of one water molecule have a small positive charge and are attracted to the small negative charge of the oxygen atoms in the neighbouring water molecule. At temperatures above 4 °C, the molecules of water move too fast for the forces of attraction to pull the molecules together. As the temperature decreases, the forces of attraction place the molecules into an organized structure, freezing the water, which takes up more space than the disorganized molecules in liquid water.