Chemistry Lecture #65: Specific Heat, Heat of Fusion, & Heat of Vaporization

It takes energy to raise the temperature of a substance. The amount of energy needed to raise the temperature of one gram of a substance by one degree Celsius is its *specific heat.*

Different substances have different specific heats. Aluminum has a specific heat of 0.903 J/(g °C). This means that it takes 0.903 Joules of energy to raise the temperature of 1 gram of aluminum by 1 degree Celsius.

We can use a formula to calculate the amount of energy needed to raise the temperature of a substance. The formula is

$$Q = mc\Delta T$$

Q = energy in joules (J)
m = mass of substance in grams (g)
c = specific heat of substance in J/(g°C)
Δ T = Change in temperature in °C (Final Temp. - Initial Temp.)

Ice has a specific heat of 2.06 J/(g°C). How much energy does it take to raise the temperature of 6.00 g of ice at -5.00 °C to 0.00 °C?

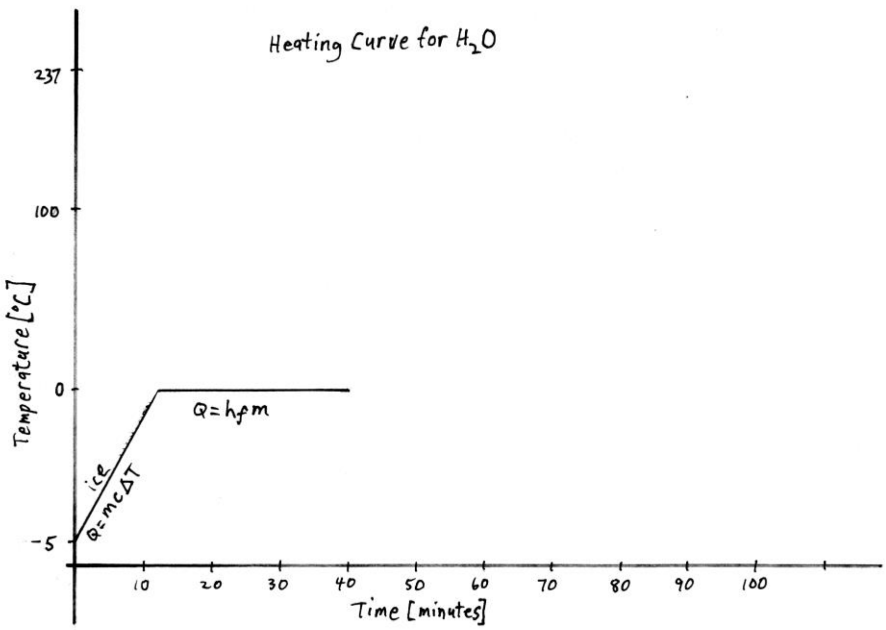
Answer:

Q = ? m = 6.00 g c = 2.06 J/(g °C)

ΔT = 0.00 ° C - (-5 °C) = 5.00 °C

$$Q = mc\Delta T = (6.00\ g)\left(\frac{2.06\ J}{g\ °C}\right)(5.00\ °C) = 61.8\ J \text{ of energy}$$

If you heat a block of ice and measure the change in temperature over time, something interesting happens when the ice reaches 0.00 °C. The graph below is a plot of temperature vs. time.



Notice that the ice increases in temperature until it reaches 0.00 °C. At 0.00 °C, the ice does not increase in temperature - it stays at 0.00 °C, even though it continues to absorb heat. At this temperature, the added heat will not change the temperature. The heat will, however, change the ice from a solid into a liquid.

This is how the melting point of a substance is determined. Heat is added to a solid, and when the temperature stops changing and remains constant, you've reached the melting point.

The energy needed to convert one gram of a solid into a liquid when it is at its melting point is the *heat of fusion* (h_f). Sometimes we call it the enthalpy of fusion. The heat of fusion for ice is 334 J/g. This means that it takes 334 joules of energy to melt one gram of ice when it is at zero degrees Celsius.

To calculate the amount of energy needed to melt a certain amount of substance, we use the formula

$$Q = h_f m$$

Q = energy in joules (J)
h_f = heat of fusion in Joules/gram (J/g)
m = mass of substance in grams (g)

How much energy does it take to melt 6.00 g of ice at 0.00 °C?

Answer:
Q = ? h_f = 334 J/g m = 6.00 g

$$Q = h_f m = \frac{334\ \text{J}}{\text{g}} \times 6.00\ \text{g} = 2004 \text{ or } 2.00 \times 10^3 \text{ joules}$$

When solid ice at 0.00 °C becomes liquid water at 0.00 °C, the addition of heat will cause the temperature to increase. Different states of matter have different specific heats. The specific heat of liquid water is 4.18 J/(g °C).

How much energy does it take to raise the temperature of 6.00 g of water at 0.00 °C to 100 °C?

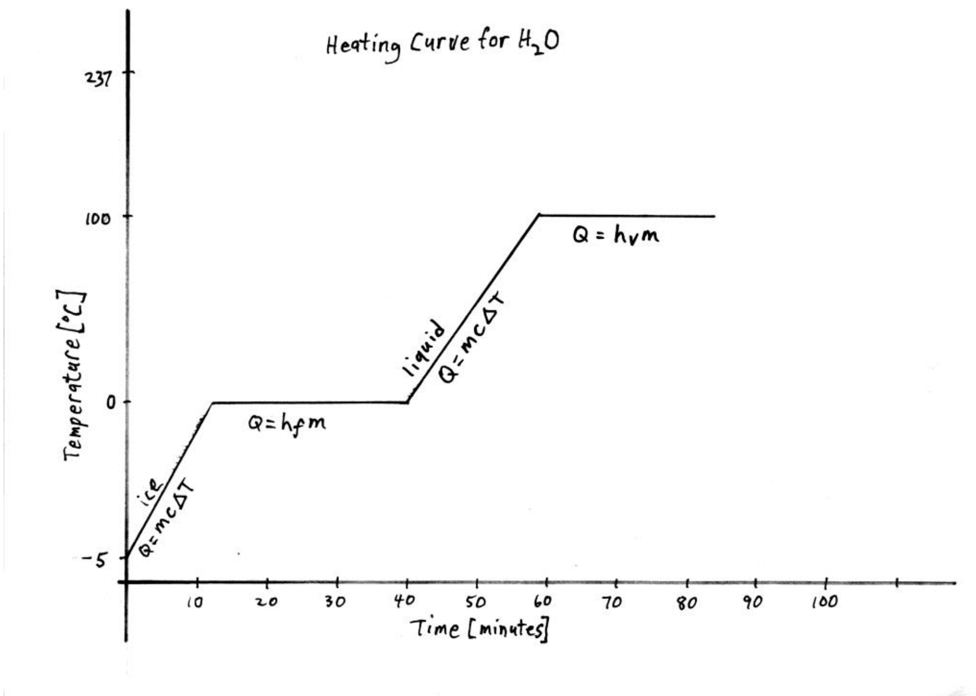
Answer:

Q = ? m = 6.00 g c = 4.18 J/(g °C)

ΔT = 100 °C - 0.00 °C = 100 °C

$$Q = mc\Delta T = (6.00\ g)\left(\frac{4.18\ J}{g\ °C}\right)(100\ °C) = 2508 \text{ or } 2.51 \times 10^{3}\ J$$

If we continue to plot the change in temperature of our 6.00 g of liquid water, we see that the temperature increases from 0.00 °C to 100 °C. But at 100 °C, the temperature stays constant as heat is added.



The addition of heat to liquid water at 100 °C will not raise the temperature, but it will convert the liquid into steam or vapor. When the temperature of the liquid remains constant in spite of the addition of heat, you have reached the boiling point.

The energy needed to convert a liquid at its boiling point into a gas is the *heat of vaporization* (h_v). Sometimes this is called enthalpy of vaporization. The heat of vaporization for water is 2260 J/g. This means that it takes 2260 joules of energy to convert one gram of water at its boiling point into vapor.

To calculate the energy needed to vaporize a substance, use the formula

$$Q = h_v m$$

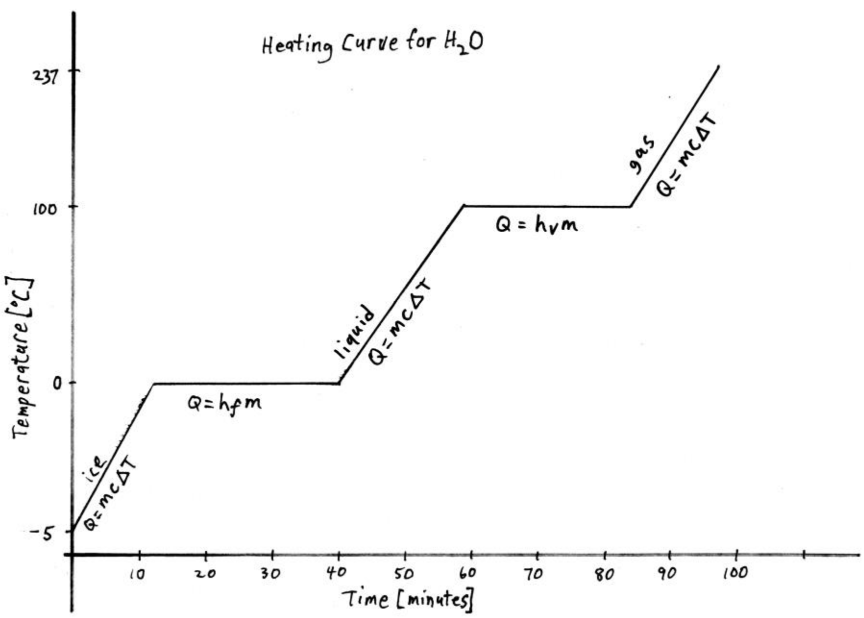
Q = energy in joules (J)
h_v = heat of vaporization in Joules/gram (J/g)
m = mass of substance in grams (g)

How much energy does it take to convert 6.00 g of water at 100 °C into vapor?

Answer:
$Q = ?$ $h_v = 2260$ J/g $m = 6.00$ g

$$Q = h_v m = \frac{2260\ J}{g} \times 6.00\ g = 13560 \text{ or } 1.36 \times 10^4\ J$$

Once all the water has been converted into vapor, the addition of heat will cause the vapor to increase in temperature. The specific heat of water vapor is 2.02 J/(g °C). The graph below shows the increase in temperature after the water has been vaporized.



How much energy does it take to raise the temperature of 6.00 g of water vapor at 100 °C to 237 °C?

Answer:

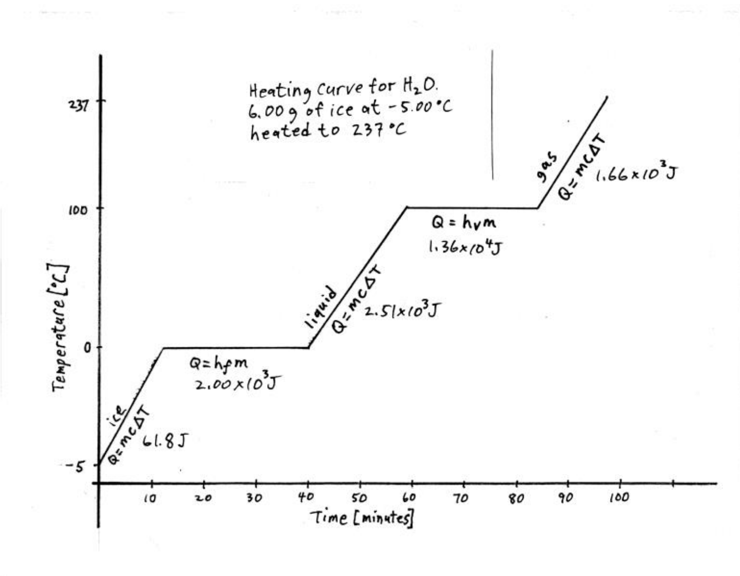
Q = ? m = 6.00 g c = 2.02 J/(g °C)

ΔT = 237 °C - 100 °C = 137 °C

$$Q = mc\Delta T = 6.00\ g\ \frac{(2.02\ J)}{g\ °C}\ (137\ °C) = 1660.44 \text{ or } 1.66 \times 10^3\ J$$

What is the total amount of energy needed to convert 6.00 g of ice at -5.00 °C into vapor at 237 °C?

Answer:



Raise the temp. of ice from -5.00 °C to 0.00 °C: 61.8 J

Melt the ice after it reaches 0.00 °C: 2.00×10^3J

Raise the temp. of water from 0.00 °C to 100 °C: 2.51×10^3 J

Convert the water to vapor after it reaches 100 °C: 1.36×10^4 J

Raise the temp. of vapor from 100 °C to 237 °C: 1.66×10^3 J

Total amount of energy: 19831.8 or 1.98×10^4 J