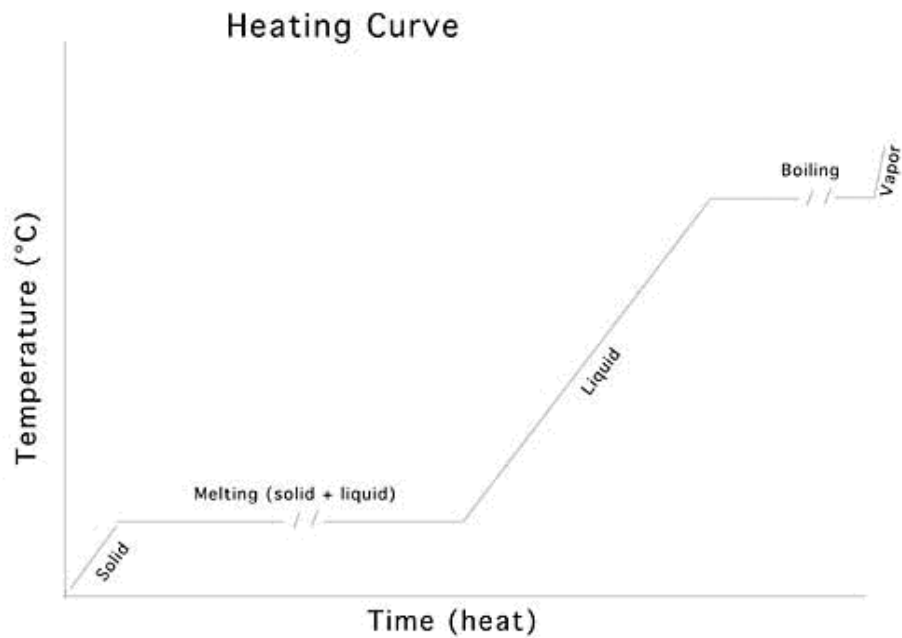


## Heating and Cooling Curves

- Under normal circumstances, particles will undergo more than one type of change when heated or cooled
- During a phase change, the temperature will not change



- Parts of the graph with a temperature change have slopes relative to their specific heat capacities, parts of the curve during phase changes are flat. The length of the horizontal line for phase change should be appropriate for the  $\Delta H$  for the specific phase change
- Given the appropriate information, you must be able to **draw and interpret** a heating/cooling curve for a specific substance

Example: Draw the curve to represent a 2.5 kg block of ice heated from  $-20^{\circ}\text{C}$  to  $120^{\circ}\text{C}$

Answer: Write down each  $T_i$  and  $T_f$ , and insert the melting point and boiling point for the substance. These are provided for you, either in a data table or in the question.

$$T_i = -20^{\circ}\text{C}$$

melting point =  $0^{\circ}\text{C}$  (will be a horizontal line here)

boiling point =  $100^{\circ}\text{C}$  (will be a horizontal line here)

$$T_f = 120^{\circ}\text{C}$$

Check out the different specific heat capacities ( $c$ ) for each phase of water -these give you some idea of the slopes of your curve.  $c$  for liquid water is  $4.184\text{ J/g}^{\circ}\text{C}$ , for ice it is  $2.10\text{ J/g}^{\circ}\text{C}$ , and for steam it is  $2.01\text{ J/g}^{\circ}\text{C}$ . Your slopes for the first and last temperature curves should be half that of the middle one

Check out the molar enthalpy of fusion,  $\Delta H_{\text{fus}} = 6.02\text{ kJ/mol}$ , and for vaporization,  $\Delta H_{\text{vap}} = 40.7\text{ kJ/mol}$ , these give you an idea of how long to put the horizontal lines of the curve at each phase change. Obviously, the horizontal line at the liquid to gas phase must be much longer than the solid to liquid line because much more energy is required to boil water than to melt ice.

Example : Draw the curve to represent the cooling of a 9.0 g sample of aluminum from 750 °C to 660 °C. ( bp for aluminum is 1350 °C, mp for aluminum is 660 °C , specific heat capacity (c) is 0.900 J/g °C,  $\Delta H_{\text{fus}}$  is 8.4 kJ/mol,  $\Delta H_{\text{vap}}$  22 kJ/mol)

$T_i = 750 \text{ }^\circ\text{C}$  (we're starting below the boiling point so it is a liquid)

$mp = 660 \text{ }^\circ\text{C}$  ( phase change from liquid to solid - horizontal line)

$T_f = 660 \text{ }^\circ\text{C}$

$\Delta H_{\text{fus}}$  is 8.4 kJ/mol( gives you an idea of length of horizontal line)

$c_{\text{Al}} = 0.900 \text{ J/g }^\circ\text{C}$  ( gives you an idea of slope during the temperature change)

## Calculating the Energy Involved in This Type of Multi-Step Change

To calculate the energy involved, we need to calculate the energy change for each step and then add them all together. REMEMBER TO USE THE APPROPRIATE FORMULA FOR  $q$ . For the steps with a temperature change you'll use  $q = mc\Delta T$  and for the phase change steps, you'll use  $n\Delta H$ . Also keep in mind that the  $q$  for  $mc\Delta T$  is in Joules and the  $q$  for  $n\Delta H$  is in kilojoules!

In our example #1, the 2.5 kg block of ice heated from  $-20^{\circ}\text{C}$  to  $120^{\circ}\text{C}$ . Look at your graph, there are five energy changes.

$$\Delta E_{\text{Total}} = q_1 + q_2 + q_3 + q_4 + q_5 \quad (\text{probably best calculated in kJ rather than J})$$

$$\begin{aligned} q_1 &= mc\Delta T \\ &= (2.5 \times 10^3 \text{ g}) (2.10 \text{ J/g}^{\circ}\text{C}) (20.0^{\circ}\text{C}) \\ &= 105000 \text{ J} \\ &= 105 \text{ kJ} \end{aligned}$$

$$\begin{aligned} q_2 &= n\Delta H_{\text{fus}} \\ &= \frac{(2.5 \times 10^3 \text{ g})(6.02 \text{ kJ/mol})}{18.02 \text{ g/mol}} \\ &= 835.2 \text{ kJ} \end{aligned}$$

$$\begin{aligned} q_3 &= mc\Delta T \\ &= (2.5 \times 10^3 \text{ g}) (4.184 \text{ J/g}^{\circ}\text{C}) (100^{\circ}\text{C}) \\ &= 1\,460\,000 \text{ J} \\ &= 1046 \text{ kJ} \end{aligned}$$

$$\begin{aligned} q_4 &= n\Delta H_{\text{vap}} \\ &= \frac{(2.5 \times 10^3 \text{ g}) (40.7 \text{ kJ/mol})}{18.02 \text{ g/mol}} \\ &= 5646.5 \text{ kJ} \end{aligned}$$

$$\begin{aligned} q_5 &= mc\Delta T \\ &= (2.5 \times 10^3 \text{ g}) (2.01 \text{ J/g}^{\circ}\text{C}) (20^{\circ}\text{C}) \\ &= 100\,500 \text{ J} \\ &= 100.5 \text{ kJ} \end{aligned}$$

$$\begin{aligned} \Delta E_{\text{Total}} &= 105 \text{ kJ} + 835.2 \text{ kJ} + 1046 \text{ kJ} + 5646.5 \text{ kJ} + 100.5 \text{ kJ} \\ &= 7.7 \times 10^3 \text{ kJ} \end{aligned}$$

Example #2 Calculate the total energy in the second example.

A 9.0 g sample of aluminum from 750 °C to 660 °C. ( bp for aluminum is 1350 °C, mp for aluminum is 660 °C , specific heat capacity (c) is 0.900 J/g °C,  $\Delta H_{\text{fus}}$  is 8.4 kJ/mol,  $\Delta H_{\text{vap}}$  22 kJ/mol)

There are only two steps.

$$\begin{aligned}q_1 &= mc\Delta T \\&= (9.0 \text{ g}) (0.900 \text{ J/g}^\circ\text{C}) (-90^\circ\text{C}) \\&= -729 \text{ J} \\&= -7.29 \times 10^{-1} \text{ kJ}\end{aligned}$$

$$\begin{aligned}q_2 &= n\Delta H_{\text{solid}} && \text{(How do we know the } \Delta H_{\text{solid}} \text{ ? It's the} \\& && \text{inverse of } \Delta H_{\text{fus}} \text{ )} \\&= \frac{(9.0 \text{ g}) (-8.4 \text{ kJ/mol})}{26.98 \text{ g/mol}} \\&= -2.80 \text{ kJ}\end{aligned}$$

$$\begin{aligned}\Delta E_{\text{total}} &= q_1 + q_2 \\&= -7.29 \times 10^{-1} \text{ kJ} + -2.80 \text{ kJ} \\&= -3.5 \text{ kJ}\end{aligned}$$

**IF YOU ARE GIVEN ONE OF THESE MULTI-STEP ENERGY CHANGES, HEATING OR COOLING CURVE, YOU SHOULD ALWAYS DO A SKTCH OF THE CURVE FIRST, TO KEEP TRACK OF STEPS TO DO!!!**