

Multi-Step Problems with Changes of State

Ck12 Science

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1.14 Multi-Step Problems with Changes of State

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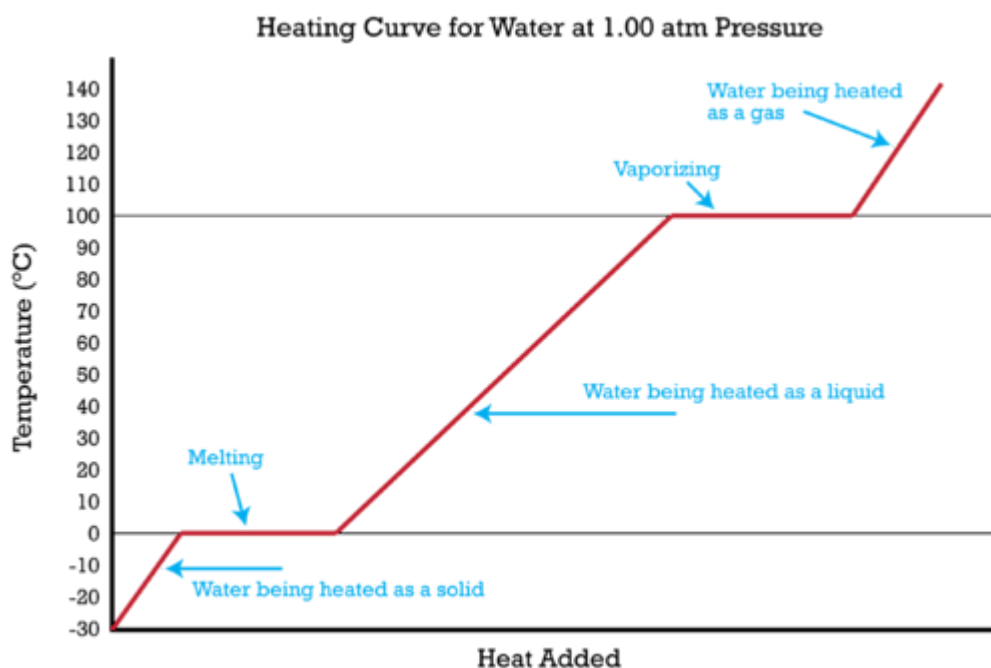
[Figure 1]

Which takes more **heat** – **melting** or **boiling**?

You have a cube of ice. Which process will take more **energy** – the **melting** of that ice cube or the conversion of the **water** to steam? The short answer is that more energy is needed to convert the water to steam. The long answer is really a question: how do you get from one point to the other? What is the **temperature** of the ice? What is the mass of that ice cube? A lot goes into taking the material from the starting point to the end-point.

Multi-Step Problems with Changes of State

Heating curves show the phase changes that a substance undergoes as **heat** is continuously absorbed.

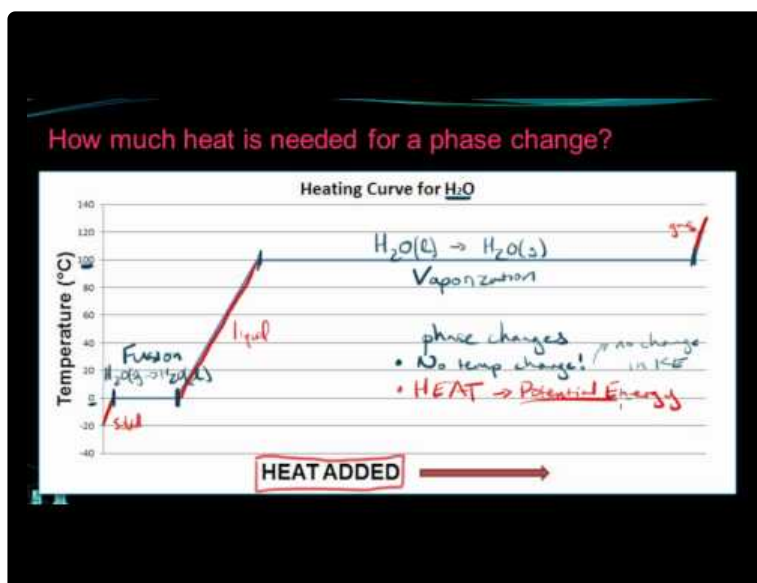


[Figure 2]

Heating curve of water.

The **specific heat** of a substance allows us to calculate the **heat** absorbed or released as the **temperature** of the substance changes. It is possible to combine that type of problem with a **change of state** to solve a problem involving multiple steps. **Figure above** shows ice at -30°C being converted in a five-step process to gaseous **water** (steam) at 140°C . It is now possible to calculate the heat absorbed during that entire process. The process and the required calculation is summarized below.

1. Ice is heated from -30°C to 0°C . The heat absorbed is calculated by using the **specific heat** of ice and the equation $\Delta H = c_p \times m \times \Delta T$.
2. Ice is melted at 0°C . The heat absorbed is calculated by multiplying the moles of ice by the molar heat of fusion.
3. **Water** at 0°C is heated to 100°C . The heat absorbed is calculated by using the **specific heat** of water and the equation $\Delta H = c_p \times m \times \Delta T$.
4. Water is vaporized to steam at 100°C . The heat absorbed is calculated by multiplying the moles of water by the molar heat of vaporization.
5. Steam is heated from 100°C to 140°C . The heat absorbed is calculated by using the specific heat of steam and the equation $\Delta H = c_p \times m \times \Delta T$.



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Sample Problem: Multi-Step Problems using a Heating Curve

Calculate the total amount of heat absorbed (in kJ) when 2.00 mol of ice at -30.0°C is converted to steam at 140.0°C. The required specific heats can be found in the table in "Heat Capacity and Specific Heat".

Step 1: List the known quantities and plan the problem.

Known

- 2.00 mol ice = 36.04 g ice
- $c_p(\text{ice}) = 2.06 \text{ J/g}^\circ\text{C}$
- $c_p(\text{water}) = 4.18 \text{ J/g}^\circ\text{C}$
- $c_p(\text{steam}) = 1.87 \text{ J/g}^\circ\text{C}$
- $\Delta H_{\text{fus}} = 6.01 \text{ kJ/mol}$
- $\Delta H_{\text{vap}} = 40.7 \text{ kJ/mol}$

Unknown

- $\Delta H_{\text{total}} = ? \text{ kJ}$

Follow the steps previously described. Note that the mass of the water is needed for the calculations that involve the specific heat, while the moles of water is needed for the calculations that involve **changes of state**. All heat quantities must be in kilojoules so that they can be added together to get a total for the five-step process.

Step 2: Solve.

$$1. \Delta H_1 = 2.06 \text{ J/g}^\circ\text{C} \times 36.04 \text{ g} \times 30^\circ\text{C} \times \frac{1 \text{ kJ}}{1000 \text{ J}} = 2.23 \text{ kJ}$$

$$2. \Delta H_2 = 2.00 \text{ mol} \times \frac{6.01 \text{ kJ}}{1 \text{ mol}} = 12.0 \text{ kJ}$$

$$3. \Delta H_3 = 4.18 \text{ J/g}^\circ\text{C} \times 36.04 \text{ g} \times 100^\circ\text{C} \times \frac{1 \text{ kJ}}{1000 \text{ J}} = 15.1 \text{ kJ}$$

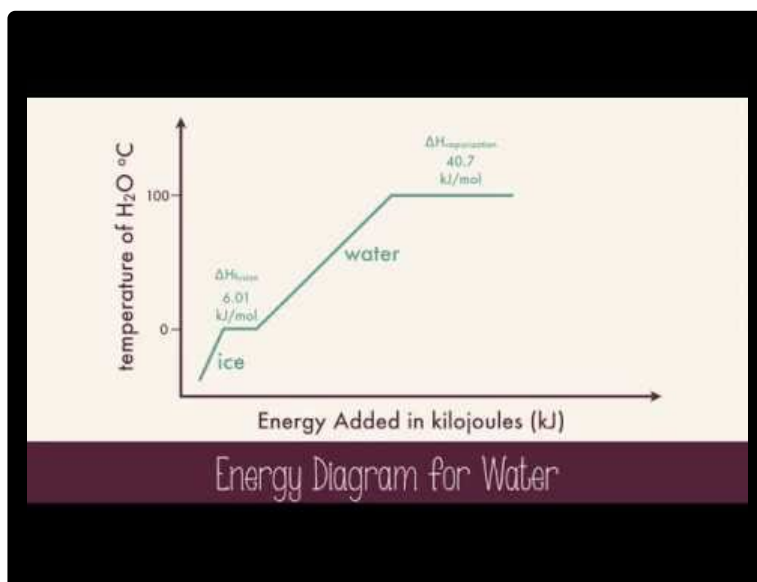
$$4. \Delta H_4 = 2.00 \text{ mol} \times \frac{40.7 \text{ kJ}}{1 \text{ mol}} = 81.4 \text{ kJ}$$

$$5. \Delta H_5 = 1.87 \text{ J/g}^\circ\text{C} \times 36.04 \text{ g} \times 40^\circ\text{C} \times \frac{1 \text{ kJ}}{1000 \text{ J}} = 2.70 \text{ kJ}$$

$$\Delta H_{\text{total}} = \Delta H_1 + \Delta H_2 + \Delta H_3 + \Delta H_4 + \Delta H_5 = 113.4 \text{ kJ}$$

Step 3: Think about your result.

The total heat absorbed as the ice at -30°C is heated to steam at 140°C is 113.4 kJ. The largest absorption of heat comes during the vaporization of the liquid water.



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Summary

- Multi-step calculations for changes of state are described.

Review

1. Why are two different sets of units used?
2. What other units problem do you need to be aware of?
3. What would you need to know to do calculations like this for acetone?

1.0 REFERENCES

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