Phase Changes & Heating Curves

Unit: Thermochemistry (Heat)

MA Curriculum Frameworks (2016): HS-PS1-2, HS-PS1-3, HS-PS3-4b

Mastery Objective(s): (Students will be able to…)

- Determine the amount of heat required for all of the phase changes that occur over a given temperature range.

Success Criteria:

- Variables are correctly identified and substituted correctly into the correct equations.
- Algebra is correct and rounding to appropriate number of significant figures is reasonable.

Tier 2 Vocabulary: specific heat capacity, heating curve

Language Objectives:

- Explain what the heat is used for in each step of a heating curve.

Labs, Activities & Demonstrations:

- Evaporation from washcloth.
- Fire & ice (latent heat of paraffin).

Notes:

phase: a term that relates to how rigidly the atoms or molecules in a substance are connected.

solid: molecules are rigidly connected. A solid has a definite shape and volume.

liquid: molecules are loosely connected—bonds are continuously forming and breaking. A liquid has a definite volume, but not a definite shape.

gas: molecules are not connected. A gas has neither a definite shape nor a definite volume. Gases will expand to fill whatever space they occupy.

plasma: the system has enough heat to remove electrons from atoms, which means the system is comprised of particles with rapidly changing charges.

phase change: when an object or substance changes from one phase to another through gaining or losing heat.

Use this space for summary and/or additional notes:

Breaking bonds requires energy. Forming bonds releases energy. This is true for the bonds that hold a solid or liquid together as well as for chemical bonds (regardless of what previous teachers may have told you!)

I.e., you need to add energy to turn a solid to a liquid (melt it), or to turn a liquid to a gas (boil it). Energy is released when a gas condenses or a liquid freezes. (*E.g.,* ice in your ice tray needs to give off heat in order to freeze. Your freezer needs to remove that heat in order to make this happen.)

The reason evaporation causes cooling is because the system (the water) needs to absorb heat from its surroundings (*e.g.,* your body) in order to make the change from a liquid to a gas (vapor). When the water absorbs heat from you and evaporates, you have less heat, which means you have cooled off.

Calculating the Heat of Phase Changes

<u>heat of fusion</u> (ΔH_{fus}) (sometimes called "latent heat" or "latent heat of fusion"): the amount of heat required to melt one kilogram of a substance. This is also the heat released when one kilogram of a liquid substance freezes. For example, the heat of fusion of water is $334\,\frac{\text{J}}{\text{g}}$. The heat required to melt a sample of water is therefore:

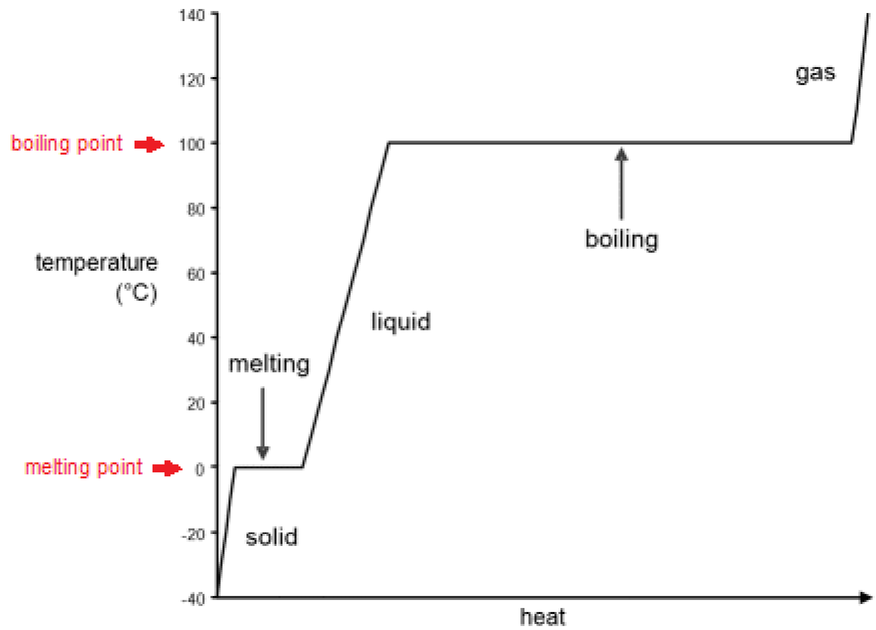
$$Q = m\Delta H_{fus} = m(334\,\tfrac{\text{J}}{\text{g}})$$

<u>heat of vaporization</u> (ΔH_{vap}): the amount of heat required to vaporize (boil) one kilogram of a substance. This is also the heat released when one kilogram of a gas condenses. For example, the heat of vaporization of water is $2260\,\frac{\text{J}}{\text{g}}$. The heat required to boil a sample of water is therefore:

$$Q = m\Delta H_{vap} = m(2260\,\tfrac{\text{J}}{\text{g}})$$

Use this space for summary and/or additional notes:

heating curve: a graph of temperature *vs.* heat added. The following is a heating curve for water:



In the "solid" portion of the curve, the sample is solid water (ice). As heat is added, the temperature increases. The specific heat capacity of ice is $2.11\,\frac{\text{J}}{\text{g}\cdot{}^\circ\text{C}}$, so the heat required is:

$$Q_{solid} = mC\Delta T = m(2.11\,\tfrac{\text{J}}{\text{g}^\circ\text{C}})\Delta T$$

In the "melting" portion of the curve, the sample is a mixture of ice and water. As heat is added, the ice melts, but the temperature remains at 0°C until all of the ice is melted. The heat of fusion of ice is $334\,\frac{\text{J}}{\text{g}}$, so the heat required is:

$$Q_{melt} = m\Delta H_{fus} = m(334\,\tfrac{\text{J}}{\text{g}})$$

In the "liquid" portion of the curve, the sample is liquid water. As heat is added, the temperature increases. The specific heat capacity of liquid water is $4.181\,\frac{\text{J}}{\text{g}\cdot{}^\circ\text{C}}$, so the heat required is:

$$Q_{liquid} = mC\Delta T = m(4.181\,\tfrac{\text{J}}{\text{g}^\circ\text{C}})\Delta T$$

Use this space for summary and/or additional notes:

In the “boiling” portion of the curve, the sample is a mixture of water and water vapor (steam). As heat is added, the water boils, but the temperature remains at 100°C until all of the water has boiled. The heat of vaporization of water is $2260\,\frac{\text{J}}{\text{g}}$, so the heat required is:

$$Q_{melt} = m\Delta H_{vap} = m(2260\,\tfrac{\text{J}}{\text{g}})$$

In the “gas” portion of the curve, the sample is water vapor (steam). As heat is added, the temperature increases. The specific heat capacity of steam is approximately $2.08\,\frac{\text{J}}{\text{g}\cdot{}^\circ\text{C}}$. (This is at 100 °C; the specific heat capacity of steam decreases as the temperature increases.) The heat required is:

$$Q_{gas} = mC\Delta T = m(2.08\,\tfrac{\text{J}}{\text{g}^\circ\text{C}})\Delta T$$

Steps for Solving Heating Curve Problems

A heating curve problem is a problem in which a substance is heated across a temperature range that passes through the melting and/or boiling point of the substance, which means the problem includes heating or cooling steps and melting/freezing or boiling/condensing steps.

1. Sketch the heating curve for the substance over the temperature range in question. Be sure to include the melting and boiling steps as well as the heating steps.

2. From your sketch, determine whether the temperature range in the problem passes through the melting and/or boiling point of the substance.

3. Split the problem into:
    a. Heating (or cooling) steps within each temperature range.
    b. Melting or boiling (or freezing or condensing) steps.

4. Find the heat required for each step.
    a. For the heating/cooling steps, use the equation $Q = mC\Delta T$.
    b. For melting/freezing steps, use the equation $Q = m\Delta H_{fus}$.
    c. For boiling/condensing steps, use the equation $Q = m\Delta H_{vap}$.

5. Add the values of *Q* from each step to find the total.

Use this space for summary and/or additional notes:

Sample Problem

Q: How much heat would it take to raise the temperature of 15.0 g of H_2O from −25.0 °C to +130.0 °C?

A: The H_2O starts out as ice. We need to:

1. Heat the ice from −25.0 °C to its melting point (0 °C).
2. Melt the ice.
3. Heat the water up to its boiling point (from 0 °C to 100 °C).
4. Boil the water.
5. Heat the steam from 100 °C to 130 °C.
6. Add up the heat for each step to find the total.

heat solid: $Q_1 = mC\Delta T = (15)(2.11)(25) = 791.25\text{ J}$

melt the ice: $Q_2 = m\Delta H_{fus} = (15)(334) = 5\,010\text{ J}$

heat liquid: $Q_3 = mC\Delta T = (15)(4.181)(100) = 6\,270\text{ J}$

boil: $Q_4 = m\Delta H_{vap} = (15)(2260) = 33\,900\text{ J}$

heat gas: $Q_5 = mC\Delta T = (15)(2.08)(30) = 936\text{ J}$

$$Q = Q_1 + Q_2 + Q_3 + Q_4 + Q_5$$
$$Q = 791 + 5\,010 + 6\,270 + 33\,900 + 936 = 46\,910\text{ J}$$

Use this space for summary and/or additional notes:

Homework Problems

For the following problems, use data from the following table:

	C (sol.) $\left(\frac{kJ}{kg\cdot°C}\right)$	**M.P.** (°C)	**Δ*H*fus** $\left(\frac{kJ}{kg}\right)$	**C (liq)** $\left(\frac{kJ}{kg\cdot°C}\right)$	**B.P.** (°C)	**Δ*H*vap** $\left(\frac{kJ}{kg}\right)$	**C_p (gas)** $\left(\frac{kJ}{kg\cdot°C}\right)$
water	2.11	0	334	4.18	100	2260	2.08*
potassium	0.560	62	61.4	1.070	760	2025	0.671
mercury	0.142	−39	11.3	0.140	357	293	0.104
silver	0.217	962	111	0.318	2212	2360	—

*Note that because of the volume change from heating, the specific heat capacity of gases, C_p, increases with increasing temperature.

1. A 0.0250 kg sample of water is heated from −40.0°C to 150. °C.
   a. Sketch the heating curve for the above process. Label the starting temperature, melting point, boiling point, and final temperature on the *y*-axis.

   b. Calculate the heat required for each step of the heating curve, and the total heat required.

   Answer: 80.01 kJ

Use this space for summary and/or additional notes:

2. A 0.085 kg sample of mercury is heated from 25°C to 500. °C.

   a. Sketch the heating curve for the above process. Label the starting temperature, melting point, boiling point, and final temperature on the *y*-axis.

   b. Calculate the heat required for each step of the heating curve, and the total heat required.

   Answer: 30.12 kJ

Use this space for summary and/or additional notes:

3. A 0.045 kg block of silver at a temperature of 22°C is heated with 20.0 kJ of energy.

   a. Calculate the total heat required by calculating the heat for each step until the entire 20.0 kJ is accounted for.

   b. What is the final temperature and what is the physical state (solid, liquid, gas) of the silver at that temperature?

      Answer: liquid, 1 369°C

Use this space for summary and/or additional notes: