Heat in Changes of State

Review

- So far we've learned that:
  - Energy is the capacity to do work or cause a temperature change.
  - Heat is the movement of energy due to a temperature difference.
    - Heat naturally flows from hot to cold.
    - Heat flow stops when temperatures are the same.
  - Energy is measured in Joules (J) or calories (cal).
    - Large amounts of energy are measured in kilojoules (kJ) or kilocalories (kcal).

Review

- So far we've learned that:
  - The amount of heat needed to warm an object by 1ºC is that object's heat capacity.
    - Heat capacity depends on chemical composition and on mass.
    - The amount of heat needed to warm 1 gram of a substance by 1ºC is that substance's specific heat.

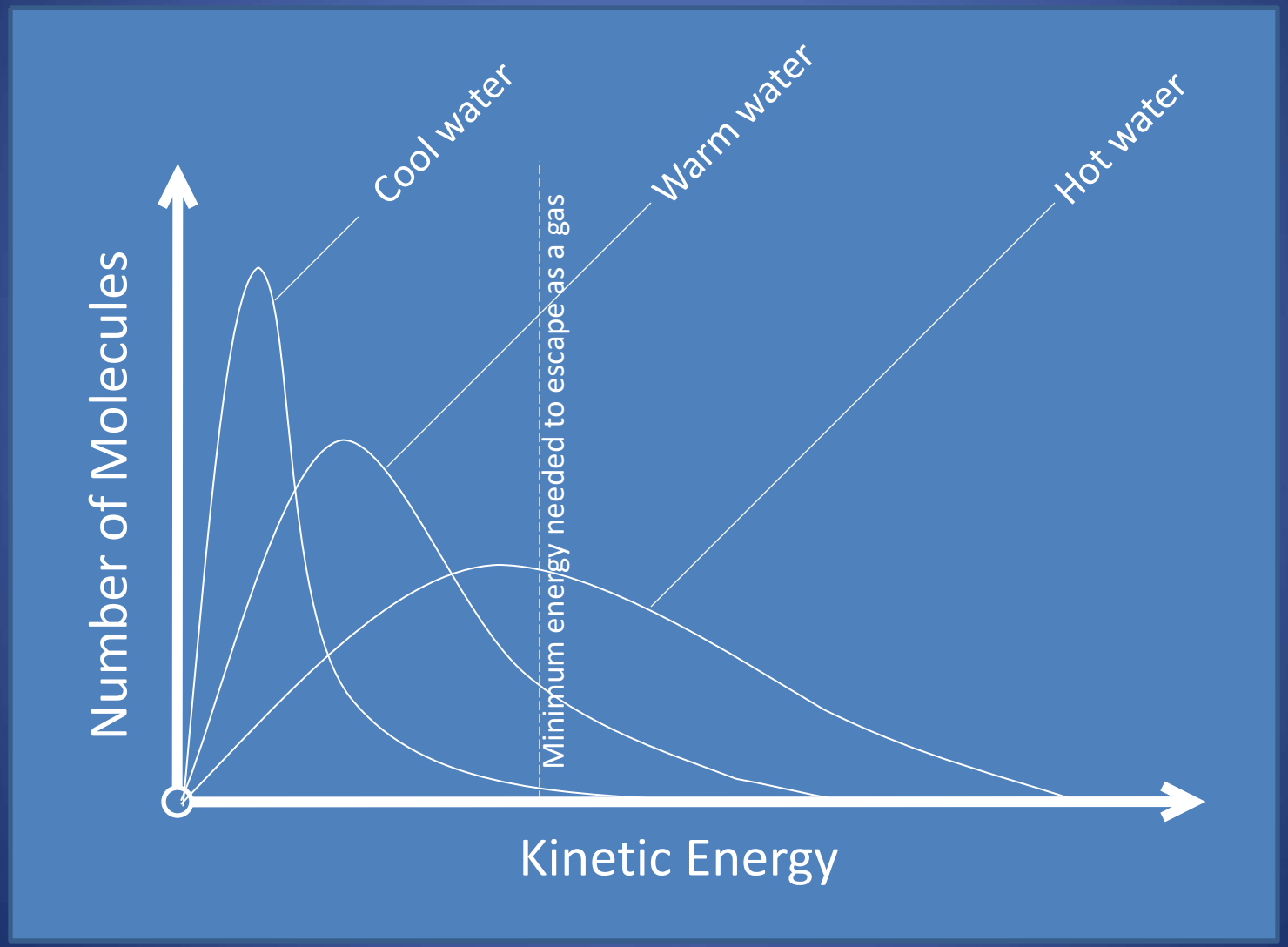
Review

- So far we've learned that:
  - The amount of heated needed to warm up a certain mass of a substance is given by the equation $q = mc\Delta T$
    - q = heat (in J)
    - m = mass (in g)
    - c = specific heat (in J/g°C)
    - ΔT = change in temperature (in °C)
  - Thermochemical equations include enthalpy changes and can be used in stoichiometric calculations of heat output or absorption.

Phase Changes

- When heat energy is added to water at 20ºC, the water warms up.
  - If heat is added continuously, the water will continue to get warmer until it reaches 100ºC (at standard pressure).
- As the water warms, its molecules move faster and faster.
  - An increasing number of molecules have the energy necessary to escape from the liquid phase.

Temperature and Kinetic Energy



Phase Changes

- It takes some energy (4.18 J/g) to warm water by 1ºC, but it takes *a lot more energy* to cause water molecules to break their attractive forces and escape as gas molecules.
  - Each gram of water takes 2270 Joules to convert it from liquid to water vapor.
- Analogy: If two powerful magnets are stuck together, I can slide them over each other relatively easily, but to actually pull them apart takes much more effort.

Phase Changes

- Heat of fusion (H_{fus}) = the heat needed to melt 1 gram of a substance at its melting point.
  - Also, the heat given off when 1 gram of a substance changes from liquid to solid.
  - For water, H_{fus} = 334 J/g
- Heat of vaporization (H_{vap}) = the heat needed to boil 1 gram of a substance at its boiling point.
  - Also, the heat given off when 1 gram of a substance changes from gas to liquid.
  - For water, H_{vap} = 2270 J/g.

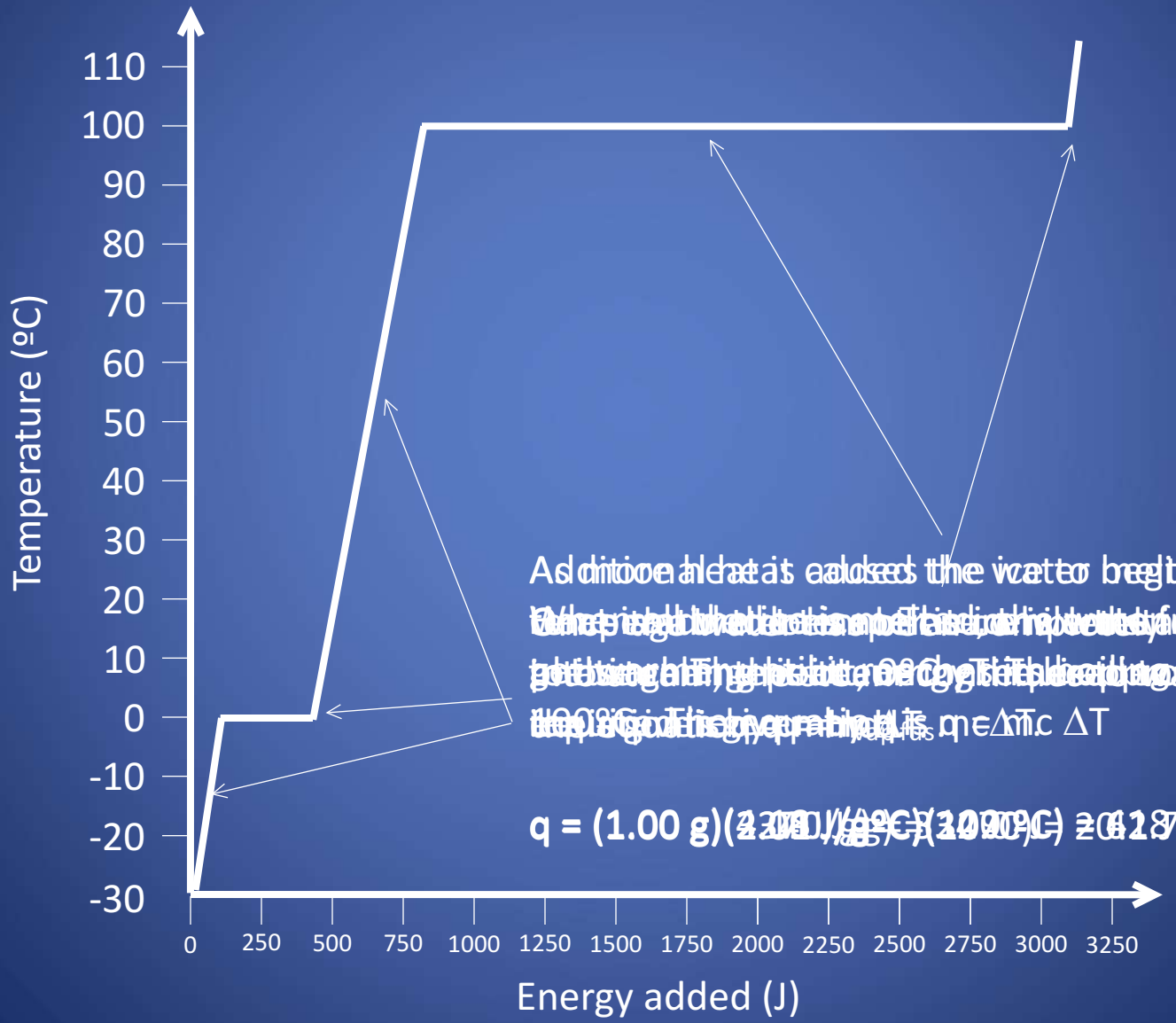
Phase Changes

- Equation used to calculate energy changes during phase changes:
  - $q = mH$
    - Melting/freezing: $H = H_{fus}$
    - Boiling/condensing: $H = H_{vap}$
  - Notice the lack of ΔT.
    - No temperature change during a phase change.

Phase Changes

- Suppose that a block of ice is heated to its melting temperature (0ºC).
  - If more heat is added, what happens?
  - All the added heat goes to changing the ice to liquid water.
  - The resulting water *does not get warmer* until all the ice is melted.
- Why not?
  - Remember that heat flows from warm to cool.
    - If any water got warmer than 0ºC while there was still ice in the mixture, it would have to give its energy to the ice, which would contribute to melting the ice.
    - The water would subsequently cool back down to 0ºC.

Heating curve for 1 gram of water



Phase Changes

- How much heat energy is needed to melt 44.0 grams of formic acid at its melting point? The heat of fusion of formic acid is 97.99 J/g.
  - $q = mH_{fus}$
  - $q = (44.0\ g)(97.99\ J/g)$
  - $q = 4310\ J$

Phase Changes

- What mass of glycerol will give off 1950 J of heat energy when it condenses from its gaseous state into its liquid state? The heat of vaporization of glycerol is 200.62 J/g.
  - $q = mH_{vap}$
  - 1950 J = m (200.62 J/g)
  - m = 9.72 g

Phase Changes

- How much heat is needed to change 40.0 grams of ice at -15.0ºC to water at 22.0ºC?
  - c_{ice} = 2.09 J/gºC
  - H_{fus} = 334 J/g
  - c_{water} = 4.18 J/gºC
- Three heat additions:
  - $q_1 = mc_{ice}\Delta T$
  - $q_2 = mH_{fus}$
  - $q_3 = mc_{water}\ \Delta T$
  - $q_1 + q_2 + q_3 = q_{total}$

Phase Changes

- q_1 = (40.0 g)(2.09 J/gºC)(15.0ºC) = 1250 J
- q_2 = (40.0 g)(334 J/g) = 13,400 J
- q_3 = (40.0 g)(4.18 J/gºC)(22.0ºC) = 3680 J
- q_{total} = 1250 J + 13,400 J + 3680 J = 18,300 J