# LECTURE 07: Phase transitions

Select LEARNING OBJECTIVES:

- Introduce a P vs T phase diagram identifying equilibrium states and phase equilibrium locations.
- Be able to use latent heat to understand phase transitions.
- Be able to analyze a temperature vs energy graph relating slopes to specific heat and identifying key regions such as states of matter and phase transitions.

TEXTBOOK CHAPTERS:

- Giancoli (Physics Principles with Applications 7$^{th}$) :: 13-11, 14-5
- Knight (College Physics : A strategic approach 3$^{rd}$) :: 12.5
- BoxSand :: Heat

WARM UP: Questions?

Consider a pot of water on a stove which is initially at 20 °C. Turning on the stove will add thermal energy to the water via heat. As the water's temperature raises from 20°C to 100 °C we can determine the amount of heat added by using our results from the specific heat discussion ( $Q = m\,c\,\Delta T$ ). As you are monitoring the temperature of the water you notice something interesting, at 100°C the water begings to boil and gets converted to steam (a gas) but the temperature of the water does not change (the temperature of the steam is also 100 °C). The stove is still on so thermal energy is still being added to the system but the temperature is not changing. If the temperature is not changing then we can no longer determine the heat added to the system by means of $Q = m\,c\,\Delta T$ because $\Delta T=0$. Can we understand this observation via our microscopic model? Recall that temperature is a macroscopic measure of the microscopic average translational kinetic energy of a system. Thermal energy is the sum of all the microscopic forms of energy (kinetic + potential "bonds" ). Thus at some point, the thermal energy is large enough to start breaking bonds within the system and any additional heat added to the system goes into the energy needed to break those bonds rather than going into the translational kinetic energy.

The problem at hand is, how do we quantify this additional heat that is being added to our system if the temperature does not change. Careful experiments can be constructed to find this additional heat; from these experiments we would conclude that the additional heat is proportional to the mass of the substance. If a system is freezing or melting the proportional constant is labeled $L_f$ and referred to as the latent heat of fusion; likewise if the system is evaporating or condensing the proportionality constant is labeled $L_v$ and referred to as the latent heat of vaporization. The latent heats of fusion and vaporization are both material properties. The additional heat added or removed from a system as a phase change occurs and the temperature remains constant is referred to as the heat of transformation.

HEAT OF TRANSFORMATION

$$Q_f = \pm m L_f$$

± : ADD AD HOC BASED ON ...
$L_f$ : LATENT HEAT OF FUSION

SOLID → LIQUID (+) [MELTING]

LIQUID → SOLID (−) [FREEZING]

$$Q_v = \pm m L_v$$

± : ADD AD HOC BASED ON ..
$L_v$ : LATENT HEAT OF VAPORIZATION

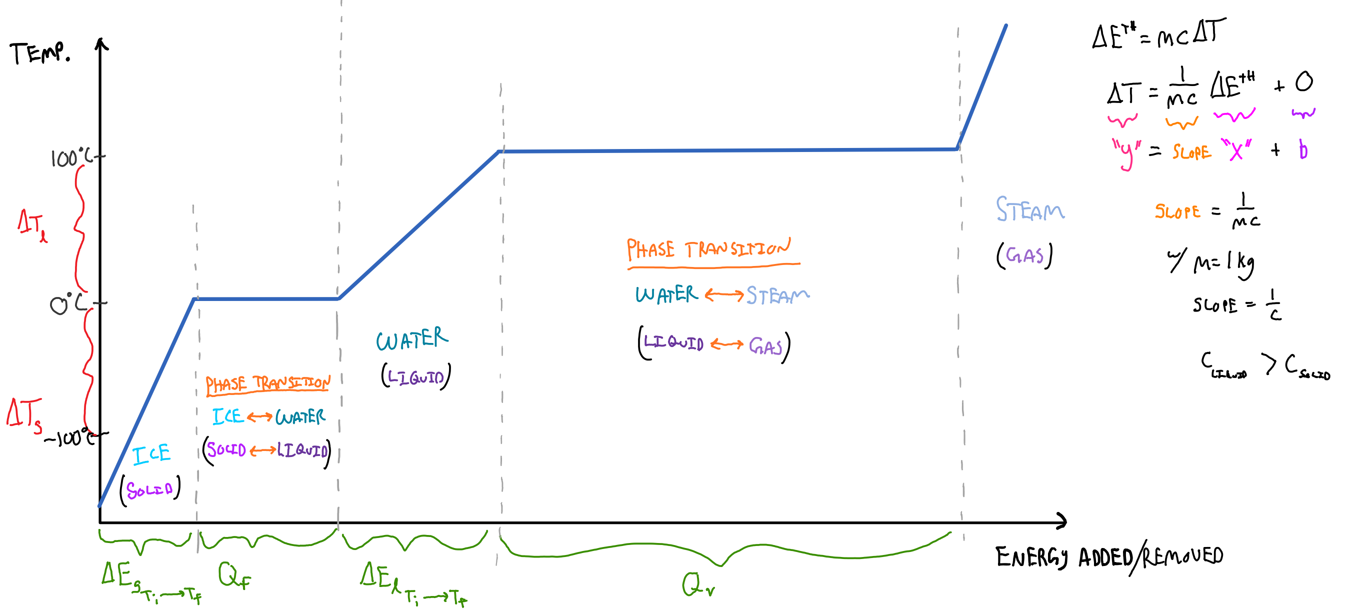
LIQUID → GAS (+) [EVAPORATING]

GAS → LIQUID (−) [CONDENSING]

PRACTICE: How much thermal energy must be removed to freeze 0.43 kg of water at 0°C to ice at 0°C? The specific heat capacity of water is 4190 J/(kg K). The latent heat of vaporization for water is 2260 kJ/kg. The latent heat of fusion for water is 333 kJ/kg.

PRACTICE: How much thermal energy does a freezer have to remove from 0.43 kg of water at 20°C to make ice at -10°C?

Let's go back to the experiment with a pot of water on a stove. This time we will start with pure ice in the pot and record the temperature as heat is added to the system. As the temperature of the ice increases and eventually begins to melt we will record the thermal energy added. Likewise, as the temperature of the water increases and eventually evaporates, we will collect the steam and continue to measure its temperature and added thermal energy. A graph that shows the results of this experiment is shown below.

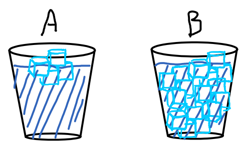



PRACTICE: If water is initially at -100 °C, and put in a microwave that deposits a constant rate of energy, which will take a longer amount of time?

(a) Reaching the liquid state.
(b) Going from the liquid to the gas state.
(c) Both with take the same amount of time.

Questions for discussion:

(1) Two glasses of water contain ice as shown in the figure below. Both are in equilibrium. Glass B has more ice in it than glass A. Which glass is at a lower temperature?




(2) When a solid melts or a liquid boils, the temperature does not increase even though energy is being added to the system. Where does this energy go?