Multi-Phase

1 Overview

In equilibrium, we can have different phases of matter (gas, liquid, solid). So far we only focus on individual phases of homogeneous substances. Now we consider the multi-phase system.

2 Process

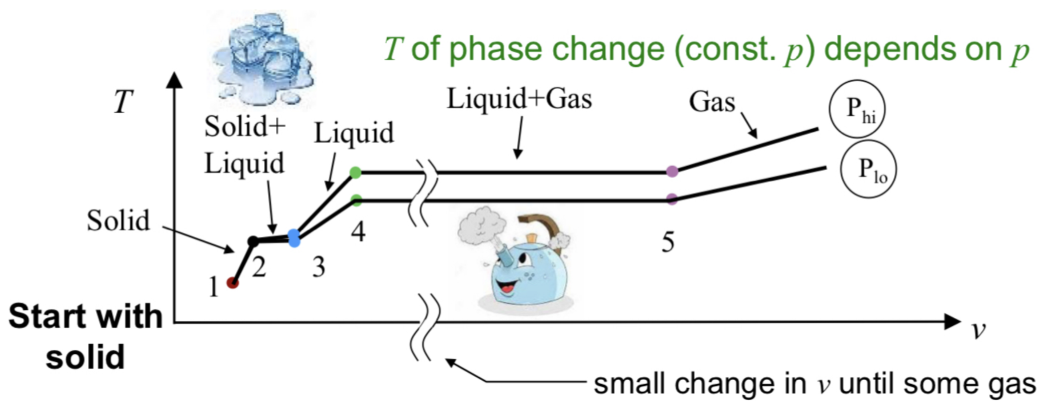

Figure 1: Phase Change Process

The processes include:

1. 2 to 3: Melting
2. 4 to 5: Evaporation
3. 3 to 2: Freezing
4. 5 to 4: Condensation

3 T-v Diagram

Phase space is actually 3D:

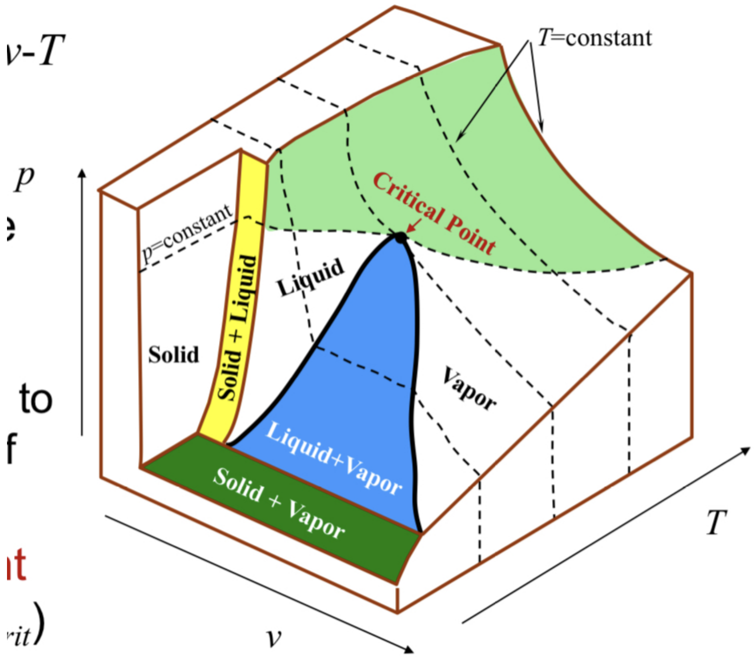

Figure 2: p, V, T diagram

But we can only take the $T - v$ diagram out, as a 2D diagram:

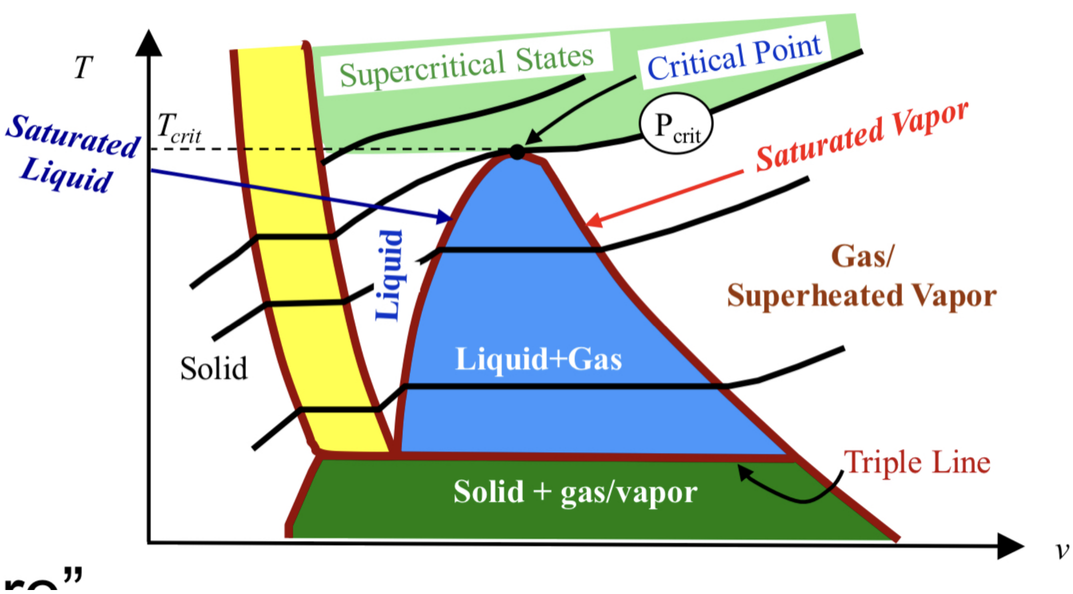

Figure 3: T, V diagram

Some remarks:

1. **Triple Line:** 3 phases can coexist at same T and p.
2. **Critical Point:** Maximum T and p for distinct liquid/gas phase.
3. **Supercritical States:** refers to the state of a substance when it is **above** its critical temperature and critical pressure. At these conditions, the distinction

between the liquid and gas phases disappears, and the substance exists as a single phase known as a supercritical fluid.

4. **Saturated Liquid/Vapor:** boundary between pure phase and two-phase mixture

5. **Superheated Vapor:** refers to a vapor that is at a temperature higher than its saturation temperature for a given pressure. In other words, it's a vapor that has been heated beyond the point where it first becomes a vapor (i.e., beyond the boiling point for that pressure).

4 Mixed Phase Regions

In mixed phase regions, pressure and temperature are not independent anymore, we need to define a new intensive variable to characterize composition, which is called **quality**:

$$x = \frac{m_g}{m_{mixture}} = \frac{m_g}{m_l + m_g} \tag{1}$$

Which gives fraction of mass that is gas. Also, $x = Y_{vap}$, which is vapor mass fraction, and $1 - x = Y_{liq}$, which is liquid mass fraction.

Using this, we can get the extensive TD property, such as volume:

$$V_{mix} = m_g v_g + m_l v_l = m_{mix}[\frac{m_g v_g}{m_{mix}} + \frac{m_l v_l}{m_{mix}}] \tag{2}$$

Therefore:

$$V_{mix} = m_{mix}[x v_g + (1 - x) v_l] \tag{3}$$

$$v_{mix} = x v_g + (1 - x) v_l = v_l + x(v_g - v_l) \tag{4}$$

Normally we use $v_l g = v_g - v_l$ for simplification.

5 Non-Equilibrium Phase Change

Rapid processes, such as sudden cooling or depressurization when cooling/heating can lead to non-equilibrium phase transitions.