We will cover,

- *Phase Diagrams*
- *State Principle and Quality*
- *Evaluating Properties*
**P-v Diagram**

- **Critical Point**
- **Compressed liquid**
- **Saturated liquid line**
- **Two-phase dome**
- **Saturated vapor line**
- **Superheated vapor**
- **increasing direction of temperature**
- **constant temperature line**
$T$-$v$ Diagram

- Compressed liquid
- Two-phase dome
- Critical Point
- Superheated vapor
- Constant pressure line
- Increasing direction of pressure
- Saturated liquid line
- Saturated vapor line
State Principle

Two independent, intensive thermodynamic properties are sufficient to fully determine the thermodynamic state of a pure substance.
The “Two-Phase” Dome

• A mixture of liquid and vapor

• Temperature and pressure are NOT independent in the two-phase dome
  – One specifies the other
  – Example: boiling point of water at different altitudes

• need another independent property to completely specify the state:
  – concept of quality
Introducing Quality

• Define properties in the “Two-Phase” dome

• For example:
  – extensive property: internal energy
  – using quality, its intensive counterpart can be expressed as a mass-weighted average of the saturated liquid and saturated vapor values

\[
U = U_f + U_g
\]

\[
mu = m_f u_f + m_g u_g
\]

\[
u = \frac{m_f}{m} u_f + \frac{m_g}{m} u_g
\]

\[
u = (1 - x) u_f + x u_g
\]

• Internal energy in the above example can be replaced by any other extensive property, e.g. volume, enthalpy, entropy, etc.
Introducing Quality (Cont’d)

• **Definition:** mass fraction of vapor in the mixture

\[ x = \frac{m_g}{m_f + m_g} \]

• **Geometric interpretation** on phase diagram:

\[ x = \frac{a}{b} \]

  – saturated liquid: \( x = 0 \)
  – saturated vapor: \( x = 1 \)

• Serves as another independent thermodynamic variable in the “Two-phase” dome
Phase Determination (Case 1)

- **Case 1:** Given $P$ and $T$
  - Look up saturation table
  - Compare given $P$ and $T$ against saturation values in the table

- In pressure table,
  - Recall constant pressure line on $T$-$v$ diagram
  - If $T < T_{\text{sat}}(P)$, compressed liquid.
  - If $T = T_{\text{sat}}(P)$, saturated liquid-vapor mixture.
  - If $T > T_{\text{sat}}(P)$, superheated vapor.
Phase Determination (Case 1 Cont’d)

- **Case 1**: Given $P$ and $T$
  - Look up saturation table
  - Compare given $P$ and $T$ against saturation values in the table

- **In temperature table,**
  - Recall constant temperature line on $P$-$v$ diagram
  - If $P > P_{\text{sat}}(T)$, compressed liquid.
  - If $P = P_{\text{sat}}(T)$, saturated liquid-vapor mixture.
  - If $P < P_{\text{sat}}(T)$, superheated vapor.
Phase Determination (Case 2)

- **Case 2:** Given $P$ (or $T$) and $v$ (or $u$, $h$, $s$)
  - Look up saturation table
  - Find saturated liquid and vapor values for $v$ (or $u$, $h$, $s$) at $P_{sat} = P$

1) If $v < v_f(P_{sat})$, compressed liquid.
2) If $v = v_f(P_{sat})$, saturated liquid.
3) If $v_f(P_{sat}) < v < v_g(P_{sat})$, saturated liquid-vapor mixture.
4) If $v = v_g(P_{sat})$, saturated vapor.
5) If $v > v_g(P_{sat})$, superheated vapor.
Summary

- **Compressed** liquid (quality is undefined, any two intensive thermodynamic properties suffice)

- Saturated liquid \( (x = 0) \)

- Saturated **liquid-vapor** mixture \( (0 < x < 1) \)

- Saturated vapor \( (x = 1) \)

- **Superheated** vapor (quality is undefined, any two intensive thermodynamic properties suffice)
Flow Chart

Determine phase of substance

Compare with saturation table

Compressed Liquid

Direct look up

Two-phase Mixture

Determine quality

Superheated Vapor

Direct look up

Interpolate other properties