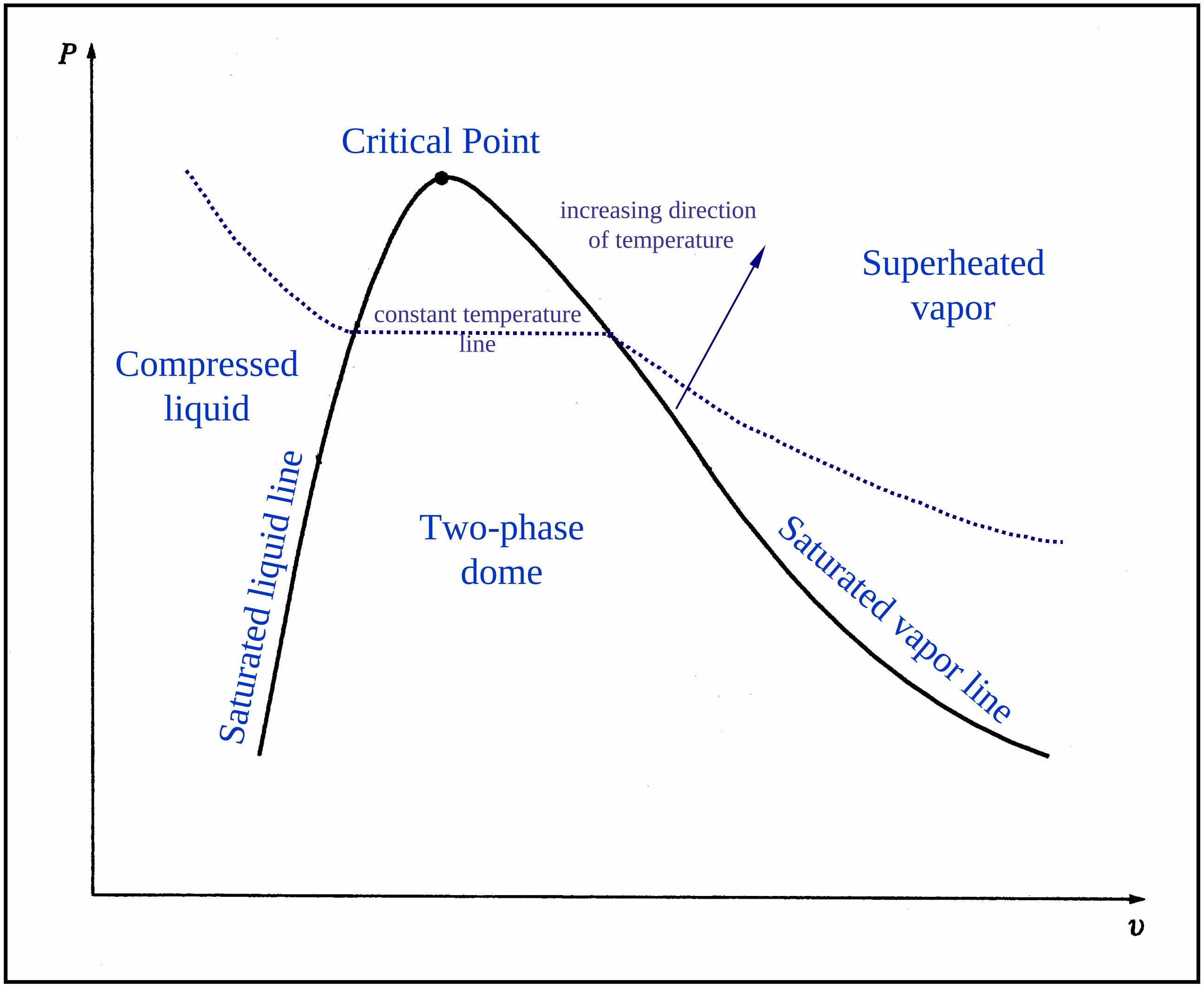
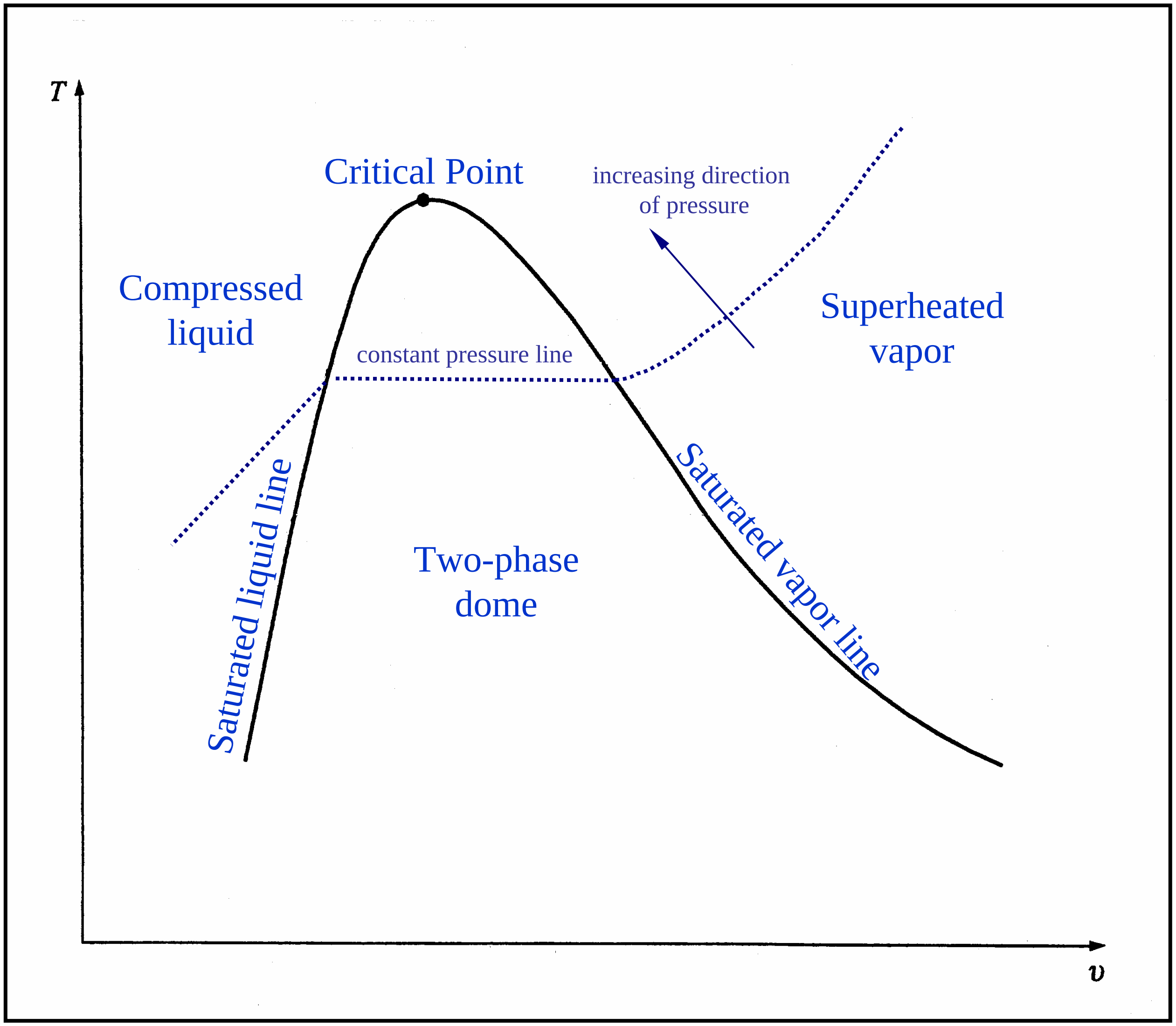
We will cover,

- ***Phase Diagrams***
- ***State Principle and Quality***
- ***Evaluating Properties***


P
Critical Point
increasing direction
of temperature
Superheated
vapor
constant temperature
line
Compressed
liquid
Saturated liquid line
Two-phase
dome
Saturated vapor line
v


T
v
Critical Point
increasing direction
of pressure
Compressed
liquid
Superheated
vapor
constant pressure line
Saturated liquid line
Two-phase
dome
Saturated vapor line

Two independent, intensive thermodynamic properties are sufficient to fully determine the thermodynamic state of a pure substance.

- A <u>mixture</u> of <u>liquid</u> and <u>vapor</u>
- Temperature and pressure are <u>NOT</u> independent in the <u>two-phase</u> dome
  - One specifies the other
  - Example: boiling point of water at different altitudes
- need another <u>independent</u> property to <u>completely</u> specify the state:
  - concept of <u>quality</u>

- 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.*

- Definition: mass fraction of vapor in the mixture

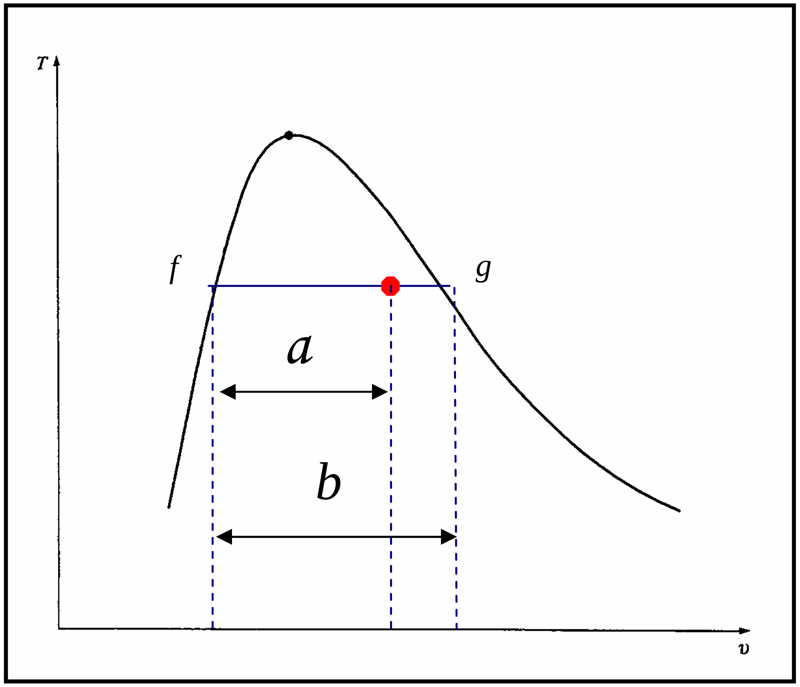
$$x = \frac{m_g}{m_f + m_g}$$

- Geometric interpretation on phase diagram:

$$x = \frac{a}{b}$$

  - saturated liquid: $x = 0$
  - saturated vapor: $x = 1$

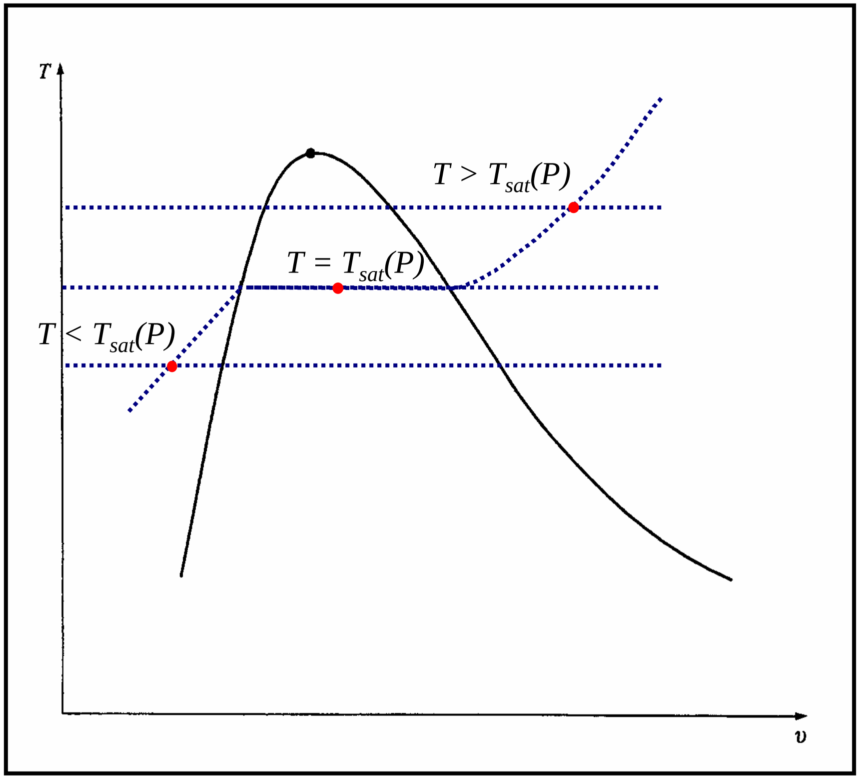
- Serves as another independent thermodynamic variable in the "Two-phase" dome



- <u>Case 1:</u> Given P and T
  - Look up saturation table
  - Compare given P and T against saturation values in the table

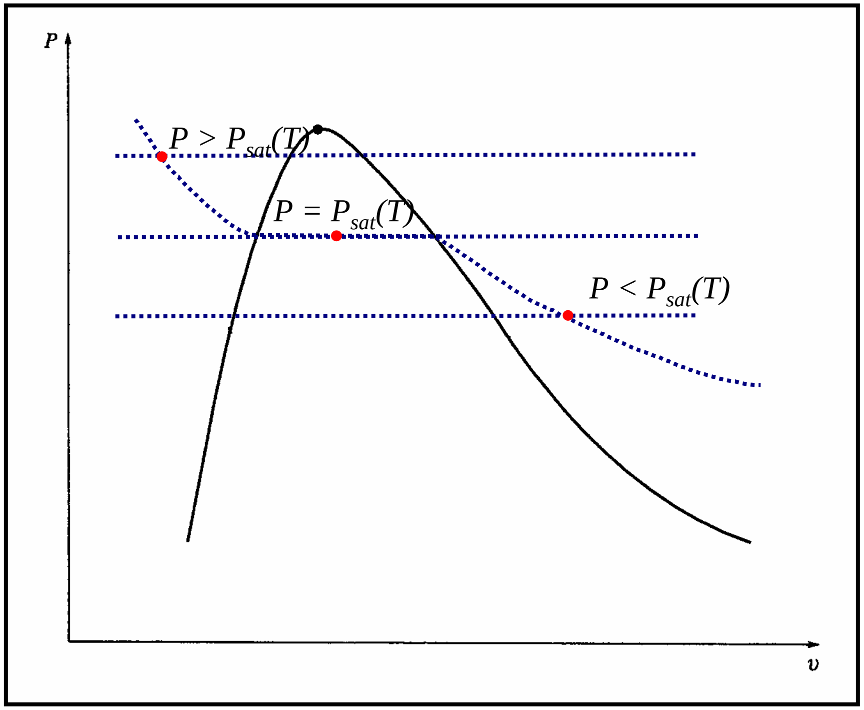
➢ In pressure table,

- Recall constant pressure line on T-v diagram
- If $T < T_{sat}(P)$, <u>compressed liquid</u>.
- If $T = T_{sat}(P)$, <u>saturated liquid-vapor mixture</u>.
- If $T > T_{sat}(P)$, <u>superheated vapor</u>.



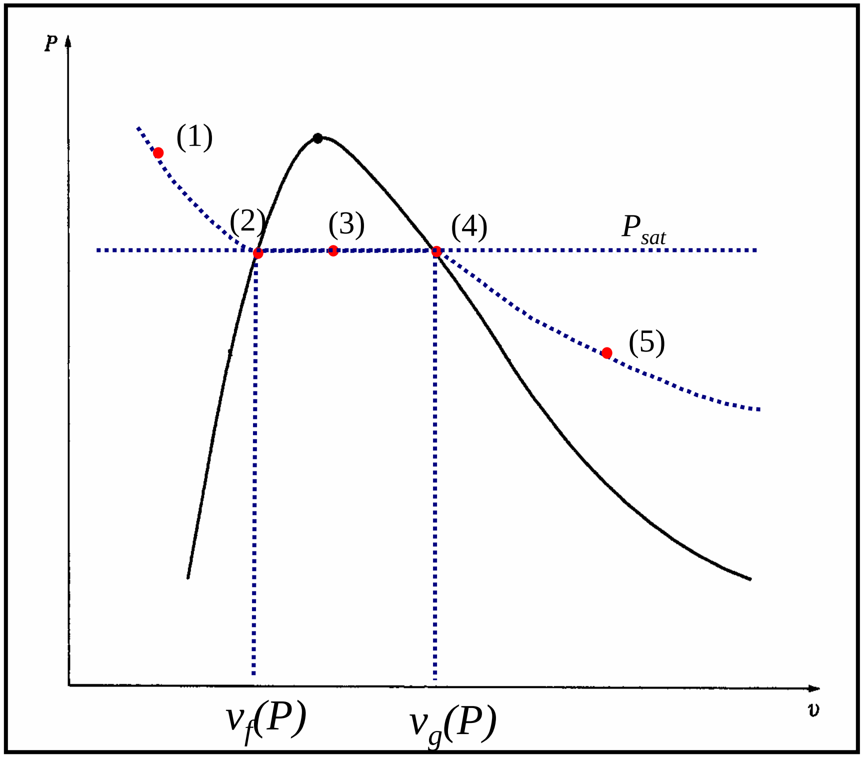
- <u>Case 1:</u> Given *P* and *T*
  - Look up saturation table
  - Compare given *P* and *T* against saturation values in the table

➢ In temperature table,
  - Recall constant temperature line on *P*-*v* diagram
  - If $P > P_{sat}(T)$, <u>compressed liquid</u>.
  - If $P = P_{sat}(T)$, <u>saturated liquid-vapor mixture</u>.
  - If $P < P_{sat}(T)$, <u>superheated vapor.</u>

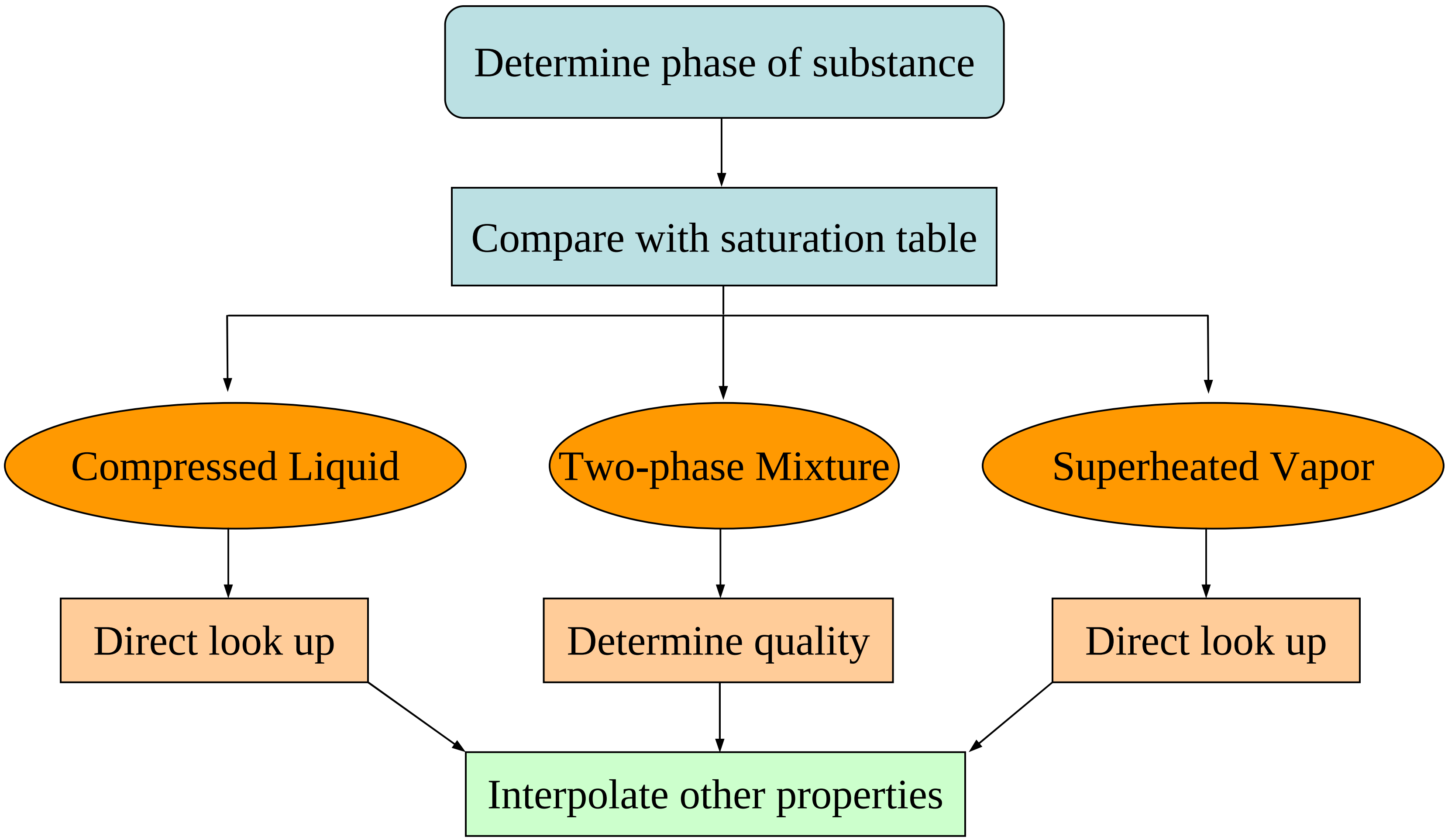


- <u>Case 2:</u> Given *P* (or *T*) and *v* (or *u, h, s*)
  - Look up saturation table
  - Find saturated liquid and vapor values for *v (or u, h, s)* at $P_{sat} = P$

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



- 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)


Determine phase of substance
Compare with saturation table
Compressed Liquid
Two-phase Mixture
Superheated Vapor
Direct look up
Determine quality
Direct look up
Interpolate other properties