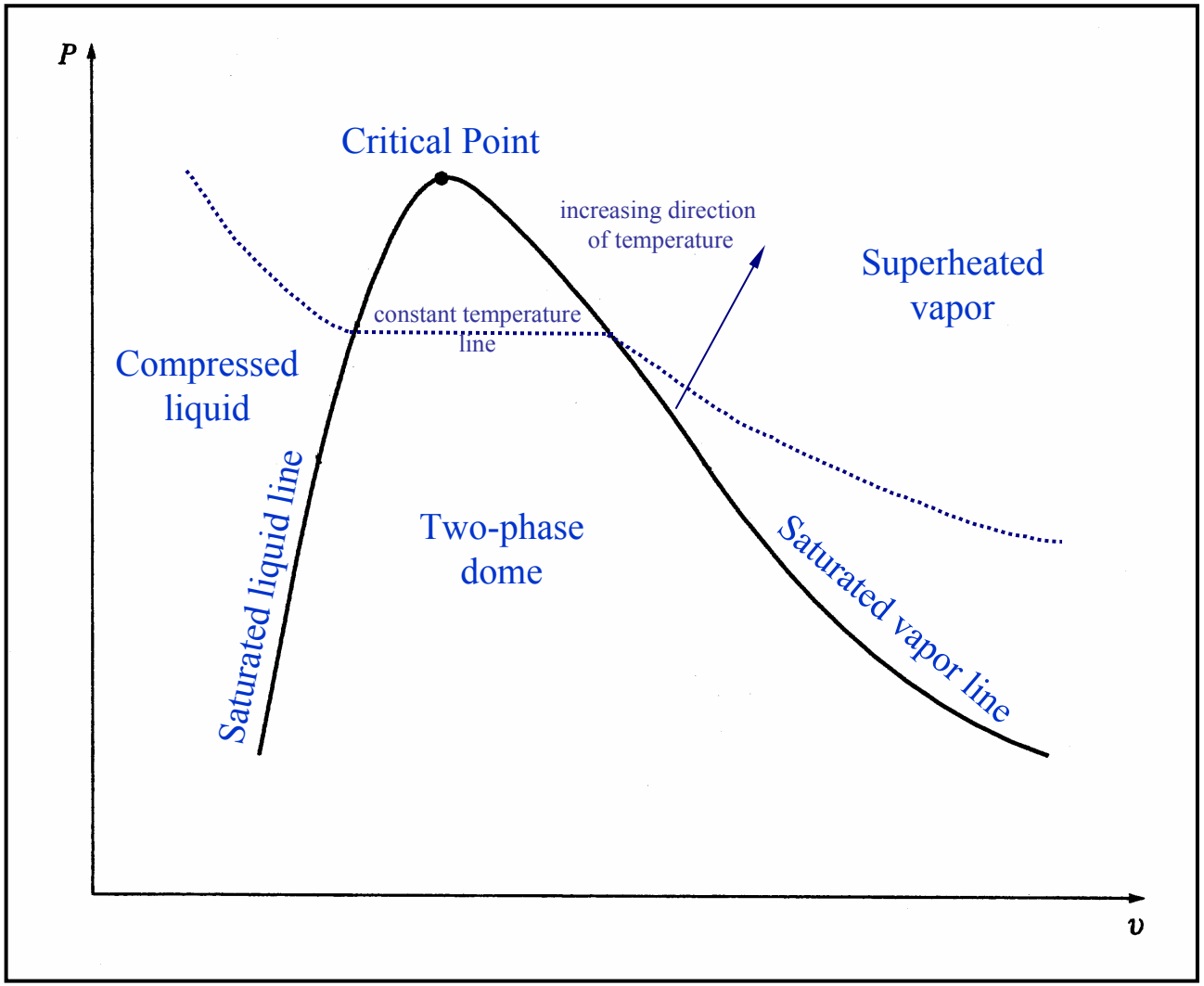
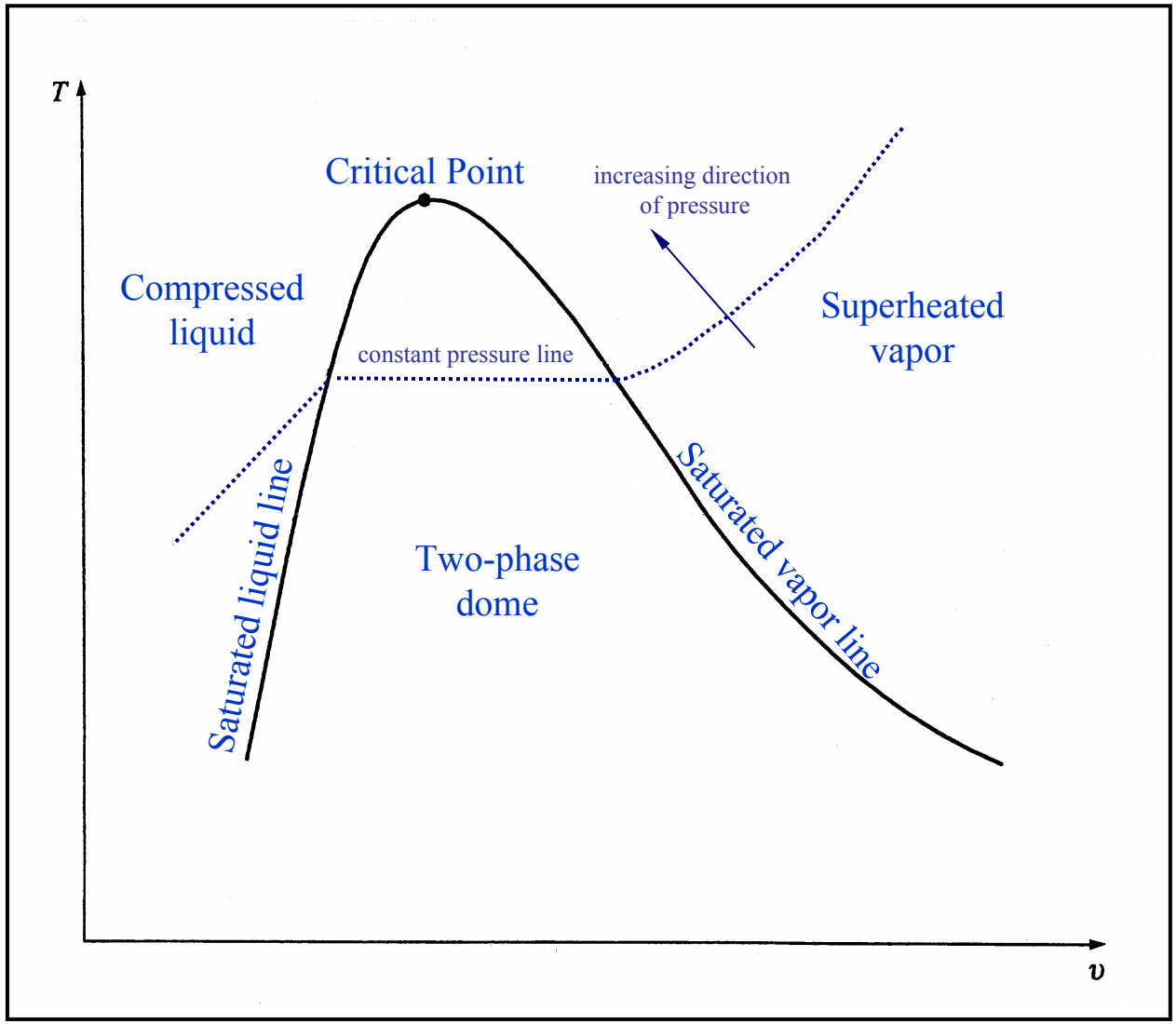
We will cover,

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

P-v Diagram


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 Diagram


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

State Principle

Two <u>independent, intensive</u> thermodynamic properties are <u>sufficient</u> to fully determine the thermodynamic state of a <u>pure</u> 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 <u>quality</u>, its <u>intensive</u> counterpart can be expressed as a <u>mass-weighted average</u> of the <u>saturated liquid</u> and <u>saturated vapor values</u>

$$U = U_f + U_g$$

$$mu = m_f u_f + m_g u_g$$

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

$$u = (1 - x)\, u_f + x\, u_g$$

- 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

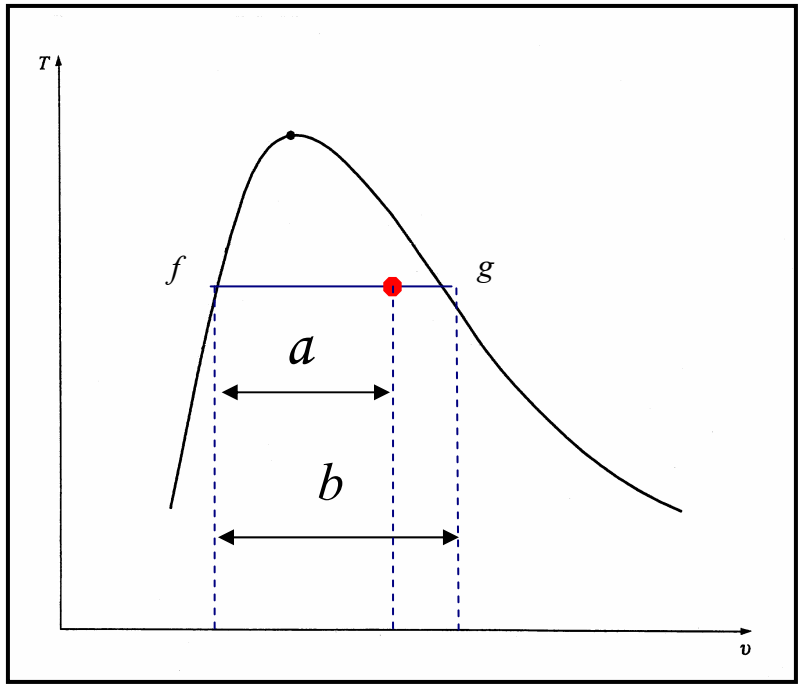
$$x = \frac{m_g}{m_f + m_g}$$

- <u>Geometric interpretation</u> on phase diagram:

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

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

- Serves as another <u>independent</u> thermodynamic variable in the "Two-phase" dome

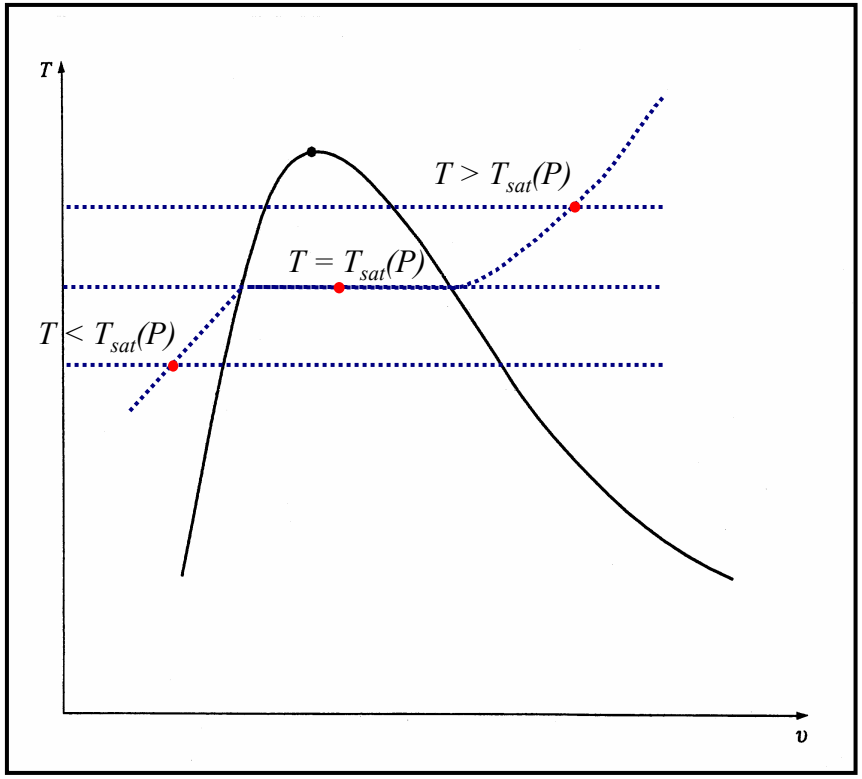


Phase Determination (Case 1)

- 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 $T < T_{sat}(P)$, compressed liquid.
- If $T = T_{sat}(P)$, saturated liquid-vapor mixture.
- If $T > T_{sat}(P)$, superheated vapor.

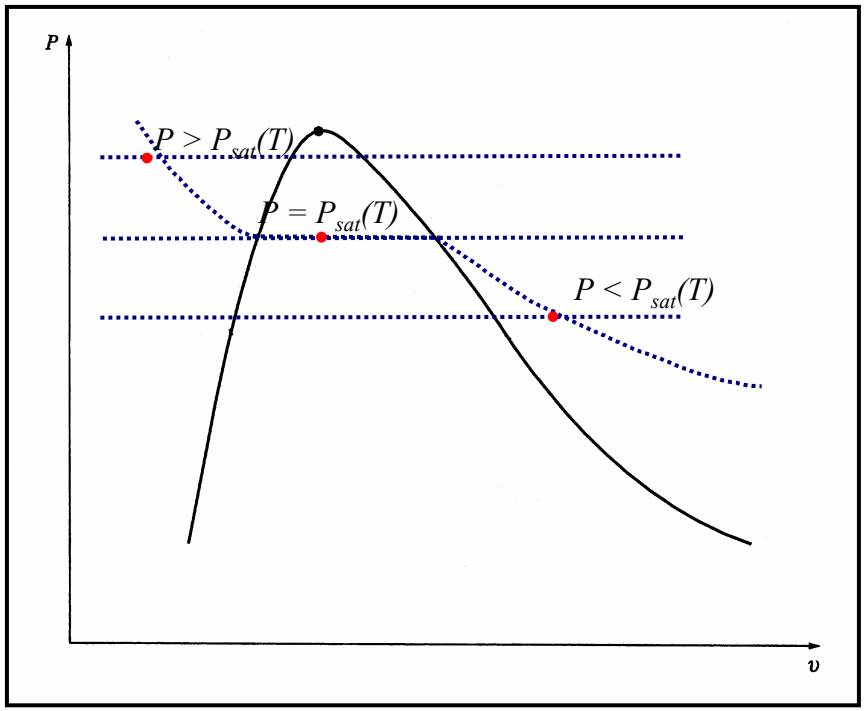


Phase Determination (Case 1 Cont'd)

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

➢ In temperature table,

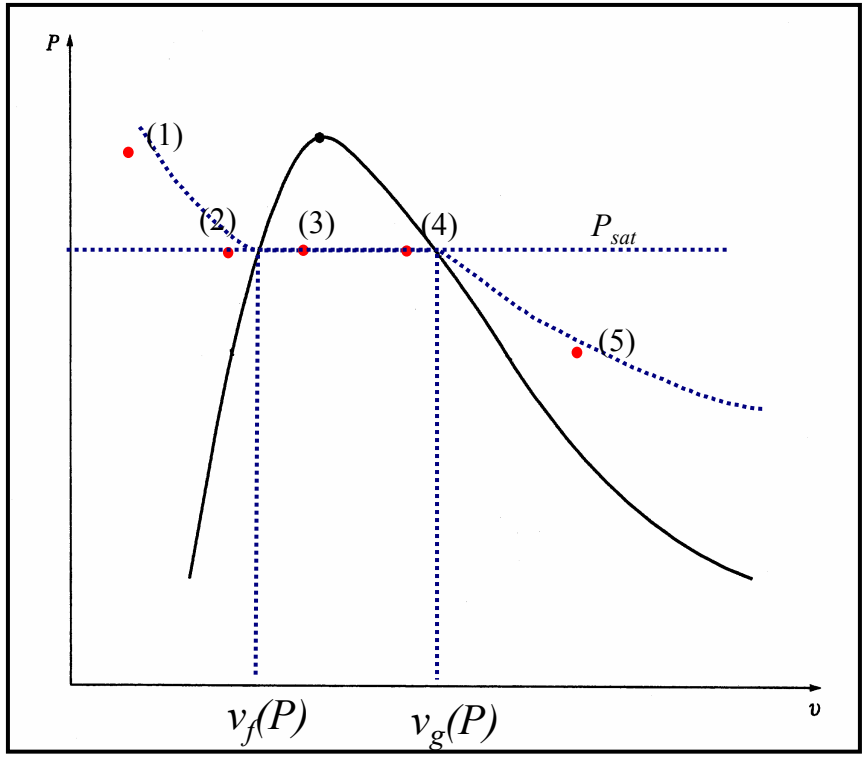
- Recall constant temperature line on *P-v* diagram
- If $P > P_{sat}(T)$, compressed liquid.
- If $P = P_{sat}(T)$, saturated liquid-vapor mixture.
- If $P < P_{sat}(T)$, superheated vapor.



Phase Determination (Case 2)

- <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 $P_{sat} = P$

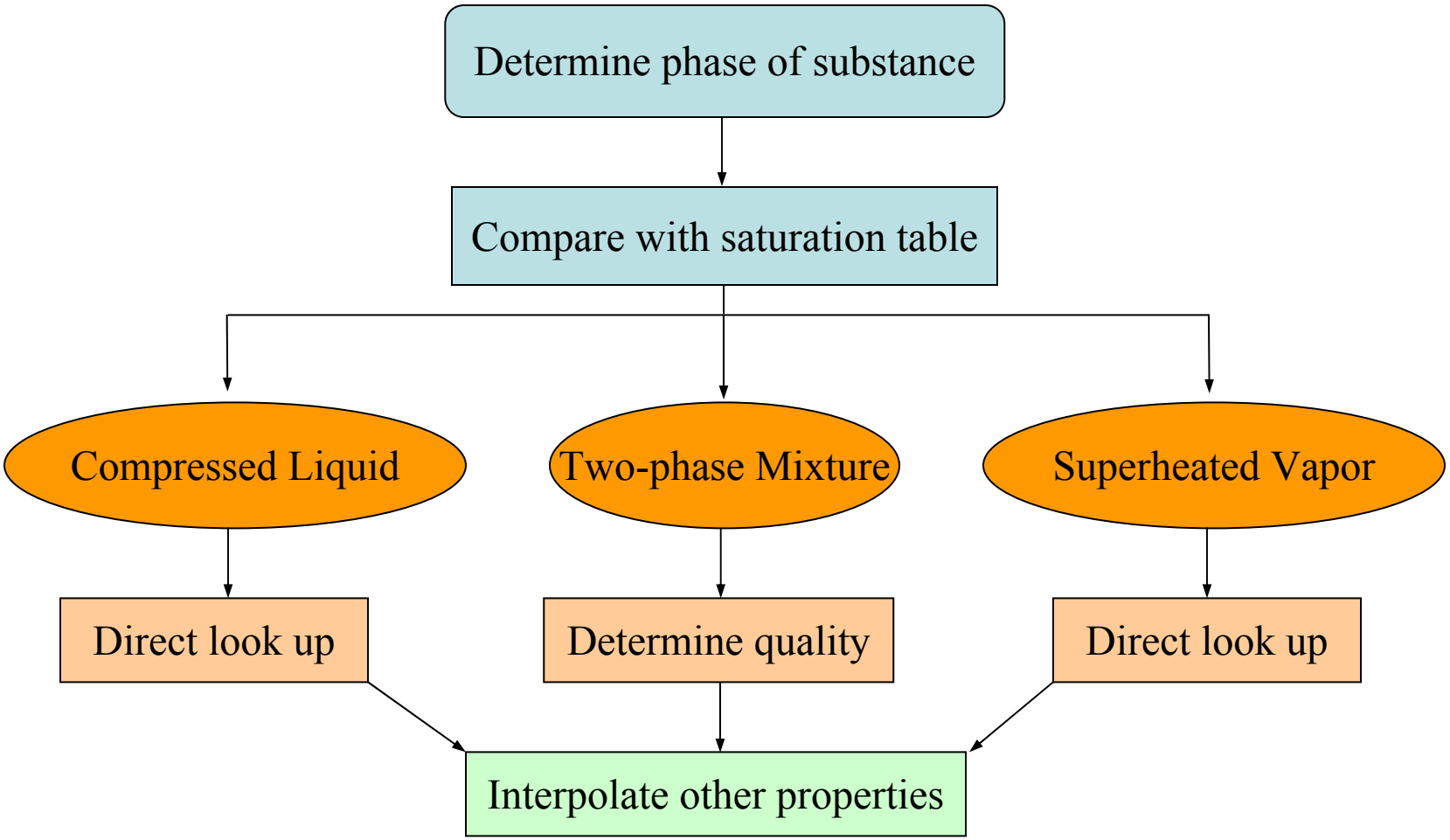
1) If $v < v_f(P_{sat})$, <u>compressed liquid</u>.
2) If $v = v_f(P_{sat})$, <u>saturated liquid.</u>
3) If $v_f(P_{sat}) < v < v_g(P_{sat})$, <u>saturated liquid-vapor mixture.</u>
4) If $v = v_g(P_{sat})$, <u>saturated vapor.</u>
5) If $v > v_g(P_{sat})$, <u>superheated vapor.</u>



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
Two-phase Mixture
Superheated Vapor
Direct look up
Determine quality
Direct look up
Interpolate other properties