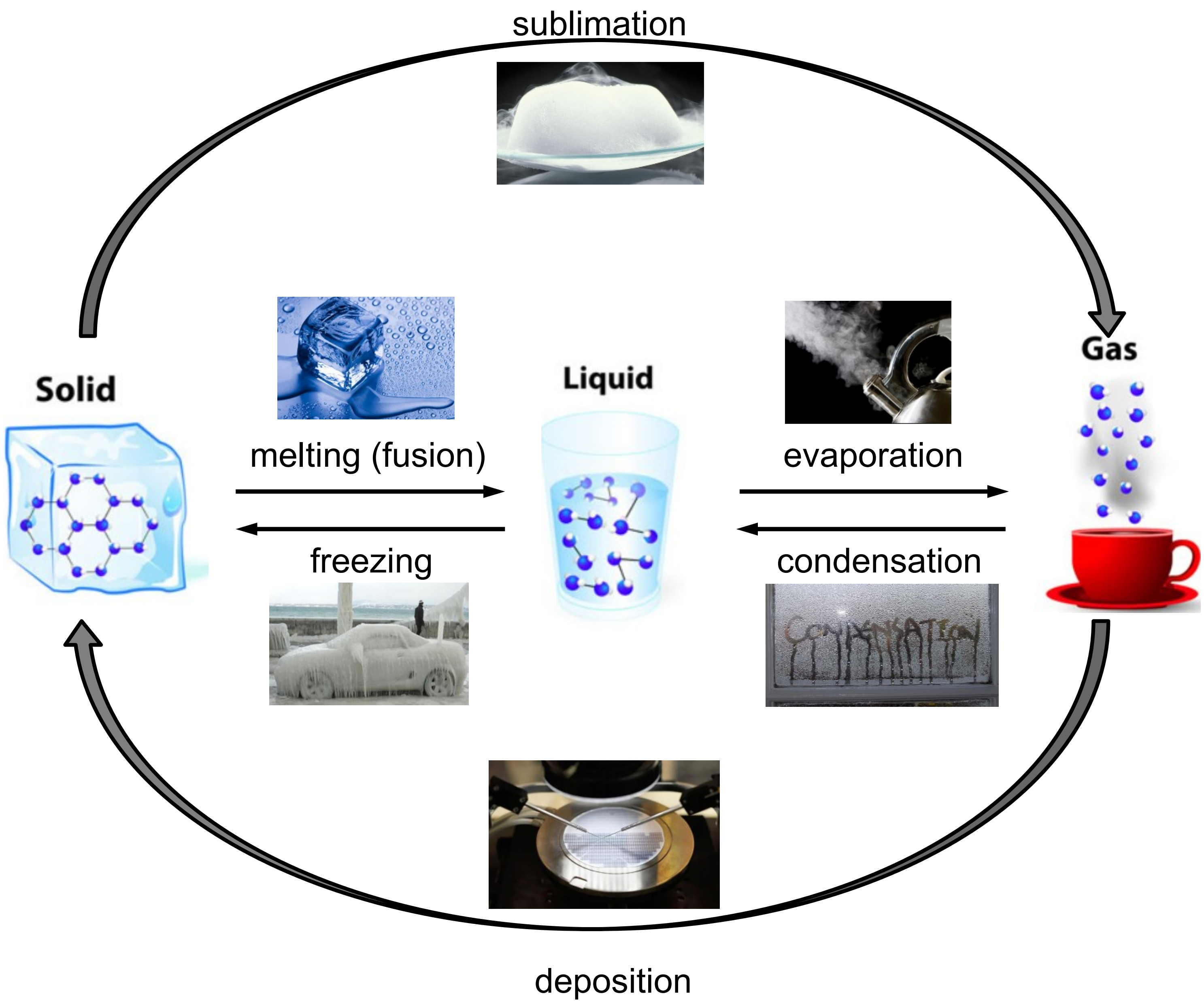
Lecture 2

Topic 1.2
Properties of Pure Substances

Phase change in pure substances

Reading:
Ch 2 Borgnakke & Sonntag Ed. 8
Ch3. Cengel & Boles Ed. 7

Phase Change: Brief Introduction



Phase Change: Brief Introduction

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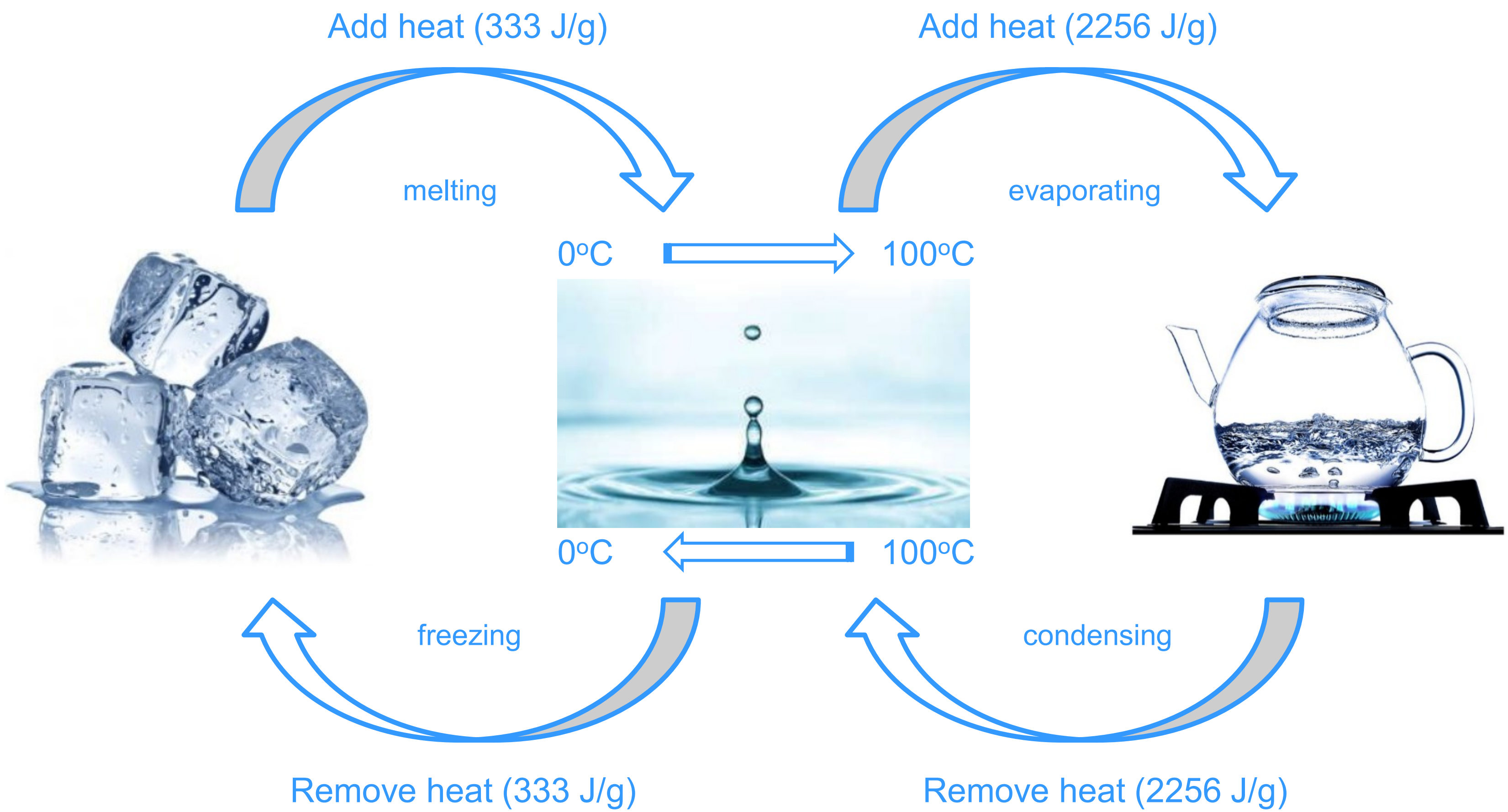
- Energy must be <u>added</u> or <u>removed</u> from system to cause phase change
- Latent Heat (or Enthalpy) of
  - Fusion (solid ↔ liquid)
  - Vaporization (liquid ↔ Gas)



1.2.1 Pure Substance

<u>Pure Substance</u>

- Substance that is homogeneous (i.e. uniform thermodynamic property throughout)
- Can exist in more than one phase (solid, liquid, gas), but chemical composition is the same in all phases

Examples of pure substances:

1. Water (solid, liquid, and vapor phases)
2. Mixture of liquid water and water vapor
3. Carbon dioxide, CO_2
4. Nitrogen, N_2

Non-pure substances

1. Mixtures: $H_2O + N_2$, air ($N_2 + O_2$)

1.2.2 Phase Boundary

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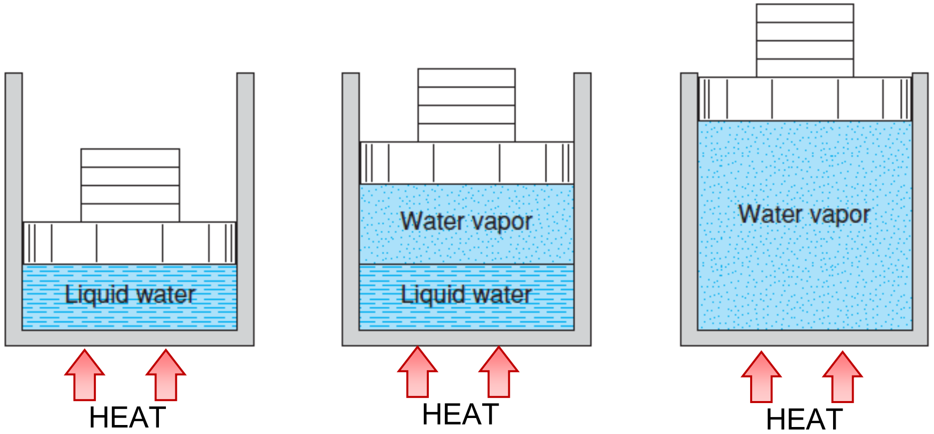

- Piston-cylinder device:
  - Water at T = 20^{o}C, 101.3 kPa
  - Piston mass (constant)
  - Ignore friction
- Heat is added to system
  - Liquid temperature increases to 100^{o}C
  - Evaporation begins (liquid → water vapor).
    - One substance, two phases (liquid + vapor); phase boundary
    - Volume increase (expansion)
    - T = 100^{o}C during evaporation (at constant pressure)
    - Eventually, all liquid evaporates to vapor
      - Volume increase, temp & press constant
- Heat is added to vapor
  - Both volume and temperature increase

1.2.2 Phase Boundary

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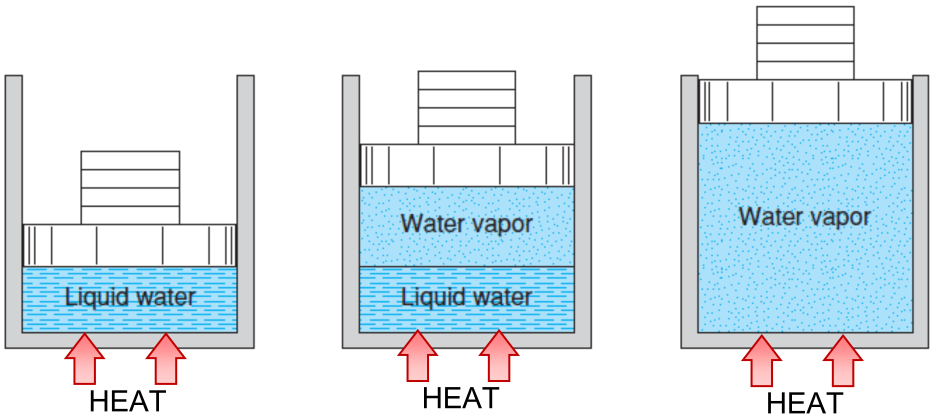
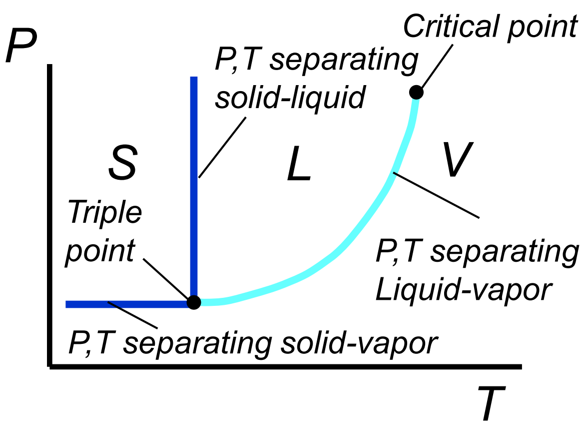


- Liquid-vapor saturation line:
  - Temp. at which vaporization occurs (100^{o}C in example).
  - ***Vaporization line***: boarder between liquid-vapor (boiling point)
  - Sat. Temp. is dependent on pressure
- Solid-liquid saturation line (consider cooling)
  - Remove heat; liquid temp. decreases
  - At 0^{o}C ice forms (solid + liquid mixture)
  - ***Fusion line***: boarder between solid-liquid
  - Beyond fusion line; only solid



- Decrease pressure; curves approach
  - ***Triple point***: all 3 phases can co-exist.
  - ***Sublimation line***: boarder between solid-vapor
- Vaporization curve stops at ***critical point*** (no boiling above this point)

1.2.2 Phase Boundary

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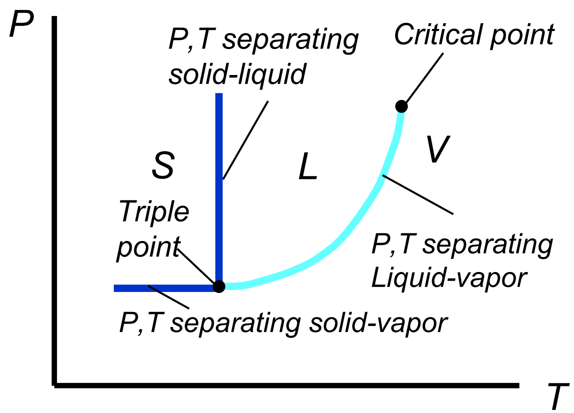
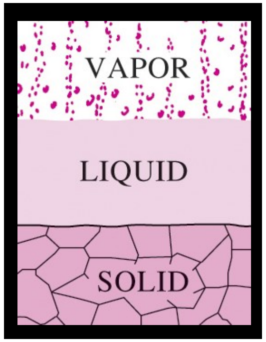
Sublimation, triple-point, & Critical Point



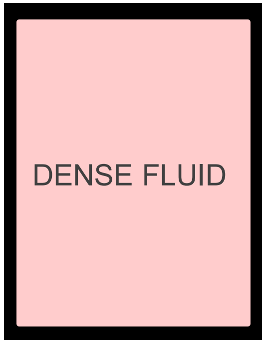
Sublimation

Triple-point



V & L & S in equilibrium. (water: 0.01°C, 0.6117 kPa).

Critical-point

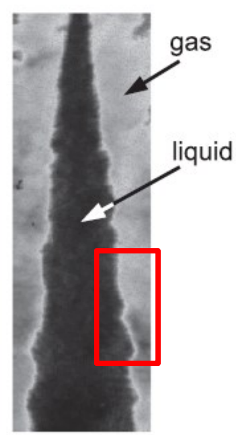


L & V in equilibrium (water: 373.95°C, 22.064 MPa).

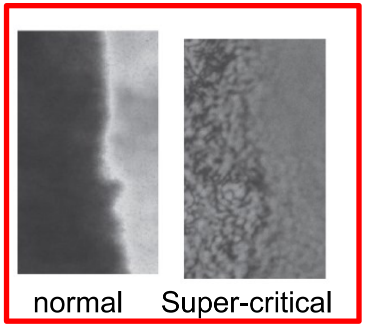
Triple Point: Cyclohexane

https://www.youtube.com/watch?v=XEbMHmDhq2I

Critical Point:



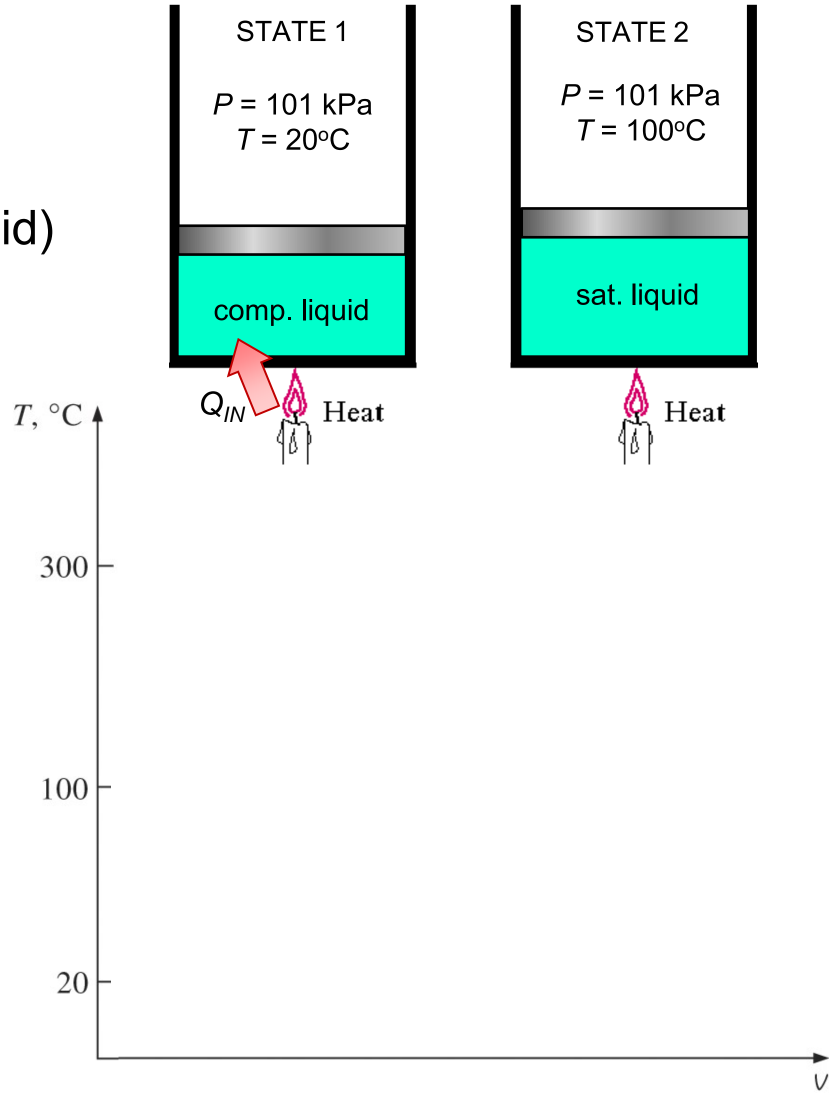
Injection of fuel – high efficiency diesel engine



1.2.3 Phase Diagrams

- Consider heating experiment again. Describe process on a temperature-specific volume diagram (*T-v*)

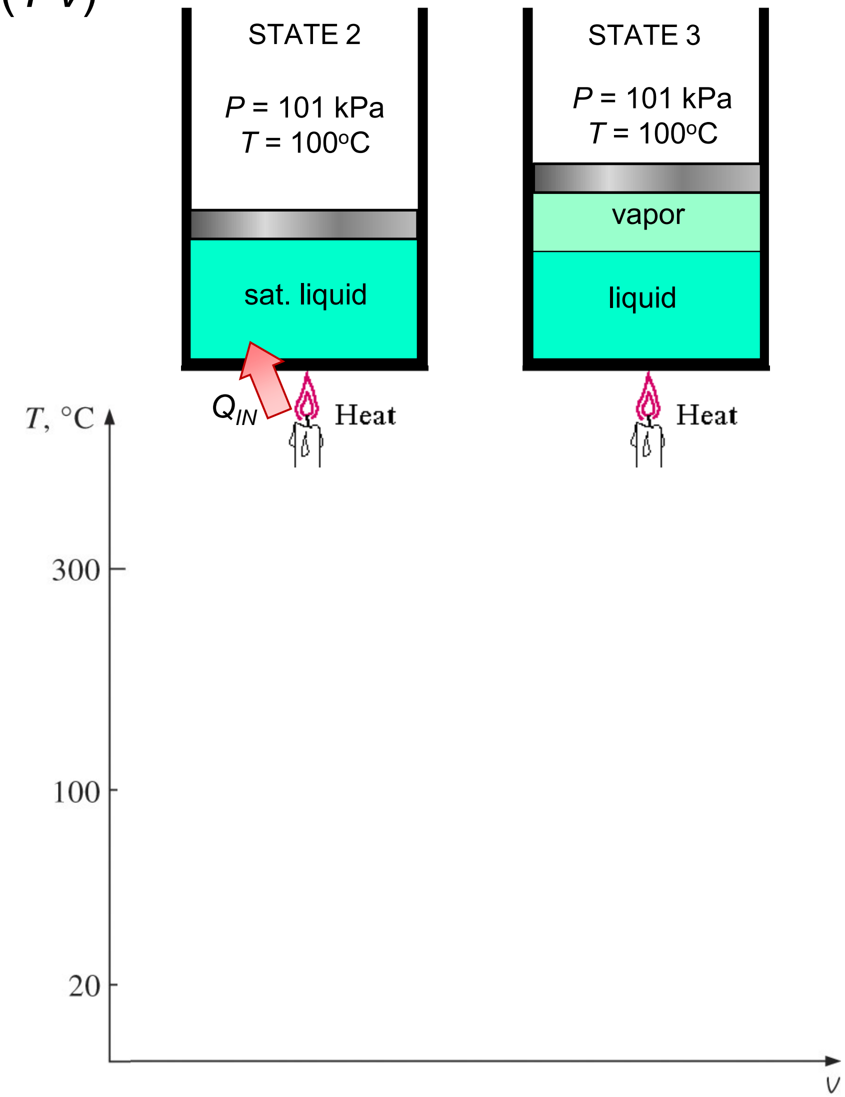
- <u>System</u>: water (20C, 101.3kPa)
- <u>State 1</u>: Liquid water (compressed liquid)
- <u>Process 1-2</u>:
  - Constant pressure heat addition (Q_{IN})
  - T increases, v increases
  - Phase: liquid
- <u>State 2</u>: Saturated liquid
  - T = 100°C; 100% liquid
  - Onset of boiling
  - Energy addition will create vapor at constant T
  - Energy reduction will lower liquid temperature



1.2.3 Phase Diagrams

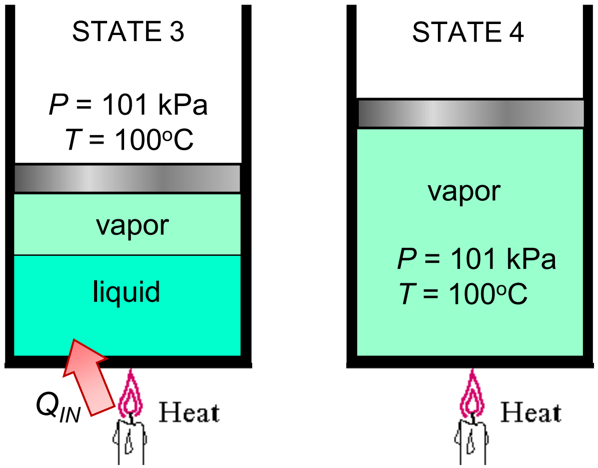
- Consider heating experiment again, but now describe process on a temperature-specific volume diagram (*T-v*)

- System: water
- State 2: Saturated liquid
- Process 2-3:
  - Constant pressure heat addition (Q_{IN})
  - T constant, v increases
  - Phase: saturated mixture → liq.+vap.
- State 3: Saturated mixture
  - X% vapor, (1-X)% liquid
  - Energy addition: vapor ↑, liquid ↓
  - Energy reduction: liquid ↑, vapor ↓
  - T = constant during process

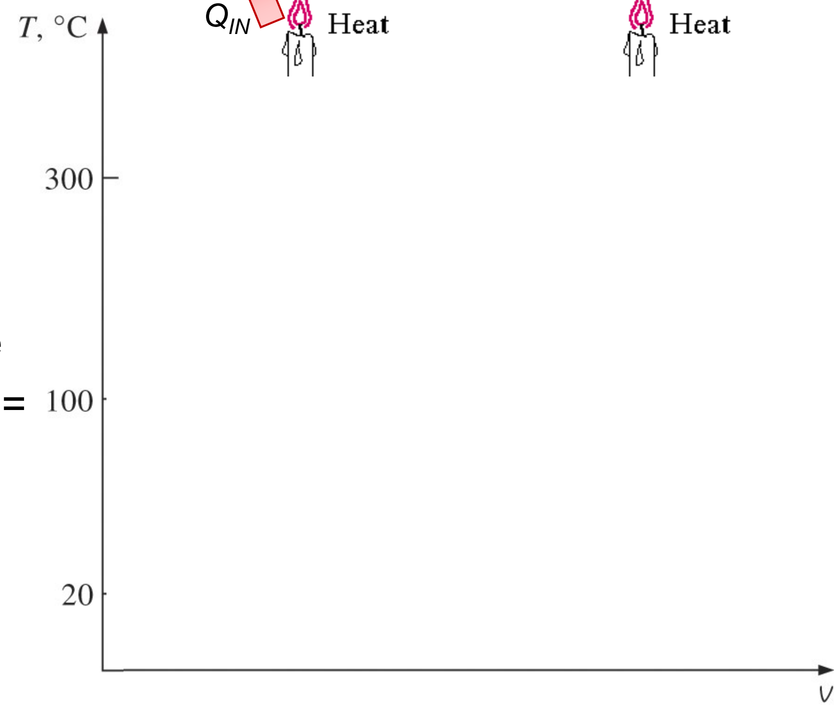


1.2.3 Phase Diagrams

- Consider heating experiment again, but now describe process on a temperature-specific volume diagram (*T-v*)



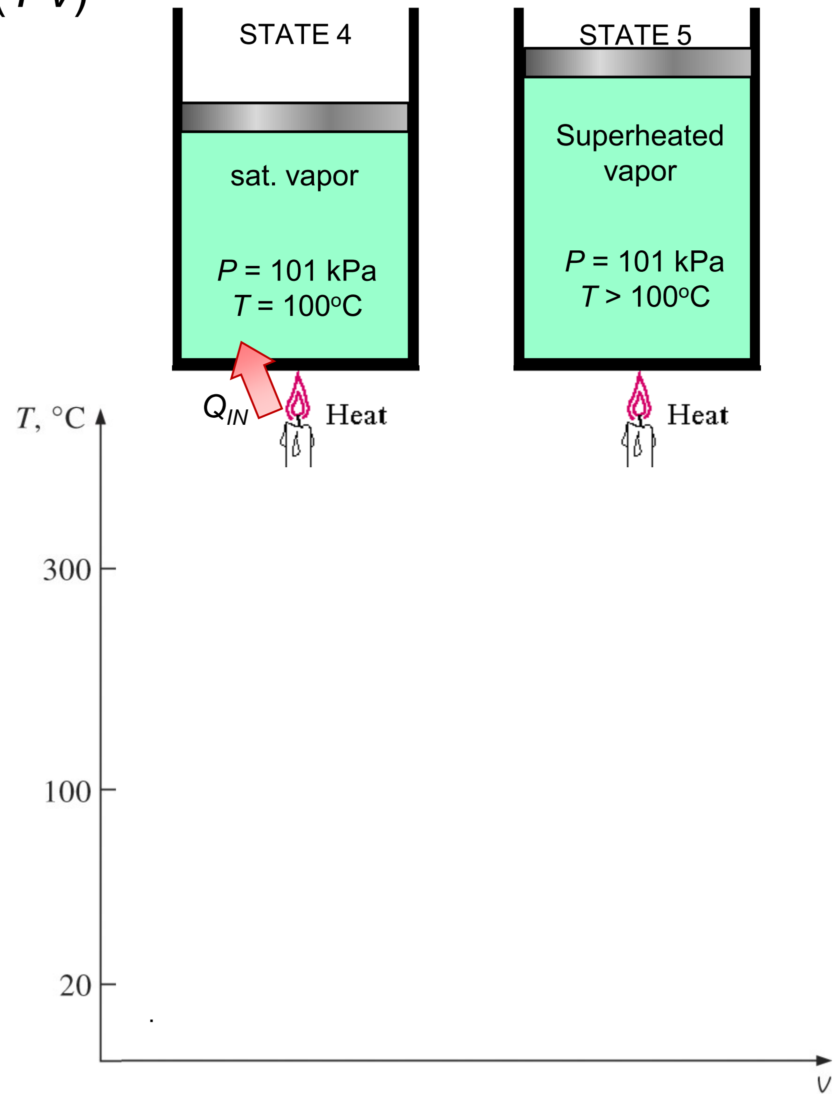
- <u>System</u>: water
- <u>State 3</u>: liq. + vap. mixture
- <u>Process 3-4</u>:
  - Constant pressure heat addition (Q_{IN})
  - T constant, v increases
  - Phase: sat. mixture → sat. vapor
- <u>State 4</u>: Saturated vapor
  - 100% vapor
  - Energy addition: vapor temp. increase
  - Energy reduction: liquid ↑, vapor ↓; (T = constant)



1.2.3 Phase Diagrams

- Consider heating experiment again, but now describe process on a temperature-specific volume diagram (*T*-*v*)

- System: water
- State 4: Saturated vapor
- Process 4-5:
  - Constant pressure heat addition (Q_{IN})
  - T increases, v increases
  - Phase: sat. vapor → s. heated vapor
- State 5: Superheated vapor
  - Above saturated temperature at 101kPa
  - Energy addition: vapor temp. increase
  - Energy reduction: vapor temp. decrease



1.2.4 P-v-T Surface

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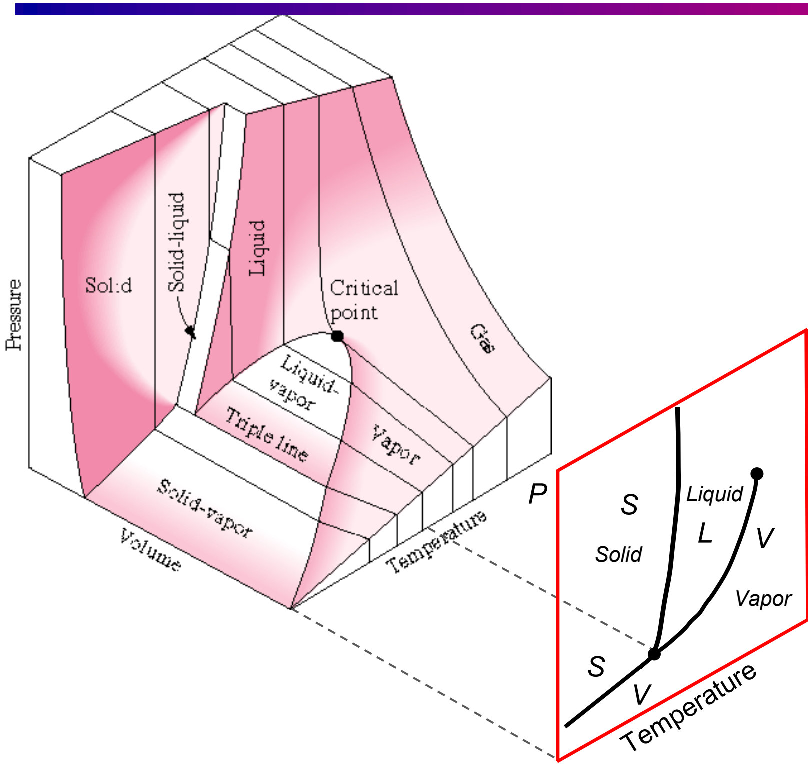
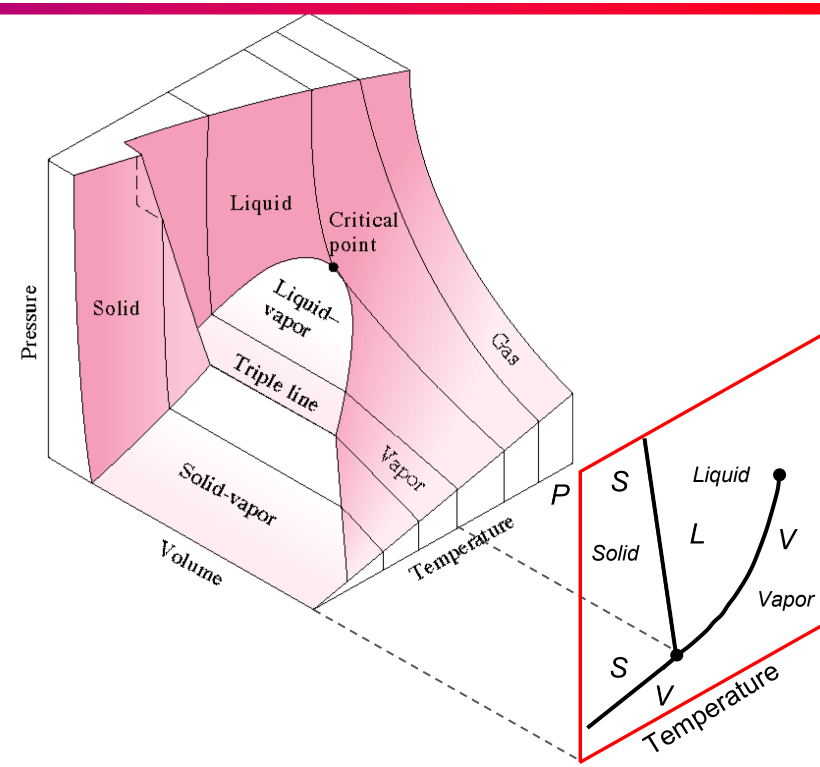


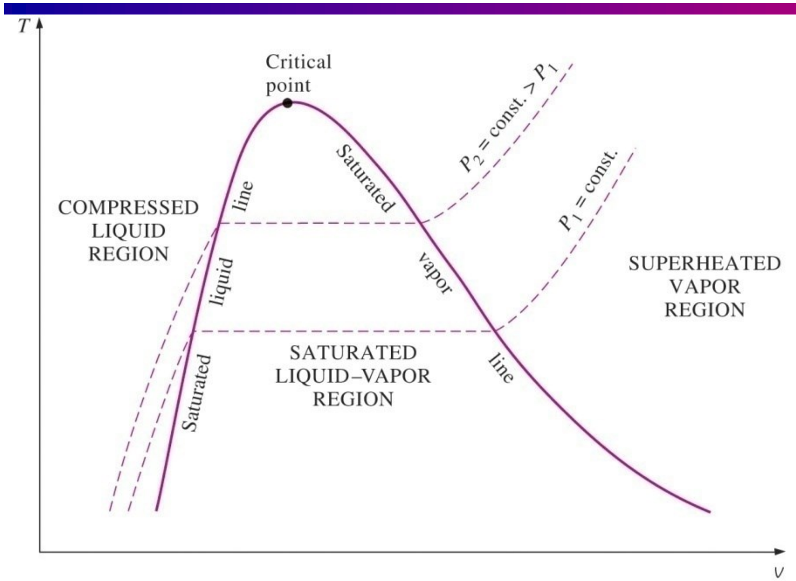
P-v-T Surface for a Substance
that <u>contracts</u> upon freezing

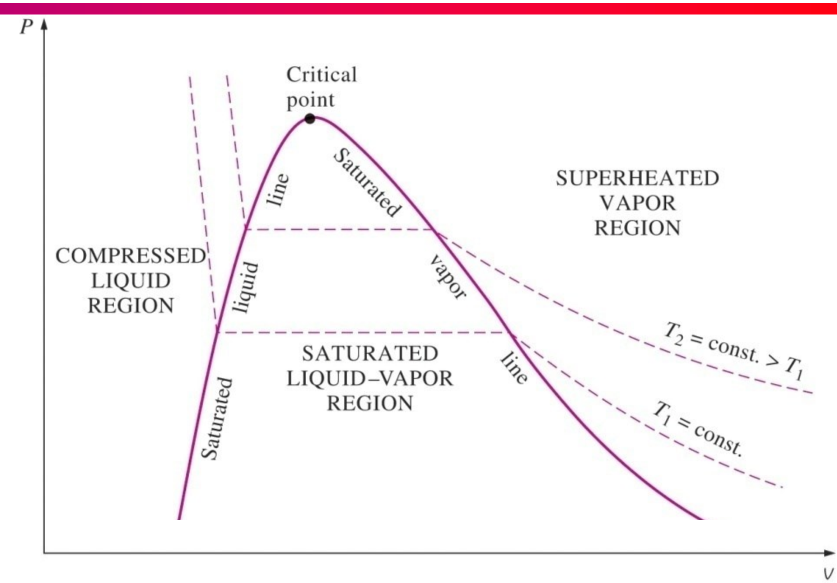


P-v-T Surface for a Substance
that <u>expands</u> upon freezing

- The P-v-T surfaces: relationship of thermodynamic states and phases for 2 independent variables.
- More convenient to work with 2-D diagrams, such as P-v and T-v diagrams.

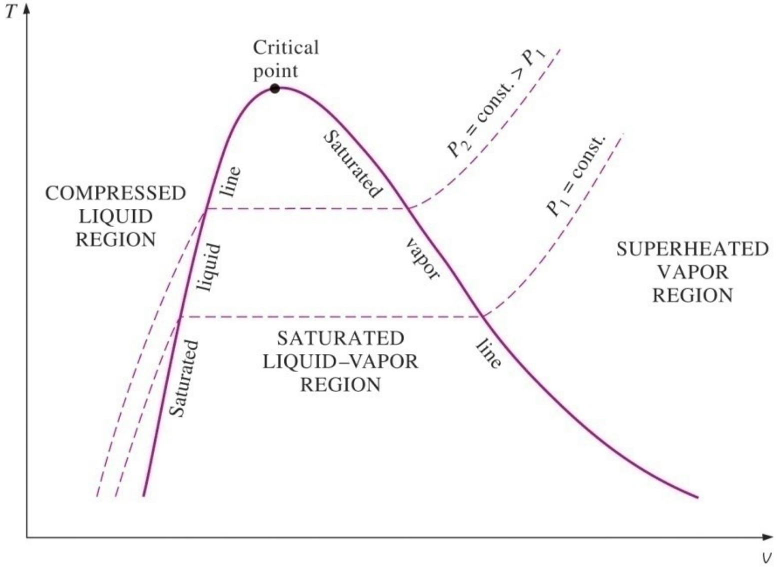
1.2.4.1 T-v & P-v Diagrams

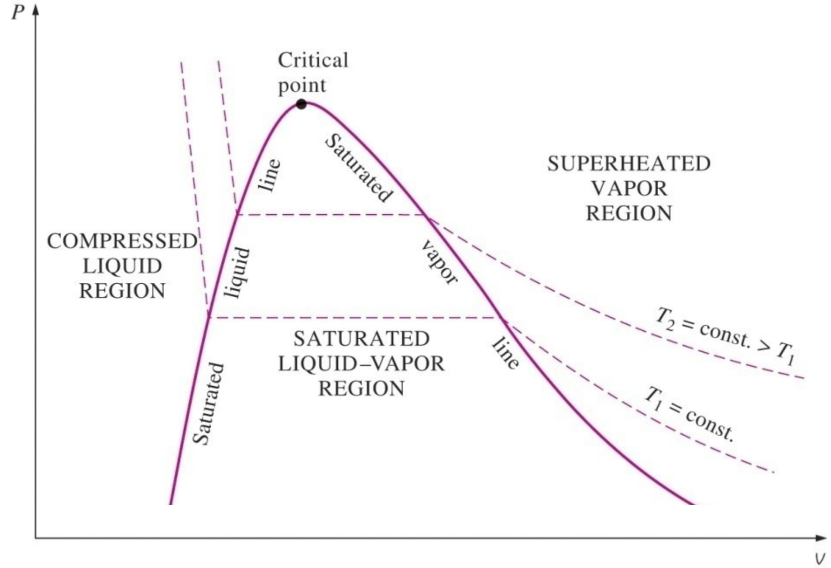




- Identify state & phase
- Phases of interest
  - (1) Compressed liquid, (2) Saturated Liq.-Vap. Mixture, (3) Superheated vapor
- Liquid-vapor "Dome"
  - Line separating these phases
- Lines of constant *P, T*
  - *P* lines: upward slope in *T-v.* Lines shifts upwards as *P* increases
  - *T* lines: downward slope in *P-v.* Lines shifts upwards as *T* increases
  - *P, T* lines are straight in vapor dome

1.2.4.1 T-v & P-v Diagrams





- Compressed Liquid
  - Any point LEFT of Saturated Liquid Line
- Saturated Liquid
  - Any point ON the Saturated Liquid Line
- Saturated Liquid-Vapor Mixture
  - Any point WITHIN Liq.-Vap. “Dome”
- Saturated Vapor
  - Any point ON the Saturated Vapor Line
- Superheated Vapor
  - Any point RIGHT of Saturated Vapor Line

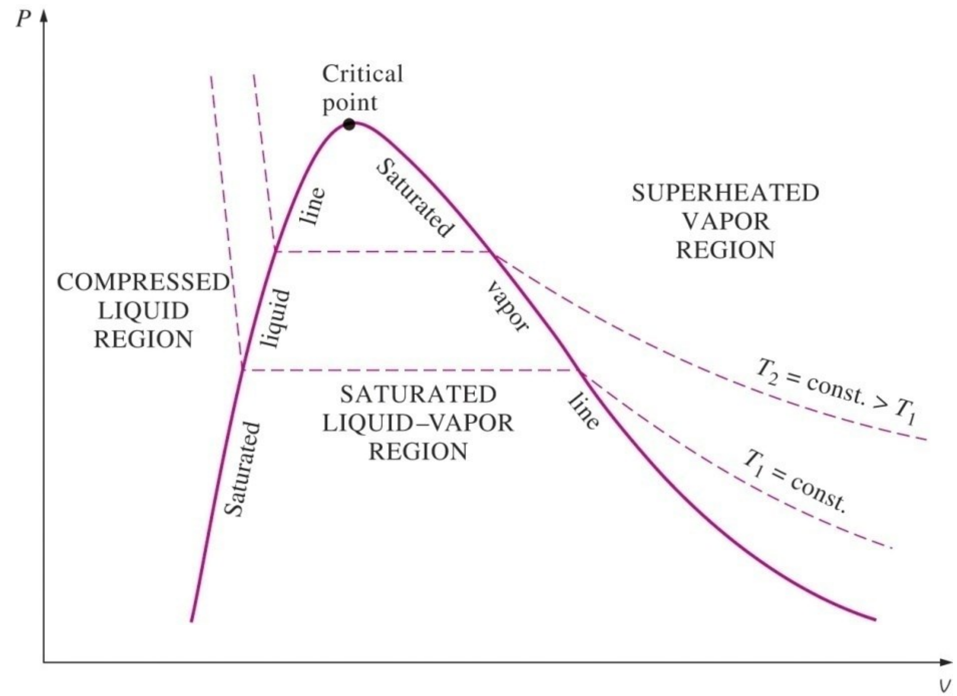
1.2.4.1 Exercises: *P-v-T* Diagrams

Exercise 1-1: P-*v* Diagram

Plot the following processes on a *P-v* diagram for water

<u>Process 1-2-3-4-1:</u>

- 1→2: Specific volume (*v*) increase from saturated liquid to saturated vapor under constant press.
- 2→3: Press. decrease to saturated liquid-vapor mixture under constant *v.*
- 3→4: *v* decrease to saturated liquid under constant press.
- 4→1: P & *v* increase as saturated liquid back to pt. 1.



<u>Process A-B-C-D:</u>

- A→B: *v* increase from compressed liquid to saturated vapor under constant temp.
- B→C: Press. decrease to saturated liq.-vap. Mixture under constant *v*.
- C→D: Press. decrease to superheated vapor under constant temp.

<u>Extra:</u>

- Starting pts can be anywhere in specified area
- 1→2 & 3→4: “constant temperature”
- pt 3: anywhere below pt 2 in ‘Dome’
- A→B: “pressure decreases”
- pt C: anywhere below pt B in ‘Dome’
- C→D: “volume increases”

1.2.4.1 Exercises: *P-v-T* Diagrams

Exercise 1-2: *T-v* Diagram

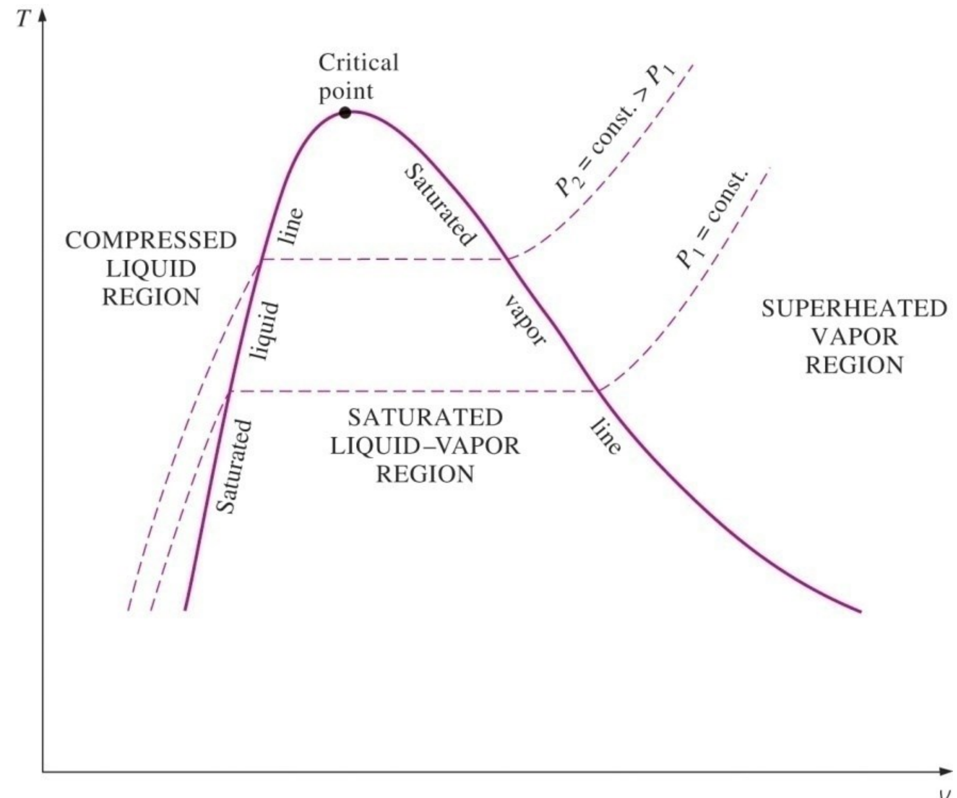
Plot the following processes on a *T-v* diagram for water

Process 1-2-3-4:

- 1→2: Temp. decrease from superheated vapor to saturated liquid-vapor mixture under constant press.
- 2→3: Temp. decrease to saturated liquid-vapor mixture under constant *v.*
- 3→4: Temperature decrease to compressed liquid under constant press.

Process A-B-C-D:

- A→B: Temp. increase from compressed liquid to superheated vapor under constant press.
- B→C: Temp. decrease to saturated vapor under constant specific volume (*v*).
- C→D: Energy decrease to saturated liquid under constant press.

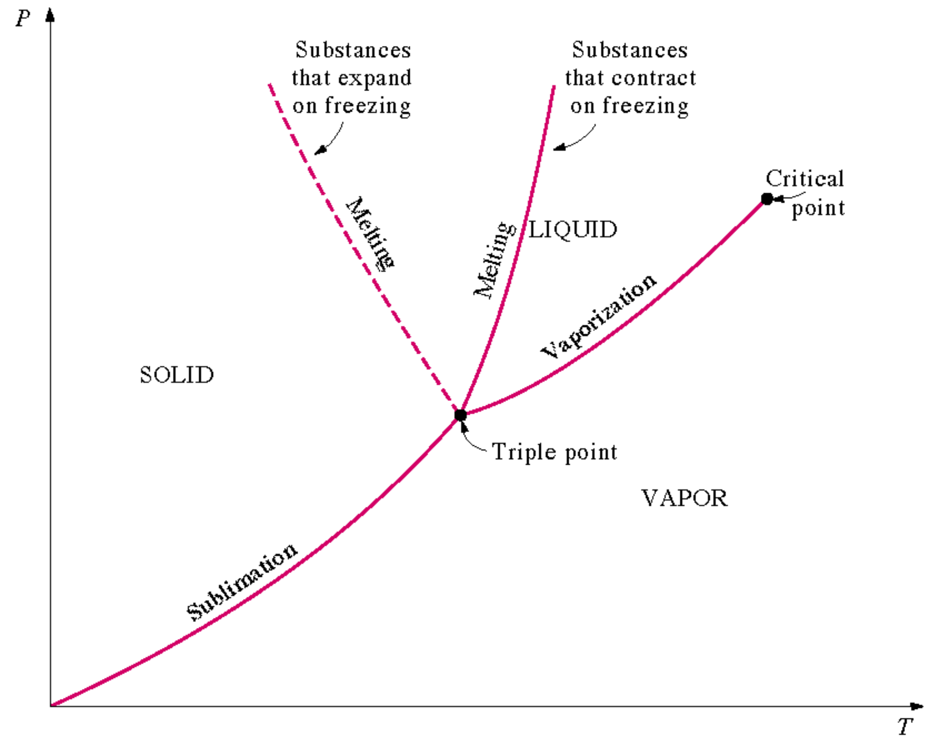


- Starting points: anywhere in designated area
- Read all processes to help you trace the "entire process"
- Some starting locations are more optimal than others

1.2.4.1 Exercises: *P-v-T* Diagrams

Exercise 1-3: *P-T* Diagram

Plot the following processes on a *P-T* diagram for water



Process 1-2-3

- 1→2: Temp. decrease from saturated vapor to a solid under constant press.
- 2→3: Press. decrease from solid to a vapor under constant temp.

Process A-B-C-D (substance that contracts on freezing)

- A→B: Press. increase from triple point to a solid under constant temp.
- B→C: Temp. increase to saturated liquid under constant press.
- C→D: Press. Decrease to saturated vapor under constant temp.

- You can locate starting points anywhere in designated area
- Be sure to read all processes to help you trace the “entire process”
- Some starting locations are more optimal than others