# Lecture 7 – Property charts

Purdue ME 200, Thermodynamics I

Kevin J. Kircher, kircher@purdue.edu

# Outline

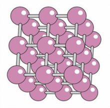
The state principle

Visualizing a surface $z = f(x, y)$

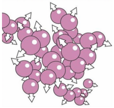
Property charts for pure simple compressible systems

# Solids, liquids and gases

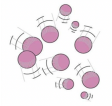
- in **solids**, particles (molecules/atoms) vibrate in fixed positions



- in **liquids**, particles flow around each other



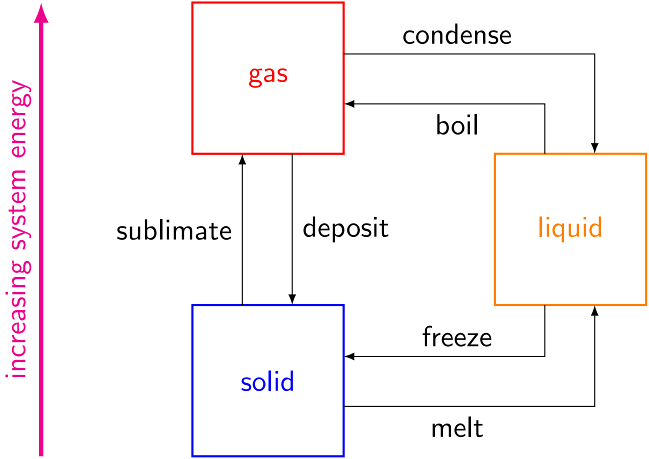
- in **gases** (aka **vapors**), particles zoom around, far apart



# Phases

- a **phase** is
  - a quantity of matter
  - with homogeneous structure (all solid, all liquid, or all gas)
  - and homogeneous composition (same compounds throughout)
- a system can contain multiple phases
- two substances that mix can form a single phase (nitrogen gas + oxygen gas = 1 phase)
- substances that don't mix form multiple phases (liquid water + liquid oil = 2 phases)

# Phase changes



# Pure substances

- a **pure** substance has fixed, uniform composition
- a pure substance can have multiple phases
  (liquid water + water vapor = pure)
- a pure substance can have multiple compounds
  (air $\approx$ nitrogen gas + oxygen gas = pure)
- but its composition can't change over time
  (humid air stops being pure when its water vapor condenses)

# Simple compressible systems

- **simple** systems have only one type of work interaction
- for **simple compressible** systems, that's boundary work,

$$W = \int_{V_1}^{V_2} p \mathrm{d}V$$

# The state principle

- why do we care about simple compressible systems?
  - ◇ they include a bunch of practically interesting systems
  - ◇ it only takes two properties to define their equilibrium states (specifically, any two independent, intensive properties)

↗ this is the **state principle** for simple compressible systems ↖

- it makes it easier to specify input data for thermo problems

⋆ the state principle assumes no center-of-mass motion
  - ◇ no ΔKE (otherwise we'd need to specify CoM velocity)
  - ◇ no ΔPE (otherwise we'd need to specify CoM elevation)

# Implications of the state principle

- in equilibrium, all properties can be inferred from the state
- so for simple compressible systems in equilibrium,
  - ◇ any two independent, intensive properties known

  $\Longrightarrow$ **all** properties known
- e.g. for an ideal gas, any two of $(p, v, T)$ determine the third

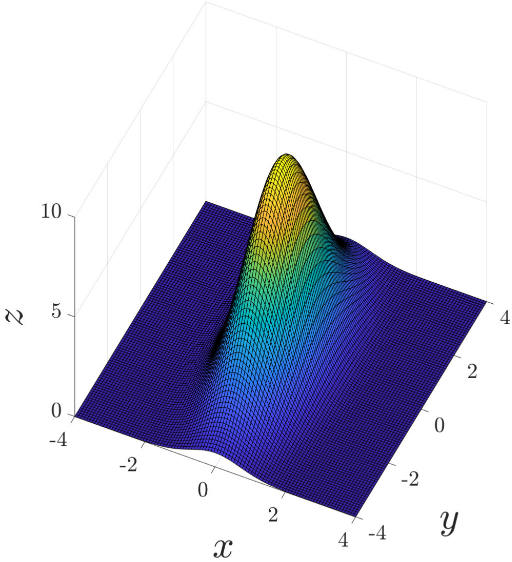
# Outline

The state principle

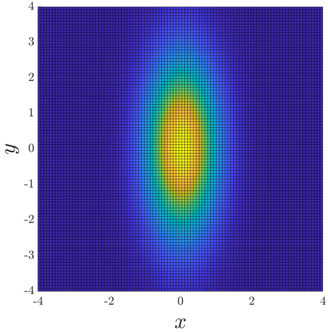
Visualizing a surface $z = f(x, y)$

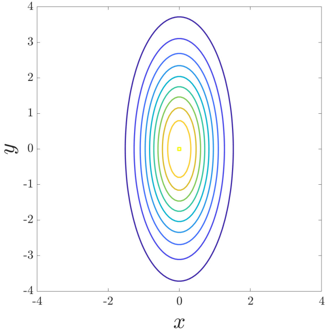
Property charts for pure simple compressible systems

# Three-dimensional surface plot

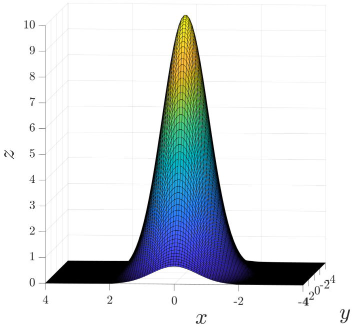


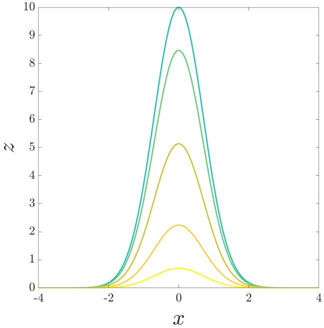
# Projection onto $x$-$y$ plane



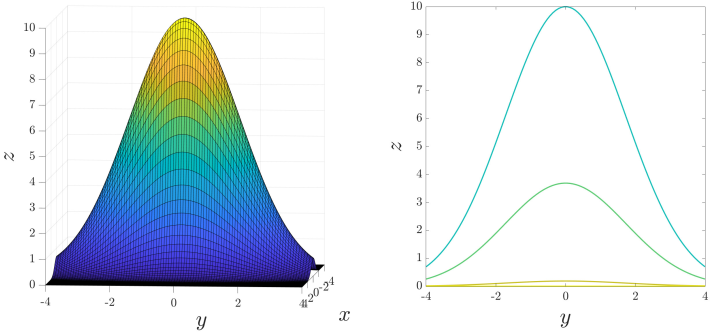



# Projection onto $x$-$z$ plane



# Projection onto $y$-$z$ plane



# Outline

The state principle

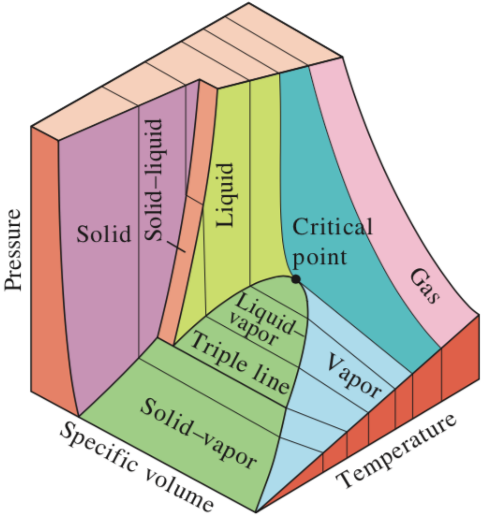
Visualizing a surface $z = f(x, y)$

Property charts for pure simple compressible systems

# The $p$-$v$-$T$ surface

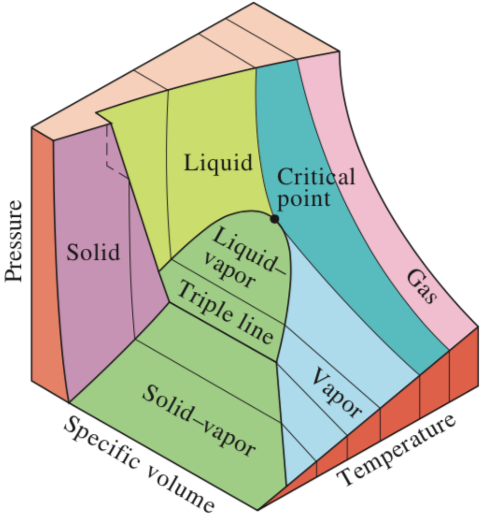
- for pure simple compressible systems, we can treat
  - ◇ $v$ and $T$ as independent variables (like $x$ and $y$)
  - ◇ $p$ as a function of $v$ and $T$ (like $z = f(x, y)$)
- the $p$-$v$-$T$ surface displays all equilibrium states
- a substance in equilibrium can't leave its $p$-$v$-$T$ surface
- $p$-$v$-$T$ surfaces look different for different substances

# The $p$-$v$-$T$ surface in three dimensions



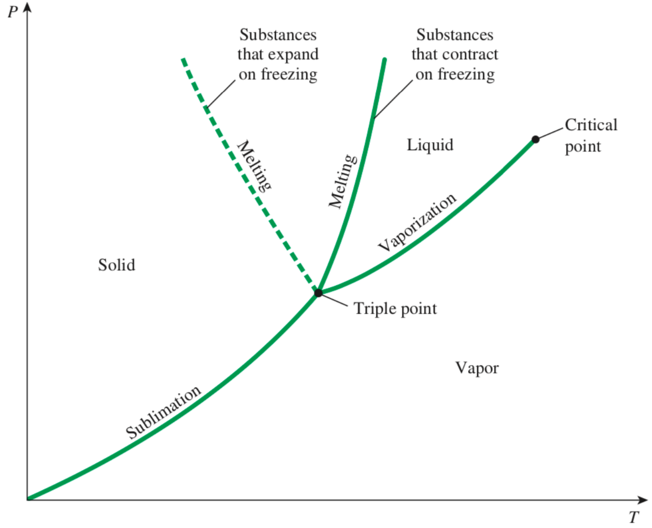

Cengel and Boles, *Thermodynamics: An Engineering Approach* (2019)

# The $p$-$v$-$T$ surface in three dimensions (continued)



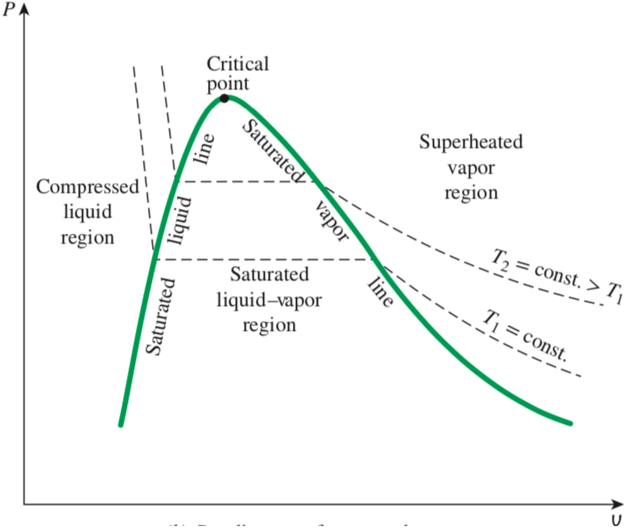

Cengel and Boles, *Thermodynamics: An Engineering Approach* (2019)

# Projection onto the $p$-$T$ plane (phase diagram)



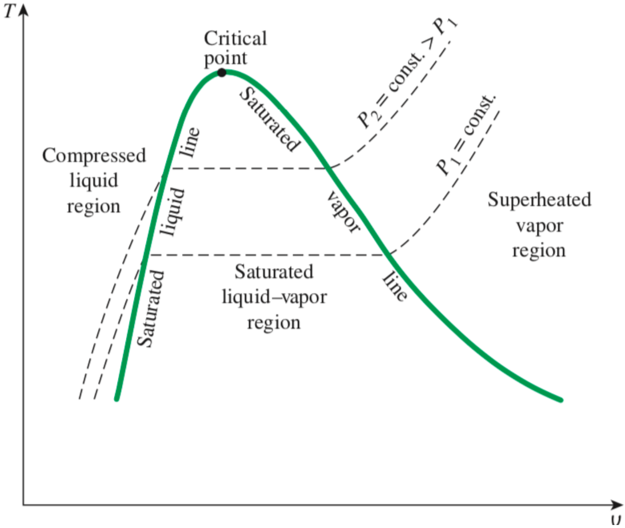

Cengel and Boles, *Thermodynamics: An Engineering Approach* (2019)

# Projection onto the $p$-$v$ plane ($p$-$v$ diagram)




Cengel and Boles, *Thermodynamics: An Engineering Approach* (2019)

# Projection onto the $T$-$v$ plane ($T$-$v$ diagram)




Cengel and Boles, *Thermodynamics: An Engineering Approach* (2019)