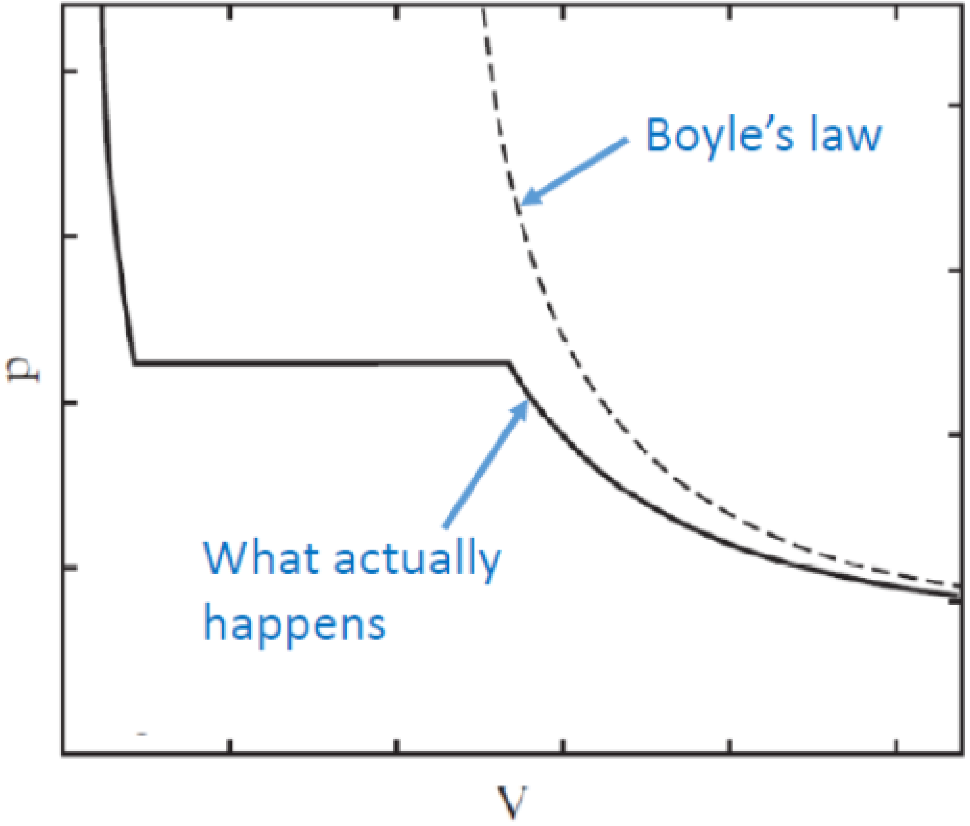
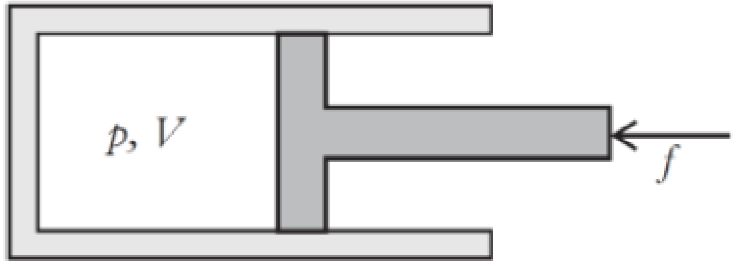
Thermodynamics lecture 12. Phase change

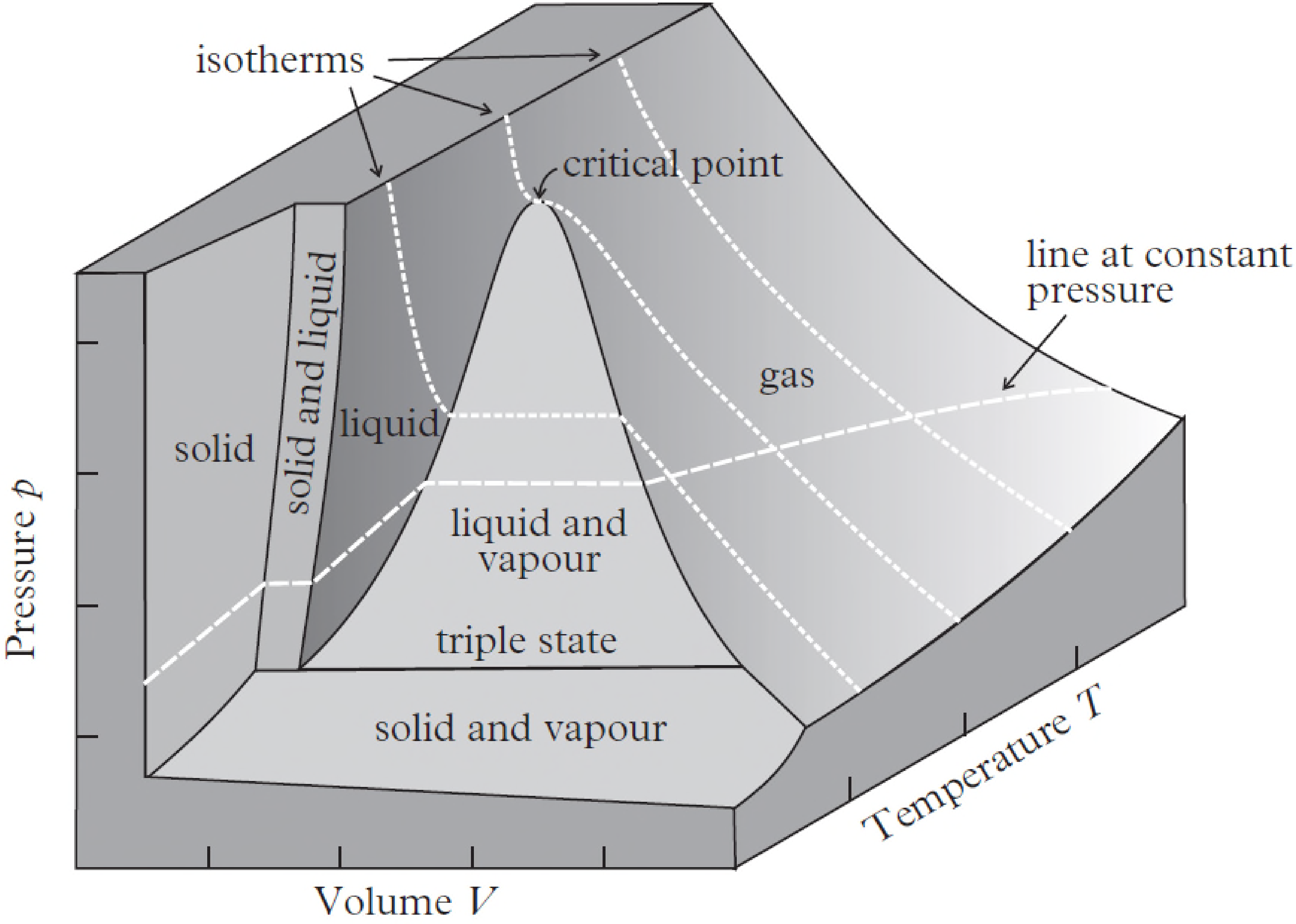
1. Phase change terminology
2. Basic properties of first-order phase transition
3. Clausius-Clapeyron equation
4. Van der Waals treatment and Maxwell construction (off syllabus)

Compressing an ordinary substance

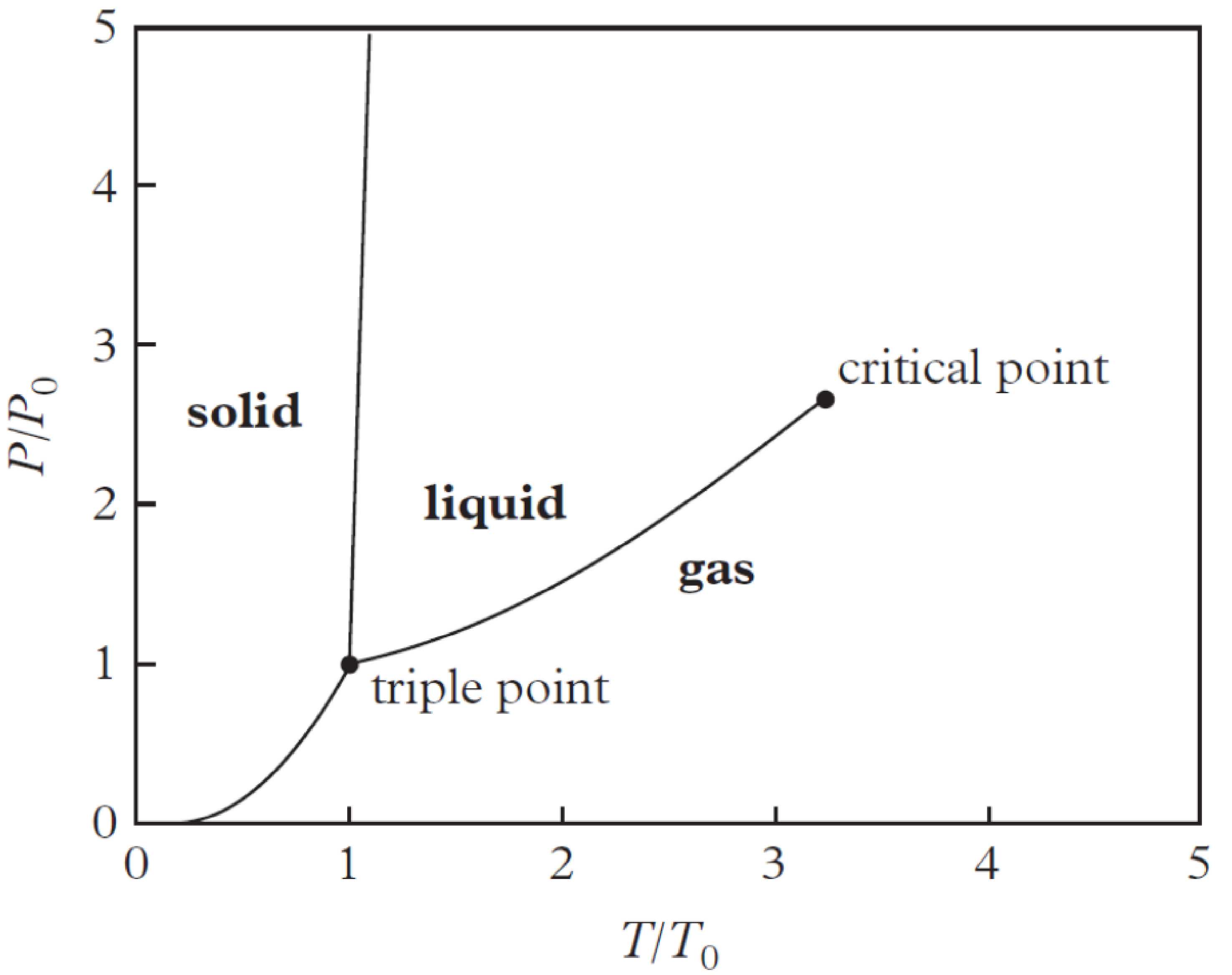




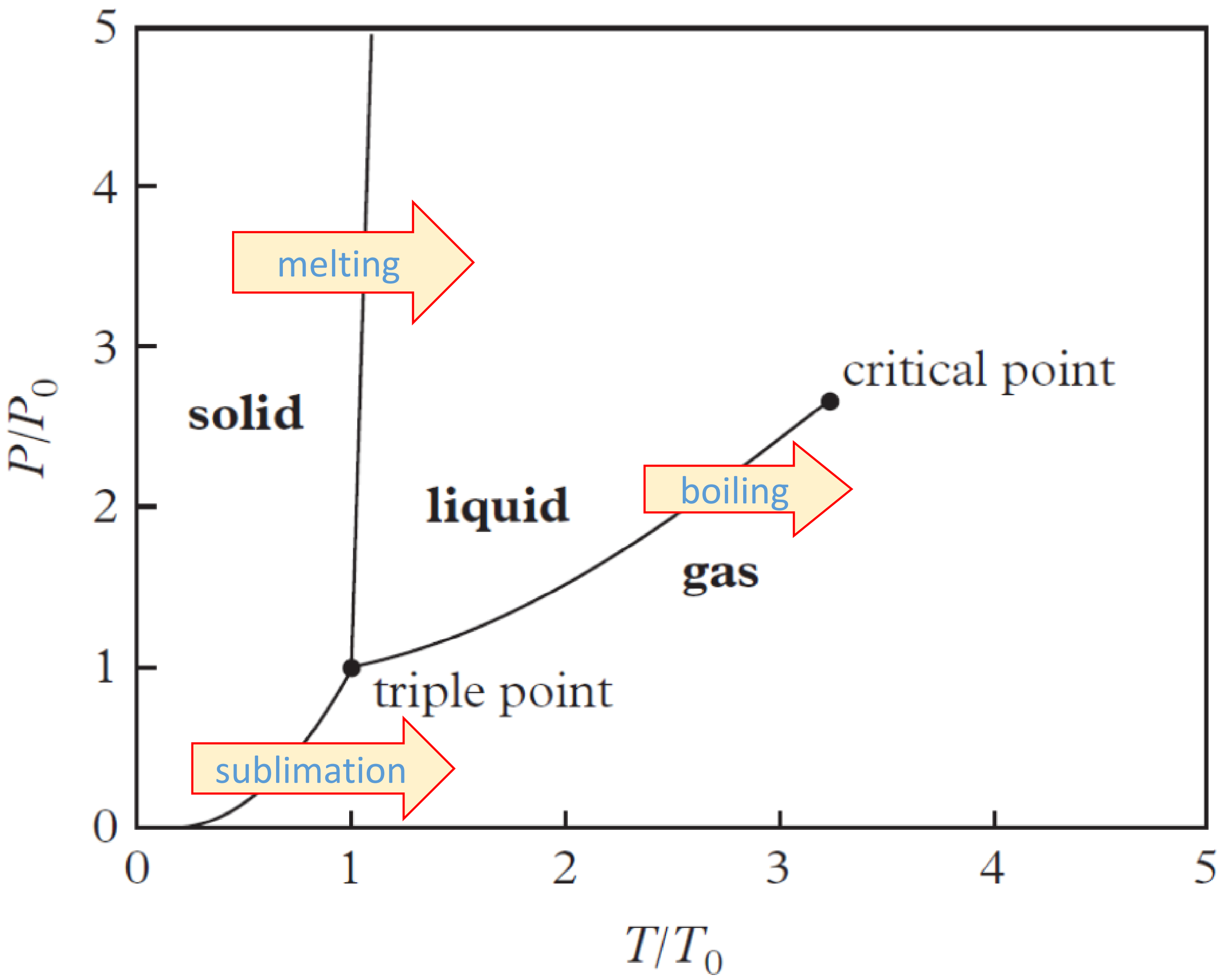
pVT surface of an ordinary substance



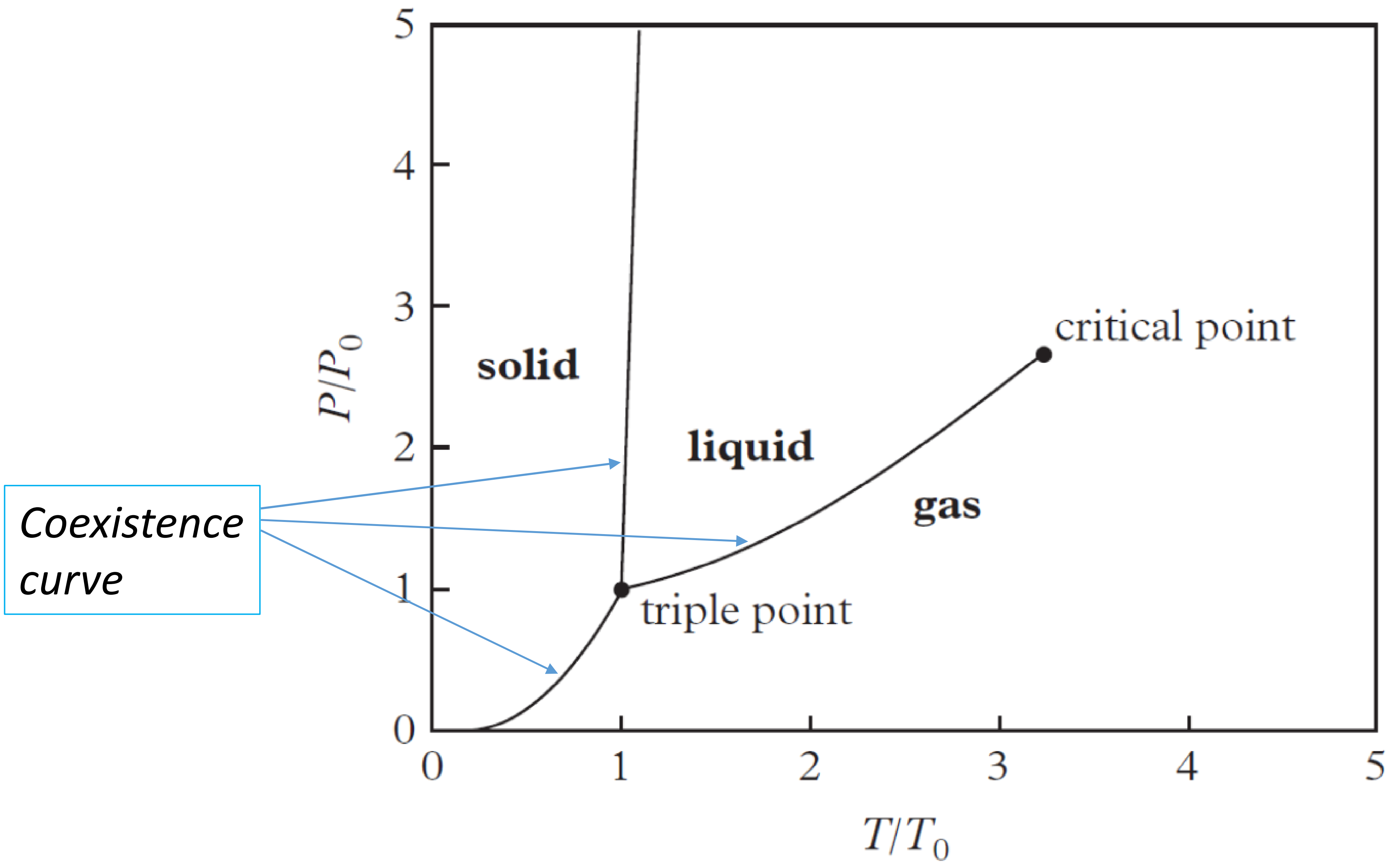
Phase diagram



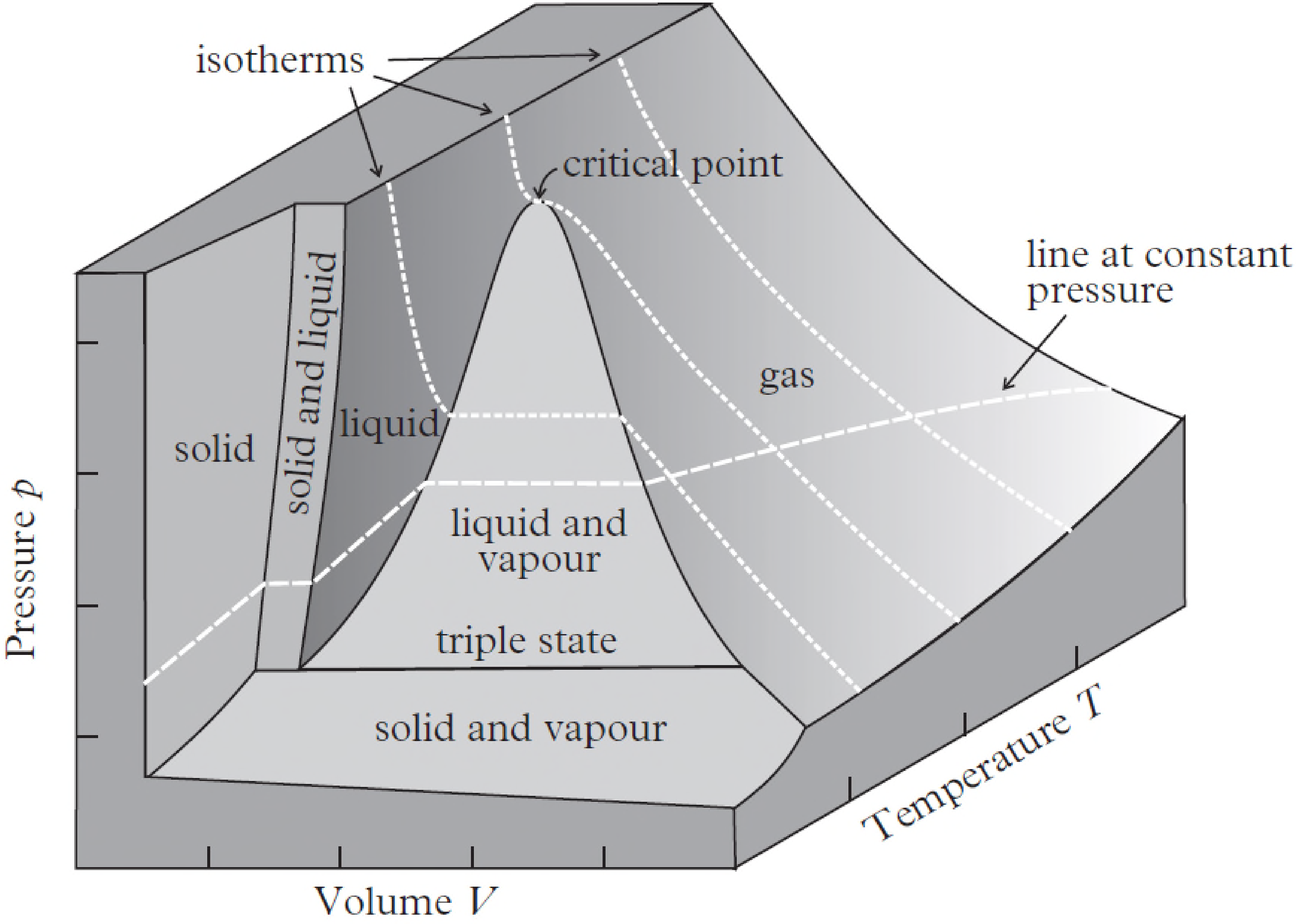
Phase diagram



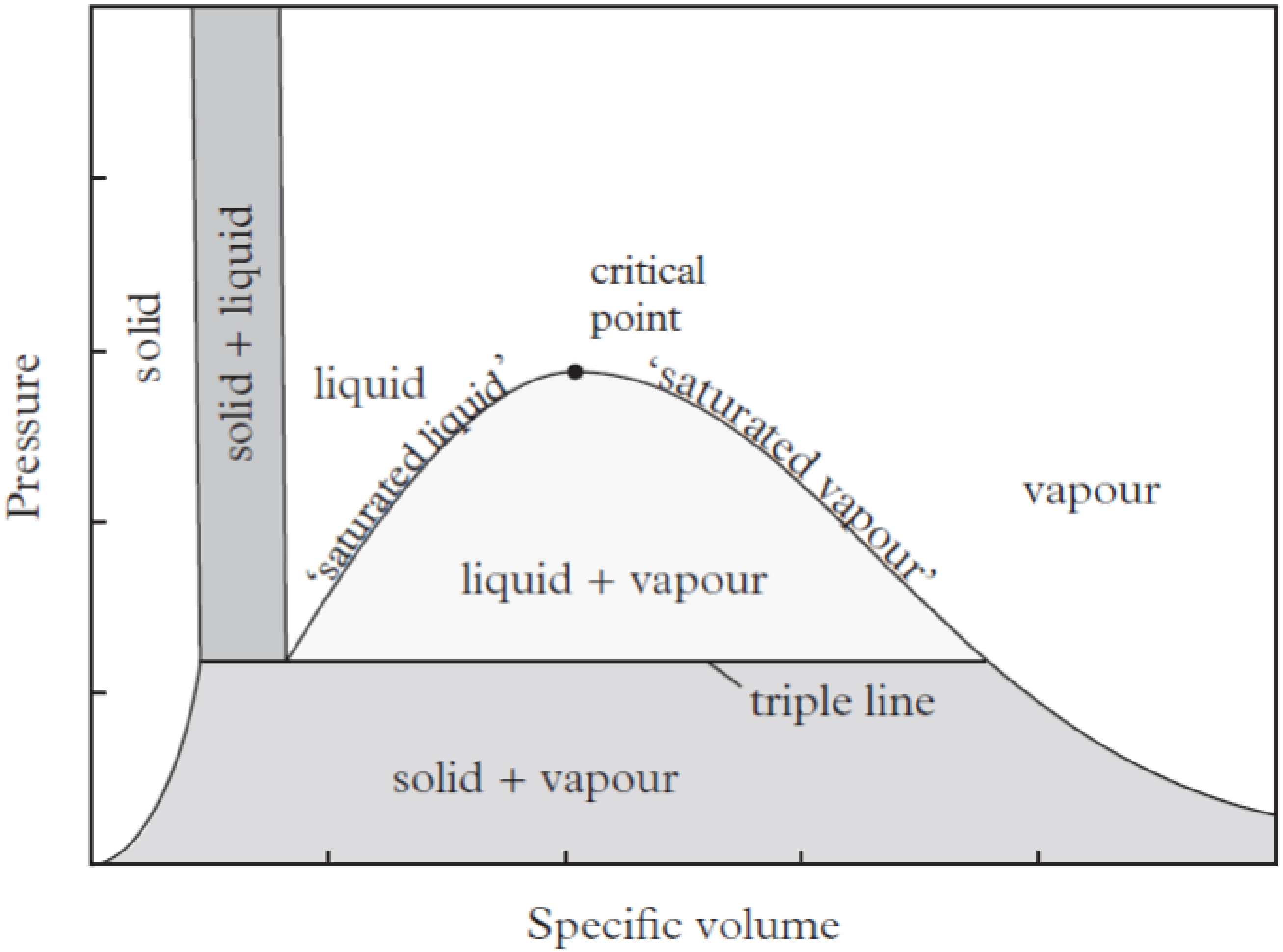
Phase diagram



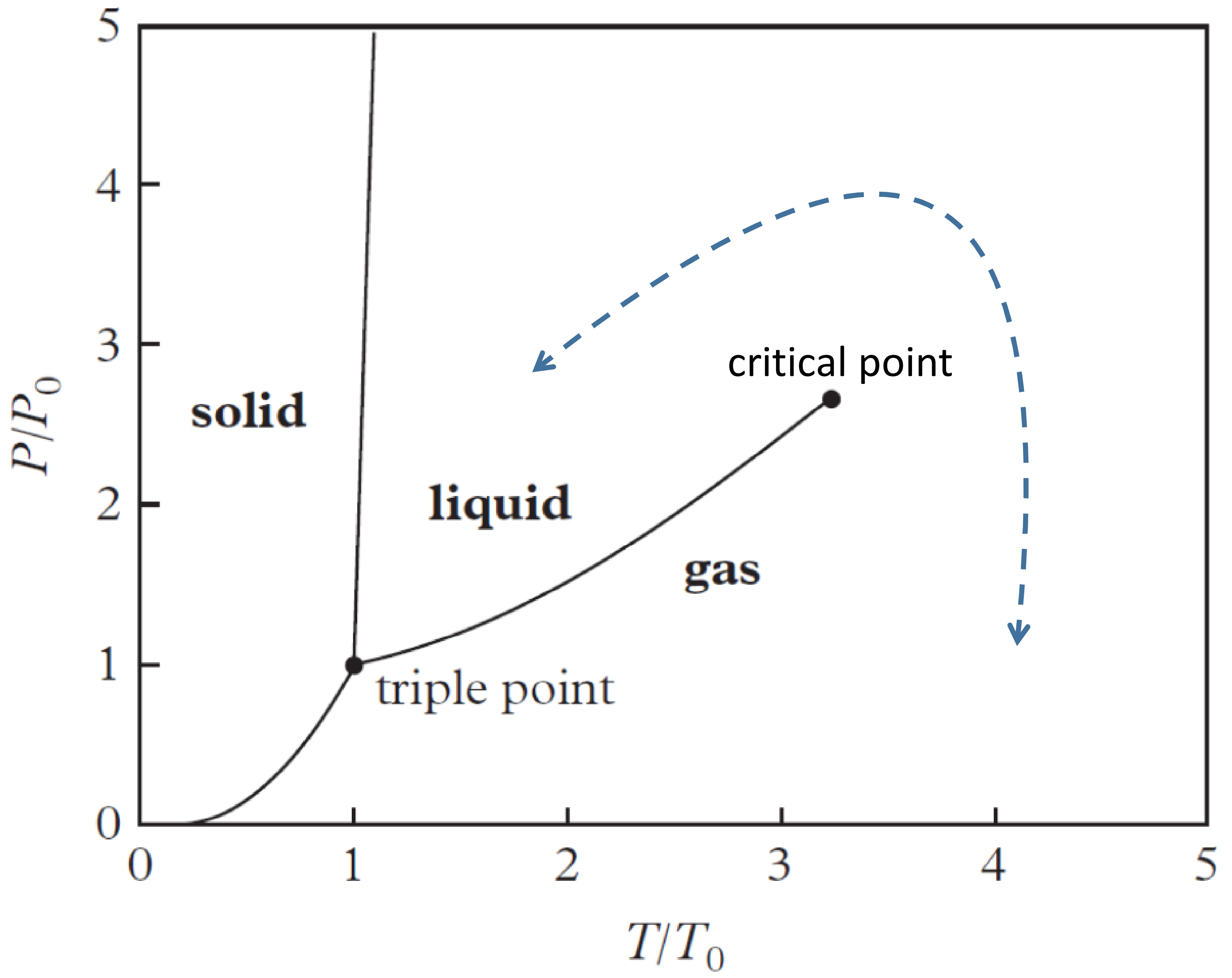
pVT surface of an ordinary substance



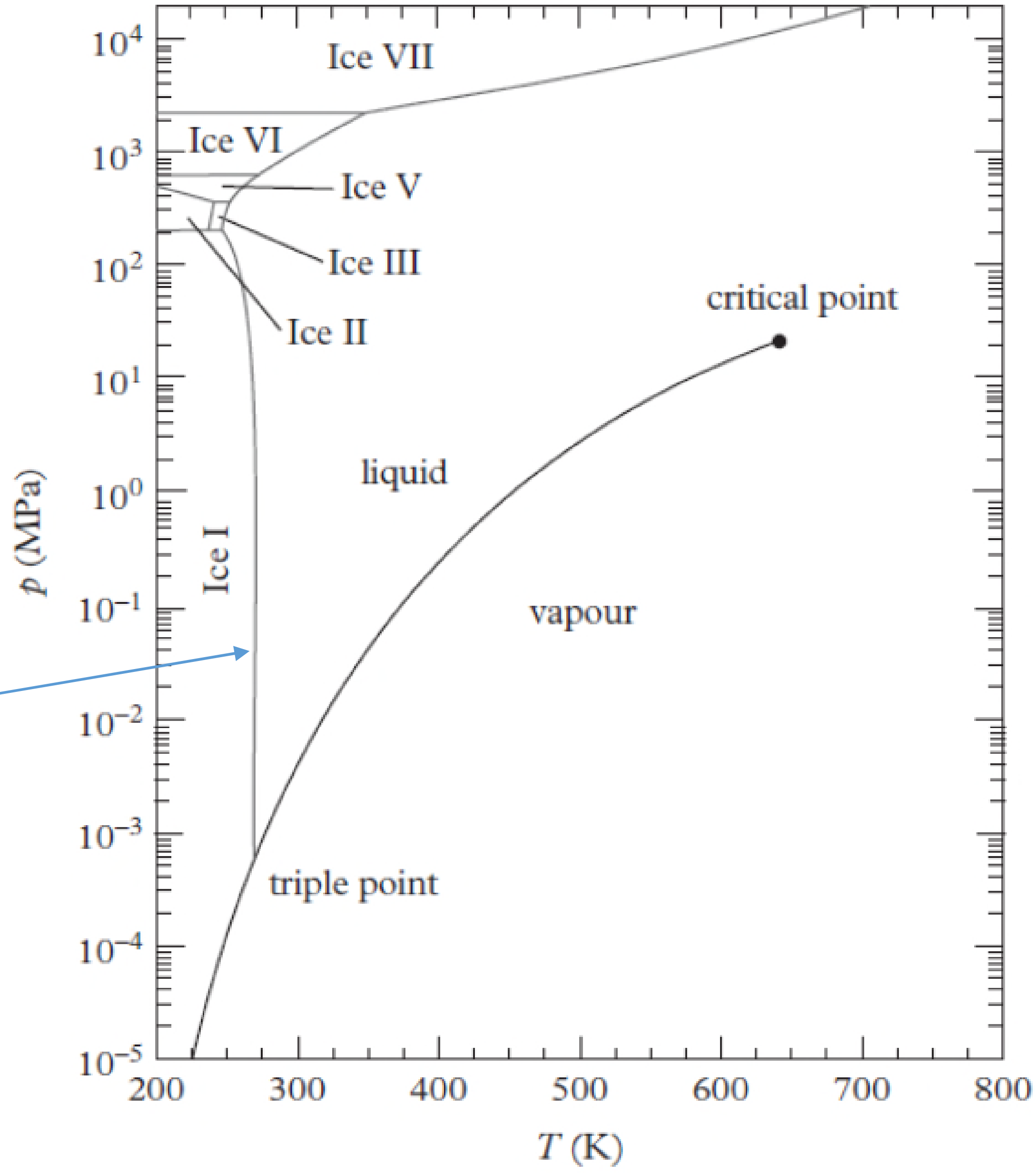
A vapour which would begin to condense if the temperature were lowered is called "**saturated**".
(similarly a pure liquid which would begin to boil if the temperature were raised may be called a "saturated liquid" but this second terminology is less widely used.)



A system can pass between **liquid and gas** without any phase transition!



Phase diagram for water ($H_2 0$)



Unusual case: the slope of the melting line is negative (if you squeeze ice then it may melt)

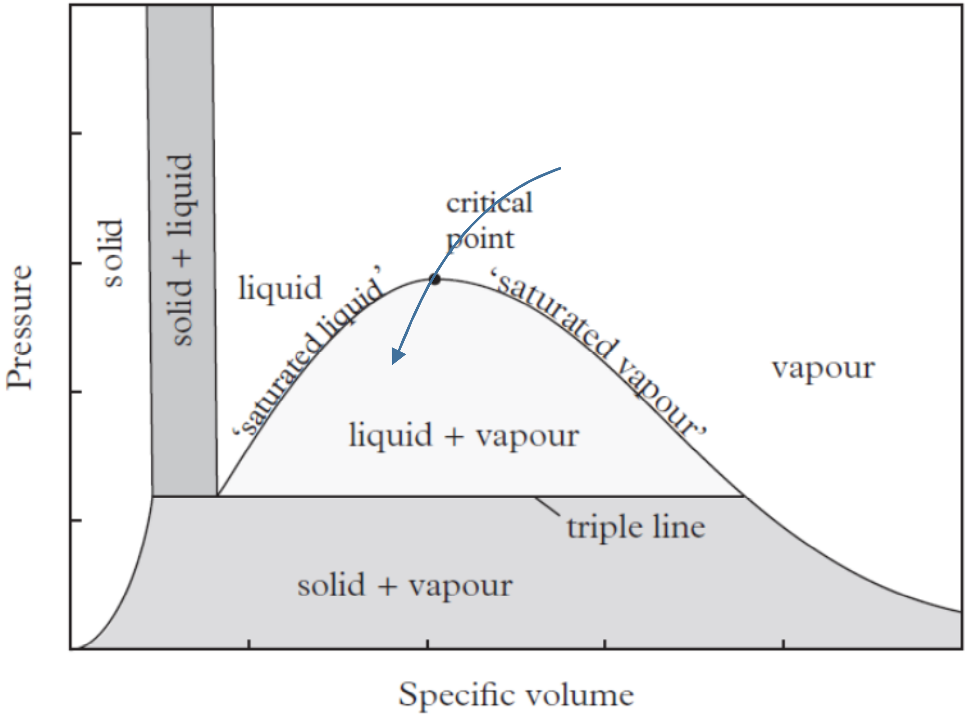
Different types of phase transition

1. ***First order*** phase transition
    - there is a discontinuity in various properties
    - there are metastable phases (superheating and supercooling)
    - in almost all cases there is a discontinuity in S(T) and therefore a latent heat

    - Examples: liquid-vapour; solid-liquid; solid-vapour; superconductivity in presence of applied B field; ferromagnetism; some solid-solid (allotrope) transitions

2. ***Continuous*** phase transition
    - S(T) is continuous but some derivative is not (e.g. continuous S but discontinuity in Cp)
    - no metastable phases and no latent heat

    - Examples: liquid-vapour via the critical point; superconductivity at B=0; many order-disorder transitions in solids; Bose-Einstein condensation

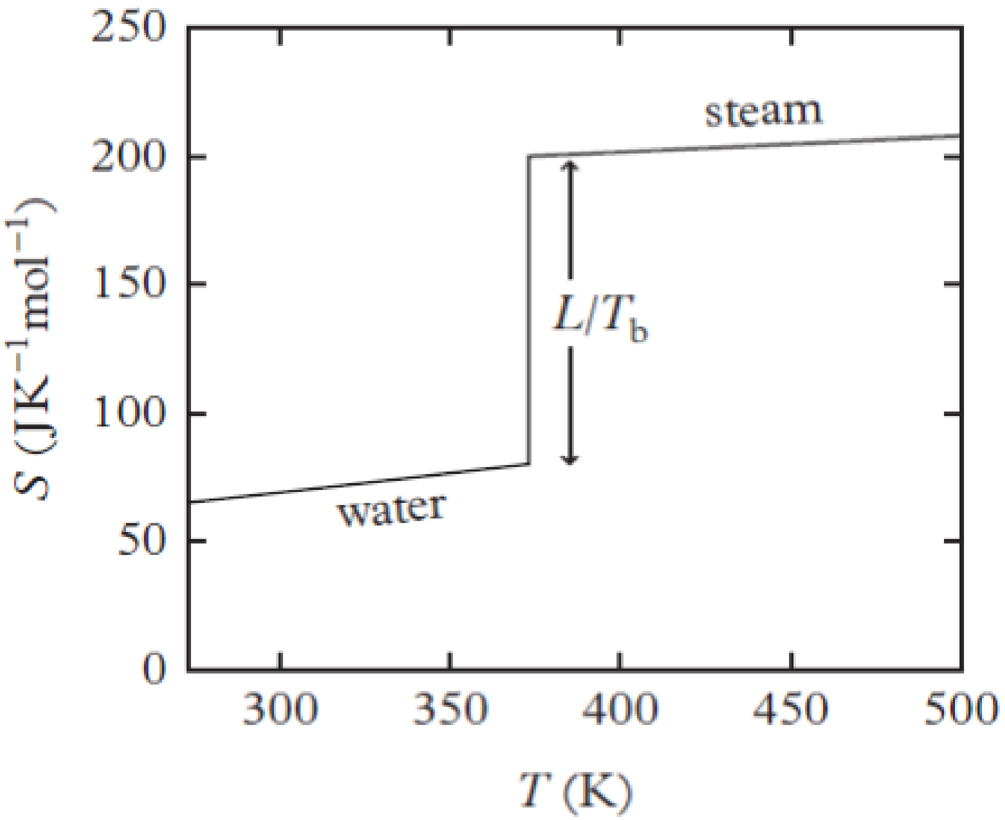


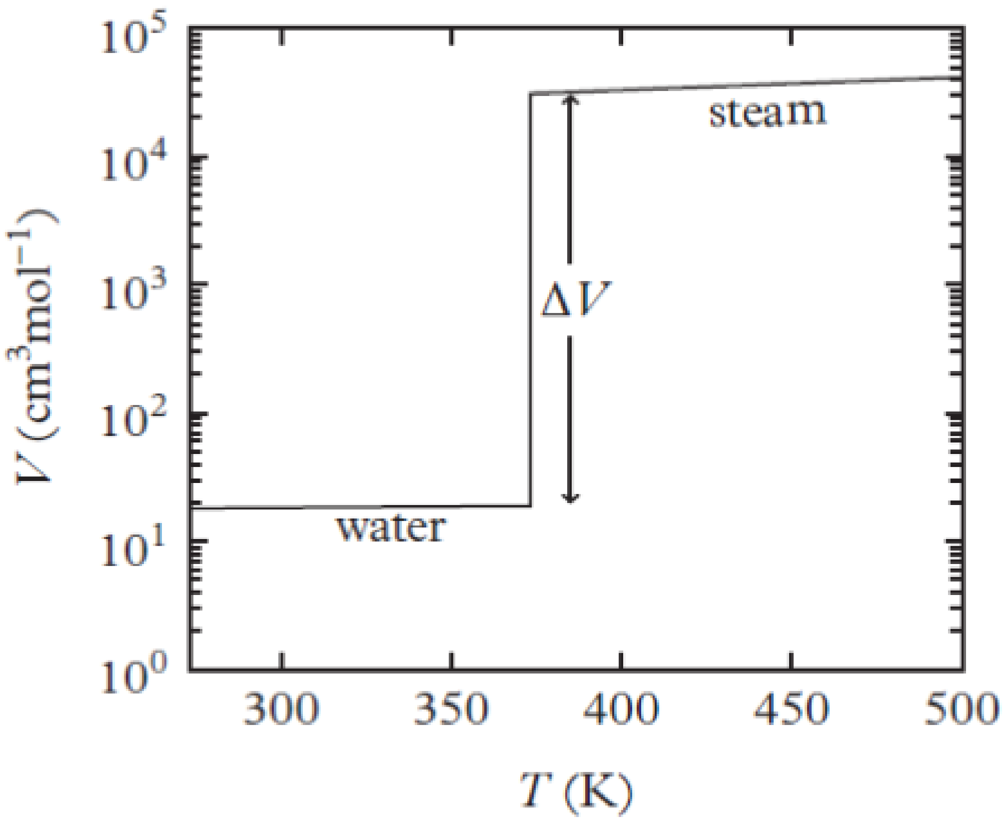
Thermodynamics lecture 12. # Phase change

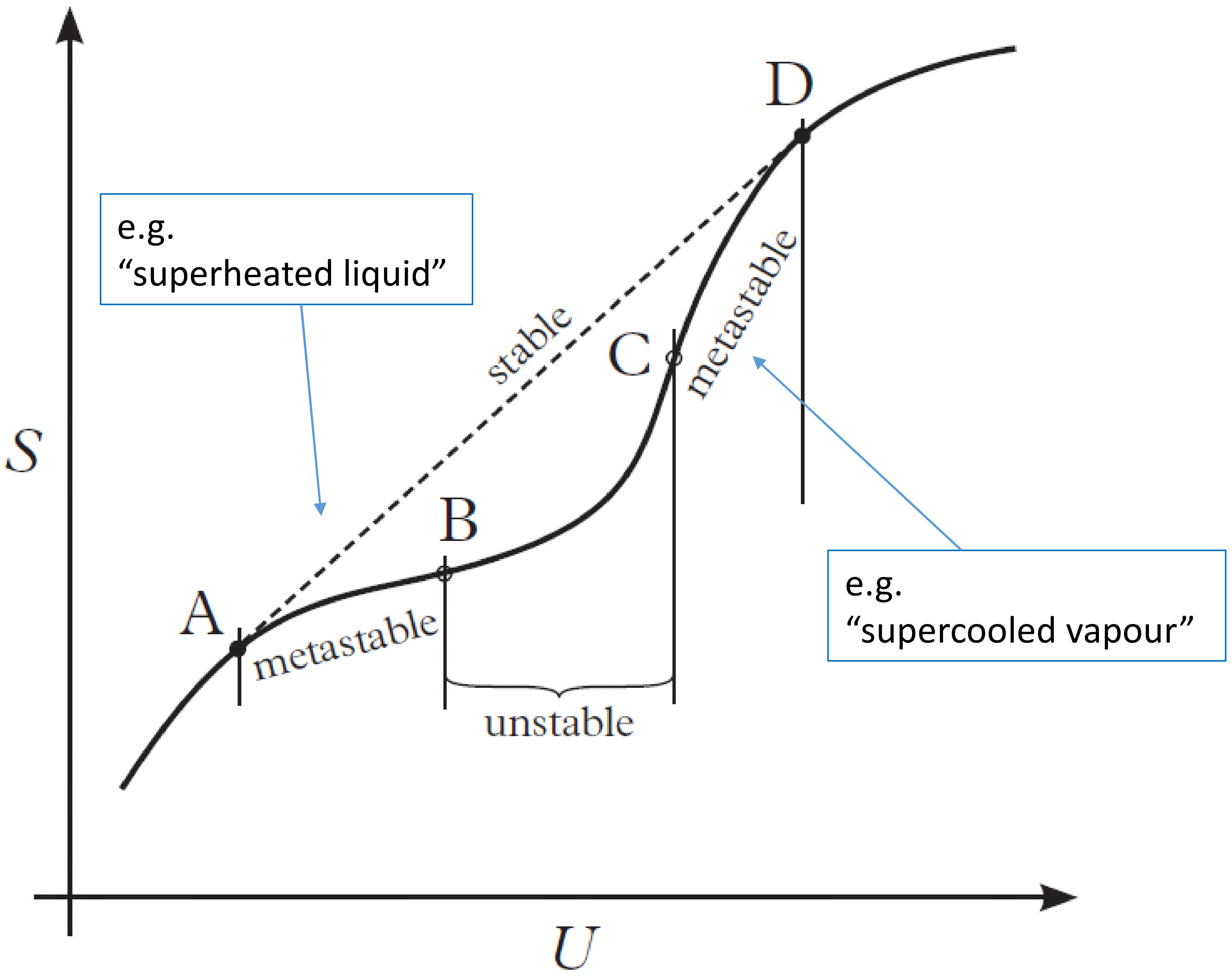
1. Phase change terminology
2. Basic properties of first-order phase transition
3. Clausius-Clapeyron equation
4. Van der Waals treatment and Maxwell construction (off syllabus)
5. (If time: some observations on chemical potential)

Entropy and volume changes for water (H_2O)

Note large volume change (x 1000)





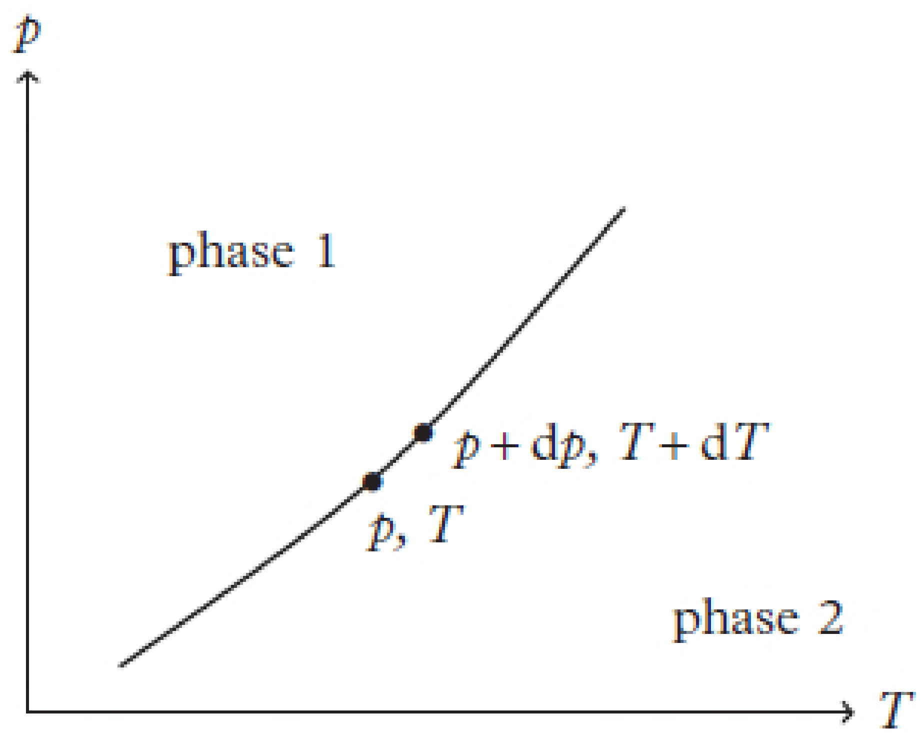


e.g.
"superheated liquid"
e.g.
"supercooled vapour"
S
U
A
B
C
D
stable
metastable
metastable
unstable

Thermodynamics lecture 12. **Phase change**

1. Phase change terminology
2. Basic properties of first-order phase transition
3. Clausius-Clapeyron equation
4. Van der Waals treatment and Maxwell construction (off syllabus)
5. (If time: some observations on chemical potential)

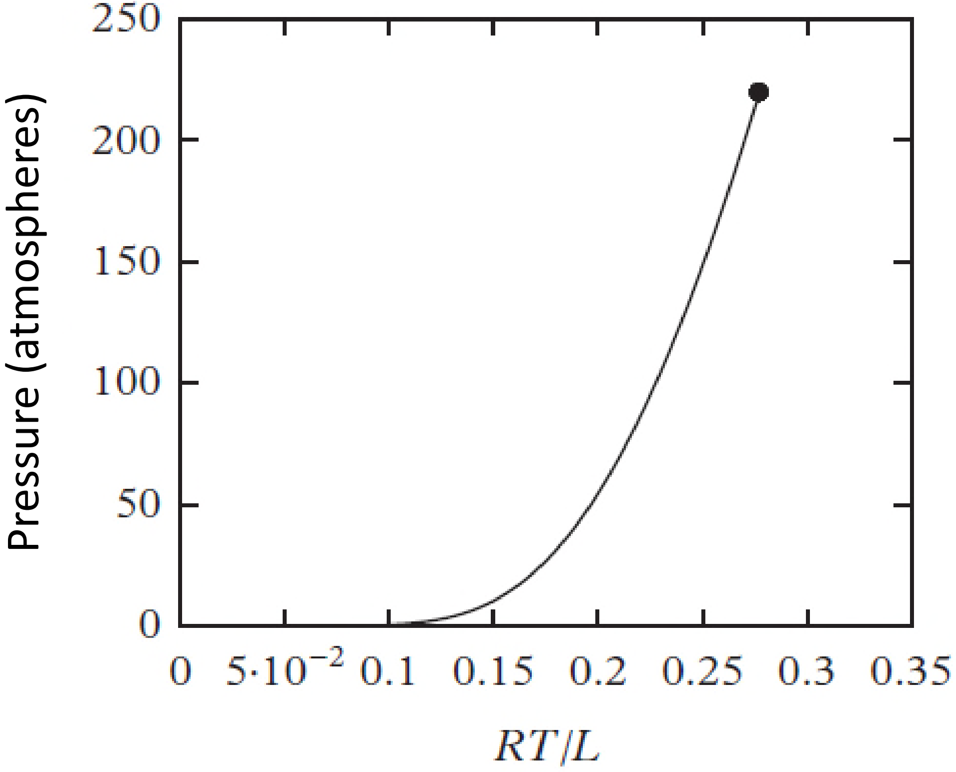
Deriving the **Clausius-Clapeyron equation** (which describes the coexistence curve for a first-order phase transition)



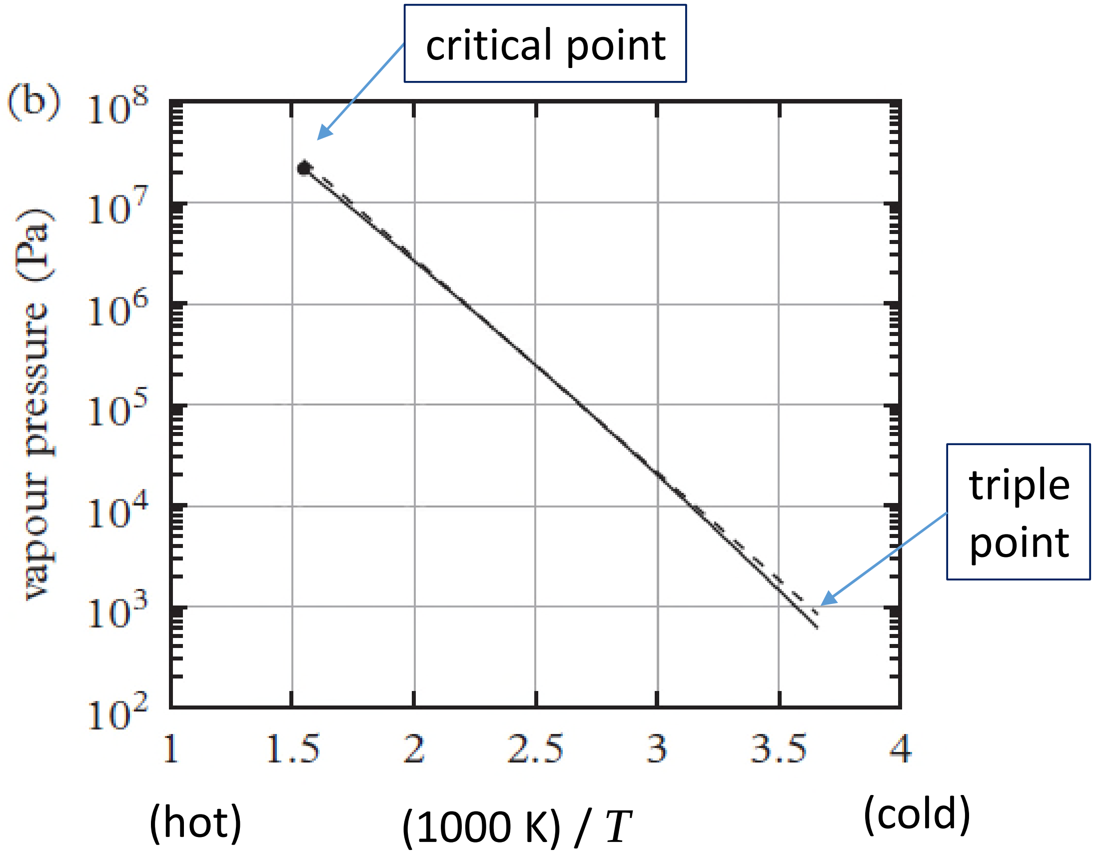
Consider neighbouring points on a co-existence line

$$p = p_0\, e^{-L/RT}$$

Generic case with L=9 R



pressure vs. inverse-temperature for water

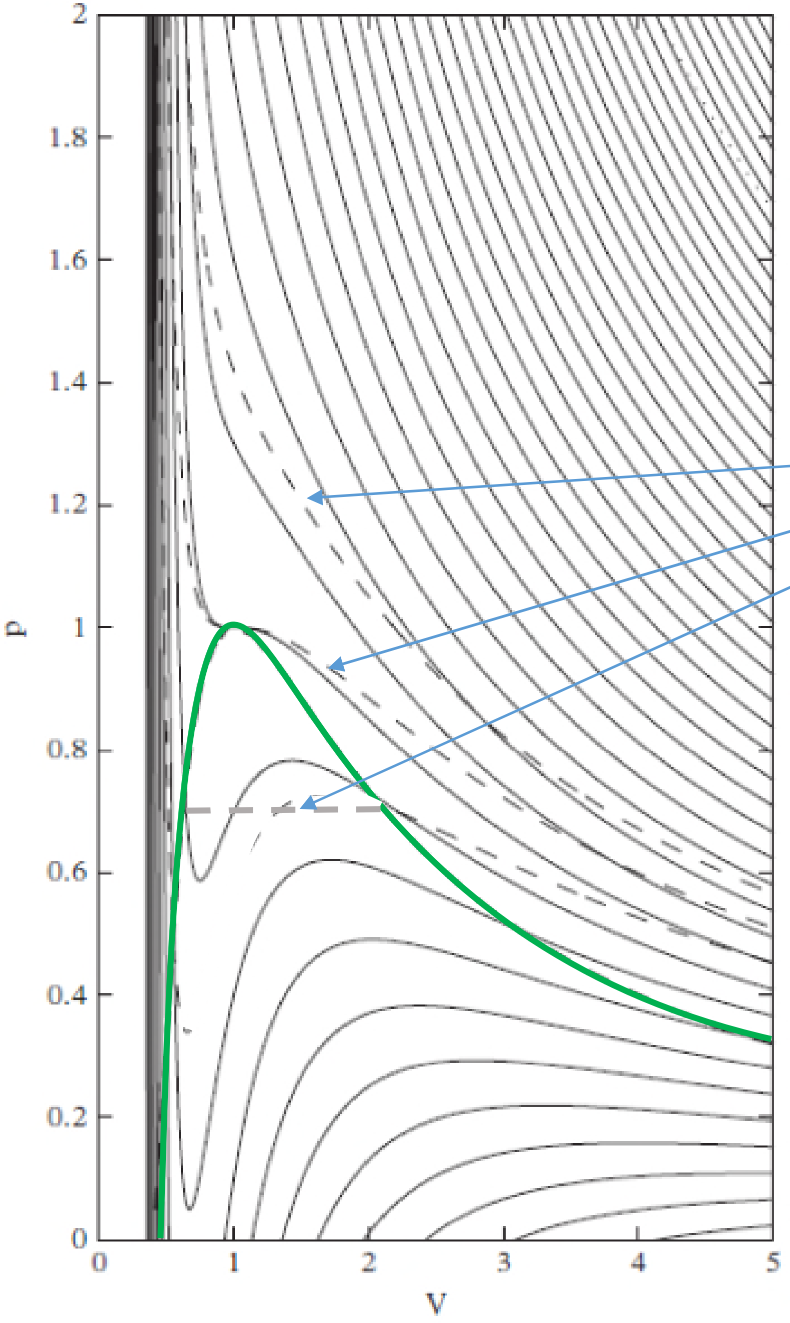


full curve = measured;
dashed = prediction from simple treatment

Thermodynamics lecture 12. # Phase change

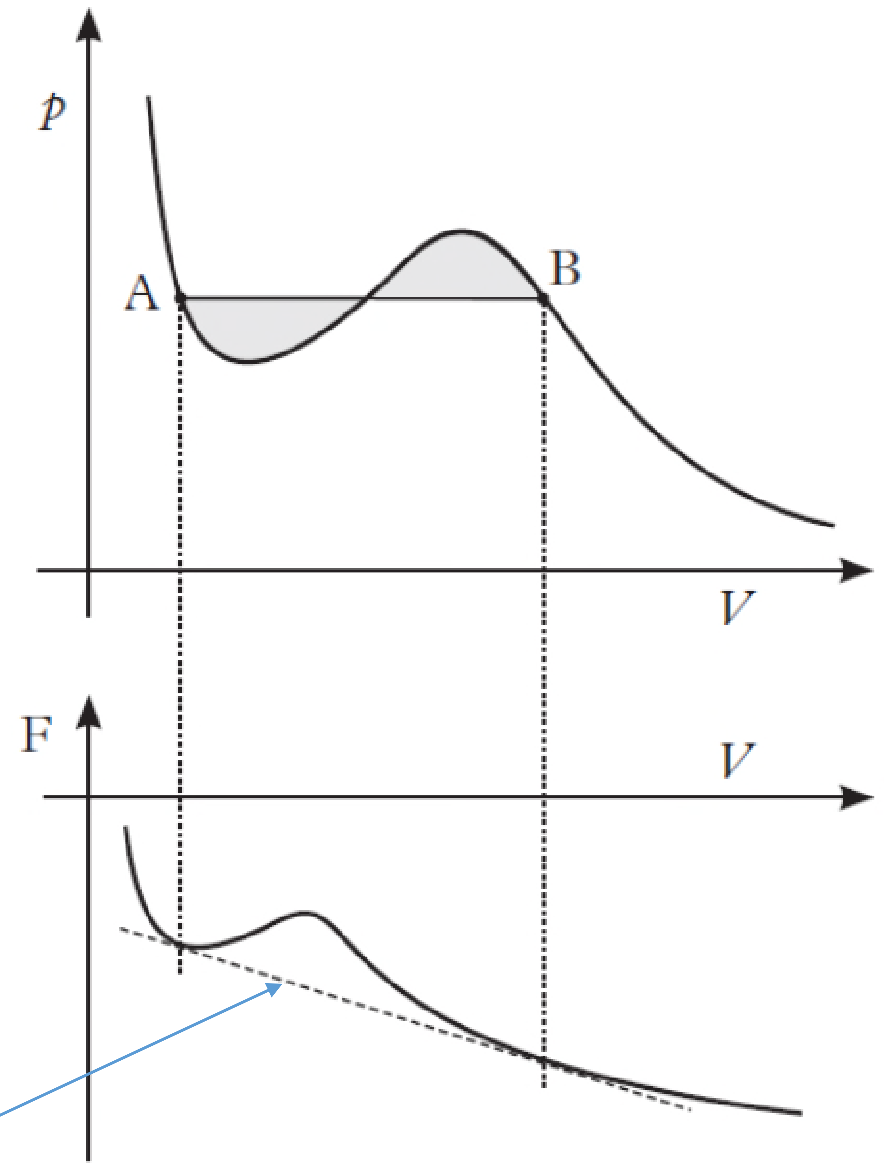
1. Phase change terminology
2. Basic properties of first-order phase transition
3. Clausius-Clapeyron equation
4. Van der Waals treatment and Maxwell construction (off syllabus)
5. (If time: some observations on chemical potential)

Isotherms predicted by van der Waals equation



Dashed lines: what a real gas does

Deriving the Maxwell construction



Constant $(\partial F/\partial V)_T$
so constant p