

Thermodynamics lecture 2.

W.A.L.T. (we are learning today)

- Some mathematical methods with partial differentiation and functions of state.
- “improper” or “inexact” differential
- Zeroth law → temperature and equation of state
 - We learn both a method of reasoning
 - and the result: temperature can be defined, and every system has an equation of state for temperature
- Some examples equations of state
 - Including, for example, gas and one kind of magnet

Function of state \leftrightarrow proper differential

Pressure p

Volume V

Temperature T

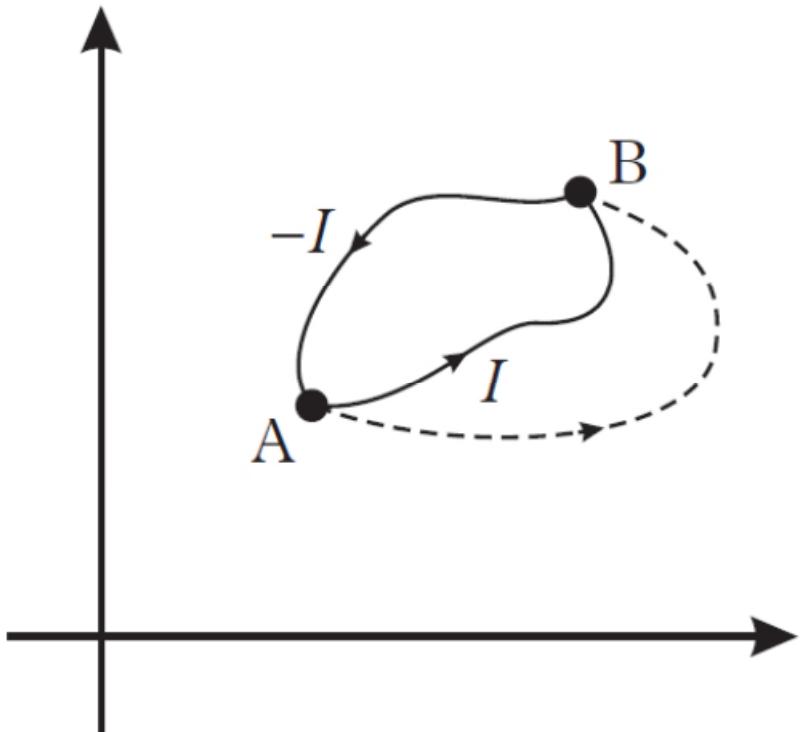
dp, dV, dT

Not function of state \leftrightarrow improper differential

Work W

dW, dQ

Heat Q

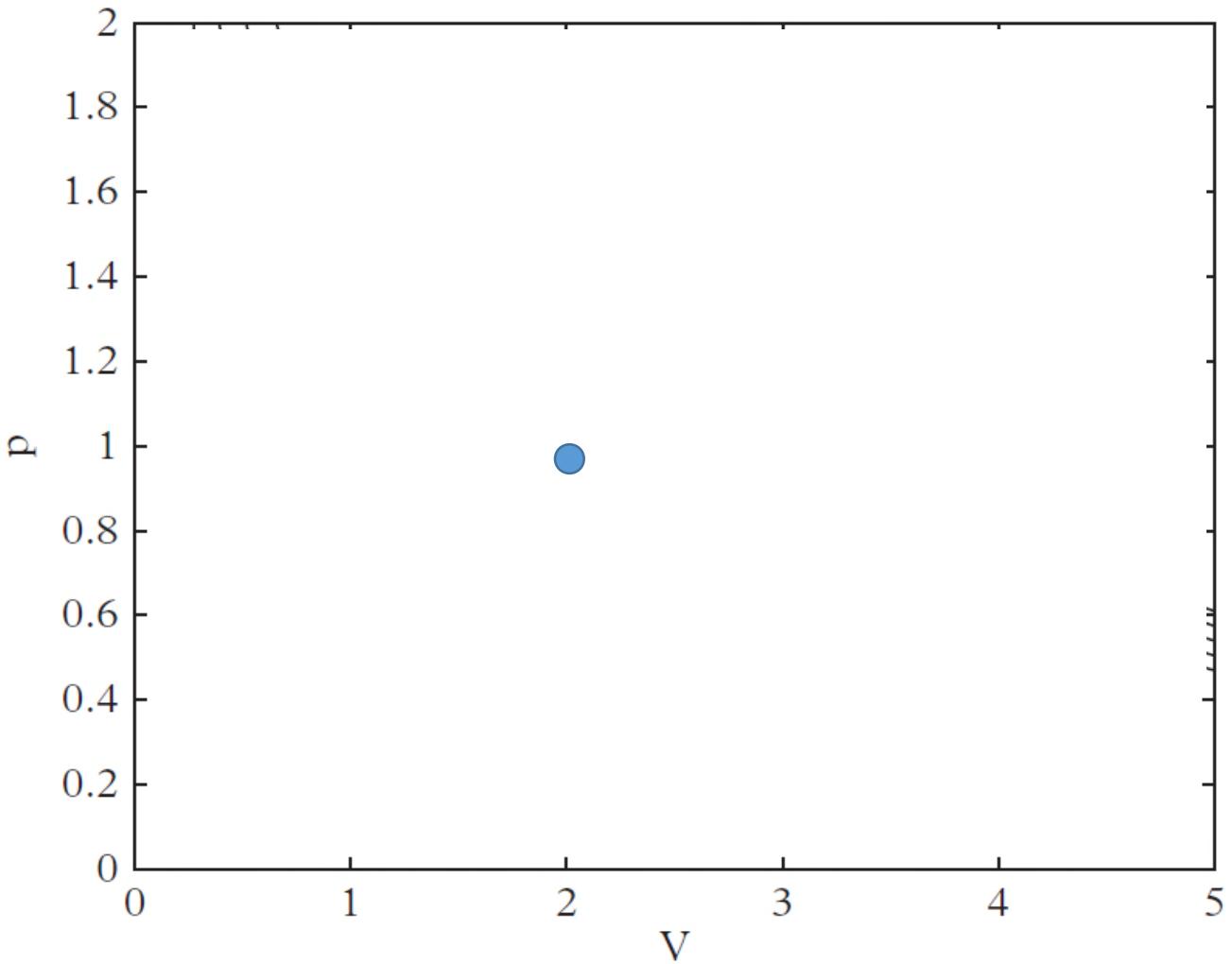
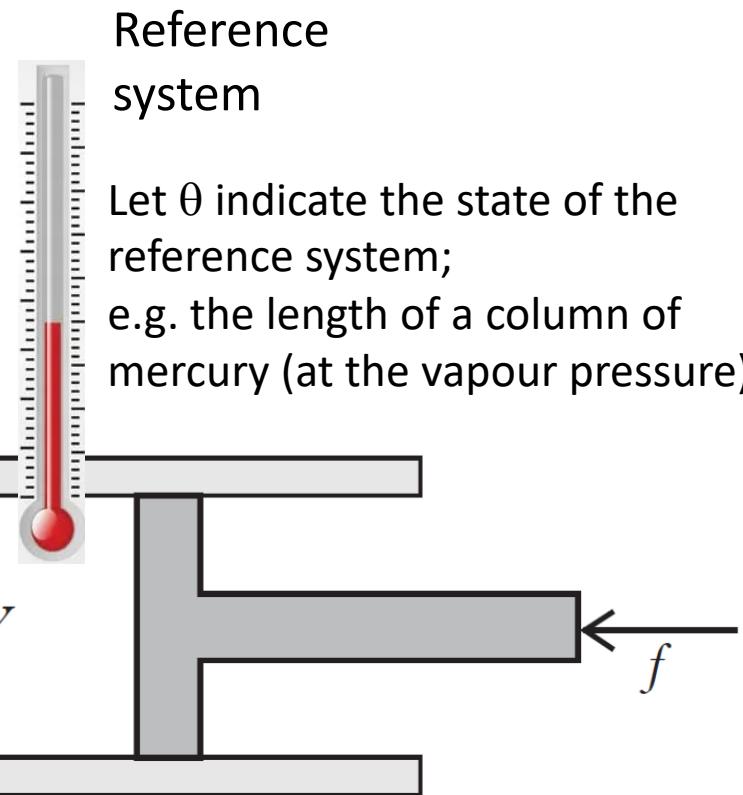


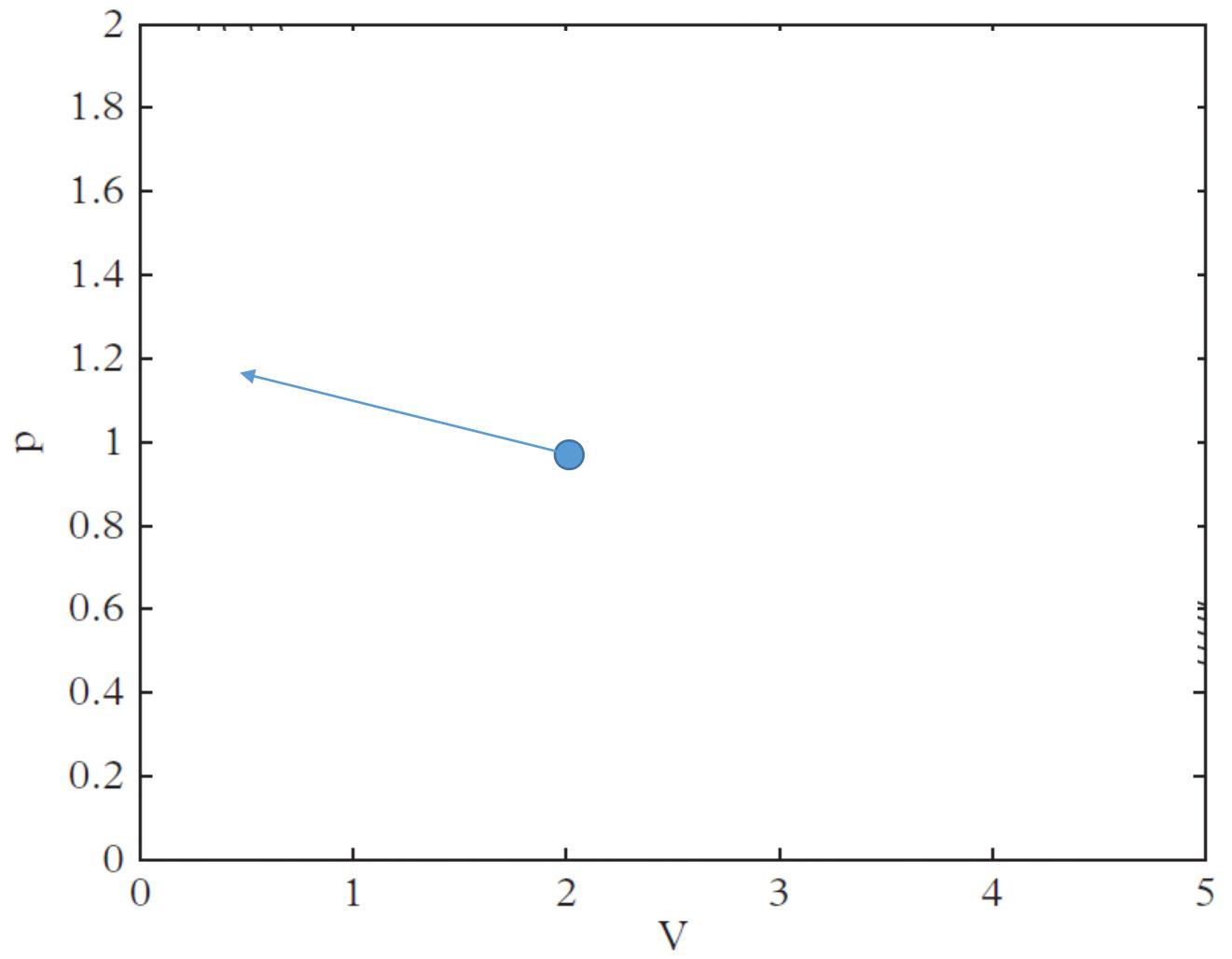
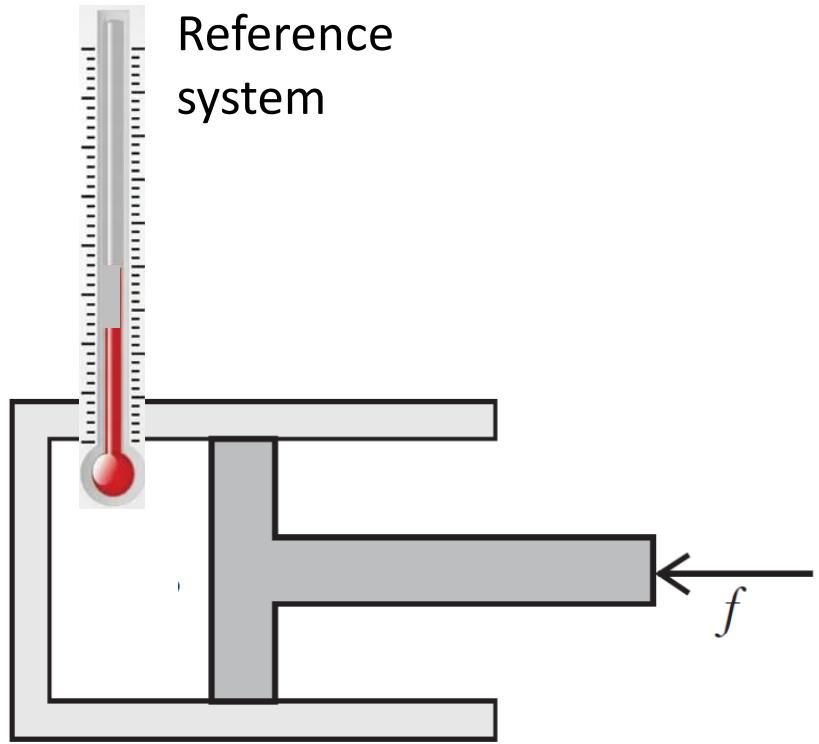
Theorem:

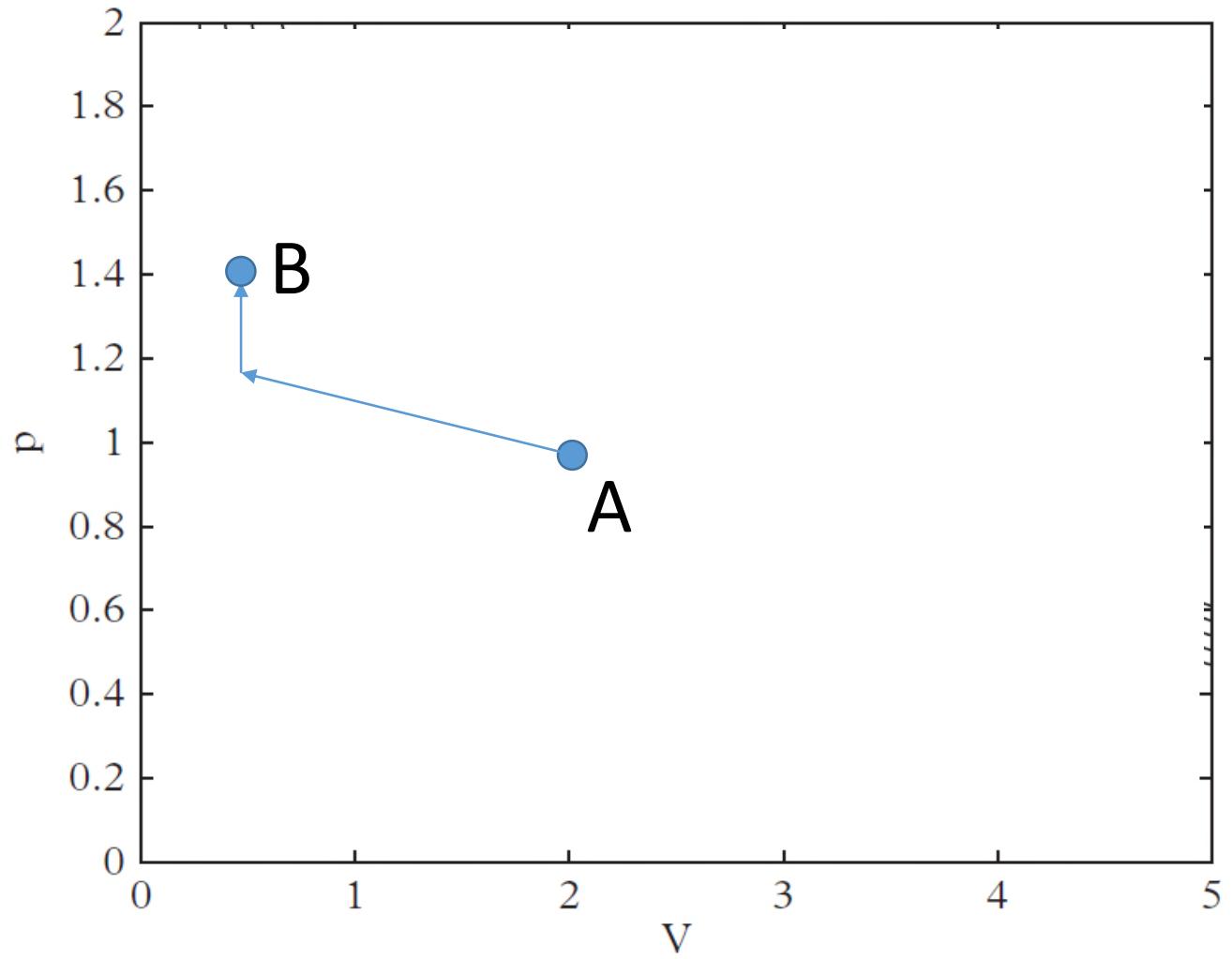
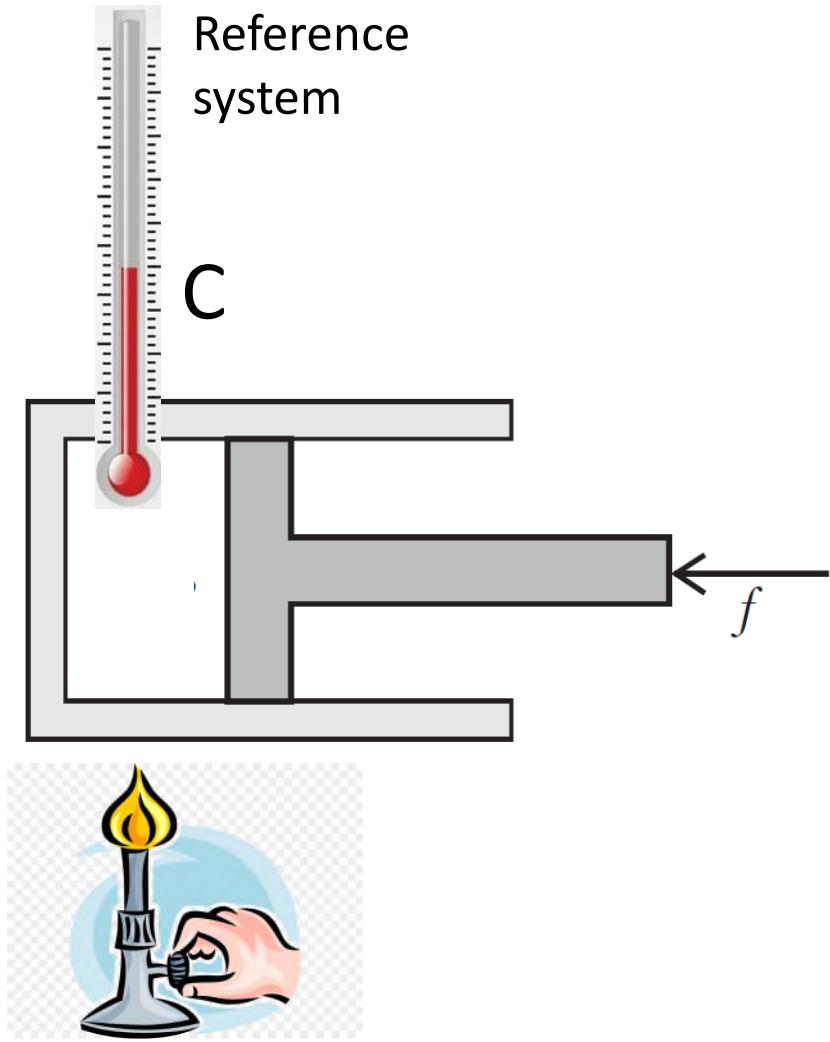
If the integral of a function f is zero around all closed paths, then f is a function of state.

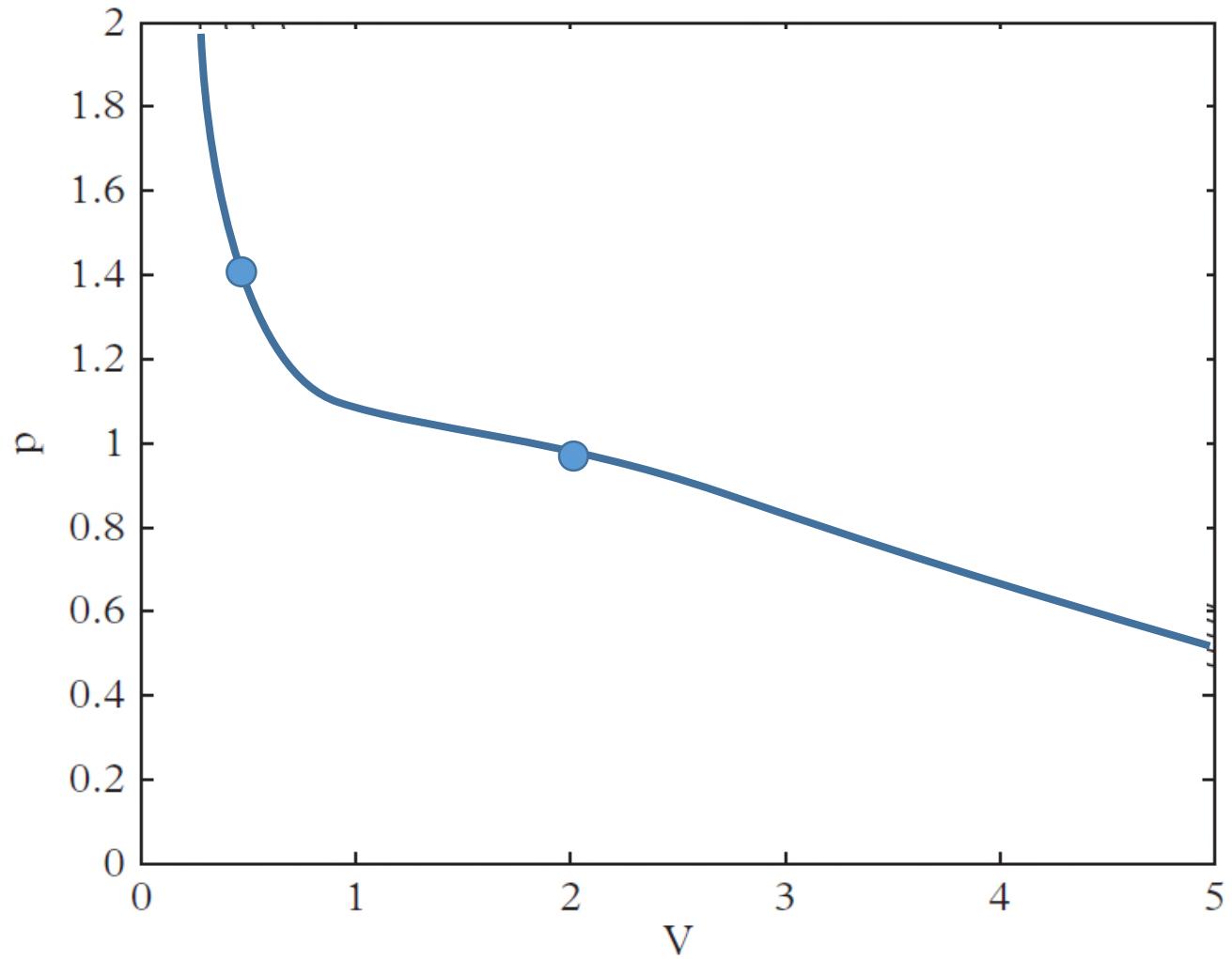
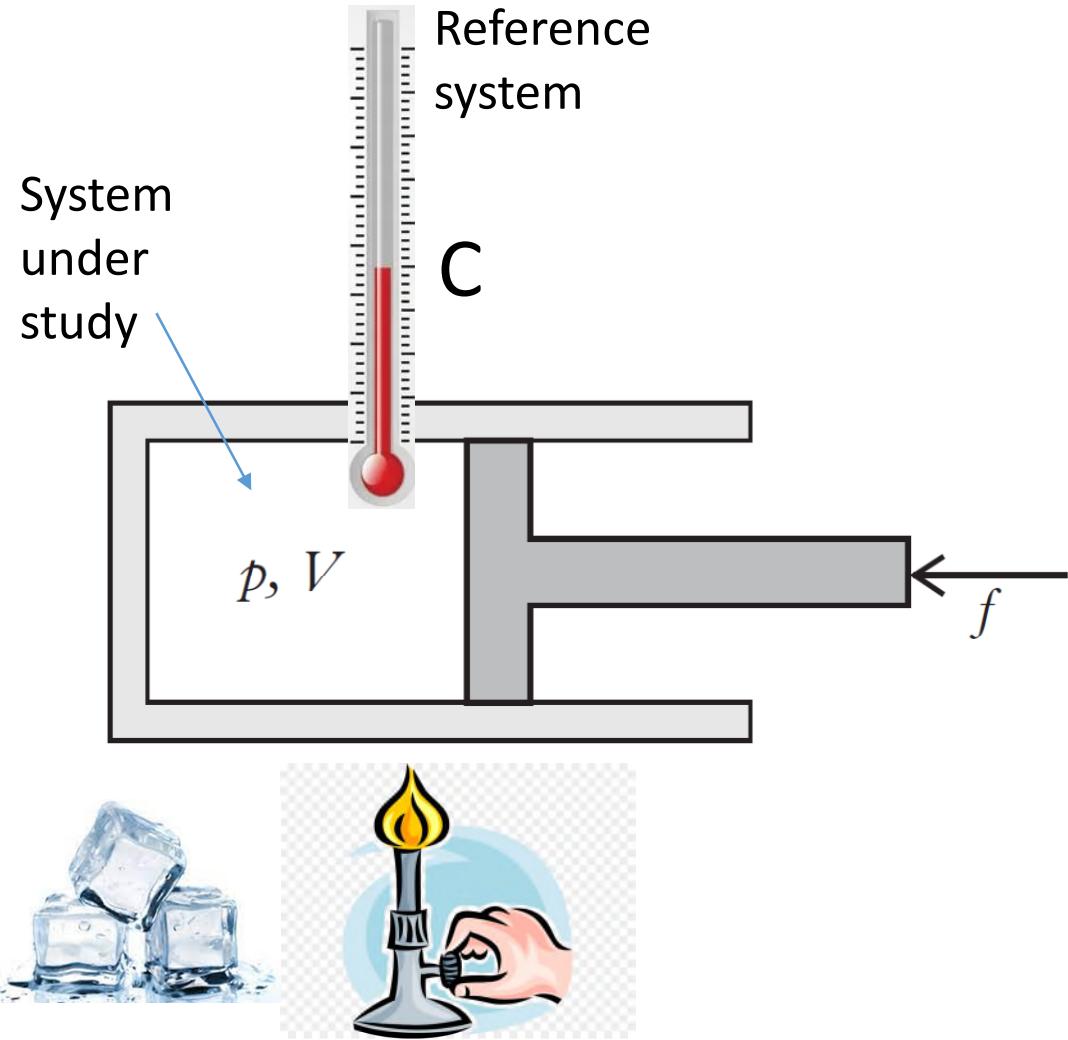
Zeroth law,
empirical temperature
and equation of state

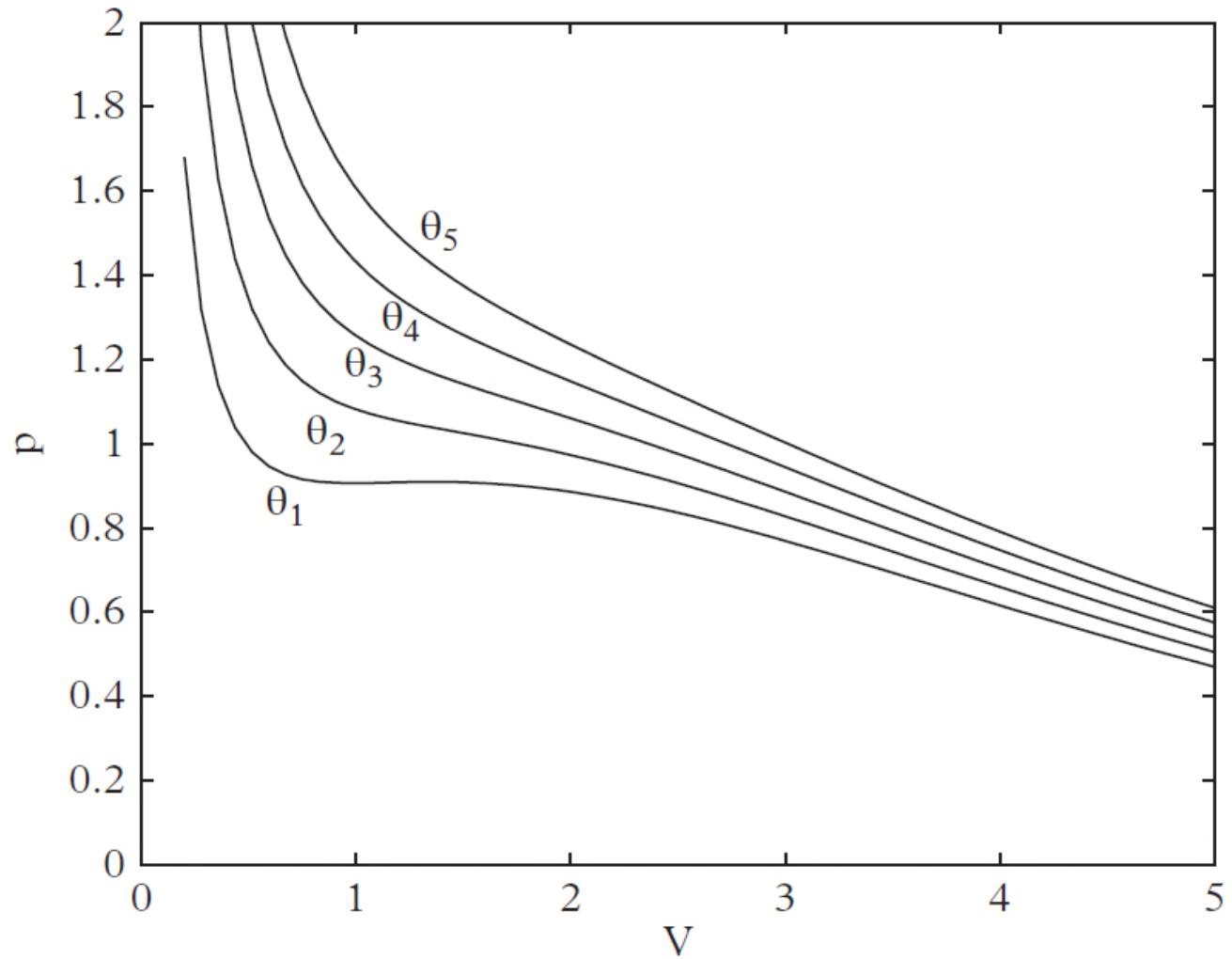
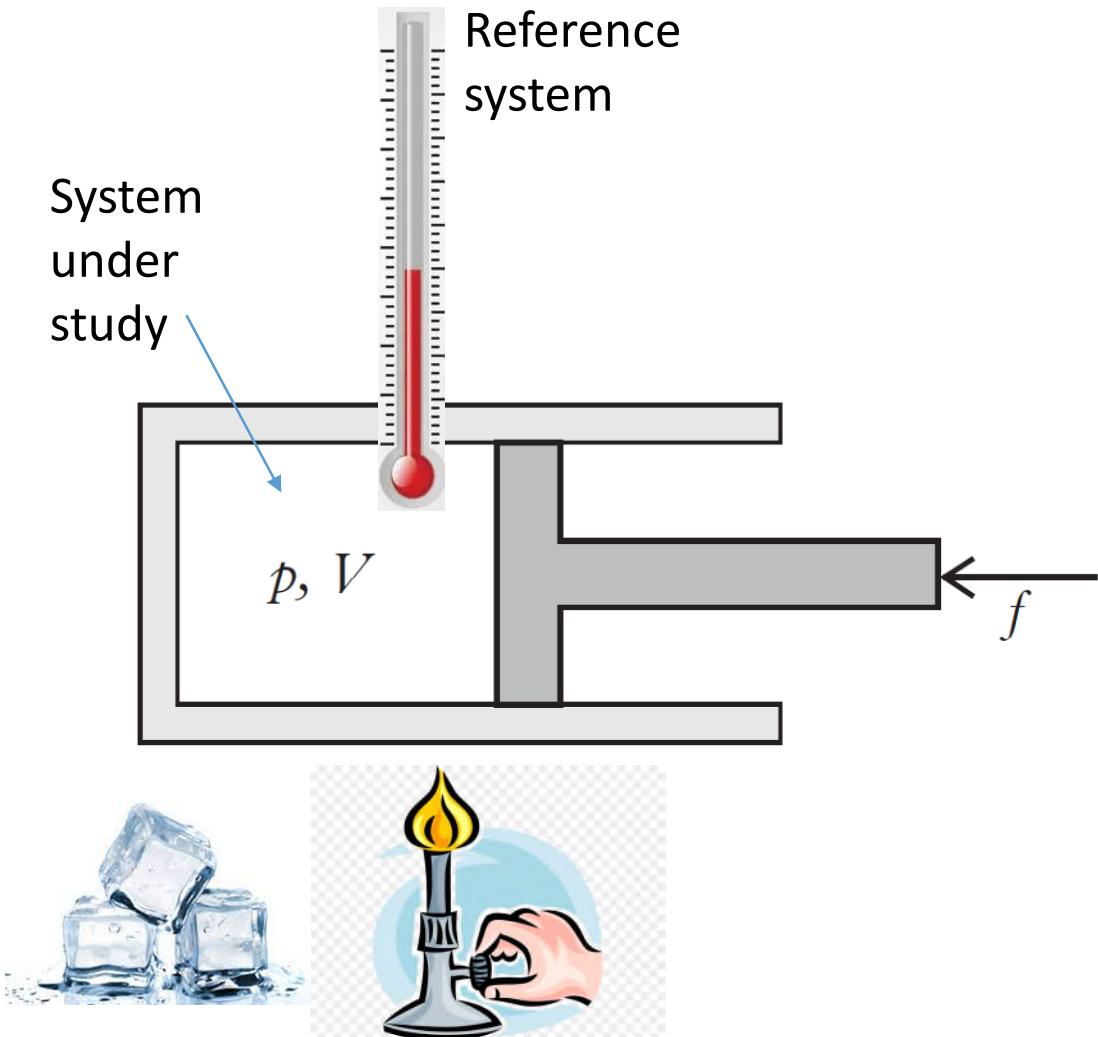
System
under
study









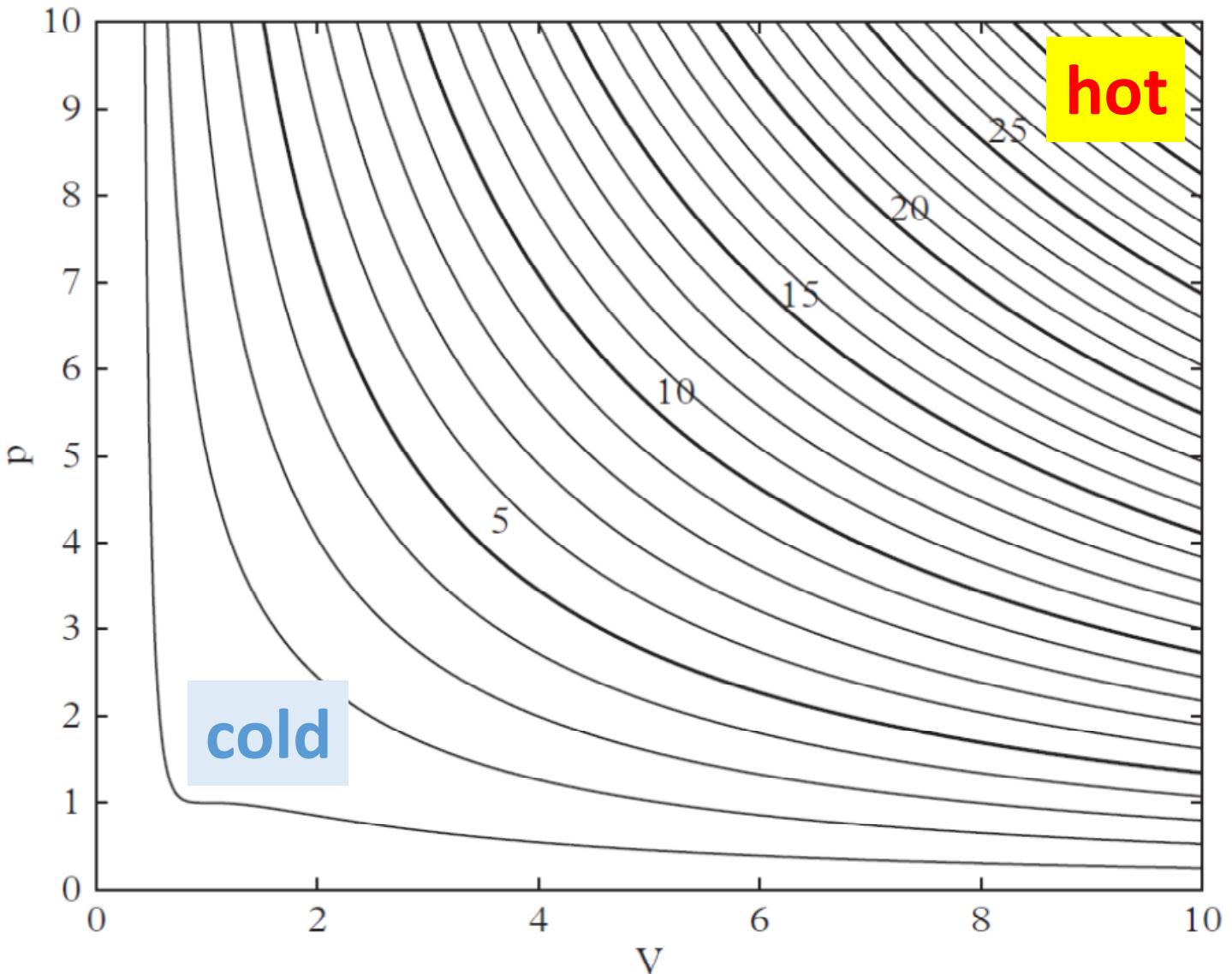


Here θ indicates the state of the reference system;
e.g. the length of a column of mercury (at the vapour pressure)

van der Waals equation
of state
(reasonably accurate for
most gases if the
pressure is not too high)

$$\left(p + \frac{N^2 a}{V^2} \right) (V - Nb) = Nk_B T$$

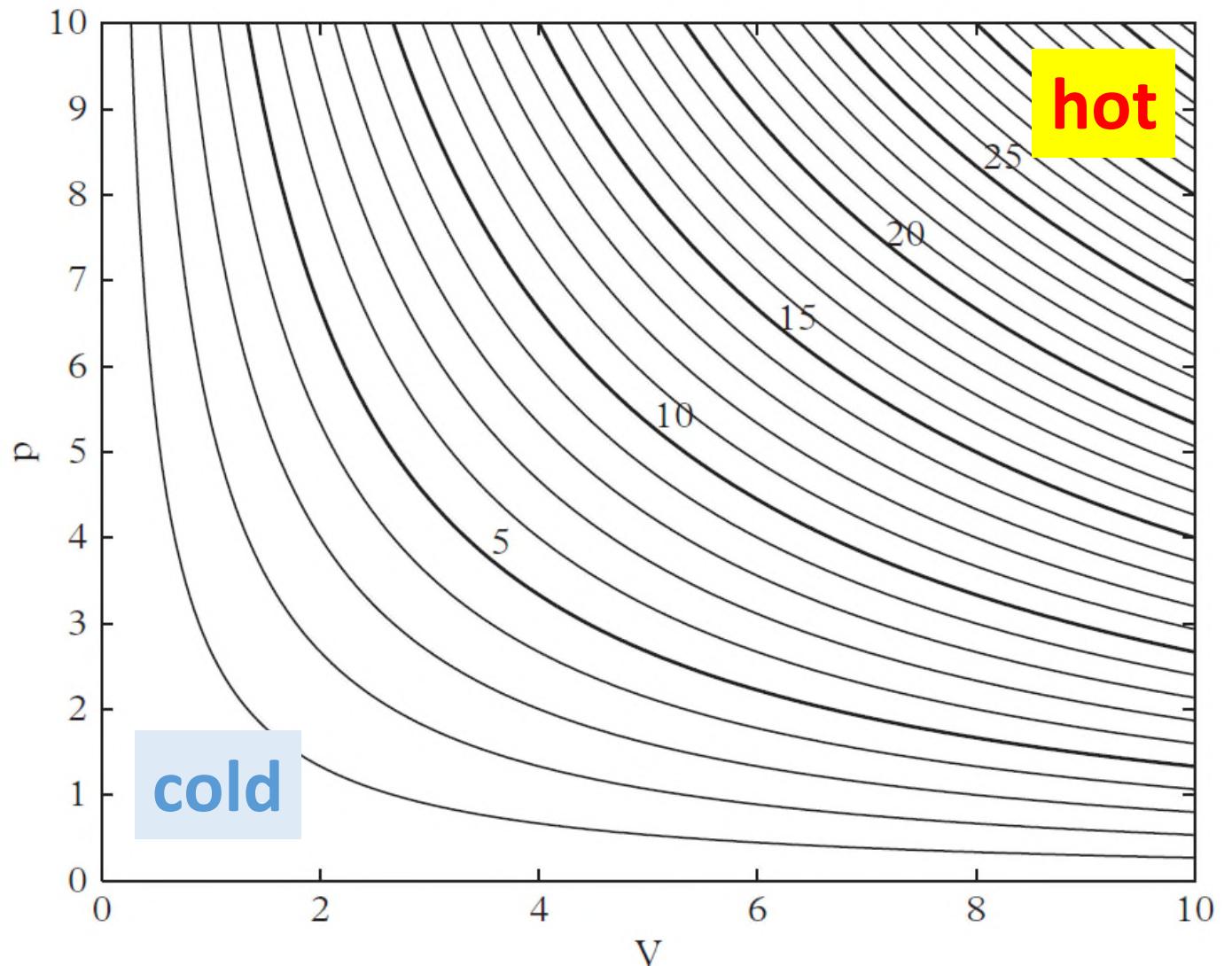
N = number of molecules
a,b = constants which depend on the type of gas



Isotherms of **van der Waals** gas, in the gaseous (not liquid) region

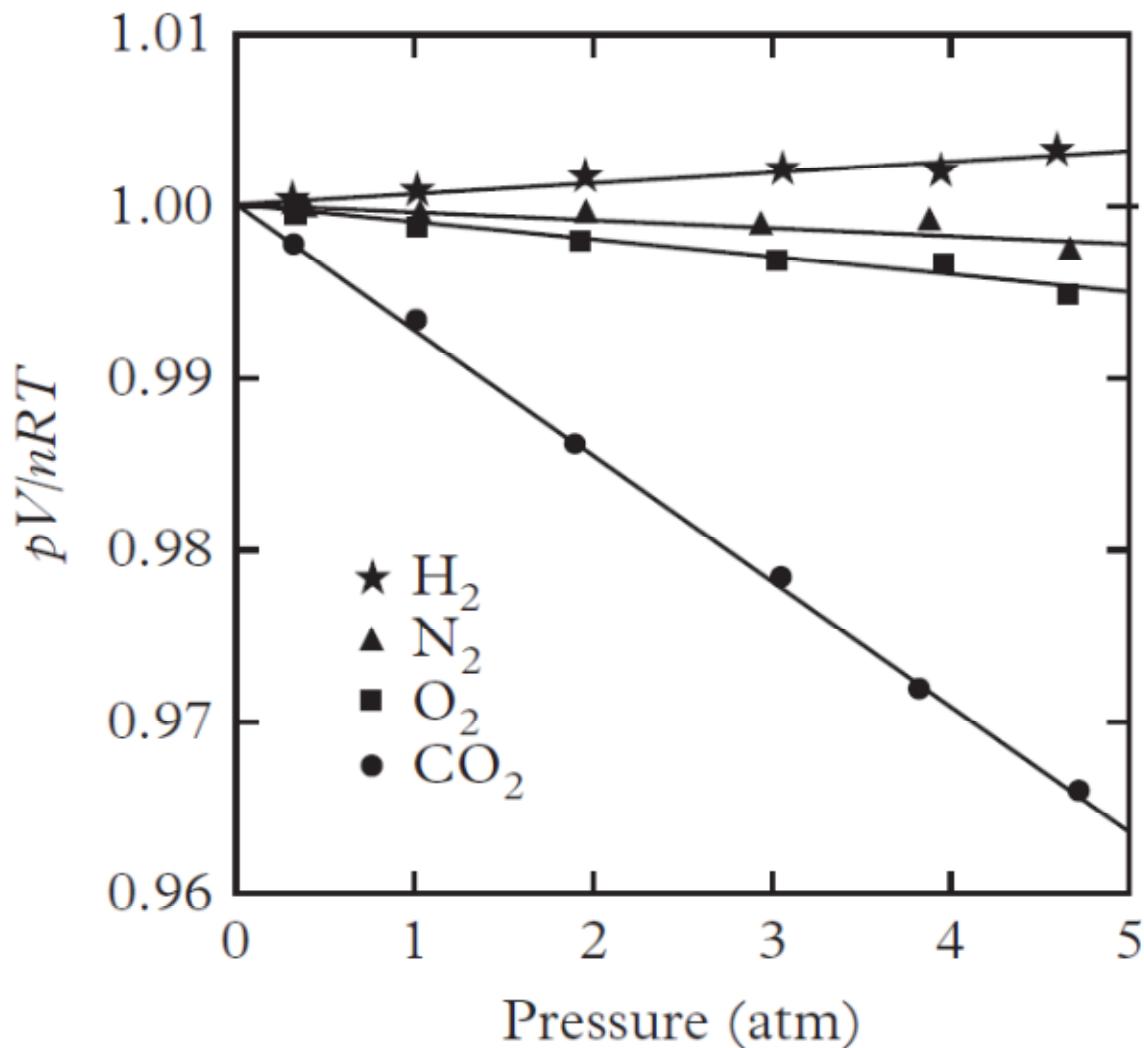
Ideal gas

$$pV = Nk_B T$$



Isotherms of ideal gas

Real gases tend to ideal at low pressure



Definition of an ideal gas

- (1) *Boyle's law: pV is constant at fixed temperature.*
- (2) *Joule's law: The internal energy is independent of pressure at fixed temperature.*

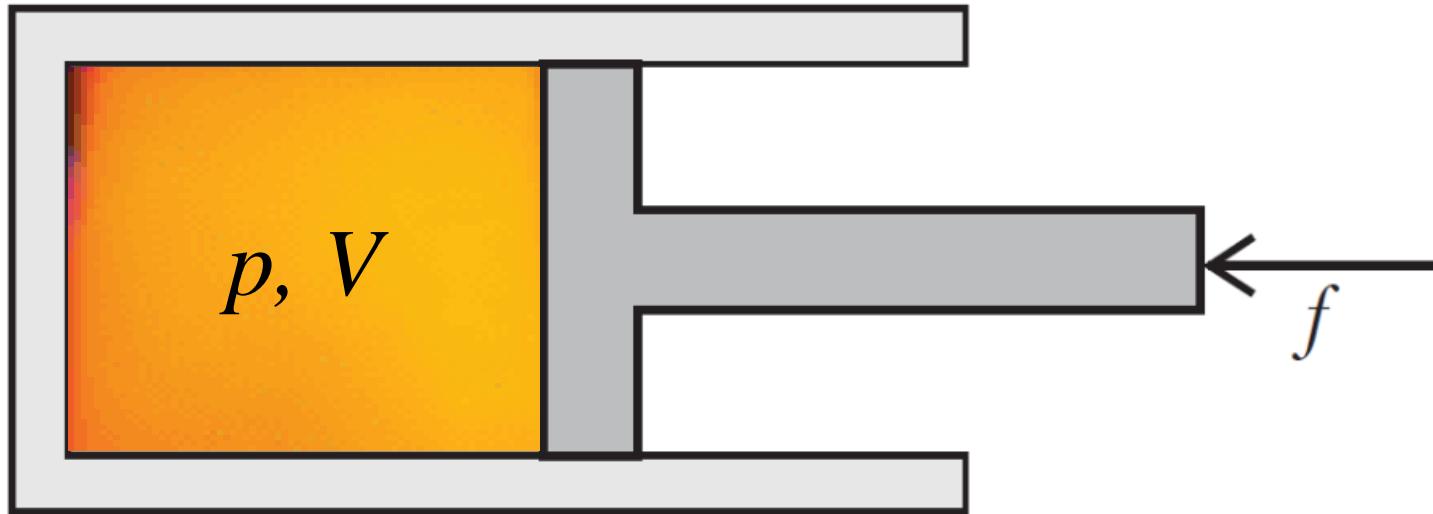
- (1) Implies $pV = f(T)$ for some function f .
- (2) Is often written $U = U(T)$.

We will show later that (1) and (2) together imply $f = \text{const} \times T$, for a fixed amount of gas,

$$\text{hence } pV = Nk_B T$$

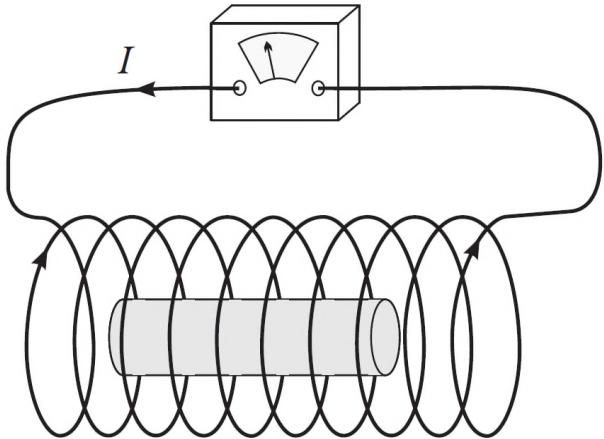
Thermal radiation

electromagnetic waves in a cavity in equilibrium at temperature T .



Equation of state: $p = aT^4$

Paramagnetism



State can be specified by \mathbf{M} , \mathbf{B} , where
magnetization \mathbf{M} = magnetic dipole moment
per unit volume.

Let

$$\mathbf{H} \equiv \frac{1}{\mu_0} \mathbf{B} - \mathbf{M}$$

Then for paramagnet, $\mathbf{M} = \chi \mathbf{H}$

where χ is called *magnetic susceptibility*.

Example equation of state:

Curie's law

$$\mathbf{M} = \frac{a}{T} \mathbf{H} \simeq \frac{a}{\mu_0 T} \mathbf{B}$$

