Physics 2c Lecture 3

Recap: Ideal Gas
New Today:
Phase Transitions
Start Chapter 21

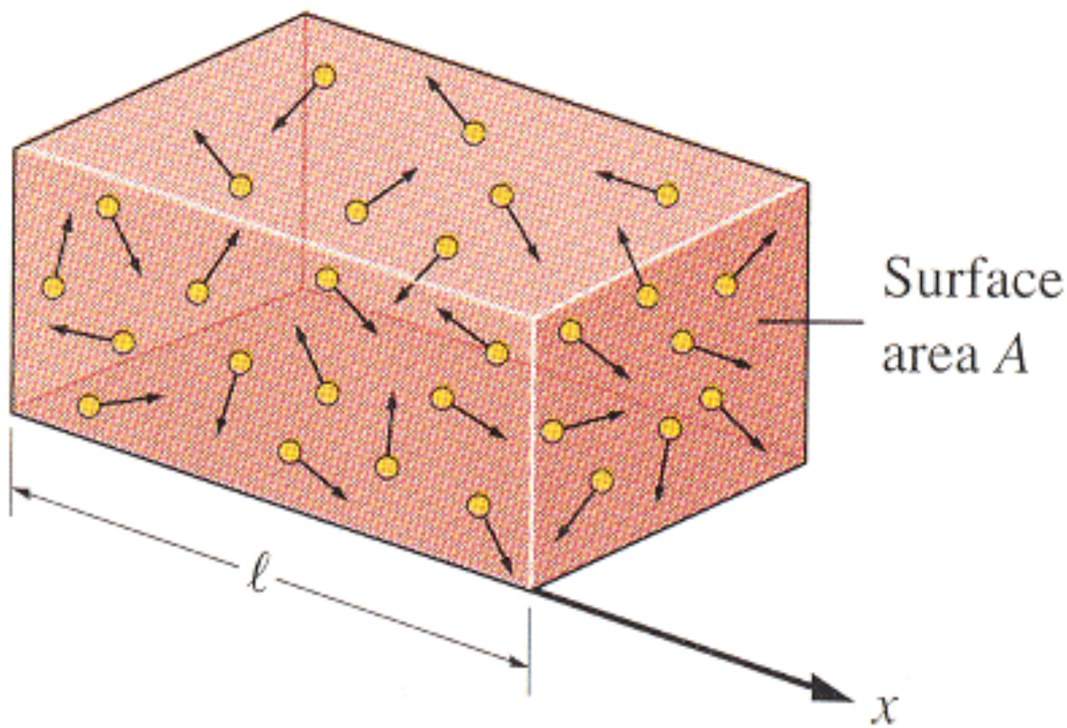
Ideal Gas Law

$$PV = N\,kT = nRT$$

P = Pressure
V = Volume
N = number of gas molecules
T = temperature
k = 1.38 x 1e-23 Joule/Kelvin = Boltzmann constant
n = number of moles of gas
R = N-Avogadro k = 8.314 J/(K mol)

Determined originally based on experimental observation.

Mental model for gas



Kinetic Theory of Ideal Gas

Assumptions to derive Ideal Gas Law:

1. All collisions are elastic, conserving energy and momentum.
2. Movement of molecules is random. No preferred direction.
3. Large # of identical molecules of mass m, no structure, no size.
4. All energy in the gas exists in form of kinetic energy of its molecules.

With this we derived the relationship between P,V, and <Ekin> for an ideal gas in a rectangular box:

$$PV = 2/3\ N \langle E_{kin} \rangle$$

by comparison, we then conclude:

$$\langle E_{kin} \rangle = 3/2\ kT$$

Equipartition theorem

When a system is in thermodynamic equilibrium, the average energy per molecule is 1/2 kT for each degree of freedom.

Aside on Equipartition Theorem

- Once you release the requirement of molecule being structureless you get:

$$\langle E_{internal} \rangle = f/2\ kT$$

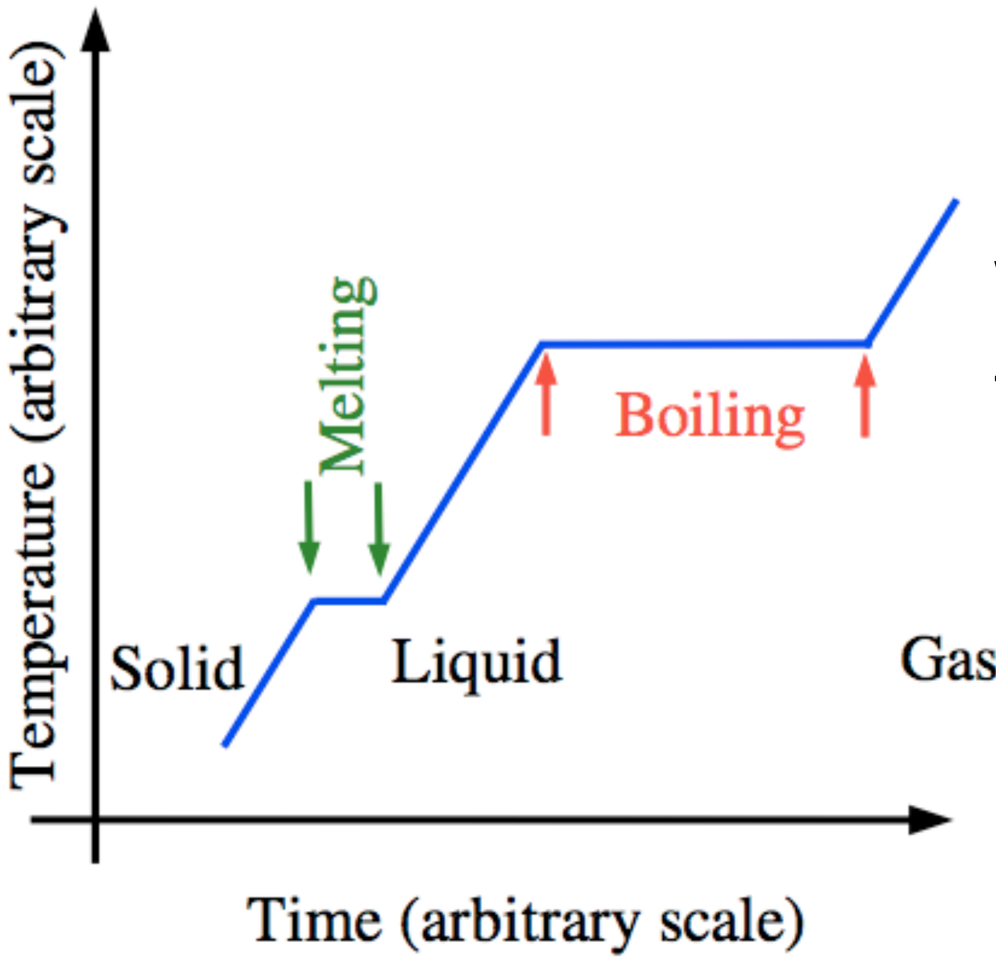
f = # of degrees of freedom of the gas molecules.

Phase Transitions

Gedanken Experiment

- Imagine you put a block of ice in a pan.
- Put it on a stove.
- Add heat to the block of ice at a constant rate.
- Measure the temperature versus time: T(t).
- What does this curve for T(t) look like?

Heat & Phase Change



We measure T(t) as the compound absorbs energy at a fixed rate.

We see phase transitions.

T does not change while the compound goes through the phase transition.

Heat of fusion = L_f
Heat of vaporization = L_v

Example 20-5

- 600g water at 20 degree Celsius on 1.5kW stove.
- How long will it take to boil the pan dry?

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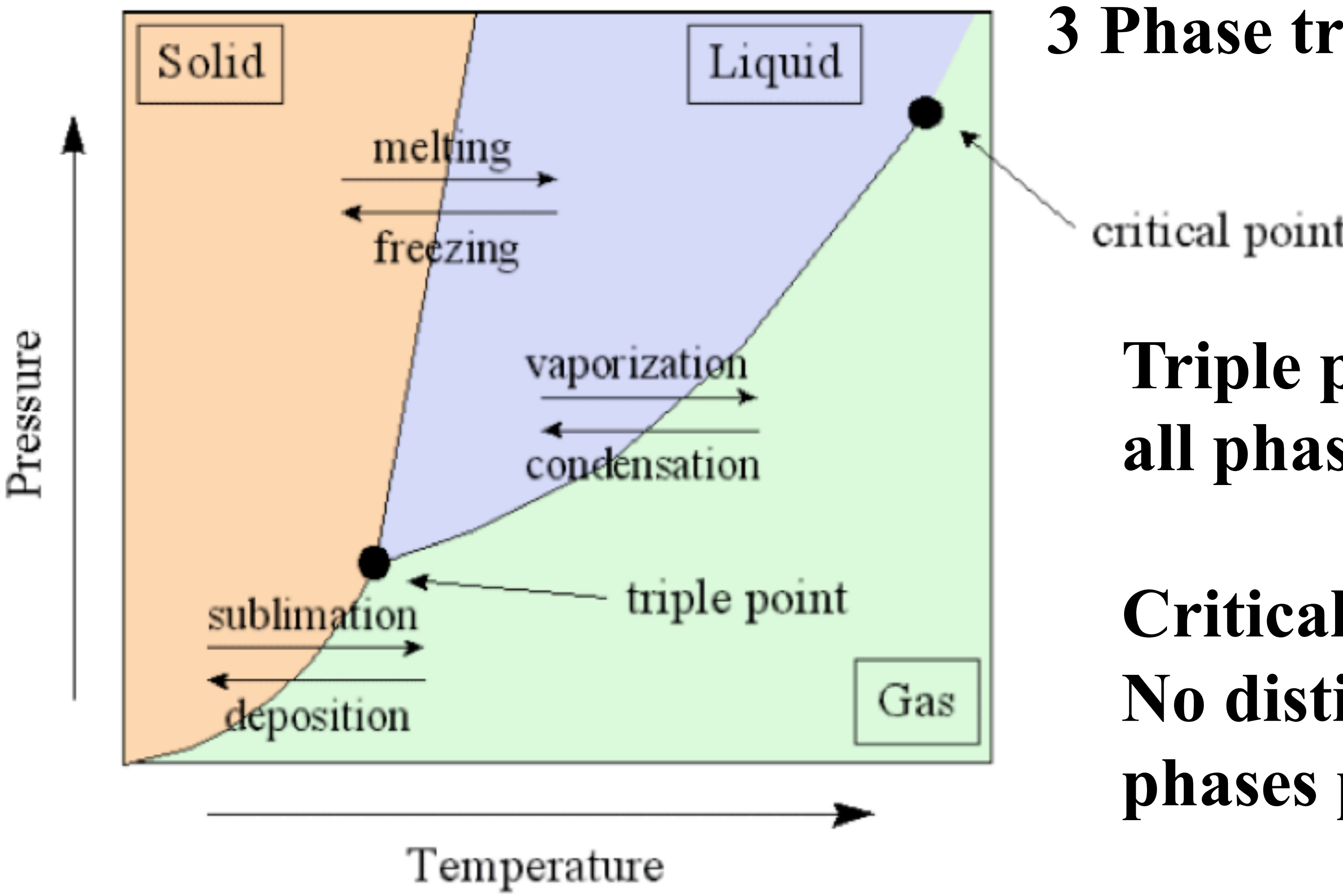
$$\Delta Q_{heating} = mc\Delta T$$

$$\Delta Q_{boiling} = mL_v$$

"Typical" Phase Diagram

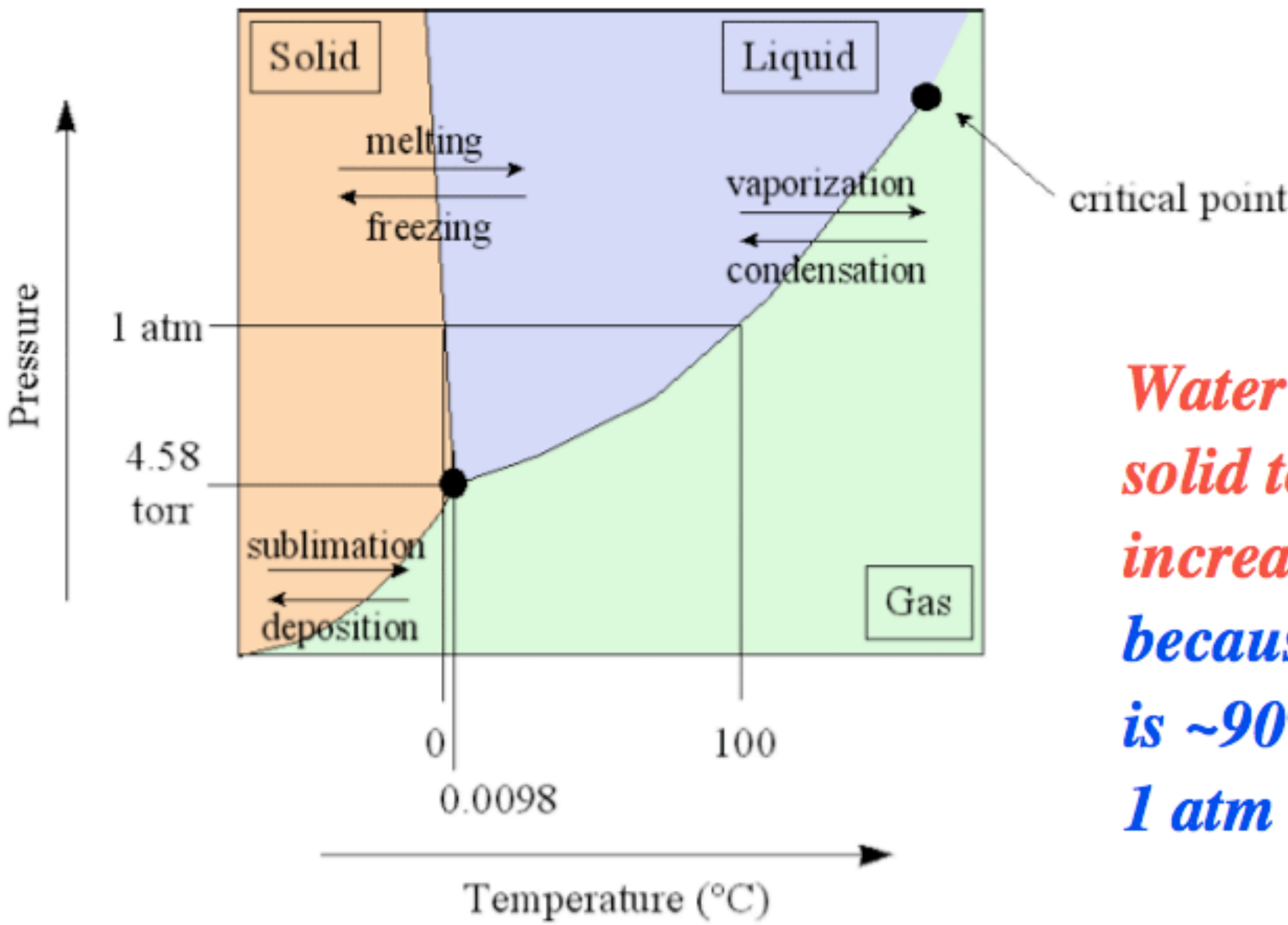


3 Phases: solid, liquid, gas
3 Phase transitions.

Triple point:
all phases coexist.

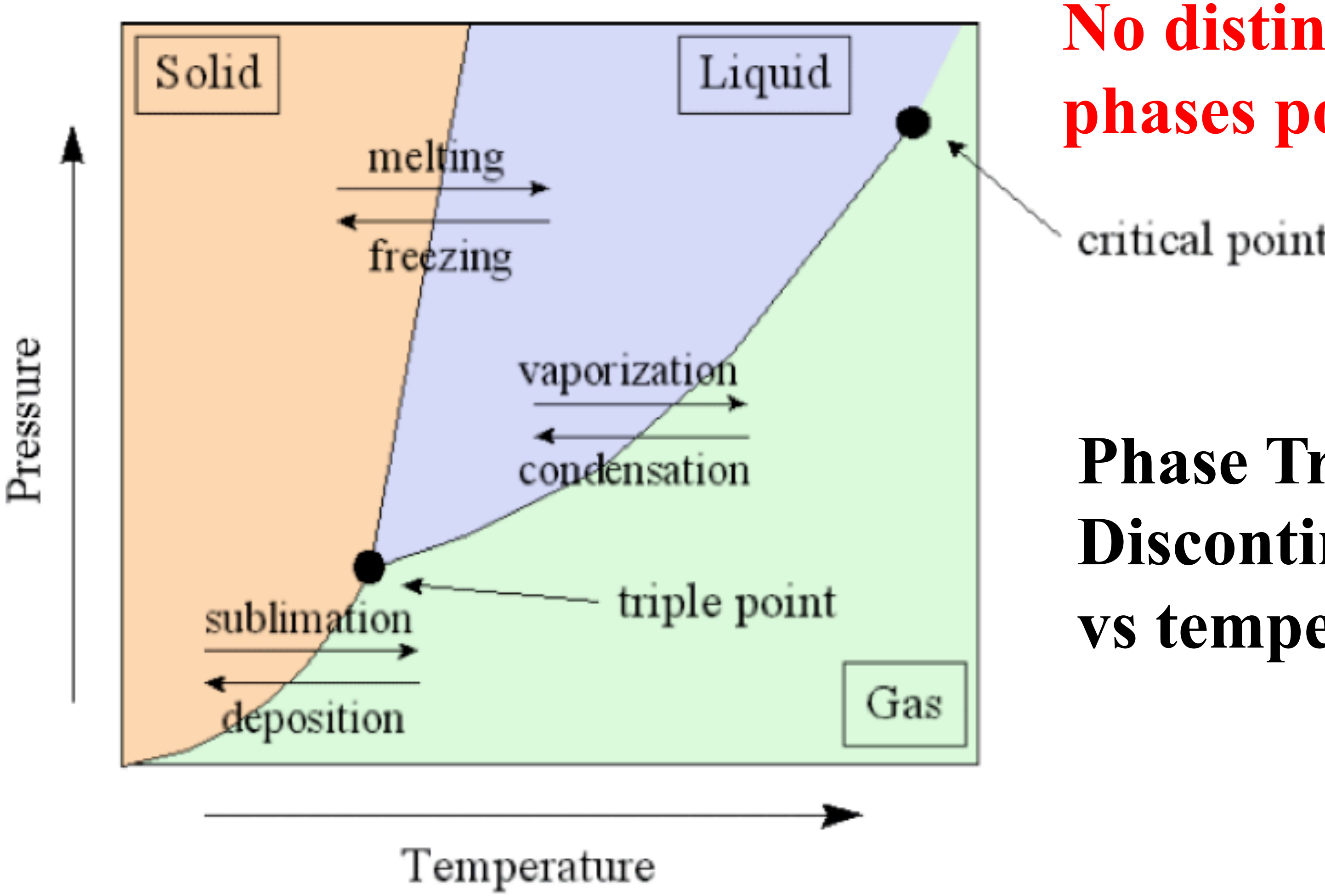
Critical point:
No distinction between phases possible.

Phase Transition for Water



Water can go from solid to liquid by increasing the pressure because the density of ice is ~90% that of water at 1 atm and 0 degree Celsius.

A word about critical point



Critical point:
No distinction between phases possible.

Phase Transition = Discontinuity in density vs temperature.

Phase Transitions as a general concept.

- The idea of “phase transitions” is broadly applicable across a wide range of areas.
  - Metal alloys:
    - Characteristics of alloy change as function of admixture of different metals.
  - Superconductivity and superfluidity at low temperatures.
  - Traffic patterns as a function of traffic density.

Quiz content next Monday

- Everything up to here !!!
- I.e. all of chapter 19 & 20 !!!
- This includes content in the book that we did not cover in class.

Chapter 21

1st law of thermodynamics
Thermodynamic processes
Specific Heat of an ideal gas

Why the struggle?

- We will discuss thermodynamic processes, and their curves in the PV diagram in some detail.
- This leads up to heat engines & refrigerators.

The vast majority of engines you encounter in your life are heat engines. It's thus good to know how they work!

1st Law of Thermodynamics

$$dU = dQ - W$$

It's simple energy conservation. Change in internal energy of the gas (U) must be balanced in the heat you put in minus the work the gas does.

Internal Energy of Gas

- As we saw in derivation of ideal gas law:
- U = N <kinetic energy>
- Where N=number of particles, and <> denotes averaging over all particles.

Aside on (ir-)reversibility

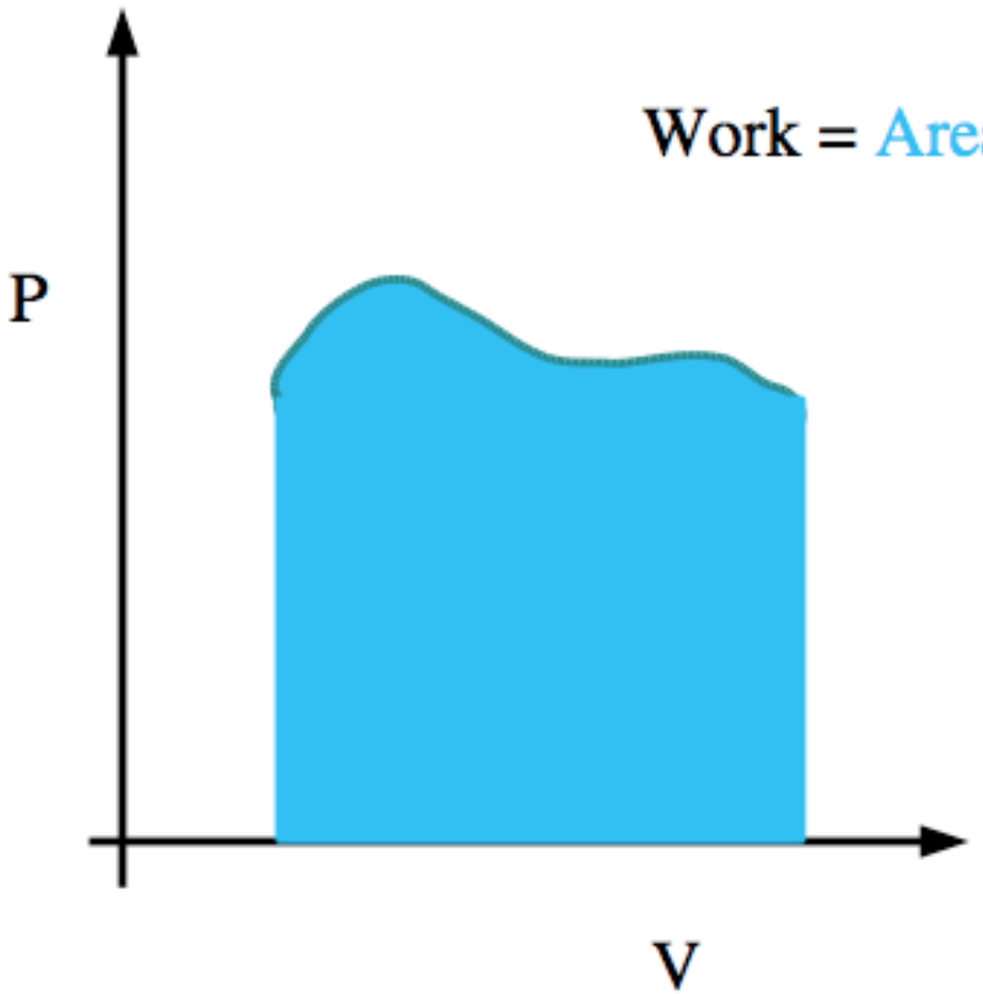
For the sake of today:

A process is called “reversible” if you can run it backwards, and thus create a circular thermodynamic process that obeys energy conservation.

Many practical processes are reversible to within some reasonable approximation.

Some important processes are fundamentally irreversible. (e.g. anything to do with friction)

PV diagram and Work



Gas does work if it expands.

W > 0

Work is done on gas if it shrinks.

W < 0

Favorite 4 types of processes

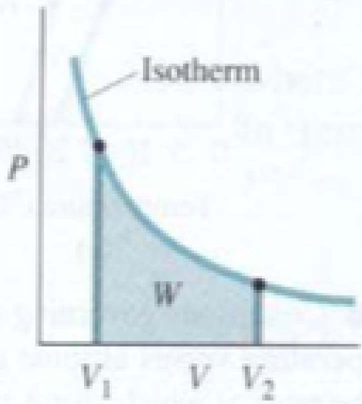
- Isothermal: T=const dU=0
- Isobaric: P=const
- Isochore: V=const W=0
- Adiabat: dQ=0

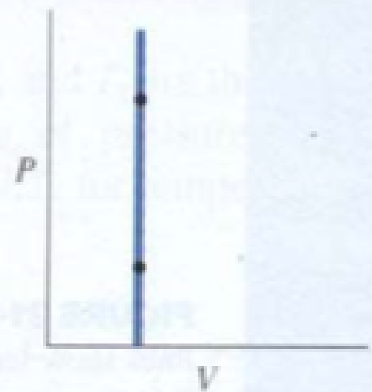
This covers all the players in the game!

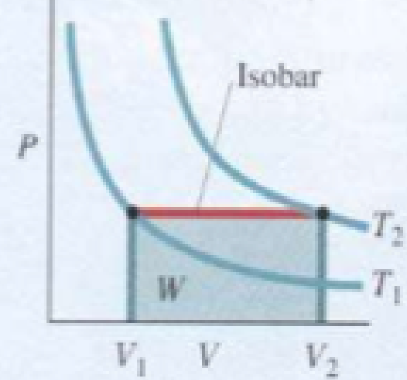
4 Processes

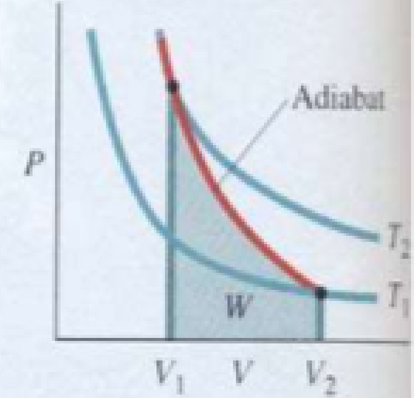
TABLE 21-1 *Ideal Gas Processes*

PV diagram









	ISOTHERMAL	CONSTANT-VOLUME	ISOBARIC	ADIABATIC
Defining characteristic	T = constant	V = constant	P = constant	$Q = 0$
First law	$Q = W$	$Q = \Delta U$	$Q = \Delta U + W$	$\Delta U = -W$
Work done by gas	$W = nRT \ln\left(\frac{V_2}{V_1}\right)$	0	$W = P(V_2 - V_1)$	$W = \frac{P_1 V_1 - P_2 V_2}{\gamma - 1}$
Other relations	PV = constant	$Q = nC_V \Delta T$	$Q = nC_P \Delta T$ $C_P = C_V + R$	PV^{γ} = constant $TV^{\gamma-1}$ = constant