معهد المستقبل العالي للهندسة بالفيوم

FUTURE HIGH INSTITUTE OF ENGINEERING IN FAYOUM

Kinetic theory &
the behaviour of gases

Dr - Abdelrahman Ragab

Evidence for atoms

- crystals – regularity of surfaces, cleaving:

Crystals

- **Regularity of Surfaces:** Crystals often exhibit regular, geometric shapes due to the ordered arrangement of their atoms or molecules.
- **Cleaving:** Crystals can cleave along specific planes, breaking into smaller pieces with smooth, flat surfaces. This property is related to the crystal's internal structure.

- mixing different liquids:**Miscibility:** Liquids that can mix completely

with each other are called miscible. Examples include water and alcohol.

- **Immiscibility:** Liquids that do not mix are called immiscible. Oil and water are examples of immiscible liquids.
- **Emulsions:** When immiscible liquids are combined with a third substance (emulsifier), they can form a stable mixture called an emulsion. Mayonnaise is a common example of an emulsion.

Evidence for atoms

change of volume: solid gas, liquid gas

Change of Volume

- **Solid to Gas (Sublimation):** Some substances can directly change from a solid to a gaseous state without passing through the liquid phase. This is called sublimation. An example is dry ice (solid carbon dioxide).
- **Liquid to Gas (Vaporization):** The process of a liquid turning into a gas is called vaporization. Boiling and evaporation are examples of vaporization.

Evidence for atoms

- air occupies space and has mass:

- **Air Occupies Space and Has Mass**

- **Density:** Air has a density, meaning it has mass per unit volume. This is why air exerts pressure on objects.
- **Compressibility:** Air is compressible, meaning its volume can be reduced by applying pressure.

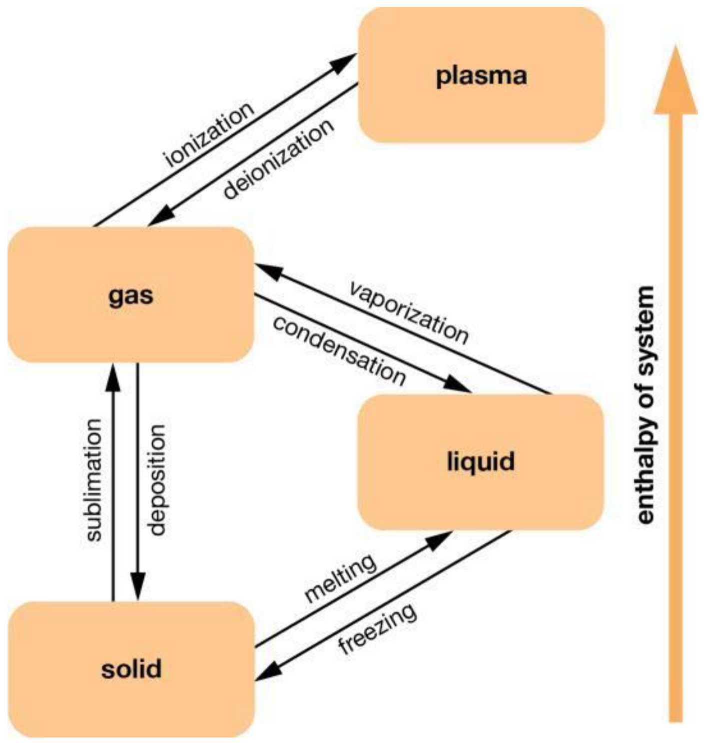
- diffusion: solid into solid, solid into liquid, gas into gas

Diffusion

- **Diffusion:** The movement of particles from a region of higher concentration to a region of lower concentration is called diffusion.
-
- **Types of Diffusion:**
  - **Solid into solid:** Diffusion can occur between solids, but it is a very slow process.
  - **Solid into liquid:** A solid can dissolve in a liquid, allowing its particles to diffuse through the liquid.
  - **Gas into gas:** Diffusion between gases is relatively rapid due to the high kinetic energy of gas molecules.

Many states of matter

solid, liquid, gas, plasma …



superfluids, liquid crystals, solid solutions, aerogels, foams, thin films, colloids, immiscible liquid mixtures, gas dissolved in liquid, condensed matter, biopolymers…..

Molecular models

- solid
- liquid
- gas

Discuss, first in pairs, then in groups:

How does each model account for observable physical behaviour – shape, ability to flow, elasticity, surface, changes of state?

Solids, Liquids, and Gases

INTRODUCTION

The three states of matter are solid, liquid and gaseous states.

One substance can exist in one state at room temperature but the other two states are available at different temperatures. For example water exists as liquefied at room temperature but exists as gas and solid above 100^{0} C and below 0^{0} C.

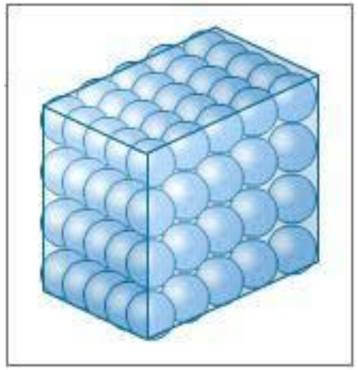
Solid <----------> liquid <-------> Gas

There are some cases in which there will be direct transformation of solid into gaseous state or vice versa without obtaining liquid state. This is called sublimation.

Solid < ------------ > gas   example: camphor, naphthalene

Materials can be classified as solids, liquids, or gases based on whether their shapes and volumes are definite or variable.

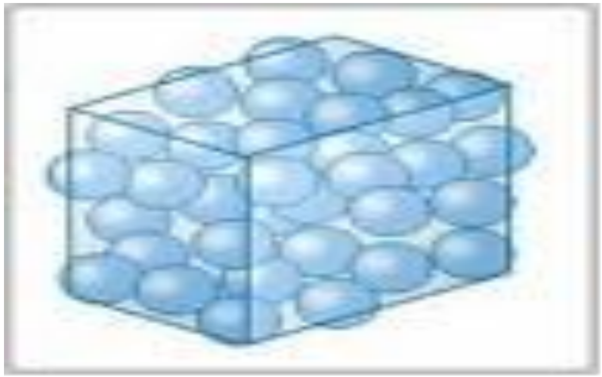
- **Solid** – a state of matter in which materials have a definite shape and a definite volume.
- The term definite means that the shape or volume of a pencil will not change as you move it from a desk to your backpack. However, the term definite doesn't mean that the shape or volume of that pencil can never change. After all, you can change the shape of a pencil by sharpening it.
- The arrangement of molecules in a solid is pictured below.



Liquid – a state of matter in which a material has a definite volume but not a definite shape.

-A liquid always has the same shape as it container and can be poured from one container to another.

-The arrangement of molecules in a liquid is pictured below.



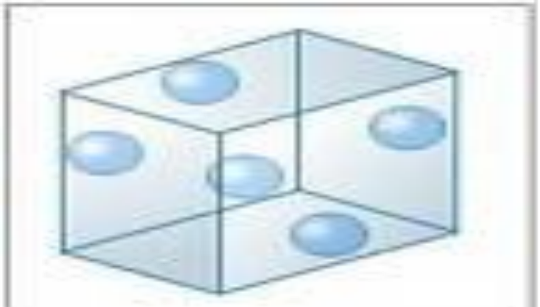
Gas – a state of matter in which a material has neither a definite shape nor a definite volume.

-A gas takes the shape and volume of its container.

-If you picture a balloon, the shape of the helium gas is the same as the shape of the balloon itself.

-The volume of the helium in a balloon is equal to the volume of the balloon.

-The arrangement of molecules in a gas is pictured below.



Plasma – a state that exists extremely high temperatures

-99% of all matter that can be observed in the universe exists in a state that is not common on Earth.

Kinetic Energy – the energy an object has due to its motion

-The faster an object goes, the greater its kinetic energy.

-According to the kinetic theory of matter, particles inside a moving baseball are moving along with the particles of air that the baseball is traveling through.

-Kinetic theory of matter says that all particle of matter are in constant motion.

Gases: bulk properties

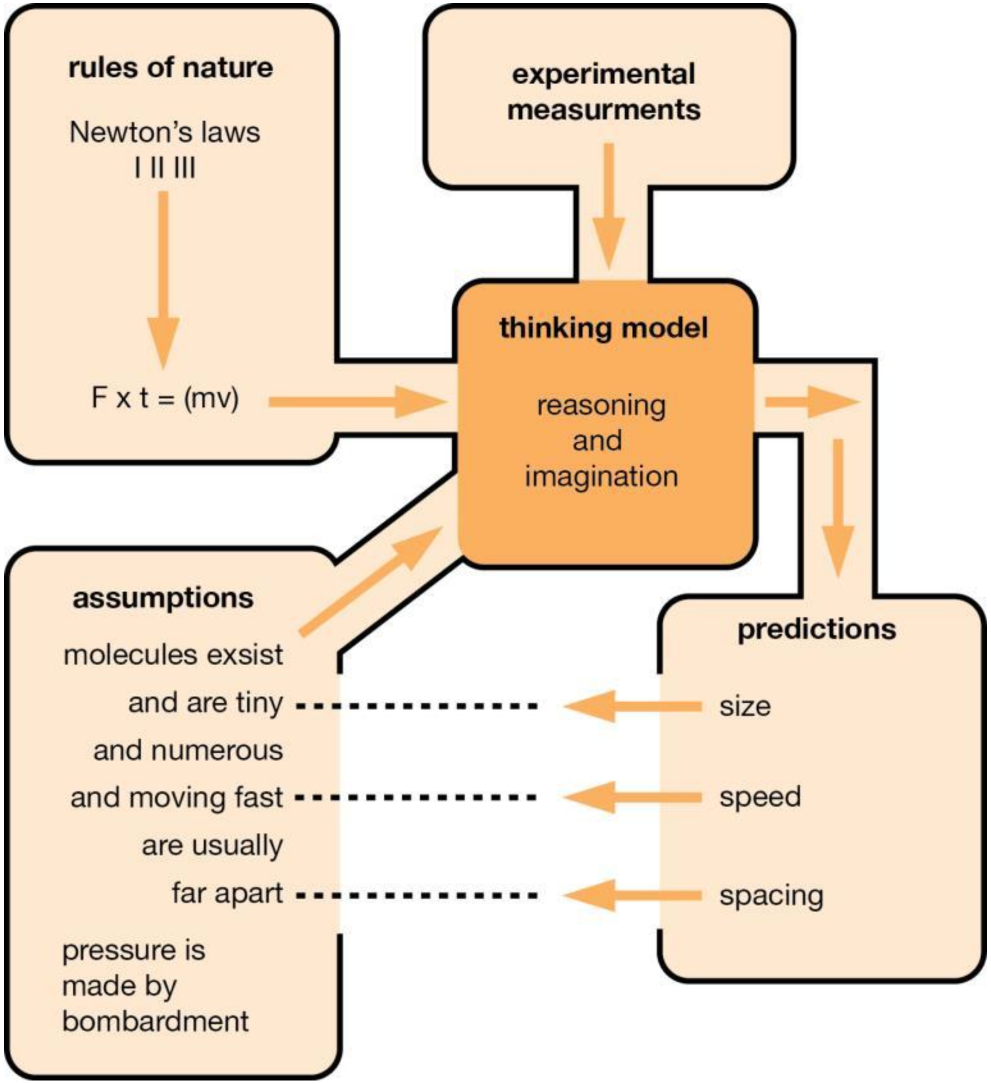
quantity	**symbol**	**SI unit**
pressure	p	Pa (Nm^{-2})
volume	V	m^3
temperature	T	kelvin, K
density	ρ	$kg\ m^{-3}$

pressure = force applied over a unit area.

$$p = \frac{F}{A}$$

An ideal gas

- huge number of point molecules (occupy negligible volume) in continual random motion (and so ‘kinetic’)
- colliding elastically with each other and with container walls
- no forces between the molecules, except in collision
- time in collisions very small compared to time between collisions
- distance travelled between collisions (‘mean free path’) depends on gas density
- average speed of molecules depends on gas temperature
- in a gas composed of different molecules, the average molecular E_k is the same for all, so those with larger mass have smaller speed


rules of nature
Newton's laws
I II III
F x t = (mv)
experimental
measurments
thinking model
reasoning
and
imagination
assumptions
molecules exsist
and are tiny
and numerous
and moving fast
are usually
far apart
pressure is
made by
bombardment
predictions
size
speed
spacing

Gas Laws

Purpose of the Experiment

To demonstrate the complexities involved in measuring properties of gases related to:

1.) Complications in weighing due to the buoyancy of air;

2.) Problems in pressure measurements over water; and,

3.) Non-ideality of Gases.

Physical Characteristics of Gases

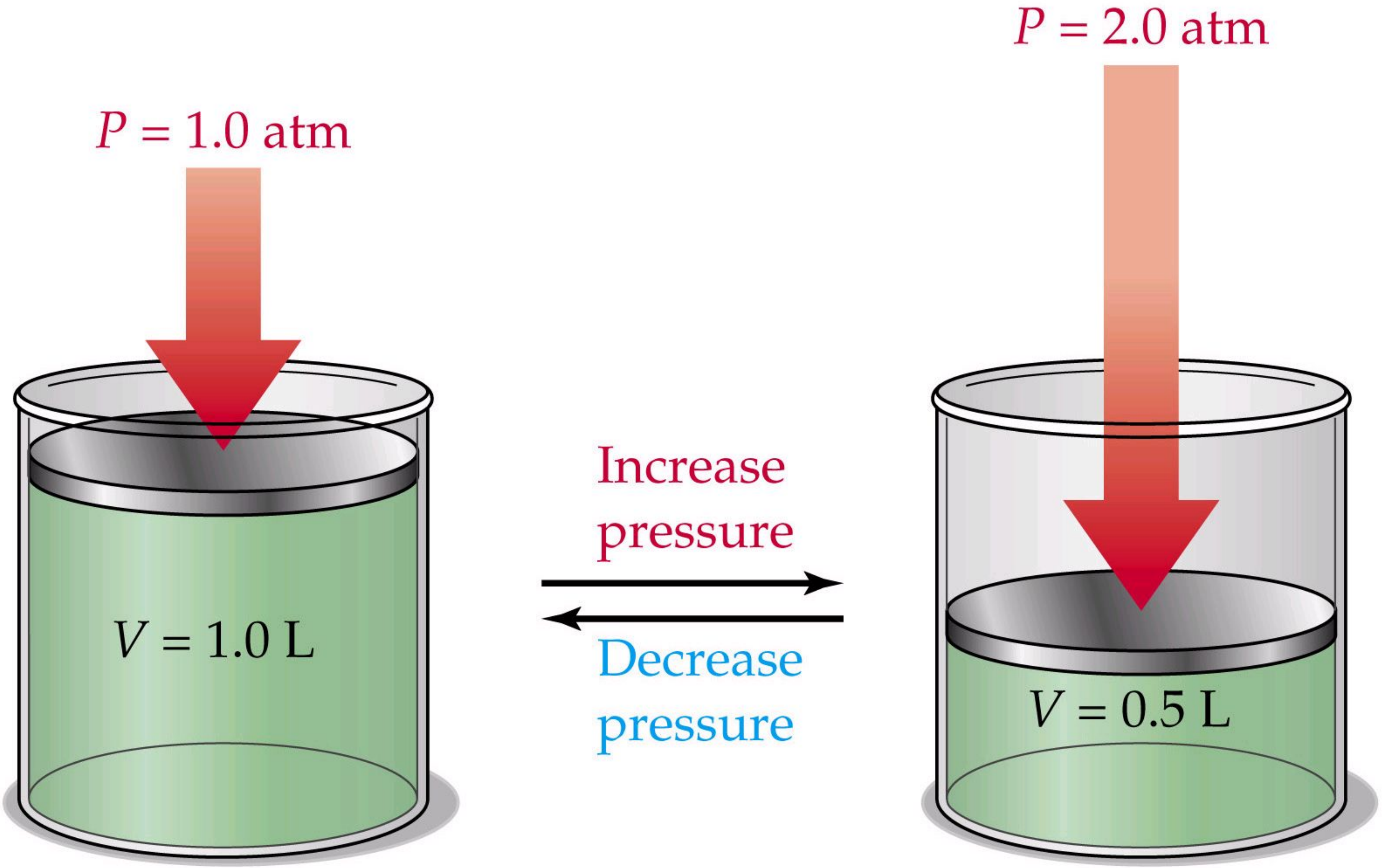
Physical Characteristics	Typical Units
Volume, **V**	liters (**L**)
Pressure, **P**	atmosphere (1 **atm** = 1.015×10^5 N/m^2)
Temperature, **T**	Kelvin (**K**)
Number of atoms or molecules, **n**	**mole** (1 mol = 6.022×10^{23} atoms or molecules)

Boyle's Law

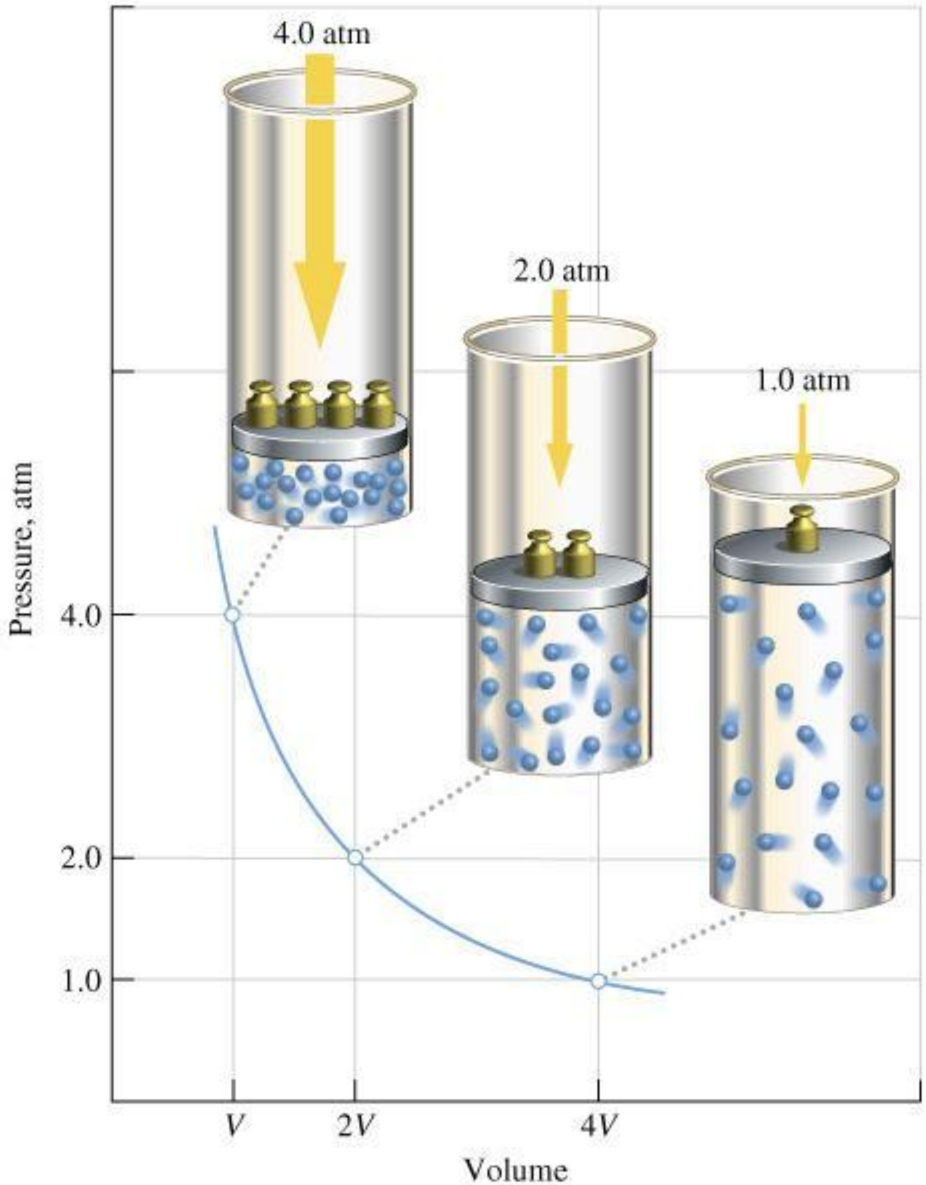
"Father of Modern Chemistry"
Robert Boyle
Chemist & Natural Philosopher
Listmore, Ireland
January 25, 1627 – December 30, 1690

- **Pressure and volume are inversely related** at **constant temperature**.
- **PV = K**
- As one goes up, the other goes down.
- $P_1V_1 = P_2V_2$

Boyle's Law: $P_1V_1 = P_2V_2$



Boyle's Law: $P_1V_1 = P_2V_2$

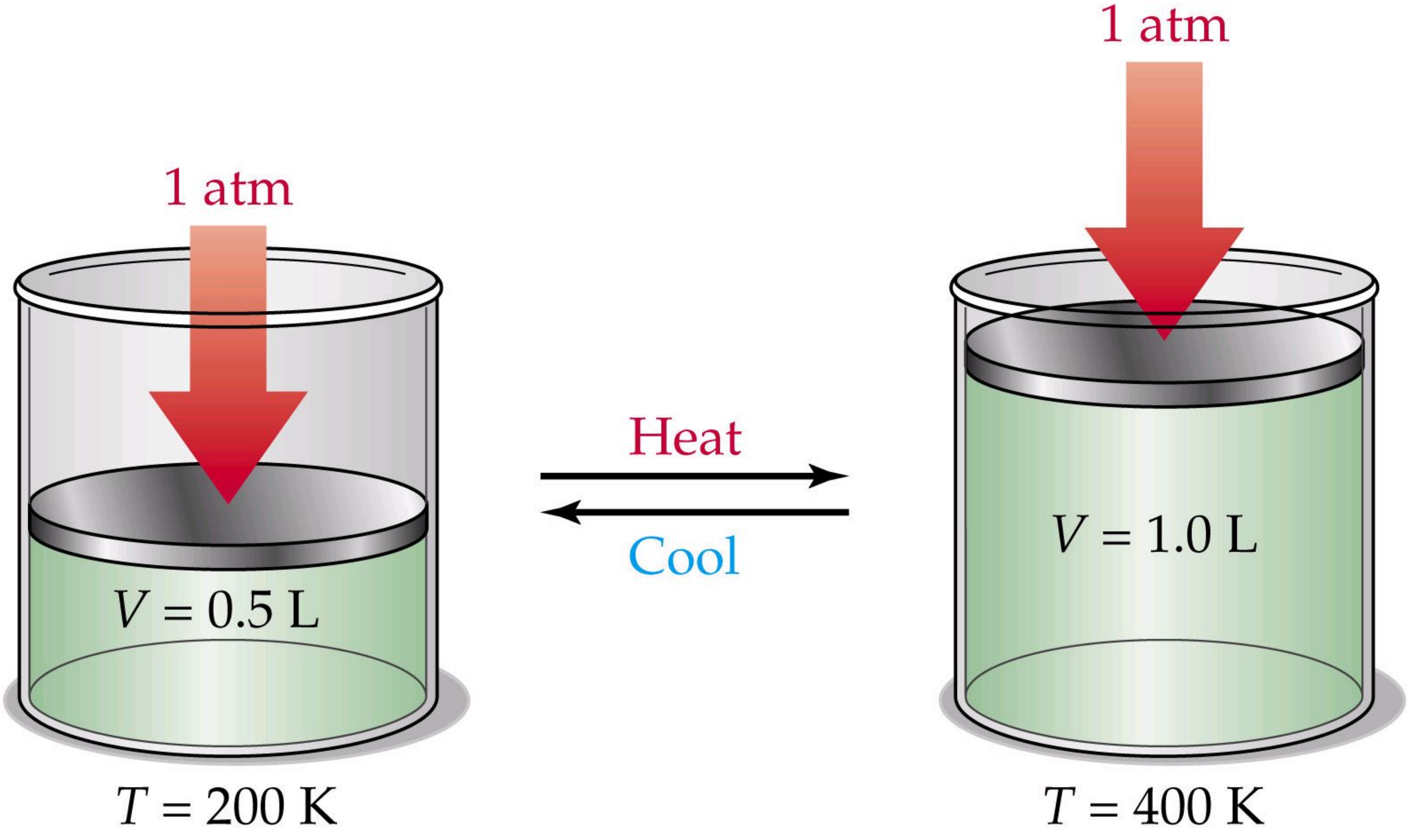


Charles' Law

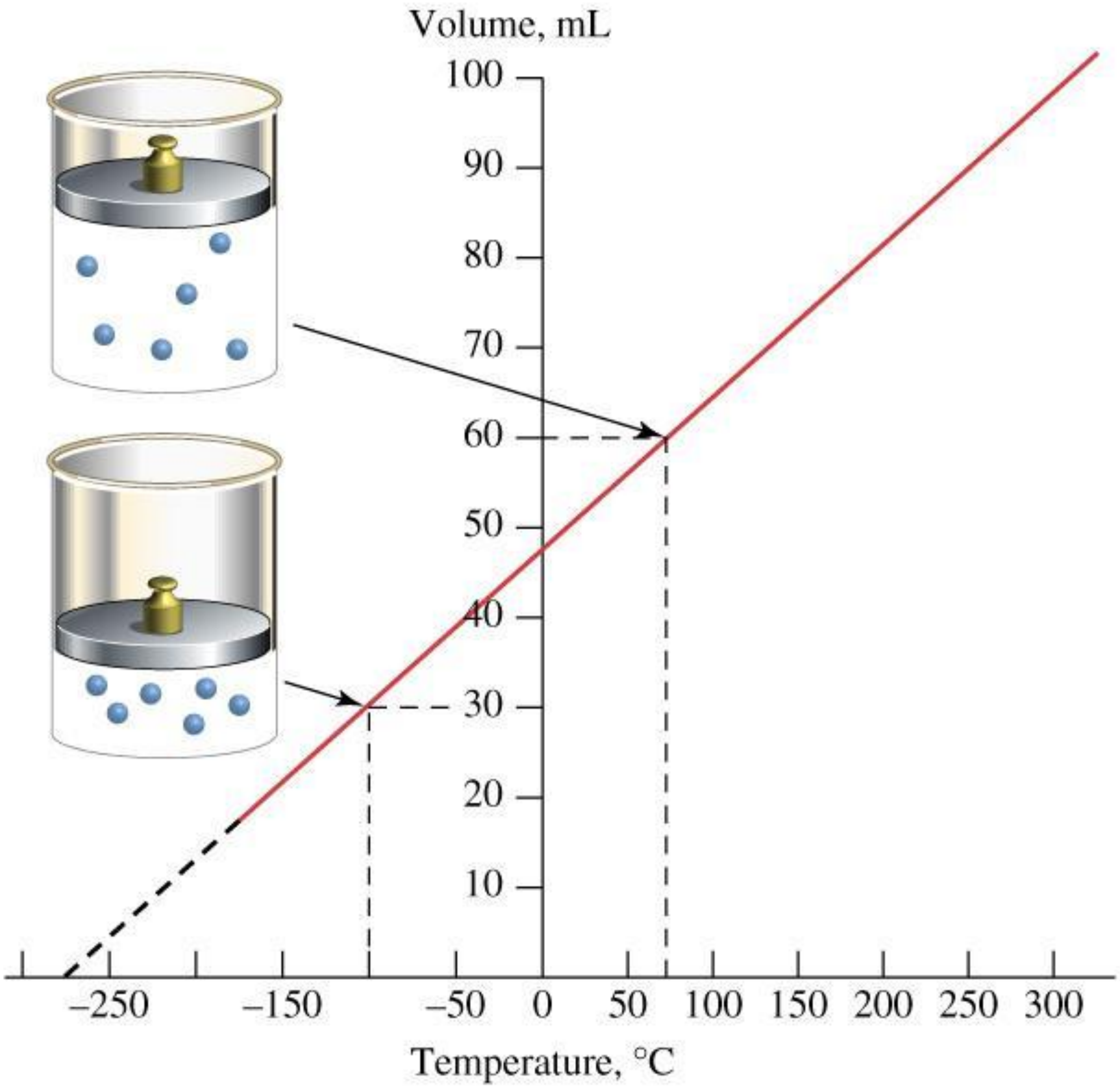
- **Volume** of a gas **varies directly with** the absolute **temperature** at **constant pressure.**
- **$V = KT$**
- **$V_1 / T_1 = V_2 / T_2$**

Jacques-Alexandre Charles
Mathematician, Physicist, Inventor
Beaugency, France
November 12, 1746 – April 7, 1823

Charles' Law: $V_1/T_1 = V_2/T_2$



Charles' Law: $V_1/T_1 = V_2/T_2$

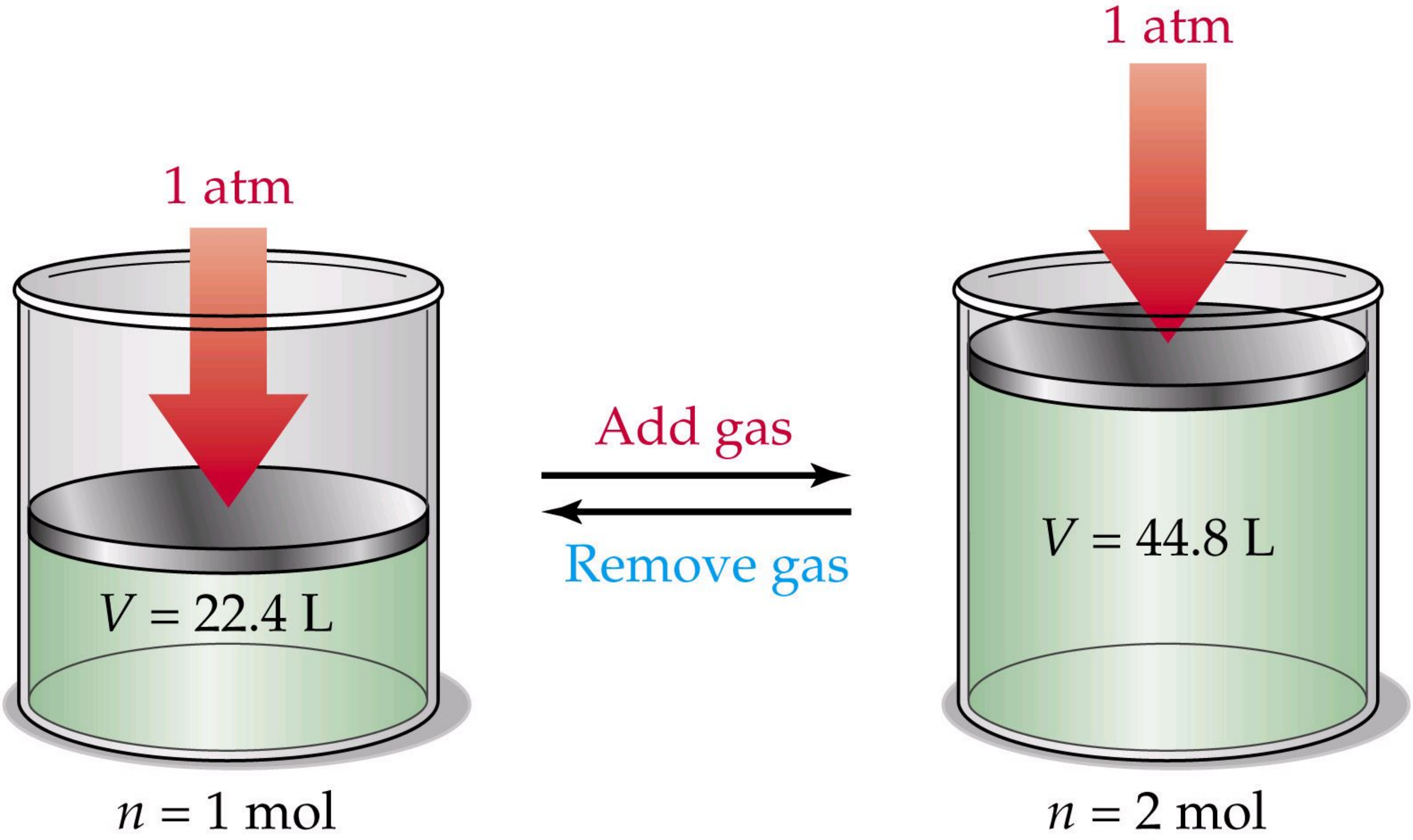


Avogadro's Law

Amedeo Avogadro
Physicist
Turin, Italy
August 9, 1776 – July 9, 1856

- At **constant temperature and pressure**, the **volume** of a gas is **directly related to the number of moles**.
- $V = K n$
- $V_1 / n_1 = V_2 / n_2$

Avogadro's Law: $V_1/n_1=V_2/n_2$



Gay-Lussac Law

- At **constant volume**, **pressure** and **absolute temperature** are **directly related**.
- **$P = k\,T$**
- **$P_1 / T_1 = P_2 / T_2$**

Joseph-Louis Gay-Lussac
Experimentalist
Limoges, France
December 6, 1778 – May 9, 1850

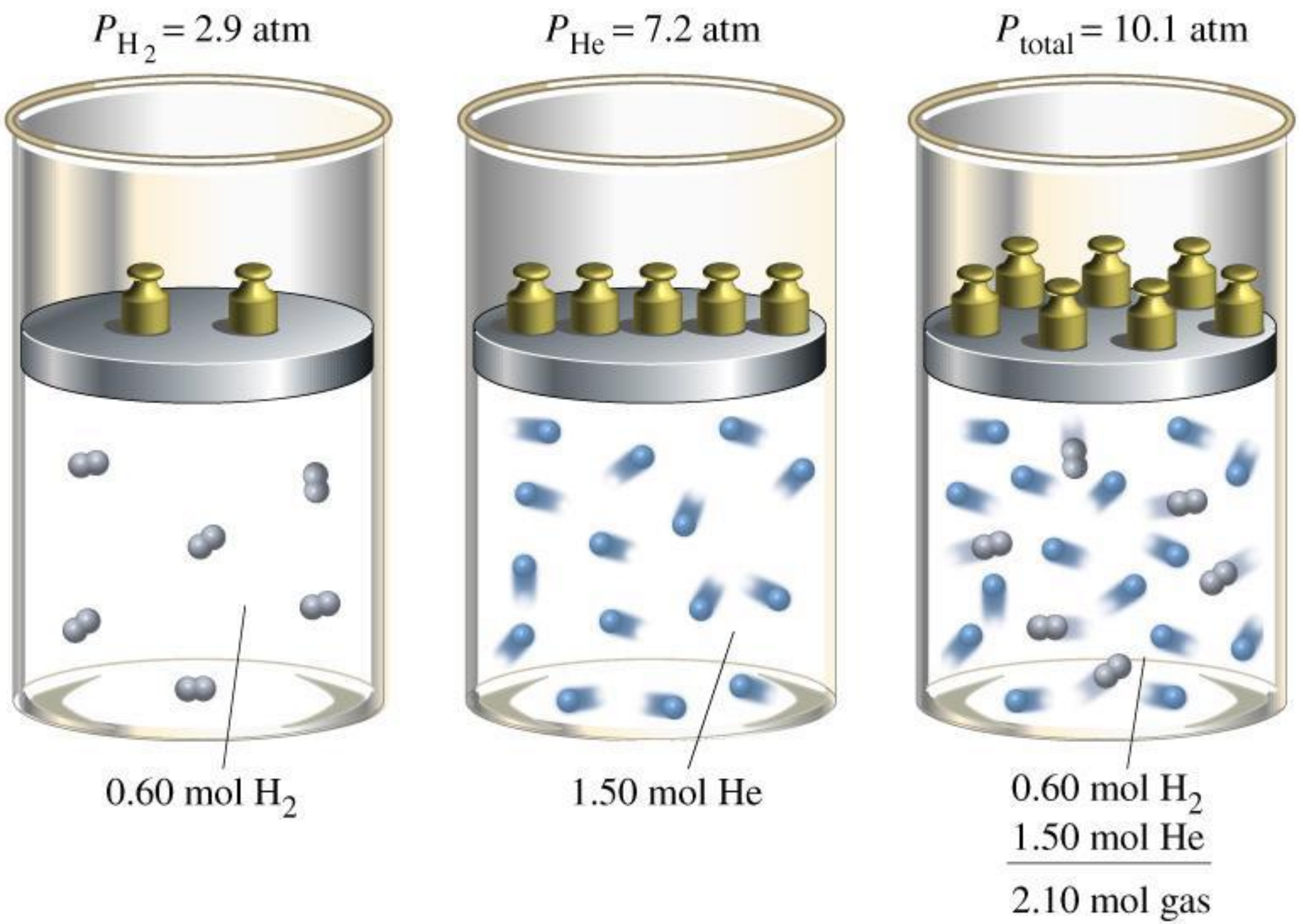
Dalton's Law

- The **total pressure** in a container is the **sum of the pressure each gas** would exert if it were alone in the container.
- The total pressure is the sum of the partial pressures.
- $P_{Total} = P_1 + P_2 + P_3 + P_4 + P_5 \ldots$

(For each gas $P = nRT/V$)

John Dalton
Chemist & Physicist
Eaglesfield, Cumberland, England
September 6, 1766 – July 27, 1844

Dalton's Law



(a) 5.0 L at 20 °C **(b)** 5.0 L at 20 °C **(c)** 5.0 L at 20 °C

Vapor Pressure

- ***Water evaporates!***
- When that water evaporates, the **vapor has a pressure**.
- Gases are often collected over water so the **vapor pressure of water** must be **subtracted** **from the total pressure**.

Differences Between Ideal and Real Gases

	Ideal Gas	Real Gas
Obey PV=nRT	Always	Only at very low P and high T
Molecular volume	Zero	Small but nonzero
Molecular attractions	Zero	Small
Molecular repulsions	Zero	Small

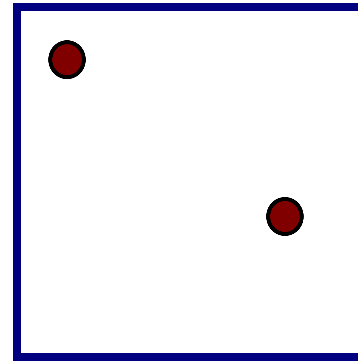
Real Gases

- **Real molecules** **do take up space** and **do interact** with each other (especially polar molecules).
- Need to **add correction factors** to the ideal gas law to account for these.

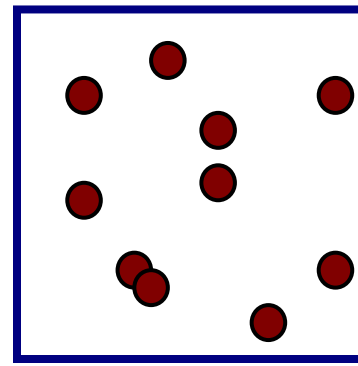
Ideally, the VOLUME of the molecules was neglected:

Ar gas, ~to scale, in a box 3nm x 3nm x3nm

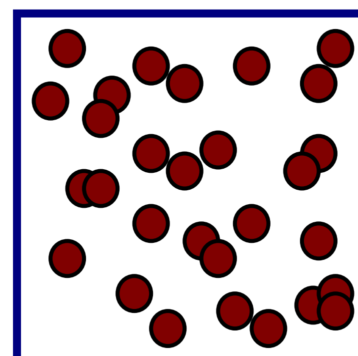
at **1** Atmosphere Pressure



at **10** Atmospheres Pressure



at **30** Atmospheres Pressure



But since real gases do have volume, we need:

Volume Correction

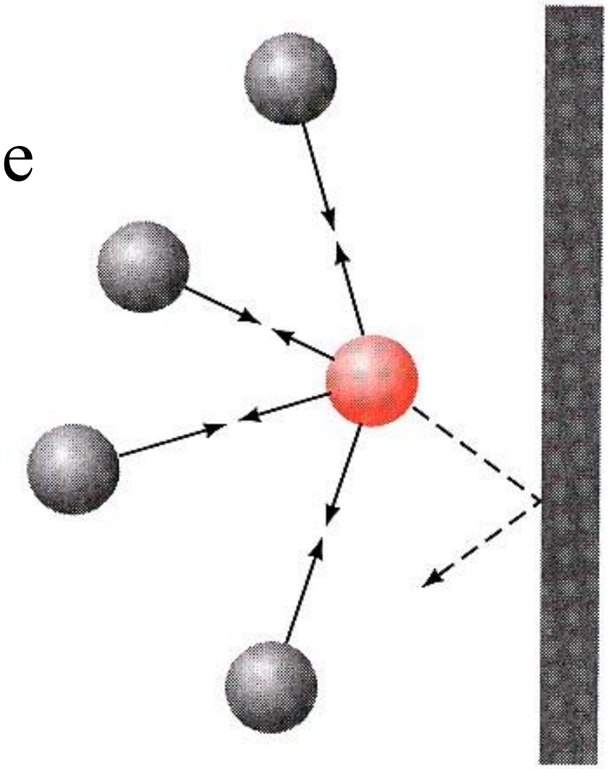
- The **actual volume** free to move in is **less** because of particle size.
- **More molecules** will have **more effect**.
- Corrected volume **$V' = V - nb$**
- "**b**" is a constant that **differs for each gas**.

Pressure Correction

- Because the **molecules are attracted** to each other, the **pressure** on the container will be **less than ideal**.

- Pressure **depends on** the **number of molecules per liter**.

- Since **two molecules interact**, the **effect must be squared**.



$$P_{observed} = P - a\left(\frac{n}{V}\right)^2$$

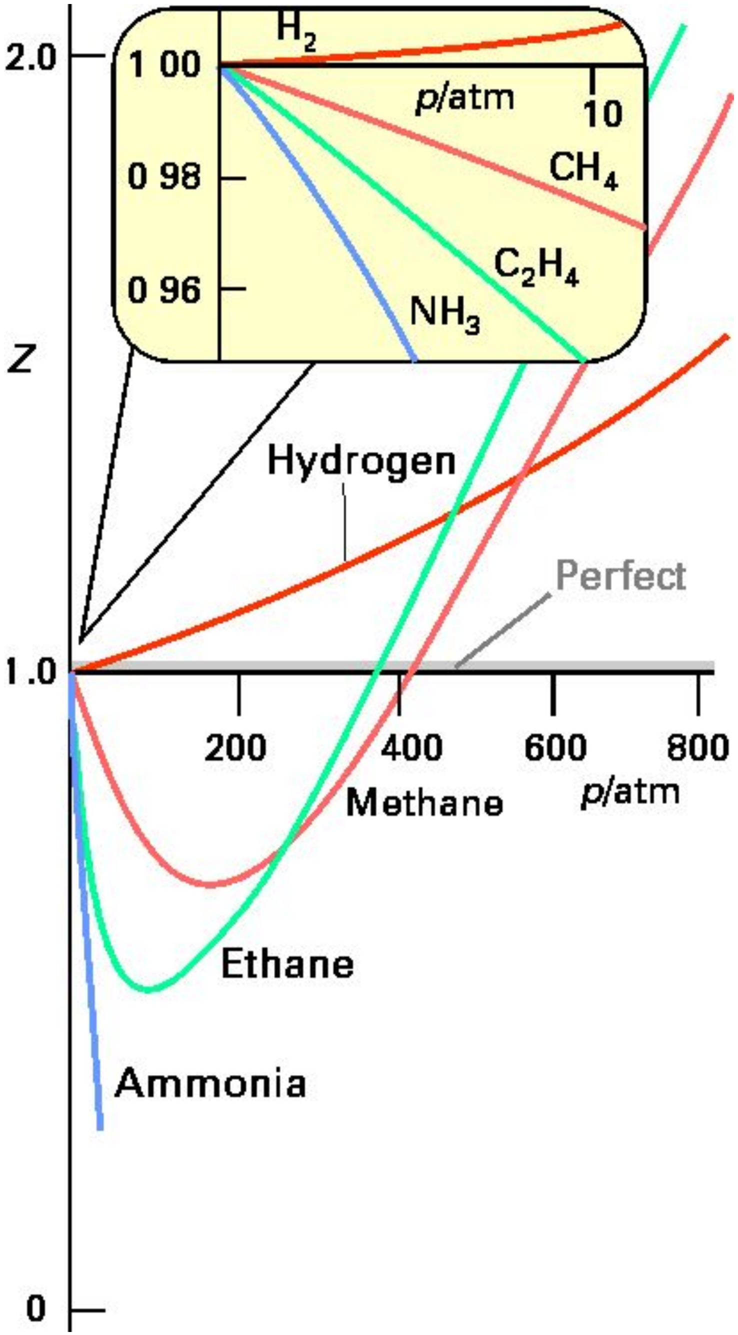
Van der Waal's equation

$$[P_{obs} + a\left(\frac{n}{V}\right)^2](V - nb) = nRT$$

Corrected Pressure **Corrected Volume**

- "**a**" and "**b**" are **determined by experiment**
- "**a**" and "**b**" are **different for each gas**
- **bigger molecules** have **larger "b"**
- "**a**" depends on both **size** **and** **polarity**

Johannes Diderik van der Waals
Mathematician & Physicist
Leyden, The Netherlands
November 23, 1837 – March 8, 1923



Compressibility Factor

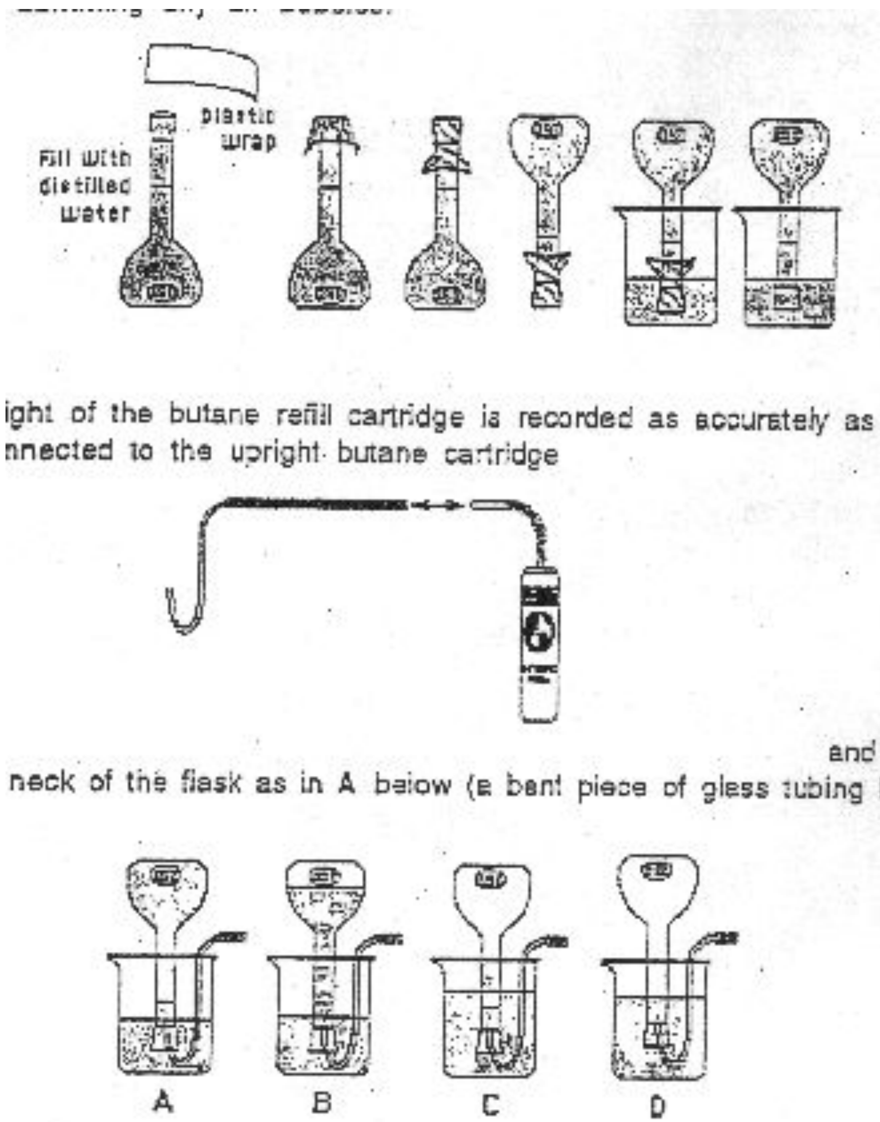
The most useful way of displaying this new law for real molecules is to plot the compressibility factor, **Z** :

For **n = 1**

$$Z = PV / RT$$

Ideal Gases have **Z = 1**

Part 1: Molar Volume of Butane



Page 194-195 in your Lab Packet

If you would like to take notes, these slides start on page 201 of your Lab Packet.

Molar mass of butane (C_4H_{10}) = ____________ g/mole

Mass of butane: ____________

n or n_B= ________

Molar mass of butane (C_4H_{10}) = ___________ g/mole

$(12.011 \times 4) + (1.008 \times 10) = 58.124$

Mass of butane: ___________

Initial weight of cartridge – final weight of cartridge

n or n_B = ________

$$\frac{\text{mass of butane}}{\text{Molar mass of butane}}$$

Ask your TA for the Lab Temperature and Pressure*

T = _____ ^{o}C P = ______torr V = ______L

T = _____ K P = ______atm 0.500 L

Note: K = ^{o}C + 273.15 & 1 atm = 760 torr

Apparent molar volume, (V_m = V / n) of butane at experimental T & P: V_m = _________ L / mole

0.500 L → **V/n** ← n → Calculated earlier

***These will be posted on the chalkboard.**

Verify the values are for your session before recording in your book.

Apparent molar volume of butane at STP; V_m = _____ L/mole

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

- P_1: Lab pressure
- V_1: 0.500 L
- P_2: 1 atm or 760 torr
- V_2: calculate
- T_1: Lab temperature (K)
- T_2: 273.15 K

$$V_m = \frac{V}{n}$$

- V_m: calculate
- V: V_2
- n: Already calculated

Partial pressure of water vapor in flask: P_w = ______torr

$$x = \ln P_w\,(torr) = 20.943 - \frac{5300}{T}$$

$$P_{vdw} = \frac{nRT}{(V - nb)} - \frac{an^2}{V^2}$$

$$P_w = 20.943 - \frac{5300}{T}$$

calculate x

Lab temperature (K)

$$P_w\,(torr) = e^x$$

Partial pressure of butane in flask: __________ torr

__________atm

calculate → $P_B = P_{total} - P_w$ ← calculated in previous step (torr)

↑

Lab pressure (torr)

Partial pressure of butane: P_{vdw} = __________ atm

0.08206 L.atm/mole. K

Lab temp.

Already calculated

14.47 atm .L^2/mole^2

calculate → $$P_{vdw} = \frac{n R T}{(V - n b)} - \frac{a n^2}{V^2}$$

0.500 L

0.1226 L/mole

0.500 L

Compressibility factor for butane : Z_B = ________

Partial pressure of butane in flask (atm)
Calculated earlier

0.500 L

$$Z_B = \frac{P_B V}{n_B R T}$$

$$Z_B = \frac{P_B V}{n_B R T}$$

calculate → Z_B

Lab temperature (K)

same as "n"
already calculated

0.08206 L.atm/mole. K

Estimated second Virial Coefficient for Butane at room temperature:

$B_B =$ ____________ L/mole

0.500 L

calculate

$$B_B = (Z_B - 1) \times \frac{V}{n}$$

$B_B = (Z - 1) \times \frac{V}{n}$

already calculated

Calculated in previous step
Compressibility factor for butane

Part 2: Buoyancy Effect

Filling Ziplok bag with butane gas

Page 197
in your
Lab Packet

Initial mass cartridge__________g bag ___________ g

Final mass __________g ____________g

Change in mass __________g ____________g

Discrepancy is the difference between these two masses

Discrepancy: ___________g

Moles of Butane in bag: n = ______ moles

Change in cartridge mass

calculate → $n = \frac{\text{mass}}{\text{Molar mass}}$

58.124 g/mole

Calculated volume of Butane in bag: ____L

Calculated in previous step

calculate →

$$V = \frac{n \times B_B}{(Z_B - 1)}$$

$V = \frac{n \times B_B}{(Z_B - 1)}$

Estimated second Virial Coefficient for Butane at room temperature Calculated in Part 1 (p 195).

Compressibility factor for Butane Calculated in Part 1 (p 195).

Estimated density of air at experimental T and P: d= _____g / L

Buoyancy effect of displaced volume of air
(the mass discrepancy)

calculate

$$d = \frac{mass}{volume}$$

$$d = \frac{mass}{volume}$$

Calculated volume of Butane in bag
(calculated in previous step)

Estimated Molar mass of air: ______g/mole

Estimated density of air
(calculated in previous step)

0.08206 L.atm/mole. K

calculate

$$M = \frac{d\,R\,T}{P}$$

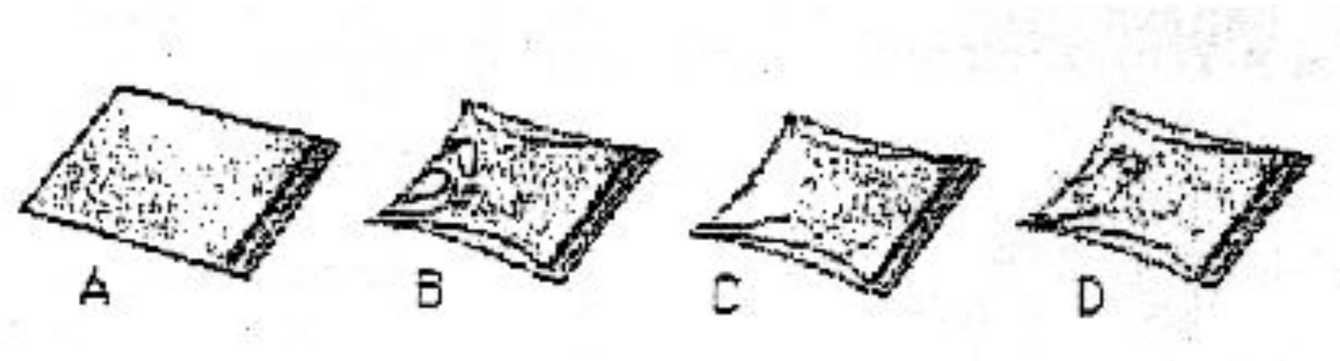
$M = \frac{d\,R\,T}{P}$

Lab temperature (K)

Lab pressure (atm)

Part 3: Conservation of Mass

Gas generating reaction in a closed system



Page 199
in your
Lab Packet

Part 3: Conservation of Mass

Gas generating reaction in a closed system

Molar mass of $NaHCO_3$: ______g/mole

Moles of $NaHCO_3$: ________ mole

Part 3: Conservation of Mass

Gas generating reaction in a closed system

Molar mass of $NaHCO_3$: ______g/mole

(22.990) + (1.008) + (12.011) + (3 × 15.999) = 84.006 g/mole

Moles of $NaHCO_3$: ________ mole

$$\text{moles} = \frac{\text{mass}}{\text{Molar mass}}$$

Weight of bag and reaction components:

Before reaction: ______ g after reaction : _______ g

Discrepancy is the difference between these two weights.

Discrepancy: ______g

Estimated volume of expansion: ________ L

calculate → $V = \dfrac{\text{weight discrepancy}}{\text{density of air}}$

Determined in Part 2 (p 197).

Reaction:

1 $NaHCO_3(aq) + CH_3CO_2H(aq) \rightarrow$ _____ + 1 $CO_2(g)$ + ______

Expected moles of CO_2(gas) : ____________ moles

Expected volume of gas at laboratory T & P: _____L

0.08206 L.atm/mole.K

Expected moles of CO_2
(from previous step)

Lab temp. (K)

calculate

$$V_{gas} = \frac{n_{CO_2}RT \big/ P_{atm}}{1 - \left[P_W \big/ P_{atm} \right]}$$

Lab pressure (atm)

Lab pressure (atm)

Partial pressure of water vapor. (**Note: Convert your Pw to atm**.)
(You calculated Pw in torr in Part 1 – p 195.)

Check Out from the Stockroom

1000 ml beaker
500 ml volumetric flask
Tygon tubing with Hook
Butane cylinder
1 piece of plastic wrap
1 quart Ziploc Bag
5 dram vial with lid*

In The Hood:

50% Acetic Acid in a
500 ml plastic dispenser

By Balances:

Sodium bicarbonate, $NaHCO_3$

Clean Up:

***Dispose of liquid waste in appropriate container. Rinse vial and lid with water and return them to the stockroom.**

Hazards:

50% Acetic acid (corrosive, sharp, irritating odor)
Butane (flammable)

Waste:

5 gallon liquid waste for $NaHCO_3$ and acetic acid

This Week: April 28 - 30

Turn In: **Gas Laws Experiment** pp. 195-199 + calculations page. ❖

There is no Postlab! 😊

- ❖ **Students must do all calculations before leaving lab,** due to the complex nature of the calculations.
- ❖ **Calculations must be shown on a separate piece of paper**, with units to the correct number of significant figures. Datasheets need to be in ink, but calculations may be done with pen or pencil.
- ❖ **Calculations scribbled in the margins** of the lab pages are **NOT ACCEPTABLE**.

Evaluation Forms:

To evaluate Chem 1319, you should be receiving an email from the CET Committee with the following link:

https://itweb.mst.edu/auth-cgi-bin/cgiwrap/distanceed/evals/survey.pl

The ***Chemistry Outstanding TA Awards*** are based on these evaluations. So please complete the evaluations, as TAs without enough surveys completed are not considered eligible for the award.

Chem 1319 Final Exam – May 5 - 7

1 Hour Exam during regularly scheduled class time*.

You will need a calculator.

Checkout after exam. ***($35 fine for not checking out.)***

Verify all of the equipment is in the drawer.

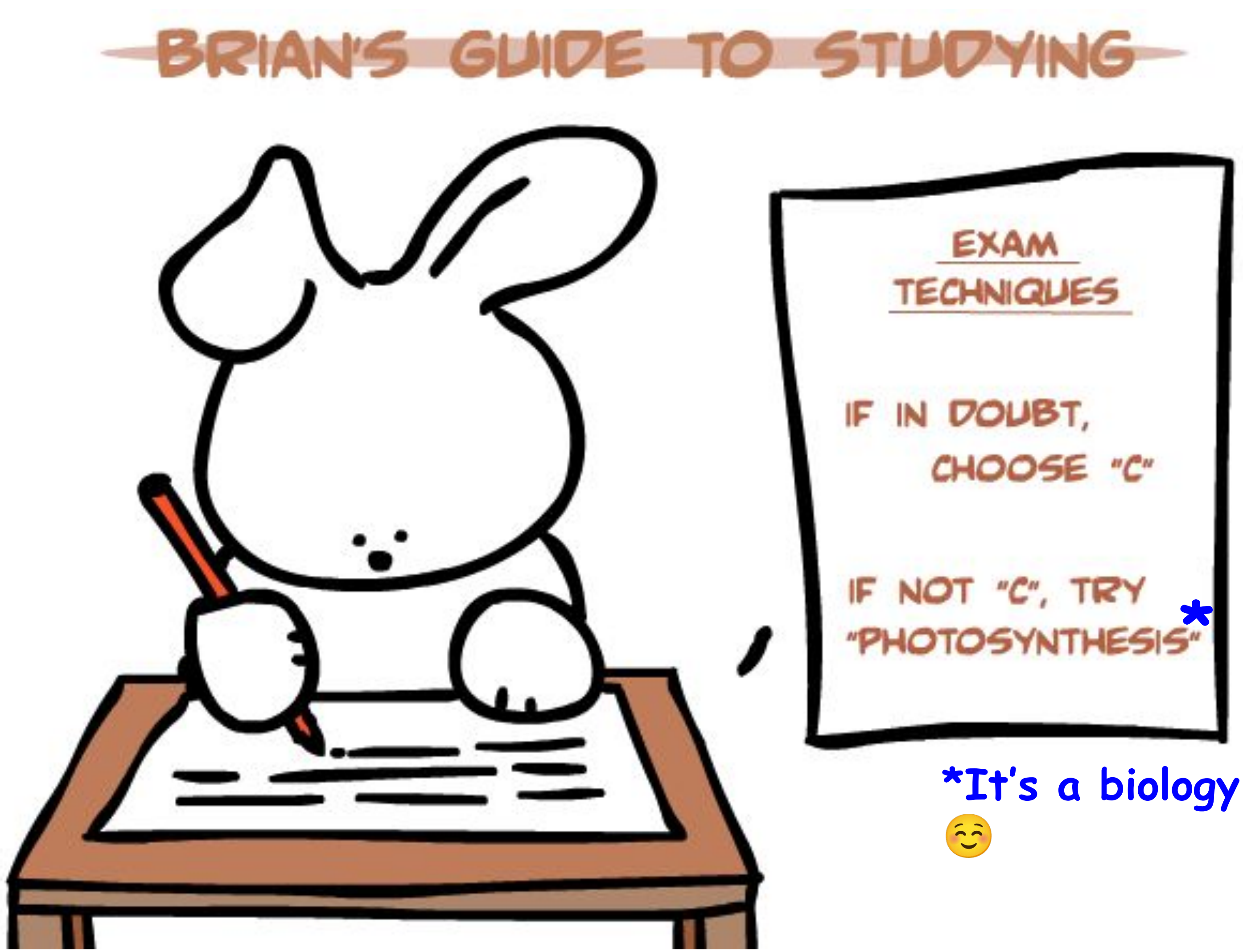
Fill in green slips for any broken items.

(This means NO Chem 1319 Final during Finals Week.)

***If you need to take the test on a different day, email Dr. Bolon.**

If you are taking the test at the testing center, email Dr. Bolon.

Review Session – Tuesday, April 28,
4:00 pm – 6:00 pm in G3 Schrenk.



*It's a biology joke! 😊

Don't be a dumb bunny! - Study!