1

Gases Make Airbags Work

- sodium azide decomposes to sodium and nitrogen.

$$2\ NaN_3(s) \rightarrow 2\ Na(s) + 3\ N_2(g)$$

Syllabus Learning Outcomes : 8, 10, and 11

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2

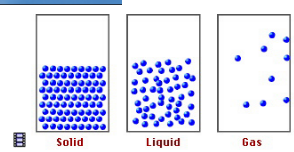
BEHAVIOR OF GASES

3

Hot Air Balloons — How Do They Work?

4

THREE STATES OF MATTER



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Gases

- Are mostly empty space.
- Expand infinitely.
- Occupy containers uniformly and completely.
- Diffuse and mix rapidly.

6

Gases Can be Modeled:

- P = pressure (atmospheres)
- V = volume of the gas (L)
- T = temperature (K)
- n = amount (moles)
- R = gas constant 0.0821 (L*atm)/(mol*K)

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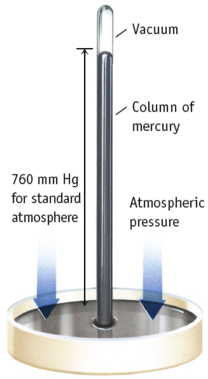
Pressure

Pressure of air is measured with a **BAROMETER** (developed by Torricelli in 1643)



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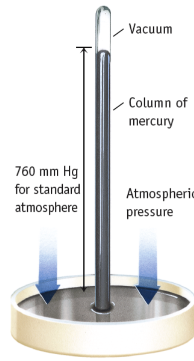
Pressure

Hg rises in tube until force of Hg (down) balances the force of atmosphere (pushing up).

P of Hg pushing down related to

- Hg density
- column height



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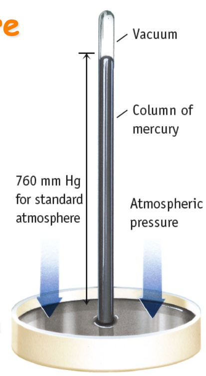
Barometers Measure Pressure

- 1 atm
  = 760 mm Hg column
  = 29.9 inches Hg
  = about 34 feet of water

SI unit is PASCAL, Pa, where 1 atm = 101.325 kPa



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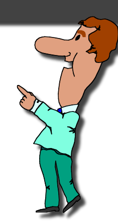
IDEAL GAS LAW

P V = n R T

- Other gas laws can be derived from the Ideal Gas Law.
- Gas law problems may have 1 or 2 sets of conditions.



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Boyle's Law

When n and T are constant

PV = (nRT) = k

$P \propto 1/V$

Means if P↑ then V↓

Doubling V halves P

$P_1V_1 = P_2V_2$

Robert Boyle

12

Boyle's Law

A bicycle pump is a good example of Boyle's law.

As the volume of the air trapped in the pump is reduced, its pressure goes up, and air is forced into the tire.

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Charles's Law

When n and P are constant,

$V = (nR/P)T = kT$

Means if V↑, then T↑

Doubling T doubles V

$V_1/T_1 = V_2/T_2$

Jacques Charles

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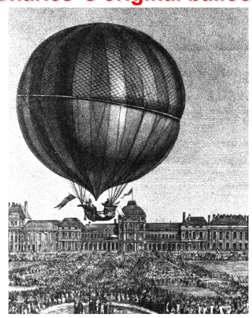
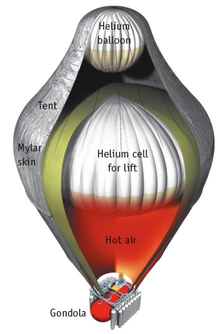
Charles's original balloon





Modern long-distance balloon

15

Charles's Law

Balloons in liquid N_2 (-196 °C) shrink.

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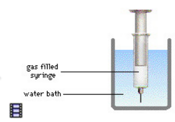
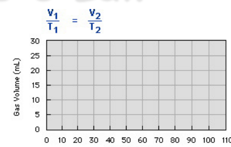
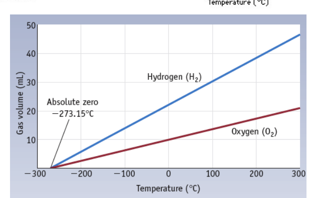
Charles's Law





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



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Avogadro's Hypothesis

When T and P are constant

$V = n\,(RT/P) = kn$

Means if V↑, then n↑

Doubling n doubles V

$$\frac{V_1}{n_1} = \frac{V_2}{n_2}$$

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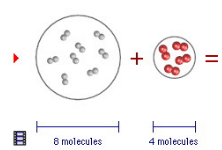
Avogadro's Hypothesis

$2\,H_2(g) + O_2(g) \rightarrow 2\,H_2O(g)$



V=kn when T and P are constant

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Standard Volume

V = 22.4 L for 1 mol of an ideal gas at standard pressure and temperature (STP)

- T = 273 K
- P = 1.00 atm

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Using PV = nRT

How much N_2 is req'd to fill a small room with a volume of 960 cubic feet (27,000 L) to P = 745 mm Hg at 25 °C?

R = 0.082057 L•atm/K•mol ⟸ Note units

Solution

1. Get all data into proper units (for R)

V = 27,000 L

T = 25 °C + 273 = 298 K

P = 745 mm Hg (1 atm/760 mm Hg) = 0.98 atm

21

Using PV = nRT

How much N_2 is req'd to fill a small room with a volume of 960 cubic feet (27,000 L) to P = 745 mm Hg at 25 °C?

2. Now calc. n = PV / RT

$$n = \frac{(0.98\ \text{atm})(2.7 \times 10^4\ \text{L})}{(0.0821\ \text{L}\cdot\text{atm/K}\cdot\text{mol})(298\ \text{K})}$$

n = 1.1×10^3 mol (or about 30 kg of gas)

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What is the final volume of tea?

	Initial	Final
T	25°C	48°C
P	759mmHg	760mmHg
V	6oz	~6oz

- Liquids & solids do not obey gas laws

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Gases with Stoichiometry

$2\ H_2O_2(liq) \longrightarrow 2\ H_2O(g) + O_2(g)$

Decompose 1.1 g of H_2O_2 in a flask with a volume of 2.50 L. What is the pressure of O_2 at 25 °C? Of H_2O?

Bombardier beetle uses decomposition of hydrogen peroxide to defend itself.

25

Gases with Stoichiometry

$2 H_2O_2(liq) \longrightarrow 2 H_2O(g) + O_2(g)$

Decompose 1.1 g of H_2O_2 in a flask with a volume of 2.50 L. What is the pressure of O_2 at 25 °C? Of H_2O?

Solution

Strategy:
Calculate moles of H_2O_2 and then moles of O_2 and H_2O.
Finally, calc. P from n, R, T, and V.

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Gases with Stoichiometry

$2 H_2O_2(liq) \longrightarrow 2 H_2O(g) + O_2(g)$

Decompose 1.1 g of H_2O_2 in a flask with a volume of 2.50 L. What is the pressure of O_2 at 25 °C? Of H_2O?

Solution

$$1.1 \text{ g } H_2O_2 \cdot \frac{1 \text{ mol}}{34.0 \text{ g}} = 0.032 \text{ mol}$$

$$0.032 \text{ mol } H_2O_2 \cdot \frac{1 \text{ mol } O_2}{2 \text{ mol } H_2O_2} = 0.016 \text{ mol } O_2$$

27

Gases with Stoichiometry

$2 H_2O_2(liq) \longrightarrow 2 H_2O(g) + O_2(g)$

Decompose 1.1 g of H_2O_2 in a flask with a volume of 2.50 L. What is the pressure of O_2 at 25 °C? Of H_2O?

Solution

$$P \text{ of } O_2 = nRT/V$$

$$= \frac{(0.016 \text{ mol})(0.0821 \text{ L}\cdot\text{atm/K}\cdot\text{mol})(298 \text{ K})}{2.50 \text{ L}}$$

P of O_2 = 0.16 atm

28

Gases with Stoichiometry

$2 H_2O_2(liq) \longrightarrow 2 H_2O(g) + O_2(g)$

What is P of H_2O? Could calculate as above. But recall Avogadro's hypothesis.

$V \propto n$ at same T and P

$P \propto n$ at same T and V

There are 2 times as many moles of H_2O as moles of O_2. P is proportional to n. Therefore, P of H_2O is twice that of O_2.

P of H_2O = 0.32 atm

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Dalton's Law of Partial Pressures

$2 H_2O_2(liq) \longrightarrow 2 H_2O(g) + O_2(g)$

0.32 atm 0.16 atm

What is the total pressure in the flask?

P_{total} in gas mixture = $P_A + P_B + \ldots$

Therefore,

$P_{total} = P(H_2O) + P(O_2) = 0.48$ atm

Dalton's Law: total P is sum of PARTIAL pressures.

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To Slide 47 UHT 23

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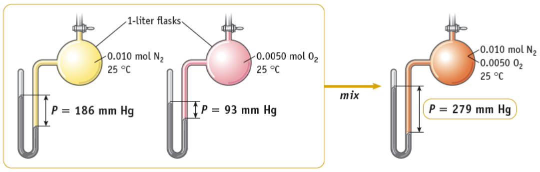
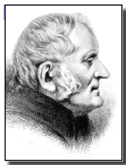
Dalton's Law





John Dalton
1766-1844

32

GAS DENSITY

Low density helium

Higher Density air

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GAS DENSITY

$PV = nRT$

$$\frac{n}{V} = \frac{P}{RT}$$

n = m/M

$$\frac{m}{M \cdot V} = \frac{P}{RT}$$

where M = molar mass

and density (d) = m/V

$$d = \frac{m}{V} = \frac{PM}{RT}$$

$d \propto M$

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The Disaster of Lake Nyos

- Lake Nyos in Cameroon was a volcanic lake.
- CO_2 built up in the lake and was released explosively on August 21, 1986.
- 1700 people and hundreds of animals died.
- See Chapter 14 for more information

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USING GAS DENSITY

The density of air at 15 °C and 1.00 atm is 1.23 g/L. What is the molar mass of air given V=1.00L?

1. Calc. moles of air.

   V = 1.00 L P = 1.00 atm T = 288 K

   n = PV/RT = 0.0423 mol

2. Calc. molar mass m = d * V

   mass/mol = 1.23 g/0.0423 mol = 29.1 g/mol

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KINETIC MOLECULAR THEORY (KMT)

KMT explains gas laws. The KMT assumptions are:

- Gases consist of molecules in constant, random motion.
- Pressure arises from collisions with container walls.
- No attractive or repulsive forces between molecules. Collisions are elastic.
- Volume of molecules is negligible.

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Kinetic Molecular Theory

Molecules in motion have kinetic energy:

KE = (1/2)(mass)(speed)^2

At the same T, all gases have the same average KE.

As T goes up for a gas, KE also increases — and so does speed.

38

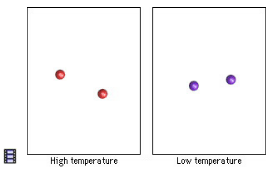
Kinetic Molecular Theory

At the same T, all gases have the same average KE.

As T goes up, KE also increases — and so does speed (u).

$\overline{KE} = 0.5\ m\overline{u^2}$

→



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Kinetic Molecular Theory

Maxwell's equation

$$\sqrt{\overline{u^2}} = \sqrt{\frac{3RT}{M}}$$

root mean square speed

- Means if T↑, then u↑
- Means if molar mass (M)↑, u↓

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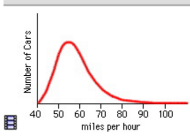
Distribution of Gas Molecule Speeds

→



- •Boltzmann plots
- •Named for Ludwig Boltzmann doubted the existence of atoms.
- • This played a role in his suicide in 1906.

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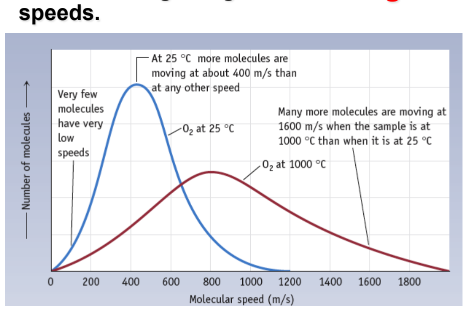
Velocity of Gas Molecules

Molecules of a given gas have a range of speeds.



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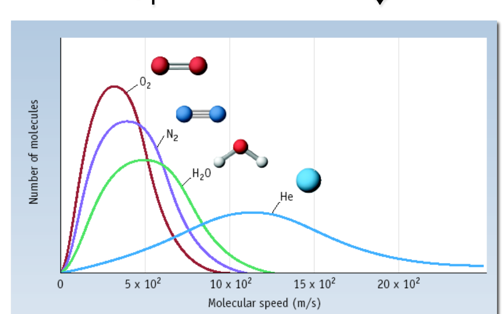
M↑ means u↓



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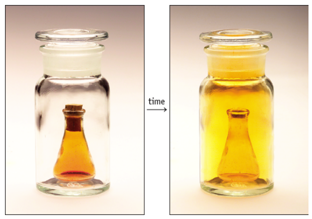
GAS DIFFUSION AND EFFUSION

DIFFUSION is the gradual mixing of molecules of different gases.



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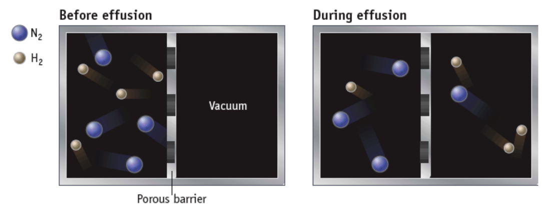
EFFUSION is the movement of gas molecules through a small hole into an empty container.



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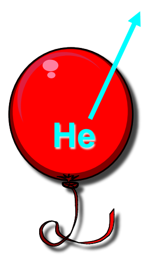
GAS EFFUSION

Molecules effuse out of a balloon at a rate (moles/second) proportional to their speed:

- Effusion↑ as T↑
- Effusion↑ as M↓

Helium (M=4) effuses faster than O_2 (M=16) at the same T.



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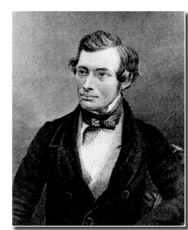
GAS EFFUSION

$$\frac{\text{Rate for A}}{\text{Rate for B}} = \sqrt{\frac{\text{M of B}}{\text{M of A}}}$$

Rate of effusion is inversely proportional to (molar mass)$^{1/2}$.



Thomas Graham

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Gas Diffusion

relation of mass to rate of diffusion

Gaseous diffusion of $NH_3(g)$ and $HCl(g)$

- HCl and NH_3 diffuse from opposite ends of tube.
- Gases meet to form NH_4Cl
- HCl heavier than NH_3
- Therefore, NH_4Cl forms closer to HCl end of tube.

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Using KMT to Understand Gas Laws

KMT assumptions are:

- Gases consist of molecules in constant, random motion.
- Pressure arises from collisions with container walls.
- No attractive or repulsive forces between molecules. Collisions elastic.
- Volume of molecules is negligible.

49

Kinetic Molecular Theory

Molecules in motion have kinetic energy:

KE = (1/2)(mass)(speed)^2

At the same T, all gases have the same average KE.

As T goes up for a gas, KE also increases — and so does speed.

50

Kinetic Molecular Theory

Maxwell's equation

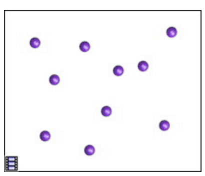
$$\underbrace{\sqrt{\overline{u^2}}}_{\text{root mean square speed}} = \sqrt{\frac{3RT}{M}}$$

- Means if T↑, then u↑
- Means if molar mass (M)↑, u↓

51

Avogadro's Hypothesis from KMT

→

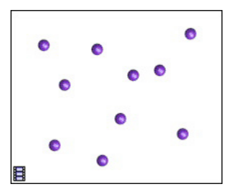


P ∝ n
V and T constant

52

P,T Relationship from KMT

→

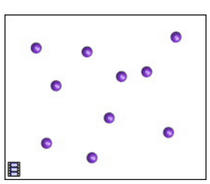


P ∝ T
n and V constant

53

Boyle's Law from KMT

→



P ∝ 1/V
n and T constant

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Real Gases Deviate from the Ideal Gas Law

- Real molecules have **volume** and have **intermolecular forces**.
- Otherwise gases could not become liquids.

High pressure and low temperature cause deviations

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Van Der Waals Modeled Deviations from Ideal Gas Law Behavior

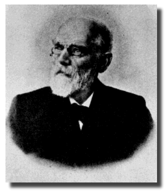
Measured P

Measured V = V(ideal)

$$\left(P + \frac{n^2 a}{V^2}\right)\left(V - nb\right) = nRT$$

intermol. forces

vol. correction



J. van der Waals

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End

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Equation from Van Der Waals

Measured P

Measured V = V(ideal)

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

intermol. forces

vol. correction

Cl_2 gas has a = 6.49, b = 0.0562

For 8.0 mol Cl_2 in a 4.0 L tank at 27 °C.

P (ideal) = nRT/V = 49.3 atm

P (van der Waals) = 29.5 atm