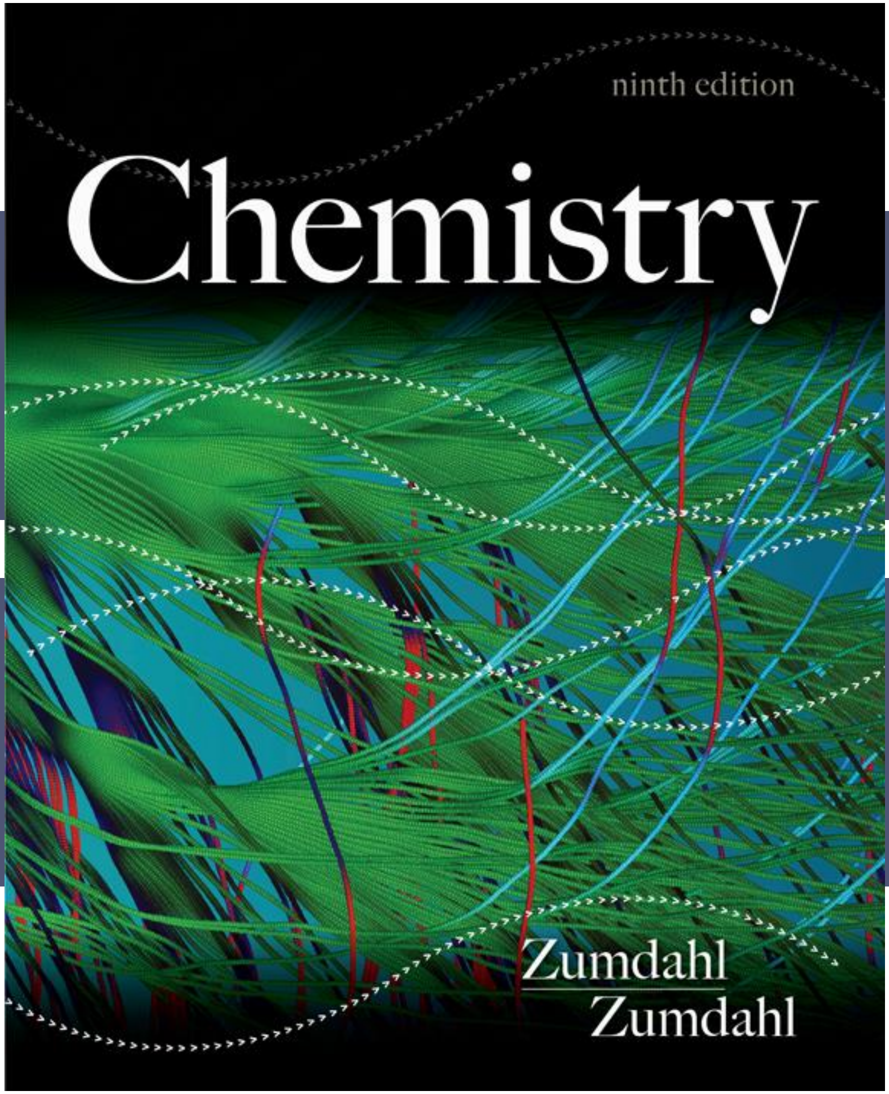


Chapter 5

Gases

Why study gases?

- An understanding of real world phenomena.
- An understanding of how science "works."

A Gas

- Uniformly fills any container.
- Easily compressed.
- Mixes completely with any other gas.
- Exerts pressure on its surroundings.

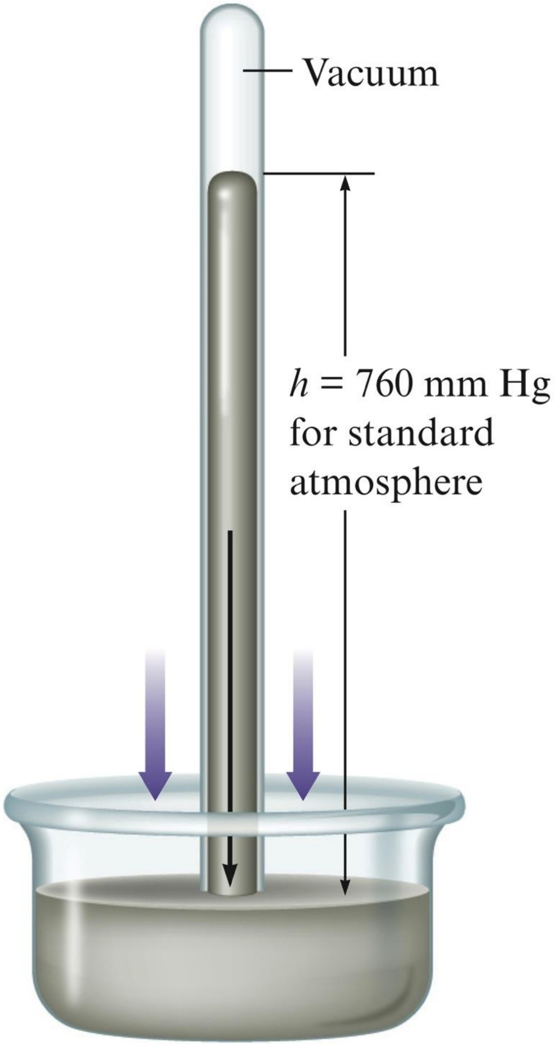
Pressure

$$\text{Pressure} = \frac{\text{force}}{\text{area}}$$

- SI units = Newton/meter^2 = 1 Pascal (Pa)
- 1 standard atmosphere = 101,325 Pa
- 1 standard atmosphere = 1 atm =
  760 mm Hg = 760 torr

Barometer

- Device used to measure atmospheric pressure.
- Mercury flows out of the tube until the pressure of the column of mercury standing on the surface of the mercury in the dish is *equal* to the pressure of the air on the rest of the surface of the mercury in the dish.



Manometer

- Device used for measuring the pressure of a gas in a container.

Vanessa Vick/Photo Researchers, Inc.

Collapsing Can

Charles D. Winters

Charles D. Winters

a

b

Pressure Conversions: An Example

The pressure of a gas is measured as 2.5 atm. Represent this pressure in both torr and pascals.

$$\left(2.5\ \cancel{\text{atm}}\right)\times\left(\frac{760\ \text{torr}}{1\ \cancel{\text{atm}}}\right) = 1.9\times10^{3}\ \text{torr}$$

$$\left(2.5\ \cancel{\text{atm}}\right)\times\left(\frac{101{,}325\ \text{Pa}}{1\ \cancel{\text{atm}}}\right) = 2.5\times10^{5}\ \text{Pa}$$

Liquid Nitrogen and a Balloon

Liquid Nitrogen and a Balloon

- What happened to the gas in the balloon?
- A decrease in temperature was followed by a decrease in the pressure and volume of the gas in the balloon.

Liquid Nitrogen and a Balloon

- This is an observation (a fact).
- It does NOT explain "why," but it does tell us "what happened."

- Gas laws can be deduced from observations like these.
- Mathematical relationships among the properties of a gas (Pressure, Volume, Temperature and Moles) can be discovered.

Boyle's Law

- Pressure and volume are inversely related (constant *T*, temperature, and *n*, # of moles of gas).
- $PV = k$ (k is a constant for a given sample of air at a specific temperature)

$$P_1 \times V_1 = P_2 \times V_2$$

Boyle's law

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EXERCISE!

A sample of helium gas occupies 12.4 L at 23°C and 0.956 atm. What volume will it occupy at 1.20 atm assuming that the temperature stays constant?

9.88 L

Charles' s Law

- Volume and Temperature (in Kelvin) are directly related (constant *P* and *n*).
- $V = bT$ (*b* is a proportionality constant)
- K = ° C + 273
- 0 K is called absolute zero.

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

Charles's Law

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EXERCISE!

Suppose a balloon containing 1.30 L of air at 24.7° C is placed into a beaker containing liquid nitrogen at –78.5° C. What will the volume of the sample of air become (at constant pressure)?

0.849 L

Avogadro's Law

- Volume and number of moles are directly related (constant *T* and *P*).
- *V* = *an* (*a* is a proportionality constant, n is thr number of moles of gaz particles)

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

EXERCISE!

If 2.45 mol of argon gas occupies a volume of 89.0 L, what volume will 2.10 mol of argon occupy under the same conditions of temperature and pressure?

76.3 L

- We can bring all of these laws together into one comprehensive law:
  - $V = bT$ (constant P and n)
  - $V = an$ (constant T and P)
  - $V = \frac{k}{P}$ (constant T and n)

$$PV = nRT$$

(where R = 0.08206 L·atm/mol·K, the universal gas constant)

EXERCISE!

An automobile tire at 23° C with an internal volume of 25.0 L is filled with air to a total pressure of 3.18 atm. Determine the number of moles of air in the tire.

3.27 mol

EXERCISE!

What is the pressure in a 304.0 L tank that contains 5.670 kg of helium at 25° C?

114 atm

EXERCISE!

At what temperature (in °C) does 121 mL of CO_2 at 27°C and 1.05 atm occupy a volume of 293 mL at a pressure of 1.40 atm?

696°C

Molar Volume of an Ideal Gas

- For 1 mole of an ideal gas at 0° C and 1 atm, the volume of the gas is 22.42 L.

$$V = \frac{nRT}{P} = \frac{(1.000\ \cancel{\text{mol}})(0.08206\ \text{L}\cdot\cancel{\text{atm}}/\cancel{\text{K}}\cdot\cancel{\text{mol}})(273.2\ \cancel{\text{K}})}{1.000\ \cancel{\text{atm}}} = 22.42\ \text{L}$$

- STP = standard temperature and pressure
  - 0° C and 1 atm
  - Therefore, the molar volume is 22.42 L at STP.

EXERCISE!

A sample of oxygen gas has a volume of 2.50 L at STP. How many grams of O_2 are present?

3.57 g

Molar Mass of a Gas

$$\text{Molar mass} = \frac{dRT}{P} = \frac{\left(\frac{\text{g}}{\cancel{\text{L}}}\right)\left(\frac{\cancel{\text{L}}\cdot\cancel{\text{atm}}}{\text{mol}\cdot\cancel{\text{K}}}\right)(\cancel{\text{K}})}{(\cancel{\text{atm}})} = \frac{\text{g}}{\text{mol}}$$

- *d* = density of gas
- *T* = temperature in Kelvin
- *P* = pressure of gas
- *R* = universal gas constant

EXERCISE!

What is the density of F_2 at STP (in g/L)?

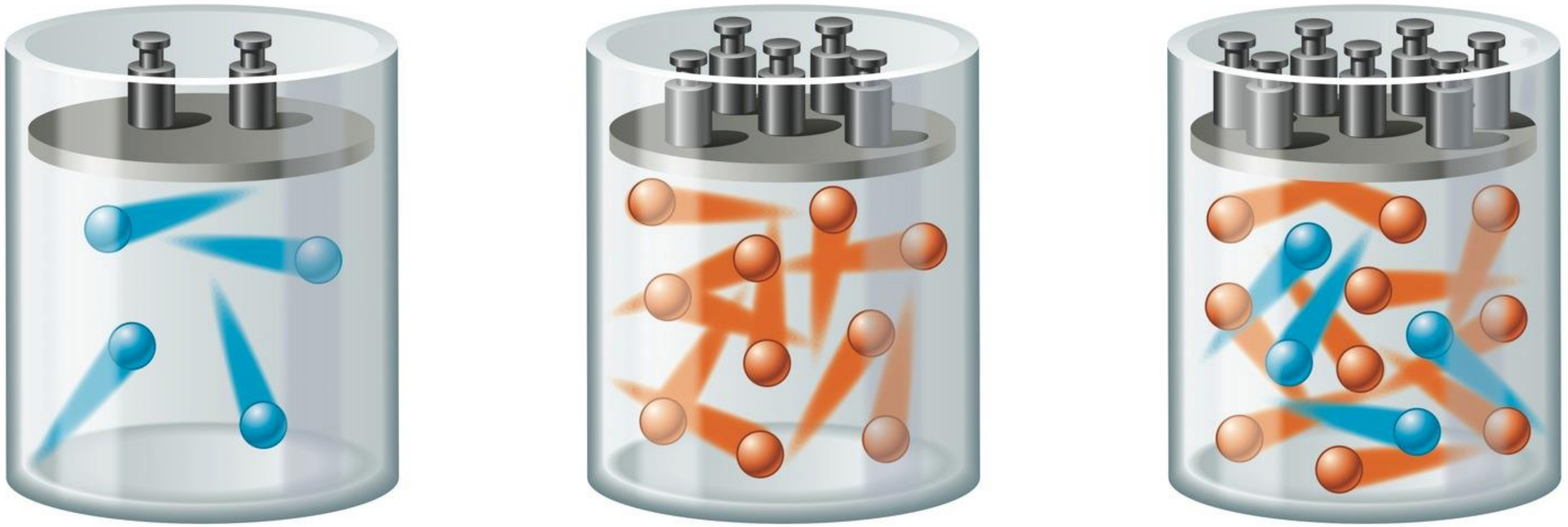
1.70 g/L

- For a mixture of gases in a container,

$$P_{Total} = P_1 + P_2 + P_3 + \dots$$

- The total pressure exerted is the sum of the pressures that each gas would exert if it were alone.

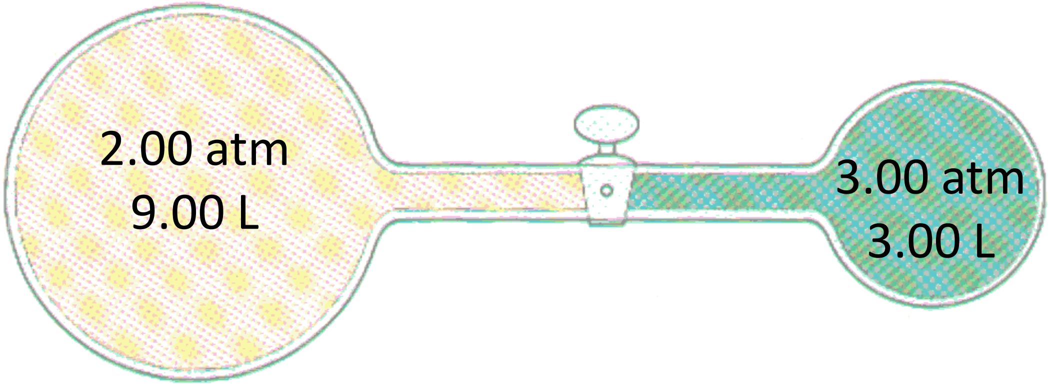
Section 5.5
Dalton's Law of Partial Pressures



EXERCISE!

Consider the following apparatus containing helium in both sides at 45° C. Initially the valve is closed.

- After the valve is opened, what is the pressure of the helium gas?



EXERCISE!

27.4 L of oxygen gas at 25.0°C and 1.30 atm, and 8.50 L of helium gas at 25.0°C and 2.00 atm were pumped into a tank with a volume of 5.81 L at 25°C.

- Calculate the new partial pressure of oxygen.

  6.13 atm

- Calculate the new partial pressure of helium.

  2.93 atm

- Calculate the new total pressure of both gases.

  9.06 atm

- So far we have considered "what happens," but not "why."
- In science, "what" always comes before "why."

Postulates of the Kinetic Molecular Theory

1) The particles are so small compared with the distances between them that *the volume of the individual particles can be assumed to be negligible (zero).*

Postulates of the Kinetic Molecular Theory

2) *The particles are in constant motion*. The collisions of the particles with the walls of the container are the cause of the pressure exerted by the gas.

Postulates of the Kinetic Molecular Theory

3) *The particles are assumed to exert no forces on each other;* they are assumed neither to attract nor to repel each other.

Postulates of the Kinetic Molecular Theory

4) The average kinetic energy of a collection of gas particles is assumed to be *directly proportional to the Kelvin temperature* of the gas.

Kinetic Molecular Theory

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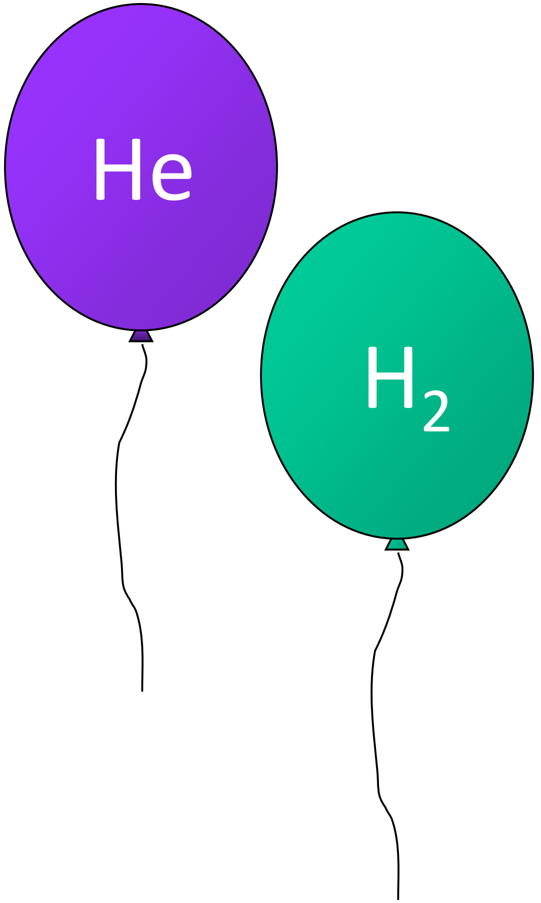
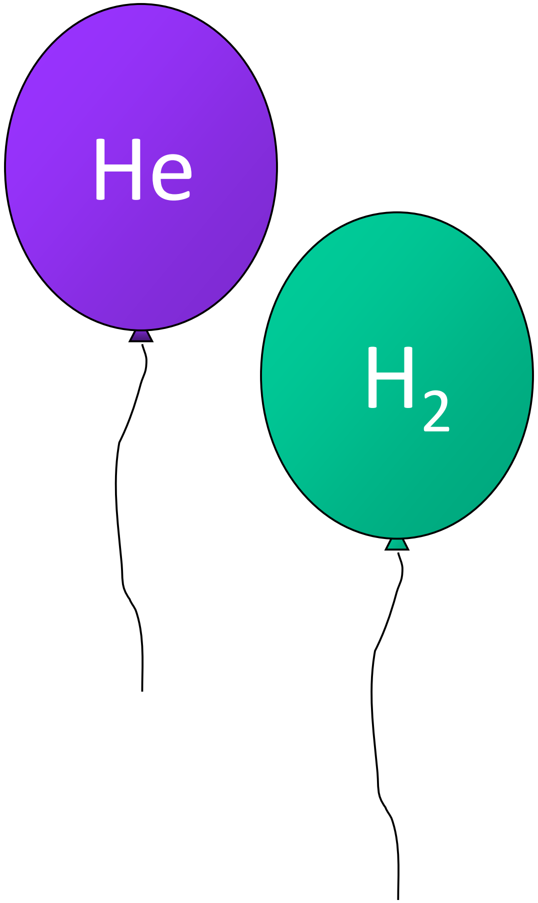
CONCEPT CHECK!

You are holding two balloons of the same volume. One contains helium, and one contains hydrogen. Complete each of the following statements with "different" or "the same" and be prepared to justify your answer.



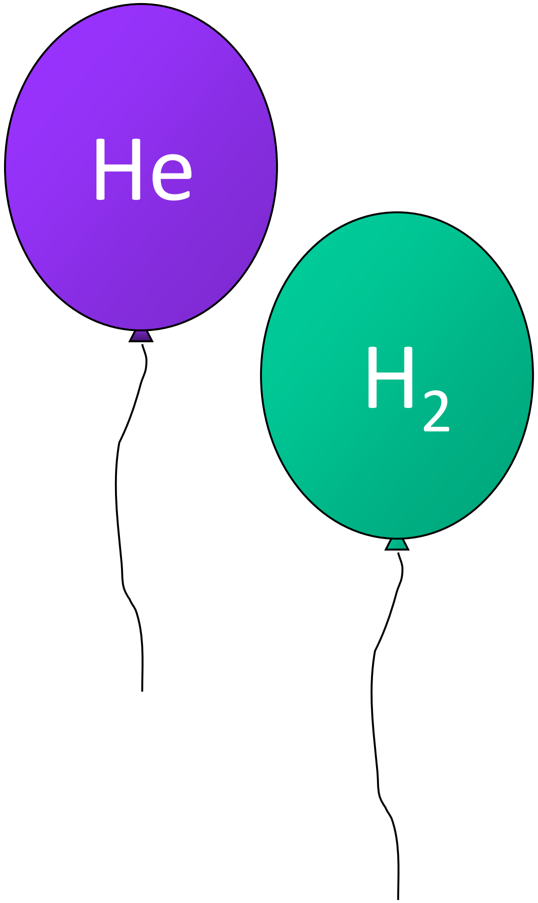
CONCEPT CHECK!

- The pressures of the gas in the two balloons are ____________.



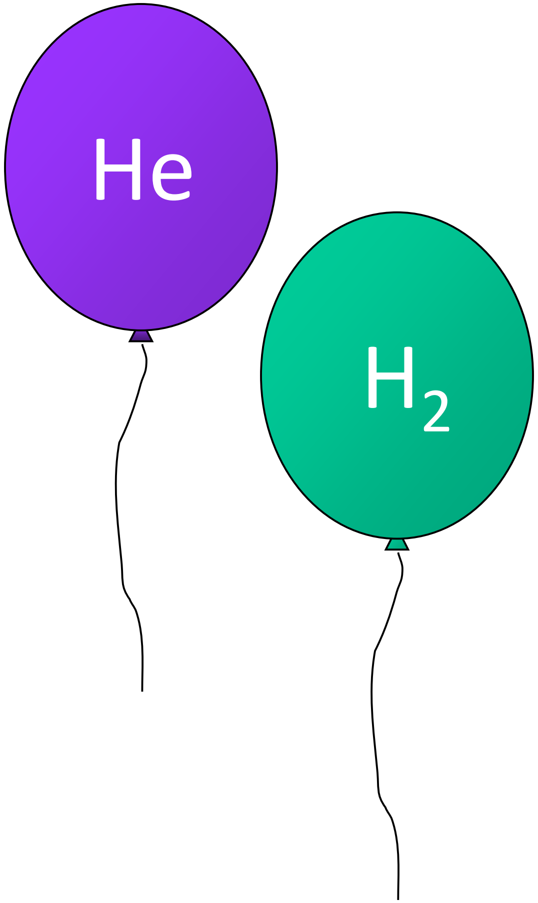
CONCEPT CHECK!

- The temperatures of the gas in the two balloons are ___________.



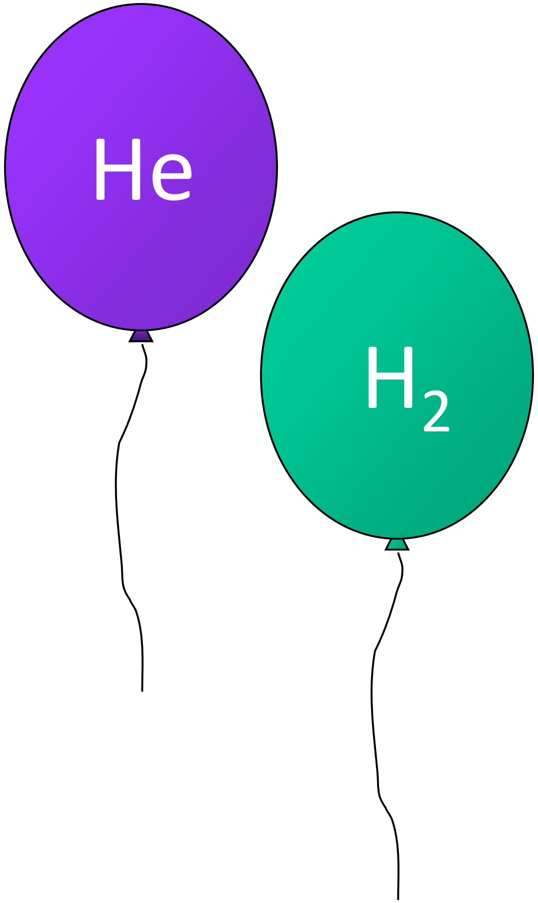
CONCEPT CHECK!

- The numbers of moles of the gas in the two balloons are ___________.



CONCEPT CHECK!

- The densities of the gas in the two balloons are ___________.



CONCEPT CHECK!

Sketch a graph of:

I. Pressure versus volume at constant temperature and moles.

Molecular View of Boyle's Law

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CONCEPT CHECK!

Sketch a graph of:

II. Volume vs. temperature (°C) at constant pressure and moles.

CONCEPT CHECK!

Sketch a graph of:

III. Volume vs. temperature (K) at constant pressure and moles.

Molecular View of Charles's Law

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CONCEPT CHECK!

Sketch a graph of:

IV. Volume vs. moles at constant temperature and pressure.

Molecular View of the Ideal Gas Law

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CONCEPT CHECK!

$$V_{Ne} = 2V_{Ar}$$

Which of the following best represents the mass ratio of Ne:Ar in the balloons?

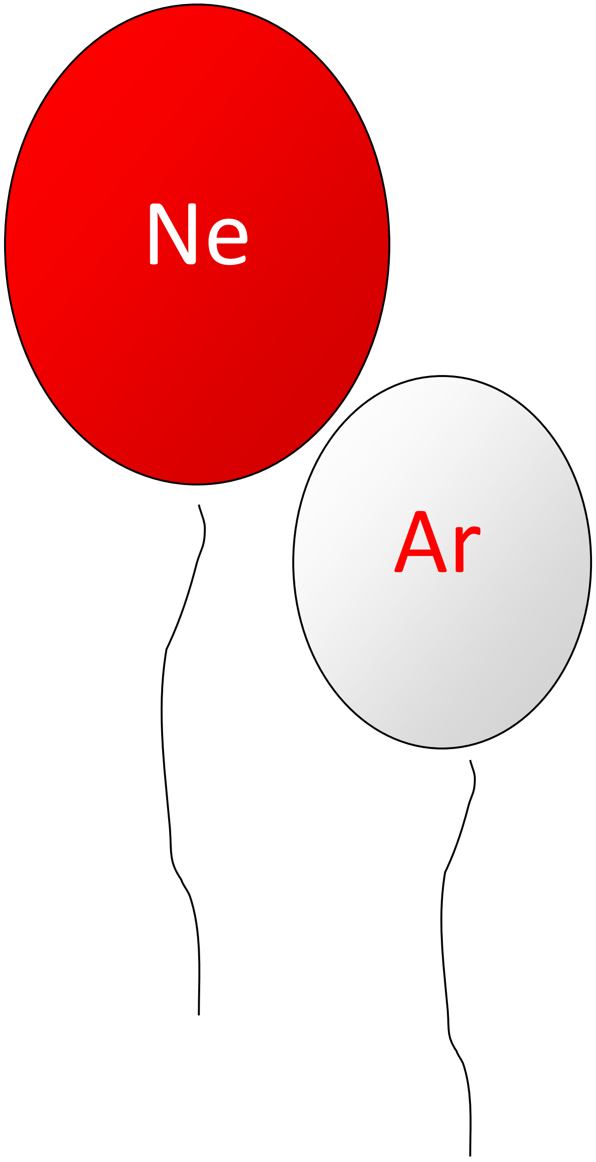
1:1

1:2

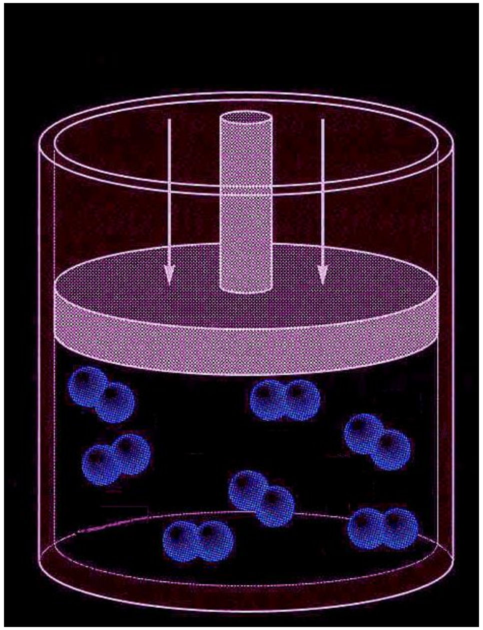
2:1

1:3

3:1



CONCEPT CHECK!



- You have a sample of nitrogen gas (N_2) in a container fitted with a piston that maintains a pressure of 6.00 atm. Initially, the gas is at 45° C in a volume of 6.00 L.
- You then cool the gas sample.

CONCEPT CHECK!

Which best explains the final result that occurs once the gas sample has cooled?

a) The pressure of the gas increases.
b) The volume of the gas increases.
c) The pressure of the gas decreases.
d) The volume of the gas decreases.
e) Both volume and pressure change.

CONCEPT CHECK!

The gas sample is then cooled to a temperature of 15° C. Solve for the new condition. (Hint: A moveable piston keeps the pressure constant overall, so what condition will change?)

5.43 L

Root Mean Square Velocity

$$u_{rms} = \sqrt{\frac{3RT}{M}}$$

R = 8.3145 J/K·mol

(J = joule = kg·m^2/s^2)

T = temperature of gas (in K)

M = mass of a mole of gas in kg

- Final units are in m/s.

- Diffusion – the mixing of gases.
- Effusion – describes the passage of a gas through a tiny orifice into an evacuated chamber.
- Rate of effusion measures the speed at which the gas is transferred into the chamber.

Effusion

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Diffusion

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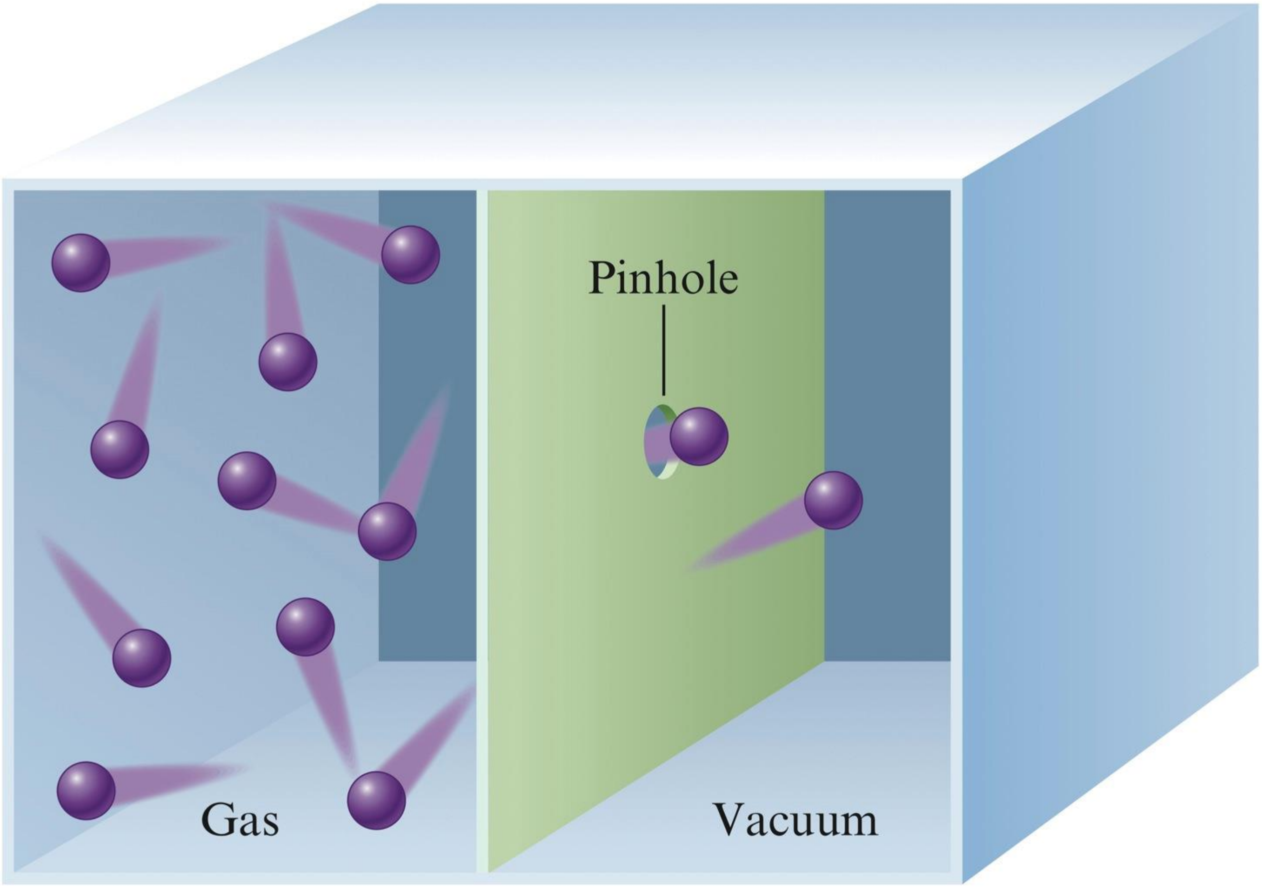

Pinhole
Gas
Vacuum

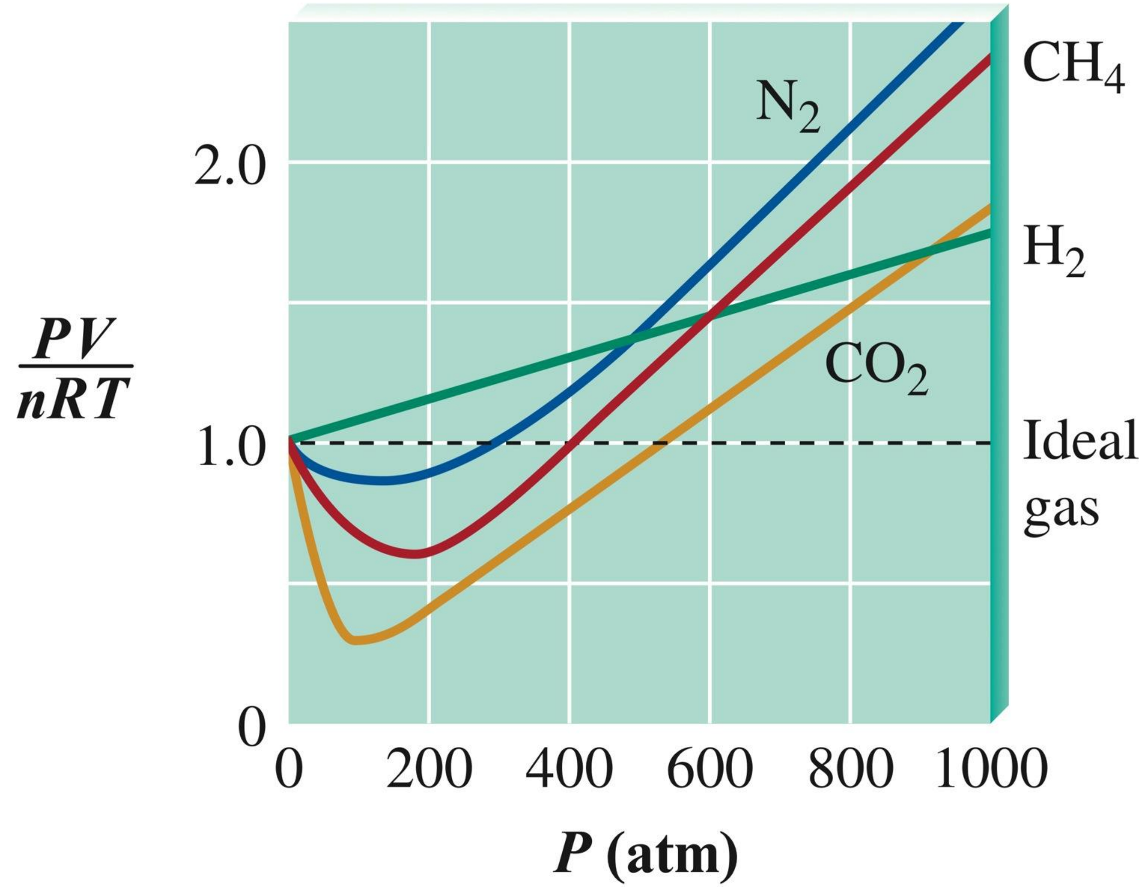
Graham's Law of Effusion

$$\frac{\text{Rate of effusion for gas 1}}{\text{Rate of effusion for gas 2}} = \frac{\sqrt{M_2}}{\sqrt{M_1}}$$

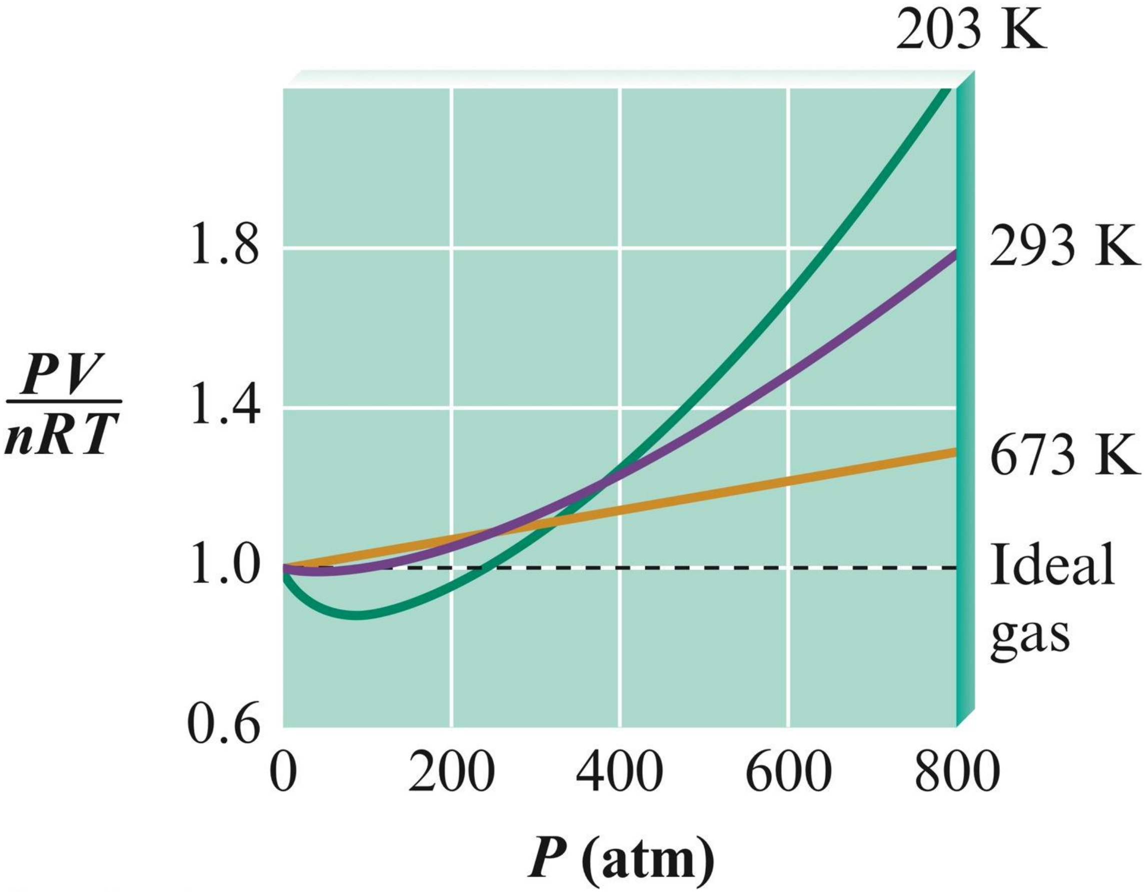
- M_1 and M_2 represent the molar masses of the gases.

- An ideal gas is a hypothetical concept. No gas exactly follows the ideal gas law.
- We must correct for non-ideal gas behavior when:
  - Pressure of the gas is high.
  - Temperature is low.
- Under these conditions:
  - Concentration of gas particles is high.
  - Attractive forces become important.

Plots of *PV/nRT* Versus *P* for Several Gases (200 K)



Plots of *PV/nRT* Versus *P* for Nitrogen Gas at Three Temperatures



Real Gases (van der Waals Equation)

$$[P_{\text{obs}} + a\,(n/V)^2] \times (V - nb) = nRT$$

↑ corrected pressure: P_{ideal}

↑ corrected volume: V_{ideal}

- For a real gas, the actual observed pressure is lower than the pressure expected for an ideal gas due to the intermolecular attractions that occur in real gases.

Values of the van der Waals Constants for Some Gases

- The value of *a* reflects how much of a correction must be made to adjust the observed pressure up to the expected ideal pressure.
- A low value for *a* reflects weak intermolecular forces among the gas molecules.

Table 5.3 | Values of the van der Waals Constants for Some Common Gases

Gas	$a\left(\frac{atm \cdot L^2}{mol^2}\right)$	$b\left(\frac{L}{mol}\right)$
He	0.0341	0.0237
Ne	0.211	0.0171
Ar	1.35	0.0322
Kr	2.32	0.0398
Xe	4.19	0.0511
H_2	0.244	0.0266
N_2	1.39	0.0391
O_2	1.36	0.0318
Cl_2	6.49	0.0562
CO_2	3.59	0.0427
CH_4	2.25	0.0428
NH_3	4.17	0.0371
H_2O	5.46	0.0305

Air Pollution

- Two main sources:
  - Transportation
  - Production of electricity
- Combustion of petroleum produces CO, CO_2, NO, and NO_2, along with unburned molecules from petroleum.

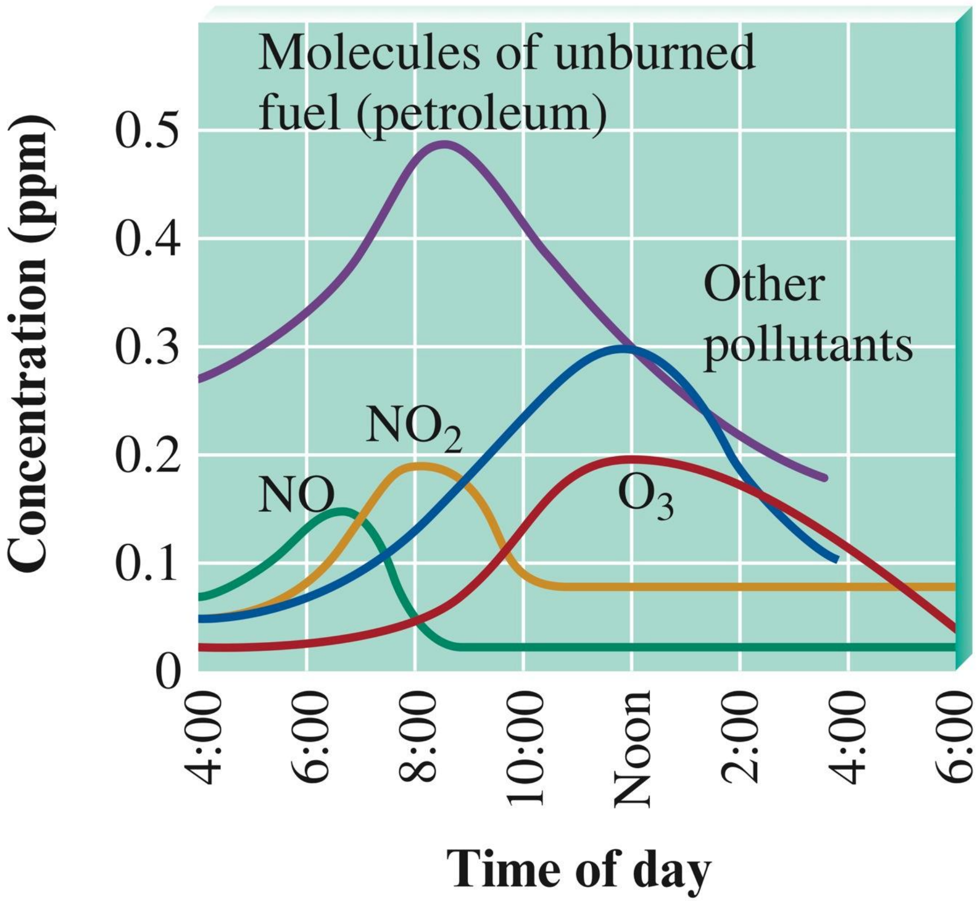
Nitrogen Oxides (Due to Cars and Trucks)

- At high temperatures, N_2 and O_2 react to form NO, which oxidizes to NO_2.
- The NO_2 breaks up into nitric oxide and free oxygen atoms.
- Oxygen atoms combine with O_2 to form ozone (O_3).

$$NO_2(g) \xrightarrow[\text{energy}]{\text{Radiant}} NO(g) + O(g)$$

$$O(g) + O_2(g) \longrightarrow O_3(g)$$

Concentration for Some Smog Components vs. Time of Day



Sulfur Oxides (Due to Burning Coal for Electricity)

- Sulfur produces SO_2 when burned.
- SO_2 oxidizes into SO_3, which combines with water droplets in the air to form sulfuric acid.

$$\text{S(in coal)} + O_2(g) \longrightarrow SO_2(g)$$

$$2SO_2(g) + O_2(g) \longrightarrow 2SO_3(g)$$

$$SO_3(g) + H_2O(l) \longrightarrow H_2SO_4(aq)$$

Sulfur Oxides (Due to Burning Coal for Electricity)

- Sulfuric acid is very corrosive and produces acid rain.
- Use of a scrubber removes SO_2 from the exhaust gas when burning coal.

A Schematic Diagram of a Scrubber