Welcome to Chemistry 154!

Chemistry for Engineering

Reminders

– **Worksheet: Unit 6**

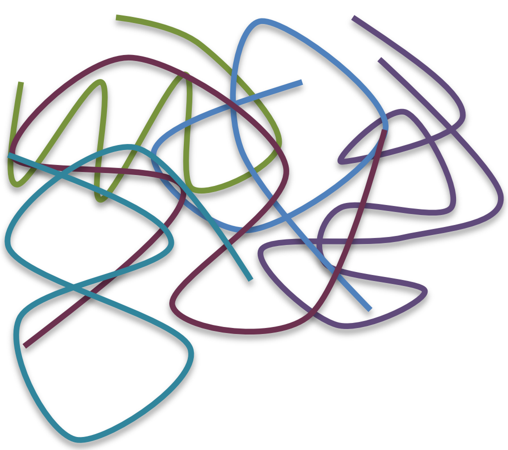
Due Nov. 1^{st} at 11:59pm

Instructor Office Hours

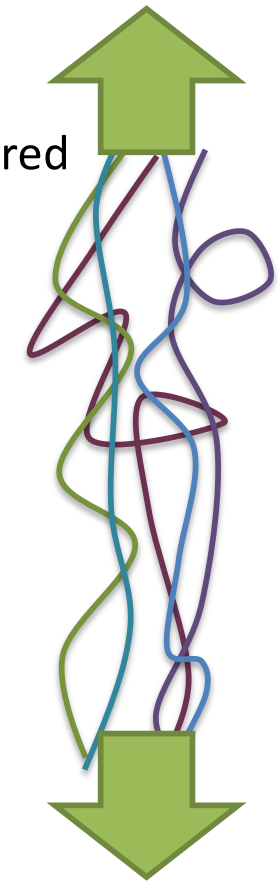
Monday and Friday 7-8pm via Zoom (All Lectures Site)

Entropic elasticity

Disordered chains



Less disordered chains



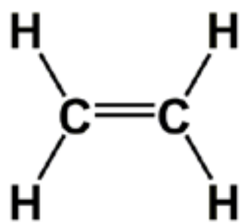
If the polymer chains are relatively disordered, the deformation can come at the expense of uncoiling and ordering the polymer: ***entropic mechanism***! $\Delta S<0$

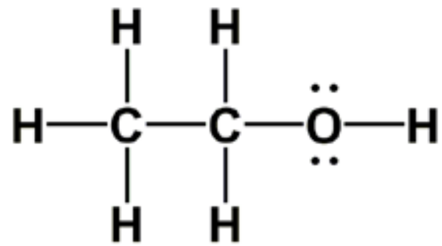
Need proof? Stretch a rubber band against your wrist or lip, it should feel warm: transferring heat to the environment

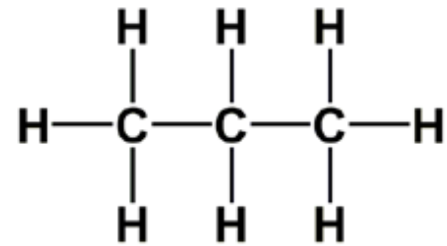
*

Condensed structures

Lewis structure



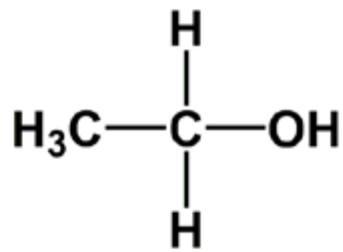


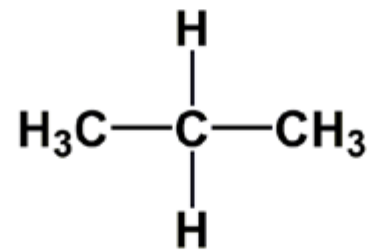


Condensed Lewis structure

$H_2C{=}CH_2$

order of atoms matters

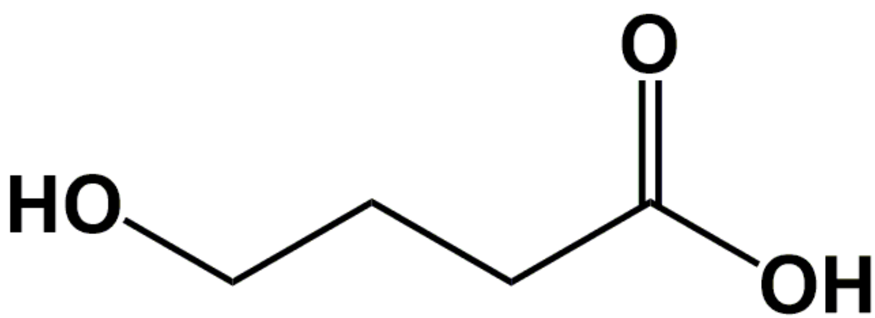




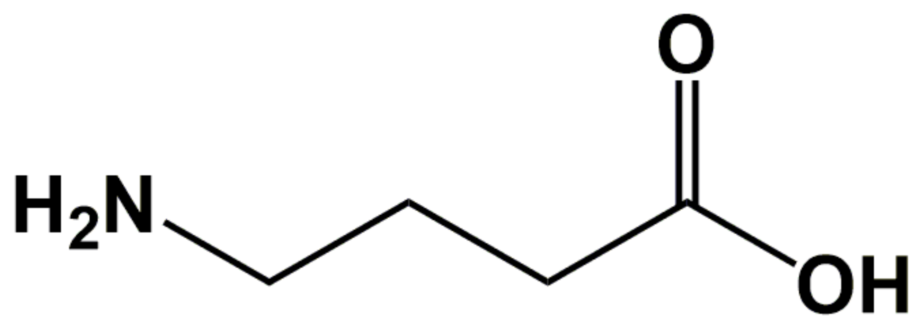
Line-bond structure

Worksheet Question #12 – GOOD QUESTION

Which of the following monomers (A or B) produces a polymer with the highest melting point? Briefly explain your reasoning. Assume the molecular weight of the resulting polymer is the same.



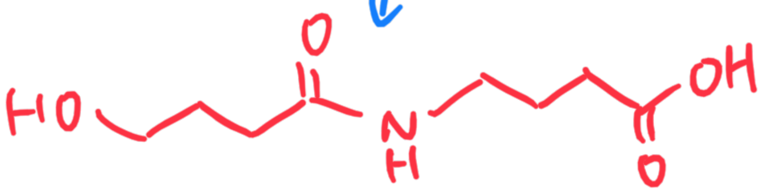
A.



B.

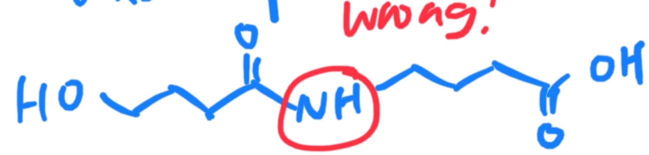
dimer example.

Amide linkage



If drawn this way:

wrong!



Unit 6
Gases

Learning Objectives

After mastering this unit you will be able to:

- Use the ideal gas law to calculate changes in the conditions of pure gases and gas mixtures.
- Describe the difference between ideal and real gases, with reference to the postulates of the kinetic molecular theory of gases.
- Use the van der Waals equation to calculate temperature, pressure, volume and number of moles of real gases.

Useful Constants

Pressure

1 atm = 760 mmHg = 760 Torr = 101325 Pa

1 bar = 100000 Pa = 0.986923 atm

Gas constant

R = 0.08206 L atm mol^{-1} K^{-1} = 8.314 J mol^{-1} K^{-1} = 62.37 L torr mol^{-1} K^{-1}

Convert R

Pressure is often reported in a variety of different units.

1 atm = 760 mmHg = 760 Torr = 101325 Pa

100000 Pa = 1 bar

In SI units, the molar gas constant is R= 8.314 J mol^{-1} K^{-1}

Work through the conversion of R to **L atm mol^{-1} K^{-1}** and **L torr mol^{-1} K^{-1}**

Ideal Gas Law (PV = nRT)

Generally gases at high temperatures and low pressures can be described by the ideal gas law.

A gas that follows this relationship is known as an ideal gas.

$$PV = nRT$$

P = Pressure
V = Volume
n = number of moles
R = gas constant
T = Temperature in K

Unless told otherwise in CHEM 154 assume all gases behave ideally.

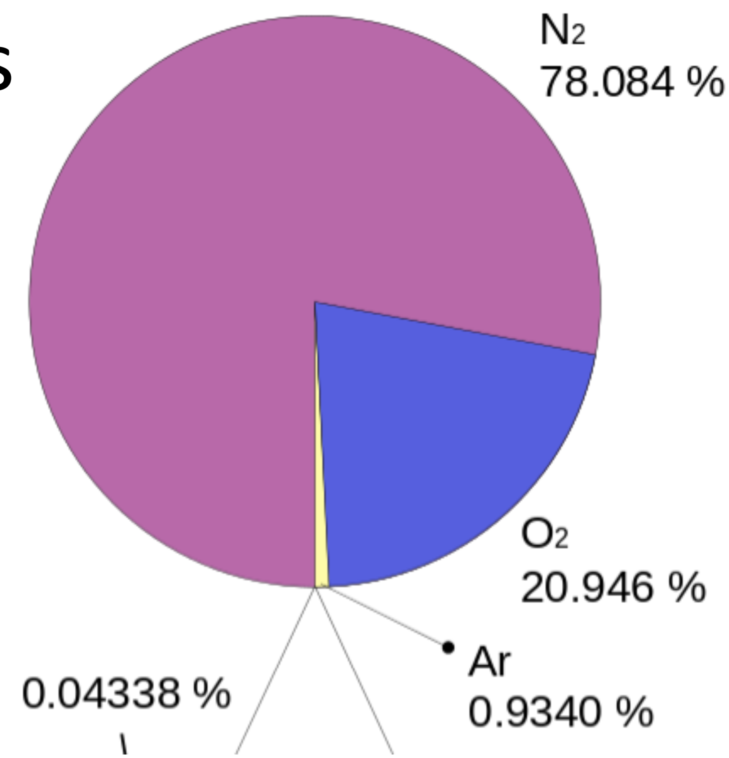
Dalton's Law of Partial Pressures

For a mixture of gases in a container of volume V, the total pressure is the sum of the partial pressures of each gas.

Partial pressure: pressure a gas would exert if it were alone.

$P_{total} = P_1 + P_2 + P_3 + \ldots$

$P_{total} V = (n_1 + n_2 + n_3 + \ldots) RT$



Mole fraction

The mole fraction (x) is the ratio of the number of moles of a given component in a mixture to the total number of moles of the mixture

$$x_1 = \frac{n_1}{n_{total}} = \frac{n_1}{n_1 + n_2 + n_3 + \cdots}$$

Consequently for ideal gases,

$$x_1 = \frac{n_1}{n_{total}} = \frac{P_1}{P_{total}}$$

Mole fraction will always be between 0 and 1.

Worksheet Question #2

The reaction of aluminum with HCl produces hydrogen gas:

35.5 mL of H_2 is collected in a sealed container over water at 26 °C and the pressure is measured to be 755 mmHg, how many moles of H_2 were produced? (The vapour pressure of water at 26 °C is 25.2 mmHg).

$$2Al_{(s)} + 6HCl_{(aq)} \rightarrow 2AlCl_{3(aq)} + 3H_{2(g)}$$

P_{H_2} = 755 mmHg − 25.2 mmHg

= 729.8 mmHg

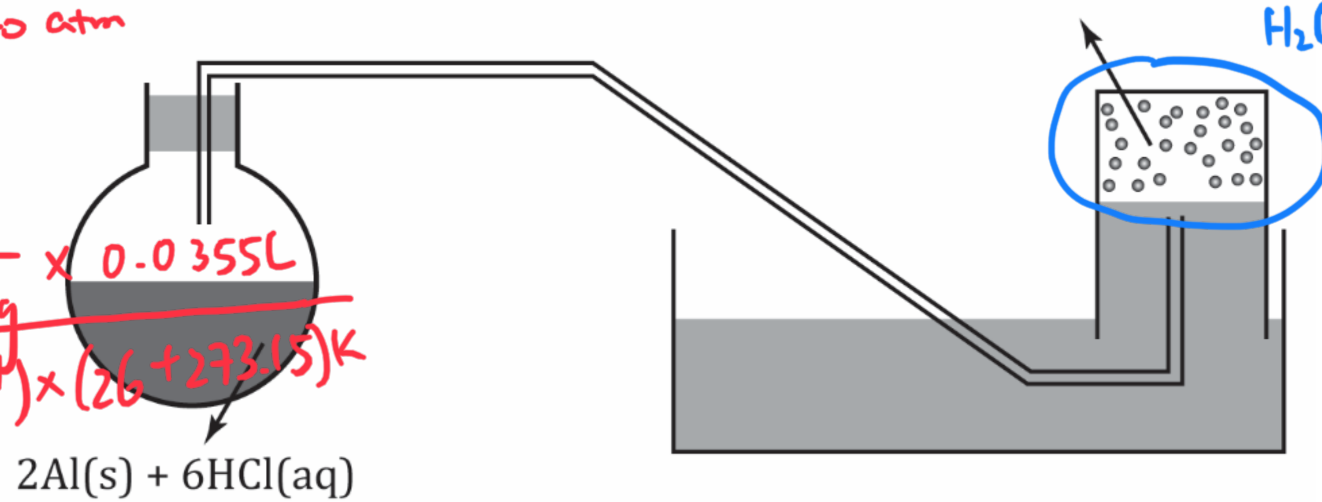
↳ Change to atm

$PV = nRT$

$$n = \frac{PV}{RT}$$

$$n = \frac{729.8\ \text{mmHg} \times \frac{1\ \text{atm}}{760\ \text{mmHg}} \times 0.0355\ \text{L}}{(0.08206\ \text{L atm mol}^{-1}\text{K}^{-1}) \times (26 + 273.15)\ \text{K}}$$

= 0.00139 mol



Total pressure from $H_2(g)$ and $H_2O(g)$

Worksheet Question #2 – Clicker Version Homework

The reaction of aluminum with HCl produces hydrogen gas…35.5 mL of H_2 is collected in a sealed container over water at 26 °C and the pressure is measured to be 755 mmHg, how many moles of H_2 were produced? (The vapour pressure of water at 26 °C is 25.2 mmHg).

$$2Al_{(s)} + 6HCl_{(aq)} \rightarrow 2AlCl_{3(aq)} + 3H_{2(g)}$$

a) 1.44 moles
b) 1.39 moles
c) 0.0160 moles
d) 0.00144 moles
e) 0.00139 moles

1 atm = 760 mmHg = 760 Torr = 101325 Pa;

100000 Pa = 1 bar

$R = 0.08206\ \text{L atm mol}^{-1}\ \text{K}^{-1} = 8.314\ \text{J mol}^{-1}\ \text{K}^{-1}$
$= 62.37\ \text{L torr mol}^{-1}\ \text{K}^{-1}$

STP: T = 273.15 K (0 Celsius) , P = 1 atm

Worksheet Question #3 – GOOD QUESTION

Aerospace engineers sometimes write the gas law in terms of the mass of the gas rather than the number of moles.

$$PV = mR_{specific}T$$

In such a formulation, the molar mass of the gas must be incorporated into the value of the gas constant (the gas constant will change for different gases, represented by $R_{specific}$ in the above equation).

a) Briefly describe an experiment that can be performed to determine $R_{specific}$.

b) Suggest a reason why this approach may be attractive for aerospace engineers.

Worksheet Question #3 – GOOD QUESTION

Aerospace engineers sometimes write the gas law in terms of the mass of the gas rather than the number of moles.

$$PV = mR_{specific}T$$

In such a formulation, the molar mass of the gas must be incorporated into the value of the gas constant (the gas constant will change for different gases, represented by $R_{specific}$ in the above equation).

a) Briefly describe an experiment that can be performed to determine $R_{specific}$.

b) Suggest a reason why this approach may be attractive for aerospace engineers.

Worksheet Question #3 – GOOD QUESTION

Aerospace engineers sometimes write the gas law in terms of the mass of the gas rather than the number of moles.

$$PV = mR_{specific}T$$

In such a formulation, the molar mass of the gas must be incorporated into the value of the gas constant (the gas constant will change for different gases, represented by $R_{specific}$ in the above equation).

c) Assume the mole fractions of O_2 and N_2 in air are 0.21 and 0.79, respectively. Calculate the average molar mass of air (the mass of one mole of air) and use this number to calculate $R_{specific}$ for air in $m^2s^{-2}K^{-1}$.

Worksheet Question #3 part C.

molar mass: $M = \frac{m}{n}$

$$PV = nRT = mR_{specific}T$$

$$R_{specific,air} = \frac{nR\cancel{T}}{m\cancel{T}} = \frac{n_{air}R}{m_{air}} = \frac{R}{M_{air}}$$

$\hookrightarrow$ molar mass

Given information:

$$X_{O_2} = 0.21 \qquad X_{N_2} = 0.79 \qquad \left(X = \frac{n_1}{n_{total}}\right)$$

$\therefore$ 1 mol of air contains 0.79 mol N_2 and 0.21 mol O_2.

mass of 1 mol air $= 0.79\,\text{mol} \times 28.01\,\frac{g}{mol} + 0.21\,\text{mol} \times 32\,\frac{g}{mol} = 28.86\,g$

$\therefore M_{air} = \frac{28.86\,g}{mol}$

because $1J = 1\,kg\,m^2 s^{-2}$

$$R_{specific,air} = \frac{R}{28.86\,g/mol} = \frac{8.314\,\frac{kg\,m^2}{s^2 \cdot K \cdot mol}}{0.02886\,kg/mol} = 288.2\,\frac{m^2}{s^2 K}$$

[redacted]

– Which major are you in/will you be in?

A. Biomedical/Chemical and Biological/Chemical

B. Civil/Mining/integrated

C. Computer/Electrical

D. Geological/Environmental

E. Mechanical/Manufacturing & Materials

Worksheet Question #4 Homework

A piston in a car engine is maintained at constant pressure during a combustion reaction. The combustion reaction is given by:

$$C_8H_{18}(g) + 12.5\ O_2(g) \rightarrow 8\ CO_2(g) + 9\ H_2O(l)$$

Using the ideal gas law, identify possible reason(s) that would cause the piston volume to change.

Click in:
A. I'm done!
B. I'm stuck… ☹
C. I'm still working

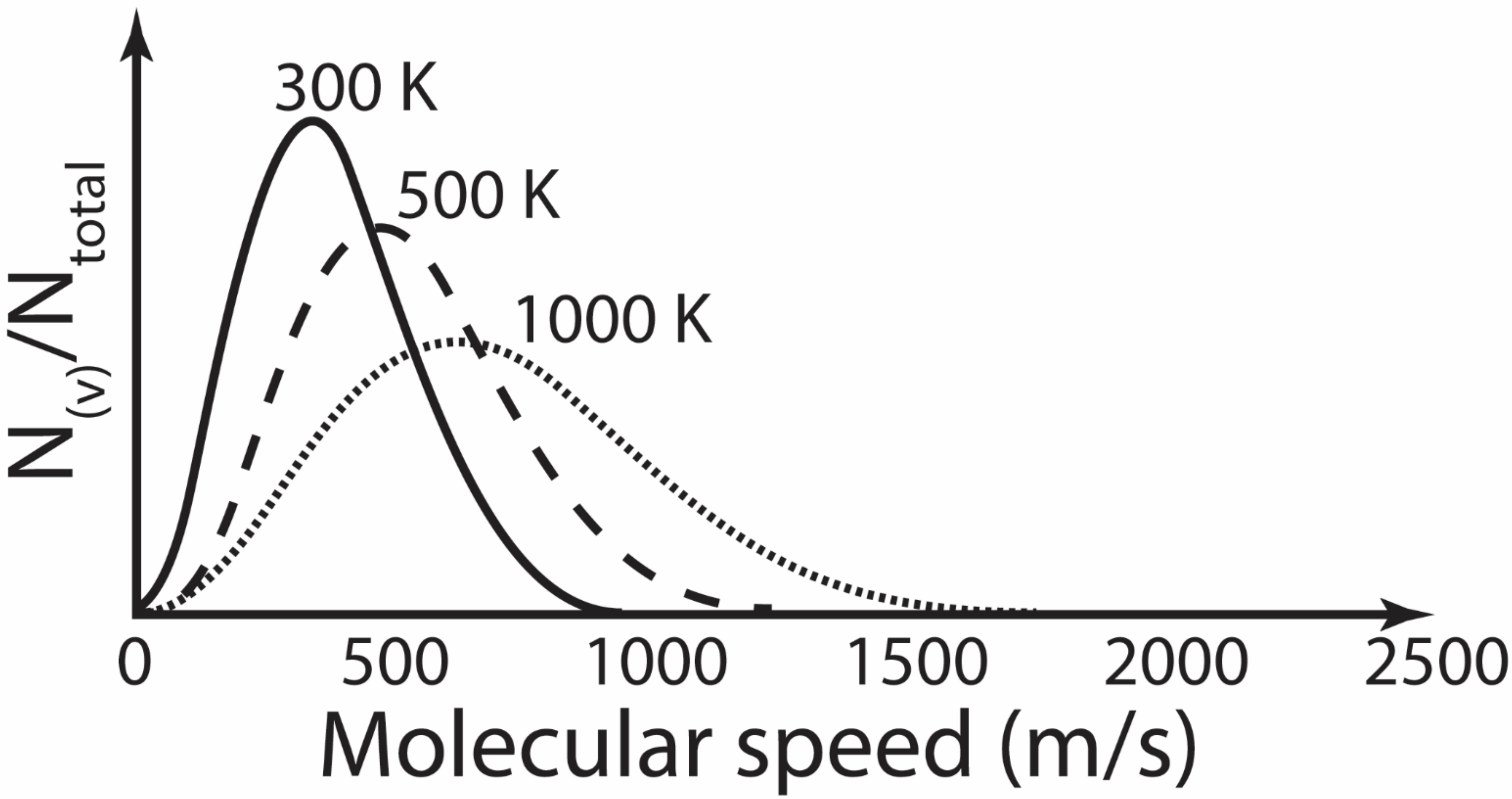
Kinetic molecular theory

Postulates:

1. A gas is made up of a vast number of particles which are in constant random motion.
2. Gas particles occupy no volume.
3. Gas molecules move in straight lines except when they collide with other molecules or with the walls of the container. These collisions are elastic.
4. Gas molecules interact with one another only when collisions occur.
5. Average kinetic energy (KE) of gas molecules is proportional to the temperature. $\frac{3}{2}RT$

Kinetic Energy and Temperature

As temperature increases the average speed (hence kinetic energy) increases, according to the Maxwell-Boltzmann distribution



Clicker Question

According to the KMT of gases, the average kinetic energy of gas particles is…

a) …inversely proportional to the square of the absolute temperature of the gas
b) …directly proportional to the number of moles of gas
c) …directly proportional to the absolute temperature of the gas

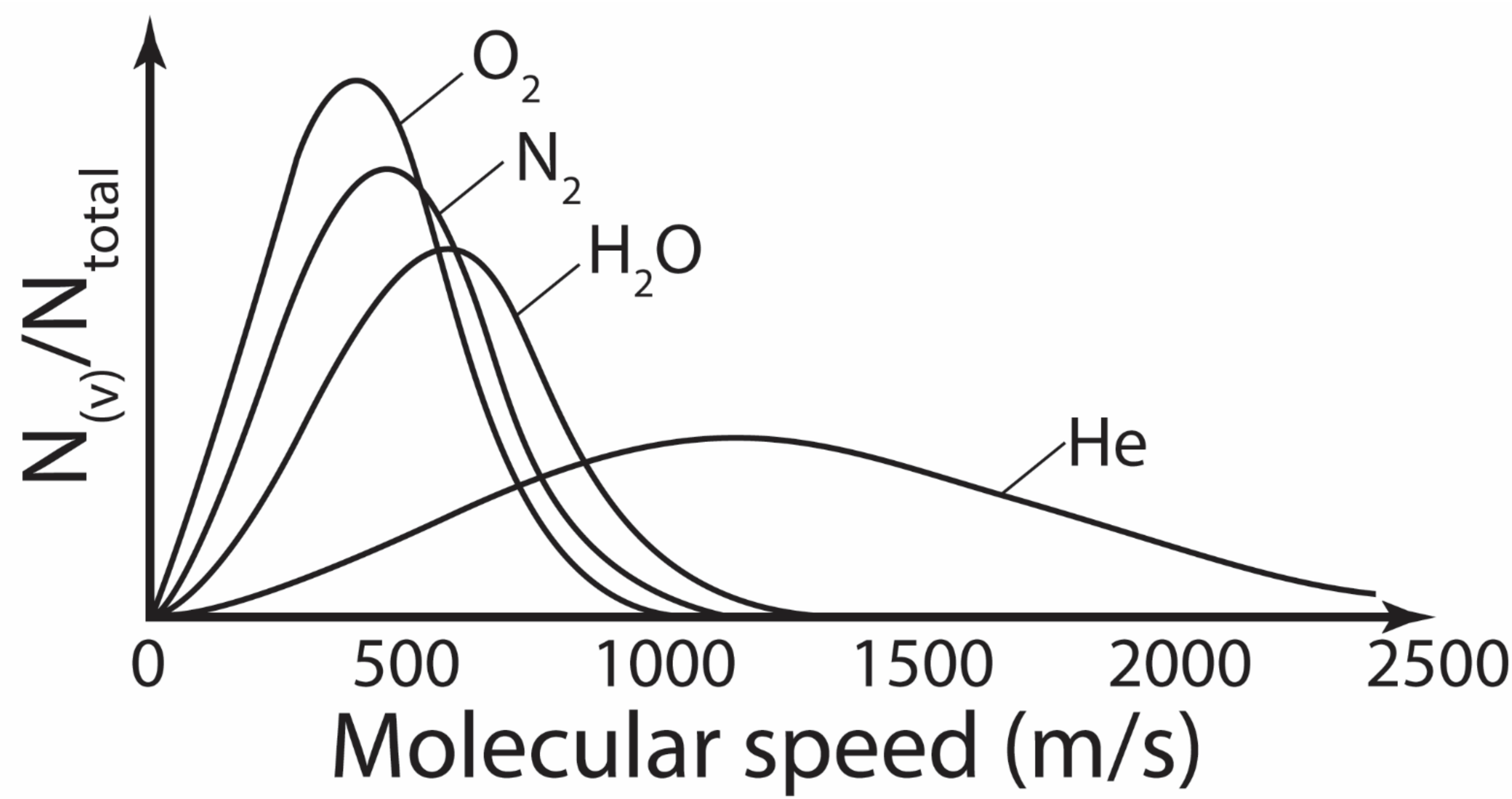
Clicker Question

According to KMT, the average velocity of gas particles…

a) Is higher for He than for Ne
b) Is lower for He than for Ne
c) Is the same for He and Ne

Kinetic Energy and gas identity

At fixed temperature, the identity of the gas affects the speed of the molecules.



Clicker Question

If a liter of CO_2 is compared to a liter of H_2, both at 25 °C and one atmosphere pressure, then:

a) The CO_2 and H_2 molecules have the same average speed
b) there are more H_2 molecules than CO_2 molecules
c) the average kinetic energy of the CO_2 molecules is greater than that of the H_2 molecules
d) The CO_2 molecules are, on the average, moving more slowly than the H_2 molecules
e) the mass of one liter of CO_2 equals the mass of one liter of H_2

Real gases

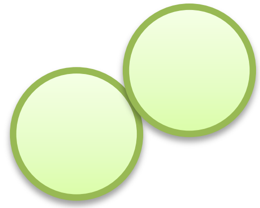
The ideal gas model assumes molecules do not interact. Real molecules **do** have interactions.

At low densities (low pressure), molecules in the gas spend little time close together so the effect of any interactions is negligible and the ideal gas equation can be quite accurate.

At high densities (high pressure), interactions start to have an effect and more accurate gas equations are needed, such as the virial equation or the van der Waals equation.

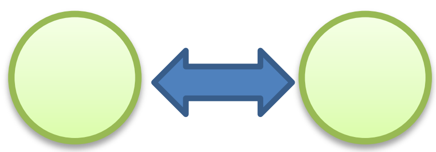
van der Waals equation

a and b are determined experimentally



[b] L/mol
Accounts for volume of particle

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



[a] bar L^2/mol^2
Also accounts for interactions among particles (pressure is a force per area)

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

a: particle interactions

b: effective volume of particle

① divide both sides by V

number density ρ

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

$$\left(P + a\left(\frac{n}{V}\right)^2\right)\left(1 - \frac{n}{V}b\right) = \frac{nRT}{V}$$

$$(P + a\rho^2)(1 - \rho b) = \rho RT$$

$$P + a\rho^2 = \frac{\rho RT}{1 - \rho b}$$

$$P = \frac{\rho RT}{1 - \rho b} - a\rho^2$$

② divide both sides by ρRT, we get:

$$Z = \frac{P}{\rho RT} = \frac{1}{1 - \rho b} - \frac{a\rho}{RT}$$

compressibility factor

for ideal gases, $Z = 1$