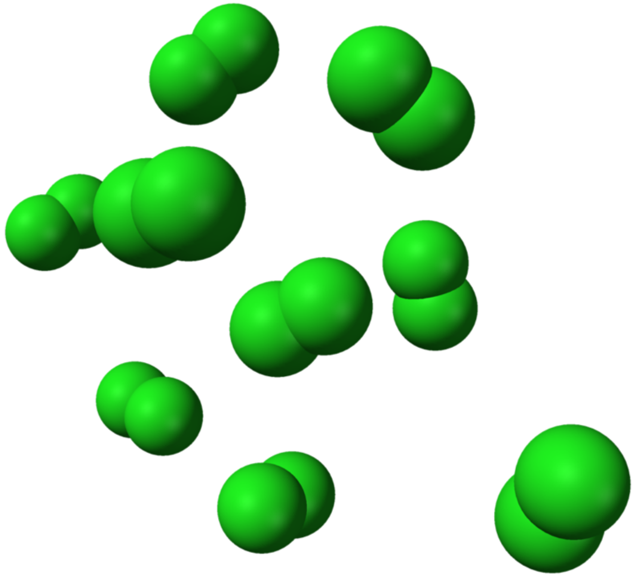


CH301 Unit 1

GAS LAWS, KINETIC MOLECULAR THEORY, GAS MIXTURES

Goals for Our Second Review

- Your first exam is in about 1 week!
- Recap the ideal gas law
- Kinetic Molecular Theory
  - 3 important relationships
  - Working problems with KMT
- Partial Pressures
  - Solving a stoichiometry problem with partial pressures

Wrapping up the Ideal Gas Law

- The relationship between these state functions is presented in the following equation:

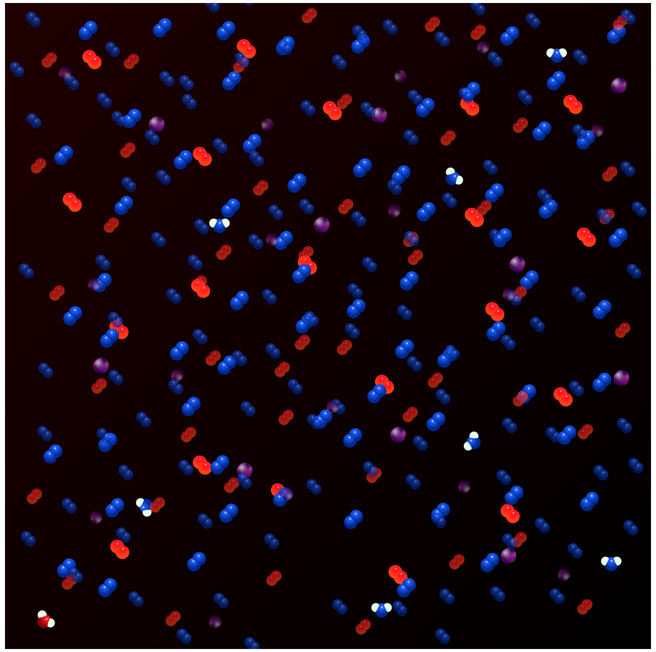
$$PV = nRT$$

- Key points:
  - State functions on the same side have an **inverse** relationship
  - State functions on opposite sides have a **direct** relationship
  - R is a **constant**, not a state function
  - Temperature is always in Kelvin
    - Why? Kelvin can only be expressed as a value 0 or greater. If you used Celsius, you would get negative volumes, pressures, and numbers of moles at certain temperatures
- Common error: choosing the correct R value
  - The role of R is to cancel your units. If it does not match the units of pressure, volume, moles, and temperature, you will end up with the wrong value.
  - The units of R stem from the following relationship:

$$\frac{PV}{nT} = R$$

Kinetic Molecular Theory

1. Gases are constantly moving in random directions
2. The distance between particles is large compared to the particle size
   - True ideal gases have relatively **no volume**
3. All particles have perfectly elastic collisions
   - There is no energy loss in the system to collisions; energy cannot be created or destroyed based on Newtonian Physics
4. No other forces act upon ideal gases
   - There are no attractive or repulsive forces that act upon ideal gas particles



Main conclusions: the ideal gas law works because when these pillars of KMT hold true in a system. The ideal gas law fails us when our assumptions do not hold true (when the size of the particles is large compared to the **volume** of the container; when there are significant attractions or repulsions – **intermolecular forces**– in a system)

Kinetic Molecular Theory: Relationships

- Kinetic Molecules Theory gives us three key relationships that you should know as equations and by definition (in words)

1. Kinetic Energy vs. Temperature

$$E_k = \frac{3}{2}RT$$

   - Kinetic energy is dependent solely on the **temperature** of a gaseous system (direct relationship)
   - This equation expresses kinetic energy in **Joules per mole**
   - R = **8.314 J / mol K**

$$E_k = \frac{3}{2}kT$$ ← **Energy per molecule (J)**

   - $k = \frac{R}{N_a}$

2. Mass vs. Velocity
3. Temperature vs. Velocity

Remember that in physics we describe kinetic energy with the equation:

$$\frac{1}{2}mv^2$$

KMT: Mass vs. Velocity; Velocity vs. Temperature

1. Kinetic Energy vs. Temperature

Based on the equation:

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

We can determine that velocity is proportional to the **square root of temperature** and the **inverse square root** of mass.

1. **Mass vs. Velocity (V_{rms})**
   - Velocity is proportional to the inverse square root of mass.
   - When temperature is constant, lighter particles move faster

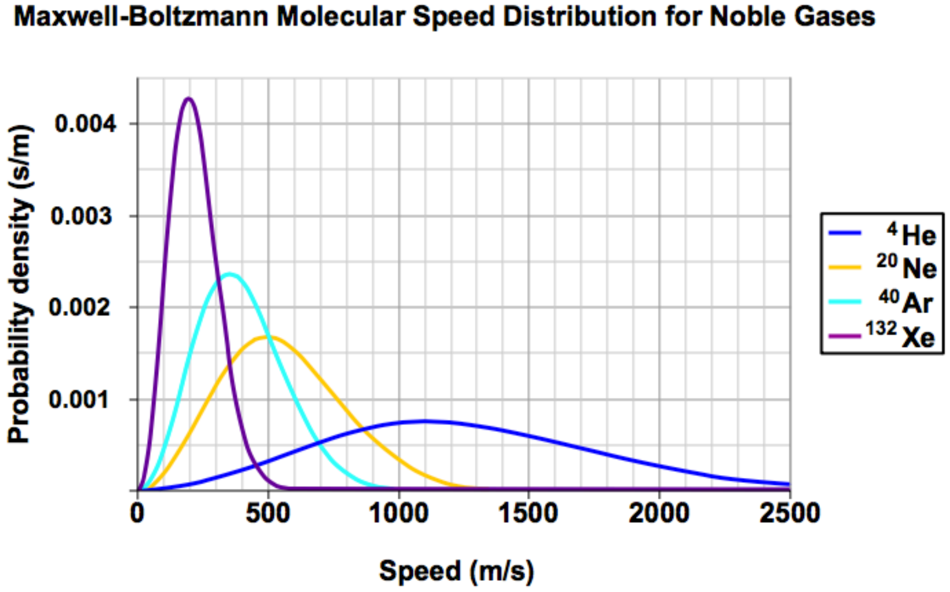
$$\frac{v_1}{v_2} = \sqrt{\frac{M_2}{M_1}}$$

2. **Velocity (V_{rms}) vs. Temperature**
   - Velocity is proportional to the inverse square of temperature
   - When dealing with the same species gas, particles move faster at higher temperatures

$$\frac{v_1}{v_2} = \sqrt{\frac{T_1}{T_2}}$$

Pay very close attention to how the 1 and 2 match up in these relationships

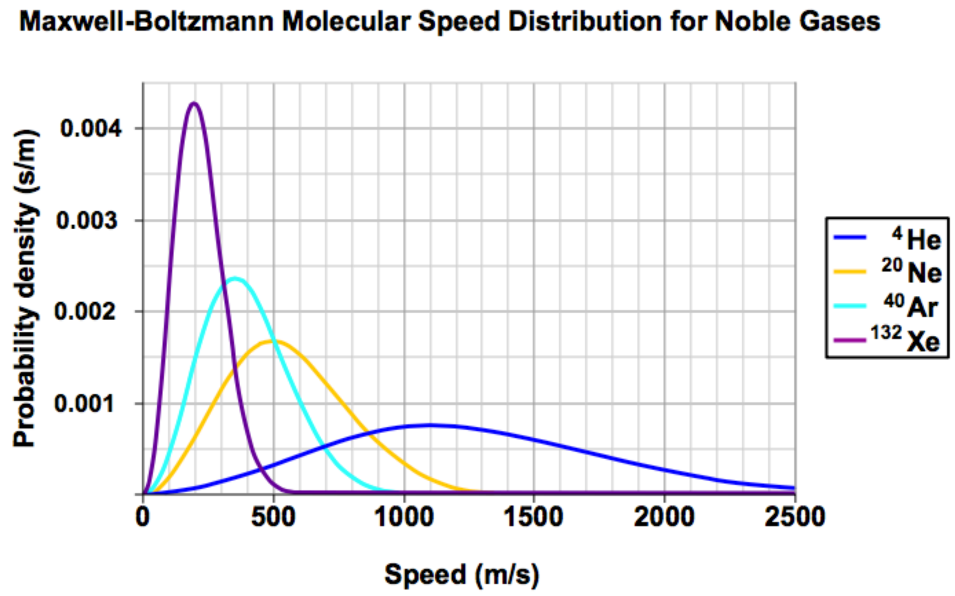
KMT: Mass vs. Velocity; Velocity vs. Temperature



- Some key features of this graph include:
  - Each curve looks like a unimodal distribution with a "tail" that approaches the limit infinity
  - Molecules are traveling at a variety of speeds but there is a clear average
  - The actual V_{rms} is slightly to the right of the peak

1. **Mass vs. Velocity (V_{rms})**
   - We can see that the heavier gases move slower and the lighter gases move faster
   - The faster the gas, the wider the distribution
2. **Velocity (V_{rms}) vs. Temperature**
   - If you were working with the same gas, a similar graph could be created by modifying temperature instead.
   - If you were working with Helium and your temperatures are 300K, 500K, 700K, and 1000K, which line represents 1000K and which line represents 300K?

KMT: Mass vs. Velocity; Velocity vs. Temperature



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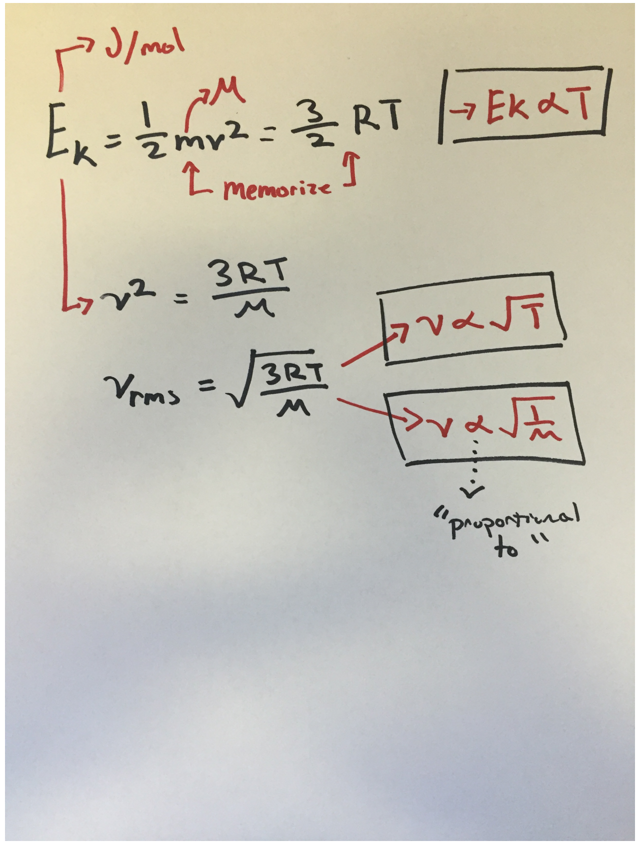
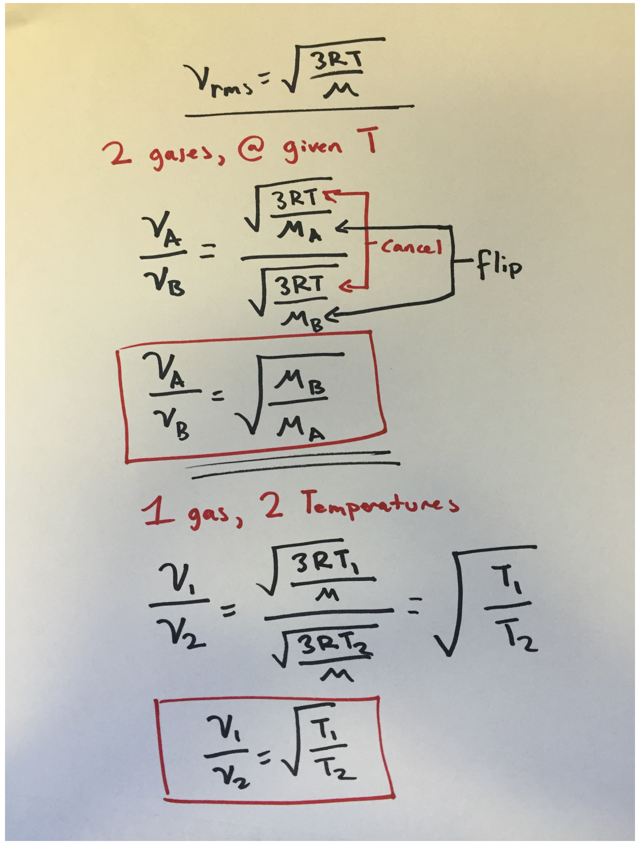
   - We can see that the heavier gases move slower and the lighter gases move faster
   - The faster the gas, the wider the distribution
2. **Velocity (V_{rms}) vs. Temperature**
   - If you were working with the same gas, a similar graph could be created by modifying temperature instead.
   - The blue line would represent the hottest temperature and the purple line would represent the coldest temperature.

KMT Review Notes





One More Relationship!

- Questions might arise that take velocity, mass, and temperature relationships one step further and incorporate time.
  - This relationship states that a faster object (higher v) will take less time to go the same distance as a slower object (lower v).
  - Obvious, but helpful to think this way
- Velocity and time have an inverse relationship:

$$\frac{V_1}{V_2} = \frac{t_2}{t_1}$$

- We can rewrite the previous relationships like this:

$$\frac{t_2}{t_1} = \frac{v_1}{v_2} = \sqrt{\frac{M_2}{M_1}}$$

- The equation above states that heavier objects take longer to travel a given distance when temperature is held constant

KMT Questions

Suppose you have samples of neon and nitrogen gas in a closed system. It takes your neon sample 3 minutes to travel a given distance.

Question 1:

Calculate the length of time necessary for your nitrogen gas to travel the same distance.

Note: before doing any math on this problem, ask yourself which sample will move quicker. This will help eliminate answer choices and help you think about the problem logically.

Hint: when setting up ratios in KMT problems, arrange your equation so that your unknown is on top.

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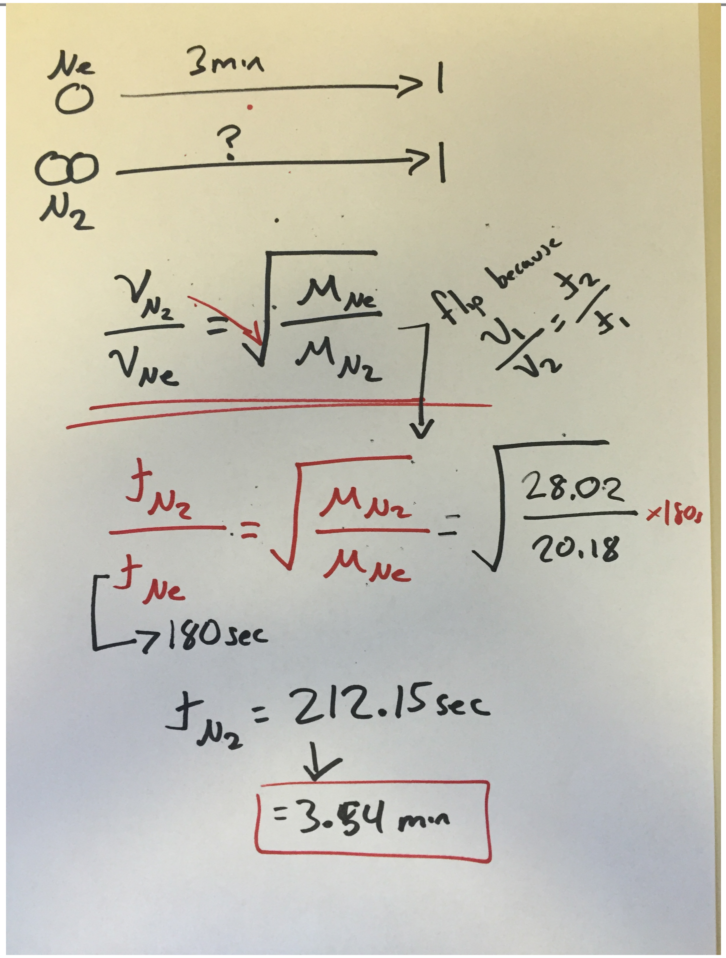
Note: before doing any math on this problem, ask yourself which sample will move quicker. This will help eliminate answer choices and help you think about the problem logically.

The neon will move faster because nitrogen is heavier. You should expect your answer to be greater than 3 minutes

Hint: when setting up ratios in KMT problems, arrange your equation so that your unknown is on top.

Ans: 3.54 minutes

KMT Questions



KMT Questions

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Question 1:

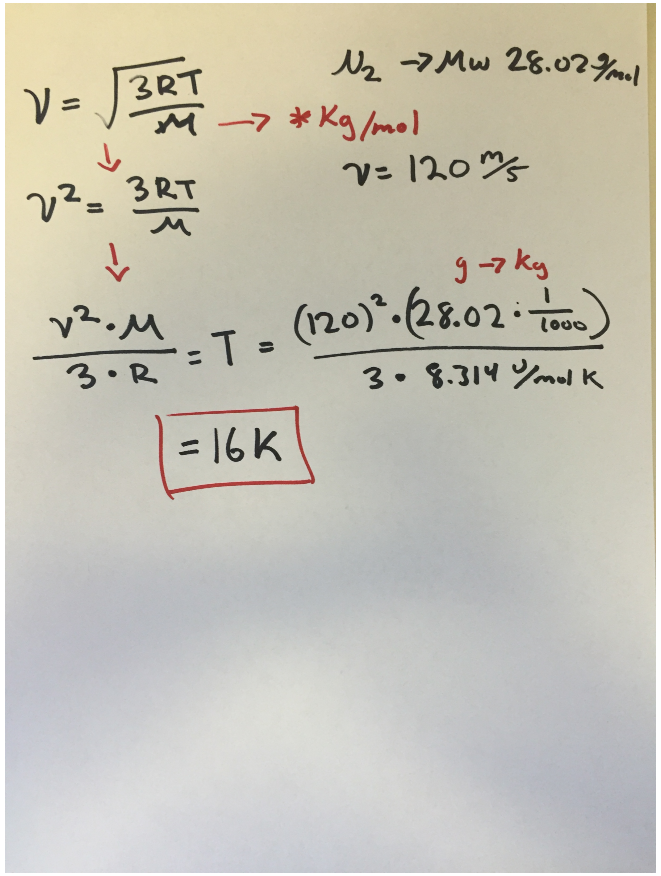
Calculate the length of time necessary for your nitrogen gas to travel the same distance.

Ans: 3.54 minutes

Question 2:

What is the temperature of your closed system if your nitrogen gas traveled at an average velocity of 120 m/s? Note: I slightly changed this question from the review to give a better answer

KMT Questions



$v = \sqrt{\frac{3RT}{M}}$ → * Kg/mol

N_2 → Mw 28.02 g/mol

$v = 120$ m/s

$v^2 = \frac{3RT}{M}$

g → kg

$$\frac{v^2 \cdot M}{3 \cdot R} = T = \frac{(120)^2 \cdot \left(28.02 \cdot \frac{1}{1000}\right)}{3 \cdot 8.314\ J/mol\ K}$$

= 16K

KMT Questions

Suppose you have samples of neon and nitrogen gas in a closed system. It takes your neon sample 3 minutes to travel a given distance.

Question 1:

Calculate the length of time necessary for your nitrogen gas to travel the same distance.

Ans: 3.54 minutes

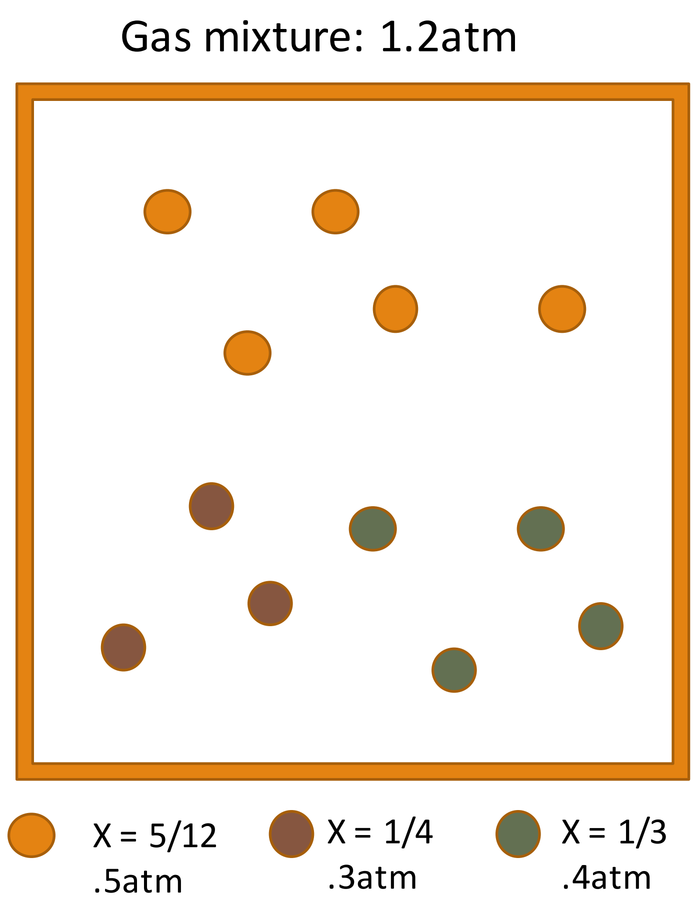
Question 2:

What is the temperature of your closed system if your nitrogen gas traveled at an average velocity of 120 m/s?

Ans: 16.1K

Partial Pressure

- Partial pressure is a method for quantifying the pressures exerted by individual species in a gas mixture.
- Three terms are necessary for understanding partial pressures:
  1. Total pressure (P or P_{total}): the "actual" pressure of the system
  2. Partial pressure (P_i): the pressure exerted by a single species (i)
  3. Mole fraction (X_i): the ratio between the number of moles of a single species (i) and the total number of moles in the system
- Dalton's Law of Partial Pressures:
  - The total pressure is equal to the sum of partial pressures
  - $P_{total} = P_a + P_b \ldots + P_i$
- Dalton's Law "Restated:"
  - The partial pressure of a gas species, i, is equal to the total pressure times the mole fraction of *i.*
  - $P_i = X_i P_{total}$



Partial Pressure Stoichiometry

Suppose you run the gas phase reaction shown below:

$2A_{(g)} + 4B_{(g)} \rightarrow 3C_{(g)} + D_{(g)}$

If you start with 8atm of A and 8atm of B, what is the mole fraction of D in the final system (assuming your reaction goes to completion)?

Partial Pressure Stoichiometry

Suppose you run the gas phase reaction shown below:

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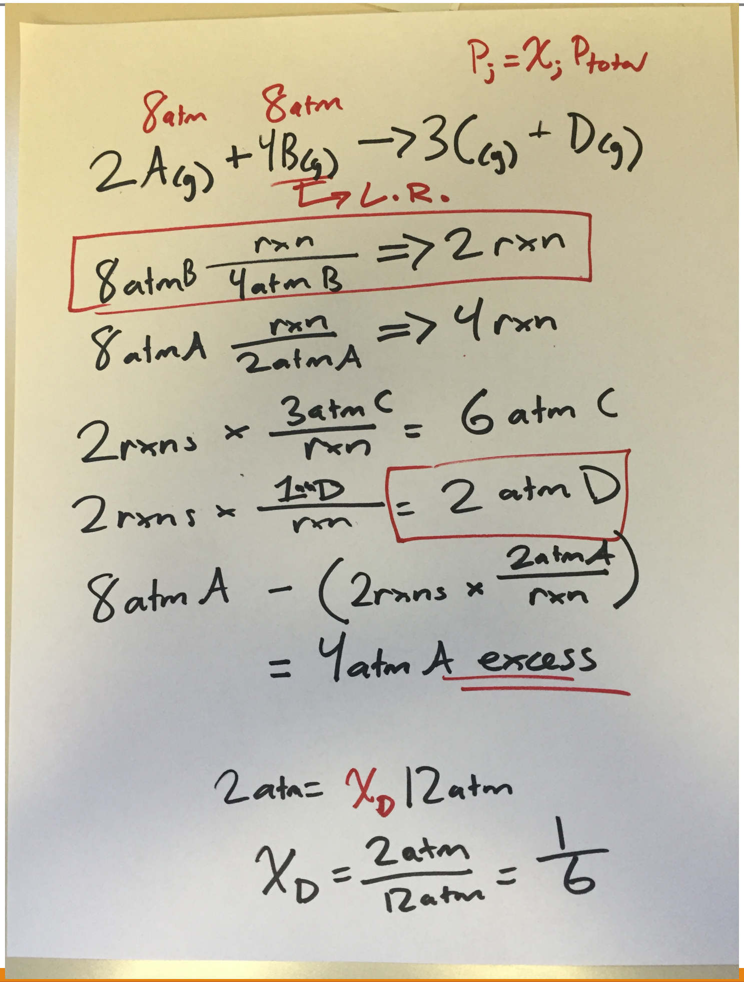

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Total pressure = 12atm

Partial pressure of D = 2atm

Mole Fraction of D = 1/6

Important things coming up:

- While the ideal gas law and KMT are very convenient models for gases, we need to all consider when they do not work
- The last topic we will cover is non-ideal gases
  - Deviating from ideal gases: understanding that gas molecules have volume and there are very small but non-negligible interactions between them
- Exam!