Chapter 4: Gases
What we will learn about now...

- We will learn how volume, pressure, temperature are related.
- You probably know much of this qualitatively, but we’ll learn it quantitatively as well with the ideal gas law. And link it with what you already know.
- Learn how the ideal gas law describes mixtures of gasses with Dalton’s law of partial pressures.
- Relate the microscopic and the macroscopic with the kinetic molecular theory.
- Then we learn why all this ideal gas law work is a partial lie (like so much in general chemistry) and learn to correct for deviations from ideality.
Gases

- Particles move essentially ____________
- Unlike liquids and solids ______________
- This means that they are _____________ and exert _________________________
- Like a liquid they don't have a _________________________
- They will expand to ______________
- They will mix evenly amongst each other.
- They are lower in density than liquids or solids
Pressure of a Gas

- **SI units**
  - Pressure = force/area or N/m²
  - Called a “pascal” or Pa

- **Other units**
  - Torr, atm, mmHg
  - 1 atm = 760 mmHg = 101,325 Pa

- On your own practice: convert 825 mmHg to atm, Pa and kPa.
Barometers

- A vacuum tube is placed in a dish of mercury.

- Atmospheric pressure pushes the mercury into the tube.

- The higher the atmospheric pressure the higher the mercury goes.
Suppose you were marooned on a tropical island and had to use seawater (density 1.10 \( \text{g cm}^{-3} \)) to make a barometer. What height would the water reach in your barometer when a mercury barometer would reach 73.5 cm? The density of mercury is 13.6 \( \text{g cm}^{-3} \).

So why don’t we use water for barometers?
What is an Ideal Gas?

- Molecules move __________
- __________________________
- They have ________________
- All collisions are _________
- Many gases can be treated as ideal
  - Works well at ____________
  - Works well at __________________________
Lets do some predicting:

http://phet.colorado.edu/en/simulation/gas-properties
The Gas Laws: Boyle’s Law

- Relates Pressure to Volume.
- If you __________ the volume the pressure ______________.
- If you decrease the volume pressure increases.
- True when moles of __________________________ are held constant.

\[ P \propto \frac{1}{V} \]
Boyle’s Law Graph

You should be able to replicate this!
The Gas Laws: Charles Law

\[ V \propto T \]

- Occasionally referred to as Gay-Lussac’s
- As temperature increases volume
  \[ \text{________} \]
- As temperature decreases volume
  \[ \text{________} \]
- True when pressure and the number of moles are held constant.
The Gas Laws: Avogadro’s Law

- Relates moles to volume
- As the number of moles increase the volume
- True when _____________ are held constant.

\[ V \propto n \]
The Gas Laws: Charles Law

Heating or cooling a gas at constant pressure

Heating or cooling a gas at constant volume

Charles’s Law
\[ V = \left( \frac{nR}{P} \right) T \]
\( \frac{nR}{P} \) is constant

Charles’s Law
\[ P = \left( \frac{nR}{V} \right) T \]
\( \frac{nR}{V} \) is constant
Charles’s Law Graph

You should be able to replicate this!
Ideal Gas Law

- This is the combination of all the other ones.

- You can use this equation to do all the Boyle’s, Charle’s and Avagadro’s problems by deciding what is constant and cancelling them out.

- R is the ideal gas constant.

Question: What units must pressure, volume and temperature be in?
Ideal Gas Law: Example

Sulfur hexafluoride (SF$_6$) is a colorless, odorless, very unreactive gas. Calculate the pressure exerted by 1.82 moles of the gas in a steel vessel of volume 5.43 L at 69.5 °C
Ideal Gas Law: You Try

Calculate the volume occupied by 2.12 moles of nitric oxide (NO) at 6.54 atm and 76 °C
Ideal Gas Law

The ideal gas law can be used to find how one variable changes as others change.

For example how would we figure out the new volume if a balloon that had a volume of 0.55 L at sea level (1.0 atm) where the temperature is 70 °C is allowed to rise to a height of 6.5 km, where the pressure is 0.40 atm and the temperature is 60 °C.

Need to do some manipulations to the ideal gas law.

From here you can solve most any problem by cancelling out what is constant and solving for the unknown

\[ R_1 = \frac{P_1V_1}{n_1t_1} \quad R_2 = \frac{P_2V_2}{n_2t_2} \]
Example

For example how would we figure out the new volume if a balloon that had a volume of 0.55 L at sea level (1.0 atm) where the temperature is 70 °C is allowed to rise to a height of 6.5 km, where the pressure is 0.40 atm and the temperature is 60 °C

\[
\frac{P_1 V_1}{n_1 t_1} = \frac{P_2 V_2}{n_2 t_2}
\]

\[
V_1 = 0.55 \text{L} \quad T_1 = 70 + 273 \\
P_1 = 1 \text{atm} \quad P_2 = 0.4 \text{ atm} \\
T_2 = 60 + 273 \quad V_2 = ?
\]
Examples:

- Argon is an inert gas used in lightbulbs to retard the vaporization of the tungsten filament. A certain lightbulb containing argon at 1.20 atm and 18°C is heated to 85°C. Calculate the final pressure.

- A bubble rises from the bottom of a lake where the temperature and pressure are 8°C and 6.4 atm, to the water’s surface where the temperature is 25°C and the pressure is 1.0 atm. Find the volume of the bubble at the surface if its initial volume was 2.1 mL.

- Octane (C₈H₁₈) is in gasoline, when combusted it produces carbon dioxide and water. How many liters of O₂ measured at 0.974 atm and 24°C are required to burn 1.00g of octane.
THE SCIENCE NEWS CYCLE

Start Here

Your Research
Conclusion: A is correlated with B (p=0.56), given C, assuming D and under E conditions.

...is translated by...

UNIVERSITY PR OFFICE
(YES, YOU HAVE ONE)

FOR IMMEDIATE RELEASE:
SCIENTISTS FIND POTENTIAL LINK BETWEEN A AND B
(Under certain conditions).

...which is then picked up by...

NEWS WIRE ORGANIZATIONS
A CAUSES B, SAY SCIENTISTS.

...who are read by...

THE INTERNETS

Scientists out to kill us again.
POSTED BY RANDOM DUDE
Comments (377)
OMG! i kneew it!!
WTH???????

...then noticed by...

CNN Cable NEWS
We saw it on a Blog!
A causes B all the time
What will this mean for Obama?
BREAKING NEWS BREAKING NEWS BREAKING NEWS BREAKING NEWS

...and caught on...

LOCAL EYEWITNESS NEWS
WHAT YOU DON'T KNOW ABOUT "A"... CAN KILL YOU! MORE AT 11...

...eventually making it to...

YOUR GRANDMA
I'M WEARING THIS TO WARD OFF "A"
Density Calculations

- The density is equal to mass divided by volume

- Molar density is equal to mols divided by volume

- Rearranging the ideal gas law
Molar Mass Calculation

- Molar mass units ___________
- Density of substance is _________
- Molar density is ____________

Interconvert between the three by using dimensional analysis
Density Example:

Phosgene is a highly toxic gas made up of carbon oxygen and chlorine atoms. Its density at 1.05 atm and 25 °C is 4.24 g/L. What is the molar mass of phosgene? If phosgene is made up of 12.1% C, 16.2% O and 71.7% Cl what is the molecular formula?
Dalton’s Law of Partial Pressures

- Partial Pressure: Pressures of individual components of gases
- Dalton’s law of partial pressures: total pressure of a mixture of gases is equal to sum of individual components pressures.
Dalton’s Law of Partial Pressures

\[ P_{\text{total}} = \frac{n_a RT}{V} + \frac{n_b RT}{V} + \frac{n_c RT}{V} \ldots \]
Mole Fraction

\[ \chi_a = \frac{n_a}{n_{total}} \quad \quad P_a = \chi_a P_t \]

- \[ \chi_a = \frac{n_a}{n_{total}} \]: to moles of part over moles of whole
- So partial pressure \[ \chi_a P_t \]
Let's do this with a picture first:

Given that the total pressure of the box is 10 units, what is the pressure of each gas?

What if the total pressure of the box is 30 units, what is the pressure of each gas?
Examples:

- The contents of a tank of natural gas at 1.20 atm is analyzed. The analysis showed the following mole percents: 88.6% CH$_4$, 8.9% C$_2$H$_6$, 2.5% C$_3$H$_8$. What is the partial pressure of each gas in the tank?

- A sample of oxygen gas is collected over water at 25°C (vapor pressure H$_2$O=23.8 mmHg). The wet gas occupies a volume of 7.28 L at a total pressure of 1.25 bar. If all the water is removed, what volume will the dry oxygen occupy at a pressure of 1.07 atm and a temperature of 37°C?
Combining Concepts: Gas Stoichiometry

The picture below shows two bulbs connected by a stopcock. The 6.00-L bulb contains nitric oxide at a pressure of 0.600 atm, and the 1.50-L bulb contains oxygen at a pressure of 2.50 atm.

![Diagram of two bulbs connected by a stopcock with NO and O₂ symbols](image)

After the stopcock is opened, the gases mix and react:

\[ 2\text{NO}(g) + \text{O}_2(g) \rightarrow 2\text{NO}_2(g) \]

Determine which gases remain after the reaction goes to completion and calculate their partial pressures. The temperature at the beginning and the end of the experiment is 22 °C.

Which gases are present at the end of the experiment?

- [ ] NO
- [ ] O₂
- [ ] NO₂

What are the partial pressures of the gases? If the gas was consumed completely, put 0 for the answer.

\[ P_{\text{NO}} = \square \text{ atm} \]
\[ P_{\text{O}_2} = \square \text{ atm} \]
\[ P_{\text{NO}_2} = \square \text{ atm} \]
Combining Concepts: Gas Stoichiometry

Hydrazine, \( \text{N}_2\text{H}_4 \), may react with oxygen to form nitrogen gas and water.

\[
\text{N}_2\text{H}_4(aq) + \text{O}_2(g) \rightarrow \text{N}_2(g) + 2\text{H}_2\text{O}(l)
\]

If 2.45 g of \( \text{N}_2\text{H}_4 \) reacts and produces 0.750 L of \( \text{N}_2 \), at 295 K and 1.00 atm, what is the percent yield of the reaction?

%
Combining Concepts: Gas Stoichiometry

The combustion of octane, $\text{C}_8\text{H}_{18}$, proceeds according to the reaction

$$2\text{C}_8\text{H}_{18}(l) + 25\text{O}_2(g) \rightarrow 16\text{CO}_2(g) + 18\text{H}_2\text{O}(l)$$

If 538 mol of octane combusts, what volume of carbon dioxide is produced at 18.0 °C and 0.995 atm?
Example

Consider two containers connected by a valve that can be opened or closed. Initially the pressure and volumes are as marked. Find the final pressure after the valve is opened.
Kinetic Molecular Theory of Gas

What is Kinetic energy?

Kinetic theory of gases
- Assume molecules are point masses (___________________________
  __________________________)
- Constant random motion, collisions are completely _____________
  energy can be transferred, but total energy ____________________.
- Gas molecules are neither ______________________________
- AVERAGE kinetic energy is proportional to _________________
Lets look at this in more detail: AVERAGE kinetic energy is proportional to temperature

- This means that at a given temperature two different gas molecules will have the same ____________.

- What does this mean about the relation between mass and speed?

- They are __________________________
Kinetic Molecular Theory: Pressure

- Pressure is created by ______________ between molecules and the container.
- The faster the molecules hit the container the ________________.
- The ________________ the molecules hit the container the more pressure
- Who do each of those relate to the ideal gas law?
- Don’t worry too much about the derivation in the book, it is fyi only, I will not test you on it.
Wait what was with that equation again....?

\[ KE = \frac{1}{2} m \bar{u}^2 \]

- What is this \( \bar{u}^2 \) you speak of?
- \( \bar{u}^2 \) is the ______________________
- Molecules aren’t all traveling at the same speed, there is a distribution.
According to kinetic theory of gases, total kinetic energy per mol is $\frac{3}{2}RT$.

If KE of 1 atom is $\frac{1}{2}(m\bar{v}^2)$,
- so KE of 10 atoms would be $10 \times \frac{1}{2}(m\bar{v}^2)$
- so KE of 1 mol would be $6.02 \times 10^{23}(\frac{1}{2}(m\bar{v}^2))$. We’ll note that $M$ (fancy M in your book).

So......

What does that mean about speed vs. mass?

inversely proportional
Example 5.16 from book:

- Calculate rms of Helium and Nitrogen molecules. \( u_{rms} = \sqrt{\frac{3RT}{M}} \)

\[
\text{He} \quad u_{rms} = \sqrt{\frac{3 \times 8.314 \frac{J}{K\cdot\text{mol}} \times 298K}{4.003 \times 10^{-3} \frac{\text{kg}}{\text{mol}}}} = \sqrt{1.86 \times 10^6 \frac{J}{\text{kg}}} = 1.36 \times 10^3 \text{m/s}
\]

\[
\text{N}_2 \quad u_{rms} = \sqrt{\frac{3 \times 8.314 \frac{J}{K\cdot\text{mol}} \times 298K}{2.65 \times 10^5 \frac{\text{kg}}{\text{mol}}}} = \sqrt{2.65 \times 10^5 \frac{J}{\text{kg}}} = 515 \text{m/s}
\]

So He is faster. To escape gravity a molecule must have a certain velocity, which is more likely to escape earth’s gravity? (escape velocity needed \(1.1 \times 10^4 \text{ m/s}\)) What does this mean about the composition of our atmosphere?
Diffusion and Effusion

Diffusion:

Effusion: gas goes from one container under pressure through a small opening into an
Effusion Application

- “Enriched” uranium needs to be 90% U-235
- U-235 is only 0.7205% natural abundance

4000 stages, half mile long, six stories high
Tenneseeee

KernEnergie, Berlin
Diffusion and Effusion

solve for temperature

For two different species at the same temperature:

rearranging:

Renaming rms and square rooting each side
Examples:

○ A gas effuses 1.55 times faster than propane C₃H₈ at the same temperature and pressure. Is the gas heavier or lighter? What is the Molar mass?

○ What is the ratio of the rate of effusion of the most abundant gas N₂ and the lightest gas H₂?

○ Rank the following in order of increasing speed of effusion and increasing time of effusion: NO Ar N₂ N₂O₅

○ It takes 12.6 s for 1.73x10⁻³ mol of CO to effuse through a pinhole. Under the same conditions, how long will it take for the same amount of CO₂ to effuse through the same pinhole.

○ At what temperature will a molecule of uranium hexafluoride, the densest gas known, have the same average speed as a molecule of the lightest gas, hydrogen at 37 degrees C
Real Gases

- Reminder: Ideal gases assume ...
- True for some conditions not others:

- Before Class Thinking Point: When is this most likely to be true why?
Attraction:

- When molecules are moving quickly attraction ____________
- When molecules are moving slower, attraction becomes ________________________________.
- Under what conditions would this not be negligible?
  - Hint: how is temperature related to speed?
  - How is mass related to speed?
  - How do intermolecular forces relate to attraction?
Volume

- In ideal gases, the volume ______________________
- This means that the space between molecules is very ______________________ in comparison to the ______________________
- When does this become false?
Compression Factor

Compression factor, actual volume divided by volume of ideal gas.

Molecules attract when they are ___________________.

Repel when they become close enough that their ____________

More it deviates from ____, the ____________________.
Van der Waals Equation

\[
(P + \frac{an^2}{V^2})(V - nb) = nrt
\]

- One way in which deviations can be accounted for:
- \(a\) and \(b\) are __________________________
- There are other ways this is done.

You will obviously not be required to know the \(a\) and \(b\) value for gases. I will give them to you if you need them.
Exercises

A sample of methane gas is at 50 °C and 20 atm. Would you expect it to behave more or less ideally if:

- a) the pressure were reduced to 1 atm
- b) the temperature were reduced to -50°C

At 37 °C 3.0 mols of He is in a container of 2.0 L, what is the pressure in the container.