Chapter 5. Gases and the Kinetic-Molecular Theory

5.1 An Overview of the Physical States of Matter
The reason we study gases in Chemistry:

The observable properties of gases give us a window into what’s happening at the _______________ _______________.

For example, ask yourself:
- Why
- Why
- Why

5.2 Gas Pressure and its Measurement

- 4 variables completely describe the state of any gas:

- Methods of measuring pressure:
  - manometer
  - barometer
  - height of Hg an expression of pressure

(Problem 5.6, Page 170.) On a cool, rainy day, the barometric pressure is 725 mm Hg. Calculate the barometric pressure in centimeters of water (cm H$_2$O). (d of Hg = 13.5 g/mL; d of H$_2$O = 1.00 g/mL)

Convert this to ft of H$_2$O.

- Definition of pressure:
- SI unit of force:
- SI unit of area:
- therefore, 1 Pa =

This is a very small unit!
Two important gas laws:

**Ideal gas law:**

**Combined gas law:**

Start with the Combined Gas Law:

*Two special cases:*

1. Constant T
2. Constant P

Next, consider Avogadro's hypothesis and Avogadro's Law:

**Avogadro's hypothesis:** Equal volumes of gases at the same temperature and pressure contain:

<table>
<thead>
<tr>
<th>Ex</th>
<th>Ar</th>
<th>Ne</th>
<th>H₂</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.00 L</td>
<td>1.00 L</td>
<td>1.00 L</td>
</tr>
<tr>
<td></td>
<td>1.00 atm</td>
<td>1.00 atm</td>
<td>1.00 atm</td>
</tr>
<tr>
<td></td>
<td>0ºC</td>
<td>0ºC</td>
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**Avogadro's Law:** at constant T & P, the volume of a gas is directly proportional to ______________

Two important consequences of Avogadro's hypothesis and Avogadro's Law:

1. We can focus on ______________ in stoichiometry problems:
   \[ \text{N}_2(g) + 3\text{H}_2(g) \to 2\text{NH}_3(g) \]

   Be careful: 1) 
2) 

**Example:** How many liters of nitrogen gas are required to react with 12.0 L of hydrogen gas to form ammonia, if both gases are measured at the same temperature and pressure?
2. The molar volume of a gas at ______________ is _____________________.

   STP =
   This gives us these conversion factors:
   Be careful!  
   1) 
   2)

   **Important Term: Molar**
   molar –
   molar mass –
   molar volume of a gas –
   molar enthalpy of combustion –
   molar enthalpy of formation –

   **Example:** Consider the following reaction:
   \[
   \text{MgCO}_3(s) + 2\text{HCl}(aq) \rightarrow \text{MgCl}_2(aq) + \text{H}_2\text{O}(l) + \text{CO}_2(g)
   \]
   What volume of CO\(_2\) gas, measured at 0°C and 1 atm pressure, will be formed by the complete reaction of 50.0 g of MgCO\(_3\) with excess hydrochloric acid? (Given: the molar mass of MgCO\(_3\) is 84.3 g/mol.)

   **Example:** Consider the following reaction:
   \[
   2 \text{Al}(s) + 6\text{HCl}(aq) \rightarrow 2\text{AlCl}_3(aq) + 3\text{H}_2(g)
   \]
   What volume of hydrogen gas, measured at 0°C and 1 atm pressure, will be formed by complete reaction of 108 g of solid aluminum?

   **Example:** What is the molar volume of an ideal gas at 760. torr and 546 K?

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**5.4-5.5 Further Applications of the Ideal Gas Law and Gas Stoichiometry**

**Molar Mass from density**

   Derivation of an important relationship:
   molar mass:
   rearrange:
   ideal gas law:
   substitute:
   rearrange:

   **Example:** Uranium hexafluoride is a solid at room temperature, but it boils at 56°C. Determine the density of uranium hexafluroide at 60° C and 745 torr.
Dalton’s Law of Partial Pressures

- Definition of Partial Pressure:

- Easy way to express Dalton’s Law:

- More useful form of Dalton’s Law:

  \[ P_A = X_A \]

Example: A 10.0 L container contains 5.00 g of oxygen and 7.50 g of nitrogen at 25.0°C. What is the partial pressure of each gas, and what is the total pressure?

Collecting Gases Over Water

eample: (# 5.48, p. 172) Aluminum reacts with excess hydrochloric acid to form aqueous aluminum chloride and 35.8 mL of hydrogen gas over water at 27°C and 751 mmHg. How many grams of aluminum reacted?

  First, determine vapor pressure of water at 27°C from table, page 157
  26°C, \( P_{\text{H}_2\text{O}} = 25.2 \text{ torr} \)
  28°C, \( P_{\text{H}_2\text{O}} = 28.3 \text{ torr} \)
  \[ \text{extrapolate: } P_{\text{H}_2\text{O}} = \frac{25.2 + 28.3}{2} = 26.75 \text{ torr at 27°C} \]

5.6 The Kinetic Molecular Theory of Gases

Two main questions:
1. What causes pressure?
2. How can we explain the gas laws?
   - Boyle’s Law
   - Charles’ Law
   - Avogadro’s Law
   - Dalton’s Law

Main idea behind KMT:

4 Postulates of the KMT:
The Kinetic-Molecular Theory can be used to explain the properties of gases.

- The pressure of a gas is caused by
  
  - Boyle’s Law
  
  - Dalton’s Law of Partial Pressure

**Two Boltzmann Distributions, based on temperature and mass:**

<table>
<thead>
<tr>
<th>At two different temperatures</th>
<th>Two different gases (e.g., O₂ and He)</th>
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<td>(fig. 5.12, p. 161)</td>
<td>(fig. 5.17, p. 163)</td>
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**Effusion/Diffusion**

1. Diffusion:

2. Effusion:

3. Graham’s Law of effusion: the rate of effusion of a gas (through a small hole or orifice) is inversely proportional to the square root of the molar mass of the gas.

\[
\frac{r_1}{r_2} = \sqrt{\frac{M_2}{M_1}}
\]

where \( r_1 \) = rate of effusion of gas 1, \( M_1 \) = molar mass of gas 1

4. **Example:** Suppose an unknown gas has been observed to effuse one-half as fast as oxygen. What is the molecular weight of the unknown gas?

5. Two important points:
   - Lighter gases _________________________________________________________
   - Diffusion works __________________________________________________________

**5.7 Deviation from Ideal Behavior**

1. What is an “ideal gas”?

2. What does it mean for a gas to deviate from ideal behavior?
3. Most gases deviate from ideal behavior at _____________ and __________________  
   This is easy to remember because:

4. Plot of PV/nRT vs P

5. Gases deviate from ideal behavior at high pressure because:

6. Gases deviate from ideal behavior at low temperature because:

7. The van der Waals equation is an attempt to correct the ideal gas equation for real gases.
   
   \[
   \left( P + \frac{a}{V^2} \right) (V - nb) = nRT 
   \]

8. Pressure correction, because the pressure exerted by the gas is ________________ it would be if there were no 
   attractive forces between gas molecules.

9. Volume correction, because the volume available to the molecule is ________________ 
   the total volume of the container.

10. \textbf{a} and \textbf{b} are constants that are experimentally determined for each gas.
    
    • The constant \textbf{a} is a measure of:
    • The constant \textbf{b} is a measure of:
    
    • Example: for \text{He}, \quad a = 0.034 \quad b = 0.0237 \quad (i.e., very little correction necessary)
    for \text{CCl}_4, \quad a = 20.39 \quad b = 0.1383