Chapter 19

Molecules and Compounds
Mini Quiz

Which elements will react with water the same way that Na does?

A. Ar
B. B
C. Cl
D. K
E. Mg
Another

Which of the following has the highest ionization energy?

A. Na (Z=11)
B. Al (Z=13)
C. Cl (Z=17)
D. Ar (Z=18)
Molecules & Compounds

- What elements, compounds and molecules are.
- How you read a chemical formula.
- How you read a chemical equation.
- What a balanced equation is.
Most elements exist as individual atoms tacked together.

* e.g. metals
Noble gases exist as individual atoms in a gas.
Molecule

- 2 or more atoms linked together as one unit
  - the element hydrogen exists as two bound H atoms
  - sulfuric acid – hydrogen, oxygen, and sulfur -- a “compound”
Evidence for molecules

- Mass spectrometers directly detect molecules
  - for hydrogen, we see particles with mass 1 as expected, and we also see particles with mass 2
  - many other examples
Compound

- A group of identical molecules each of which is composed of at least two different kinds of atoms.

- Represented by a formula
Chemical formulas

The number of copies of a given atom in a molecule is indicated by a subscript.
- Two hydrogen – $H_2$
- Water – $H_2O$
- Sulfuric acid – $H_2SO_4$

The number of copies of a molecule is indicated by a number in front of the molecular formula
- $5\text{ NH}_3$
**Notation**

<table>
<thead>
<tr>
<th>Chemical Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>He</td>
<td>atom of helium</td>
</tr>
<tr>
<td>O₂</td>
<td>molecule with two atoms of oxygen</td>
</tr>
<tr>
<td>NaCl</td>
<td>“simplest formula” 1 atom (actually ion) of sodium and 1 ion of chlorine</td>
</tr>
<tr>
<td>HNO₃</td>
<td>molecule with 1 atom of hydrogen and Nitrogen and 3 atoms of oxygen</td>
</tr>
<tr>
<td>3H₂O</td>
<td>3 water molecules</td>
</tr>
<tr>
<td>O₃</td>
<td>molecule with 3 atoms of oxygen -- ozone</td>
</tr>
</tbody>
</table>
Questions

- The element sulfur usually exists as $S_8$ molecules. Is it a compound?

- *Do all compounds exist as molecules?*
Diatomic elements

- Always come in packages of 2
- Have No Fear of Ice Cold Beer
- Super 7: H\textsubscript{2}, N\textsubscript{2}, F\textsubscript{2}, O\textsubscript{2}, I\textsubscript{2}, Cl\textsubscript{2} & Br\textsubscript{2}
“Ionic Compounds”

- consist of ions stacked together
  - sodium chloride
Characteristics of Compounds

- **number of different compounds is unlimited**
  - water, $\text{H}_2\text{O}$
  - carbon dioxide, $\text{CO}_2$
  - methane, $\text{CH}_4$
  - ammonia, $\text{NH}_3$

- **If you change the ratio of atoms, you change the compound**
  - 2 atoms of H + 1 atom of O = **water** $\text{H}_2\text{O}$
  - 2 atoms of H + 2 atoms of O = **hydrogen peroxide** $\text{H}_2\text{O}_2$
The Law of Definite Proportion

- The elements that make up a compound are always present in definite proportions (not just any ratio will do)

- Always integer ratios (no \( \frac{1}{2} \) atoms)
  - This shows up in chemical formulas and reactions
Formulas

**molecular formulas**

\[
\begin{align*}
F_2 & \quad CO_2 & \quad Cl_2 & \quad CH_4 & \quad H_2 \\
CO & \quad SF_6 & \quad O_2 & \\
\end{align*}
\]

**simplest formulas** *(for materials which don't exist as molecules)*

\[
\begin{align*}
Na & \quad NaCl & \quad Mg \\
\end{align*}
\]
How and Why?

♫ How and why are atoms bound together into molecules?
Chemical Bonds

1. Hydrogen atoms do not normally attract one another because they are electrically neutral.
   ▲ How do they “find” one another?

2. What kind of orbital is a hydrogen electron in before bonding? After bonding?

3. Are there other possible orbitals for molecular hydrogen?
Hydrogen: $\text{H}_2$

A new kind of orbital - molecular orbital

What is the effect of $e^-$ density here?

If the new molecular orbital is lower in an energy well, $e^-$’s go to this state, then can’t get out -- stable unless energy added.
Chemical bond - an analogy

1. The system (magnet + steel) has **potential energy**.
2. The system **loses** energy on impact through heat and sound.
3. Until the energy can be replaced from outside the system, the piece of steel remains “stuck” to the magnet.
A **chemical bond** between two atoms exists when the **electrons** in the two atoms have **less energy** when the atoms are together than when they are apart.

Atoms agree that they are happier if they transfer electrons (producing ions) or share electrons (producing molecules).
What is a Chemical Reaction?

- A chemical reaction occurs when two (or more) atoms, molecules, or ions come close enough together that chemical bonds are made or broken.

- A chemical bond forms if the electrons in the atoms have less energy when the atoms are together than when they are apart.
Is a compound a mixture?

- A mixture is a loose, **physical** combination of elements and/or compounds. **No chemical bonds** need to be broken to separate a mixture into its compounds or different molecules.

  **Example:** $\text{H}_2, \text{O}_2$ in a balloon

  Why don’t the hydrogen atoms and the oxygen atoms “find” each other and form water ($\text{H}_2\text{O}$)?
A Chemical Reaction

- $H_2 + O_2$ needs energy - to break existing bonds
  - Heat it
  - $H + H + O + O$
  - Energy released as electrons find a new, deeper energy well
  - $H_2O$

What happens to the energy and the disorder of the system as water molecules are formed?
What is the “bond”?

*electromagnetic force*
A Chemical Equation

The equation is balanced when the number of each kind of atom is the same on both sides of the arrow.

- Hydrogen + Oxygen yields water

\[
H_2 + O_2 \rightarrow H_2O \quad \text{NO!!!!}
\]

\[
H + H + O + O \rightarrow H_2O + O \quad \text{NO!!!!}
\]

\[
2H_2 + O_2 \rightarrow 2H_2O \quad \text{Yes}
\]

Why not \[
H_2 + O_2 \rightarrow H_2O_2
\]
Electrolysis of water: same reaction backwards

- When an electric current passes through water, chemical bonds are broken and remade.

- **Electrolysis - a chemical reaction**
  
  The net effect is:

  \[ \text{H}_2\text{O} \rightarrow \text{H}_2 + \text{O}_2 \]

  (balanced?)
Recipe for Balancing Chemical Equations

1. Decide what you are making (Chapter 20).
2. Write ingredients (reactants) on one side of the arrow, and products on the other.
3. Check to see if any of the reactants are diatomic.
4. Balance the equation by playing with the number of copies of atoms and molecules,
   NEVER THE NUMBER OF ATOMS THAT MAKE UP THE MOLECULE
Quick Quiz

How many Hydrogen are there in:

- $4\text{H}_2\text{O}$
- $2\text{C}_6\text{H}_{12}\text{O}_6$
- $11\text{NH}_3$
Another Example

Aluminum + Oxygen make $\text{Al}_2\text{O}_3$

1. Write down reactants and products
   \[
   \text{Al} + \text{O} \rightarrow \text{Al}_2\text{O}_3
   \]

2. Check for diatomic elements
   \[
   \text{Al} + \text{O}_2 \rightarrow \text{Al}_2\text{O}_3
   \]

3. Balance by changing copies of molecules
   Al is by itself, so it’ll be easy
   Oxygen – need a multiple of 2 and 3 --put 6 on each side
   \[
   4\text{Al} + 3\text{O}_2 \rightarrow 2\text{Al}_2\text{O}_3
   \]
Burning balloons.

- Facts: Each balloon has the same number of gas molecules per unit volume.
- But the amount of fuel in each gas molecule dependence on the number of carbons. Butane (4 C) > Ethane (2C) > Methane (1C)
Which reactions are balanced?

(a) \[ \text{H}_2 + \text{O}_2 \rightarrow \text{H}_2\text{O} \]
(b) \[ \text{C} + \text{O}_2 \rightarrow \text{CO}_2 \]
(c) \[ \text{C} + \text{O}_2 \rightarrow 2\text{CO} \]
(d) \[ 4\text{Na} + \text{O}_2 \rightarrow 2\text{Na}_2\text{O} \]
(e) \[ 4\text{Al} + 3\text{O}_2 \rightarrow 2\text{Al}_2\text{O}_3 \]
(f) \[ \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2 \rightarrow 6\text{CO}_2 + 6\text{H}_2\text{O} \]
(g) \[ 2\text{K} + \text{S} \rightarrow 2\text{K}_2\text{S} \]
Network Matter

*consists of atoms and ions stacked together

- magnesium
- sodium chloride
- quartz
Let’s Look at Some Molecules!

- We will see single, double and triple bonds.
- Introducing the carboxyl group (found in organic acids).
- Notice the shape and structure of molecules, especially the carbon molecules. Look for the tetrahedral shape of CH₄.
How Do We Know What’s Going On?

- **Spectroscopy**
  - **Vibrational**
    - Spectroscopy of aspirin, ibuprofen, naproxen – vibration of \(-C=O\) marked by ibuprofen the red lines
    - Bond vibration absorbs energy in infrared region

- **aspirin**
- **ibuprofen**
- **naproxen**
More on how we know...

- **Mass Spectrometry**
  
  ▶ Fragment molecules into smaller parts and measure the masses of the various parts.
  
  ▶ Provides a molecule “fingerprint”

- Other methods include electronic spectroscopy and crystallography

- aspirin
- ibuprofen
- naproxen