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A Visual Guide to General Chemistry Topics

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This thesis for honors recognition has been approved for the
Department of Chemistry.

[Signatures and dates]

Director  5/1/17

Reader  5/1/2017

Reader  5/1/2017
Abstract

A Visual Guide to General Chemistry Topics

Using some of the most frequently asked questions during General and Essentials of Chemistry tutoring sessions, this compilation of illustrated worksheets and concept maps was assembled. Left black and white, the pages of this booklet are meant to help facilitate student interaction with their own notes, allowing them to color code, fill in, and annotate whatever they see fit. In bringing material that is typically presented to students via textbook or plain text in a way that is illustrated and creative, it helps to reach the visual side of students’ brains and allow them to see connections that they might otherwise not. The pages in this booklet are meant to be used both as standalone pages, and as a compiled book. Suggested use of the pages include “whiting out” portions of pages, allowing students to fill them in themselves, or giving the pages to students after lecture has occurred, allowing the pages to act as a visual review of important concepts. Additionally, students should be encouraged to make their own “visual notes”.
This honors thesis was created with the intent of bridging some of the fundamental concepts learned by first-semester general chemistry students with an illustrative approach. The effectiveness of using more visuals in chemical education is well documented in scientific literature\textsuperscript{1,2,3,4}. In a *Journal of Chemical Education* study done by Furlan et. al. in 2007, using illustrative and artistic means to teach chemical concepts “motivated [students] to search for additional chemistry information on the topic, and increased [the students’] chemistry understanding”\textsuperscript{5}.

One of the main struggles that students new to chemistry face is the visualization of small-scale interactions invisible to the human eye. This visualization of reactions between molecules and atoms make it difficult for students to apply fundamental chemical equations and theories. With this in mind, I have created each page of this thesis in an attempt to combine illustrative representations of molecular interactions and chemical processes with equations and explanations. One of the most frequently used illustrative schemes I have used is a concept map, seen on pages 5, 6, 11, 13, 14, and 17-19. The reasoning behind this decision is based not only through personal experience with the utility and effectiveness of concept maps, but also based on a study published in 2013 by Drs. Mustafa and Murset in the *International Journal on New Trends in Education and Their Implications*\textsuperscript{6}. Concept maps have been proven to increase students’ ability to find new connections between concepts, increase understanding of complex material, and strengthen overall understanding of the content.

With this thesis, I hope to provide students a visual approach to learning some of the material that the General Chemistry I course teaches. The pages cover material that I frequently found myself explaining to students enrolled in both General Chemistry I and Essentials of Chemistry. The illustrations drawn, while some created specifically for this thesis, come from my own personal experience as a tutor and the images that were drawn while explaining concepts.

-Victoria Kong
Class of ’17
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Let's talk about what chemistry is...

As chemists, we are concerned with the identification and characterization of materials and compounds. Moreover, we are interested in how these materials interact, combine, and change.

The logic and reasoning behind these interactions can be traced back to simple arguments of electrostatic attraction and repulsion!
For solids, liquids, and gases, there is a certain vocabulary we must use in order to describe the particle behavior. There are macroscopic and microscopic particle behaviors.

**MACROSCOPIC**: large-scale particle behaviors, typically observable to the human eye.

**MICROSCOPIC**: small-scale particle behaviors... use your imagination!

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**Level of Fluidity**: (also known as viscosity)

- **Very fluid = not viscous**
- **Not fluid = very viscous**

**Volume**

- Rocks have a fixed volume. They do not fill the shape or volume of their container.
- Helium gas does not.

**Shape**

- My hand is a fixed shape, but Playdoh is not. Playdoh assumes the shape of the container but NOT its volume!

**Particles can...**

- Touch be far apart
- Collide frequently
- Liquid: kinetic energy of particles is intermediate and attractions can be temporarily overcome
- Solid H₂O: kinetic energy of particles is not high enough to overcome the attractions between each particle

**Density (mass per volume)**

- Oil is less dense than water
- Water is more dense than oil

---

**Macroscopic**

- We can see these properties

---

**Microscopic**

- We typically can't see these properties.
**Liquid Properties**

**Density**: NOT related to intermolecular forces.

\[\text{WEIGHT per VOLUME}\]

\[
\begin{array}{l}
5 \text{mL of Solution A} \\
5 \text{mL of Solution B}
\end{array}
\]

Solution A + B have the same volume, but solution A is much heavier so: sol. A = more dense than B

**Viscosity**: Resistance to flow.

As intermolecular forces increases, viscosity increases.

\[
\begin{array}{l}
\text{Water is not very viscous.} \\
\text{Chocolate syrup is very viscous.}
\end{array}
\]

Chocolate syrup has particles that interact with stronger intermolecular forces. It is more viscous.

**Surface Tension**: Resistance to surface penetration.

As intermolecular forces increase, surface tension increases.

\[
\text{Water droplets on a penny display the high surface tension, and thus strong intermolecular forces present between water molecules.}
\]
Vapor Pressure: the pressure exerted by liquid molecules in the gas phase

- **High** vapor pressures → **Weaker** intermolecular forces → **Lower** boiling temperatures → **Faster** evaporation rates at room temperature → More volatile

Boiling Point: temperature at which the vapor pressure of a liquid equals the gas pressure above it

"Normal" Boiling Point: temperature at which the vapor pressure of a liquid equals 760 torr (=1 atm)
Unit Conversions to Know

1 liter =

- $1 \times 10^{-12}$ picoliters (p)
- $1 \times 10^{-9}$ nanoliters (n)
- $1 \times 10^{-6}$ microliters (μ)
- $1 \times 10^{-2}$ centiliters (c)
- $1 \times 10^{-1}$ deciliters (d)
- $1 \times 10^{3}$ kiloliters (k)
- $1 \times 10^{6}$ megaliters (M)

L = liter
m = meter
g = gram
M = mole

1 liter = 1 dm$^3$
1 mL = 1 cm$^3$

$10^3$ cm$^3$ = $10^3$ mL$^3$ = 1 L

0° Celsius = 32° Fahrenheit = 273 Kelvin

1 inch = 2.54 cm
1 lb = 16 ounces = 454 grams
1 quart = 0.946 Liters

A container w/ a volume of:

1 cm$^3$ can hold 1 mL of liquid

1 atm = 760 mmHg = 760 torr
### Molecular and Ionic Compounds

<table>
<thead>
<tr>
<th>Molecular</th>
<th>Ionic</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Molecular Structure" /></td>
<td><img src="image2.png" alt="Ionic Structure" /></td>
</tr>
</tbody>
</table>

**Molecular**
- Covalently bound neutral atoms
- Electrons are shared equally
- **I'm so glad we could share!**
- **You make me complete!**
- Not good electrical conductivity
- **We've tried hooking our covalently bound molecules to a 50V battery. They still report no electrical current. Molecules must not be very conductive.**
- Covalent bonds are quite weak. It does not take a lot of energy to break them apart.
- **I'm sorry Jack. There's no room, let go of my electron!**

**Ionic**
- Ionically bound cations and anions
- Unequal sharing of electrons, in which anions “take” electrons from the cations
- **That's him, officer. He stole my electron!**
- Anions “steal” electrons
- Cations “lose” electrons
- Good electrical conductors in a liquid medium, usually made of a metal or non-metal or recognizable polyatomic ions
- Ionic bonds are the strongest type of chemical bond

**#1**
- **IONIC BOND**
- “Strongest chemical bond in the world.”
Do I have a strong electrolyte, weak electrolyte, or non-electrolyte?

Do you have a mix of elements?

No, it is a molecular compound with nonmetal atoms (and no ammonium)

Yes, it is an ionic compound

Metal and a nonmetal?

Metal + a recognizable polyatomic ion?

Ammonium (NH4+) as your cation?

Is it an acid? (formula typically starts w/ hydrogen)

No

Yes

Is it a base?

No

Non-electrolyte!

Yes

Is it a strong base?

No

Weak electrolyte (incomplete dissociation)

Strong Electrolyte! (dissociates completely)

Is it a strong acid?

Yes

(HCl, HBr, HI, HClO4, HClO3, HNO3, H2SO4)

No
**What's the Difference:**

**Liquid** and **Aqueous Solutions**

**Solution:**
- homogeneous mixture of 2 or more substances, typically
- a **Solute** and a **Solvent**

**Liquid:**
- the elements and/or compound is in its liquid state

**Aqueous Solution:**
- water is the solvent

**Solutions can be:**
- **Solid:** Salt Water
- **Liquid:** Vodka Water
- **Gas:** O₂ gas in water

**When the solutes are dissolved:**
- that is when we say the solute is **aqueous**
- **Non-Electrolyte**

**Strong Electrolyte**
- ions in solution

**Weak Electrolyte**
- some ions in solution

**Strong Electrolyte**
- ions in solution

When the solutes are dissolved:
- that is when we say the solute is aqueous
- **Non-Electrolyte**
Parts of a Periodic Table Element

**Element Name**
NeON
20.180

**Molar Mass**
$\text{Ne} = \frac{20.180 \text{ grams}}{1 \text{ mol Ne}}$

**Chemical Symbol**
Ne

**Atomic Number**
10

($\#$ of protons, which is also equal to the $\#$ of electrons in a neutral atom)

**Neon is a Noble Gas**, which means its electron shells are completely full.

$\#$ of electrons in each electron shell
2

$\text{Ne}$
A "mole" is a unit of measurement that chemists use to quantify a NUMBER of things. (More precisely, it is the number of atoms in 12 grams of carbon - 12!)

For example:

1 dozen chickens can be compared to...

1 mole of atoms

12 chickens

6.022142 \times 10^{23} 

OXYGEN ATOMS (also known as AVOGADRO's constant)

★ REMEMBER: A "mole" has a unit attached! A mole is just another UNIT of measurement for large quantities of small entities (atoms, molecules, particles).

* you must specify moles of WHAT *
How many atoms are in a compound?

→ REMEMBER!

- A compound is a substance made of 2 or more chemical elements that are chemically bound together.
- Example: Water = \( H_2O \) = 2 Hydrogen atoms, 1 oxygen atom = \( \text{H-O-H} \) covalent bonds.

- A mole is another word for: \( 6.022 \times 10^{23} \) atoms, molecules, protons, etc.

So... how many atoms of hydrogen and how many atoms of oxygen are in 1 mole of water?

1 mole of water = 1 mole of \( H_2O \)

\[ \begin{align*}
1 \text{ mole} & \rightarrow 1 \text{ mole} = 6.022 \times 10^{23} \text{ atoms} \\
& \rightarrow 6.022 \times 10^{23} \text{ atoms of } H_2O
\end{align*} \]

- 1 atom of \( H_2O \) = 2 atoms of \( H \) + 1 atom of \( O \)

\[ \begin{align*}
& \rightarrow 6.022 \text{ atoms } H_2O \left( \frac{2 \text{ atoms } H}{1 \text{ atom } H_2O} \right) \\
& = 1.2044 \times 10^{24} \text{ atoms } H
\end{align*} \]

- 6.022 atoms \( H_2O \) \left( \frac{1 \text{ atom } O}{1 \text{ atom } H_2O} \right)

\[ \begin{align*}
& = 6.022 \times 10^{23} \text{ atoms } O
\end{align*} \]

Train - Track Method:

\[ \begin{align*}
\frac{1 \text{ mole } H_2O}{1 \text{ mole } H_2O} & = \frac{6.022 \times 10^{23} \text{ atoms } H_2O}{6.022 \times 10^{23} \text{ atoms } H_2O} \\
\frac{2 \text{ atoms } H}{1 \text{ atom } H_2O} & = \frac{1.2044 \times 10^{24} \text{ atoms } H}{6.022 \times 10^{23} \text{ atoms } O}
\end{align*} \]

\[ \frac{1 \text{ mole } H_2O}{1 \text{ mole } H_2O} = \frac{1 \text{ atom } O}{1 \text{ atom } H_2O} = \frac{6.022 \times 10^{23} \text{ atoms } O}{6.022 \times 10^{23} \text{ atoms } O} \]

\[ \begin{align*}
& = \frac{1.2044 \times 10^{24} \text{ atoms } H}{6.022 \times 10^{23} \text{ atoms } O}
\end{align*} \]
**CONVERSION ROADMAP**

**Volume of Gas at STP**

@STP, 1 mole of gas occupies 22.4 L

\[
\frac{1 \text{ mol}}{22.4 \text{ L}} \times 22.4 \text{ L} = 1 \text{ mol}
\]

\[\text{MOLE}\]

\[\times \frac{\text{molar mass}^*}{1 \text{ mol}}\]

**Mass**

\[\frac{1 \text{ mol}}{\text{molar mass}^*} \times \frac{1 \text{ mol}}{6.022 \times 10^{23} \text{ particles}} \times 6.022 \times 10^{23} \text{ particles} = 1 \text{ mol}\]

**Representative Particles**

Atoms, molecules, protons, etc.

\[\text{Avogadro's Number} = 6.022 \times 10^{23}\]

* molar mass comes from the periodic table! (ex: carbon = \(\frac{12.01 \text{ g}}{1 \text{ mol}}\))
Dissecting our GAS LAWS

How are all our VARIABLES (P, V, n, + T) related?

Pressure and Volume: **Boyle’s Law**

\[ P_1 V_1 = P_2 V_2 \]

- Decrease the volume: pressure increases
- Increase the volume: pressure decreases

Temperature and Volume: **Charles’ Law**

\[ \frac{V_1}{T_1} = \frac{V_2}{T_2} \]

- Decrease the temperature: volume decreases
- Increase the temperature: volume increases
Amount of gas (in moles) and Volume: AVOGADRO'S LAW

- decrease amount of moles = volume decreases
- increase amount of moles = volume increases

\[ \frac{V_1}{n_1} = \frac{V_2}{n_2} \]

COMBINED GAS LAW: (the number of moles is CONSTANT)

- this law takes ONE SYSTEM with a set number of moles of gas and tells us the effects of changing the system's pressure, volume, or temperature

BOYLE'S LAW

\[ \frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2} \]

CHARLES' LAW

This law COMBINES BOYLE'S + CHARLES' LAWS
IDEAL GAS LAW

What do we assume when we use this equation?

1. Gases are made up of molecules which are in constant, random motion in a straight line $\rightarrow \quad \not\rightarrow$ not $\rightarrow \rightarrow$ our $\rightarrow$

2. The molecules behave as rigid spheres $\odot$ not $\odot$

3. Pressure is due to collisions between the molecules and container walls

4. All collisions are elastic (this means that there is no loss of kinetic energy during or after collisions occur)

5. Gas temperature is proportional to the average kinetic energy of the molecules

6. There are no (or negligible) intermolecular forces between gas molecules

7. The volume occupied by the molecules themselves is negligible relative to the container volume

The Ideal Gas Law:

$$PV = nRT$$

- $P =$ pressure in atm
- $V =$ volume in liters
- $n =$ moles in mol
- $T =$ temperature in Kelvin
- $R =$ 0.08206 L atm

Remember: all of your units must cancel!!
PERIODIC TABLE trends

Atomic Radius Increases

Electron Affinity Increases
Ionization Energy Increases
Electron Affinity Increases
Ionization Energy Increases
**Explaining Periodic Table Trends**

**Electron Affinity:** the amount of "desire" an atom has for electrons.

**Trend:** As you move **UP** and to the **RIGHT,** electron affinity increases.

**WHY?**

1. **As you move **UP** the periodic table → atoms have less electrons ↓ less electron shells**

   [Diagram showing electron shells]

   **Beryllium** has 4 protons and 2 electron shells. The 2 electron shells do not shield the positive nuclear charge very well.

   **Beryllium**
   
   | 4 protons | 2 e- shells |

   **Magnesium** has 12 protons and 3 electron shells. The shells shield the positive nuclear charge, reducing electron affinity.

   **Magnesium**
   
   | 12 protons | 3 e- shells |

2. **As you move **RIGHT** across the periodic table → electrons are added within a shell**

   [Diagram showing electron shells]

   **Greater affinity for electrons * shells become closer & closer to being completely "full"**

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2. (Electron Affinity continued)

Remember: atoms are "happiest" when they have full e- shells.

- this means:
  
  2 electrons in the first shell
  8 electrons in the second shell
  18 electrons in the third shell
  etc.

Beryllium is 6 electrons away from being "happy". It has a moderate electron affinity.

Fluorine is only one electron away from being "happy" (aka, having a full 2nd electron shell). It has a very high electron affinity.

**IONIZATION ENERGY**: the amount of energy required to remove an electron.

Trend: As you move UP and to the RIGHT, ionization energy increases.

WHY?

1. As you move UP the periodic table -> atoms have less electrons

   - electrons are held tighter to the nucleus
   - nuclear positive charge is more exposed
   - less shielding of nuclear protons
   - harder to "pull" an e- away
   - higher ionization energy

Helium's outer electrons are held very close to the nucleus, so it takes a lot of energy to ionize.

Neon's outer electrons are further away from the nucleus, so they are easier to remove. It takes less energy to ionize Neon than Helium.
2. (Ionization Energy Continued)
   As you move **RIGHT** across the periodic table → more protons are added

   - **higher Ionization energy** ← **harder to “pull” an electron away** ← **electrons in outer shell are held tighter** ← **increase in nuclear charge**

   ![Lithium diagram](Lithium.png)
   Lithium has only 3 protons and 2 electron shells. The outer electron is not held as tightly as a lower ionization energy.

   ![Nitrogen diagram](Nitrogen.png)
   Nitrogen has 5 protons and only 2 electron shells. The outer electrons are held much more closely than those of lithium = higher ionization energy.

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**ATOMIC RADIUS**: The size of an atom from the center of the nucleus to the boundary of the surrounding electron cloud.

**Trend**: As you move **DOWN** and **LEFT** of the periodic table, atomic radius increases.

**WHY?**

1. As you move **DOWN** the periodic table → more electrons are added

   ![Helium vs Neon](Helium Neon.png)
   Helium vs Neon. Greater atomic radius with more electron shells.

2. As you move **LEFT** across the periodic table → less protons in the nucleus

   ![Lithium vs Boron](Lithium Boron.png)
   Lithium vs Boron. Larger atomic radius with electrons held less tightly due to weaker nuclear charge.
References


