Introduction to Stoichiometry

Reading: Ch 3 section 10	Homework: Chapter 3: 93*, 95, 97*, 99*, 101

* = 'important' homework question

<u>Foundation</u>: The Atomic Theory (John Dalton, 1803):

3. Atoms are not changed into different types of atom(s) via chemical reactions. Atoms can neither be created nor destroyed

4. Compounds are formed when atoms of more than one type are combined. A compound always has the same relative number and kind of atoms

<u>Stoichiometry</u>: "The relationships among the quantities of reactants and products involved in a chemical reaction".

<u>Notes</u>

Recall: A chemist's goal is to explain *macroscopic* phenomena in terms of the repeated, identical reactions of its component *microscopic* particles. Recall the burning of charcoal example from week 1….

Balanced chemical equations (*micro scale*) are used to describe larger (*macro scale*) events, e.g. The burning of charcoal (carbon) in air (contains oxygen gas) to produce carbon dioxide gas and heat :

$$C(s) \quad + \quad O_2(g) \quad \rightarrow \quad CO_2\,(g)$$

This reaction is repeated many trillions of times when a charcoal brick is burnt in air to produce carbon dioxide gas and heat at a labor day 'cook out'

What does each symbol represent in the above chemical reaction?

Symbol	Represents
$C(s)$	A single atom of carbon in the charcoal brick (a reactant)
$O_2(g)$	A single molecule of oxygen gas from the air (a reactant)
→	A chemical symbol meaning 'goes to' or 'is converted in to'
$CO_2\,(g)$	A single molecule of carbon dioxide gas produced from the reaction (the product)

Types of Chemical Reactions

Fact: There are FIVE general types of chemical reactions.

1. Combination Reactions - two or more types of material become one new material:

   Generic: A + Z → AZ

   Example: $C(s) + O_2(g) \rightarrow CO_2(g)$

   Note: All combustion (adding oxygen) reactions are classed as combination reactions.

2. Decomposition Reactions - a material becomes two or more new materials:

   Generic: AZ → A + Z

   Example: $CaCO_3(s) \rightarrow CaO(s) + CO_2(g)$

   Note: Decomposition reactions may be considered the reverse of combination reactions.

3. Single Replacement ('Prom') reactions - a more reactive material replaces a less reactive one in a compound:

Random internet prom pic.

   Generic: A + BZ → AZ + B

   Example: $Sn(s) + 2HCl(aq) \rightarrow SnCl_2(aq) + H_2(g)$

   Note: The material replaced (B or H^+ above) is said to be LESS reactive than it's replacement (A or Sn above).

4. Double Replacement reactions - the respective ionic partners of a pair of dissolved ionic compounds are swapped, most often resulting in the formation of solid product(s):

gerr!

Generic: AX + BZ → AZ + BX

Example: $AgNO_3$(aq) + NaCl(aq) → AgCl(s) + $NaNO_3$(aq)

Note: These types of reactions typically take place between dissolved ionic compounds, and typically result in one of the new materials forming a solid precipitate (ppt)

5. Neutralization reactions - very similar to double replacement, but ALWAYS between an acid and a base:

Generic: HA + MOH → MA + HOH
(acid + base → salt + water, H_2O)

Example: HCl(aq) + NaOH(aq) → NaCl(aq) + H_2O(l)

Note: These types of reactions are called neutralizations because acid (H^+) and basic (OH^-) ions react with each other to form water (H_2O). Such reactions typically liberate large amounts of heat (highly exothermic).

Task: Identify the following reactions as either: *combination*, *decomposition*, *single replacement*, *double replacement* or *neutralization*. **Additionally, write the formula equivalent of each reaction below its word equation version**.

sulfur(s) + oxygen gas → sulfur dioxide gas

magnesium carbonate(s) → magnesium oxide(s) + carbon dioxide gas

zinc(s) + copper (II) nitrate sol^{n}. → metallic copper + zinc (II) nitrate sol^{n}.

sodium hydroxide solution + hydrochloric acid solution →

Balancing Chemical Equations – Conservation of Mass Law

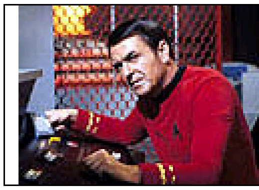
Law of Conservation of Mass: Atoms are neither created nor destroyed during a chemical reaction - *they just change, add or lose partners*:

e.g. $C(s) + O_2(g) \rightarrow CO_2(g)$

There must (by definition) be the same number and type of each atom on both sides of the equation (i.e. *before* and *after* the reaction).**The reactants and products must also have equal masses**. Why?

Application: Rules for balancing chemical equations

1. Construct an *unbalanced* equation (sometimes using a word equation, as in lab). MAKE SURE THE FORMULAS ARE CORRECT, ONCE THEY ARE, DON'T 'MESS' WITH THEM!

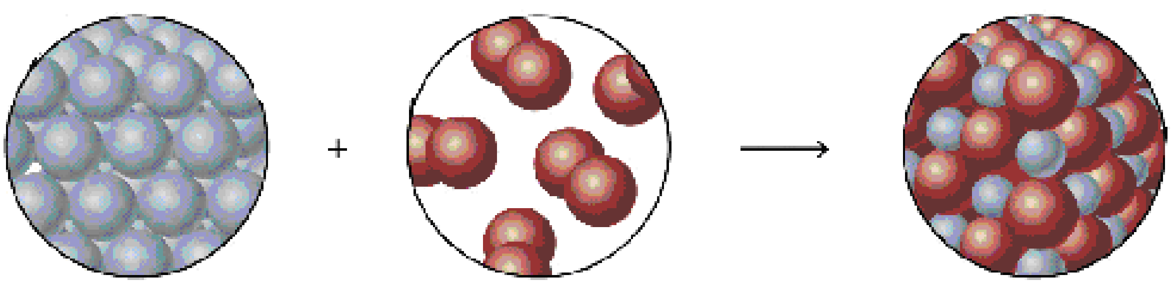


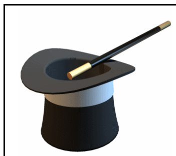
'Captain, I can 'ney change the laws 'o physics!'

***….or chemistry either, Scotty* – CORRECT CHEMICAL FORMULAS CAN NOT BE ALTERED ONCE WRITEN!**

E.g.: Write an *unbalanced* equation using formulas for the combustion of magnesium (as seen in lab).

Magnesium metal (s) + Oxygen gas → Magnesium Oxide (s)





You know how to identify and write the name of either ionic or covalent (molecular) materials. What's the trick?

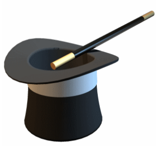
⇒ Simply convert names to formulas first

2. Use *balancing numbers* (whole numbers that appear IN FRONT of formulas) to balance the equation: i.e. ensure that the law of conservation of mass is obeyed.

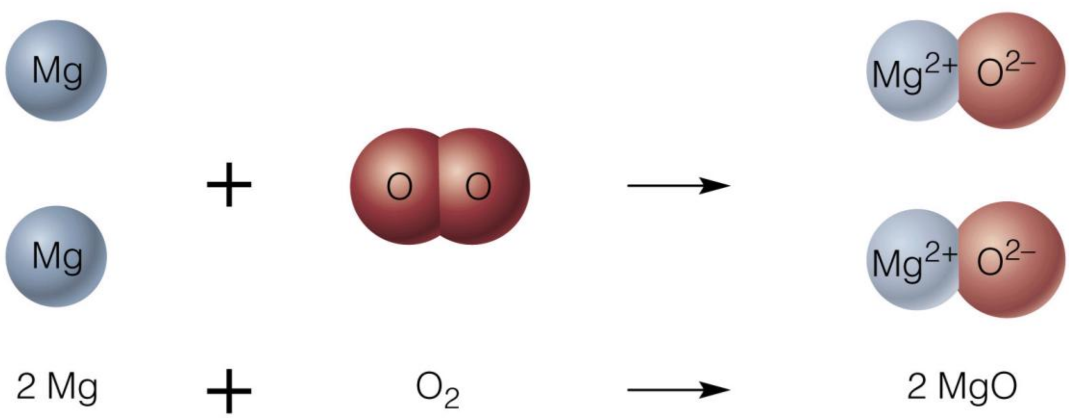
UNDER NO CIRCUMSTANCES BE TEMPTED TO CHANGE THE FORMULAS!

E.g.: Balance the following equation:

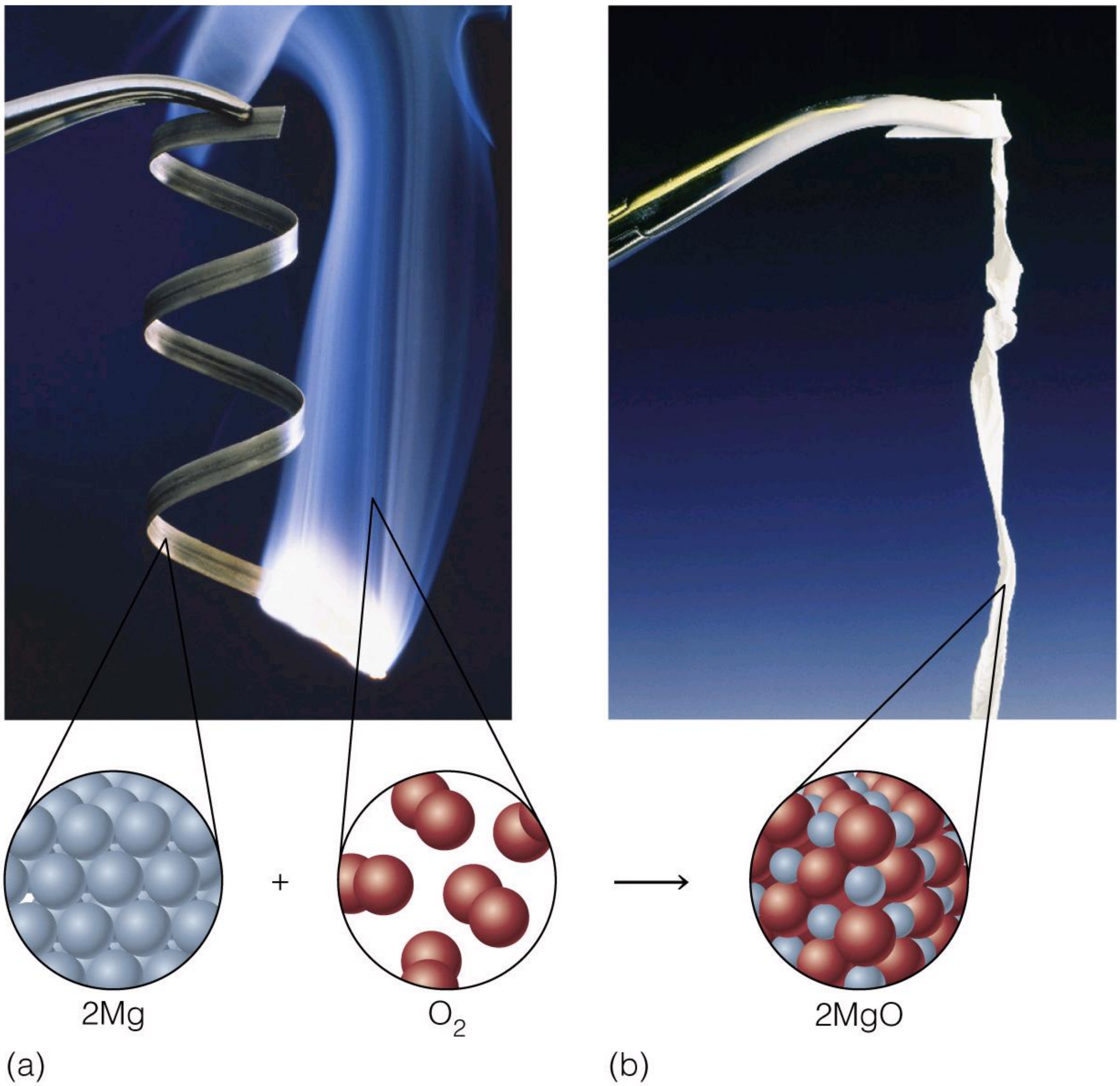
$$\_\_\_\ Mg\ (s)\ +\ \_\_\_\ O_2\ (g)\ \rightarrow\ \_\_\_\ MgO\ (s)$$

 **Apply the 'tennis' approach:** **Balance a single type of atom on the left, then see what happens on the right; then balance a different type of atom on the right, then see what happens on the left etc. until done.**	Walk through: Balance # Mg atoms left and right Balance # O atoms left and right (re) Balance # Mg atoms left and right -

Micro scale view:



Remember: As in this example, a chemist explains macro-scale phenomena in terms of a single (repeated many, many times….) microscopic description



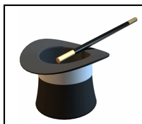
Task: Work in small groups to write balanced equations for the following.

1. The combustion of hydrogen gas to make water

2. The combustion of sodium metal to make its oxide

3. The dissolving of sodium metal in water to give sodium hydroxide and hydrogen gas.

4. The combustion of methane (CH_4).



The products of combustion for *organic* materials are carbon dioxide and water. Use the 'tennis' approach for balancing the C, H and then O atoms in order for organic (C, H and/or O containing) molecules

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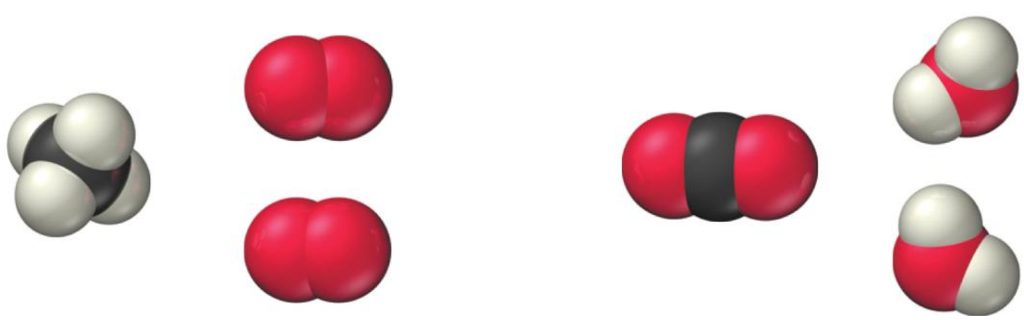
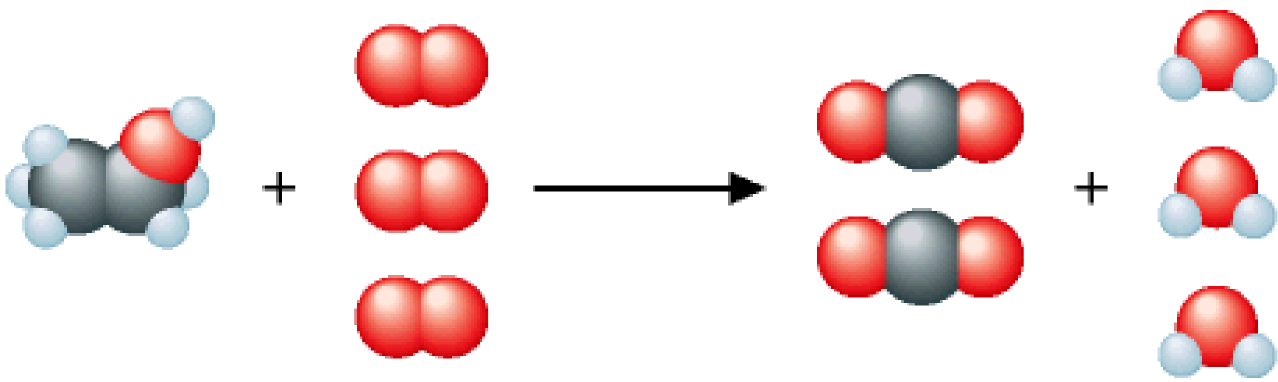
$$CH_4(g) \quad + \quad 2\,O_2(g) \longrightarrow CO_2(g) \quad + \quad 2\,H_2O(g)$$



5. The combustion of Ethanol (CH_3CH_2OH)

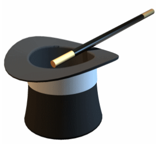


6. The combustion of sugar ($C_6H_{12}O_6$).

Recap of skills learnt so far:

- Be able to write balanced chemical equation from a word description of the chemical process (this is what you are often required to do in lab)
- Be able to identify any reaction as belonging to one of the 5 general types of reaction - *combination*, *decomposition*, *single replacement*, *double replacement* or *neutralization*.

Tricks



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2. Use *balancing numbers* (whole numbers that appear IN FRONT of formulas) to balance the equation: i.e. ensure that the law of conservation of mass is obeyed.

Tip: Apply the 'tennis' approach when balancing equations - balance a single type of atom on the left, then see what happens on the right; then balance a different type of atom on the right, then see what happens on the left etc. until done.

UNDER NO CIRCUMSTANCES BE TEMPTED TO CHANGE THE FORMULAS WHEN BALANCING AN EQUATION

Review Question: Write a balanced reaction for the combustion of propane (C_3H_8(g)) in air. What general type of reaction is this?

"Balance"

Wrap up: Try the following questions (taken from the first practice midterm). See the next page for the answers

a. The burning of liquid butane (C_4H_{10} (l)) in air

b. The Neutralization of battery acid (sulfuric acid solution) with caustic soda (sodium hydroxide solution)

c. The reaction of solid diphosphorus pentoxide with water to form aqueous phosphoric acid

d. The decomposition of chalk ($CaCO_3$), when heated, to form solid calcium oxide and carbon dioxide gas

e. The reaction of metallic zinc with aqueous sulfuric acid to form aqueous zinc (II) sulfate and hydrogen gas

Answers:

a. The burning of liquid butane (C_4H_{10} (l)) in air

$$2C_4H_{10}\,(l) \;+\; 13O_2\,(g) \;\rightarrow\; 8CO_2\,(g) \;+\; 10H_2O\,(g)$$

b. The Neutralization of battery acid (sulfuric acid solution) with caustic soda (sodium hydroxide solution)

$$H_2SO_4\,(aq) \;+\; 2NaOH\,(aq) \;\rightarrow\; Na_2SO_4\,(aq) \;+\; 2H_2O\,(l)$$

c. The reaction of solid diphosphorus pentoxide with water to form aqueous phosphoric acid

$$P_2O_5\,(s) \;+\; +\; 3H_2O\,(l) \;\rightarrow\; 2H_3PO_4\,(aq)$$

d. The decomposition of chalk ($CaCO_3$), when heated, to form solid calcium oxide and carbon dioxide gas

$$CaCO_3\,(s) \;\rightarrow\; CaO\,(s) \;+\; CO_2\,(g)$$

e. The reaction of metallic zinc with aqueous sulfuric acid to form aqueous zinc(II)sulfate and hydrogen gas

$$Zn(s) \;+\; H_2SO_4\,(aq) \;\rightarrow\; ZnSO_4\,(aq) \;+\; H_2\,(g)$$