Chemical Reactions

A. Chemical Reactions And The Law Of Conservation Of Mass

1. A **CHEMICAL REACTION** is a change that produces new materials with different properties from the starting materials. Various types of evidence indicate that chemical reactions occur. Observations that accompany a chemical reaction are:

   - temperature change
   - change in colour
   - new phases may be formed

   A **CHEMICAL REACTION EQUATION** is an equation that shows the chemical used up and produced during a chemical reaction.

   The general form of a chemical equation is:

   REACTANTS → PRODUCTS

   Reactants are the starting materials and are found to the left of the arrow and **products** are the materials that are formed and are found to the right of the arrow. The arrow (→) means produces or yields.

2. A chemical reaction can be described by a word equation or a formula equation.

WORD EQUATIONS are chemical equations that use **words** to describe the reactants and products.

FORMULA EQUATIONS use **chemical symbols** to represent the reactants and products.

Observation:

Sodium reacts violently with chlorine gas to form a white solid of sodium chloride.

Word Equation:

Sodium + Chlorine $\rightarrow$ Sodium Chloride

Formula Equation:

$$2Na + Cl_2 \rightarrow 2NaCl$$

The numbers **"2"** in front of the Na and the NaCl are called **COEFFICIENTS** and they indicate the number of molecules of each species involved in the reaction. Although there is no number in front of the Cl_2, it is understood that the coefficient is **"1"**.

3. A **SYSTEM** is the part of the universe that is being studied in a particular situation. Systems can be either open or closed.

In a **CLOSED** system, nothing can enter or leave the system.

In an **OPEN** system, things can enter and leave the system.

When a chemical reaction occurs in a closed system, the mass of the reactants equal the mass of the products. This is a statement of the **LAW OF CONSERVATION OF MASS.**

LAW OF CONSERVATION OF MASS

The total mass in a closed system does not change during a chemical reaction.

4. Chemical equations need to be **BALANCED** to obey the Law of Conservation of Atom. Balancing an equation involves **placing coefficients in front of each chemical species so that there are the same number of each type of atom on each side of the equation.**

EXAMPLE 6.1	**BALANCING EQUATIONS**
Problem	Balance the following equation: $H_2 + O_2 \rightarrow H_2O$
Solution	$\_\_\_H_2 + \_\_\_O_2 \rightarrow \_\_\_H_2O$

Balancing equations is a **trial and error process**. There are no "hard–and–fast" set of rules for balancing equations; however, the following suggestions will make balancing easier.

a) Coefficients must be used to balance equation, you cannot change the formulas.

b) Scan the equation to identify atoms which only occur in only one species on each side of the equation.

c) Metal atoms often dictate what happens in the reaction, so they should be balanced first. If there are no metal atoms, start with atoms that only appear in one chemical species on either side of the equation. Avoid "H" and "O" because they tend to appear many chemical species.

d) Try to balance all of the atoms in a particular species first before going on to other species.

e) Assume that chemical species that do not have coefficients have zero atoms or molecules. In other words treat a blank as a zero.

f) Try to balance entire groups of polyatomic ions (e.g., SO_4, PO_4, NO_3, etc.) when possible.

g) Leave diatomic elements to the end. If an atom is part of a diatomic element, fractions can be used to balance equations.

$$2 \text{ H–atoms} = 1\ H_2$$

$$1 \text{ H–atom} = {}^{1}/_{2}\ H_2$$

$$5 \text{ H–atoms} = {}^{5}/_{2}\ H_2$$

$$\text{“x” H–atoms} = {}^{x}/_{2}\ H_2$$

Fractions can be removed by multiplying the entire equation by 2.

EXAMPLE 6.2	**BALANCING EQUATIONS**
Problem	Balance the following equation: __Al + __O_2 → __Al_2O_3
Solution	First balance Al __Al + __O_2 → __Al_2O_3 Next, 3 O–atoms are needed on the left __Al + __O_2 → __Al_2O_3 Multiply the entire equation by 2 to remove fraction __Al + __O_2 → __Al_2O_3

EXAMPLE 6.3	**BALANCING EQUATIONS**
Problem	Balance the following equation: $\_\_(NH_4)_3PO_4 + \_\_NaOH \rightarrow \_\_Na_3PO_4 + \_\_NH_3 + \_\_H_2O$
Solution	First balance Na $\_\_(NH_4)_3PO_4 + \_\_NaOH \rightarrow \_\_Na_3PO_4 + \_\_NH_3 + \_\_H_2O$ Next, balance PO_4 group $\_\_(NH_4)_3PO_4 + \_\_NaOH \rightarrow \_\_Na_3PO_4 + \_\_NH_3 + \_\_H_2O$ There are 3 N–atoms on the left so 3 are needed on the right $\_\_(NH_4)_3PO_4 + \_\_NaOH \rightarrow \_\_Na_3PO_4 + \_\_NH_3 + \_\_H_2O$ Finally, balance the O-atoms $\_\_(NH_4)_3PO_4 + \_\_NaOH \rightarrow \_\_Na_3PO_4 + \_\_NH_3 + \_\_H_2O$

EXAMPLE 6.4	**BALANCING EQUATIONS**
Problem	Balance the following equation: $\_\_C_{19}H_{17}NO_3 + \_\_O_2 \rightarrow \_\_CO_2 + \_\_H_2O + \_\_N_2$
Solution	No metal atoms, so start with C $\_\_C_{19}H_{17}NO_3 + \_\_O_2 \rightarrow \_\_CO_2 + \_\_H_2O + \_\_N_2$ Since 1 N–atom on left, put $^1/_2$ in front of N_2 $\_\_C_{19}H_{17}NO_3 + \_\_O_2 \rightarrow \_\_CO_2 + \_\_H_2O + \_\_N_2$ Clear fraction by multiplying equation by 2 $\_\_C_{19}H_{17}NO_3 + \_\_O_2 \rightarrow \_\_CO_2 + \_\_H_2O + \_\_N_2$ Balance H–atoms next $\_\_C_{19}H_{17}NO_3 + \_\_O_2 \rightarrow \_\_CO_2 + \_\_H_2O + \_\_N_2$ Balance O–atoms $\_\_C_{19}H_{17}NO_3 + \_\_O_2 \rightarrow \_\_CO_2 + \_\_H_2O + \_\_N_2$ Finally, remove fraction by multiplying by 2 $\_\_C_{19}H_{17}NO_3 + \_\_O_2 \rightarrow \_\_CO_2 + \_\_H_2O + \_\_N_2$

SAMPLE PROBLEMS 6.1	**BALANCING EQUATIONS**
Problem	Balance the following equations: __Na + __O_2 → __Na_2O __N_2 + __H_2 → __NH_3 __C_7H_{16} + __O_2 → __CO_2 + __H_2O __$MoCl_3$ + __O_2 + __AgCl → __$MoCl_4$ + __Ag_2O __$Cr_2(SO_4)_3$ + __KI + __KIO_3 + __H_2O → __$Cr(OH)_3$ + __K_2SO_4 + __I_2

B. Writing Phases In Reaction Equations And Using Chemical Word Equations

1. Besides showing the number and types of molecules, a chemical equation can also show the phases in which the reactants and products exist. The phases are shown by including the following symbols in parentheses immediately following the chemical formula.

   (s) = solid, (l) = liquid, (g) = gas,

   (aq) = aqueous (dissolved in water)

   $$2Hg_{(l)} + O_{2(g)} \rightarrow 2HgO_{(s)}$$

   Liquid mercury plus oxygen gas produce solid mercury (II) oxide

2. Notice that oxygen gas is diatomic (O_2). There are seven elements that are diatomic and they must be memorized. These seven diatomic elements are: **I_2, Br_2, Cl_2, F_2, O_2, N_2, and H_2**. There are two polyatomic elements **P_4** and **S_8**.

   Remember the pneumonic:

   I Bring **Cl**ay **F**rom **O**ur **N**ew **H**ouse **4 P**aving **8 S**idewalks

   Also the words “crystals”, “powder”, and “precipitate” all mean the phase is **SOLID**. A **PRECIPITATE** is a solid that forms when two liquids or aqueous solutions react.

EXAMPLE 6.5	**WRITING FORMULA EQUATIONS FROM WORD EQUATIONS**
Problem	Write balanced formula equations for the following word equations: a) Solid sodium reacts with chlorine gas to produce solid sodium chloride. b) Aqueous hydrochloric acid reacts with calcium carbonate crystals, producing aqueous calcium chloride, gaseous carbon dioxide, and liquid water.
Solution	a) $2Na_{(s)} + Cl_{2(g)} \rightarrow 2NaCl_{(s)}$ b) $2HCl_{(aq)} + CaCO_{3(s)} \rightarrow CaCl_{2(aq)} + CO_{2(g)} + H_2O_{(l)}$

C. Types Of Chemical Reactions

1. SYNTHESIS (or COMBINATION)

- A **SYNTHESIS** or combination reaction involves the combination of two or more substances to form a compound.
- Synthesis reactions can be represented by the general equation:

$$A + B \rightarrow AB$$

Where A and B represent elements and AB is a compound.

- **Reactants are two elements** and **product is compound** made of two elements joined together. Use the most common charges for each ion.

e.g. $C_{(s)} + O_{2(g)} \rightarrow CO_{2(g)}$

$2H_{2(g)} + O_{2(g)} \rightarrow 2H_2O_{(g)}$

2. DECOMPOSITION

- A **DECOMPOSITION** reaction involves breaking down molecules into simpler substances.
- Decomposition reactions can be represented by the general equation:

$$AB \rightarrow A + B$$

- **Reactants are a single compound** and **products are the elements** that make up the compound.

e.g. $2H_2O_{(l)} \rightarrow 2H_{2(g)} + O_{2(g)}$

3. SINGLE REPLACEMENT

- A **SINGLE REPLACEMENT** reaction involves replacing one atom in a compound by another atom.
- Single replacement reactions can be represented by the general equation:

$$A + BX \rightarrow B + AX$$

- **Reactants are an element and a compound** and **products are an element and a compound**. If "A" is a metal, it will replace the metal ion "B" in the compound. If "A" is a nonmetal, it will replace the nonmetal "X" in the compound.

e.g. $CuI_2 + Br_2 \rightarrow CuBr_2 + I_2$

4. DOUBLE REPLACEMENT

- A **DOUBLE REPLACEMENT** reaction involves an exchange of atoms or groups between two different compounds
- Double replacement reactions can be represented by the general equation:

$$AB + XY \rightarrow AY + XB$$

- **Reactants are two compounds** and **products are two compounds**. Assume that reactants are made up of ions. Make up products by having positive ions (written first) exchanging partners. **Pay attention to the charges of the ions when writing formulas of products.**

e.g. $Cu(NO_3)_2 + NaS \rightarrow CuS + 2NaNO_3$

- There is a special case of double replacement reaction that involves the reaction of an ACID with a BASE. These reactions are called Neutralization reactions. A acid has a chemical formula starting with “H” and bases have chemical formulas ending in “OH”.

  e.g. $HCl + NaOH \rightarrow HOH + NaCl$

  $H_2SO_4 + 2KOH \rightarrow 2HOH + K_2SO_4$

5. **COMBUSTION of Hydrocarbons**

- **COMBUSTION** is a general term referring to the rapid reaction of a substance with oxygen to produce large amounts of hear and light. An important case of combustion involves organic compounds whose formulas start with carbon.

- When a **HYDROCARBON** (a compound made up of C and H) undergoes combustion, the products are **carbon dioxide, CO_2, and water, H_2O.**

- The combustion of a hydrocarbon can be represented by the general equation:

$$\text{Hydrocarbon} + O_2 \rightarrow CO_2 + H_2O$$

- **Reactants are hydrocarbon (C–H) and oxygen (O_2)** and **products are carbon dioxide (CO_2) and water (H_2O).**

$$C_5H_{12} + 8O_2 \rightarrow 5CO_2 + 6H_2O$$

- **ORGANIC COMPOUNDS** are hydrocarbons that contain other elements like oxygen and sulphur.

- Burning an organic compound containing **OXYGEN** does not change the balancing procedure

$$C_5H_{12}O_2 + 7O_2 \rightarrow 5CO_2 + 6H_2O$$

- Burning an organic compound containing **SULPHUR** produces $SO_{2(g)}$.

$$C_5H_{12}S + 9O_2 \rightarrow 5CO_2 + 6H_2O + SO_2$$

TYPE	HOW TO RECOGNIZE REACTANTS	HOW TO PREDICT PRODUCTS
Synthesis or Combination	2 elements	combine elements into one compound
Decomposition	1 compound	Break compound down into its elements
Single Replacement	Element + Compound	Interchange metals (or nonmetals) present
Double Replacement	Compound + Compound	Interchange positive ions in compounds
Neutralization	Acid + Base	Water is one product; remaining ions combine to form a salt
Combustion of Hydrocarbon	Compound starting with “C” + O_2	CO_2 + H_2O (if H present) + SO_2 (if S present)

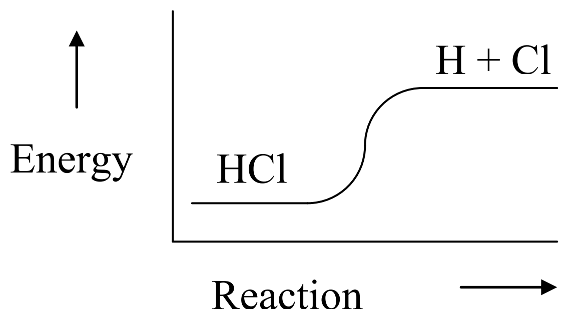
D. Energy Changes In Chemical Reactions

1. Molecules are held together by chemical bonds. In order to break these bonds, **energy needs to be added to the bond**. Conversely, when a bond is formed energy is released.

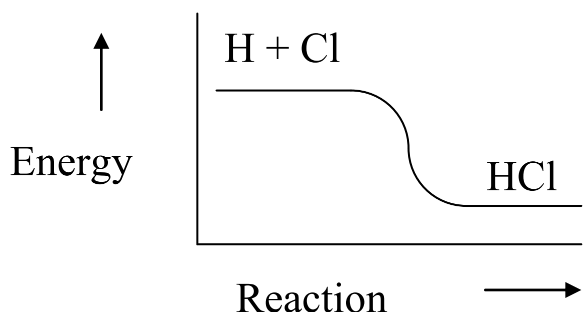
   The reaction:

   $$HCl + \text{energy} \rightarrow H + Cl$$

   is shown graphically as

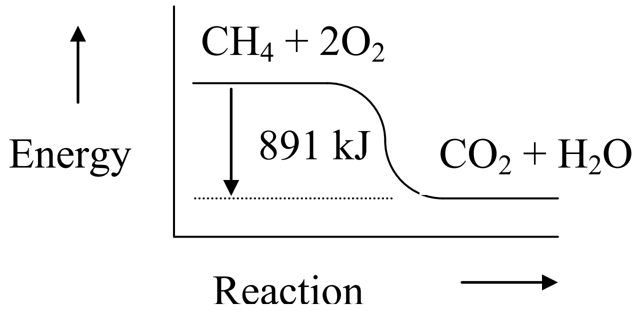


   Since the separated atom gained energy, they appear higher than the reactant. When the atoms join together to form a bond energy is released.



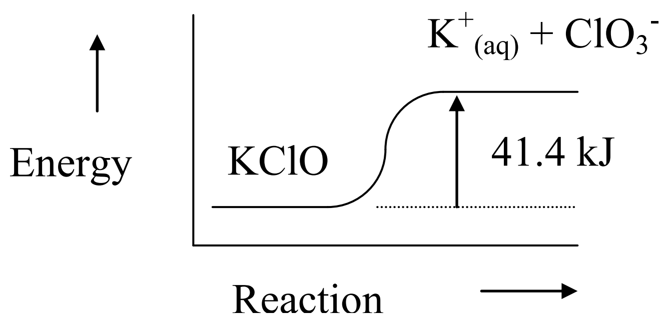
2. An **EXOTHERMIC** reaction gives off heat to the surroundings. (Heat **EX**its from the reaction.)

$$CH_4 + 2O_2 \rightarrow CO_2 + H_2O + 891\ kJ$$



3. An **ENDOTHERMIC** reaction absorbs heat from the surroundings. (Heat **EN**ters the reaction.)

$$KClO_{3(s)} + 41.4\ kJ \rightarrow K^+_{(aq)} + ClO_3^-{}_{(aq)}$$



A distinction must be made between the reacting chemicals and the surroundings. In a **exothermic** reaction, the chemicals give off energy to their surroundings. Since the surrounding absorb the energy given off, **the surrounding feels warmer.**

In an **endothermic** reaction, the chemical absorb energy from their surroundings. Since the surroundings lose energy, **the surroundings feel cooler.**