Chemical Reactions BASICS

There are 5 simple reactions in this chemistry class (but more are coming later in the year).

They are synthesis, decomposition, single replacement, double replacement, and combustion.

You will be expected to recognize them with real chemistry symbols, or with "abstract" letters that stand in for actual chemicals. Examples for each are below.

Each reaction has certain characteristics that make it different from the other types of reactions.

Memorize these five, along with their example reactions so that you can draw upon this later in the year.

Word equations describe the chemical reaction in words only. The "skeleton" equation is when you introduce the chemical symbols, all written with proper ion to ion - or atom to atom ratios - but the equation is NOT balanced.

Balancing reactions takes practice. It converts the skeleton into proper final form, so that the law of conservation of matter is taken into consideration (the number of atoms or moles in the reactants equals the number of atoms or moles in the products). You can never finish with an unbalanced equation and be correct.

Balanced equations include PHASE SYMBOLS, indicating what phase of matter (S, L, G or AQ) that the substance is in during that part of the reaction.
Abbreviations S, L, G, and AQ, get put into <u>subscript</u> parenthesis.

All metals are SOLID (except Hg). Nonmetal gases are H_2, He, Ne, Ar, Kr, Xe, Rn, F_2, O_2, and Cl_2.

Nonmetal liquids is Br_2. The rest are nonmetal solids: B, C, Si, P, S, As, Se, Te and I_2.

Ionic compounds (cation/anion pairs) are SOLIDS, unless clearly in water and soluble from Table F.

EXAMPLES: $H_2O_{(L)}$ for liquid water, $H_2O_{(S)}$ for ice, or $H_2O_{(G)}$ for steam.

$HCl_{(AQ)}$ for hydrochloric acid or $NaCl_{(AQ)}$
They stand for hydrogen monochloride dissolved into water, or sodium chloride dissolved into water, as a solution.
Water cannot be aqueous, it can't be dissolved in itself.

A reminder: All elements on the periodic table exist as single atoms - except for the HONClBrIF twins, which are the diatomic molecules.

THE SYNTHESIS REACTION (1/5)

Are the reactions that combines smaller things into a larger chemical compound. The demo in class was the reaction of hydrogen combining with the oxygen in the air to form water. This reaction had hydrogen gas in a balloon, some invisible oxygen gas in the air, and a candle was used to both melt the balloon and to provide enough energy to start the reaction. The hydrogen combined with the oxygen in an explosion of fire and sound, and the water formed was instantly vaporized by the heat. Reactions that give off heat are called EXOTHERMIC. This was an extremely fast synthesis that was also an exothermic reaction. Sometimes this is called COMBINATION reaction as well.

Word Equation: hydrogen plus oxygen yields water

Skeleton Equation: $H_2 + O_2 \rightarrow H_2O$

BALANCED EQUATION: $2H_{2(G)} + O_{2(G)} \rightarrow 2H_2O_{(G)}$

Other synthesis reactions include: iron rusting by combining with oxygen, magnesium oxide forming when magnesium gets hot enough to combine with oxygen in the air, or ammonia forming from hydrogen and nitrogen gases.

Abstractly, this can be represented by: $X + Y \rightarrow XY$

Remember in class to protect your ears, and try not to blink too much or you miss this…

Another example word equation:

sodium and chlorine make sodium chloride

Skeleton Equation: $Na + Cl_2 \rightarrow NaCl$

BALANCED EQUATION:

$2Na_{(S)} + Cl_{2(G)} \rightarrow 2NaCl_{(S)}$

THE DECOMPOSITION REACTION (2/5)

Defined: the reaction that breaks up larger substances into two or more smaller substances. It is the reverse of synthesis. The demo in class was the reaction of hydrogen peroxide breaking down into water and oxygen gas. This particular reaction was also SO SLOW to watch you could not be sure it was happening. To speed it up the teacher added potassium iodide.

That worked as a **catalyst: a substance that speeds up a chemical reaction but does not affect any other part of the reaction.**

This reaction gave off a lot of heat, making it an EXOTHERMIC reaction. Oddly, that same amount of energy would have been given off without the catalyst, just so slowly that the heat would not be noticeable without a very accurate thermometer.

The heat given off is a constant, the catalyst just made it all be given off in a very short period of time. We will learn much more about heats of reactions (ΔH) later in the year.

Word Equation: hydrogen peroxide decomposes into water & oxygen

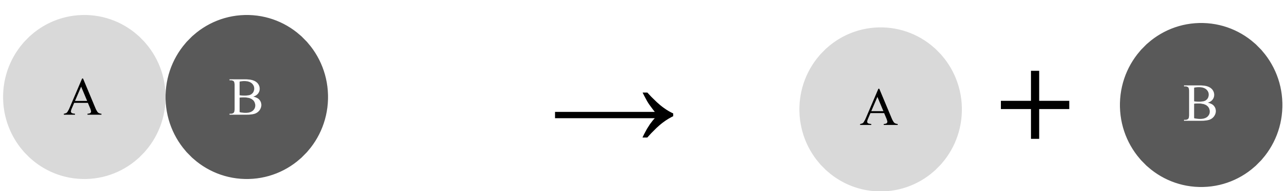
Skeleton Equation: $H_2O_2 \rightarrow H_2O + O_2$

BALANCED EQUATION: $2H_2O_{2AQ)} \xrightarrow{KI_{(S)}} 2H_2O_{(L)} + O_{2(G)}$

The hydrogen peroxide used in the demo was a 30% solution dissolved into water.
PURE hydrogen peroxide could be a LIQUID, but technically speaking, ours was a solution.

Other decomposition reactions include: ammonia breaking down into hydrogen and nitrogen, copper II carbonate breaking down into copper II oxide (black solid) and carbon dioxide (gas).

Abstractly, this can be represented by: $AB \rightarrow A + B$ or, $XY \rightarrow X + Y$



Another common decomposition reaction is when water breaks down into hydrogen and oxygen gases. To do this we'll use a Hoffmann Apparatus, which runs electricity through the water (puts energy in to break the bonds). Water does not conduct electricity by itself. Water can only conduct if there are LOOSE MOBILE IONS in solution. That means an aqueous salt dissolves and then comes apart into cations and anions. There are six examples of salts "ionizing" or "dissociating" near the bottom of table I in your reference tables. From potassium nitrate to lithium bromide. All AQ salts, and all acids ionize this way, they do NOT react with water, but water is shown above the arrow in the symbols.

THE SINGLE REPLACEMENT REACTION (3/5)

To understand this reaction you need a bit more chemistry background. When most ionic compounds are added to water they can ionize, which means that the cation part and the anion part can separate and these ions literally float around dissolved in the water. They form an aqueous solution.

Ex: $NaCl_{(S)} \rightarrow Na^{+1}_{(AQ)} + Cl^{-1}_{(AQ)}$ (loose, mobile ions)

We will learn more how this happens later in the year. Since these ions are now loose from each other, when a new substance is added into the solution, sometimes this new substance can push one of these ions out of solution and take its place.

This gives the reaction its name: the single replacement reaction. One substance replaces ONE PART of the ionic compound in solution. This only happens with an ionic compound in solution.

To further complicate things, depending upon what is in solution and what is added, the reaction can happen or it will not. Lucky for us TABLE J exists to guide us.

Table J is called the ACTIVITY SERIES. It lists in 2 columns, the activity level or better said: the REACTIVITY LEVEL of a lot of substances.

A single replacement reaction has 3 parts, the single substance that gets added into the aqueous solution (which has 2 parts itself). for example:

$$Mg_{(S)} + HCl_{(AQ)} \rightarrow$$

the 3 parts are the **Mg atom**, the **H^{+1} cation** and the **Cl^{-1} anion**.

If we look at Table J, we see that 2 of these 3 parts, are one side of table J.

(this always happens: 2 of 3 parts are on one side - in this case on the left).

Locate both Mg and H on the table. Since Mg is HIGHER UP on the table, that means that magnesium has a higher activity level, it would be able to bump out the hydrogen in a single replacement reaction. So,

the skeleton would be: $Mg + HCl \rightarrow MgCl_2 + H_2$

balanced chemical equation: $Mg_{(S)} + 2HCl_{(AQ)} \rightarrow MgCl_{2(AQ)} + H_{2(G)}$

Mg replaces the H in solution, the chloride is the spectator ion here.
This is a CATION REPLACEMENT single replacement reaction, the Mg atom replaces the H^{+1} cation in solution.

Metals	Non-Metals
most active	
Li	F_2
Rb	Cl_2
K	Br_2
Cs	I_2
Ba	
Sr	
Ca	
Na	
Mg	
Al	
Ti	
Mn	
Zn	
Cr	
Fe	
Co	
Ni	
Sn	
Pb	
H*	
Cu	
Ag	
Au	
least active	

*H is a non metal that acts like a metal in SR reactions

Some single replacement reactions will not occur, if you add an atom that is LOWER on the list, meaning it is not reactive enough to replace the “higher” ion already in solution.

For example, in class I put my GOLD WEDDING BAND into hydrochloric acid. Since Au is lower than the hydrogen, there is NO REACTION. The proper form for this is:

$$Au_{(S)} + HCl_{(AQ)} \rightarrow X \quad \text{(no reaction)}$$

We use Table J to determine whether or not a single replacement reaction is spontaneous will occur as written, or if it will not. We do not need to do every possible reaction since this table will give us the answer.

Sometimes, **2 of the 3 parts of the reaction will both be on the RIGHT SIDE OF THE TABLE**. The same "rules" apply, if a single part is higher on the right side of table J it can replace itself into the solution. A "standard" example of this is:

$$Cl_{2(G)} + 2NaBr_{(AQ)} \rightarrow 2NaCl_{(AQ)} + Br_{2(G)}$$

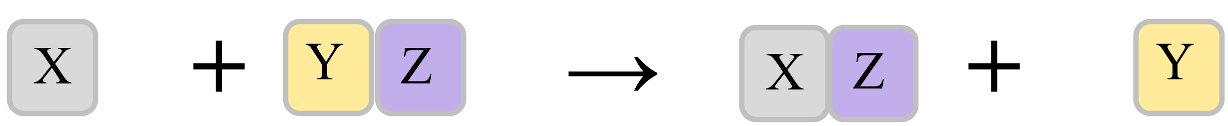
This is an ANION REPLACMENT SINGLE REPLACEMENT reaction, in that chlorine replaces the Br^{-1} anion in solution. The Na+1 is the spectator ion.

Abstractly, this can be represented three different ways…

A + BC ⟶ AC + B (when 2 of the three are on the LEFT side of Table J) CATION REPLACEMENT

M + NP ⟶ no reaction

R + ST ⟶ SR + T (when 2 of the 3 are on the RIGHT side of Table J) ANION REPLACEMENT



Atoms	+	AQ	→	Different AQ	Different atoms

THE DOUBLE REPLACEMENT REACTION (4/5)

This reaction is what it sounds to be, a double switch by two different solutions of ionic compounds. The cations and anions are separated (ionized) from each other in the aqueous solutions as loose, mobile ions.

When two different solutions of separated ions are combined, the cations will trade anions in a double switch. This results in two new ionic compounds forming.

If we get a new aqueous solution, and a solid precipitate forming, that is double replacement. Sometimes the 2 products are both aqueous, and no solid forms.
That is not a chemical reaction, that is just a mixture.

In our class we will balance ALL double replacement reaction set ups, then we'll use Table F to determine the phases of the products.

Table J can show that some possible single replacement reactions cannot occur and therefore no balancing is possible. Not here! For double replacement you will balance and table "F" the products. Only then might you discover that one is a "no reaction". A "no reaction" means the solutions MIXED.

The original two solutions will be ionized into the water - another way to say that they are dissolved in water completely. When the solutions are combined together, and the cations switch their anions, new compounds formed will also be soluble and remain dissolved and the other will precipitate out of solution as a solid. These insoluble compounds will form precipitates which we can see.

The number of potential double replacement reactions is great. TABLE F exists to help us determine which kinds of ionic compounds will be soluble (AQ) or insoluble (S).

Using this table can be difficult at first (not unlike tying one's shoes, or learning how to use a swing at the park) but it is remarkably simple once you practice a bit.

Example word equation…

calcium chloride + sodium carbonate forms calcium carbonate + sodium chloride

The skeleton chemical reaction is...

$$\_CaCl_{2(AQ)} + \_Na_2CO_{3(AQ)} \rightarrow \_CaCO_{3(\ )} + \_NaCl_{(\ )}$$

Next page this continues…

(again) The skeleton chemical reaction is...

$$\_CaCl_{2(AQ)} + \_Na_2CO_{3(AQ)} \rightarrow \_CaCO_{3(\ )} + \_NaCl_{(\ )}$$

The balanced chemical reaction is...

$$CaCl_{2(AQ)} + Na_2CO_{3(AQ)} \rightarrow CaCO_{3(\ )} + 2NaCl_{(\ )}$$

The balanced chemical reaction with PHASES is...

$$CaCl_{2(AQ)} + Na_2CO_{3(AQ)} \rightarrow CaCO_{3(S)} + 2NaCl_{(AQ)}$$

Table F shows that halides (group 17 ions) are usually AQ, but with 3 exceptions. Ca is not an exception so the $CaCl_2$ is aqueous. If you are an ion in group 1, like sodium, you are AQ with no exceptions. Both reactants are clearly AQ.

Product one, table F shows most carbonates are SOLIDS (an exception is the reactant sodium Na_2CO_3). The last product is clearly AQ, sodium ions always are AQ and most halides are too.

The solid precipitate is the PROOF, or EVIDENCE that a double replacement reaction happened.

Occasionally this may happen: $NH_4Br_{(AQ)} + KCl_{(AQ)} \rightarrow NH_4Cl_{(AQ)} + KBr_{(AQ)}$

Both products are AQ, which means this is NOT a chemical reaction. This is just a mixture!

If you are careful to look over the table F, and READ IT SLOWLY, you can't go wrong with deciding if an ionic compound will be AQ or S when in water.

Just remember soluble = dissolves into water, making an aqueous solution.
Insoluble = not able to dissolve into waster. It stays solid—or a solid PRECIPITATE forms.

Abstractly, visualize it this way: $AB + XY \rightarrow AY + XB$

(be sure to trade anions, the cations ALWAYS stay in the front of the compound formula)

Another way to remember this is that it's like a SQUARE DANCE (switch your partners!)

Cation	Anion	+	Cation	Anion	→	Cation	Anion	+	Cation	Anion

THE COMBUSTION REACTION (5/5)

This reaction is truly the most basic. A compound containing ONLY hydrogen & carbon must combine with oxygen to form ONLY carbon dioxide and water.
A HYDROCARBON is a compound that has ONLY hydrogen and carbon in it.

Examples of hydrocarbons include methane (CH_4), octane (C_8H_{18}), and butane (C_4H_{10}).

The products must always be carbon dioxide and water. There can be NO OTHER PRODUCTS. This rule makes combustion easy to recognize. Combustion reactions are always rather EXOTHERMIC, they give off lots of heat.

Word Equation: methane plus oxygen yields carbon dioxide and water

Skeleton Equation: $CH_4 + O_2 \rightarrow H_2O + CO_2$

BALANCED EQUATION: $CH_{4(G)} + 2O_{2(G)} \rightarrow CO_{2(G)} + 2H_2O_{(G)}$

Another BALANCED EQUATION: $C_3H_{8(G)} + 5O_{2(G)} \rightarrow 3CO_{2(G)} + 4H_2O_{(G)}$

Abstractly, visualize this reaction this way…
any hydrocarbon reacts with oxygen gas, forming into carbon dioxide and water and heat!

$$HC + O_{2(G)} \rightarrow CO_{2(G)} + H_2O_{(G)} + \text{ENERGY!}$$

Incomplete combustion can occur if there is not enough oxygen to covert all of the carbon into CO_2 Some can be formed into CO, or even just C. There are many variations on this reaction called incomplete combustion, but importantly: not all of the carbon can become carbon dioxide.

Example A: $2CH_{4(G)} + 3O_{2(G)} \rightarrow C_{(S)} + CO_{2(G)} + 4H_2O_{(G)}$

Example B: $2CH_{4(G)} + 3O_{2(G)} \rightarrow 2CO_{(G)} + 4H_2O_{(G)}$

There are many other incomplete combustion reactions in addition to these. They do not occur with enough oxygen to turn all the carbon into CO_2 gas.

At right, friends enjoy a camp fire. This is an example of the burning of a hydrocarbon (wood) by rapidly combining it with oxygen in the air, producing carbon dioxide and water (vapor), and lots of energy is released as light & heat.

These 5 reactions all are BASIC reactions that will help further our study of matter and how it reacts. There are of course some asterisks out there waiting to surprise us. That is okay and we'll keep an eye out for them. There are several other reactions we will cover later on, such as acid base neutralization reactions, and several nuclear reactions (which do not follow all the same rules).