Acids and Bases AS 90944

Aspects of acids and bases will be selected from:

Atomic structure

- ❑ electron arrangement of atoms and monatomic ions of the first 20 elements (a periodic table will be provided)
- ❑ ionic bonding
- ❑ names and formulae of ionic compounds using a given table of ions.

Properties

- ❑ acids release hydrogen ions in water (HCl ; hydrochloric acid, H_2SO_4 : sulphuric acid, HNO_3 : nitric acid)
- ❑ reactions (of acids with bases) to form salts (Bases include metal oxides, hydroxides, carbonates and hydrogen carbonates)
- ❑ pH and effects on indicators.

Uses

- ❑ neutralisation
- ❑ carbon dioxide formation
- ❑ salt formation.

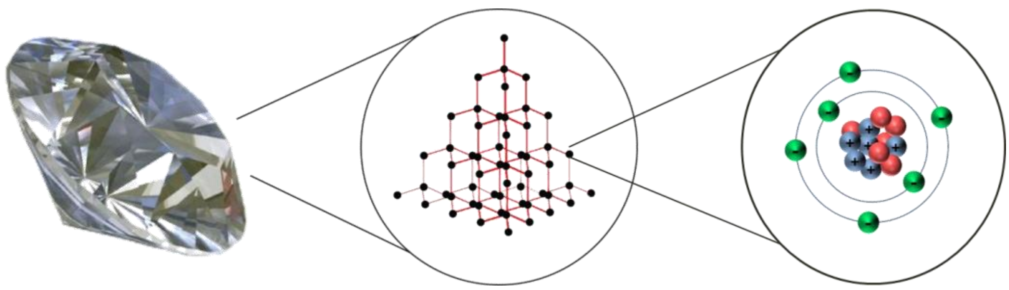
- ❑ Rates of reaction and particle theory.

Introduction

Chemistry is the study of matter and energy and the interaction between them. The elements are the building blocks of all types of matter in the universe. Each element consists of only one type of atom, each with its specific number of protons known as its atomic number.

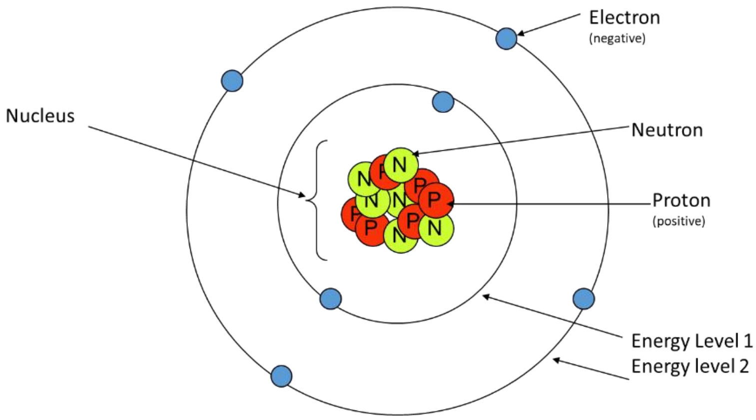
All Matter is made up of particles called atoms

An atom is the smallest neutral particle that makes up matter. The type of atom and the way these atoms are arranged and connected to each other determines the type of matter – and therefore the physical and chemical properties of the matter.



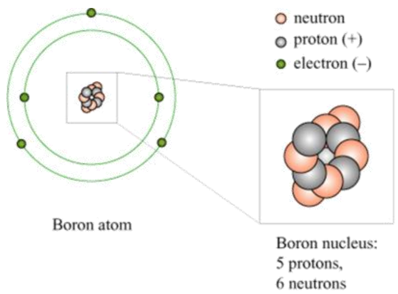
Atoms contain protons, electrons and neutrons

Atoms are made up of smaller particles, the number of these determine the type of atom. Atoms have a central nucleus, which contains protons (p) and neutrons (n). Electrons (e) orbit outside the nucleus, arranged in energy levels.

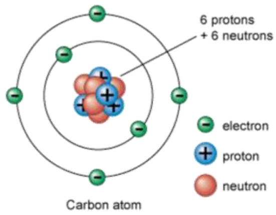


Each different type of element has a different number of protons in its atoms

Positive protons bond to each other with a special type of force in the centre of an atom, called the nucleus. Each type of atom has a specific number of protons. Neutral neutrons in approximately the same number as protons, also join together with the protons to form the nucleus. The positive charge of the nucleus holds the same number of negative electrons in position around it.



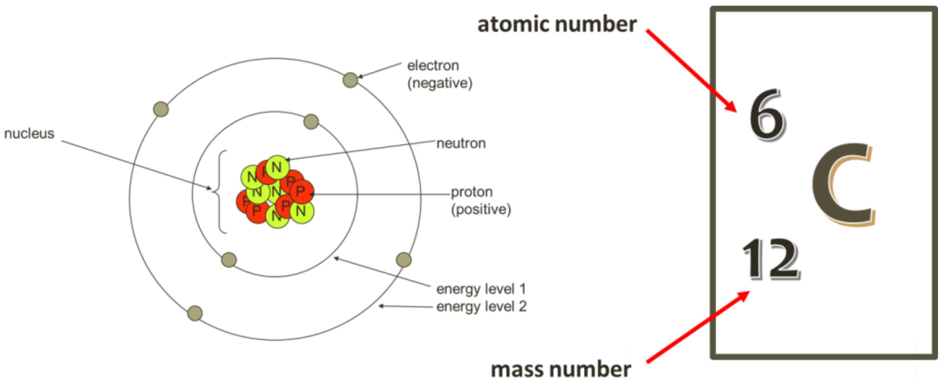
All Boron atoms have 5 protons in their nucleus.



All Carbon atoms have 6 protons in their nucleus.

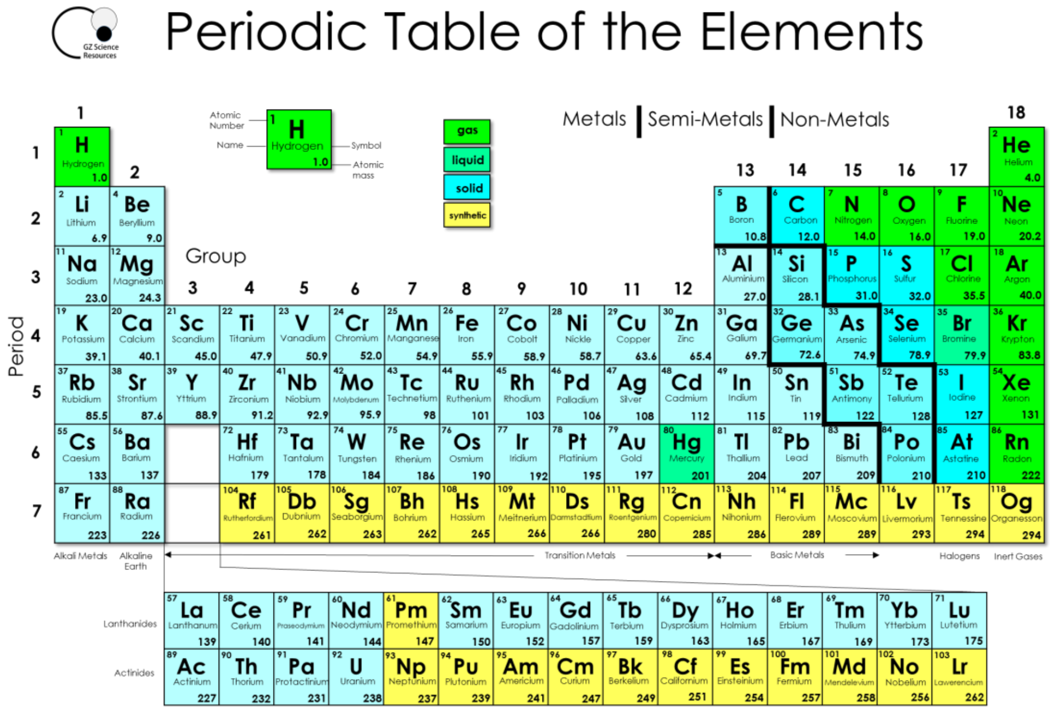
Atomic and Mass number

The atomic number is unique for each element. An atom has the same number of electrons as protons. The atomic number of an atom is equal to the number of protons. The mass number of an atom is equal to the number of protons and neutrons. Both numbers are normally found in the periodic table.

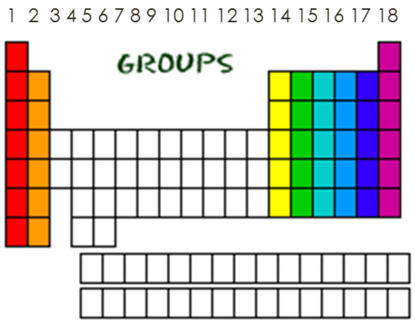


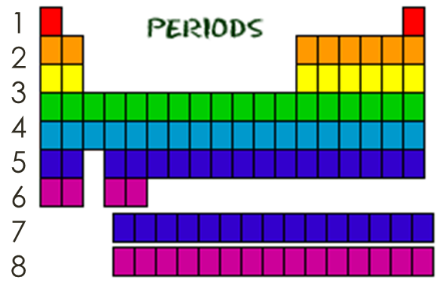
The periodic table organises elements by atomic number

The elements increase in atomic number as you move from left to right and from top to bottom of the periodic table.



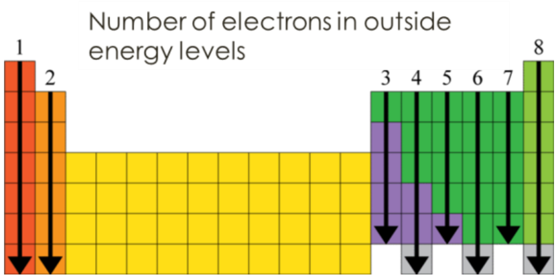
The Periodic Table is also organised into groups that go down a column numbered from 1 to 18, from left to right and Periods that go across a row numbered from 1 to 8, from top to bottom





There is a relationship between the group number and the number of outer electrons.

The elements in a group have the same number of electrons in their outer energy level. Every element in the first column (group one) has one electron in its outer energy level. Every element on the second column (group two) has two electrons in the outer energy level.



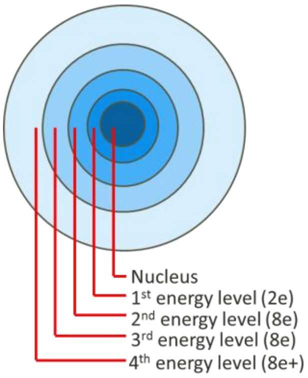
In this unit, we can leave out the central group of elements in the yellow block. Note: for groups 13 to 18 it is only the last number that relates to number of electrons. i.e. group 13 has 3, group 14 has 4…

The electrons in an atom are arranged in a series of energy levels.

Electrons move or 'orbit' around the nucleus in energy levels or shells. The energy levels further away from the nucleus are able to fit more electrons. The first energy level is filled first, followed by the second and so on until all the electrons (the same number of protons in an atom) have been used.

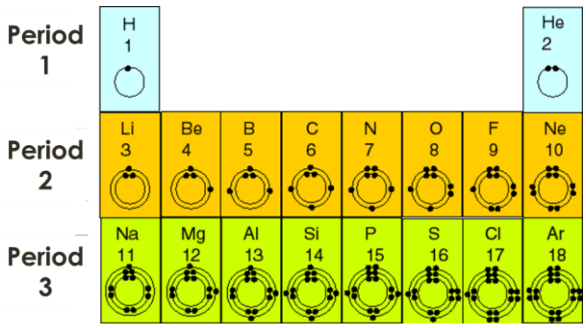
Maximum numbers of electrons in each energy level are:

- 2 in the first EL (nearest the nucleus)
- 8 in the second EL
- 8 in the third EL (before the fourth shell starts to fill)
- 8+ in the fourth EL



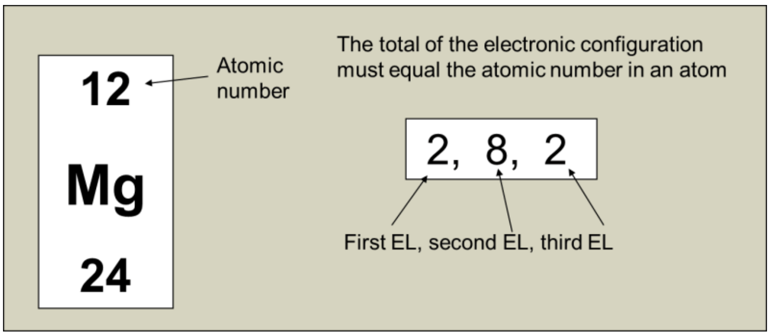
There is a relationship between the period number and the number of electron shells an atom has.

In the periodic table, elements have something in common if they are in the same period. All of the elements in a period have the same number of electron energy levels. Every element in the top row (the first period) has one energy level for its electrons) All of the elements in the second row (the second period) have two energy levels for their electrons. It continues down the periodic table the same way.



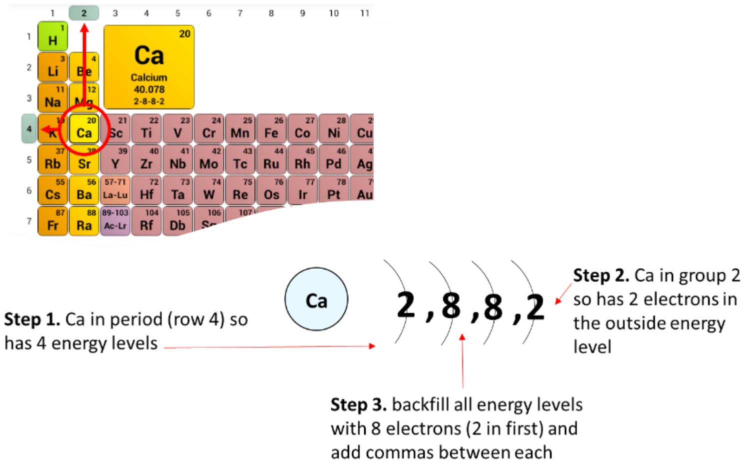
Electron configuration

A shorthand way of describing the way electrons are arranged in an atom is called the *electron configuration*. The information for the number of electrons is found by an elements Atomic Number (number of electrons = number of protons in a neutral atom). Each EL is filled to its maximum capacity, starting with the lowest EL first (EL number 1). A comma separates the EL. The EL are filled until all the electrons are placed.



Using the Periodic table to write electron configurations

Period number gives number of energy levels. The last number of group gives electrons in outer energy level. i.e. group 17 - 7 electrons in outer energy level.

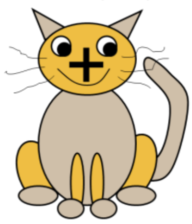


Ions are formed by gain or loss of electrons

Ions are atoms or groups of atoms with electrical charge. Elements are most stable when the outer energy level (valence shell) is full. Elements can lose or gain electrons when they react with other chemicals to form ions.

Atoms that lose electrons form positively charged ions, or cations. Atoms that gain electrons form negatively charged ions, or anions.

Cation (Cat)



Metals lose electrons to form Cations. They have 1-3 electrons in their outside energy level

Anion (an Iron)

Non-Metals gain electrons to form Anions. They have 7-8 electrons in their outside energy level.

Ion Chart – Positive Ions (metals)

You will be given an ion chart for assessments, but you will need to remember the ions names, as they will not be on the chart.

Charge on Ions					
1+		2+		3+	
sodium	Na^+	magnesium	Mg^{2+}	aluminium	Al^{3+}
potassium	K^+	iron (II)	Fe^{2+}	iron (III)	Fe^{3+}
silver	Ag^+	copper (II)	Cu^{2+}		
ammonium	NH_4^+	zinc	Zn^{2+}		
Hydrogen	H^+	barium	Ba^{2+}		
Lithium	Li^+	lead	Pb^{2+}		

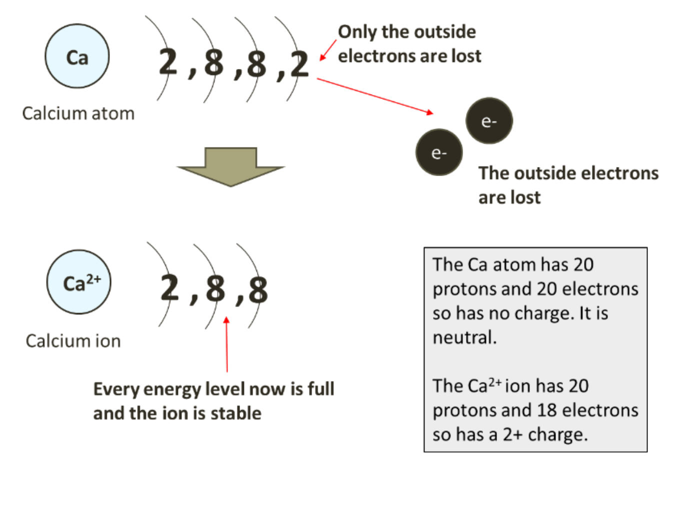
Ion chart – negative ions (non-metals)

Charge on ions			
1-		2-	
chloride	Cl^-	carbonate	CO_3^{2-}
iodide	I^-	oxide	O^{2-}
hydroxide	OH^-	sulfide	S^{2-}
hydrogen carbonate	HCO_3^-	sulfate	SO_4^{2-}
fluoride	F^-		
bromide	Br^-		
nitrate	NO_3^-		

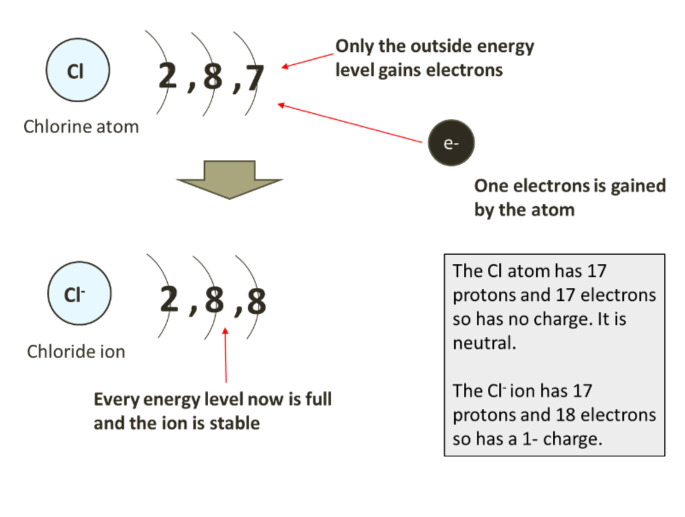
Electron configurations of ions

The charge on the ion relates to how many electrons are lost or gained from the atom

Positive ions (metals)



Negative ions (non-metals)



The difference between an ion and an atom is that an atom has a neutral charge as it has not gained or lost electrons and therefore has the same number of protons (+) and electrons (–) whereas an ion has a charge as the atom it was formed from has either gained or lost electrons to form a full outer shell and therefore has a different number of protons (+) from the number of electrons (–).

Compounds

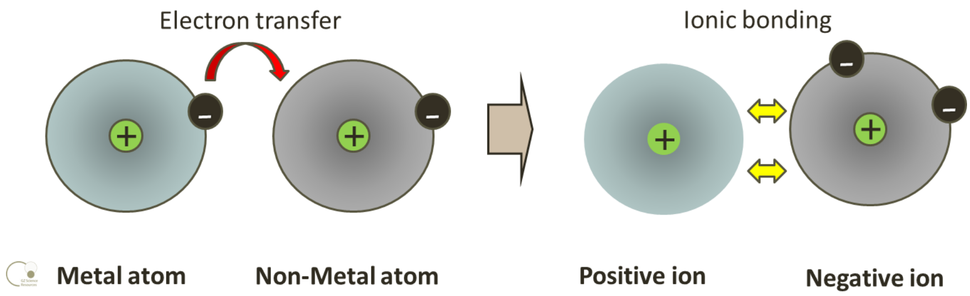
Compounds form from two or more different elements bonded together. The compounds are often more stable than the elements they originated from and may release this extra energy in the form of heat and/or light when bonding together. There are two main types of bonding holding atoms together in a compound; Ionic and Covalent.

Ionic Bonding

When the atoms react, they transfer electrons and form an ionic bond. An ionic bond is the attraction between a positive ion and a negative ion. It is formed because opposite charges will attract one another.

One atom takes valence (outside energy level) electrons from another to form ions and the resulting negative and positive ions hold together with electrostatic attraction. This type of bonding occurs when a metal and non-metal react and there is a transfer of electrons to form ions. The ions then combine in a set ratio to form a neutral compound with negative and positive charges balanced out.

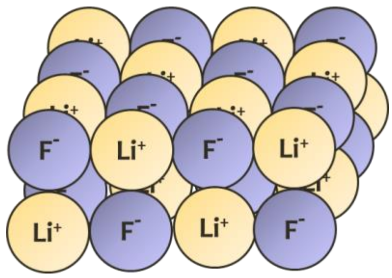
Ionic Bonding



Ionic compounds are the product of chemical reactions between metal and non-metal ions

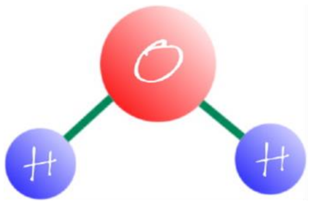
Compounds are neutral substances. For ionic compounds, the charges of the positive ions are balanced by the charges of the negative ions.

Some compounds are ionic compounds, since they are made up of cations and anions. The Anion (F) takes the electrons off the Cation (Li) so their outer energy levels have a stable 8 electrons each. Anions and Cations have a strong electrostatic attraction for each other so they bond together as a compound.



Chemical compound formula

Elements in a compound combine in fixed amounts. It is possible to write a formula for a compound.



H_2O

This formula for water (H_2O) tells us that there are 2 Hydrogen atoms and 1 Oxygen atom in a molecule of water

A formula tells you the type of atoms that are in a compound and the number of each atom.

2 Mg atoms — 4 N atoms — 12 O atoms

$$2\ Mg(NO_3)_2$$

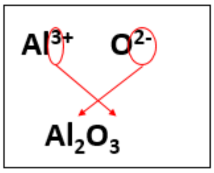
A number in front of the compound tells you how many molecules there are.

A number after an atom tells you how many atoms of that type are in the molecule.

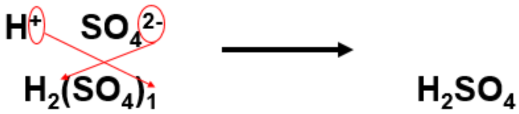
A number after brackets tells you how many times to multiply every atom inside the brackets.

Writing Chemical compound formula

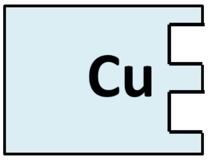
1. Write down the ions (with charges) that react to form the compound. Cation comes before Anion.



2. Cross and drop the charge numbers.
3. Place brackets around a compound ion.
4. If the numbers are both the same remove.
5. If any of the numbers are a 1 they are removed
6. Remove any brackets if not followed by a number



The visual method for balancing compounds



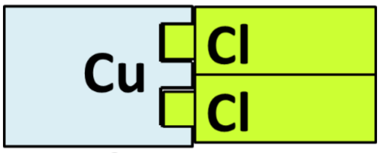
Copper

Copper forms a positive copper ion of Cu^{2+}. It loses 2 electrons – shown by the 2 "missing spaces" in the shape

Chloride

Chlorine forms a negative chloride ion of Cl^{-}. It gains 1 electron – shown by the 1 "extra tab" in the shape

If we want to form a balanced ionic compound then each space in the positive ion must be filled by a tab from the negative ion. In this case, 2 chloride ions are needed for each copper ion to form copper chloride.



Copper Chloride

The visual ion chart

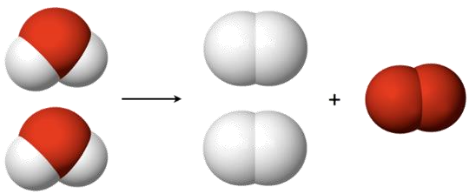
Cation			Anion	
1+	2+	3+	2-	1-
H Hydrogen	Mg Magnesium	Fe Iron (III)	O Oxide	Cl Chloride
Na Sodium	Ca Calcium		SO_4 Sulfate	OH Hydroxide
K Potassium	Cu Copper	Al Aluminium	CO_3 Carbonate	NO_3 Nitrate
NH_4 Ammonium	Pb Lead		S Sulfide	HCO_3 Hydrogen Carbonate
Ag Silver	Zn Zinc	Fe Iron (III)		F fluoride
Li Lithium	Fe Iron (II)			

Chemical Reactions - reactants & products

A chemical reaction is a process that produces a chemical change to one or more substances. A chemical reaction will produce a new substance. Other observations may include a temperature change, a colour change or production of gas.

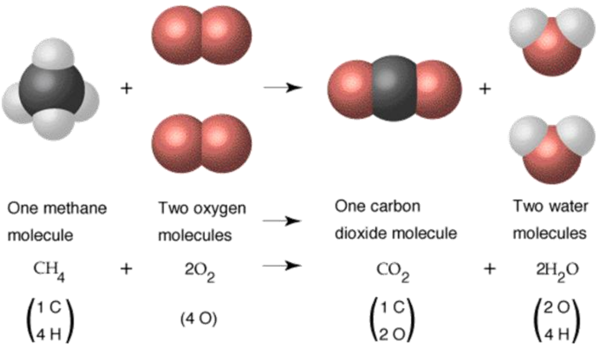
Chemicals that are used in a chemical reaction are known as reactants. Those that are formed are known as products. Chemical reactions between particles involve breaking bonds and forming new bonds.

Reactants → Products

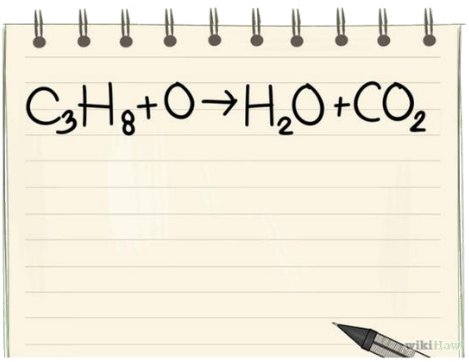


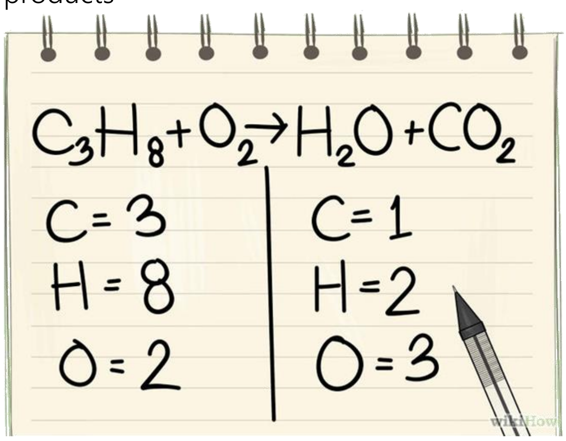
Chemical equations

Compounds and elements can react together to form new substances in a chemical reaction. We use a chemical equation to show the substances we start with, called reactants, and the substances that are formed called products. Balanced equations must have the same number of atoms on each side of the equation i.e. reactants and products.



Balancing Chemical equations

<table>
<tr>
<td>1. To balance an equation first write down the equation


The total number of each type of atom must be the same for reactants and products if they equation is balanced</td>
<td>2. Count the total number of each atom for reactants and products


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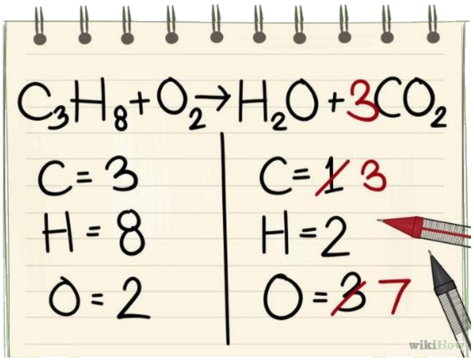
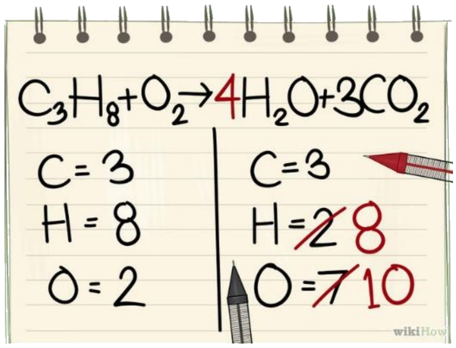
3. Starting with the first atom (C) multiply until it is the same on both sides – and place this number in front of the compound. You may change the number of another atom but you can sort this as you move down the list

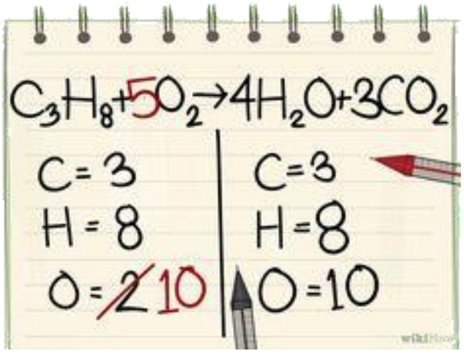


4. Moving down the list to the next atom (H) multiply until both sides are the same – again you may also increase another atom but sort that out after

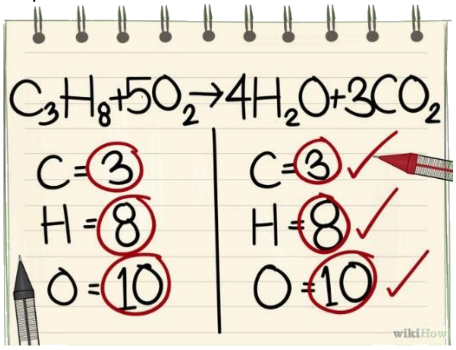


Only put numbers in front of compounds NOT after an atom as this changes the formula.

5. Moving to the last atom on this list (O) multiply until it is the same number on both sides



6. If all atoms are the same number on both sides then the equation is balanced!



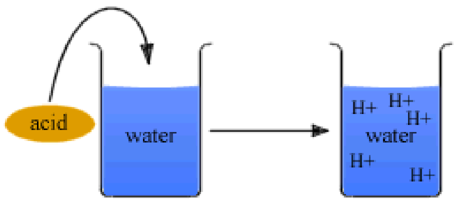
Sometimes you may have to go back and rebalance another atom again for the second time.

Acids – their characteristics

Acids are a family of substances which all show acidic characteristics or properties. These properties relate to how the acids react with other chemicals. They have a sour taste and react with metals. Acids can be found in nature and called organic acids or manufactured in the laboratory and called mineral acids.

An Acid donates its Hydrogen ion (H+), which is really just a proton - the electron remains behind.

Common acids include the strong acids HNO_3 - nitric acid, HCl^- hydrochloric acid, and H_2SO_4 – sulfuric acid



Common acids - names and formula

Name	Chemical formula	Salts formed
hydrochloric acid	HCl	-chlorides (Cl^-)
sulfuric acid	H_2SO_4	-sulfates (SO_4^{2-})
nitric acid	HNO_3	-nitrates (NO_3^-)

Bases – their characteristics

Bases are a family of chemicals that can remove acid particles (H^+) from a solution. They have opposite properties from acids. Bases have a slippery feel to them and common household bases include floor clearers and antacid tablets to fix indigestion. Bases that dissolve into water are called an alkali, and produce OH^- ions.

A Base accepts a Hydrogen ion that have been donated from an Acid. They release hydroxide ions into solution.

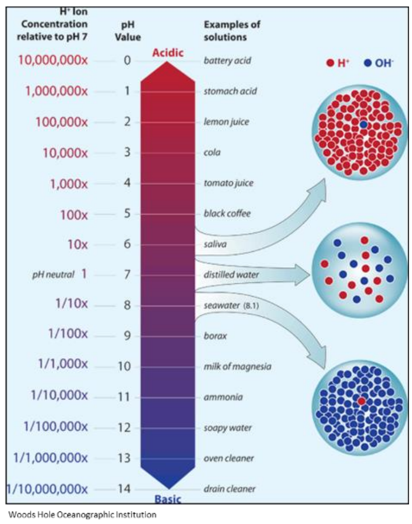
Common bases include the strong bases NaOH – sodium hydroxide and other metal oxides, hydroxides, carbonates and hydrogen carbonates

Name	Chemical formula
sodium hydroxide	$NaOH$
calcium hydroxide	$Ca(OH)_2$
sodium hydrogen carbonate	$NaHCO_3$
calcium carbonate	$CaCO_3$

The pH scale measures level of acidity and alkalinity

The pH scale measures how acidic or alkaline a substance is. Substances with a pH of 7 are neutral, substances with a pH greater than 7 are alkaline (or 'basic') and substances with a pH lower than 7 are acidic. Alkalis are 'bases' that are soluble in water. (All alkalis are bases but not all bases are alkalis.)

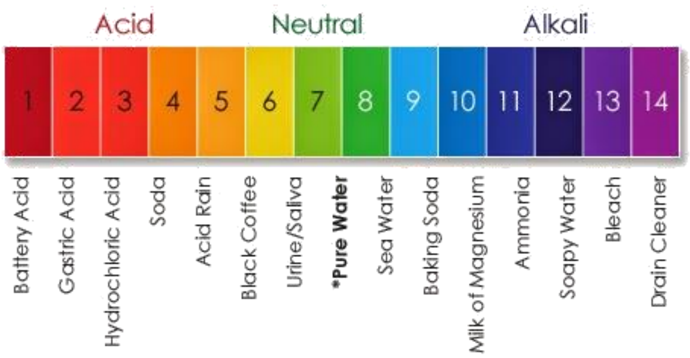
The pH of a substance is determined by the concentration of hydrogen ions. The higher the concentration of hydrogen ions the lower the pH.



Acidic, Alkaline or Neutral in terms of the pH scale

- Acids have a pH less than 7
- Neutral substances have a pH of 7
- Alkalis have pH values greater than 7

The pH scale is logarithmic and as a result, each whole pH value below 7 is ten times more acidic than the next higher value. For example, pH 4 is ten times more acidic than pH 5 and 100 times more acidic than pH 6.



GZ Science Resources

Indicators are used to determine whether substances are acid, base or neutral.

Indicators can be used to determine the pH of a solution by the colour change. The most common indicator is found on litmus paper. It is red with acids and blue with bases. Universal Indicator, which is a solution of a mixture of indicators, and shows a full range of colours for the pH scale.

Red and Blue Litmus paper works as an indicator

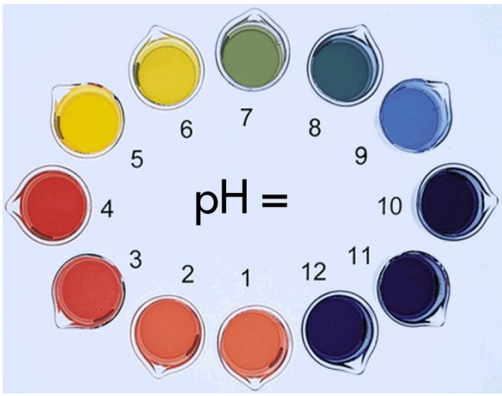
Added to…	Blue Litmus	Red litmus
Acid solution	Turns red	Stays red
Neutral solution	Stays blue	Stays red
Base solution	Stays blue	Turns blue

Blue litmus paper turning red in acid

Red litmus paper turning blue in base

Universal Indicator is used to give the pH

The Universal Indicator is similar to the Litmus paper in that the acids turn the indicator mostly red and the bases turn the indicator mostly blue. It does have an advantage over the litmus paper, as it shows neutral by having a green colour and has different colours to estimate the pH of the solution not just, whether it is acid or base.



Putting it all together

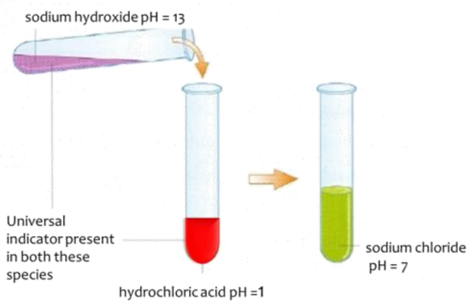
Blue litmus					
Red litmus					
Universal indicator					
pH	**1 - 2**	**3 - 6**	**7**	**8 - 12**	**13 - 14**
description	**Strong Acids** Readily donate all their protons when dissolved	**Weak Acids** donate only a small proportion of protons	**Neutral solution**	**Weak Bases** Accept only a small proportion of protons	**Strong Bases** Readily accept protons
H_3O^+ / OH^- concentration	Concentration of H+ ions is **greater** than that of OH- ions		Concentration of H+ ions is the **same** as that of OH- ions		Concentration of H+ ions is **less** than that of OH- ions

Increasing acidity ⟵ ⟶ Increasing alkalinity

During neutralisation reactions, hydrogen ions combine with hydroxide ions to form water molecules.

Neutralisation is a reaction where an acid reacts with an alkali to form a neutral solution of a salt and water. (And sometimes carbon dioxide gas)

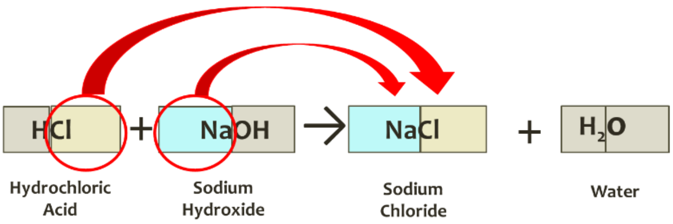
Acid + Alkali → Salt + Water



Names of salts

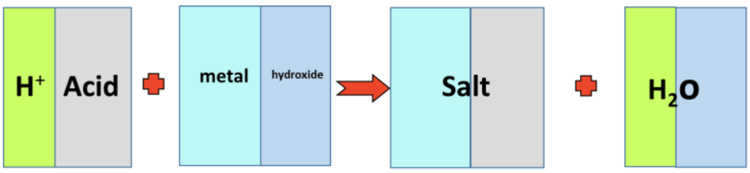
When salts are formed the name depends upon the acid reacted and the metal that forms part of the base compound.

Name of acid	Name of salt formed	Formula of ion
hydrochloric acid	chloride	Cl^-
sulfuric acid	sulfate	SO_4^{2-}
nitric acid	nitrate	NO_3^-



Acids and Hydroxides

Hydroxides neutralise acids and a salt and water are formed

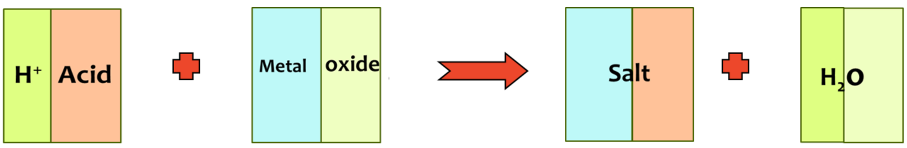


$2HCl + Cu(OH)_2 \rightarrow CuCl_2 + 2H_2O$

Hydrochloric acid, copper hydroxide, copper chloride, water

Acid and Oxide reactions

Acids react with metals oxides in a neutralisation reaction to give a metal salt and water.

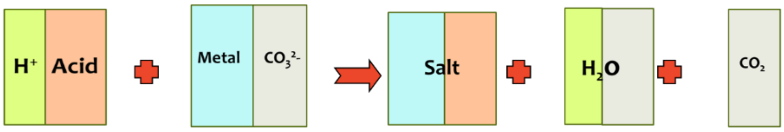


$2HCl + CuO \rightarrow CuCl_2 + H_2O$

Hydrochloric acid, copper oxide, copper chloride, water

Acid and Carbonate reactions

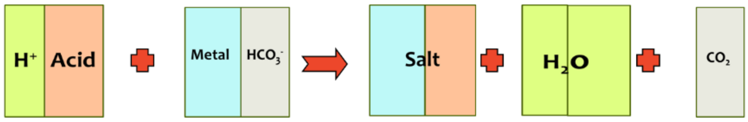
Acids react with Carbonates to give a salt and water and carbon dioxide. We can test to see if carbon dioxide has formed by bubbling the gas into another test tube filled with limewater. The limewater will turn cloudy if the gas is carbon dioxide.



H_2SO_4	+	$CaCO_3$	→	$CaSO_4$	+	H_2O	+	CO_2
sulfuric acid		calcium carbonate		calcium sulfate		water		carbon dioxide

Acid and Hydrogen Carbonate reactions

Acids react with Hydrogen Carbonates to give a salt and water and carbon dioxide. Hydrogen carbonate and acid also produce carbon dioxide gas that can be tested with limewater.



H_2SO_4	+	$2NaHCO_3$	→	Na_2SO_4	+	$2H_2O$	+	$2CO_2$
Sulfuric Acid		sodium hydrogen carbonate		sodium sulfate		water		carbon dioxide

Acid reactions summary

1. Acid and Metal Oxide
General equation acid + metal oxide → salt + water
Word equation nitric acid + copper oxide → copper nitrate + water
Formula equation $2HNO_3 + CuO \rightarrow Cu(NO_3)_2 + H_2O$

2. Acid and Metal Hydroxide
General equation acid + metal hydroxide → salt + water
Word equation nitric acid + copper hydroxide → copper nitrate + water
Formula equation $2HNO_3 + Cu(OH)_2 \rightarrow Cu(NO_3)_2 + 2H_2O$

3. Acid and Metal Hydrogen Carbonates
General equation acid + metal hydrogen carbonate → salt + water + carbon dioxide
Word equation sulfuric acid + sodium hydrogen carbonate → sodium sulfate + water +carbon dioxide
Formula equation $H_2SO_4 + 2NaHCO_3 \rightarrow Na_2SO_4 + 2H_2O + 2CO_2$

4. Acid and Metal Carbonate
General equation acid + metal carbonate → salt + water + carbon dioxide
Word equation hydrochloric acid + magnesium carbonate → magnesium chloride + water + carbon dioxide
Formula equation $2HCl + MgCO_3 \rightarrow MgCl_2 + H_2O + CO_2$

Reaction Rate

The reaction rate is the speed at which a chemical reaction occurs. This is measured by how quickly the reactants change into products or how quickly one of the reactants disappears.

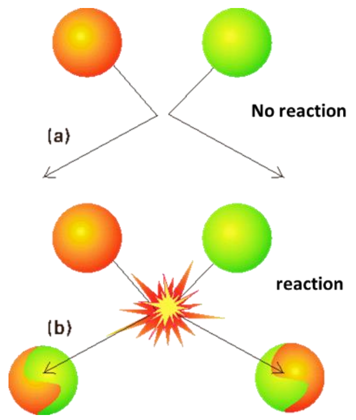
Reactions can vary in their reaction rate

Collision Theory

Chemical reactions between particles of substances only occur when the following conditions have been met:

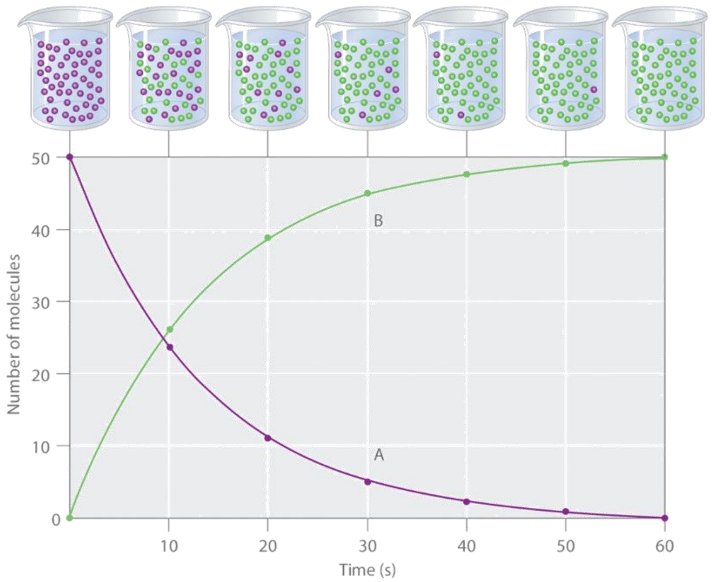
- ❑ Particles must collide.
- ❑ With enough energy (called activation energy EA)
- ❑ And with the correct orientation

If these conditions are met, the collision will be considered successful. (Effective)



Reactions over time

Reactions take place over time. As the amount of reactants decrease the amount of products increase. The reaction rate is shown as a curve because the amount of reactants at the start is greater and the reaction rate slows as they decrease

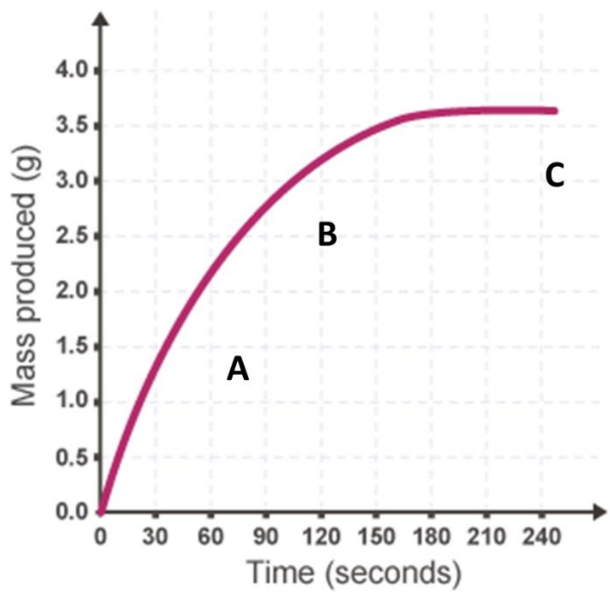


Reaction rate is the speed at which a chemical reaction occurs

A. Reactions start out relatively fast because there is a much higher concentration of reactant particles available to collide and therefore the frequency of collisions will be high. The gradient of the line on the graph for products formed will be high.

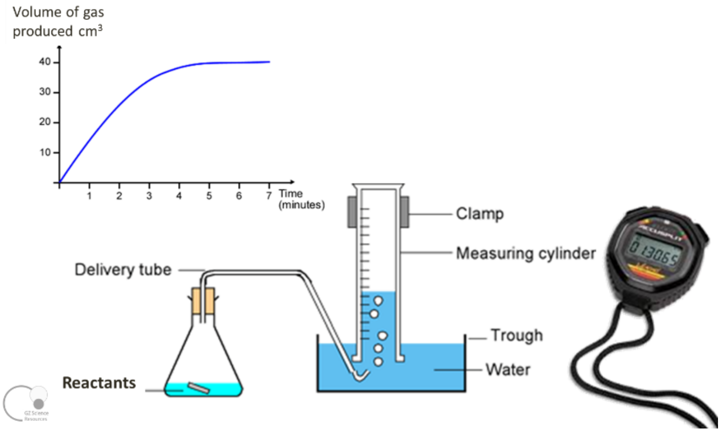
B. As the reaction proceeds there will be less reactant particles available to collide as many have already reacted to form products. The gradient of the line will be lower.

C. When the reaction has come to completion, when all of the reactants have reacted to form particles, then there will be no further collisions and the gradient of the line will be zero.



Measuring the rate of reaction

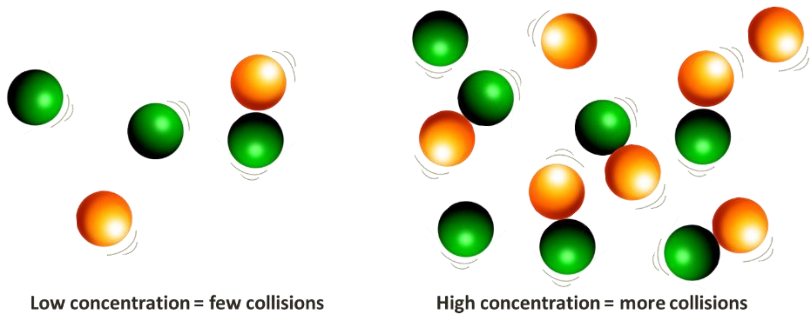
When gas is one of the products, it can be collected in an upside down cylinder. The water displacement is a measure of the volume of gas produced. The amount produced needs to be recorded at set time intervals and then graphed.



Reaction rate can be increased by increasing the concentration

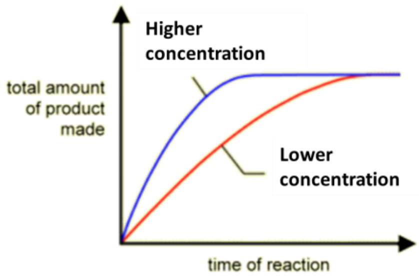
If there is a higher concentration of a reactant, there is a greater chance that particles will collide because there is less space between particles. There are more particles per unit volume. The higher frequency of collisions means there are more successful collisions per unit of time and this will increase the rate of the reaction.

If there is a lower concentration, there will be fewer collisions and the reaction rate will decrease.



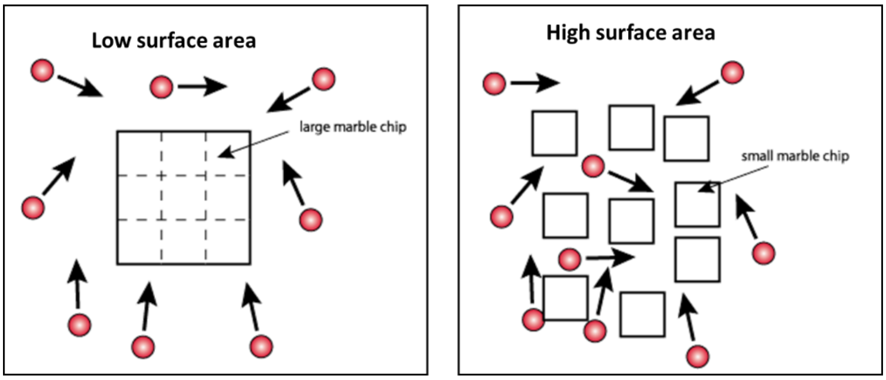
It is important to note that the total amount of product made depends upon the total amount of reactants at the start. A solution that contains only half the particles of another will require twice the volume to produce the same quantity of product.

Also, note that the proportion of successful collisions does not change by increasing the concentration only the frequency (amount of collisions per unit of time) of collisions is increased.

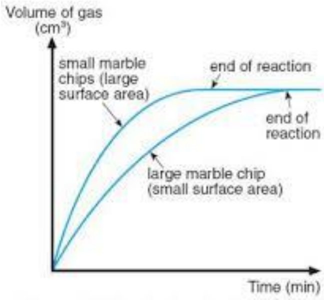


Reaction rate can be increased by increasing the Surface Area

Surface area can be increased by grinding and crushing large lumps into a finer powder. The smaller the pieces the greater the surface area.



By increasing surface area, a greater number of reactant particles are exposed and therefore able to collide. The frequency of collisions (number of collisions per unit of time) will increase and therefore the number of successful collisions so the reaction rate will also increase.



An example is comparing the reaction between marble (calcium carbonate) and hydrochloric acid to produce carbon dioxide gas.

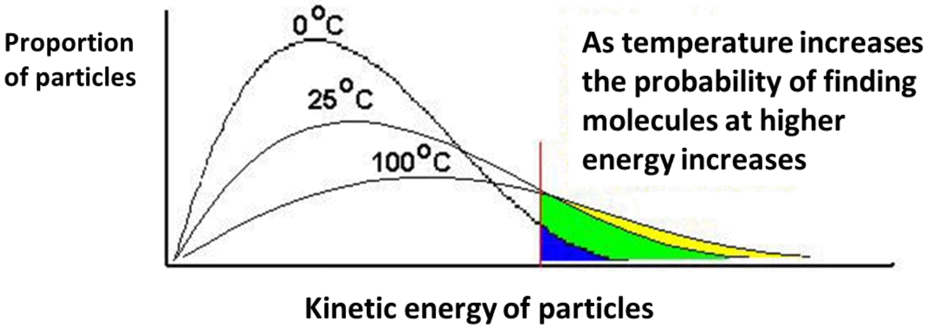
Note: although the reaction rate is higher for the smaller marble chips the total amount of gas (CO_2) produced is the same for both reactions as they both started off with the same amount of reactants.

Reaction rate can be increased by increasing the Temperature

Increasing temperature effects the reaction rate in two ways.

Firstly, when you raise the temperature of a system, the particles move around a lot more (because they have more kinetic energy). When they move around more, they are more likely to collide and the frequency of collisions increases, therefore the number of successful collisions increase and so reaction rate increases as well. When you lower the temperature, the molecules are slower and collide less frequently therefore the reaction rate decreases.

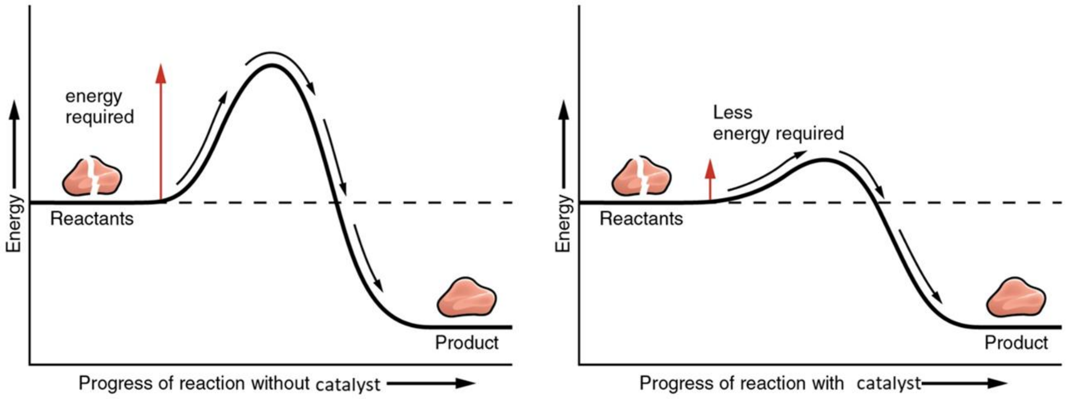
Secondly, at a higher temperature a larger proportion of particles have sufficient (kinetic) energy to have the energy required during a collision for it to be successful and therefore a reaction to occur. This increases the proportion of successful collisions and therefore the reaction rate.



Reaction rate can be increased by using a catalyst.

A catalyst is a substance that increases the reaction rate without being used up or forming part of the products. Only some reactions have catalysts that are effective, but for many reactions, there is no catalyst that works.

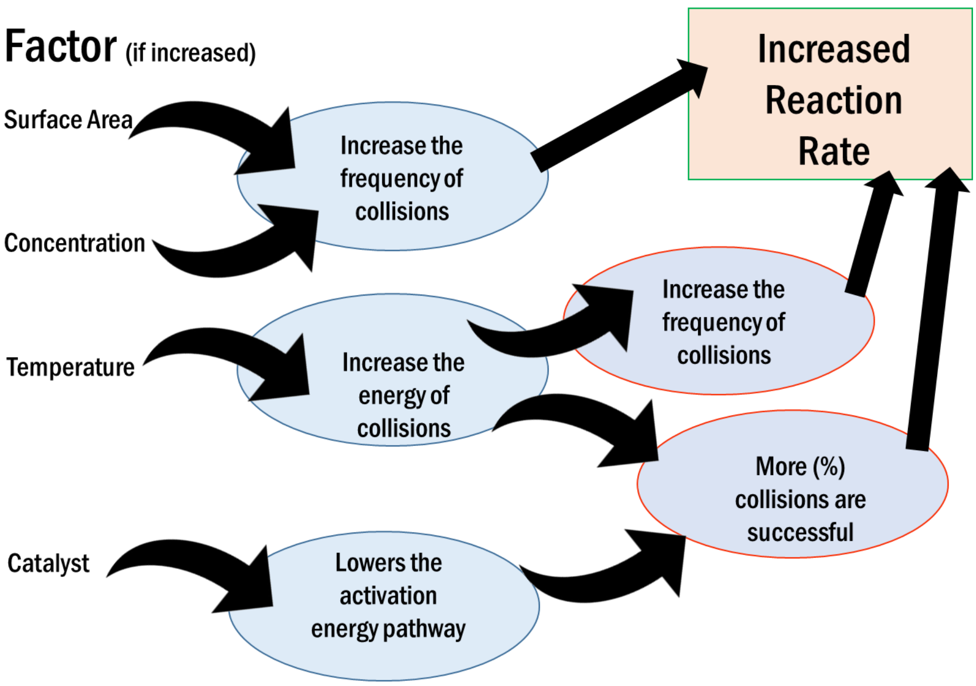
A catalyst lowers the minimum amount of energy required for a reaction to take place. This means that the particles can successfully collide with less energy than they required before the catalyst was added. A greater proportion of particles will successfully collide, and therefore the reaction rate will be increased.



Factors affecting Reaction Rate

Increase the frequency of collisions	Increase the energy of collisions	Make it easier for reaction to occur
➢By **increasing surface area**: smaller pieces of reactant expose more reactant particles to collisions. Stirring will also in crease the reaction rate ➢By **increasing the concentrations**: more reactant particles exist in a given volume so more collisions occur (per unit volume)	>by **increasing temperature**: particles move faster so have more kinetic energy. More collisions will be effective (successful) Note: increasing temp also increases frequency of collisions (collisions per unit time)	>by **using a catalyst**: allows reaction to occur with less energy so more collisions are effective (successful)

Reaction rate can also be slowed down by decreasing these



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