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CHAPTER 1

Chemistry

1.1 Atoms

Atoms are composed of three subatomic particles:

1. Proton (+)
2. Neutron (=)
3. Electron (-)

Where the proton has a positive charge, the neutron has a neutral charge, and the electron has a negative charge. The proton and neutron are located inside the nucleus of an atom, and the electron is located on the outside of the nucleus (see figure below).

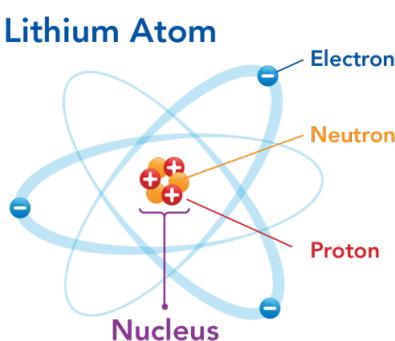


Figure 1.1: a 3d image of an atom

Terms: Here are some terms of the different type of atoms

- **Isotopes:** Atoms that have the same ionic number but different mass numbers; atoms with \pm a certain number of neutrons.
- **Ions:** Atoms that have the same atomic number but a different number of electrons.

- **Cation:** A positively charged ion.
- **Anion:** A negatively charged ion.

Note: Atoms become ions when there is a loss/gain of electrons. Protons do not move.

1.1.0.1 Examples

1. Below is an example of a normal atom vs an ionic atom of sodium

Sodium vs Sodium Isotope

	Na	Na ⁺
Protons	11	11
Electrons	11	10
Neutrons	12	12

And in this case, we have Na⁺ to show that the sodium ion is positively charged, meaning it is missing 1 electron.

2. Below is an example of a normal atom vs an ionic atom of lithium

Lithium vs Lithium Isotope

	Li	Li ⁺
Protons	3	3
Electrons	3	4
Neutrons	3	3

And in this case, the isotope of lithium gained an electron so that it is negatively charged.

1.2 The Periodic Table

The periodic table is a table that consists of all the elements in the world of which are sorted by *groups* and *rows*. Additionally, each element fits into a certain class of element.

Periodic table of the elements

period group 1*																			18	
1	H	2																	He	
2	Li	Be																	Ne	
3	Na	Mg	3	4	5	6	7	8	9	10	11	12							Ar	
4	K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	31	Ga	32	Ge	As	Se	Br	36
5	Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	49	50	51	52	53	54	Xe	
6	Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	80	81	82	83	84	85	86	Rn
7	Fr	Ra	Ac	Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	111	112	113	114	115	116	117	118	Og
lanthanoid series		6	58	59	60	61	62	63	64	65	66	67	68	69	70	71	Lu			
actinoid series		7	90	91	92	93	94	95	96	97	98	99	100	101	102	103	Lr			

*Numbering system adopted by the International Union of Pure and Applied Chemistry (IUPAC). © Encyclopædia Britannica, Inc.

Figure 1.2: the periodic table

- **Group:** A group is a column in the periodic table.

- **Period:** A period is a row in the periodic table.

Each element on the periodic table has the format of an example below

7	14.01
N	3.04
Nitrogen	
-3	

And we can list the following:

- The 7 is the **atomic number**; number of protons/electrons
- 14.01 is the **atomic mass**; weight of the atom
- The element's symbol N
- The name of the element "Nitrogen"
- The ionic charge; the most common charge for when this element becomes an ion. For example, if iron (Fe) has a 2+ charge, it means that it has lost 2 electrons, since it becomes positive by 2+

1.2.1 Patterns and Trends

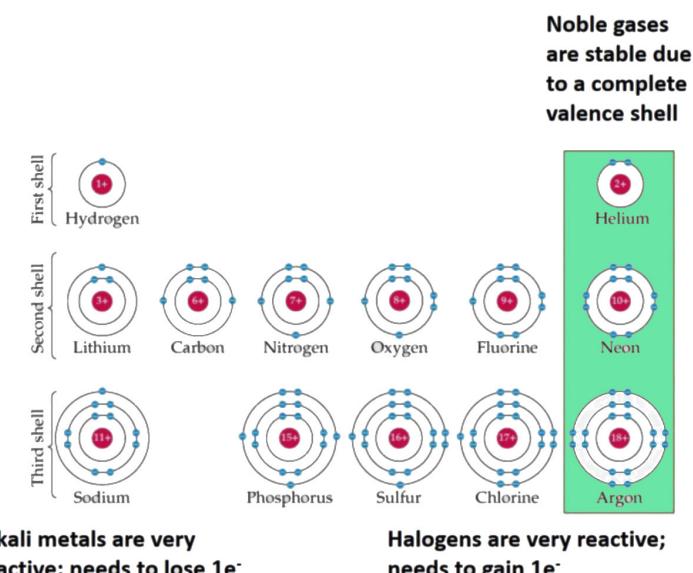
Some patterns and trends in the periodic table are listed below:

- Atomic number steadily increases across the periodic table.
- In the periodic table, in period 6 and period 7, you can see how there are lanthanides and actinides which are the last two periods in the periodic table; they just don't fit because it would make the table look very clumped.
- The number of energy levels (energy shells) steadily increases down a group.
- Metals tend to LOSE electrons, and therefore they are mostly cations.
- Non-metals tend to ATTRACT electrons, and therefore they are mostly anions.
- The number of valence electrons (outermost electrons) are the same within a group and increase steadily across a period.

1.2.2 Reactivity

Valence electrons determine the reactivity of an element and how compounds are formed. Elements tend to lose or gain valence electrons to form bonds and achieve stability.

- Noble gases are stable due to a complete valence shell.
 - Helium
 - Neon
 - Argon
- Alkali metals are very reactive, since they only need to lose 1 electron to complete their shell.
- Halogens are very reactive as well, since they only need to gain 1 electron to complete their shell.



1.2.3 Multivalent Elements

Some elements on the periodic table are multivalent, meaning that they have a tendency to gain/lose a different number of electrons. For example, iron (Fe) is multivalent, having either a tendency to form a 3+ charge or a 2+ charge. The reason for this most likely has to do with the outer shell configuration and experimental tests.

26	55.85
Fe	1.83
Iron	
+3, +2	

Figure 1.3: circled in red shows the 3+ and 2+ charge

Note: The ionic charge that comes first is the one that it has a higher tendency to form for. So if you are not sure which ionic charge to pick, pick the first one, which in the figure above would be 3+.

Then, how would you write out a multivalent atom? Well, you simply write the element's name and then put in parentheses the roman numerals for the ionic charge. For example, if I wanted iron with a charge of 2+, I would write Iron(II). If I wanted iron with a charge of 3+, I would write Iron(III).

1.3 Bohr-Rutherford Diagrams

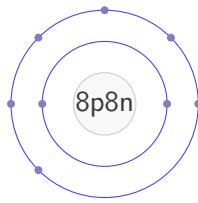
Definition 1.1. Bohr-Rutherford Diagrams Bohr-Rutherford diagrams are visual demonstrations of an atom with its electron shells and the nucleus.

Steps to draw a Bohr-Rutherford diagram:

1. Determine the number of protons, neutrons, and electrons
2. Draw the nucleus, including the number of protons and neutrons
3. Determine the number of electron shells (each complete shell follows the 2-8-8-... pattern)
4. Draw the valence electrons

Example. Draw the Bohr-Rutherford diagram for oxygen

Solution. Oxygen has $8 - 2 = 6$ valence electrons. The Bohr-Rutherford diagram is shown below



1.4 Ionic Compounds

Definition 1.2. Ionic Compounds Ionic compounds are formed by the electrostatic interaction of a cation and an anion; electrons are transferred from one element to the other. A good approach to approximate this is by understanding a cation as a metal and an anion as a non-metal, although sometimes we will have to return to the former definition. Ionic compounds are able to be formed because the electrons complete an outer shell.

Note: A subtle detail that isn't mentioned in the definition is that the elements of ionic compounds have to be of opposite charge, hence the term "ionic" in the name. That is why you need one cation and one anion. Then, if you use the latter definition coupled with the fact that ionic compounds have a complete outer shell, then that explains how they derive the *ionic charge*. For example, we see that sulfur has an ionic charge of -2 , meaning that it has a tendency to gain 2 electrons. This means that sulfur has 6 valence electrons, which can be verified by its atomic number, which explains why it has an ionic charge of -2 . Then, in order for an ionic compound to have a full outer shell, one of the ions have to be positive and the other has to be negative; hence, positive attracts negative.

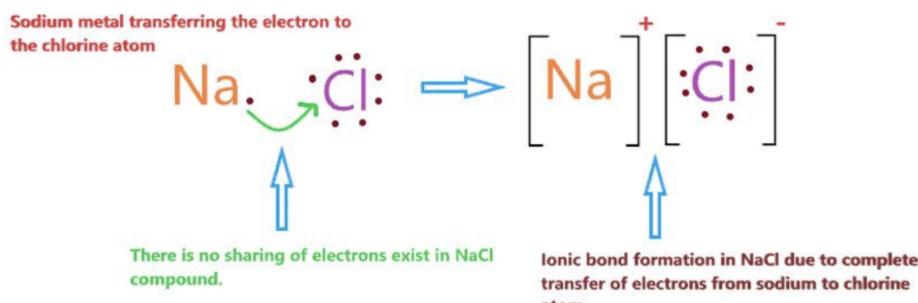


Figure 1.4: example of an ionic compound

1.4.1 Physical Properties of Ionic Compounds

Some physical properties are:

- High melting and boiling points.
- Low volatility/non-volatile.
- Generally soluble in polar solvents (such as water).
- Does not conduct electricity in the solid state.
- Conducts electricity when molten or when dissolved in water.
- Generally brittle; hard but can shatter/break easily.

Examples

Ionic Compound	Charge on Metal Ion	Melting Point
Na ₂ O	1-	1132°C
MgO	2+	2800°C

1.4.2 Naming Ionic Compounds

This is where the naming for compounds comes in. We use the following steps when naming an ionic compound:

1. Make sure that the elements are not multivalent. If they are, un criss-cross the compound (see 1.4.4).
2. Name the cation first. The name of the cation is unchanged. For example, potassium stays as potassium.
3. Name the anion second. When the anion becomes part of an ionic compound, you let the anion end in “ide”. For example, chlorine becomes chloride.
4. Combine the names from step (1) and (2). The name of KCl is therefore Potassium Chloride.
5. If the compound contains a *polyatomic ion*, do not apply step (2) to it.

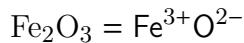
1.4.2.1 Problems

1. Write the chemical name for the following:

- (a) Fe₂O₃
- (b) Cu₂S
- (c) FeN

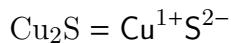
Solutions:

- (a) Iron is multivalent, so if we un criss-cross this



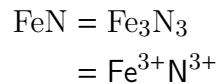
Therefore our answer is iron(III) oxide.

- (b) Copper is multivalent, so if we un criss-cross this



Therefore, our answer is copper(I) sulfide.

(c) Iron is multivalent, so we should just be able to un criss-cross this. However, if we un criss-cross this, we get $\text{Fe}^+ \text{N}^-$, which doesn't make any sense, since iron can never have an ionic charge of 1+. Therefore, we have to do some thinking. We recall that we should simplify the subscripts to the smallest ratio whenever we can. Therefore, we can actually write



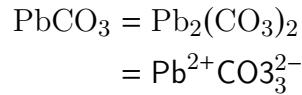
Where we use the subscript of 3 since nitrogen has an ionic charge of 3-. Therefore, our answer is iron(III) nitride.

2. Write the chemical name for the following:

- (a) KNO_3
- (b) $(\text{NH}_4)_3\text{PO}_4$
- (c) PbCO_3

Solutions:

- (a) None of these ions are multivalent, so we just get potassium nitrate.
- (b) This is actually a compound of two polyatomic ions, so our answer is just ammonium phosphate.
- (c) Lead is multivalent with a higher tendency to form as a 2+ ion, so we un criss-cross



And so our final answer is lead(II) carbonate.

1.4.3 Lewis Dot Diagrams

Definition 1.3. Lewis Dot Diagrams Lewis Dot Diagrams are diagrams that show the valence electrons of a Bohr-Rutherford Diagram. Creating Lewis Dot Diagrams:

Write the element symbol.

2. Find the number of valence electrons by looking at the group number. For groups 13-18, subtract 10 to obtain the valence electrons.
3. Place dots representing the valence electrons on the four sides of the element symbol solo before pairing up.

Example. Draw a Lewis Dot Diagram of a chlorine atom.

Solution. Chlorine has 7 valence electrons, so we represent those 7 electrons with 7 dots:



1.4.3.1 Problems

1. Draw the Lewis Dot Diagrams of:

- (a) Silicon
- (b) Calcium
- (c) Magnesium ion Mg^{2+}
- (d) Oxide ion O^{2-}

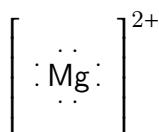
Solution. (a) Silicon has $14 - 10 = 4$ valence electrons. The Lewis Dot Diagram is



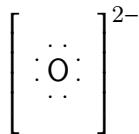
(b) Calcium has 2 valence electrons. The Lewis Dot Diagram is



(c) The magnesium ion has no valence electrons $(12 - 10) - 2 = 0 \rightarrow 8$ valence electrons. The Lewis Dot Diagram for ions is



(d) The oxygen $2-$ (oxide) ion has $(8 - 2) + 2 = 8$ valence electrons. The Lewis Dot Diagram is



1.4.4 The Criss-Cross Method

This method is used to determine the chemical formula for ionic compounds. The criss-cross method is simple: you write the elements with their ionic charges next to each other, and then you criss-cross the powers down into positive subscripts.

Note: Once you have written the subscripts for the criss-cross method, you have to simplify the ratio between the subscripts to the lowest. For example, if I had $Ti^{4+} O^{2-} = Ti_2O_4$, I

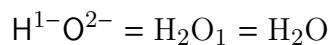
would simplify this to be TiO_2 .

Examples

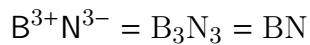
1. The chemical formula for calcium chloride is as follows: calcium has the symbol Ca with an ionic charge of 2+, and oxygen has the symbol Cl with an ionic charge of 1-. Therefore, the chemical formula using the criss-cross method will be



2. The chemical formula for water (hydrogen dioxide) is as follows: hydrogen has the symbol H with an ionic charge of 1+, and oxygen has the symbol O with an ionic charge of 2-. Therefore, the chemical formula using the criss-cross method will be



3. The chemical formula for boron nitride is as follows: boron has the symbol B with an ionic charge of 3+, and nitrogen has the symbol N with an ionic charge of 3-. Therefore, the chemical formula using the criss-cross method will be



Where we simplify the ratio 3 : 3 to be 1 : 1.

1.5 Covalent Compounds

Definition 1.4. Covalent Compounds A covalent compound is formed by a covalent bond between two elements, typically non-metals. Covalent bonding is basically the same thing as ionic bonding except that we have to forget about all the intuition behind the chemical formulas for ionic compounds. Covalent bonding is simply the regular type of bonding for atoms except that they share the electrons instead of giving them away.

Note: You do not simplify the subscripts for covalent compounds.

1.5.1 Physical Properties of Covalent Compounds

- Lower melting points and boiling points than ionic compounds
- Some of them are volatile (diatomic fluorine, chlorine, bromine)
- Not very soluble in water
- Doesn't conduct electricity very well

1.5.2 Naming Covalent Compounds

Naming covalent compounds is basically the same as naming ionic compounds, only that you have prefixes for the number of elements in a compound.

Steps for naming covalent compounds:

1. Write the name of the elements
2. Change the ending of the second element to "-ide"
3. Add prefixes to represent the number of atoms
 - (a) If mono- is the first prefix, it is understood and not written
 - (b) If the element starts with a vowel, exclude part (a) on the prefix.

Example. Determine the chemical name for PF_5

Solution. This compound has phosphorus and fluorine. Since there is 1 phosphorus and 6 fluorines, the answer will be Mono Phosphorus Penta Fluorine.

1.5.3 Polyatomic Ions

Prefixes

Number	Term
1	Mono
2	Di
3	Tri
4	Tetra
5	Penta
6	Hexa
7	Hepta
8	Octa
9	Nona
10	Deca

Definition 1.5. Polyatomic Ions A polyatomic ion is an ion that is made of more than one atom but acts as a single unit. When criss-crossing polyatomic ions, do **NOT** simplify the subscripts.

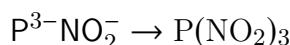
For example, nitrate acts as a single unit and has the chemical formula of NO_3^- . Another example could be hydroxide, which has a chemical formula of OH^- .

Remark.

One thing you may notice about these polyatomic ions is that they are all made by covalent bonds. We can see this because they are all made of anions, or vastly non-metals. This means that the elements that make up a polyatomic ion share their electrons and hence they act as one unit. This also gives insight as to why you can use the criss-cross method for polyatomic ions as well, since you are just treating that polyatomic ion as an entire compound.

Example. Determine the polyatomic ion of phosphorus nitrate

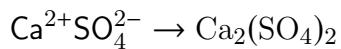
Solution. Phosphorus is P^{3-} and nitrate is NO_3^- . Using the criss-cross method



1.5.4 Problems

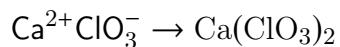
1. Write the chemical formula for calcium sulfate.

Solution. Calcium ion is Ca^{2+} and sulfate is SO_4^{2-} . The chemical formula would be



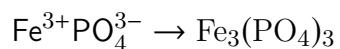
2. Write the chemical formula for calcium chlorate.

Solution. Calcium ion is Ca^{2+} and chlorate is ClO_3^- . The chemical formula would be



3. Write the chemical formula for iron(III) phosphate.

Solution. Iron(III) ion is Fe^{3+} and phosphate is PO_4^{3-} . The chemical formula would be



Where we don't simplify it, since it includes a polyatomic ion.

1.6 Types of Chemical Reactions

There are 5 major types of chemical reactions:

1. Synthesis Reaction
2. Decomposition Reaction
3. Combustion Reaction
4. Single Replacement/Displacement Reaction
5. Double Replacement/Displacement Reaction

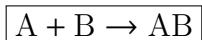
Which we will discuss in this particular order.

1.6.1 Synthesis Reaction

Definition: A synthesis reaction is a reaction that describes the process of a compound that is made from simpler materials. In some sense, “synthesis” is just a fancy word for “making”.

Note: Synthesis reactions are also sometimes called *combination reactions*.

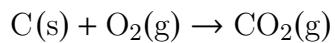
The general skeleton equation is



Where *A* and *B* are arbitrary “materials”.

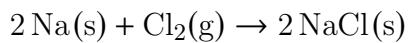
1.6.1.1 Examples

1. Carbon comes together with oxygen gas, to form carbon dioxide



And we see that in this scenario, *CO₂* is more complex than the two simple things that we started with.

2. Sodium comes together with chlorine gas to make sodium chloride

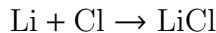


And what we end up with is more complex than what we started with.

1.6.1.2 Problems

1. Lithium and chlorine combine to produce lithium chloride. Identify the type of chemical reaction, and then write the balanced chemical equation.

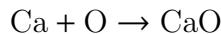
Solution: Lithium has the symbol Li and chlorine has the symbol Cl. Lithium chloride has the chemical formula $\text{Li}^+\text{Cl}^- = \text{LiCl}$. Then, we recognize that the reaction is simply a synthesis reaction, because there are only two elements involved and the chemical reaction forms a compound. Hence, we get



Which is luckily already balanced.

2. Calcium oxide is produced from calcium and oxygen. Identify the type of chemical reaction, and then write the balanced chemical reaction.

Solution: Calcium has the symbol Ca and oxygen has the symbol O. Calcium oxide has the chemical formula $\text{Ca}^{2+}\text{O}^{2-} = \text{Ca}_2\text{O}_2 = \text{CaO}$. Then, we recognize that this is a synthesis reaction, since there are two elements that form a compound. Therefore, our chemical equation is



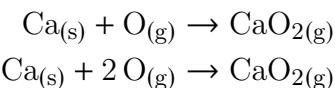
Which is luckily already balanced.

3. Carbon dioxide gas can be formed from two non-metals: solid carbon and oxygen gas. Identify the type of chemical reaction, and then write the balanced chemical reaction, including states.

Solution: Solid carbon has the symbol $\text{C}_{(s)}$ and oxygen gas has the symbol $\text{O}_{(g)}$. Then, carbon dioxide has the chemical formula $\text{Ca}^{4+}\text{O}^{2-} = \text{Ca}_2\text{O}_4 = \text{CaO}_2$.

Note: Carbon could really have an ionic charge of 4+ or 4-; it really depends on the situation. This is of course because carbon has 4 valence electrons. However, in our case, since ionic compounds can only be formed with a cation and anion, we choose carbon to have a charge of 4+.

Then, our chemical equation will become

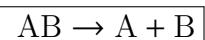


Which we balance.

1.6.2 Decomposition Reaction

Definition: A process in which a compound is broken down into simpler compounds, or all the way down to the elements that make it up. In other words, the opposite of a synthesis reaction.

The general chemical equation is



Where AB is a compound and A and B are simpler compounds or elements.

1.6.2.1 Examples

1. Water is broken down into hydrogen and oxygen



2. However, not all compounds have to be broken down into their basic elements; they can be broken down into simpler compounds instead. For example, calcium carbonate is broken down into carbon dioxide and calcium oxide

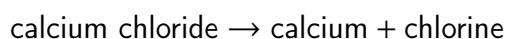


1.6.2.2 Problems

Solid calcium chloride is used to reduce dust on roads and in mines. When calcium chloride is heated to a sufficiently high temperature, it undergoes a chemical reaction that produces solid calcium and chlorine gas. Identify the type of chemical reaction, and then write the balanced chemical equation, including states.

1. Write the word equation for the reaction.

Solution: We know that this is a decomposition reaction since we are beginning with a more complex compound calcium chloride and then breaking it down into calcium and chlorine, separately. Therefore, the answer is simply

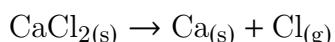


2. Identify the type of chemical reaction from the nature of the reactants and products.

Solution: Once again, this is a decomposition reaction.

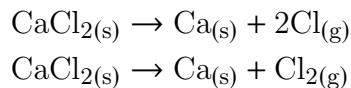
3. Use the word equation to write the skeleton equation.

Solution: Calcium has the symbol $\text{Ca}_{(s)}$ and chlorine has the symbol $\text{Cl}_{(g)}$. Then, calcium chloride has the chemical formula $\text{Ca}^{2+}\text{Cl}^{1-} = \text{CaCl}_2$. Therefore, the skeleton equation is



4. Write the balanced chemical equation for the reaction.

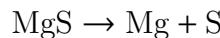
Solution: The balanced skeleton equation is simply



Where either forms work: $2\text{Cl(g)} = \text{Cl}_2\text{(g)}$.

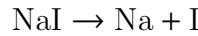
5. During a chemical reaction, magnesium and sulfur are produced from magnesium sulfide. Identify the type of chemical reaction, and then write the balanced chemical equation.

Solution: The type of chemical reaction is simply decomposition. The symbol for magnesium is Mg and the symbol for sulfur is S. The chemical formula for magnesium sulfide is $\text{Mg}^{2+}\text{S}^{2-} = \text{Mg}_2\text{S}_2 = \text{MgS}$. Therefore, the balanced chemical equation will be



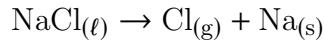
6. When heated, sodium iodide may be broken down into sodium and iodine. Identify the type of chemical reaction, and then write the balanced chemical equation.

Solution: The type of chemical reaction is not combustion but instead still decomposition. The symbol for sodium is Na and the symbol for iodine is I. The chemical formula for sodium iodide is $\text{Na}^{1+}\text{I}^{1-} = \text{NaI}$. Therefore, the balanced chemical equation will be



7. Chlorine gas is used to disinfect water in drinking supplies and pools, and in making plastics, pharmaceuticals, and fertilizers. In the lab, chlorine gas and sodium metal can be produced by passing an electric current through hot, molten, sodium chloride, which is a liquid. Identify the type of chemical reaction, and then write the balanced chemical equation, including states.

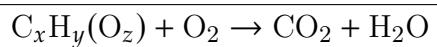
Solution: We are given that chlorine Cl is a gas, sodium Na is a metal and sodium chloride $\text{Cl}^{1-}\text{Na}^{1+} = \text{NaCl}$ (don't forget to write the cation first). Therefore, the balanced chemical equation will be



1.6.3 Combustion Reaction

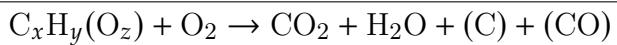
Definition: A process in which a compound containing carbon and hydrogen (and sometimes oxygen) combines with oxygen gas to produce carbon dioxide and water. Combustion is also a fancy word for burning, hence we have carbon dioxide and water.

The general chemical equation for a *complete combustion* is



Where we SOMETIMES have oxygen. Additionally, C_xH_y is a hydrocarbon molecule. We also write C_xH_y in the general chemical equation because there are many different compounds made up of only carbon and hydrogen atoms. The products of hydrocarbon combustion reaction are always carbon dioxide and water.

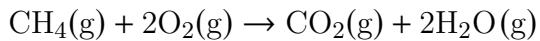
The general chemical equation for an *incomplete combustion* is



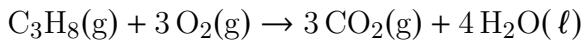
Where C and CO aren't always there.

1.6.3.1 Examples

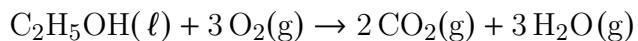
1. Methane $CH_4(g)$ combines with oxygen to form carbon dioxide and water



2. Propane $C_3H_8(g)$ is added with oxygen to form carbon dioxide and water

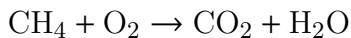


3. Ethanol $C_2H_5OH(\ell)$ is mixed with oxygen to form carbon dioxide and propane

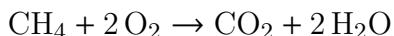


1.6.3.2 Problems

1. Determine the chemical reaction and balance the chemical equation for the following skeleton equation

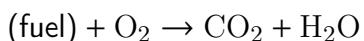


Solution: We can readily see that this is a combustion reaction. Then, the balanced chemical equation is simply

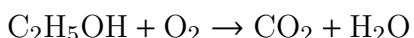


2. Given that the fuel of a combustion reaction is C_2H_5OH , determine the balanced chemical equation.

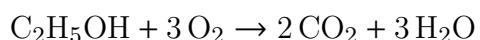
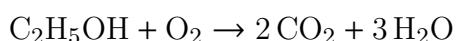
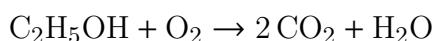
Solution: Another form for a combustion reaction is



And since we know what the fuel is, the skeleton equation is



Then, we can balance this equation

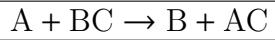


And this chemical equation is balanced.

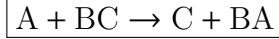
1.6.4 Single Replacement/Displacement Reaction

Definition: A reaction in which one element is substituted for another element in a compound.

The general chemical equation is



For metals switching with metals. For non-metals switching with non-metals:



Note: One thing that should be noted is that when A and C swap places, C is what we call a **diatomic molecule**. “Di-atomic” means consisting of two atoms, meaning that it will have a subscript of 2. Diatomic molecules are usually found in nature. The periodic table below shows elements that are diatomic

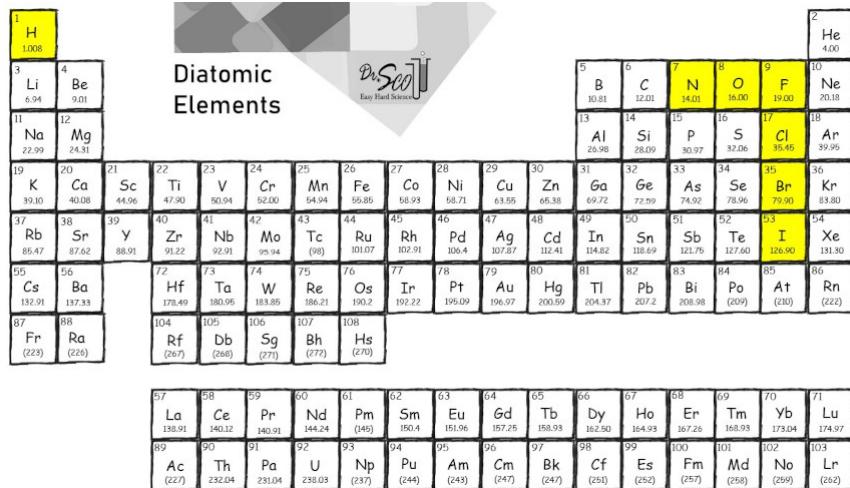
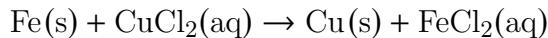


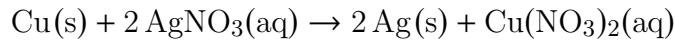
Figure 1.5: The elements in yellow are diatomic

1.6.4.1 Examples

- Iron combines with copper chloride $CuCl_2(aq)$ to make copper and iron chloride $FeCl_2$



- Copper combines with silver nitrate $AgNO_3(aq)$ to make silver and copper nitrate $Cu(NO_3)_2(aq)$



1.6.4.2 Problems

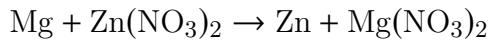
- When magnesium metal and zinc nitrate react, they form zinc and magnesium nitrate. Identify the type of chemical reaction, and then write a balanced chemical equation for the reaction.

Solution: The type of chemical reaction is obviously single replacement/displacement. Before we write the skeleton equation, we have to first determine the chemical formulas for zinc nitrate and magnesium nitrate.

For zinc nitrate, we get $\text{Zn}^{2+}\text{NO}_3^- = \text{Zn}(\text{NO}_3)_2$.

For magnesium nitrate, we have $\text{Mg}^{+2}\text{NO}_3^- = \text{Mg}(\text{NO}_3)_2$.

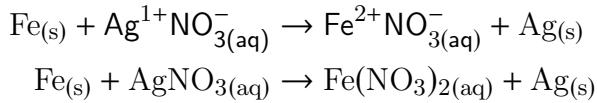
Then, the skeleton equation becomes



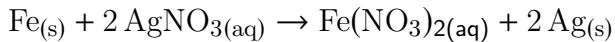
Which is luckily already balanced. We also see that magnesium and zinc, which both have a positive ionic charge, swap places.

- Iron metal is placed into a solution of silver nitrate and allowed to sit. This produces aqueous iron(II) nitrate and solid silver metal. Identify the type of chemical reaction, and then write a balanced chemical equation for the reaction, including states.

Solution: When we do the single displacement, we have to remember to calculate the chemical formulas for the ionic compounds. Therefore, the skeleton equation is



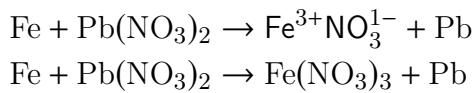
And the balanced chemical equation will be



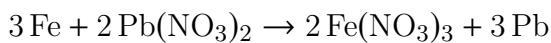
- Predict the products of the following single displacement reaction



Solution: We see that iron and lead are both metals, so those are the ones we will be displacing. This gives us



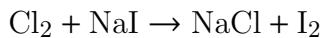
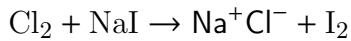
And the balanced chemical equation will simply be



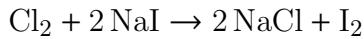
4. Predict the products



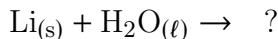
Solution: This is a single displacement reaction between two non-metals. This means that the non-metal that is by itself after the swap will be diatomic. Hence, we get



And upon balancing



5. Predict the product and balance



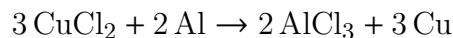
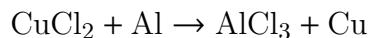
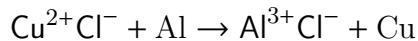
Solution: In order to solve this one, we will have to sort of redefine the definition and be more specific. Instead of swapping metals with metals and non-metals with non-metals, we will instead be swapping positively charged molecules with positively charged molecules and swapping negatively charged molecules with negatively charged molecules.

If we use the latter approach,

6. Predict the products, balance, and classify



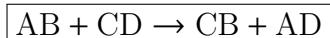
Solution: This is a single displacement reaction. The skeleton equation and balanced chemical equation will be



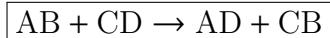
1.6.5 Double Replacement/Displacement Reaction

Definition: A reaction in which the positive and negative ions in two compounds switch places.

The general chemical equations are



For the cations switching



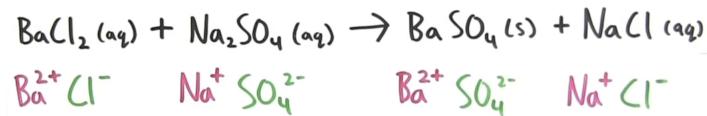
For the anions switching. For most cases, you will view cations as metals and anions as non-metals.

Note: In order for a double displacement reaction to occur, there must be the formation of either products: **water, a precipitate, or a gas**.

A precipitate is a solid formed from the reaction of two solutions (aqueous). We consider a precipitate to be an insoluble compound, meaning it can't be melted.

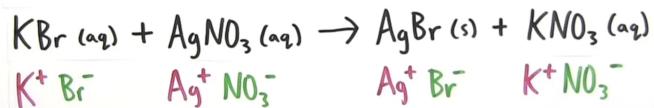
1.6.5.1 Examples

1. We begin with $\text{BaCl}_2(\text{aq})$ and $\text{Na}_2\text{SO}_4(\text{aq})$ together and the Cl and SO_4^{2-} just simply switch places



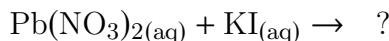
And we can see that the cations and the anions switched (alignment is messed up).

2. And for this example, "the image speaks for itself" - Hans Niemann

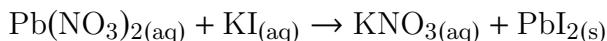


1.6.5.2 Problems

1. Predict the product of



Solution: We will be swapping lead and potassium since they are the cations



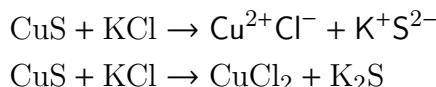
Lead(II) nitrate and potassium iodide are colourless solutions. They react to form potassium nitrate (also colourless solution) and lead(II) iodide. Lead(II) iodide precipitates out of solution and is a yellow solid; so it is very obvious when the reaction happens.

2. Predict the products of the following

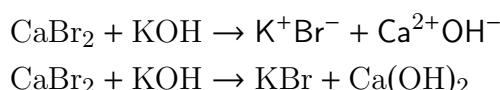
- (a) $\text{CuS} + \text{KCl} \rightarrow ?$
- (b) $\text{CaBr}_2 + \text{KOH} \rightarrow ?$
- (c) $\text{Ca}(\text{OH})_2 + \text{H}_3\text{PO}_4 \rightarrow ?$

Solutions:

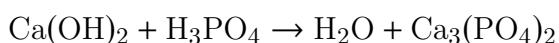
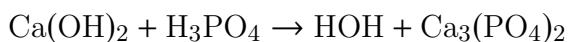
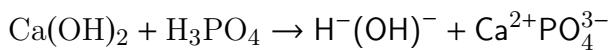
- (a) Copper is multivalent, but it has a higher tendency to form as a $2+$ ion. Then, copper and potassium will switch



- (b) Calcium and potassium are metals/cations. Therefore, they will swap



- (c) This kind of double displacement reaction is actually known as a **Neutralization Reaction**. This type of double displacement reaction only occurs when the product contains water and some kind of salt. In this case, will will swap calcium with hydrogen, since hydrogen is a cation and calcium is also a cation

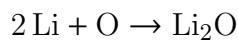
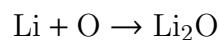
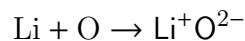


Where H_2O is water and $\text{Ca}_3(\text{PO}_4)_2$ is a kind of salt.

1.6.6 Chemical Reactions Problems

- When lithium metal and oxygen gas react, solid lithium oxide is produced. Identify the type of chemical reaction, and then write the balanced chemical reaction.

Solution: This is a synthesis reaction. The balanced chemical equation will be



- When a log burns in a fireplace, as shown in the photograph below, the hydrocarbons in the log combine with oxygen gas in the air, producing ashes and gases.

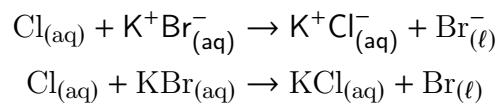
- What two gases are produced?

- The ashes weigh much less than the log that was burned. Does that mean that this combustion reaction does not follow the law of conservation of mass? Explain.

Solutions:

- In a combustion reaction, according to the general formula, the product is H_2O and CO_2 . Therefore, the two gases that will be produced will be carbon gas and oxygen gas (I think).
 - The ashes weighing less than the log doesn't mean that this combustion reaction does not follow the law of conservation of mass. The reason for this is because as per the general chemical formula for combustion reaction, there is oxygen and water produced. Therefore, the mass is not lost, and is instead preserved into those forms.
- When aqueous chlorine reacts with aqueous potassium bromide, aqueous potassium chloride and liquid bromine are produced. Identify the type of chemical reaction, and then write the balanced chemical equation, including states.

Solution: This is a single displacement reaction. The balanced chemical equation will be

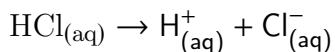


And everything is already balanced.

1.7 Acids and Bases

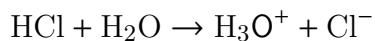
1.7.1 Arrhenius Acids and Bases

Definition 1.6. Arrhenius Acid (1) An arrhenius acid is any species that increases the concentration of H^+ in aqueous solution.



We can see that it decomposed into a H^+ proton.

(2) A substance that produces H^+ when dissolved in water.



We can see that it decomposed into a H_3O^+ compound (see note below).

Remark.

Definition (1) and (2) are both valid; in order to arrive at (2), you must do (1), and thus both are valid.

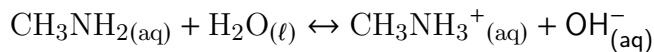
Remark.

Using the first definition of an arrhenius acid, we create the postulate that every compound that starts first with hydrogen H is an arrhenius acid. This is because it can always be decomposed into an $\text{H}_{(\text{aq})}^+$ proton. If the compound were to end with hydrogen, then it is not arrhenius, since it will be decomposed into a $\text{H}_{(\text{aq})}^-$ electron.

Definition 1.7. Arrhenius Base (1) An arrhenius base is any species that increases the concentration of OH^- in aqueous solution.



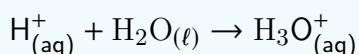
(2) A substance that produces OH^- when dissolved in water.



Note:

 Regarding arrhenius acids/bases

- In aqueous solutions, H^+ ions immediately react with water molecules to form hydronium ions, H_3O^+ . The reaction can be written as follows

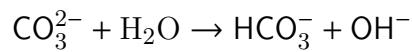


Where the hydrogen (proton) is combining with the water to form hydronium.

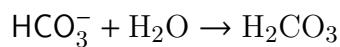
- In an acid-base or neutralization reaction, an arrhenius acid and base usually react to form water and salt:



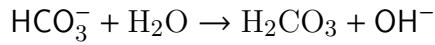
Carbonate salts can also form basic solutions. Adding water to carbonate gives



There is an increase in hydroxide OH^- so it forms a basic solution. If we had say hydrogen carbonate instead of pure carbonate ion instead



And if it is hydrogen carbonate instead



Properties of Acids and Bases

Acids	Bases
- Conducts electricity - Tastes sour - Neutralizes bases	- Conducts electricity - Tastes bitter - Neutralizes acids
Commonly Found in	
- Preservatives - Stomache - Citrus fruits - Soda	- Cleaning agents - Antacids - Baking soda

Table 1.7.1

Litmus Test

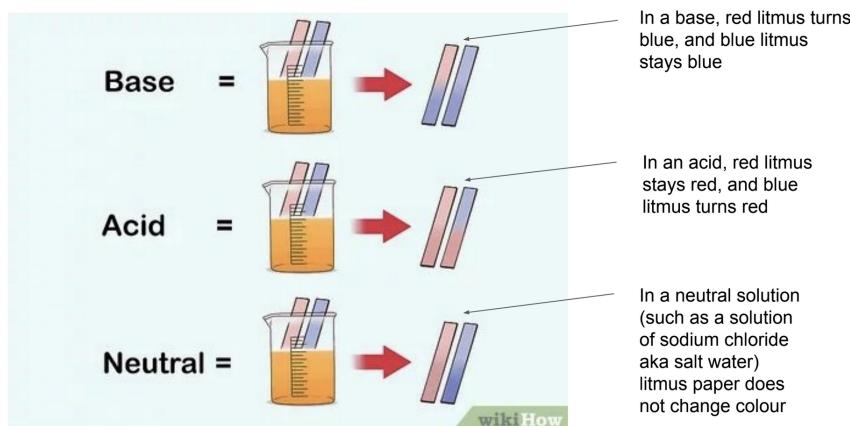


Figure 1.6: litmus test's are used to determine acidity

1.7.2 Naming Acids and Bases

The naming of acids are broken into two different kinds: **Common Binary Acid** (element anion) and (polyatomic anion) **Common Oxyacid**.

Note (Common Binary Acid): These acids all begin with the word "hydro", followed by the anion's name ending with "ic". Additionally, all of these acids are aqueous.

Common Binary Acids

Chemical Formula	Acid Name
$\text{HF}_{(\text{aq})}$	Hydrofluoric acid
$\text{HCl}_{(\text{aq})}$	Hydrochloric acid
$\text{HBr}_{(\text{aq})}$	Hydrobromic acid
$\text{HI}_{(\text{aq})}$	Hydroiodic acid
$\text{H}_2\text{S}_{(\text{aq})}$	Hydrosulfuric acid

Common Oxyacids

Chemical Formula	Acid Name
$\text{CH}_3\text{COOH}_{(\text{aq})}$	Acetic acid
$\text{H}_2\text{CO}_3_{(\text{aq})}$	Carbonic acid
$\text{HNO}_3_{(\text{aq})}$	Nitric acid
$\text{H}_3\text{PO}_4_{(\text{aq})}$	Phosphoric acid
$\text{H}_2\text{SO}_4_{(\text{aq})}$	Sulfuric acid

To name a base, simply write the first element's name and then write "hydroxide" after it.

Common Bases

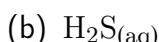
Chemical Formula	Name	Alternate Name
$\text{NaOH}_{(\text{aq})}$	Sodium hydroxide	Lye or caustic soda
$\text{LiOH}_{(\text{aq})}$	Lithium hydroxide	
$\text{KOH}_{(\text{aq})}$	Potassium hydroxide	Caustic potash
$\text{Ca}(\text{OH})$	Calcium hydroxide	Slaked lime
$\text{Mg}(\text{OH})_2$	Magnesium hydroxide	Milk of magnesia
$\text{Al}(\text{OH})_3$	Aluminum hydroxide	
NaHCO_3	Sodium hydrogen carbonate	Baking soda

1.7.2.1 Problems

1. Name the following and categorize each as an acid or a base:



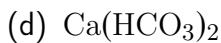
Solution. We write $\text{H}_3\text{PO}_4_{(\text{aq})} = \text{H}^+\text{PO}_4^{3-}_{(\text{aq})}$. This decomposes into H^+ and PO_4^{3-} , and there will be a concentration increase of H^+ . Therefore, this is an arrhenius acid.



Solution. This is an arrhenius acid.



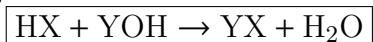
Solution. This decomposes into NH_4^+ and OH^- , so there is an increase in OH^- and therefore this is an arrhenius base.



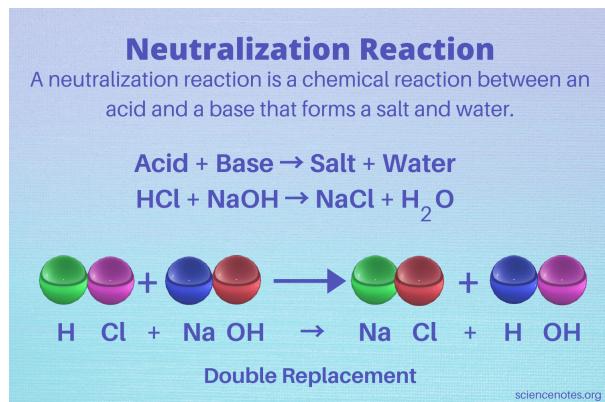
Solution. This is carbon hydrogen carbonate, which is a special case (I think) of an arrhenius base.

1.7.3 Neutralization Reaction

Definition 1.8. Neutralization Reaction A neutralization reaction can be defined as a chemical reaction in which an *acid* and *base* quantitatively react together to form a salt and water compound. In a neutralization, there is a combination of H^+ ions and OH^- ions which form water. The general formula is



Where we use X and Y instead of A and B . An example of a neutralization reaction is demonstrated below

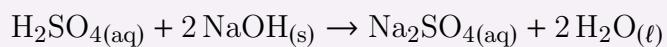


Remark.

The salts formed may be soluble or insoluble. If a salt is insoluble, a precipitate will form.

Example.

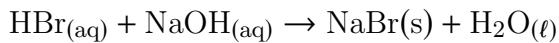
1. Sulfuric acid mixes with sodium hydroxide (base)



1.7.3.1 Problems

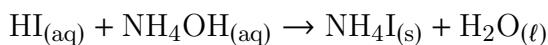
- Predict and balance the chemical equation for Hydrobromic Acid + Sodium Hydroxide.

Solution. Hydrobromic Acid = $\text{HBr}_{(\text{aq})}$ and Sodium Hydroxide = $\text{NaOH}_{(\text{aq})}$. Since this is a neutralization reaction, the balanced chemical equation is



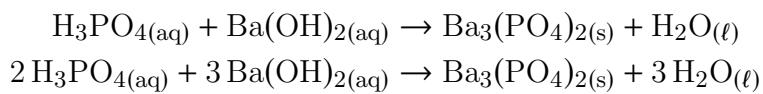
- Predict and balance the chemical equation for $\text{HI}_{(\text{aq})} + \text{NH}_4\text{OH}_{(\text{aq})}$.

Solution. Swap iodine with hydroxide so that you form a salt and water



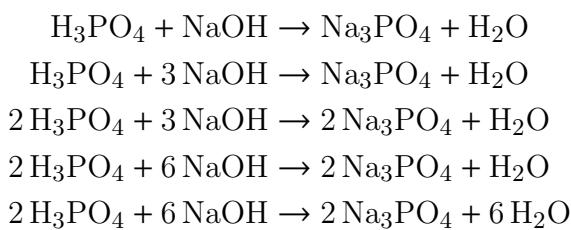
- Predict and balance the chemical equation for Phosphoric Acid + Barium Hydroxide.

Solution. Phosphoric Acid = $\text{H}_3\text{PO}_4_{(\text{aq})}$ and Barium Hydroxide = $\text{Ba}(\text{OH})_2_{(\text{aq})}$. The balanced chemical equation is



- Predict and balance the equation when phosphoric acid is mixed with sodium hydroxide.

Solution. Phosphoric acid is $\text{H}^+\text{PO}_4^{3-} = \text{H}_3\text{PO}_4$ and sodium hydroxide is NaOH . The balanced chemical equation is



1.8 pH - Potential Hydrogen

Definition 1.9. Potential Hydrogen pH Potential hydrogen, or Power of Hydrogen (pH), is a scale used to specify the acidity or basicity of an aqueous solution. The lower the pH, the more acidic.

Note (pH scale and range): The pH scale is logarithmic. **pH of 7 is neutral.**

The change in pH is logarithmic, so for every n difference in pH value, the difference between the acidity is 10^n .

Example. Substance A has a pH of 13.2. Substance B has a pH of 8.5.

- Which substance is more acidic?
- Which solution is more basic?
- How many times did the concentration change from substance A to substance B?

Solution.

- Substance B
- Substance A
- $10^{13.2-8.5} \approx 50\,119$ times more

1.8.1 Phenolphthalein

Definition 1.10. Phenolphthalein Phenolphthalein is a pH indicator with the chemical formula $C_{20}H_{14}O_4$. It is colourless in acidic solutions and pink in basic solutions.

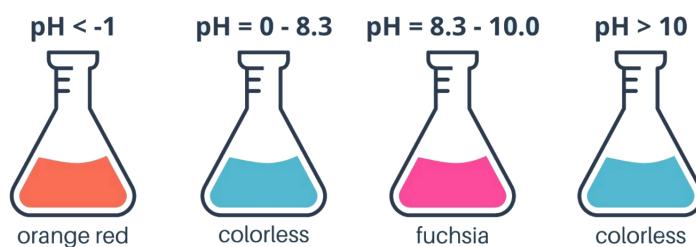


Figure 1.7: Very acidic, acidic, little above basic, above basic

1.8.2 pH in Agriculture

Plants are sensitive to the pH of soil.

1. Legumes grows well in slightly basic pH (7-10)
2. Corn grows well in mildly acidic soil (5-6)
3. Potatoes grow well in acidic soil ($\text{pH} < 5$)

1.8.3 Acid Leaching

Definition 1.11. Acid Leaching Acid leaching is the process of adding acids to soil that has been highly contaminated with base metals. Phytoremediation is the process of using plants to absorb metal toxins.

Example.

1. Sunflowers absorb toxic metals and radioactive elements.
2. Aspen trees remove lead from water.

1.8.4 pH in Consumer Products

Cleaning products can either be very acidic or basic

pH in consumer products

Product	pH
Bleach	11-13
Oven cleaner	11-13
Windex	9
Dish soap	7-8
Toilet bowl cleaner	1-3
Battery acid	0-1

1.8.5 pH in Swimming Pools

- pH of swimming pools should range from 7.2-7.8
- 7.4 pH is the sweet spot of swimming pools
- If $\text{pH} < 7$, pool water will irritate eyes

- If $\text{pH} > 8$, pool water becomes cloudy and chlorine compound will lose its disinfecting ability

Pool pH test kits are used to monitor pH

- Add $\text{HCl}_{(\text{aq})}$ (muriatic acid) to reduce pool pH
- Add $\text{Na}_2\text{CO}_{3(\text{aq})}$ to increase pool pH

1.8.6 Acid Deposition

Definition 1.12. Acid Deposition The mix of air pollutants and water that leads to acidification of soil and water systems.

Remark.

Rainwater is naturally acidic, with a pH of 5.6, due to a presence of dissolved CO_2 to form $\text{H}_2\text{CO}_{3(\text{aq})}$.