Grade 10 Science Notes

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March 30, 2023

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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).

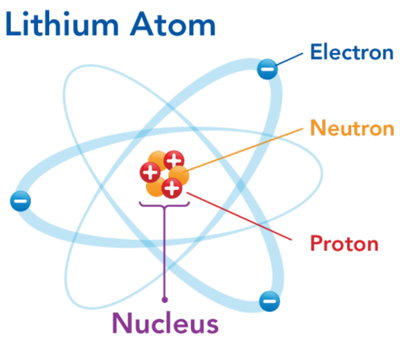


Figure 1.1: a 3d image of an atom

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 ± 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 eleemnt fits into a certain class of element.

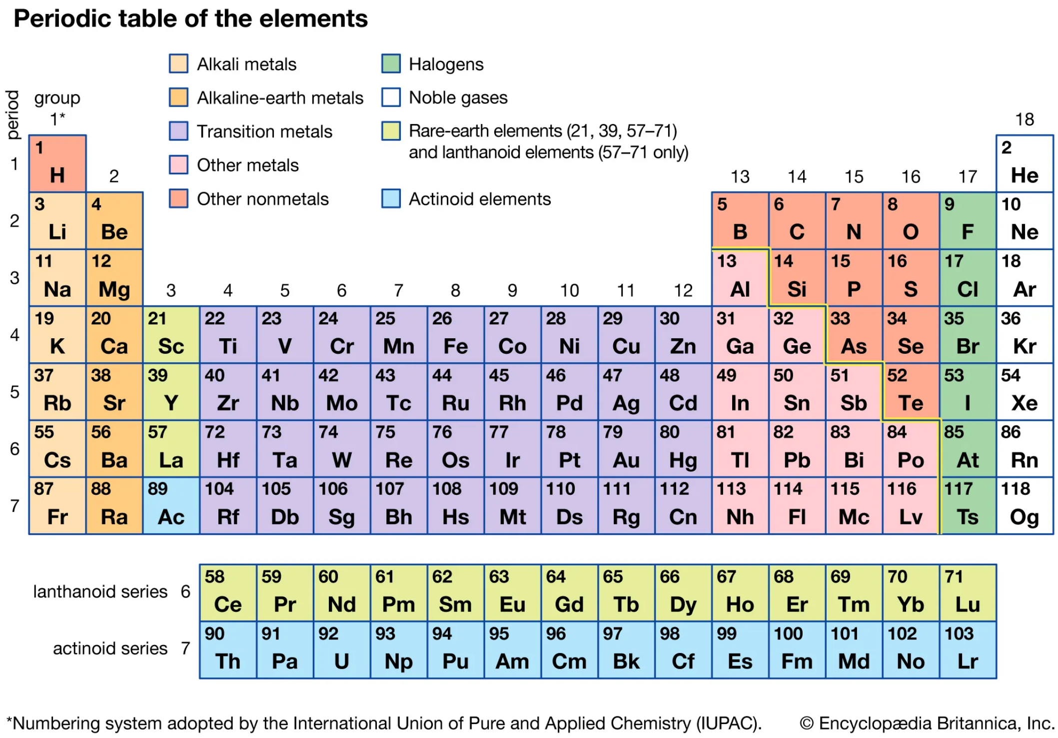
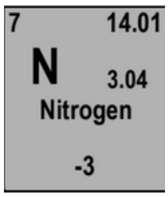


Figure 1.2: the periodic table

- **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



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 eleemnt "'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

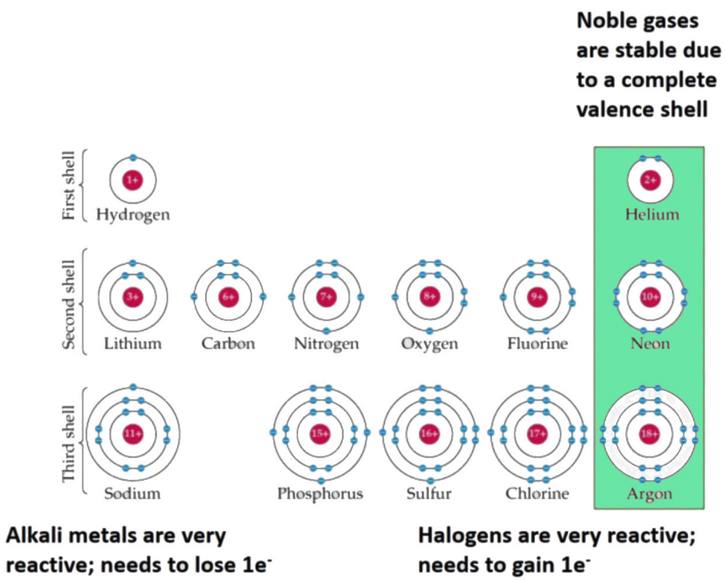
Some patterns and trends in the periodic table are listed below:

- Atomic number steadily increases accross the periodic table.
- In the periodic table, in period 6 and period 7, you can see how there are lanthanides and actinide which are the last two periods in the peridic 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
- Akali 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.

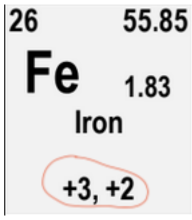


Figure 1.3: circled in red shows the $3+$ and $2+$ charge

> **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 parantheses 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

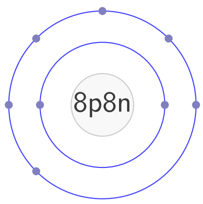
Definition 1.1. Bohr-Rutherford Diagrams Bohr-Rutherford diagrams are visual demonstrations of an atom with its electron shells and the nucleus.

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.

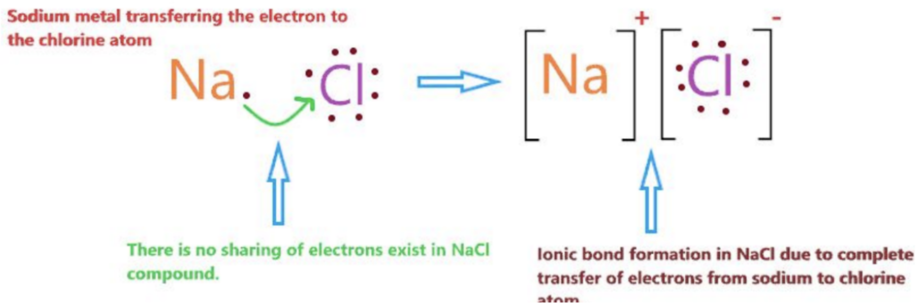


Figure 1.4: example of an ionic compound

1.4.1 Physical Properties of Ionic Compounds

Some physical properties are:

- High melting and boiling points.
- Low volatility/non-volatile.
- Generally soluable 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_2O	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) Fe_2O_3
   (b) Cu_2S
   (c) FeN

   Solutions:

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

   $$Fe_2O_3 = Fe^{3+}O^{2-}$$

   Therefore our answer is iron(III) oxide.

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

   $$Cu_2S = Cu^{1+}S^{2-}$$

   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 $\mathrm{Fe}^{+}\mathrm{N}^{-}$, 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

$$\begin{aligned} FeN &= Fe_3N_3 \\ &= \mathrm{Fe}^{3+}\mathrm{N}^{3+} \end{aligned}$$

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) $(NH_4)_3PO_4$

   (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

$$\begin{aligned} PbCO_3 &= Pb_2(CO_3)_2 \\ &= \mathrm{Pb}^{2+}\mathrm{CO3}_3^{2-} \end{aligned}$$

   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:

$$:\underset{\cdot}{\overset{\cdot\cdot}{\text{Cl}}}:$$

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

$$:\overset{\cdot\cdot}{\text{Si}}$$

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

$$:\text{Ca}$$

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

$$\left[\,:\underset{\cdot\cdot}{\overset{\cdot\cdot}{\text{Mg}}}:\,\right]^{2+}$$

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

$$\left[\,:\underset{\cdot\cdot}{\overset{\cdot\cdot}{\text{O}}}:\,\right]^{2-}$$

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 $\mathrm{TiO_2}$.

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

$$\mathsf{Ca}^{2+}\mathsf{Cl}^{1-} = \mathrm{Ca_1Cl_2} = \mathrm{CaCl_2}$$

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

$$\mathsf{H}^{1-}\mathsf{O}^{2-} = \mathrm{H_2O_1} = \mathrm{H_2O}$$

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

$$\mathsf{B}^{3+}\mathsf{N}^{3-} = \mathrm{B_3N_3} = \mathrm{BN}$$

   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 soluable 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_2^-. Using the criss-cross method

$$P^{3-}NO_2^- \rightarrow P(NO_2)_3$$

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

$$Ca^{2+}SO_4^{2-} \longrightarrow Ca_2(SO_4)_2$$

2. Write the chemical formula for calcium chlorate.

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

$$Ca^{2+}ClO_3^- \longrightarrow Ca(ClO_3)_2$$

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

$$Fe^{3+}PO_4^{3-} \longrightarrow Fe_3(PO_4)_3$$

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

$$\boxed{\mathrm{A + B \rightarrow AB}}$$

Where A and B are arbitrary "materials".

1.6.1.1 Examples

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

   $$\mathrm{C(s) + O_2(g) \rightarrow CO_2(g)}$$

   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

   $$\mathrm{2\,Na(s) + Cl_2(g) \rightarrow 2\,NaCl(s)}$$

   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 $Li^+Cl^- = \mathrm{LiCl}$. 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

   $$\mathrm{Li} + \mathrm{Cl} \longrightarrow \mathrm{LiCl}$$

   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 $Ca^{2+}O^{2-} = \mathrm{Ca_2O_2} = \mathrm{CaO}$. Then, we recognize that this is a synthesis reaction, since there are two elements that form a compound. Therefore, our chemical equation is

   $$\mathrm{Ca} + \mathrm{O} \longrightarrow \mathrm{CaO}$$

   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 $C_{(s)}$ and oxygen gas has the symbol $O_{(g)}$. Then, carbon dioxide has the chemical formula $Ca^{4+}O^{2-} = \mathrm{Ca_2O_4} = \mathrm{CaO_2}$.

   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

   $$\mathrm{Ca_{(s)}} + \mathrm{O_{(g)}} \longrightarrow \mathrm{CaO_{2(g)}}$$
   $$\mathrm{Ca_{(s)}} + 2\,\mathrm{O_{(g)}} \longrightarrow \mathrm{CaO_{2(g)}}$$

   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

$$\boxed{\mathrm{AB} \rightarrow \mathrm{A} + \mathrm{B}}$$

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

$$2\,\mathrm{H_2O}(\ell) \rightarrow 2\,\mathrm{H_2(g)} + \mathrm{O_2(g)}$$

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

$$\mathrm{CaCO_3(s)} \rightarrow \mathrm{CaO\,(s)} + \mathrm{CO_2(g)}$$

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

   calcium chloride → calcium + chlorine

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 $\mathrm{Ca_{(s)}}$ and chlorine has the symbol $\mathrm{Cl_{(g)}}$. Then, calcium chloride has the chemical formula $\mathrm{Ca^{2+}Cl^{1-}} = \mathrm{CaCl_2}$. Therefore, the skeleton equation is

$$\mathrm{CaCl_{2(s)}} \rightarrow \mathrm{Ca_{(s)}} + \mathrm{Cl_{(g)}}$$

4. Write the balanced chemical equation for the reaction.

   Solution: The balanced skeleton equation is simply

$$\mathrm{CaCl}_{2(\mathrm{s})} \longrightarrow \mathrm{Ca}_{(\mathrm{s})} + 2\mathrm{Cl}_{(\mathrm{g})}$$
$$\mathrm{CaCl}_{2(\mathrm{s})} \longrightarrow \mathrm{Ca}_{(\mathrm{s})} + \mathrm{Cl}_{2(\mathrm{g})}$$

   Where either forms work: $2\,\mathrm{Cl}_{(\mathrm{g})} = \mathrm{Cl}_{2(\mathrm{g})}$.

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 $\mathrm{Mg}^{2+}\mathrm{S}^{2-} = \mathrm{Mg}_2\mathrm{S}_2 = \mathrm{MgS}$. Therefore, the balanced chemical equation will be

$$\mathrm{MgS} \longrightarrow \mathrm{Mg} + \mathrm{S}$$

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 $\mathrm{Na}^{1+}\mathrm{I}^{1-} = \mathrm{NaI}$. Therefore, the balanced chemical equation will be

$$\mathrm{NaI} \longrightarrow \mathrm{Na} + \mathrm{I}$$

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 $\mathrm{Cl}^{1-}\mathrm{Na}^{1+} = \mathrm{NaCl}$ (don't forget to write the cation first). Therefore, the balanced chemical equation will be

$$\mathrm{NaCl}_{(\ell)} \longrightarrow \mathrm{Cl}_{(\mathrm{g})} + \mathrm{Na}_{(\mathrm{s})}$$

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

$$\boxed{C_xH_y(O_z) + O_2 \longrightarrow CO_2 + H_2O}$$

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

$$\boxed{C_xH_y(O_z) + O_2 \longrightarrow CO_2 + H_2O + (C) + (CO)}$$

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
$$CH_4(g) + 2O_2(g) \longrightarrow CO_2(g) + 2H_2O\,(g)$$
2. Propane $C_3H_8(g)$ is added with oxygen to form carbon dioxide and water
$$C_3H_8(g) + 3\,O_2(g) \longrightarrow 3\,CO_2(g) + 4\,H_2O(\ell)$$
3. Ethanol $C_2H_5OH(\ell)$ is mixed with oxygen to form carbon dioxide and propane
$$C_2H_5OH(\ell) + 3\,O_2(g) \longrightarrow 2\,CO_2(g) + 3\,H_2O\,(g)$$

1.6.3.2 Problems

1. Determine the chemical reaction and balance the chemical equation for the following skeleton equation
$$CH_4 + O_2 \longrightarrow CO_2 + H_2O$$
Solution: We can readily see that this is a combustion reaction. Then, the balanced chemical equation is simply
$$CH_4 + 2\,O_2 \longrightarrow CO_2 + 2\,H_2O$$
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
$$\text{(fuel)} + O_2 \longrightarrow CO_2 + H_2O$$
And since we know what the fuel is, the skeleton equation is
$$C_2H_5OH + O_2 \longrightarrow CO_2 + H_2O$$
Then, we can balance this equation
$$\begin{aligned} C_2H_5OH + O_2 &\longrightarrow 2\,CO_2 + H_2O \\ C_2H_5OH + O_2 &\longrightarrow 2\,CO_2 + 3\,H_2O \\ C_2H_5OH + 3\,O_2 &\longrightarrow 2\,CO_2 + 3\,H_2O \end{aligned}$$
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

$$\boxed{\mathrm{A + BC \longrightarrow B + AC}}$$

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

$$\boxed{\mathrm{A + BC \longrightarrow C + BA}}$$

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

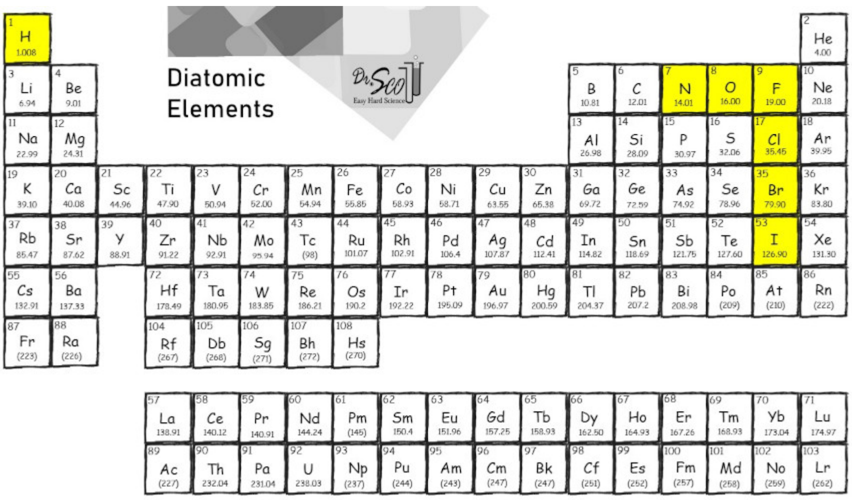


Figure 1.5: The elements in yellow are diatomic

1.6.4.1 Examples

1. Iron combines with copper chloride $\mathrm{CuCl_2(aq)}$ to make copper and iron chloride $\mathrm{FeCl_2}$

$$\mathrm{Fe(s) + CuCl_2(aq) \longrightarrow Cu(s) + FeCl_2(aq)}$$

2. Copper combines with silver nitrate $\mathrm{AgNO_3(aq)}$ to make silver and copper nitrate $\mathrm{Cu(NO_3)_2}(aq)$

$$\mathrm{Cu(s) + 2\,AgNO_3(aq) \longrightarrow 2\,Ag(s) + Cu(NO_3)_2(aq)}$$

1.6.4.2 Problems

1. 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 $Zn^{2+}NO_3^- = Zn(NO_3)_2$.

   For magnesium nitrate, we have $Mg^{+2}NO_3^- = Mg(NO_3)_2$.

   Then, the skeleton equation becomes

   $$Mg + Zn(NO_3)_2 \longrightarrow Zn + Mg(NO_3)_2$$

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

2. Iron metal is placed into a solution of silver nitrate and allowed to sit. This produces aqeuous 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

   $$Fe_{(s)} + Ag^{1+}NO^-_{3(aq)} \longrightarrow Fe^{2+}NO^-_{3(aq)} + Ag_{(s)}$$
   $$Fe_{(s)} + AgNO_{3(aq)} \longrightarrow Fe(NO_3)_{2(aq)} + Ag_{(s)}$$

   And the balanced chemical equation will be

   $$Fe_{(s)} + 2\,AgNO_{3(aq)} \longrightarrow Fe(NO_3)_{2(aq)} + 2\,Ag_{(s)}$$

3. Predict the products of the following single displacement reaction

   $$Fe + Pb(NO_3)_2 \longrightarrow \quad ?$$

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

   $$Fe + Pb(NO_3)_2 \longrightarrow Fe^{3+}NO_3^{1-} + Pb$$
   $$Fe + Pb(NO_3)_2 \longrightarrow Fe(NO_3)_3 + Pb$$

   And the balanced chemical equation will simply be

   $$3\,Fe + 2\,Pb(NO_3)_2 \longrightarrow 2\,Fe(NO_3)_3 + 3\,Pb$$

4. Predict the products

$$\mathrm{Cl_2 + NaI \rightarrow \quad ?}$$

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

$$\mathrm{Cl_2 + NaI \rightarrow Na^{+}Cl^{-} + I_2}$$
$$\mathrm{Cl_2 + NaI \rightarrow NaCl + I_2}$$

And upon balancing

$$\mathrm{Cl_2 + 2\,NaI \rightarrow 2\,NaCl + I_2}$$

5. Predict the product and balance

$$\mathrm{Li_{(s)} + H_2O_{(\ell)} \rightarrow \quad ?}$$

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 postively charged molecules and swapping negatively charged molecules with negatively charged molecules.

If we use the latter approach,

6. Predict the products, balance, and classify

$$\mathrm{Copper(II)\,Chloride + Aluminum \rightarrow \quad ?}$$

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

$$\mathrm{Cu^{2+}Cl^{-} + Al \rightarrow Al^{3+}Cl^{-} + Cu}$$
$$\mathrm{CuCl_2 + Al \rightarrow AlCl_3 + Cu}$$
$$\mathrm{3\,CuCl_2 + 2\,Al \rightarrow 2\,AlCl_3 + 3\,Cu}$$

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

$$\boxed{\mathrm{AB + CD \rightarrow CB + AD}}$$

For the cations switching

$$\boxed{\mathrm{AB + CD \rightarrow AD + CB}}$$

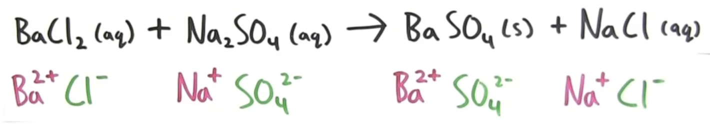
For the anions switching. For most cases, you will view cations as metals and anions as non-metals.

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 (aqeuous). We consider a precipitate to be an insoluble compound, meaning it can't be melted.

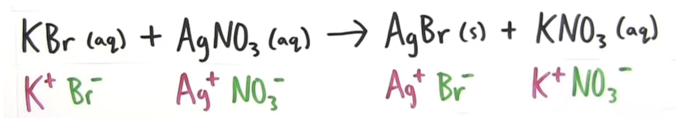
1.6.5.1 Examples

1. We begin with $\mathrm{BaCl_2(aq)}$ and $\mathrm{Na_2SO_4(aq)}$ together and the Cl and $\mathrm{SO_4}$ 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
$$\mathrm{Pb(NO_3)_{2(aq)}} + \mathrm{KI_{(aq)}} \longrightarrow \quad ?$$
   Solution: We will be swapping lead and potassium since they are the cations
$$\mathrm{Pb(NO_3)_{2(aq)}} + \mathrm{KI_{(aq)}} \longrightarrow \mathrm{KNO_{3(aq)}} + \mathrm{PbI_{2(s)}}$$
   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) $\mathrm{CuS} + \mathrm{KCl} \longrightarrow \quad ?$
   (b) $\mathrm{CaBr_2} + \mathrm{KOH} \longrightarrow \quad ?$
   (c) $\mathrm{Ca(OH)_2} + \mathrm{H_3PO_4} \longrightarrow \quad ?$

   Solutions:

   (a) Copper is multivalent, but it has a higher tendency to form as a $2+$ ion. Then, copper and potassium will switch
$$\mathrm{CuS} + \mathrm{KCl} \longrightarrow \mathsf{Cu^{2+}Cl^{-}} + \mathsf{K^{+}S^{2-}}$$
$$\mathrm{CuS} + \mathrm{KCl} \longrightarrow \mathrm{CuCl_2} + \mathrm{K_2S}$$

   (b) Calcium and potassium are metals/cations. Therefore, they will swap
$$\mathrm{CaBr_2} + \mathrm{KOH} \longrightarrow \mathsf{K^{+}Br^{-}} + \mathsf{Ca^{2+}OH^{-}}$$
$$\mathrm{CaBr_2} + \mathrm{KOH} \longrightarrow \mathrm{KBr} + \mathrm{Ca(OH)_2}$$

(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

$$\begin{aligned}
Ca(OH)_2 + H_3PO_4 &\rightarrow \mathsf{H^-(OH)^- + Ca^{2+}PO_4^{3-}} \\
Ca(OH)_2 + H_3PO_4 &\rightarrow HOH + Ca_3(PO_4)_2 \\
Ca(OH)_2 + H_3PO_4 &\rightarrow H_2O + Ca_3(PO_4)_2
\end{aligned}$$

Where H_2O is water and $Ca_3(PO_4)_2$ is a kind of salt.

1.6.6 Chemical Reactions Problems

1. 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

$$\begin{aligned}
Li + O &\rightarrow \mathsf{Li^+O^{2-}} \\
Li + O &\rightarrow Li_2O \\
2\,Li + O &\rightarrow Li_2O
\end{aligned}$$

2. 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.

   (a) What two gases are produced?

   (b) 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:

   (a) 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).

   (b) The ashes weighing less than the log doesn't mean that this combustion reactio 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.

3. When aqeuous chlorine reacts with aqeuous potassium bromide, aqeuous 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

$$\mathrm{Cl}_{(\mathrm{aq})} + \mathsf{K}^+\mathsf{Br}^-_{\mathsf{(aq)}} \longrightarrow \mathsf{K}^+\mathsf{Cl}^-_{\mathsf{(aq)}} + \mathrm{Br}^-_{(\ell)}$$
$$\mathrm{Cl}_{(\mathrm{aq})} + \mathrm{KBr}_{(\mathrm{aq})} \longrightarrow \mathrm{KCl}_{(\mathrm{aq})} + \mathrm{Br}_{(\ell)}$$

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 aqeuous solution.

$$\mathrm{HCl}_{(aq)} \longrightarrow \mathrm{H}^+_{(aq)} + \mathrm{Cl}^-_{(aq)}$$

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

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

$$\mathrm{HCl} + \mathrm{H_2O} \longrightarrow \mathrm{H_3O^+} + \mathrm{Cl^-}$$

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 $H^+_{(aq)}$ proton. If the compound were to end with hydrogen, then it is not arrhenius, since it will be decomposed into a $H^-_{(aq)}$ electron.

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

$$\mathrm{NaOH}_{(aq)} \longrightarrow \mathrm{Na}^+_{(aq)} + \mathrm{OH}^-_{(aq)}$$

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

$$\mathrm{CH_3NH_2}_{(aq)} + \mathrm{H_2O}_{(\ell)} \leftrightarrow \mathrm{CH_3NH_3}^+{}_{(aq)} + \mathrm{OH}^-_{(aq)}$$

Note: Regarding arrhenius acids/bases

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

$$\mathrm{H}^+_{(aq)} + \mathrm{H_2O}_{(\ell)} \longrightarrow \mathrm{H_3O}^+_{(aq)}$$

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:

$$\text{arrhenius acid} + \text{arrhenius base} = \text{water} + \text{salt}$$

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

$$CO_3^{2-} + H_2O \longrightarrow HCO_3^- + OH^-$$

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

$$HCO_3^- + H_2O \longrightarrow H_2CO_3$$

And if it is hydrogen carbonate instead

$$HCO_3^- + H_2O \longrightarrow H_2CO_3 + OH^-$$

Properties of Acids and Bases

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

Table 1.7.1

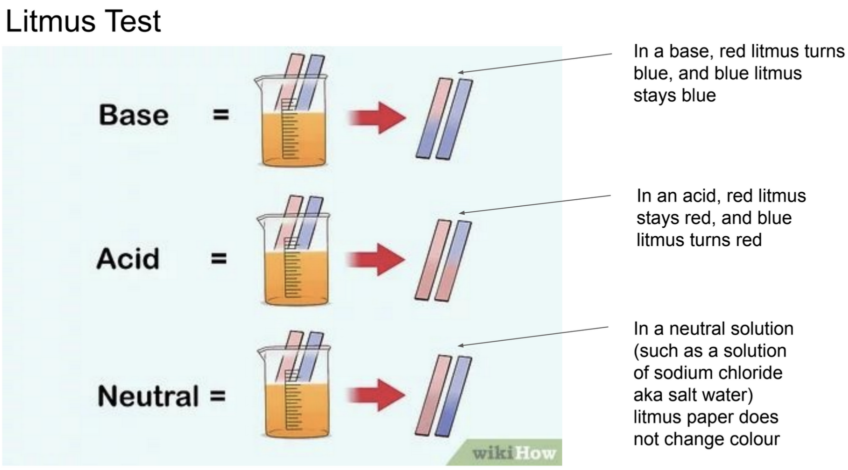


Figure 1.6: litmus test's are used to determine acidity

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 aqeuous.

Common Binary Acids

Chemical Formula	Acid Name
$HF_{(aq)}$	Hydrofluoric acid
$HCl_{(aq)}$	Hydrochloric acid
$HBr_{(aq)}$	Hydrobromic acid
$HI_{(aq)}$	Hydroiodidic acid
$H_2S_{(aq)}$	Hydrosulfuric acid

Common Oxyacids

Chemical Formula	Acid Name
$CH_3COOH_{(aq)}$	Acetic acid
$H_2CO_{3(aq)}$	Carbonic acid
$HNO_{3(aq)}$	Nitric acid
$H_3PO_{4(aq)}$	Phosphoric acid
$H_2SO_{4(aq)}$	Sulfuric acid

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

Common Bases

Chemical Formula	Name	Alternate Name
$NaOH_{(aq)}$	Sodium hydroxide	Lye or caustic soda
$LiOH_{(aq)}$	Lithium hydroxide	
$KOH_{(aq)}$	Potassium hydroxide	Caustic potash
$Ca(OH)$	Calcium hydroxide	Slaked lime
$Mg(OH)_2$	Magnesium hydroxide	Milk of mangesia
$Al(OH)_3$	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:

   (a) $H_3PO_{4(aq)}$

   > **Solution.** We write $H_3PO_{4(aq)}$ = $H^+PO_4{}^{3-}{}_{(aq)}$. This decomposes into H^+ and PO_4^{3-}, and there will be a concentration increase of H^+. Therefore, this is an arrhenius acid.

   (b) $H_2S_{(aq)}$

   > **Solution.** This is an arrhenius acid.

   (c) $NH_4OH_{(aq)}$

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

(d) $Ca(HCO_3)_2$

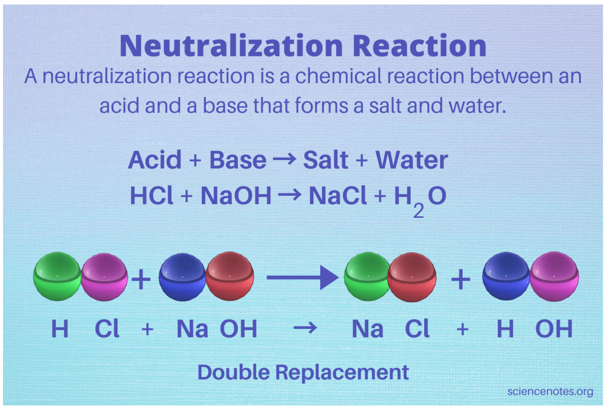
Solution. This is carbon hydrogen carbonate, which is a special case (I think) of an arrhenius base.

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

$$\boxed{\mathrm{HX + YOH \longrightarrow YX + H_2O}}$$

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)

$$\mathrm{H_2SO_{4(aq)} + 2\,NaOH_{(s)} \longrightarrow Na_2SO_{4(aq)} + 2\,H_2O_{(\ell)}}$$

1.7.3.1 Problems

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

   Solution. Hydrobromic Acid = $HBr_{(aq)}$ and Sodium Hydroxide = $NaOH_{(aq)}$. Since this is a neutralization reaction, the balanced chemcial equation is

   $$HBr_{(aq)} + NaOH_{(aq)} \longrightarrow NaBr(s) + H_2O_{(\ell)}$$

2. Predict and balance the chemical eqauation for $HI_{(aq)} + NH_4OH_{(aq)}$.

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

   $$HI_{(aq)} + NH_4OH_{(aq)} \longrightarrow NH_4I_{(s)} + H_2O_{(\ell)}$$

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

   Solution. Phosphoric Acid = $H_3PO_{4(aq)}$ and Barium Hydroxide = $Ba(OH)_{2(aq)}$. The balanced chemical equation is

   $$H_3PO_{4(aq)} + Ba(OH)_{2(aq)} \longrightarrow Ba_3(PO_4)_{2(s)} + H_2O_{(\ell)}$$
   $$2\,H_3PO_{4(aq)} + 3\,Ba(OH)_{2(aq)} \longrightarrow Ba_3(PO_4)_{2(s)} + 3\,H_2O_{(\ell)}$$

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

   Solution. Phosphoric acid is $H^+PO_4^{3-}$ = H_3PO_4 and sodium hydroxide is $NaOH$. The balanced chemical equation is

   $$H_3PO_4 + NaOH \longrightarrow Na_3PO_4 + H_2O$$
   $$H_3PO_4 + 3\,NaOH \longrightarrow Na_3PO_4 + H_2O$$
   $$2\,H_3PO_4 + 3\,NaOH \longrightarrow 2\,Na_3PO_4 + H_2O$$
   $$2\,H_3PO_4 + 6\,NaOH \longrightarrow 2\,Na_3PO_4 + H_2O$$
   $$2\,H_3PO_4 + 6\,NaOH \longrightarrow 2\,Na_3PO_4 + 6\,H_2O$$

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 aqeuous 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.

(a) Which substance is more acidic?

(b) Which solution is more basic?

(c) How many times did the concentration change from substance A to substance B?

Solution.

(a) Substance B

(b) Substance A

(c) $10^{13.2-8.5} \approx 50\,119$ times more

1.8.1 Phenolphthalein

Definition 1.10. Phenolpthalein 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.

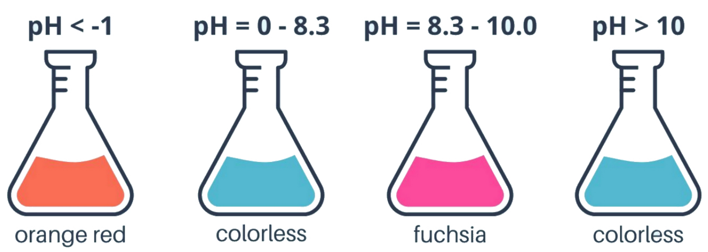


Figure 1.7: Very acidic, acidic, little above basic, above basic

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 (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 pH < 7, pool water will irritate eyes

- If pH > 8, pool water becomes cloudy and chlorine compound will lose its disenfecting ability

Pool pH test kits are used to monitor pH

- Add $HCl_{(aq)}$ (muriatic acid) to reduce pool pH
- Add $Na_2CO_{2(aq)}$ 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 prescence of dissolved CO_2 to form $H_2CO_{3(aq)}$.

CHAPTER 2

Biology

2.1 Cell Theory

Definition 2.1 (Cell Theory). The cell theory states

1. All living things are made of one or more cell.
2. The cell is the simplest unit that can carry out all life processes.
3. All cells come from pre-existing cells.

Additionally:

- Cells have not been synthesized in labs yet.
- Appeared 3.8 billion years ago.
- Hydrothermal vents created electrical gradient to form first organic molecules such as amino acids and nucleuotides.
- First cell is presumed to be self-replication RNA enclosed by phospholipids.

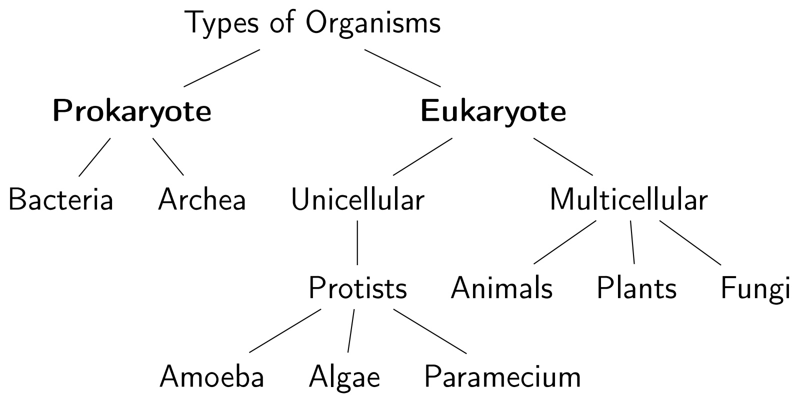
Figure 2.1: Robert Hooke invented the simple microscope to look at thin pieces of cork tree. Classical cell theory was proposed by Schwann, Schleiden, and Virchow.

2.2 Prokaryote and Eukaryote

Organisms are divided into two types: prokaryote and eukaryote.

> **Definition 2.2** (Prokaryote)**.** Organisms that have cells which contain **no nucleus**.

> **Definition 2.3** (Eukaryote)**.** Organisms that have cells which contain **a nucleus**. These fit under either **unicellular** or **multicellular**, meaning one nucleus and more than one nucleus, respectively.



2.3 Organelles

Definition 2.4 (Organelles)**.** An organelle is a small structure in a cell that is surrounded by a membrane and has a specific function.

Basically, that organelles act like the organs in your body but instead it is for the cell. There are many different organelles, varying for plants and animals.

2.3.1 Cell Membrane

Definition 2.5 (Cell Membrane)**.** The cell membrane is like the outer wall of the cell. It is semi-permeable, meaning it allows only certain substances/materials through. See Figure 2.2.

The cell membrane is made of a double layer of lipids. A lipid is a fat-like molecule that does not dissolve in water.

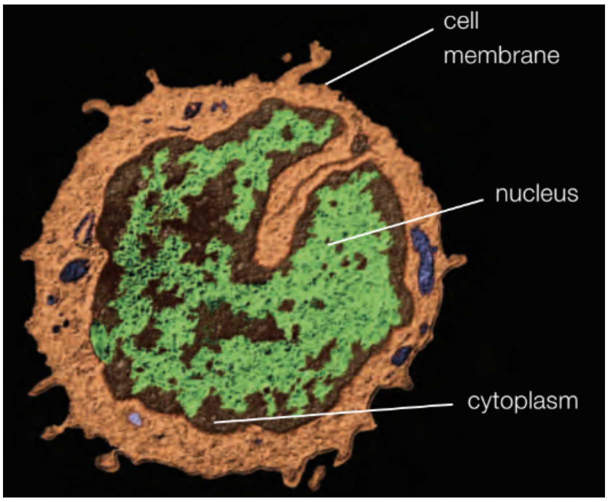


Figure 2.2: A cell showing the cell membrane, cytoplasm, and large nucleus.

2.3.2 Cytoplasm

Definition 2.6 (Cytoplasm)**.** The cytoplasm is a gel-like substance that fills the cell and surrounds organelles. Cytoplasm contains the nutrients required by the cell to carry on its life purposes. See Figure 2.2.

All organelles are suspended in cytoplasm. The physical nature of the cytoplasm allows the nutrients and organelles to move within the cell.

2.3.3 Nucleus

Definition 2.7 (Nucleus). The nucleus is the control center of the cell. It controls all activities in the cell, including growth and reproduction. One important thing is that it contains nearly all of the cell's DNA. See Figure 2.3.

Note: DNA stands for deoxyribonucleic acid. DNA is very important to the cell because it contains the coded information for making protesins and other molecules. Proteins servec many purposes and are found in various locations of the cell.

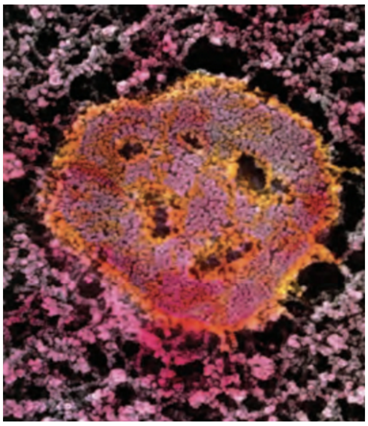


Figure 2.3: The nucleus and chromatin in a human cell, as seen through an electron microscope.

2.3.4 Vesicles

Definition 2.8 (Vesicles). Vesicles are membrane-bound organelles that store nutrients, waste, and other substances used by the cell. Vesicles can fuse with the cell membrane.

2.3.5 Vacuoles

Definition 2.9 (Vacuoles). Vacuoles are basically vesicles but bigger and do not fuse with the cell membrae. You can think of them as the storage system. See Figure 2.4./

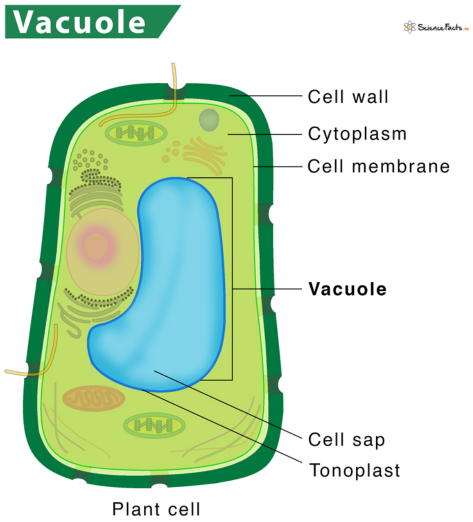


Figure 2.4: A vacuole inside of a plant. You can tell it is inside of a plant because a plant only has ONE large vacuole.

2.3.6 Mitochondria

Definition 2.10 (Mitochondria)**.** The powerhouse of the cell. The mitochondria supplies the cell with energy by converting the chemical energy within sugar into energy that the cell can use. See Figure 2.5.

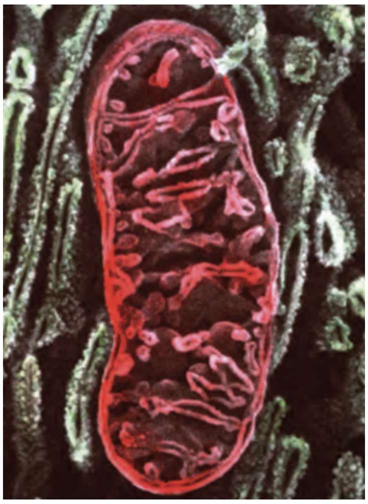


Figure 2.5: A mitochondrion, as seen through an electron micoroscope.

2.3.7 Lysosomes

Definition 2.11 (Lysosomes)**.** Lysosomes are organelles where digestion takes place. They are small organelles that are filled with enzymes. Lysosomes also break down invading bacteria and damaged cell organelles. See Figure 2.6.

Essentially, they work as the clean-up system in the cell.

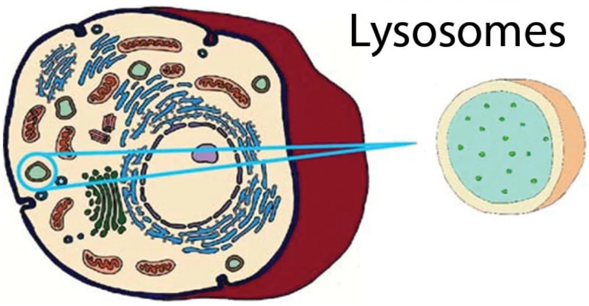


Figure 2.6: Lysosomes

Note (Enzyme): An enzyme is a protein that can speed up chemical reactions in the cell.

2.3.8 Rough Endoplasmic Reticulum

Definition 2.12 (Rough Endoplasmic Reticulum). The rough endoplasmic reticulum is like a conveyor belt for proteins and nutrients that are destined for the nucleus. The rough endoplasmic reticulum is studded with ribosomes which allows it to easily transport proteins once they are made. You can think of the rough endoplasmic reticulum as an organelle that synthesizes proteins. See Figure 2.7.

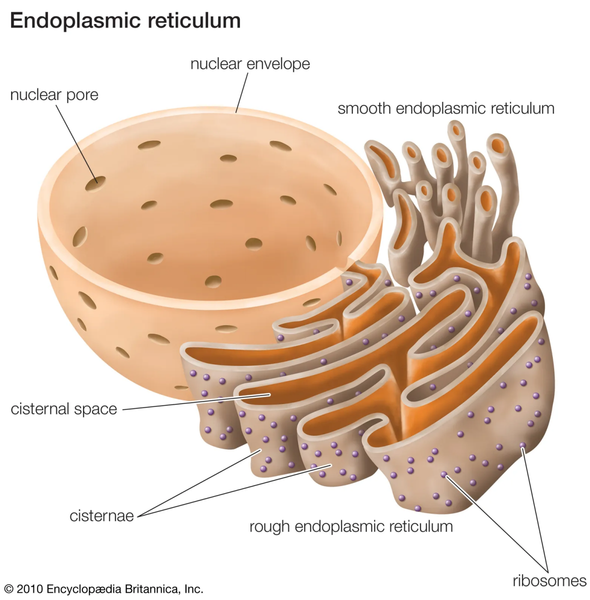


Figure 2.7: The rough and smooth endoplasmic reticulums.

2.3.9 Smooth Endoplasmic Reticulum

Definition 2.13 (Smooth Endoplasmic Reticulum)**.** Similar to the smooth endoplasmic reticulum, except that it lacks ribosomes and is involved in lipid metabolism, including the synthesis of phospholipids, steroids, and other lipids. See Figure 2.7.

Note (Lipid): Lipid is another word for "fat".

Basically, the rough endoplasmic reticulum is involved in protein synthesis and processing, whereas the smooth endoplasmic reticulum is involved in lipid metabolism and detoxification. The main difference is the prescence of ribosomes in both cases.

2.3.10 Ribosomes

Definition 2.14 (Ribosomes)**.** Ribosomes are small, dense-looking organelles that may be attached to the rough endoplasmic reticulum or free in the cytoplasm. Ribosomes are the sites where the proteins are assembled.

2.3.11 Golgi Body/Apparatus

Definition 2.15 (Golgi Body/Apparatus)**.** The golgi body receives proteins from the endoplasmic reticulum and processes them for removal from the cell. They modify, sort, and package these proteins for delivery throughout the cell or outside of the cell. The golgi body looks like a stack of flattened membranes (see Figure 2.8).

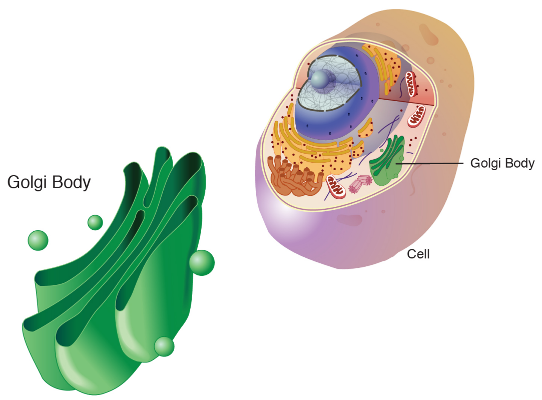


Figure 2.8: Golgi body.

2.3.12 Cytoskeleton

Definition 2.16 (Cytoskeleton). The cytoskeleton gives structure to the cell and is made of protein filaments.

2.3.13 Chloroplast

Definition 2.17 (Chloroplast). Chloroplasts are only found in plants cells and some algae. Contains a pigment called chlorophyll that absorbs light and energy to undergo photosynthesis

$$6\,\mathrm{CO_2} + 6\,\mathrm{H_2O} + \text{light} \longrightarrow \mathrm{C_6H_{12}O_6} + 6\,\mathrm{O_2}$$

Note (Thylakoids): Chloroplasts are made of little sacs called **thylakoids**. A stack of thylakoids is called a **granum**. You can think of the thylakoids as solar panels.

2.4 Histology

> **Definition 2.18** (Histology). A branch of study that concerns the study of biological tissues using a microscope.

Thin slices are placed on microscope slides to be visualized underneath a microscope. Specimens stained with various data types and chemicals to visualize organelles.

2.5 Asexual vs Sexual

2.5.1 Asexual

> **Definition 2.19** (Asexual)**.** Producing from only one parent. Exact same genes/DNA of the parent cell.

Advantages:

- Only need one parent.
- Very efficient; not many resources are required to initiate asexual reproduction.
- Happens very quicktly.

Disadvantages:

- Decreases overall genetic resilience of the population.
- In turn there will be issues with diseases wiping out the entire population. This is because if there is say ebola, then it will whipe out everyone, since everyone is the same. If it kills one person, it will kill everyone too.

2.5.2 Sexual

> **Definition 2.20** (Sexual)**.** Producing offspring by fusion of two gametes (egg and sperm). Offspring will have genetic material from both parents and newer cells will be created threw mitosis.

Advantages:

- Genetic variability of the population will be high.
- As a result, the population will be more resilient in the face of pathogens.
- For example, some people weren't affected at all by the bubonic plague because they had a slight variance in their genetics that made them immune to the disease.

Disadvantages:

- Two parents are required; slower than asexual reproduction.
- Time and energy are required to find a suitable mate for reproduction.
- Not every individual in the population gets to reproduce. Example: fat and obese people have a lower chance to reproduce than muscular people.
- Genetically heritable conditions can be passed down. Example: diabetes.

2.6 The Cell Cycle

Definition 2.21 (Cell Cycle). In your body, cells are constantly dying and being replenished. During much of the cell cycle, the cell prepares for **cell division**. The three stages are:

1. Interphase
2. Mitosis
3. Cytokinesis

See Figure 2.9.

Cell division occurs for the purpose of reproduction. There are two types, namely **asexual** and **sexual**.

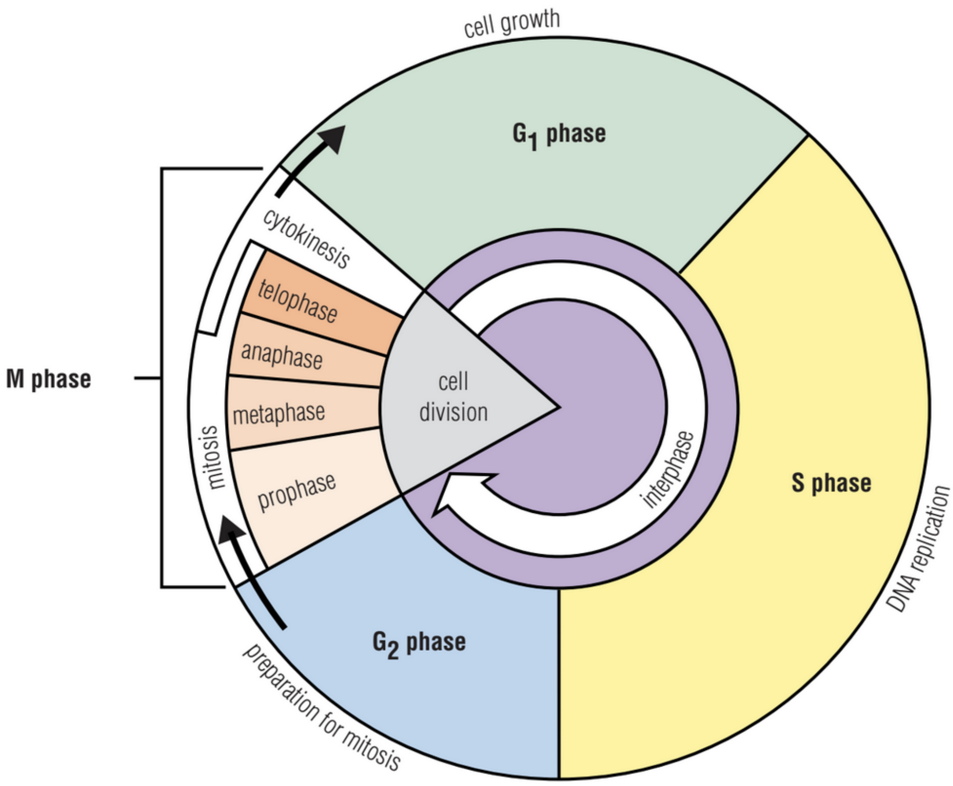


Figure 2.9: The cell cycle has four phases. During most of the cell cycle, the cell is growing, replicating its DNA, and preparing for cell division.

2.6.1 Cell Division

Definition 2.22 (Cell Division). Cell division is the process by which a single cell divides into two or more daughter cells. This process is essential for the growth and maintenance of all living organisms.

One method of cell division is known as **mitosis** (see Section 2.6.4).

Cell division allows organisms to **grow**.

- Nutrients move through diffusion (high concentration to low concentration).
- Water enters and leaves the cell through osmosis (high concentration to low concentration).
- Cells need to divide to ensure a high surface area to maximize diffusion of nutrients/waste and osmosis of water.
- We need lots of cells that will cover a greater surface area because it speeds up the process of diffusion.

Cell division allows organisms to **repair**.

- Organisms need to repair cells from damage or old age.

Repair Rate for Cells

Cell Type	Turnover Time
Stomache	2-4 days
Skin	10-30 days
Red blood cells	4 months
Liver cells	6-12 months
Brain cells	Life time

- Stages of skin regeneration:
  - New skin cells.
  - Coming to surface.
  - Degeneration process.
  - Dead skin cells.

2.6.2 Chromosomes

Definition 2.23 (Chromosomes). Each chromosome is a long piece of DNA and protein. They carry genetic information in the form of genes. The number of chromosomes between each organism varies. Chromosomes are only visible when the cell is dividing. See Figure 2.10.

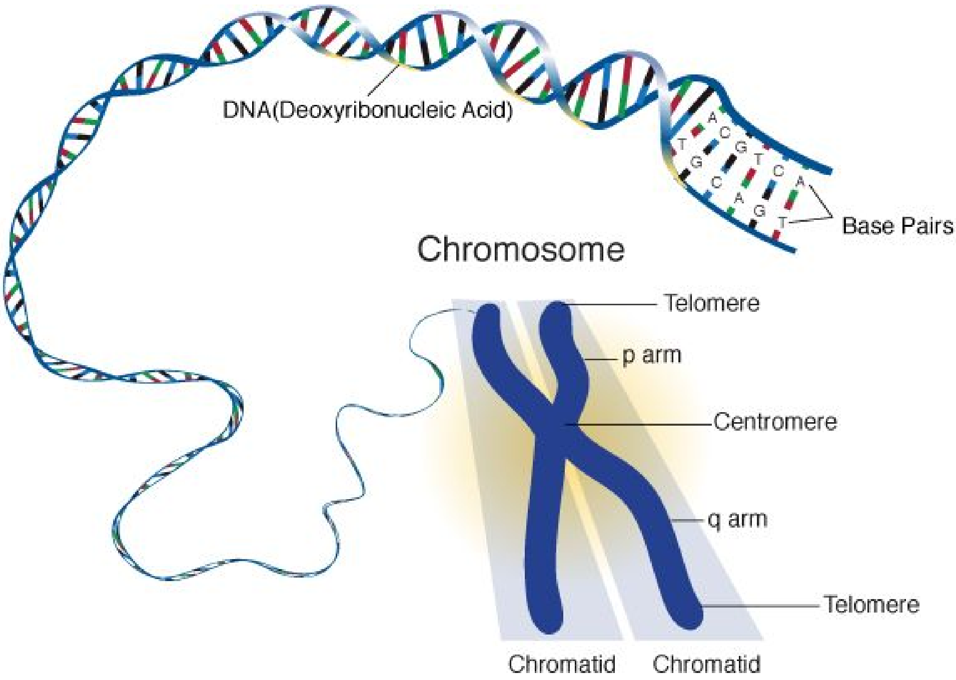


Figure 2.10: Chromosomes.

Before cell division can occur, each chromosome is copied, as shown in Figure 2.11. The chromosome consists of two identical copies, can **sister chromatids**. When the cell divides, one chromatid goes to each of the new cells.

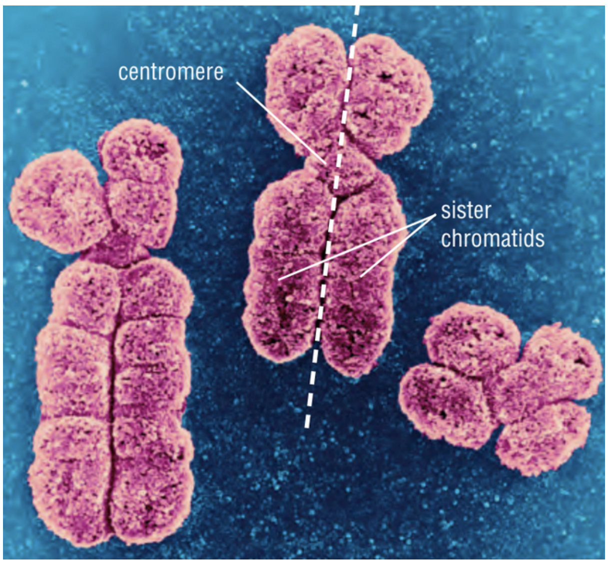


Figure 2.11: Each chromosome consists of two identical sister chromatids. The **centromere** is where the sister chromatids attach.

2.6.3 Interphase

> **Definition 2.24** (Interphase). The cell spends the most time in interphase. This phase refers to a period where the cell carries out its regular cell functions. This stage prepares

the cell for **mitosis**. There are three phases (in the particular order):

1. **G1 Phase**: the cell grows in size and carries out normal metabolic processes.
2. **S Phase**: DNA replication, resulting in the formation of two identical copies of the cell's genetic material.
3. **G2 Phase**: organelles are duplicated. The cell undergoes further growth and prepares for division by synthesizing proteins necessary for mitosis. See Figure 2.12.

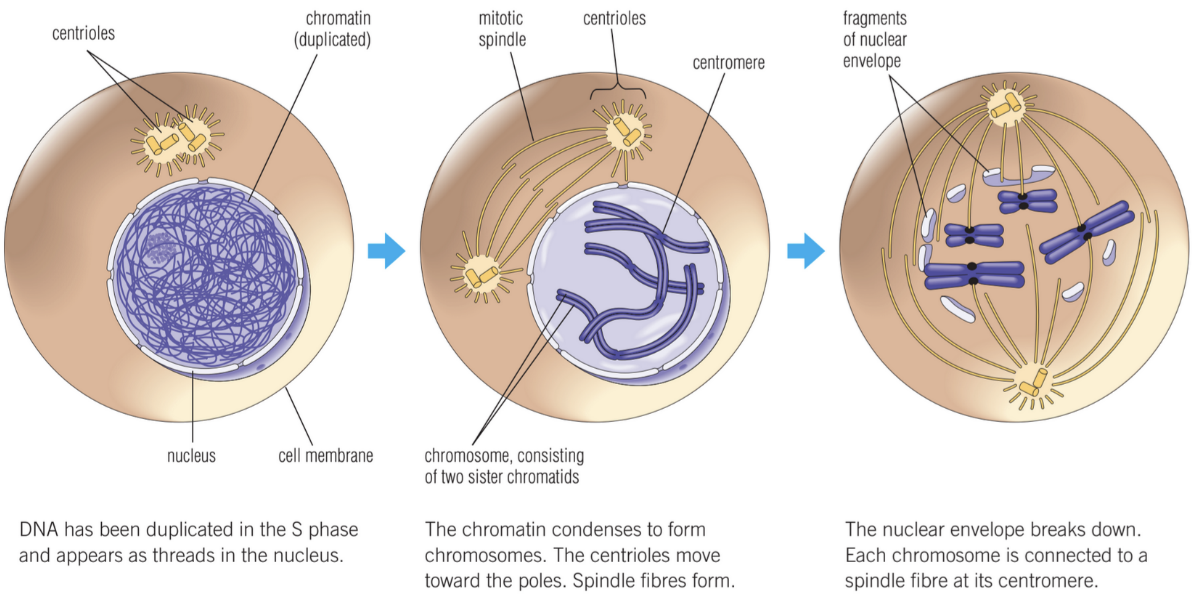


Figure 2.12: S phase and G2 phase.

Note: The cell grows until it reaches a certain size, at which it is healthier for the cell to undergo cell division.

2.6.4 Mitosis

Definition 2.25 (Mitosis). Mitosis is the stage in which DNA in the nucleus is divided. There are 4 stages of mitosis:

1. **Prophase**: the chromosomes shorten and thicken.
2. **Metaphase**: chromosomes line up in the middle of the cell.
3. **Anaphase**: chromatids break apart at the centromere and move to opposite poles.
4. **Telophase**: two nuclei formed after nuclear envelopes reform around each group of chromosomes.

See Figure 2.13.

2.6.5 Cytokinesis

Definition 2.26 (Cytokinesis). Cytokinesis is the final stage of the cell cycle, where the cytoplasm is split and two daughter cells are formed. In an animal cell, this is done through the pinching of the membrane (cleavage furrow). In a plant cell, this is done through the formation of a cell plate.

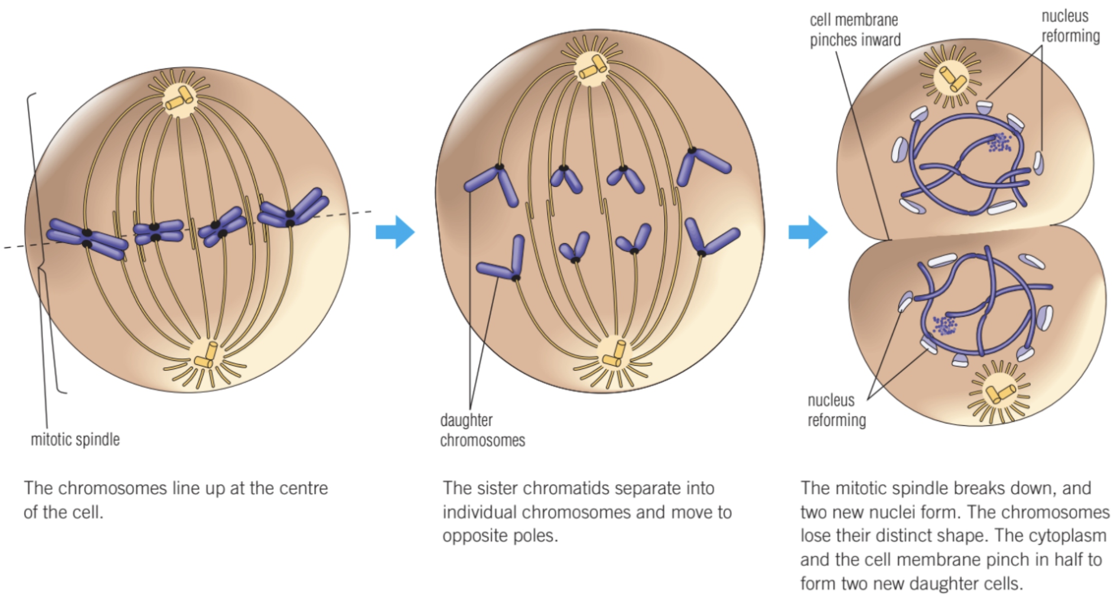


Figure 2.13: Prophase then metaphase, anaphase, and telophase then cytokinesis.

2.7 Questions

1. What is the purpose of the cell cycle?

   Solution.

   - Sustain the processes for cell division to occur.
   - Cell growth; duplication of DNA and duplication of organelles.
   - Maintain regular cell function.

2. Define the term "interphase" and describe its purpose.

   Solution. It refers to the period of time in which the cell carries out its regular cell functions. The purpose of interphase is to get the cell ready to divide (growth of the cell, duplication of the cell, duplication of DNA, duplication of organelles).

3. (a) What is mitosis?

   Solution. This is when a single parent cell divides into two new daughter cells. The parent cells and daughter cells have the same DNA.

   (b) Why is mitosis important to the cell?

   Solution. **Cell reproduction**; making new cells. **Growth**; optimization of cell surface area to cell volume ratio. High surface area to volume ratio is important. A high surface area to volume ratio maintains that nutrients can enter the cell efficiently and that waste can leave the cell efficiently.

4. Define and distinguish between the following terms: chromosomes, centromere, and sister chromatids.

   Solution.

   - **Chromosome**:
     - Genetic material.
     - Coiled version of cellular DNA called chromatin)
     - Comprised of sister chromatids.
   - **Sister chromatids**:
     - Identical copies of DNA which are part of the chromosomes.
     - Attached at the center with a centromere during prophase and metaphase.
     - The sister chromatids are separated in mitosis during anaphase.
   - **Centromere:**
     - Holds the sister chromatids together during prophase and metaphase.
     - 2 sister chromatids attached by a centromere rom the chromosome.

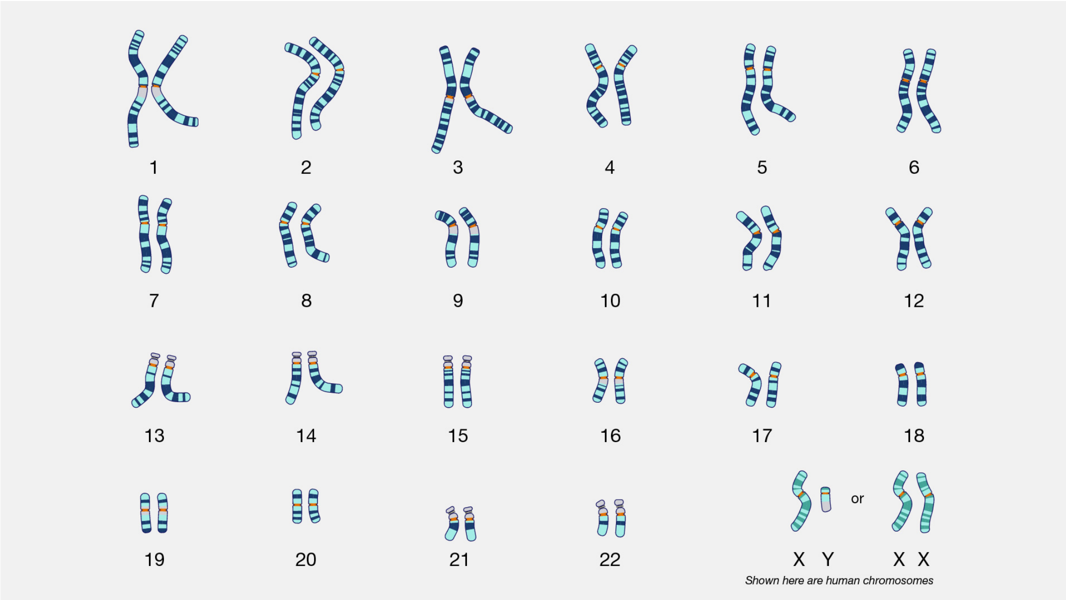


Figure 2.14: Karyotypes. In the bottom right, we see that there is XY or XX. The reason for this is because the one on the right (XY chromosome) is the male chromosome, and the one on the left (XX chromosome) is the female chromosome.

5. Explain the meaning of cytokinesis.

Solution. Happens after telephase. Is defined as the splitting/division of the cytoplasm. In an animal cell, this is done through the pinching of the membrane (we call this a cleavage furrow). In a plant cell, this is done through the formation of the cell plate.

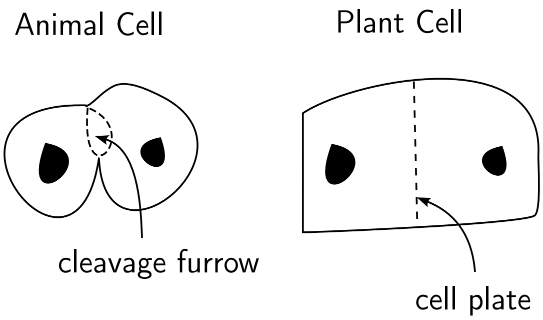


Figure 2.15: Animal Cell vs Plant Cell

2.8 Healthy Cell Checkpoints

Definition 2.27 (Healthy Cell Checkpoints). A cell will not divide if

- Signals from surrounding cells tell the cell not to divide.
- Not enough nutrients for cell growth.
- DNA has not been replicated.
- DNA is damaged.

Cell can undergo programmed cell death (apoptosis).

2.9 Cancer

Definition 2.28 (Cancer). This is a group of diseases in which cells grow and divides uncontrollably. See Figure 2.16.

This is caused by mutations to the DNA within cells which can allow rapidgrowth, fail to stop uncontrolled cell growth, or make errors when correcting DNA. Mutations are inherited or caused by environmental factors (i.e. radiation, viruses, carcinogens, etc.).

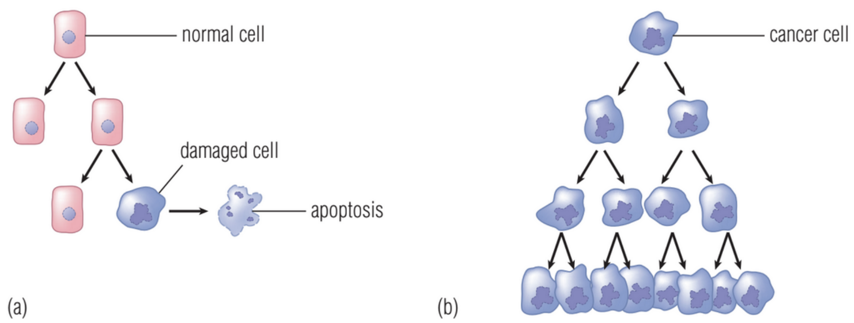


Figure 2.16: (a) Cell division and cell death in normal cells. (b) Cell division in cancer cells.

2.9.1 Stages of Cancer

Stage 0: cancer cells remain in place to form a mass cells called a tumour.
Stage 1: small tumour has not grown deeply into nearby tissues and has not spread to lymph nodes.
Stage 2 & 3: larger tumours have grown deeply into nearby tissue and may have spread to lymph nodes.
Stage 4: cancer has spread to other organs or parts of the body (metastasis).

Colorectal Cancer 5 year survival rates

Stage	Survival Rate
I	94%
II	82%
III	67%
IV	11%

2.9.2 Cancer Prevention

Healthy choices:

- Live smoke-free.
- Wear sunscreen and sun protection.
- Maintain a healthy body.
- Get vaccinated.
- Check your family history.
- Get screened regularly.

2.9.3 Cancer Treatment

- **Surgery** to physocally remove the tumour.
- **Chemotherapy** uses chemicals and drugs to kill cancer cells; taken orally to intravenously.
- **Radiation therapy** uses focused beams of radiation to target cancer cells.

2.10 Stem Cells

Definition 2.29 (Stem Cells)**.** Cells that can self-renew and differentiate into many different types of cells in the body. Two types:

1. **Embryonic stem cells** are derived from embryos and can differentiate into any cells.

2. **Adult stem cells** are found in the body and can differentate into a limited number of cell types.

See Figure 2.17.

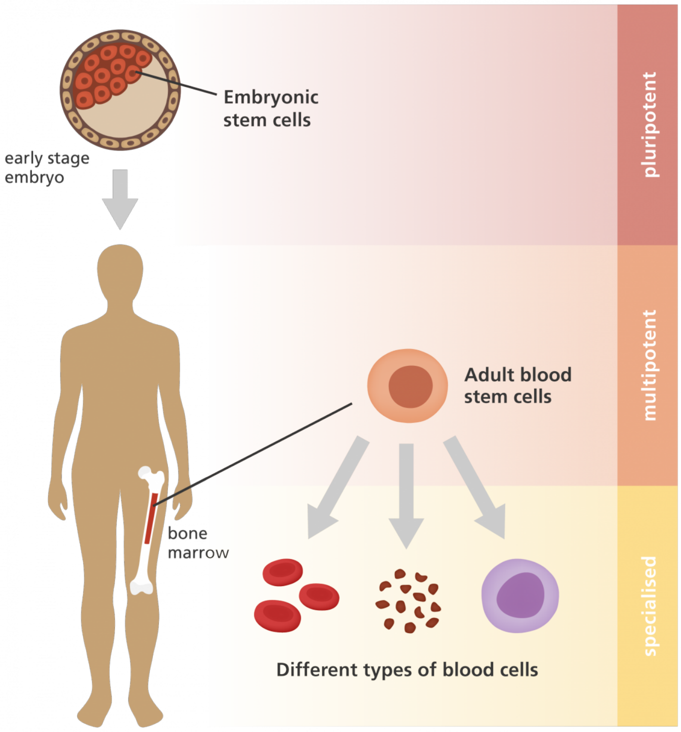


Figure 2.17: Stem Cells

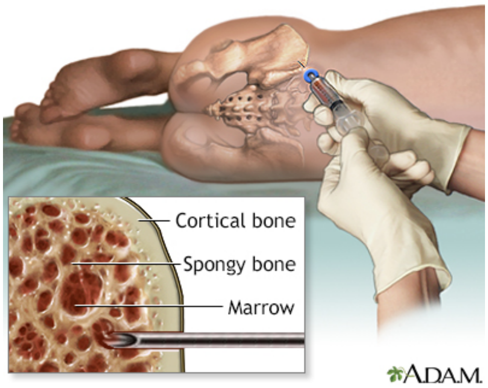
Note: Embryonic stem cells are right after fertilization.

2.10.1 Stem Cell Transplant

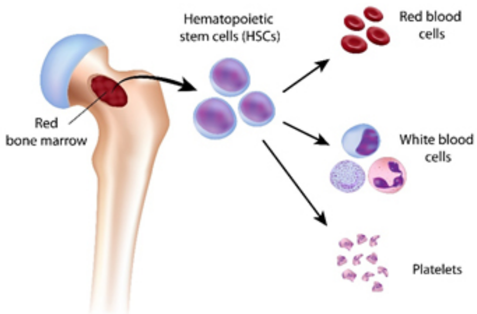
Definition 2.30 (Stem Cell Transplant)**.** Stem Cell Transplant replaces stem cells from a donor and is performed when a patient's stem cells or bone marrow have been damaged by disease, Chemotherapy, or radiation therapy.

Stem cells can be collected from the:

- Bone marrow
- Peripheral blood
- Umbilical cord



(a) Bone marrow biopsy



(b) Bone marrow stem cells

2.10.2 Hiearchy of an Organism

Definition 2.31 (Hiearchy of an Organism). The hiearchy is

$$\text{cell} \longrightarrow \text{tisue} \longrightarrow \text{organ} \longrightarrow \text{system} \longrightarrow \text{organism}$$

See Figure 2.18.

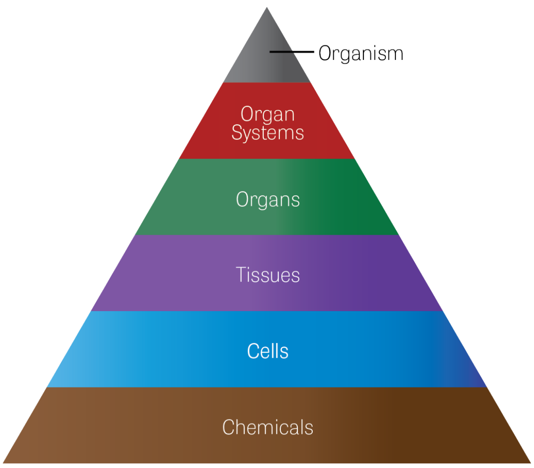


Figure 2.18: Hiearchy of an Organism

1. Cellular level heart muscle cell.
2. Tissue level heart muscle tissue.
3. Organ level heart.
4. Organ system level circulatory system.
5. Organism level deer.

- **Cell**: the smallest function unit of an organism.
- **Tissue**: a group of cells that perform a similar limited function.
  - Four main types: epithelial, connective, muscle, and nerve tissue
- **Organ**: a structure composed of different tissues to perform a complex function.
- **ORgan system**: a system of one or more organs that work together to perform a vital body function.

2.10.3 Epithelial Tissue

Definition 2.32 (Epithelial Tissue). A thin sheet that covers body surfaces and lining the internal organs.

- Skin and lining of the digestive system.
- Protection from hydration.
- Low friction surfaces.

2.10.4 Connective Tissue

Definition 2.33 (Connective Tissue). Connective tissue are various types of cells and fibres held together by a liquid, solid, or a gel, known as a matrix.

- Bones, tendons, and blood.
- **Provides support and insulation.**

2.10.5 Muscle Tissue

> **Definition 2.34** (Muscle Tissue). Muslce tissue contains proteins like actin and myosin that can contract and move.

- Muscles that make bones move.
- Muscles surrounding the digestive tract.
- Heart.

- Bundles of long cells called muscle fibres that contain specialized proteins capable of shortening or contracting.

- Movement.

2.10.6 Nerve Tissue

> **Definition 2.35** (Nerve Tissue). Nerve tissue conducts electrical signals from one part of the body to another.

- Brain.
- Nerves in sensory organs.

- Long, thin cells with fine branches at the ends capable of conducting elelectrical impulses.

- Sensory.
- Communication within the body.
- Coordination of body functions.

2.11 Stem Cells Case Study Mini-Assignment

1. What is the difference between embryonic stem cells adn adult stem cells?

   Solution. Embryonic stem cells:

   - Embryonic stem cells exist only right after the fertilization of an egg.
   - Embryonic stem cells can specialize into any kind of body cell, be it epithelial cell, a red blood cell, nerve cell, bone cell, etc.
   - Adults don't have embryonic stem cells.

   Adult stem cells:

   - Adult blood stem cells are located in the bone marrow AND in the peripheral blood.
   - Adult blood stem cells can only differentiate into either red blood cells, white blood cells, or platelets.

2. Based on the article, how would you describe what cancer is?

   Solution. As a result of some kind of mutation in the cellular DNA, this causes healthy cell checkpoints to become dysfunctional and causes uncontrollable cell growth/division. This uncontrollable growth eventually materializes as a tumor in the healthy tissue

3. Conduct some research on the following cancer treatments: chemotherapy, radiation, therapy, and surgery. Do you think that differentiation therapy has any benefits over these known treatments? Explain your reasoning.

   Solution.

   - Chemotherapy is targeted to kill cancer cells, but in the administration of chemotherapy, the drugs are targeting the healthy cells as well. Though chemotherapy may be effective in killing the cancer cells, it also damages healthy cells, which can lead to adverse effects such as nausea, hair loss, and cdecreasing in immune function.
   - Radiation therapy, uinless specifically localized, can also have adverse effects on surrounding healthy tissue.
   - Differentiation therapy is much more targeted towards turning cancer cells back into normal cells, so the use of toxic chemical is not necessary. This can decrease the number of adverse effects as well as results of this treatment.

   With this new kind of treatment, it could open many doors to groundbreaking cancer research and therapy; possible high mobilization of this particular kind of research (can lead to scientific discoveries).

2.12 Digestive System

Definition 2.36 (Digestive System). The digestives system is the organ system responsible for breaking up and digesting food, and secreting waste. The digestive tract is lined with epithelial tissue, goblet cells that release mucous, connective tissue, muscles, and nerves. See Figure 2.19.

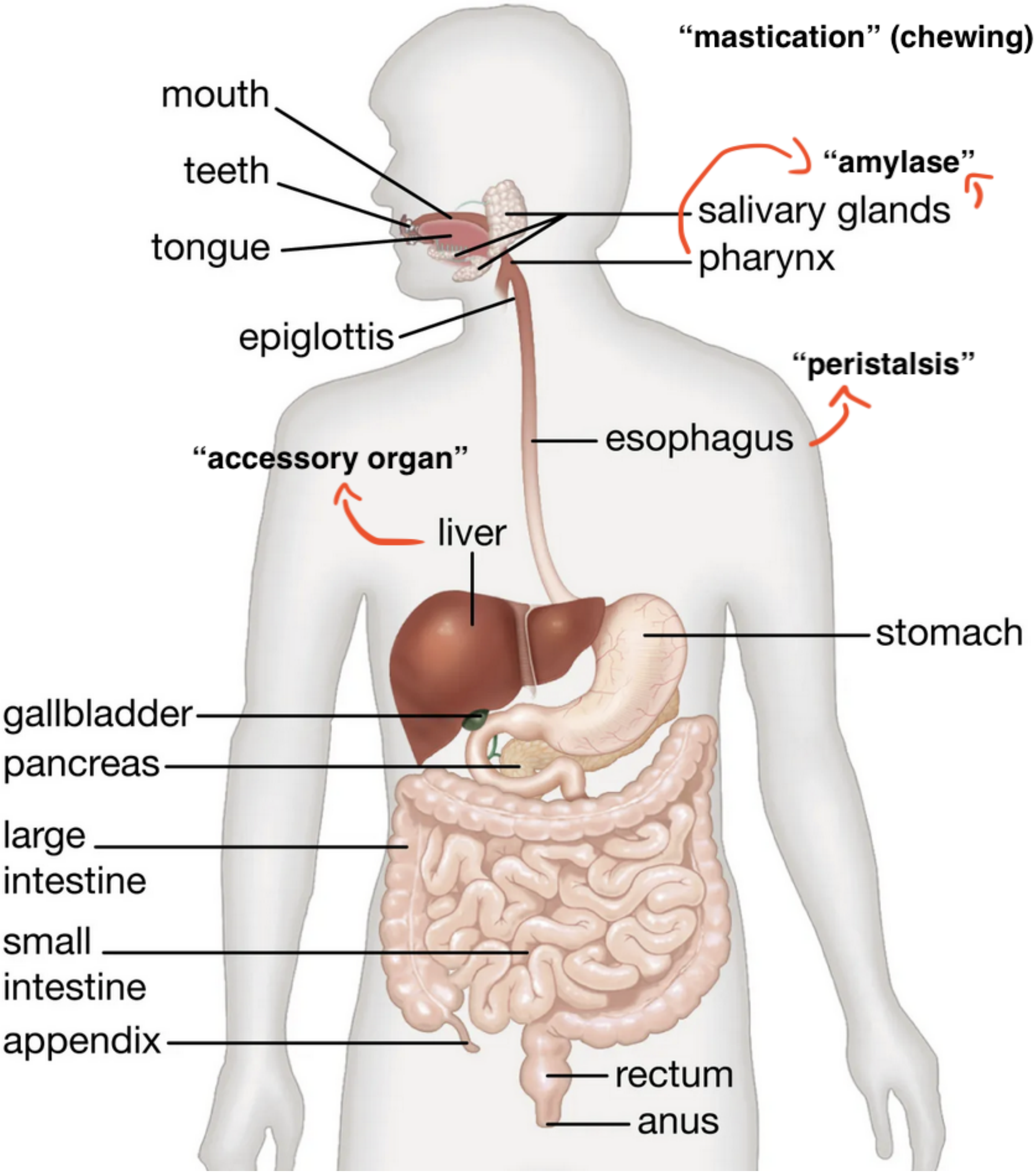


Figure 2.19: The digestive system.

2.12.1 Mouth

Definition 2.37 (Mouth). The mouth is where food enters and undergoes mechanical breakdown (mastication) and chemical breakdown through the saliva to form a bolus. The **bolus** is a ball-like mixture of food and saliva.

2.12.2 Esophagus

Definition 2.38 (Esophagus). A muscular tube that contracts through **peristalsis** to move the bolus to the stomach. See Figure 2.20.

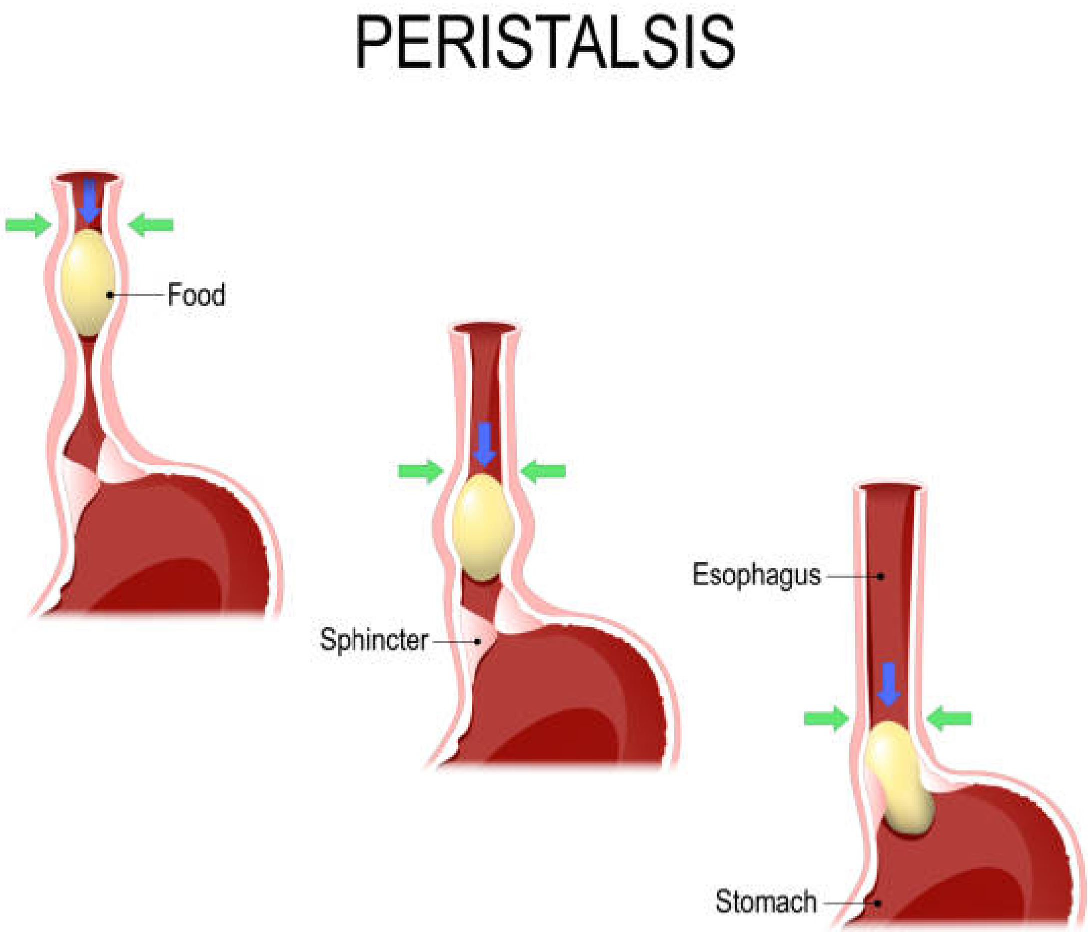


Figure 2.20: Peristalsis the **smooth muscles** create a pinch that pushes the bolus down into the stomach..

2.12.3 Epiglottis

Definition 2.39 (Epiglottis)**.** Is a flap that seals off the trachea during swalloing to direct the bolus to the esophagus.

2.12.4 Stomach

Definition 2.40 (Stomach)**.** A J-shaped organ that holds, churns, and adds acids and enzymes to turn the bolus into **chyme**. Chyme is the partially digested food that contains acids and enzymes. See Figure 2.21.

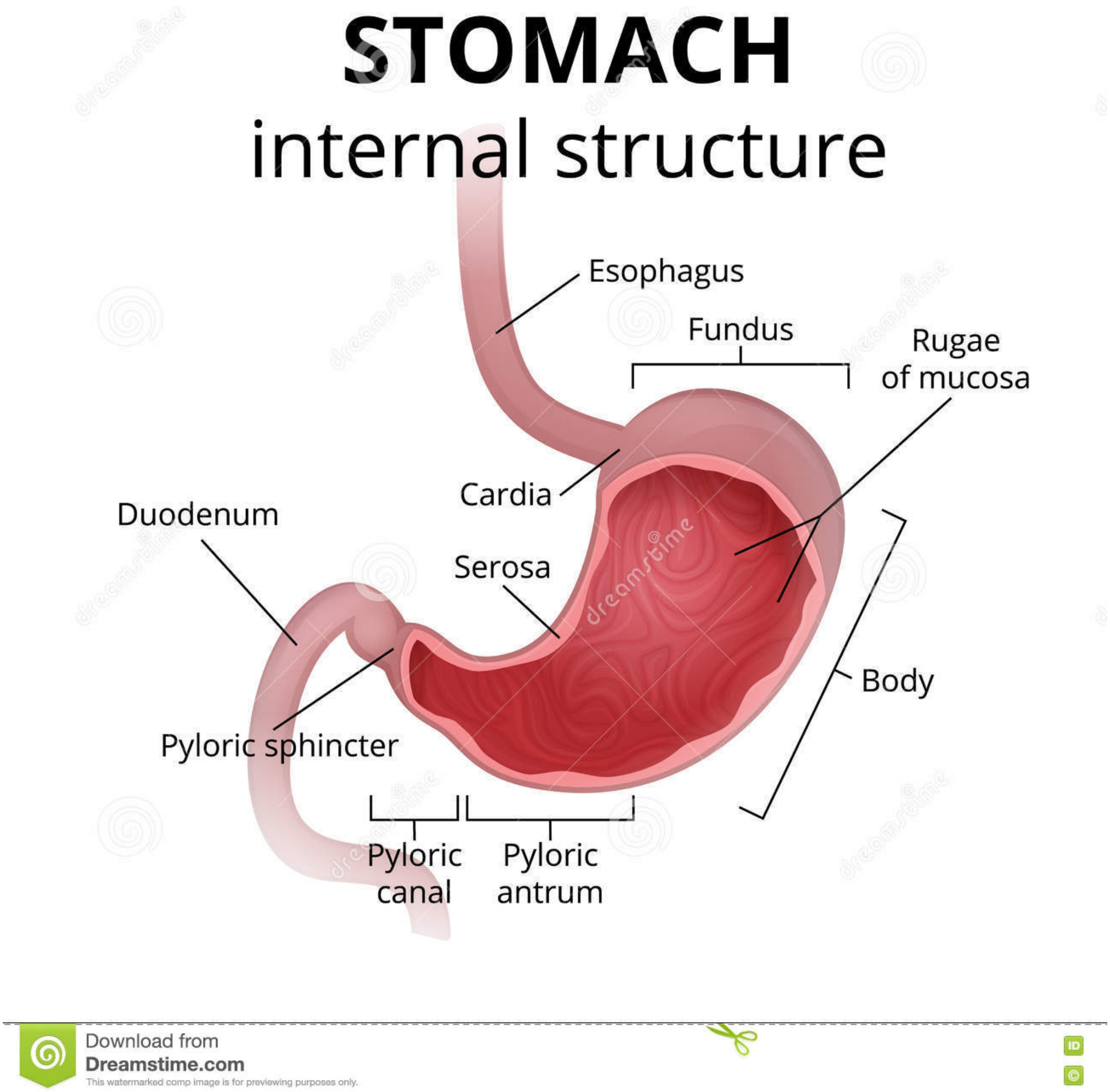


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Figure 2.21: The stomach.

2.12.5 Small Intestine

Definition 2.41 (Small Intestine)**.** The small intestine continues to digest and is the main site of absorption of nutrients. Consists of **villi** and **microvilli** to increase surface area for absorption. See Figure 2.22.

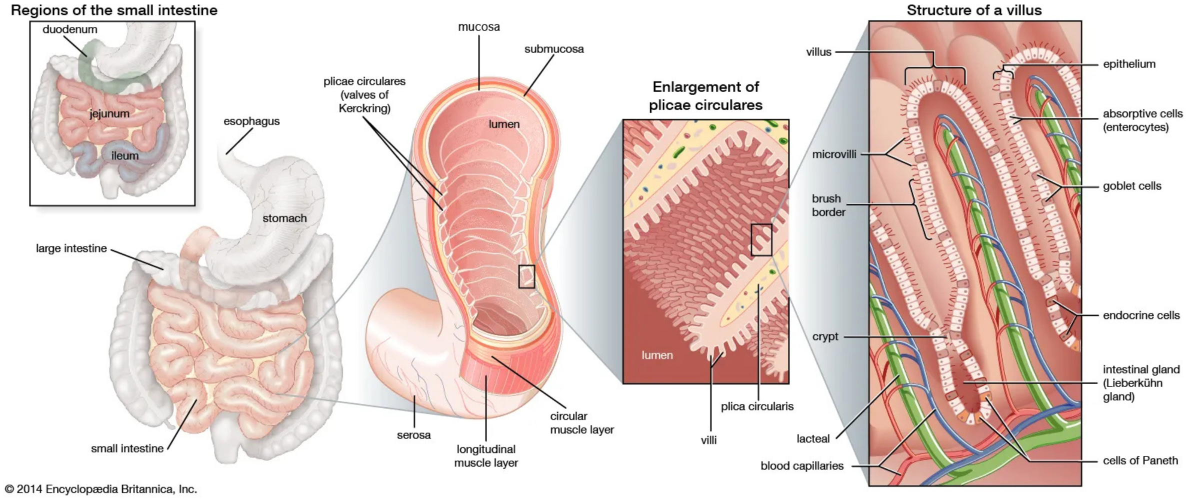

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Figure 2.22: The small intestine have small villi and further microvilli which ensures that you obtain all the nutrients from the food.

2.12.6 Large Intestine

Definition 2.42 (Large Intestine)**.** Aprobiotic environment that mainly absorbs water and minterals.

2.12.7 Appendix

Definition 2.43 (Appendix)**.** May house beneficial gut bacteria.

2.12.8 Rectum

Definition 2.44 (Rectum)**.** The end of the large intestine that temprarily stores feces.

2.12.9 Anus

Definition 2.45 (Anus)**.** An opening where feces is excreted.

2.12.10 Liver

Definition 2.46 (Liver)**.** Produces digestive enzymes and bile; also removes toxins from the blood. See Figure 2.23.

2.12.11 Gall Bladder

Definition 2.47 (Gall Bladder). Stores the bile that emulsifies fats. See Figure 2.23.

2.12.12 Pancreas

Definition 2.48 (Pancreas). Produces insulin, which is a hormone that regulates blood glucose concentration after a meal. See Figure 2.23.

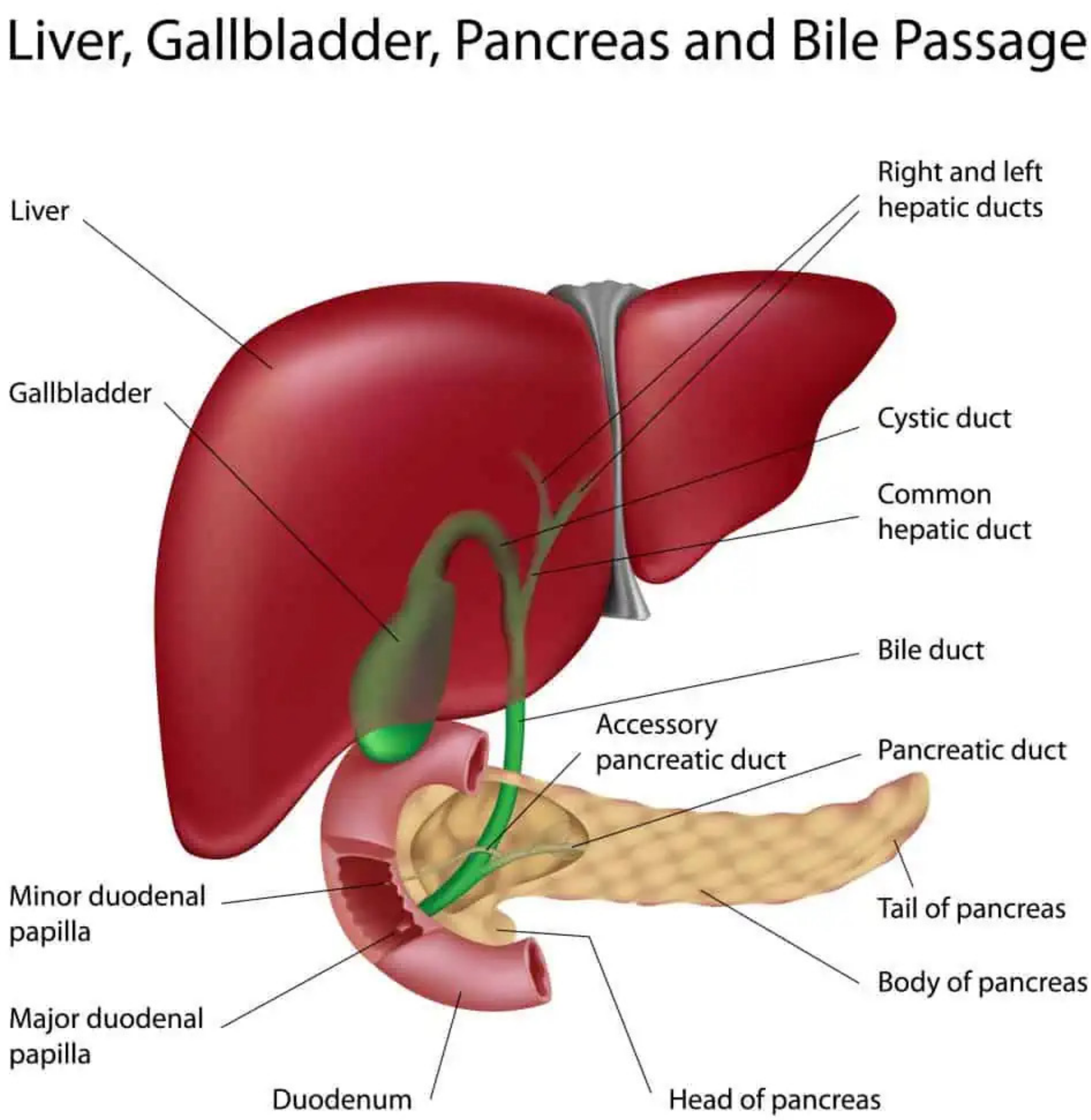

Figure 2.23: The accessory organs: the liver, gall bladder, and pancreas.