Module 2: Organisation of Living Things

Part 2 of 3
1. Nutrient and Gas Requirements

Inquiry question: What is the difference in nutrient and gas requirements between autotrophs and heterotrophs?

- Investigate the structure of autotrophs through the examination of a variety of materials, for example: (ACSBL035)
  - dissected plant materials (ACSBL032)
  - microscopic structures
  - using a range of imaging technologies to determine plant structure

The Structure of Autotrophs:

- Autotrophs are organisms that can form nutritional organic substances from simple inorganic substances such as carbon dioxide.
  - Recall: all organisms are composed of organic substances and can only use organic substances for nutrition.
  - The transformation of inorganic substances into organic substances in vital for a thriving ecosystem
  - There are two types of autotrophs: chemosynthetic and photosynthetic organisms
  - Photosynthetic organisms include those belonging to the plant kingdom and are what the HSC biology course focusses on.
  - Chemosynthetic organisms were discovered in 1977, although hypothesised much before that

- The chemical equations of chemosynthesis are very similar to that of photosynthesis. One example is:

  \[ 6CO_2 + 6H_2O + 6H_2S + 6O_2 \rightarrow C_6H_{12}O_6 + 6H_2SO_4 \]

  Carbon Dioxide + Water + Hydrogen Sulphide + Oxygen → Glucose + Sulfuric Acid

  - Different bacteria and archaea that undergo chemosynthesis have a slightly different formula, producing different products etc.

- The chemical equations of photosynthesis is:

  \[ 6CO_2 + 6H_2O + \text{light energy} \rightarrow C_6H_{12}O_6 + 6O_2 \]

  Carbon Dioxide + Water + light energy → Glucose + Oxygen

- Both forms of autotrophy use the same principle: the oxidation (losing an electron) of inorganic compounds provides the energy to catalyse a reaction between carbon dioxide and water to produce sugar

- Let’s take a look at the structures involved in photosynthesis:
  - By examining dissected plant materials, we observe that leaves and sometimes stems exhibit a green colour: this is due to the light absorbing pigment chlorophyll
- Light exists as a spectrum of different wavelengths, ranging from purple to red
- The chlorophyll pigment absorbs high levels of red and blue light, reflecting almost all green light, explaining why the pigment appears green!

![Absorption Spectrum of Chlorophyll a](image)

- To investigate where chlorophyll is found in plant cells, we need to use a range of imaging technologies such as the light microscope and the electron microscope
- The following image is a light microscope of a plant cell, which clearly shows that green pigment is isolated to organelles within the cell.

![Light Microscope Image](image)

- These organelles are called chloroplasts. The following image is an electron micrograph of a chloroplast, which helps scientists understand the structure of plant cells which allow them to produce their own food.
See Synergy Education’s Module 1: Cells as the Basis of Life (Part 2) Notes for more information on chloroplasts.
Scientific theories of transport in plants:

- Science operates under strict values for **accuracy**, truth, and answering questions. To ensure that conclusions drawn by investigations are accurate, the application of the scientific method is used.

- The scientific method is visualised below:
• Plants must use both **passive** and **active** transport to move nutrients and gasses around, much like the human body, however there is **no pumping mechanism** such as a heart, so movement is often much slower.

• Let’s look at the movement of water first!
  - Without a pumping mechanism, scientists were confused about how plants absorbed water from the soil, and how trees move water up their branches against the force of gravity.
  - Many experiments were conducted to explain this phenomenon, and in 1727 an English clergyman published his account of the movement of water by **transpiration**.
  - Transpiration is the movement of water from soil, through the plant transport system and into the air (by **evaporation**.) As water is lost to evaporation, it must be replaced, and so there is a net ‘transpiration pull’ which pulls the water up from the roots to the leaves.
  - Upon further investigation, two scientists named Joly and Dixon decided to try ‘push back’ against the flow of water from root to leaf, by increasing the atmospheric pressure.
  - They encased a maple branch inside a thick glass chamber, with the end of the branch inside a vial of water.

  - They then increased the pressure inside the chamber to 3x that of normal atmospheric pressure and still **water moved up the branch**, indicated by decreasing water levels in the vial.
  - This suggested that the movement of water through a plant was either due to **active transport** or the properties of **water** itself.
- When similar experiments were conducted with dead plant material it was discovered that living cells are not required for the transpiration of water, ruling out active transport.
- Thus, the role of the tensile and cohesive properties of water was established as a significant component of the movement of water through plants, forming the transpiration-cohesion-tension theory.

- The transpiration-cohesion-tension theory describes the movement of water through plants
  - Water molecules are tensile, meaning they are capable of being drawn out or stretched and form long cords without breaking!
  - Water molecules are also cohesive, meaning that water molecules are attracted to other water molecules.
  - These properties can be demonstrated quite easily by dipping the corner of a tissue into a glass of water
  - The molecules slowly climb up the tissue (or the plant vascular system) and carry with them other water molecules.
  - In plants, the initial movement of water occurs as a result of the evaporation of water from the leaf, which pulls other water molecules up the system from the roots.
- As stated before, living cells are NOT required for the transpiration flow.
- The walls of the xylem vessels consist of cellulose (extremely numerous microscopic fibres) each with its own surface, producing collectively a huge total surface area. The water molecules are attracted to these surfaces and carry other molecules upwards with them.
- Xylem vessels consist of fused cells that create a continuous tube for the unimpeded flow of materials.
- Because these cells have fused by breaking down their cell walls, they are no longer living.

What about photosynthesis? How did scientists figure out that plants make their own food?
- We observed that plants needed sunlight and carbon dioxide to survive, and that plants are responsible for an exceptional amount of oxygen production.
- In the late 1770s a scientist named Ingenhousz placed submerged plants in both sunlight and shade. He noticed that small bubbles were produced by the plants in the sunlight, but no bubbles were produced by the plants in the shade. Ingenhousz concluded that plants use light to produce oxygen.
- He knew it was oxygen because of what’s known as the candle experiment!
- The candle experiment involves placing a candle inside each of two sealed containers, each of which has had all the oxygen removed.
- Inside one container, a green leaf was placed, undergoing photosynthesis. When a candle was lit in the container, **ignition occurred**. This suggested the presence of oxygen, while in the other container, no ignition occurred.

- More importantly than this is how do plants get their nutrition?
- Most believed it was from **leaching** the soil, but experimentation proved this was unlikely, as plants were not removing nearly enough nutrients from the soil to survive on.
- In the 1600s Jan Baptista van Helmont performed a 5-year experiment involving a willow tree which he planted in a pot with soil. The willow tree was carefully and precisely watered over a 5-year period.
- At the end of his experiment Helmont concluded that the growth of the tree was the result of the nutrients it had received from the water and not the soil, as the mass of the tree had increased, but the mass of the soil had not equally decreased.
- His conclusions were partially correct, plants were not receiving their nutrients from the soil, and they do rely on water (but they weren’t getting nutrients from water alone!)
- Then, in the 1840s a German physicist proposed that energy cannot be created nor destroyed, only transformed and transferred.
- If plants weren’t getting their energy from soil, they must be transforming it from something around them!
- The physicist proposed that plants convert the energy of light into chemical (food) energy which became the chemical equation for photosynthesis we know today:

\[ 6\text{CO}_2 + 6\text{H}_2\text{O} \xrightarrow{\text{Sunlight}} \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2 \]

- Investigate the function of structures in a plant, including but not limited to:
  - Tracing the development and movement of the products of photosynthesis (ACSBL059, ACSBL060)

**Movement of the Products of Photosynthesis:**

- Photosynthesis can be defined by the above equation – the products of photosynthesis are glucose and oxygen.
  - So how does oxygen exit the cells, and how is CO\(_2\) obtained?
  - Like our skin, the leaves of plants have modified openings similar to pores, called stomata, which allow gases and vapour to evaporate, and hormones or oils to be released.
  - Stomata are present wherever gas exchange occurs, including on the underside of the leaf, not just on the top where sun causes the most evaporation.
  - Guard cells control the opening and closing of these stomata, regulating the exchange of gases and water vapour between the outside air and the interior of the leaf. A stoma is open when the guard cells surrounding it are swollen (turgid) with water and closed when the guard cells lose water and become flaccid.
- The vascular bundle (xylem and phloem) release and pick up the gases through the intercellular space near the stoma.

- The movement of **glucose, proteins, and nutrients** within the plant occurs in the phloem by the source to sink theory, which is described below:

1. Sugars produced at the “source” cells (photosynthesising cells) are actively transported into the phloem. This creates a high concentration of solutes within the sieve tube elements.
2. Water then enters the sieve tube elements by osmosis (moving from the xylem where solutes are in low concentration, to the phloem where solutes are in high concentration.
3. The influx of water into the phloem creates turgor pressure – pushing the materials through the sieve tube elements.
4. Cells that require sugars (the “sink” cells) receive the carbohydrates causing water to diffuse out of the sieve tube elements, relieving pressure in the phloem.
5. This cycle continues from “source to sink” by creating and relieving pressure at different points in the system.
Organisation of Living Things

Xylem

H₂O

Transpiration of water

Phloem

Companion cell

Source cell (leaf)

Translocation of sucrose

Sink cell (root)

H₂O
Gaseous Exchange Structures in Mammals:

- Typically, mammals exchange gasses with the external environment through structures called lungs, which are deeply entwined with the circulatory system.
  - This allows the gasses to rapidly reach the cells of our bodies or be expelled.
• In mammals, once blood has travelled around our body meeting our cells requirements, the blood is left **deoxygenated** and **carries toxins** (such as carbon dioxide and urea)
  - A complex transport system delivers the blood back to the lungs where carbon dioxide can be **exhaled**, and new oxygen can be picked up, while other **toxins are removed** from the blood in organs like the kidney.

• The gaseous exchange surfaces of the lungs are called **alveoli**
  - Alveoli are small sacs (like balloons) which are the final structure of the respiratory system
  
  ![Diagram of Movement of Oxygen and Carbon Dioxide In and Out of the Respiratory System]

  - Air enters the small sacs (alveoli) and comes in contact with the membrane.
  - This membrane is very permeable to gasses and allows the **passive** diffusion of gasses from the external environment i.e. from the external environment inside our lungs, to the internal environment (our blood stream.)
- Capillaries surround each alveoli, carrying carbon dioxide rich, deoxygenated blood into, and oxygenated, low-carbon-dioxide blood out of the lungs

Gaseous Exchange Structures in Insects:

- Insects have what is known as an open circulatory system, meaning the blood is not enclosed in vessels at all times (like it is in mammals)
  - Instead, oxygen enters the organisms through openings in the exoskeleton called spiracles, which are regulated by small muscles, similarly to the gas exchange of plants.
  - These openings branch off and terminate as sacs near the body cells

- Oxygen diffuses across the membrane of the sacs here, directly to the cell membranes, rather than being transported by a circulatory system
- This method of gas exchange is very inefficient compared to mammalian circulatory systems
- There are many limitations of an inefficient gas exchange system, beginning with a limited amount of oxygen for respiration. This means insects may not produce enough energy to complete all of life’s processes if they were very large, and so have to remain small and easily tire.
- Use this link to study and revise this concept!  
  https://www.youtube.com/watch?v=S5xwtdj9o&feature=youtu.be
• Trace the digestion of foods in a mammalian digestive system, including:
  - Physical digestion
  - Chemical digestion
  - Absorption of nutrients, minerals and water
  - Elimination of solid waste

Digestion in the Mammalian System:

• Physical digestion (also known as mechanical digestion) begins as soon as food enters our bodies.
  - Our teeth and jaw, along with our tongues, begin to grind and mechanically break down the food.
  - This increases the surface area of the food, allowing for more effective chemical digestion
  - The next stage of mechanical digestion occurs in the oesophagus and stomach where contractions of muscles (peristalsis) squeeze the food, kind of like kneading bread dough!
Chemical digestion is when our bodies use substances such as enzymes or solvents to break down and dissolve food.

- The breaking down of food is important as the absorption of nutrients occurs through small pores in the intestines.
- Chemical digestion begins in our mouths with the secretion of saliva.
- Saliva contains enzymes such as amylase, which breaks down large carbohydrates into simpler, more usable forms such as maltose or glucose.
- Next, food reaches the stomach where stomach acids (e.g. hydrochloric acid) and enzymes (e.g. pepsin) continue to break down food into its useable components – peptides and amino acids particularly.
- The stomach acids however have a dual purpose, and also serve to kill pathogenic bacteria and microbes.
- After the food has sat in the stomach for 1-2 hours, it moves to the duodenum and small intestine where secretions from the gall bladder, pancreas, and liver deliver more enzymes to break down food, and the liver absorbs some nutrients and toxins for cleansing.

<table>
<thead>
<tr>
<th>Enzyme</th>
<th>Site of action</th>
<th>Substrate digested</th>
<th>End products</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amylase</td>
<td>mouth, duodenum</td>
<td>starch</td>
<td>maltose, glucose</td>
</tr>
<tr>
<td>Protease</td>
<td>stomach, duodenum</td>
<td>protein</td>
<td>amino acids</td>
</tr>
<tr>
<td>Lipase</td>
<td>duodenum</td>
<td>fat</td>
<td>fatty acids, glycerol</td>
</tr>
</tbody>
</table>
• Once chemical digestion has reduced food to mostly small molecules, these nutrients must be absorbed into the blood stream for distribution.
  - To absorb these nutrients as efficiently as possible, the small intestines increase the surface area over which materials can be absorbed using small projections called villi

- Substances that are absorbed here include water, salts and mineral ions, and amino and fatty acids
- In the large intestine, the remaining “food” is transported to the anus as excess water is reabsorbed.
- Once the materials reach the anus, the excess waste is excreted.