Edexcel International A Level (IAL) Biology

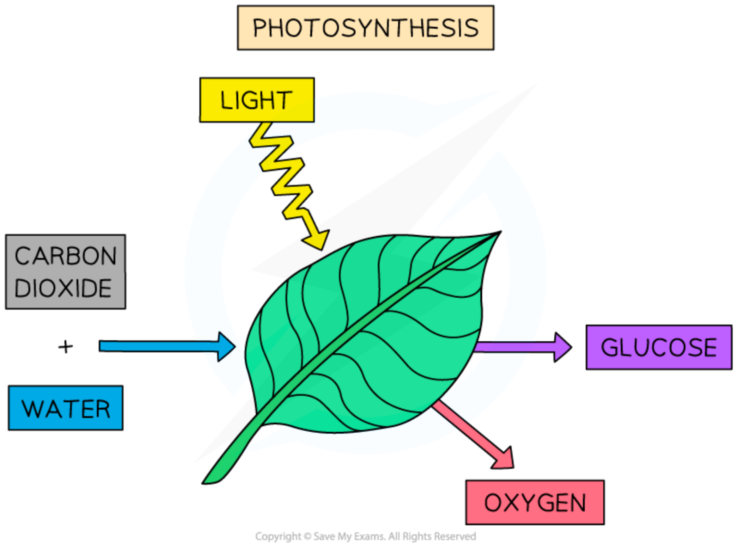
Your notes

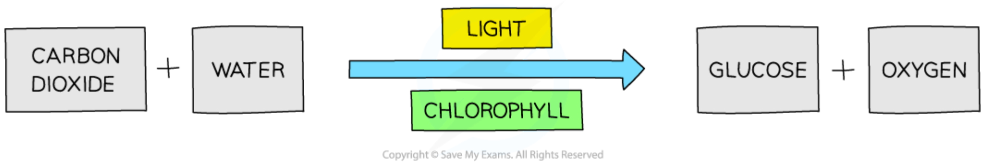
Photosynthesis

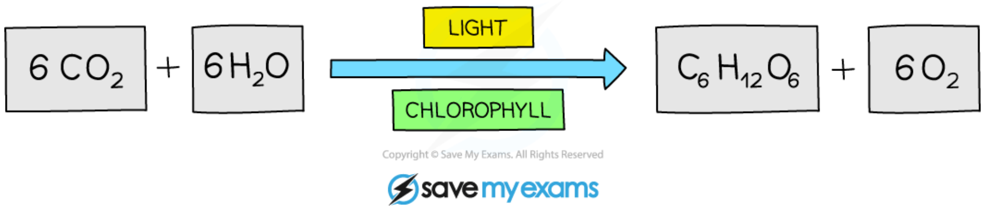
Contents

Photosynthesis: Overview

- **Photosynthesis** is a series of chemical reactions that occurs in **producers** such as plants and algae
  - Producers are also known as **autotrophs**; organisms that make their own organic compounds
- Photosynthesis converts **light energy** into **chemical energy** which is then stored in the biomass of producers
- The light energy is used to **split strong bonds** in **water molecules** (H_2O), releasing **hydrogen** and **oxygen**
- Oxygen is **released into the atmosphere** as a waste product
- Hydrogen is **combined with carbon dioxide** to produce **glucose**
  - **Chemical energy is stored** within the **bonds** in glucose molecules; glucose can therefore function as a **fuel** for respiration
  - It can be said that **hydrogen is stored in glucose** molecules





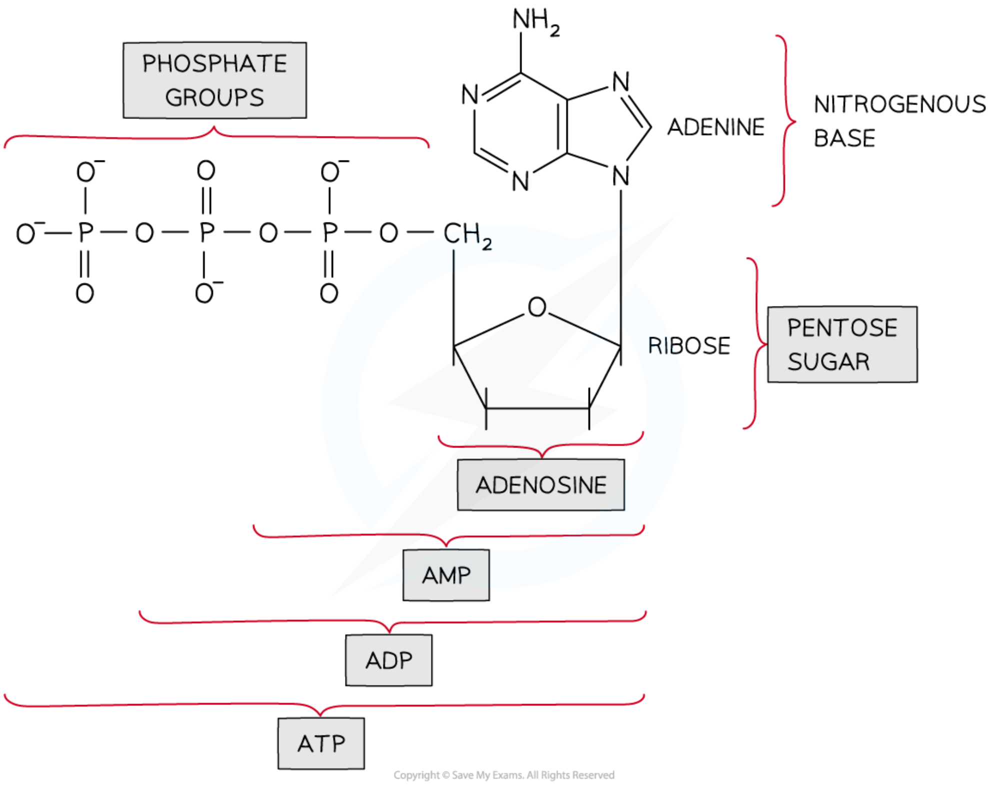


Photosynthesis requires energy from light to split water molecules. The resulting hydrogen combines with carbon dioxide and is stored in glucose, which fuels respiration. Oxygen is released as a waste product.

Your notes

ATP as an Energy Carrier in Photosynthesis

- All organisms require a **constant supply of energy** to maintain their cells and stay alive
- This energy is required e.g.
  - For building new molecules from the products of digestion during anabolic reactions
  - To move substances across cell membranes in active transport or to move substances within cells
  - For muscle contraction
  - In the conduction of nerve impulses
- In all known forms of life the molecule **adenosine triphosphate**, or **ATP**, is used to transfer and supply energy within cells
  - ATP is therefore known as the **universal energy currency**
  - ATP **diffuses** within cells to where it is needed
- ATP is a type of **nucleic acid** and is structurally very similar to the nucleotides that make up DNA and RNA
  - It is a phosphorylated **nucleotide**
    - A nucleotide consists of a nitrogenous base, a sugar, and a **single** phosphate group
    - ATP contains **three** phosphate groups, hence **tri**phosphate



ATP contains adenine, a ribose sugar, and three phosphates molecules. Removal of one phosphate creates ADP, and removal of two phosphates creates AMP.

- ATP is produced by the **addition of inorganic phosphate** (**P_i**), a type of phosphate group, to **adenosine diphosphate**, or **ADP**

ADP + P_i → ATP

  - ADP contains **two** phosphate groups, hence **di**phosphate

- ATP can be produced when the passage of electrons along a series of proteins known as the **electron transport chain** releases energy for the **phosphorylation of ADP**
  - This process occurs in the mitochondria during respiration and in chloroplasts during **photosynthesis**
    - In photosynthesis the energy originally gained by the electrons in this process comes from light, so this method of ATP production is known as **photophosphorylation**
      - Photo = light
- The **hydrolysis**, or breakdown, of ATP releases an inorganic phosphate as well as a **small amount of energy** which can be used by the cell

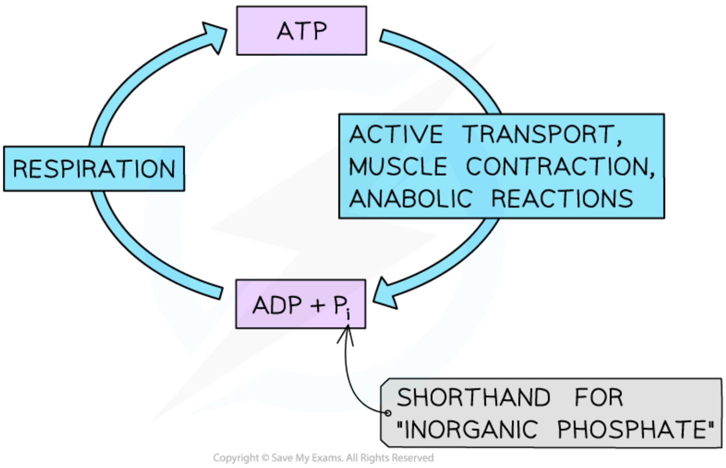
ATP → ADP + P_i

- The removal of a phosphate group is known as **dephosphorylation**
  - The hydrolysis of ATP is catalysed by the enzyme **ATPase**

Your notes

- The ADP and inorganic phosphate produced by the hydrolysis of ATP can be **recycled to make more ATP**

$$ADP + P_i \rightarrow ATP$$

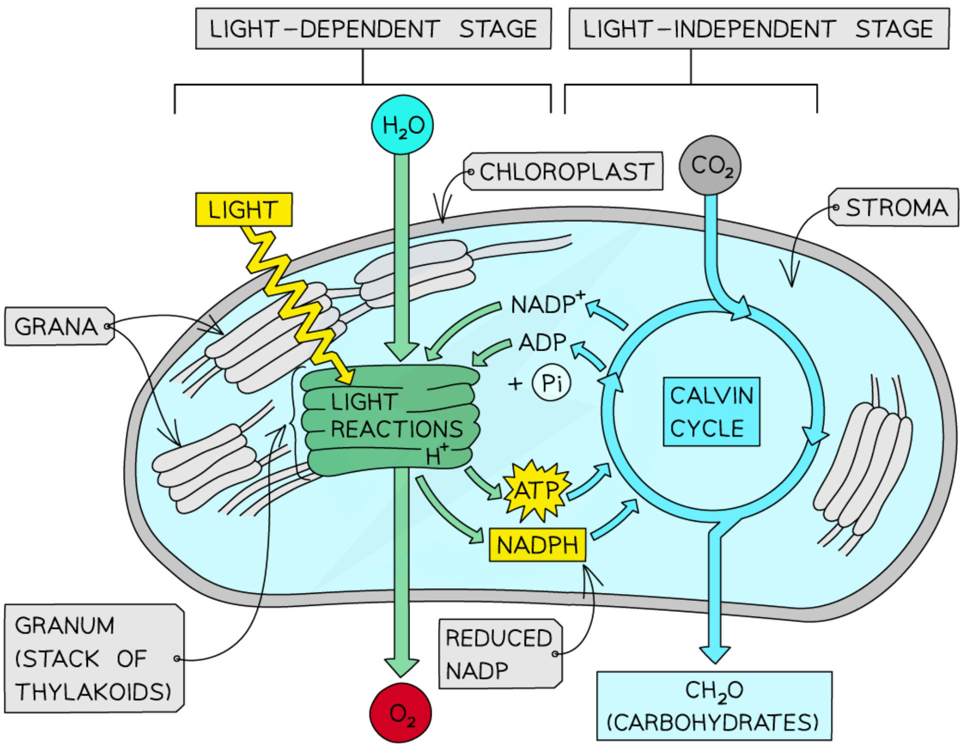


ATP is formed during respiration and can be hydrolysed to release energy for processes such as active transport, muscle contraction, and building new molecules (anabolic reactions). ATP can then be regenerated from ADP and phosphate.

Your notes

Photosynthesis: Light-Dependent Stage

- Photosynthesis takes place in two distinct stages
  - The **light-dependent reactions**, which rely on light directly
  - The **light-independent reactions**, which do not use light directly, though do rely on the products of the light-dependent reactions
- Both these sets of reactions take place within the **chloroplast**
  - The light-dependent reactions take place across the **thylakoid membrane**
  - The light-independent reactions take place in the **stroma**
- Light energy in the light-dependent reactions enables the splitting of water molecules in a reaction known as **photolysis**
  - Photolysis of one molecule of water, or H_2O, produces
    - 2 **hydrogen ions** ($2H^+$), also known as **protons**
    - 2 **electrons** ($2e^-$)
    - One atom of **oxygen** (O)
  - The hydrogen ions and electrons are used during the light-dependent reactions while the oxygen is given off as a waste product
- During the light-dependent reactions **light energy** is converted into **chemical energy** in the form of **ATP** and **reduced NADP**
  - NADP is a type of molecule called a coenzyme; its role is to **transfer hydrogen** from one molecule to another
  - When NADP gains hydrogen it is **reduced**, and can be known as either **reduced NADP** or **NADPH**
  - Remember that
    - **Reduction** is **gain of electrons**, **gain of hydrogen**, or **loss of oxygen**
    - **Oxidation** is **loss of electrons**, **loss of hydrogen**, or **gain of oxygen**
  - Reduced NADP can **reduce** other molecules by **giving away hydrogen**
  - NADP can **oxidise** other molecules by **receiving hydrogen**
- The **useful products of the light-dependent reactions, ATP and NADPH**, are transferred to the **light-independent reactions** within the chloroplast



The products of the light-dependent reaction are ATP, NADPH, and oxygen. Oxygen is given off as a waste product while ATP and NADPH pass to the light-independent reactions. The ADP and NADP produced during the light-independent reaction can pass back to the light-dependent reactions to allow more ATP and NADPH to be produced.

Production of ATP and NADPH

- ATP and NADPH are produced during the light-dependent reactions as a result of a series of events that occur on the thylakoid membrane known as **photophosphorylation**
  - Photo = light
  - Phosphorylation = the addition of phosphate; in this case to ADP to form ATP
- Two types of photophosphorylation take place
  - **Non-cyclic photophosphorylation**
    - This produces both ATP and NADPH
  - **Cyclic photophosphorylation**
    - This produces ATP only
- Both cyclic and non-cyclic photophosphorylation involve
  - A series of **membrane proteins** which together make up the **electron transport chain**
    - Electrons pass from one protein to another along the electron transport chain, releasing energy as they do so

Your notes

- **Chemiosmosis**
    - The energy released as electrons pass down the electron transport chain is used to produce ATP

Your notes

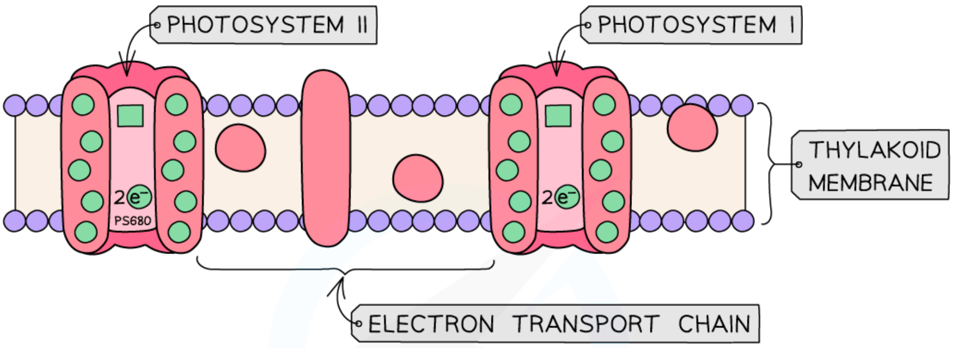
Non-cyclic photophosphorylation

- **Light energy** hits **photosystem II** in the thylakoid membrane
    - It is slightly confusing that photosystem II comes first in this sequence; the numbers simply reflect the order in which the photosystems were discovered
- Two **electrons** gain energy and are said to be **excited** to a **higher energy level**
- The excited electrons leave the photosystem and pass to the first protein in the **electron transport chain**
    - As the excited electrons leave photosystem II they are **replaced** by electrons from the **photolysis** of water
- The electrons pass down the **chain of electron carriers** known as an **electron transport chain**
- **Energy is released** as the electrons pass down the electron transport chain which enables **chemiosmosis** to occur
    - **H^+ ions** are **pumped** from a low concentration in the stroma to a high concentration in the thylakoid space, generating a concentration gradient across the thylakoid membrane
    - H^+ ions **diffuse** back across the thylakoid membrane into the stroma **via ATP synthase enzymes** embedded in the membrane
    - The movement of H^+ ions causes the ATP synthase enzyme to catalyse the **production of ATP**
- At the end of the electron transport chain the electrons from photosystem II are passed to photosystem I
- Light energy also hits photosystem I, exciting another pair of electrons which leave the photosystem
- The excited electrons from photosystem I also pass along an **electron transport chain**
- These electrons combine with **hydrogen ions** from the photolysis of water and the **coenzyme NADP** to form **reduced NADP**

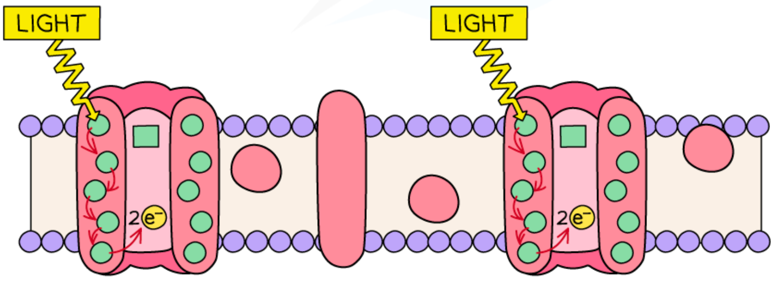
$$H^+ + 2e^- + NADP^+ \rightarrow NADPH$$

- The reduced NADP and the ATP pass to the **light-independent reactions**

1 NON-CYCLIC PHOTOPHOSPHORYLATION INVOLVES BOTH PHOTOSYSTEM I AND PHOTOSYSTEM II

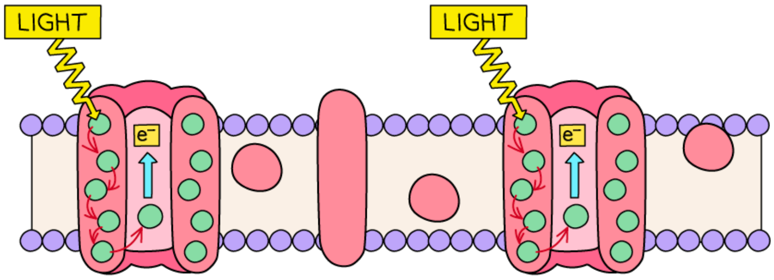


2 LIGHT IS ABSORBED BY BOTH PHOTOSYSTEMS. THE LIGHT IS PASSED TO THE PRIMARY PIGMENT OF EACH PHOTOSYSTEM

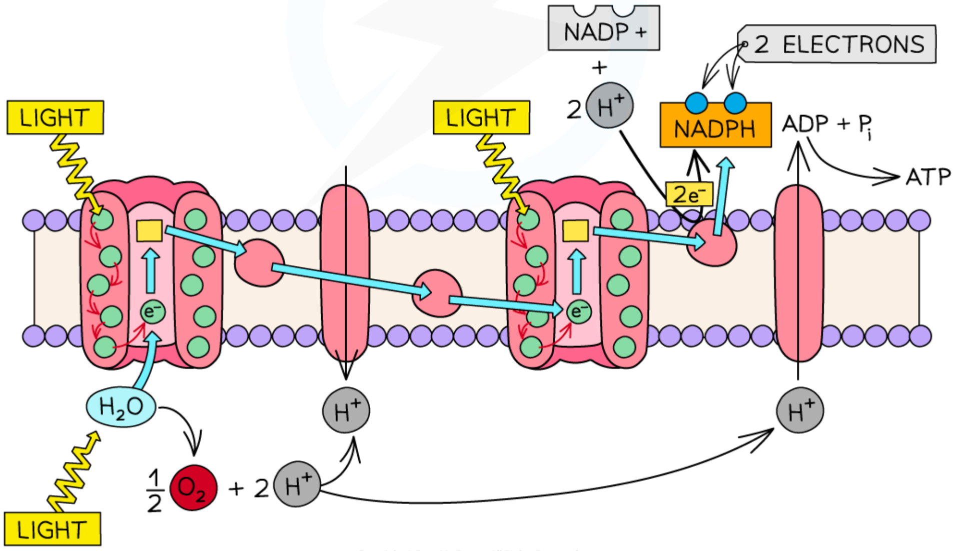


Your notes

3	PHOTOACTIVATION – ELECTRONS IN THE PRIMARY PIGMENT MOLECULE OF EACH PHOTOSYSTEM ARE EXCITED TO A HIGHER ENERGY LEVEL



4	EXCITED ELECTRONS FROM PHOTOSYSTEM II ARE PASSED TO PHOTOSYSTEM I VIA AN ELECTRON TRANSPORT CHAIN, RELEASING SUFFICIENT ENERGY TO SYNTHESISE ATP



5	ELECTRONS FROM THE PHOTOLYSIS OF WATER REPLACE THOSE LOST FROM PHOTOSYSTEM II

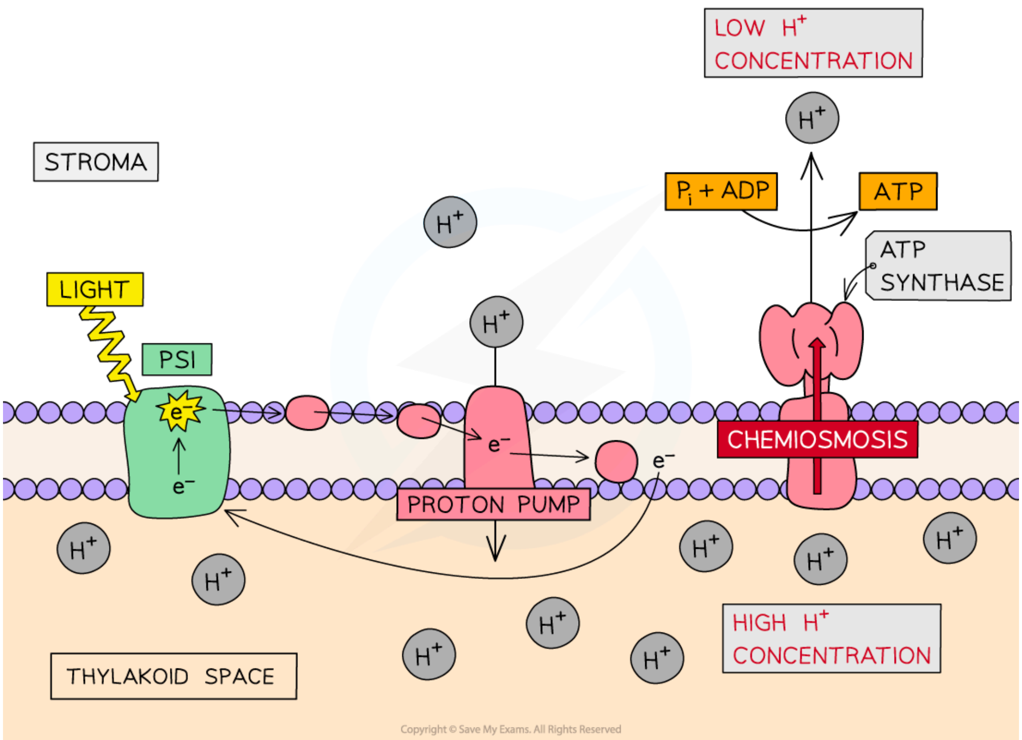
6	EXCITED ELECTRONS FROM PHOTOSYSTEM I AND HYDROGEN IONS FROM THE PHOTOLYSIS OF WATER BOTH COMBINE WITH NADP TO FORM REDUCED NADP

Non-cyclic photophosphorylation involves photosystems I and II and produces both ATP and NADPH

Cyclic photophosphorylation

- **Light** hits photosystem I

- Electrons are **excited** to a **higher energy level** and leave the photosystem
- The excited electrons pass along the **electron transport chain**, releasing energy as they do so
- The energy released as the electrons pass down the electron transport chain provides energy to drive the process of **chemiosmosis**
  - **H^+ ions** are **pumped** from a low concentration in the stroma to a high concentration in the thylakoid space, generating a concentration gradient across the thylakoid membrane
  - H^+ ions **diffuse** back across the thylakoid membrane into the stroma **via ATP synthase enzymes** embedded in the membrane
  - The movement of H^+ ions cause the ATP synthase enzyme to catalyse the **production of ATP**
- At the end of the electron transport chain the electrons **rejoin photosystem I** in a complete cycle; hence the term **cyclic** photophosphorylation
- The ATP produced enters the light-independent reaction



Cyclic photophosphorylation involves Photosystem I and produces ATP

Your notes

Fixation of Carbon from Carbon Dioxide

- The **light-independent reactions** of photosynthesis are sometimes referred to as the **Calvin cycle**
- The reactions eventually allow for the production of complex organic molecules such as
  - **Starch** for storage
  - **Sucrose** for transport
  - **Cellulose** for making cell walls
- The light-independent reactions do not require energy from light but do require **ATP** and **reduced NADP** from the light-dependent reactions
- There are three main steps within the light-independent reactions
  1. **Carbon dioxide** is combined with **ribulose bisphosphate** (RuBP), a 5-carbon (5C) compound; this yields two molecules of **glycerate 3-phosphate** (GP), a 3-carbon (3C) compound
  2. **GP is reduced** to **glyceraldehyde 3-phosphate** (GALP), another 3C compound, in a reaction involving reduced NADP and ATP
  3. **RuBP is regenerated** from GALP in reactions that use ATP

Carbon dioxide and RuBP are combined

- Carbon dioxide combines with a 5C sugar known as **RuBP** in a reaction catalysed by the enzyme **rubisco**
- The resulting 6-carbon (6C) compound is **unstable** and splits in two
- This results in two molecules of a 3C compound known as **glycerate 3-phosphate** (GP)
- The carbon dioxide has been **'fixed'**, meaning that it has been removed from the external environment and become part of a molecule inside the plant cell

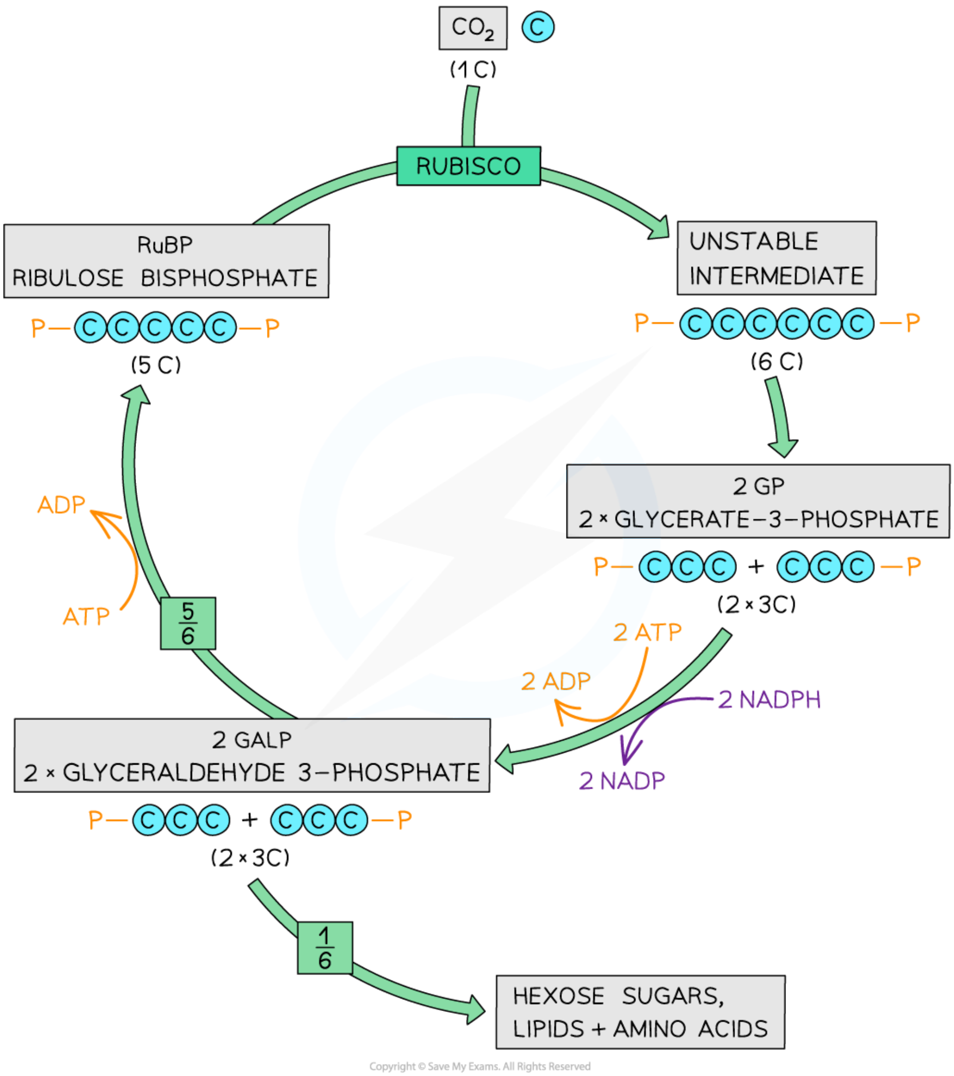
Reduction of glycerate 3-phosphate

- **Energy from ATP** and **hydrogen from reduced NADP,** both produced during the light-dependent reactions, are used to **reduce** the two 3C molecules of **GP** to two 3C molecules known as **GALP**
- Some of the carbons in GALP go towards the production of **useful organic molecules such as glucose**, while the rest remain in the Calvin cycle to allow the **regeneration of RuBP**
  - Two molecules of GALP contain six carbon atoms, five of which are needed to regenerate RuBP; this means that for every turn through the Calvin cycle only one sixth of a molecule of glucose is produced

- Glucose is a 6-carbon molecule, so **six turns of the Calvin cycle are required to produce one molecule of glucose**

Regeneration of ribulose bisphosphate

- Five sixths of the GALP molecules are used to **regenerate RuBP**
- This process **requires ATP**



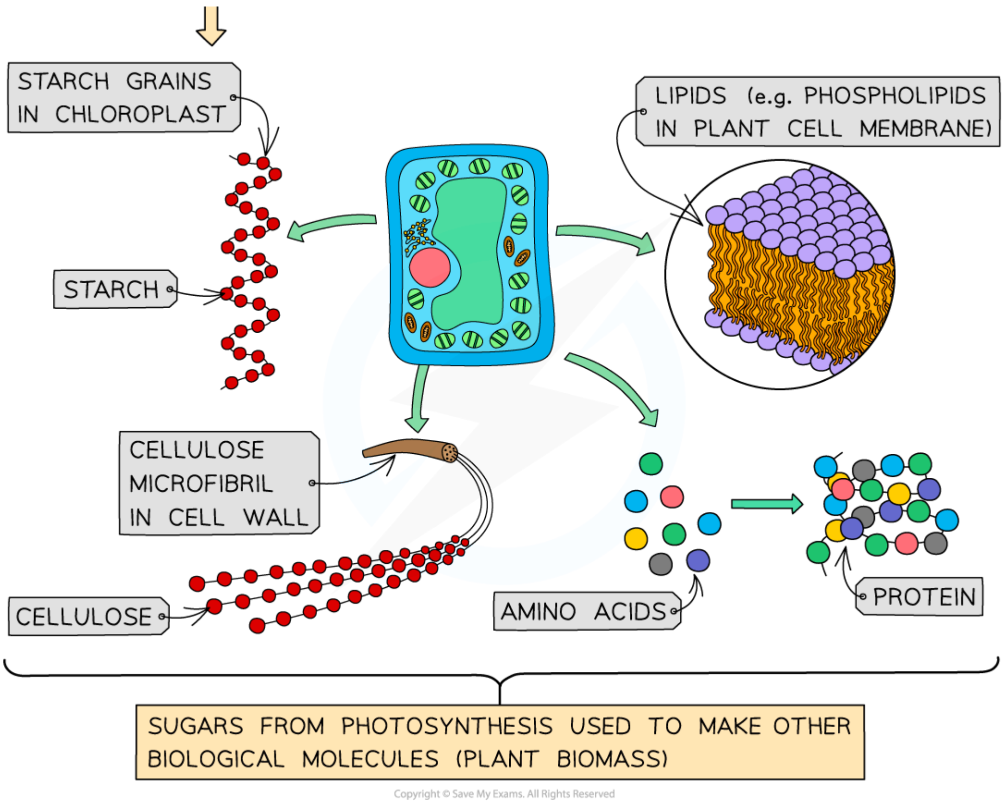
The Calvin cycle produces glucose and other important biological molecules

Products of the light-independent stage

- Intermediate molecules of the Calvin cycle, such as **glyceraldehyde 3-phosphate (GALP),** are used to produce **various other biological molecules** needed by plants, such as:
  - **Hexose sugars** e.g. glucose
    - Glucose can enter the respiration **reactions** during which **ATP** is produced

Your notes

- Hexose sugars can be converted into other hexose sugars e.g. glucose can be converted to **sucrose** for transport in the phloem
    - Hexose sugars can be joined to make polysaccharides such as **starch** and **cellulose**
  - **Glycerol** can be used for building **lipid** molecules such as triglycerides and phospholipids
  - **Fatty acids** which form the **tails** of lipid molecules such as triglycerides and phospholipids
  - **Nucleic acids** form the basis of DNA and RNA
    - Phosphates from the soil are combined with the molecules of the Calvin cycle to produce nucleic acids
  - **Acetyl coenzyme A** is important coenzyme in respiration
  - **Amino acids** which can be used in protein synthesis for building polypeptides
    - **Nitrates from the soil** need to be combined with the molecules of the Calvin cycle for amino acids to be produced
- Many of the molecules produced are used to **build new plant** biomass; these molecules are **passed on to consumers** when plant tissue is eaten



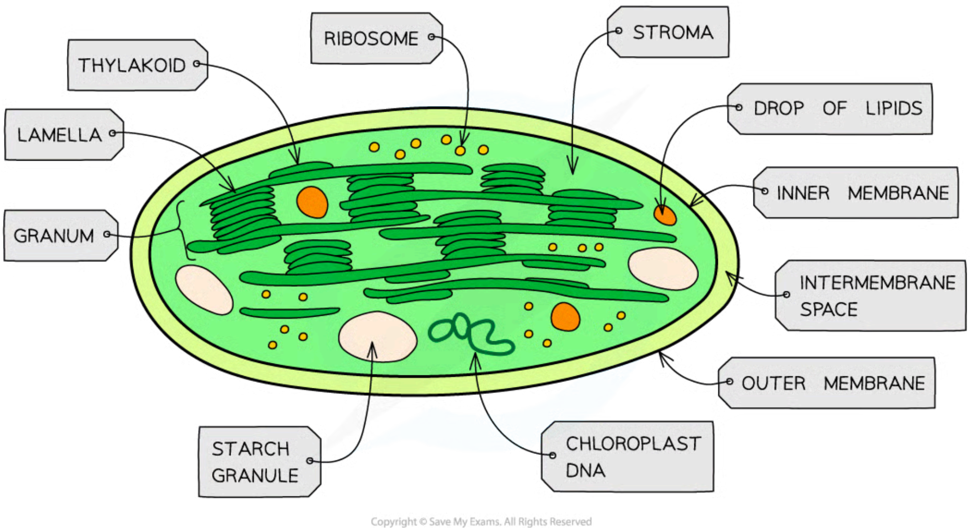
The products of photosynthesis include amino acids, polysaccharides, lipids and nucleic acids

Your notes

Your notes

Chloroplasts: Structure & Function

- Chloroplasts are the organelles in plant cells where **photosynthesis** occurs
- Each chloroplast is surrounded by a **double-membrane** known as the **chloroplast envelope**
  - Each of the envelope membranes is a phospholipid bilayer
- Chloroplasts are filled with a **cytoplasm-like** fluid known as the **stroma**
  - The stroma contains **enzymes** and **sugars**, as well as **ribosomes** and **chloroplast DNA**
  - If the chloroplast has been photosynthesising there may be **starch grains** or **lipid droplets** in the stroma
- A **separate system of membranes** is found in the stroma
  - This membrane system consists of a series of flattened fluid-filled sacs known as **thylakoids**, each surrounded by a **thylakoid membrane**
  - Thylakoids stack up to form structures known as **grana** (singular granum)
  - Grana are connected by membranous channels called **lamellae** (singular lamella), which ensure the stacks of sacs are connected but distanced from each other
- Several components that are essential for photosynthesis are **embedded in the thylakoid membranes**, including:
  - **ATP synthase enzymes**
  - Proteins called **photosystems** that contain **photosynthetic pigments** such as chlorophyll a, chlorophyll b, and carotene



Chloroplasts are the site of photosynthesis

Your notes

Chloroplast structure is related to function

- **Chloroplast envelope**
  - The double membrane **encloses the chloroplast**, keeping all of the components needed for photosynthesis close to each other
  - The transport proteins present in the inner membrane control the flow of molecules between the stroma and cytoplasm
- **Stroma**
  - The gel-like fluid contains **enzymes** that catalyse the reactions of photosynthesis
- **DNA**
  - The chloroplast DNA contains **genes** that code for some of the proteins used in photosynthesis
- **Ribosomes**
  - Ribosomes enable the translation **of proteins** coded by the chloroplast DNA
- **Thylakoid membrane**
  - There is a space between the two thylakoid membranes known as the **thylakoid space**, in which conditions can differ from the stroma e.g. a **proton gradient** can be established between the thylakoid space and the stroma
  - The space has a very small volume so a proton gradient can develop very **quickly**
- **Grana**
  - The grana create a **large surface area,** maximising the number of photosystems and allowing **maximum** light absorption
  - Grana also provide **more membrane area** for proteins such as electron carriers and ATP synthase enzymes, which together enable the **production of ATP**
- **Photosystems**
  - There are two types of photosystems; **photosystem I** and **photosystem II**, containing **different combinations of photosynthetic pigments** such as chlorophyll a, chlorophyll b, and carotene
  - Each photosystem absorbs **light of a different wavelength**, maximising light absorption e.g. photosystem I absorbs light at a wavelength of 700 nm while photosystem II absorbs light at a wavelength of 680 nm

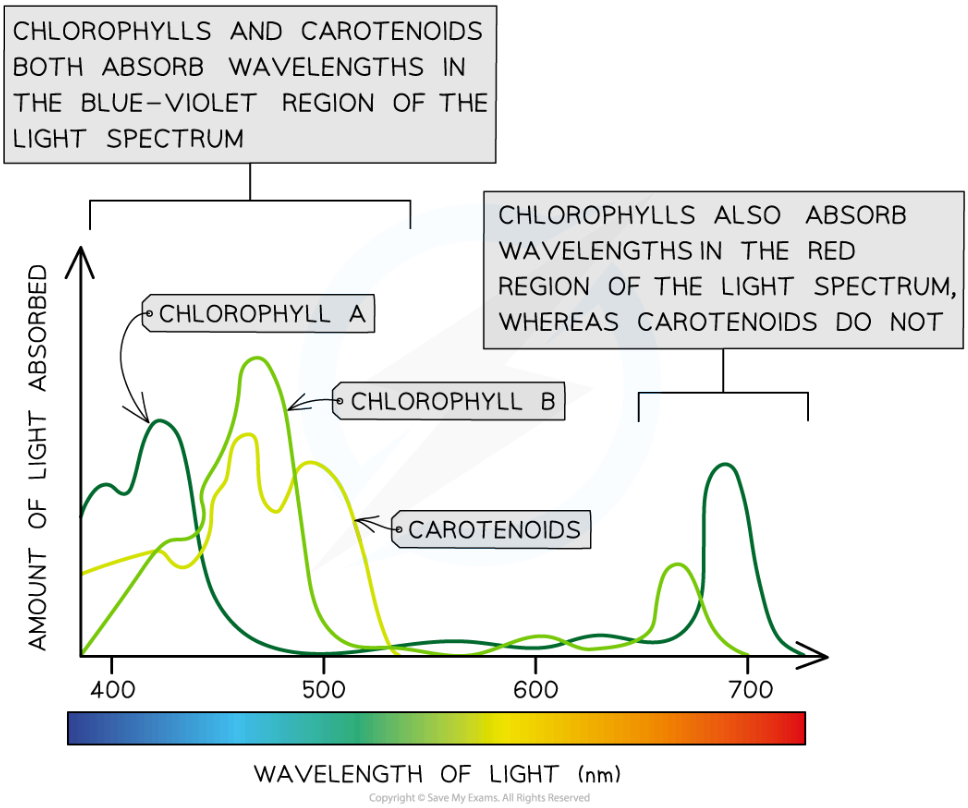
Absorption & Action Spectra

- Chloroplasts contain several different **photosynthetic pigments** within **photosystems** embedded in the **thylakoid membranes**
- Different pigments absorb light of different wavelengths
  - **Chlorophylls** absorb wavelengths in the **blue-violet and red regions** of the light spectrum, reflecting green light and appearing green in colour
  - **Carotenoids** absorb wavelengths of light mainly in the **blue-violet region** of the spectrum, reflecting yellow and orange light
    - Carotenoids often remain in leaves after the breakdown of chlorophyll in the autumn, giving some leaves their yellow, orange, and red autumn colours

Examples of Photosynthetic pigments Table

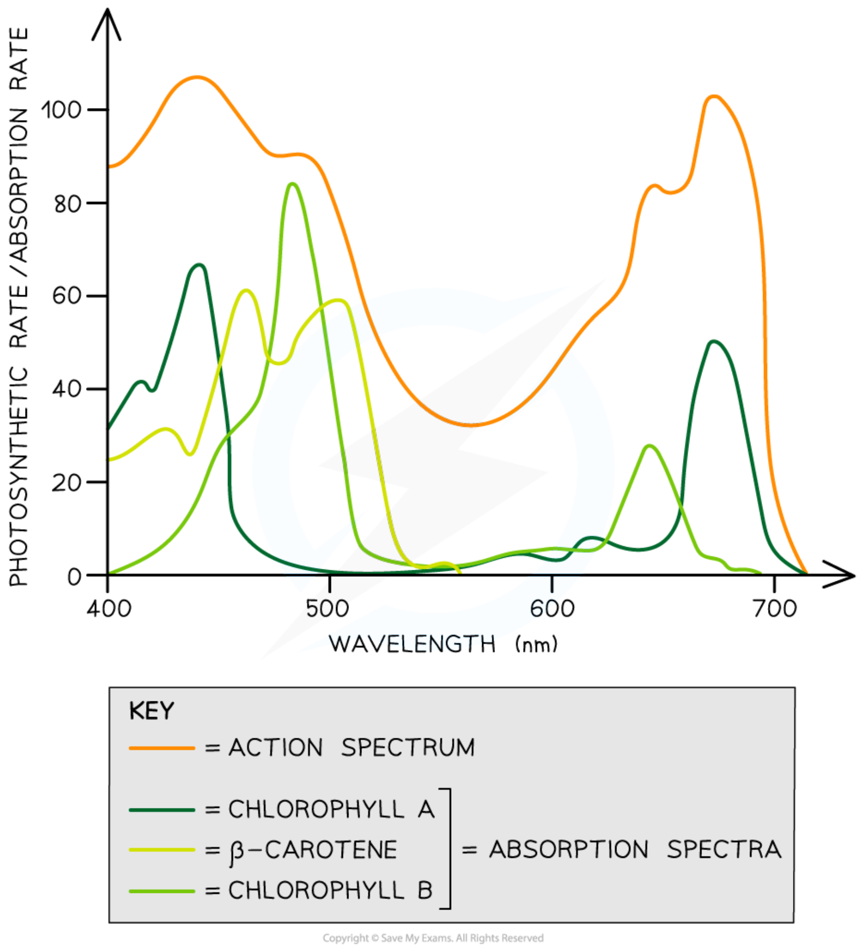
Pigment group	Name of pigment	Colour of pigment
Chlorophylls	Chlorophyll a	Blue-green
	Chlorophyll b	Yellow-green
Carotenoids	β Carotene	Orange
	Xanthophyll	Yellow

- The **amount of light at different wavelengths absorbed** by a particular pigment gives that pigment's **absorption spectrum** (plural spectra)
  - Because each type of pigment absorbs light at different wavelengths the absorption spectrum of each pigment is different



Different photosynthetic pigments absorb light of different wavelengths, giving different absorption spectra

- A plant's **rate of photosynthesis varies** depending on the **wavelengths of light available**
- The changing rate of photosynthesis at different wavelengths is known as an **action spectrum**
- Action spectra are very **closely correlated** to the absorption spectra of the different pigments
  - Having several different pigments with different absorption spectra allows plants to **photosynthesise under a wider variety of light wavelengths**; this **extends the action spectra** of plants and maximises rates of photosynthesis



Plant action spectra are closely related to the absorption spectra of the different photosynthetic pigments

Separation of Photosynthetic Pigments with Chromatography

- Chloroplasts contain several different **photosynthetic pigments** within **photosystems** embedded in their **thylakoid membranes**
- Photosynthetic pigments **absorb different wavelengths of light**, so are different in colour
  - The colour of a pigment is due to the wavelengths of light **reflected** by that pigment, e.g. chlorophylls absorb light at the red and blue ends of the visible spectrum and reflect light in the green part of the spectrum, so appear as green pigments
- Chromatography can be used to **separate and identify chloroplast pigments** that have been extracted from a leaf

Chromatography

- **Chromatography** is a technique that is used to **separate mixtures**
  - **Different components** within a mixture travel through materials at **different speeds due to their size or charge**
  - This causes different components to **separate**
  - An **R_f value** can be calculated for each component of the mixture on the basis of its rate of movement
- Two of the most common techniques for separating photosynthetic pigments are
  - **Paper chromatography**
    - The mixture of pigments is passed through paper made of cellulose
  - **Thin-layer chromatography** (TLC)
    - The mixture of pigments is passed through a thin layer of an adsorbent, e.g. silica gel
    - The pigments travel faster than through paper, so they separate more distinctly

Apparatus

- Leaf sample
- Dropping pipette
- Acetone
- Pestle and mortar
- Filter paper or TLC paper

- Pencil
- Ruler
- Capillary tube
- Beaker or boiling tube
- Chromatography solvent

Your notes

Method

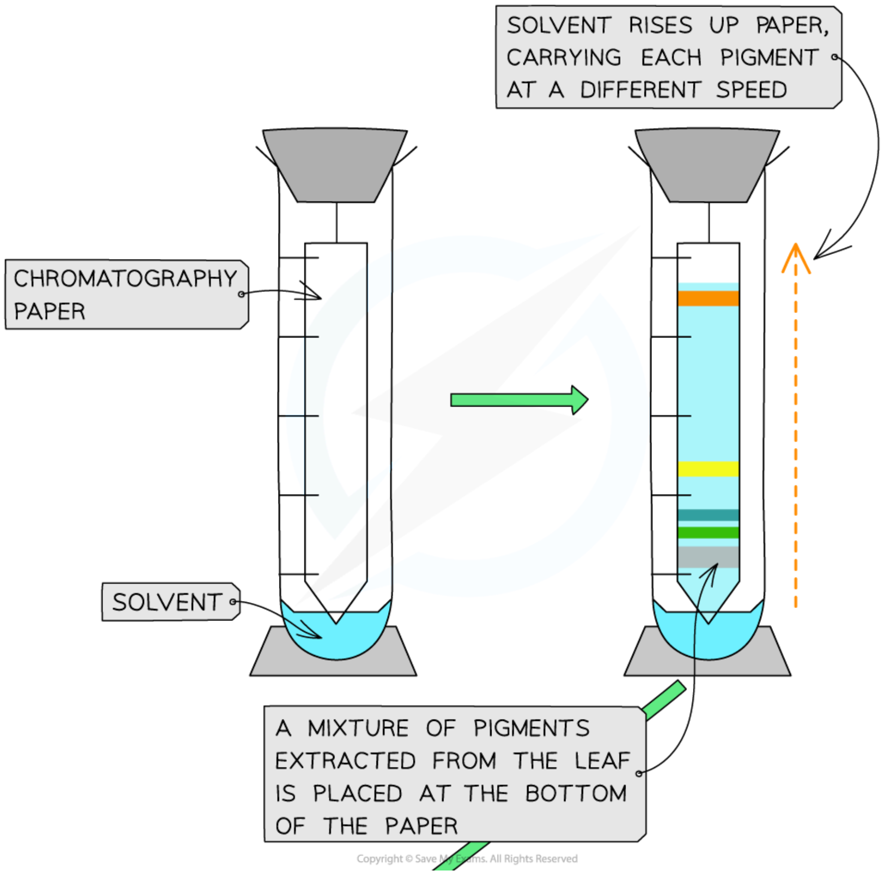
1. Draw a straight line in pencil approximately 1cm above the bottom of the paper being used, and use the pencil to draw a dot in the middle of the line; this marks where you will place the leaf sample
   - **Do not use a pen** as the ink will separate into pigments within the experiment and obscure the results
2. Cut a section of leaf and place it in a mortar
   - It is important to choose a healthy leaf that has been in direct sunlight so you can be sure it contains many active photosystems
3. Add 20 drops of acetone and use the pestle to grind up the leaf sample and release the pigments
   - Acetone is an organic solvent and therefore fats, such as the phospholipid membranes in plant cells, dissolve in it
   - Acetone and mechanical pressure are used to break down the cell, chloroplast and thylakoid membranes to release the pigments
4. Extract some of the pigment using a capillary tube and spot it onto the dot in the centre of the pencil line you have drawn
5. Suspend the paper over a beaker containing a small amount of chromatography solvent; the end of the paper closest to the pigment extract needs to touch the chromatography solvent, but the level of the solvent should be below the pencil line at this stage
   - The solvent will move up the paper
   - The pigment mixture will be **dissolved** in the **solvent** and carried with the solvent as it moves
6. Leave the paper suspended in the solvent until the solvent has almost reached the top of the paper
7. Remove the paper from the solvent and draw a pencil line marking the level of the solvent on the paper
   - The solvent may continue moving after the paper is removed from it, so it is important to draw a pencil line immediately
   - The pigments should have separated out and there should be different spots on the paper at different heights above the pencil line; these are the separate pigments
8. Calculate the R_f value for each pigment spot

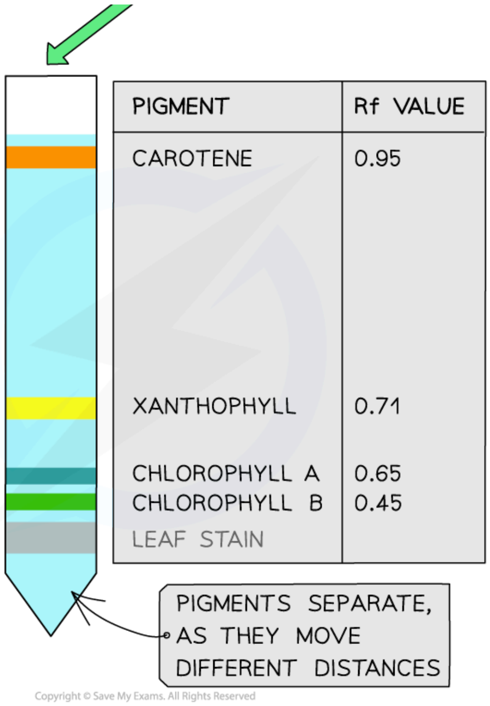
R_f **value = distance travelled by pigment ÷ distance travelled by the solvent**

- Always measure to the centre of each spot of pigment

Results

- Chromatography can be used to **separate and identify chloroplast pigments** that have been extracted from a leaf as each pigment will have a **unique** R_f value
- The R_f value is a measure of how far a dissolved pigment travel
  - Larger, less soluble molecules will travel more slowly and therefore have a **smaller** R_f **value**
  - Smaller, more soluble molecules will travel faster and therefore have a **larger** R_f **value**
- Although specific R_f values depend on the solvent that is being used, in general
  - **Carotenoids** have the **highest** R_f **values,** usually close to 1
  - **Chlorophyll *b*** has a **much lower** R_f **value**
  - **Chlorophyll *a*** has an R_f value somewhere **between** those of carotenoids and chlorophyll *b*





Chromatography can be used to separate photosynthetic pigments, which can then be identified by their R_f values.

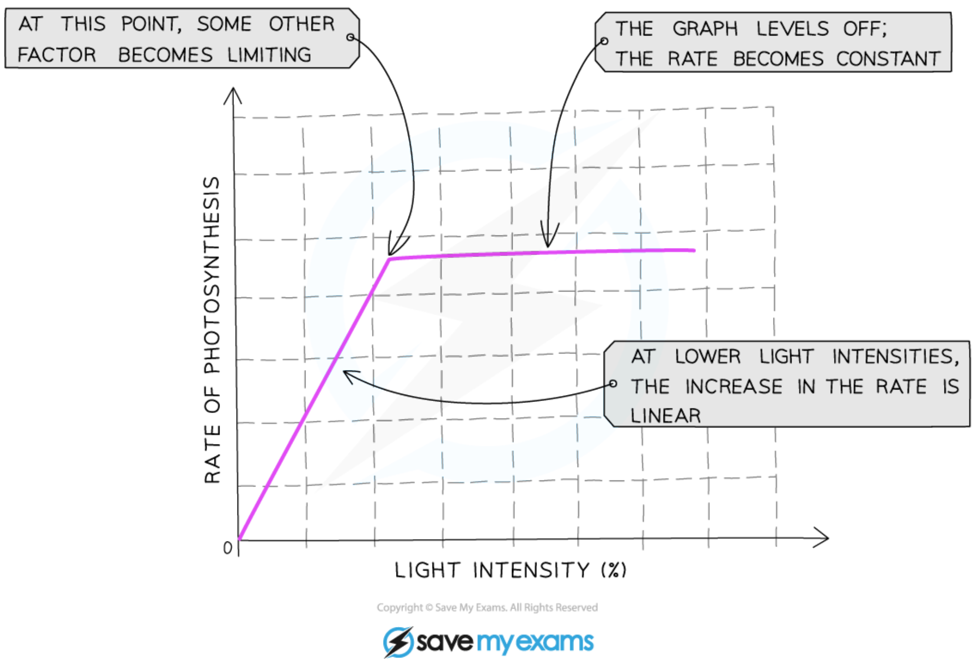
Your notes

Rate of Photosynthesis

- For **photosynthesis** to occur the following are required
  - The presence of **photosynthetic pigments**
  - A supply of **carbon dioxide**
  - A supply of **water**
  - **Light** energy
  - A **suitable temperature**
- If there is a **shortage** of any of these factors, photosynthesis cannot occur at its **maximum possible rate**
- The main external factors that affect the rate of photosynthesis are
  - **Light intensity and wavelength**
  - **Carbon dioxide concentration**
  - **Temperature**
- These are known as **limiting factors** of photosynthesis
- If any one of these factors is **below the optimum level** for the plant, its rate of photosynthesis will be **reduced**, even if the other two factors are at the optimum level
  - Note that although a lack of water can reduce the rate of photosynthesis, water shortages usually affect other processes in the plant before affecting photosynthesis and water is therefore not one of the main limiting factors

Light intensity

- **The rate of photosynthesis increases as light intensity increases**
  - The greater the light intensity, the more energy supplied to the plant and therefore **the faster the light-dependent stage** of photosynthesis can occur
  - This **produces more ATP and reduced NADP for the Calvin cycle**, which can then also occur at a greater rate
  - During this stage, light intensity is said to be a limiting factor of photosynthesis
- At some point, if light intensity continues to increase, the relationship above will no longer apply and the rate of photosynthesis will reach a **plateau**
- At this point **light intensity is no longer a limiting factor** of photosynthesis; another factor is limiting the rate
  - E.g. **temperature** being too low or too high, or not enough **carbon dioxide**

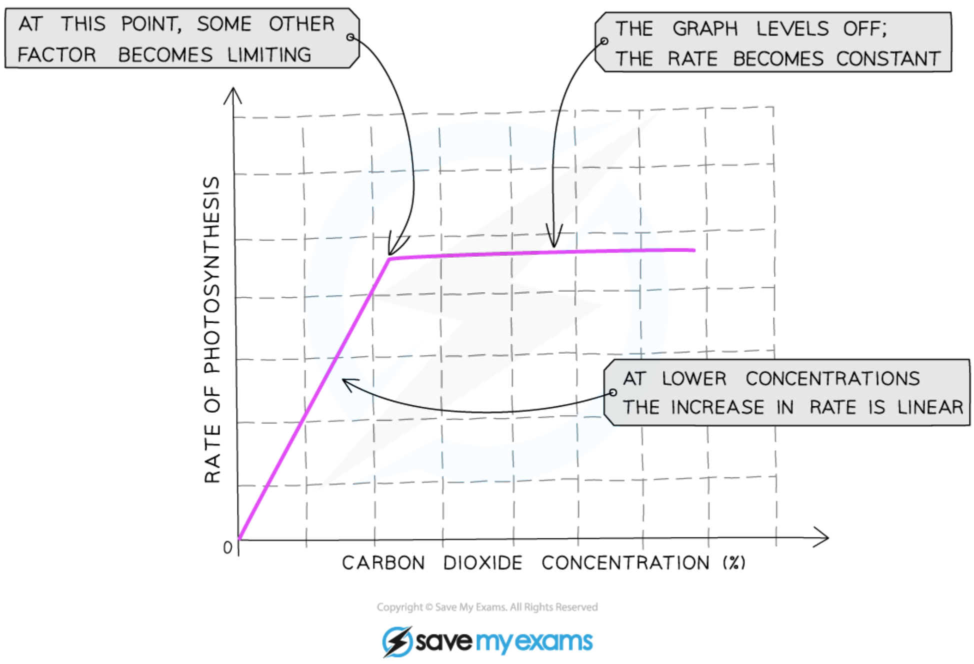


Light intensity can be a limiting factor for photosynthesis

Carbon dioxide concentration

- **The rate of photosynthesis increases as carbon dioxide concentration increases**
  - Carbon dioxide is one of the raw materials required for photosynthesis
  - It is required for the **light-independent stage of photosynthesis;** CO_2 is combined with the five-carbon compound ribulose bisphosphate (RuBP) during **carbon fixation**
  - This means the more carbon dioxide that is present, the faster this step of the **Calvin cycle** can occur and **the faster the overall rate of photosynthesis**
- This trend will continue until some other factor, e.g. temperature or light intensity, prevents the rate from increasing further

Your notes

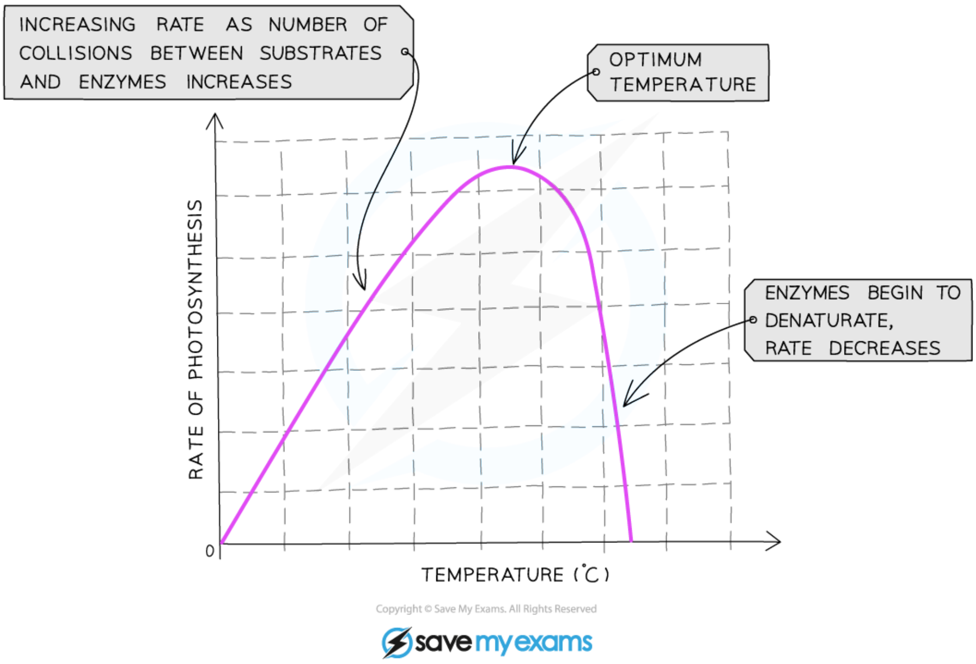


Carbon dioxide concentration can be a limiting factor for photosynthesis

Temperature

- **As temperature increases the rate of photosynthesis increases up to a point, after which the rate decreases**
  - This is because many of the reactions of photosynthesis are **catalysed by enzymes**
    - At low temperatures enzyme-catalysed reactions **occur slowly** due to a lack of kinetic energy and therefore few collisions between enzyme and substrate molecules
    - At high temperatures enzymes denature
- The **Calvin cycle is affected by temperature,** e.g. rubisco catalyses the reaction between CO_2 and the five-carbon compound ribulose bisphosphate
  - As long as there is enough light to produce ATP and NADPH in the light-dependent reaction, increasing temperature up to an **optimum temperature** will increase the rate of the light-independent reactions and therefore the rate of photosynthesis

Your notes



Temperature can be a limiting factor for photosynthesis

Investigating the rate of photosynthesis

- Investigations to determine the effects of light intensity, light wavelength, carbon dioxide concentration, and temperature on the **rate of photosynthesis** can be carried out using **aquatic plants** such as *Elodea* or *Cabomba*
  - Aquatic plants are especially useful for investigating the rate of photosynthesis because the waste oxygen gas produced can be easily collected and measured underwater
- The effect of these limiting factors on the rate of photosynthesis can be investigated in the following ways
  - **Light intensity**
    - Change the distance of a light source from a plant
  - **Light wavelength**
    - Change a colour filter placed over a light source illuminating a plant
  - **Carbon dioxide concentration**
    - Add different quantities of sodium hydrogencarbonate ($NaHCO_3$) to the water surrounding a plant; this dissolves to produce CO_2
  - **Temperature**
    - Place boiling tubes containing submerged plants in water baths of different temperatures

- Whilst changing one of these factors during an investigation, **ensure that other factors remain constant**
    - E.g. when investigating the effect of light intensity on the rate of photosynthesis, a glass tank should be placed in between the lamp and the boiling tube containing the pondweed to absorb heat from the lamp; this prevents the solution surrounding the plant from changing temperature

Your notes

Investigating the effect of light intensity on the rate of photosynthesis

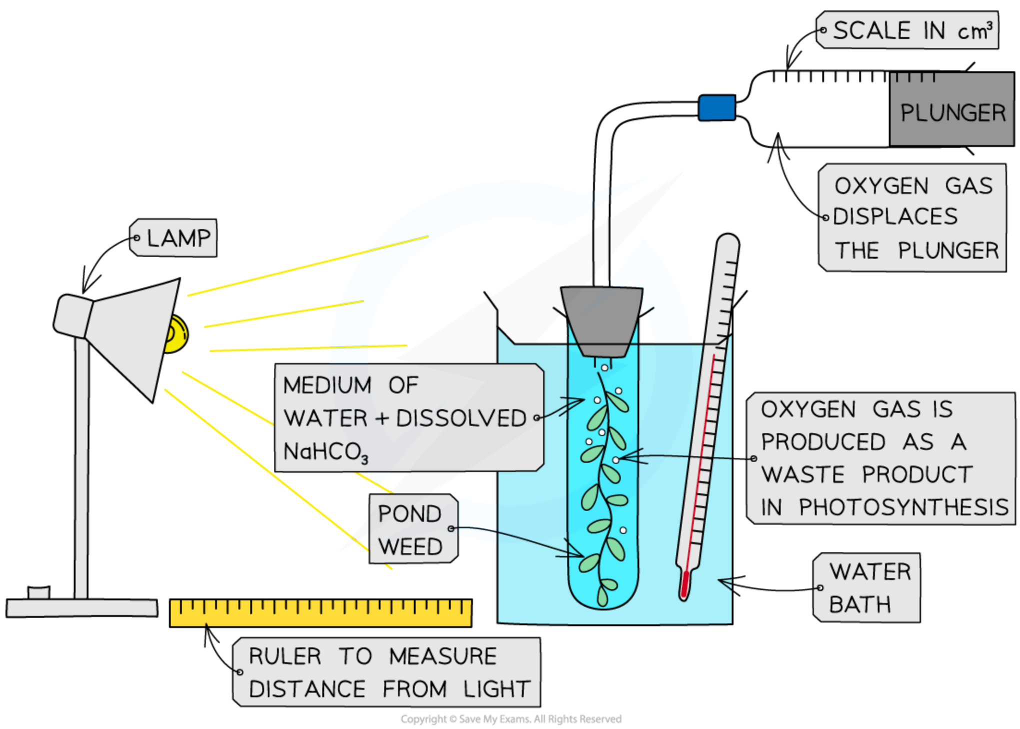
Apparatus

- Distilled water
- Boiling tube
- Beaker
- Lamp
- Aquatic plant, algae or algal beads
- Metre ruler
- Sodium hydrogen carbonate solution
- Thermometer
- Boiling tube bung and delivery tube
- Measuring syringe

Method

1. Optional: ensure the water is **well aerated** before use by **bubbling air through it**
    - This will ensure that any oxygen gas given off by the plant during the investigation forms **bubbles** instead of dissolving
2. Ensure the plant has been **well illuminated** before use
    - This will ensure that the plant contains all the enzymes required for photosynthesis and that any changes of rate are due to changes in light intensity
3. Set up the apparatus in a **darkened room** with a 10 cm distance between the lamp and the boiling tube
    - This means that no external light sources will affect the rate of photosynthesis
4. Cut the stem of the pondweed **cleanly** just before placing into the boiling tube
    - This enables bubbles of oxygen to form from the cut plant stem
5. Submerge the sample of pondweed in **sodium hydrogen carbonate solution**
    - This ensures that the pondweed has a controlled **supply of carbon dioxide**

6. Measure the volume of gas collected in the gas syringe over a **set period of time,** e.g. 1 minute; repeat this measurement e.g. 3 times
7. **Change the independent variable** by moving the light source 10 cm further away from the plant and repeat step 6
8. Repeat step 7 several more times, moving the lamp 10 cm further away from the plant each time
9. Record the results in a table and plot a graph of volume of oxygen produced per minute against the distance from the lamp



The effect of light intensity on the rate of photosynthesis can be investigated by measuring the volume of oxygen produced as a lamp is moved further away from an aquatic plant

Results

- The closer the lamp, the higher the light intensity, therefore **the volume of oxygen produced should increase as the light intensity is increased**
- At a point the volume of oxygen produced will stop increasing even if the light is moved closer
  - This is the point at which light intensity stops being the limiting factor and, e.g. temperature or concentration of carbon dioxide becomes limiting

Your notes