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A2 Biology OCR

Unit F214: Communication, Homeostasis and Energy

Module 3.1 Photosynthesis

Notes & Questions

Define the terms *autotroph* and *heterotroph.*

- **Autotroph**
  - An organism that uses simple inorganic molecules (carbon dioxide & water), and energy to synthesise complex organic molecules (glucose)
  - **Photoautotrophs** (plants, some bacteria and some protoctists) use light as a source of energy.
  - **Chemoautotrophs** (some bacteria) use chemical energy

- **Heterotroph**
  - An organism that ingests and digest complex organic molecules, releasing the chemical energy stored in them.

State that light energy is used during photosynthesis to produce complex organic molecules.

- Photosynthesis is a process used by plants and other organisms to capture the sun's energy to split off water's hydrogen from oxygen.
- Hydrogen is combined with carbon dioxide (absorbed from air or water) to form glucose and release oxygen.
- All living cells in turn use fuels derived from glucose and oxidize the hydrogen and carbon to release the sun's energy and reform water and carbon dioxide in the process of cellular respiration.
- The energy to drive this process of Photosynthesis originates from the light energy provided by the sun

Explain how respiration in plants and animals depends upon the products of photosynthesis.

- Photosynthesis
  - $\mathbf{6CO_2 + 6H_2O \lozenge C_6H_{12}O_6 + 6O_2}$
- The products of photosynthesis are;
  - Oxygen
    - aerobic respiration
    - Final electron acceptor
  - Glucose
    - Primary respiratory substrate
    - Can be respired aerobically and anaerobically

- These products can be used for respiration in both plants, animals, bacteria and fungi.
- Aerobic Respiration

- $C_6H_{12}O_6 + 6O_2$ ◊ $6CO_2 + 6H_2O$
- Note that aerobic respiration recycles the raw materials for photosynthesis

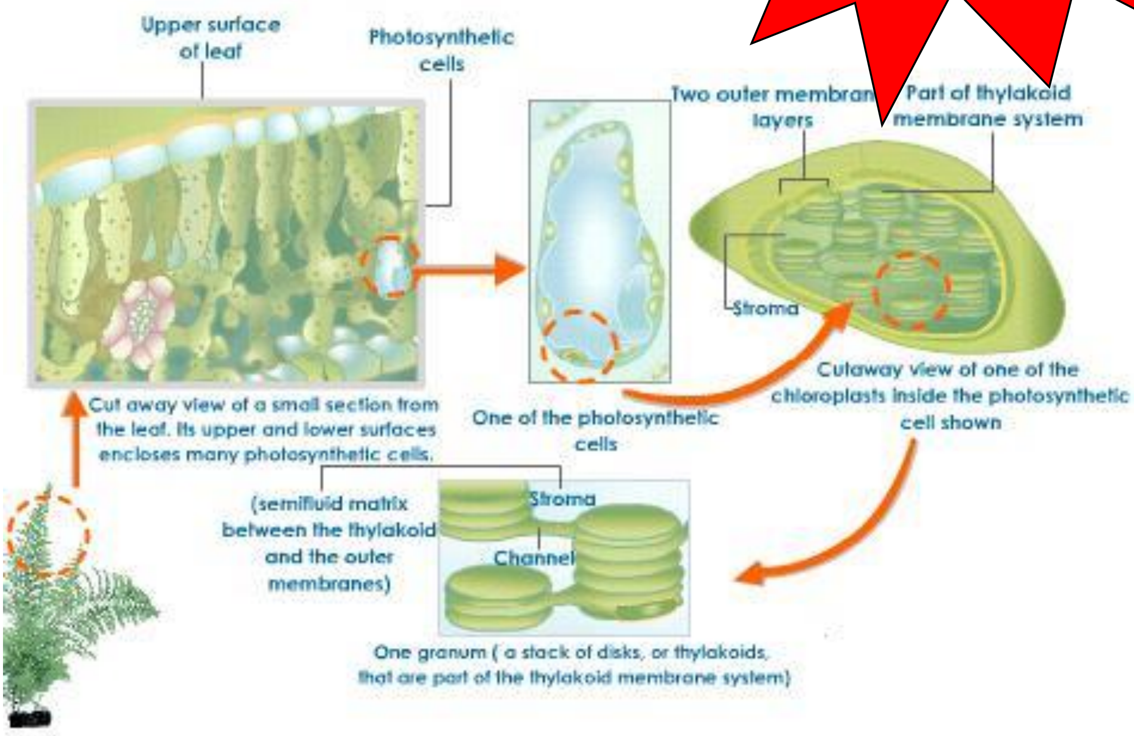
State that, in plants, photosynthesis is a two-stage process taking place in chloroplasts.

- In plants photosynthesis is a two stage process which takes place in organelles called Chloroplasts
  - The light dependent stage
    - Takes place in the thylakoid and inter-granal lamellae membranes of chloroplasts
  - The Light independent stage (The Calvin cycle)
    - Takes place in the stroma of chloroplasts

Explain, with the aid of diagrams and electron micrographs, how the structure of chloroplasts enables them to carry out their functions.

- Photosynthesis takes place in organelles called Chloroplasts
- Most chloroplasts are disk shaped and between 2-10µm long.

Remember **Chloroplasts** are **ORGANELLES** and are not **CELLS**

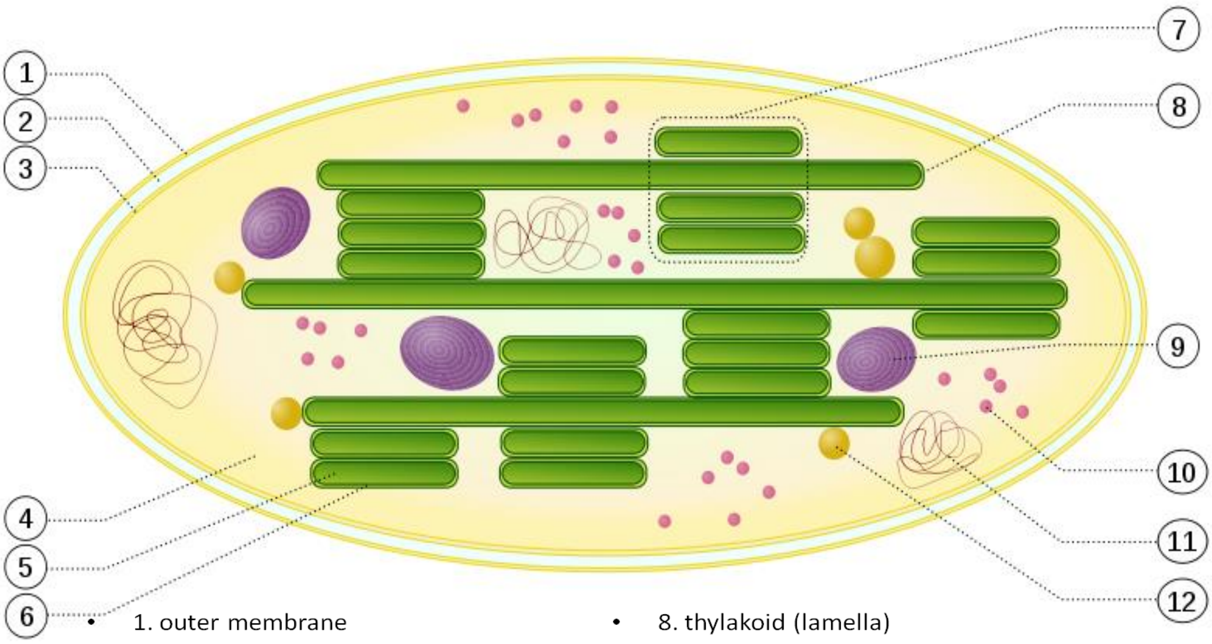


- Chloroplasts structures
    - Outer membrane
        - The outer membrane is permeable to many small ions.
    - Inner membrane
        - Has transport proteins, so controls the entry and exit of substances.
    - Stroma
        - Fluid filled matrix which contains all the enzymes for the light independent stage
        - Contains starch grains and oil droplets
        - Contains DNA and prokaryote type ribosomes
    - Thylakoid
        - Flattened membrane bound sacs
        - Holds photosytems
        - Absorb light
        - Carryout ATP synthesis
    - Gran(um/a)
        - A stack of thylakoids together
    - Intergranal lamellae
        - Joins one granum to another.

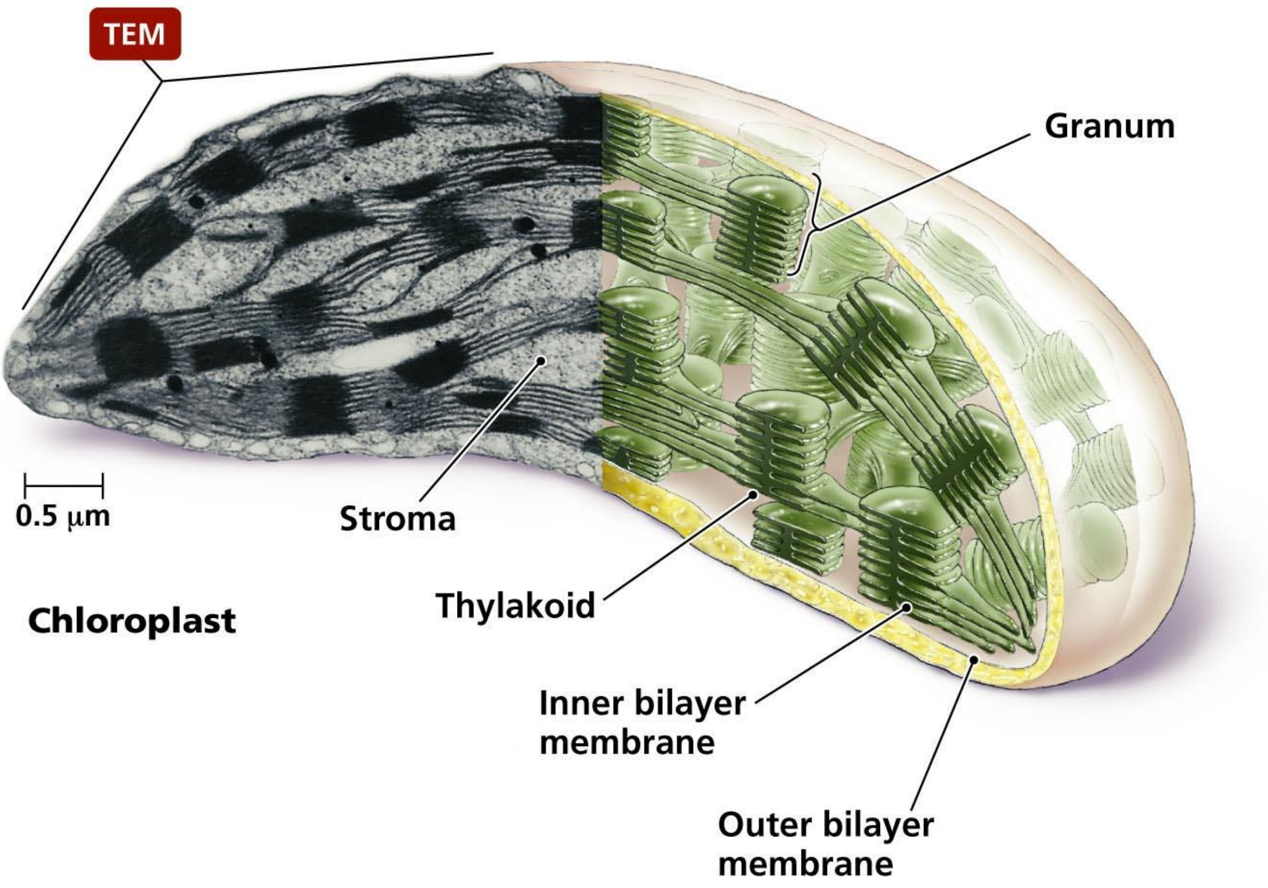
- Chloroplasts are adapted to carry out photosynthesis
    - The chloroplast has a large surface area as it is biconvex in shape
    - Many thylakoids arranged in grana creates a large surface area
    - This means many photosystems can be held
        - Funnel shaped protein structures allow maximum light absorption
        - Sites of Photophosphorylation
        - Therefore holds lots of photosynthetic pigments for absorbing light energy
        - Accessory pigments – absorb wide range of light wavelengths
            - Chlorophyll b (500nm – 640nm)
            - Carotenoids
        - Primary pigments release electrons
            - Chlorophyll a (450nm – 680nm/700nm)
    - This also means lots of ATPsynth(et)ase enzyme can be held
        - Lots of ATP production
    - This also means many electron carrier proteins can be held
    - Stroma is right next to the grana for rapid exchange of molecules between the two (E.g. ATP, NADPH etc)
    - Stroma contains many enzymes including RUBISCO
    - Contains NADP and NADPH
    - Storage of starch grains
    - DNA

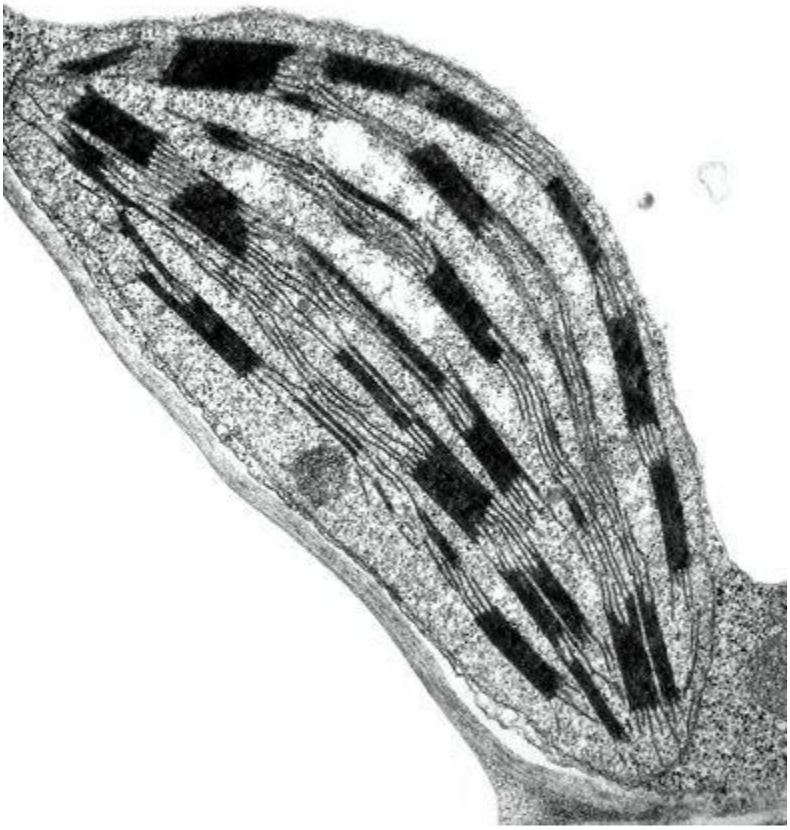
- Ribosomes
- These make the proteins/enzymes needed for photosynthesis.

Chloroplast ultrastructure



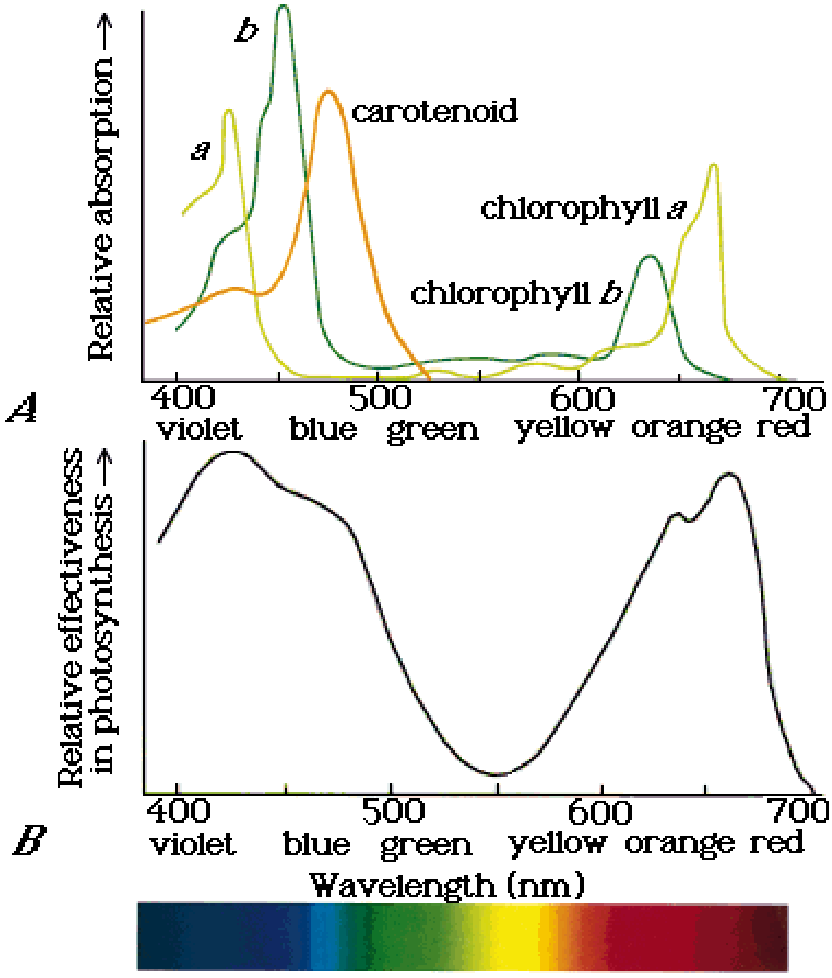
- 1. outer membrane
- 2. intermembrane space
- 3. inner membrane (1+2+3: envelope)
- 4. stroma (aqueous fluid)
- 5. thylakoid lumen (inside of thylakoid)
- 6. thylakoid membrane
- 7. granum (stack of thylakoids)
- 8. thylakoid (lamella)
- 9. starch
- 10. ribosome
- 11. plastidial DNA
- 12. plastoglobule (drop of lipids)





Define the term *photosynthetic pigment*.
&
Explain the importance of photosynthetic pigments in photosynthesis.

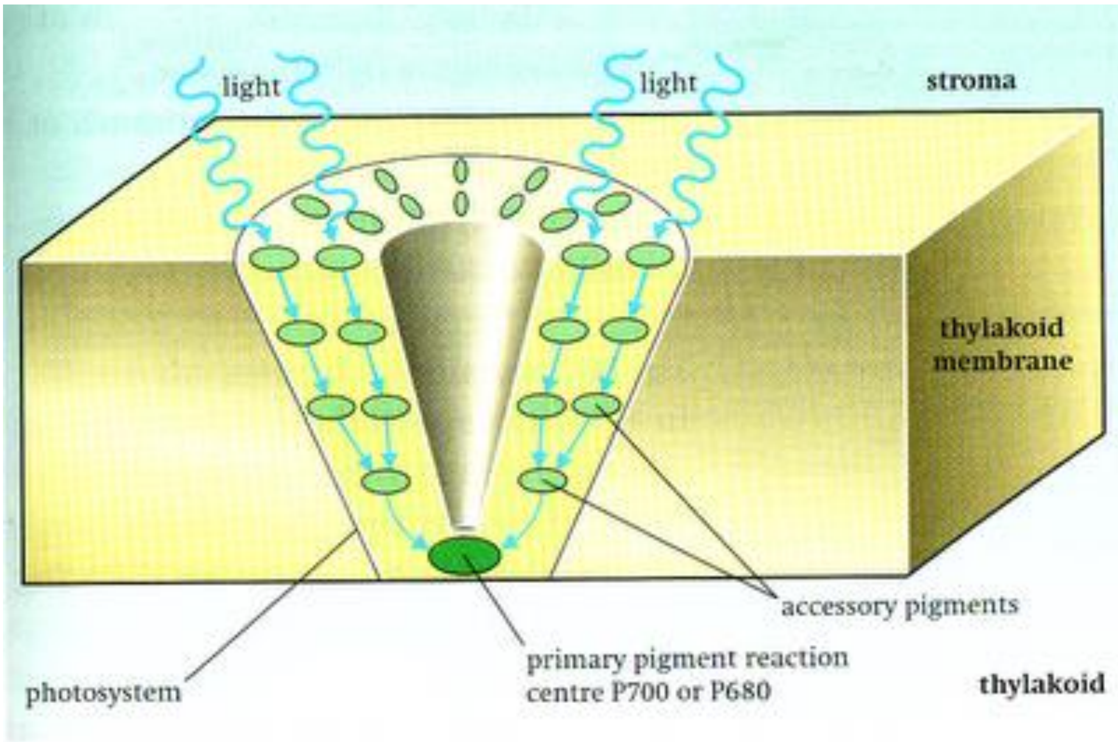
- Photosynthetic pigments
  - light absorbing
  - ref to excited electrons
  - used in light dependent stage;
  - ref. to location; e.g. chloroplasts, thylakoids,
  - Arrange in photosystems, grana, lamellae
  - different pigments absorb different wavelengths.



- **Primary Pigments – Chlorophyll a**
  - Cholorphyll a absorbs wavelengths of 450nm and either 680nm(P680) or 700nm (P700)
  - Chlorophyll a P680 is found in photosystem II (almost exclusively found in the Thylakoid membranes)
  - Chlorophyll a P700 is found in photosystem I (almost exclusively found in the intergranal lamellae)
  - Both appear yellow-green
  - Both are found in the primary pigment reaction centres
  - Release electrons when they are excited

- **Accessory pigments – Chlorophyll b and Carotenoids**
  - Both absorb different wavelengths of light that are not absorbed by chlorophyll a
  - Chlorophyll b absorbs wavelengths of 500nm and 640nm
  - Carotenoids absorbes wavelengths of around 520nm
  - Both are found at other parts of photosystem/antenna unit/surround reaction centre
  - They both transfer energy to primary pigments;
  - The main carotenoid pigments are carotene (Orange) and Xanthophyll (yellow)

- **Photosystems**
  - Proteins structures found in the thylakoid and intergranal lamellae membranes
  - They contain the photosynthetic pigments which absorb light energy



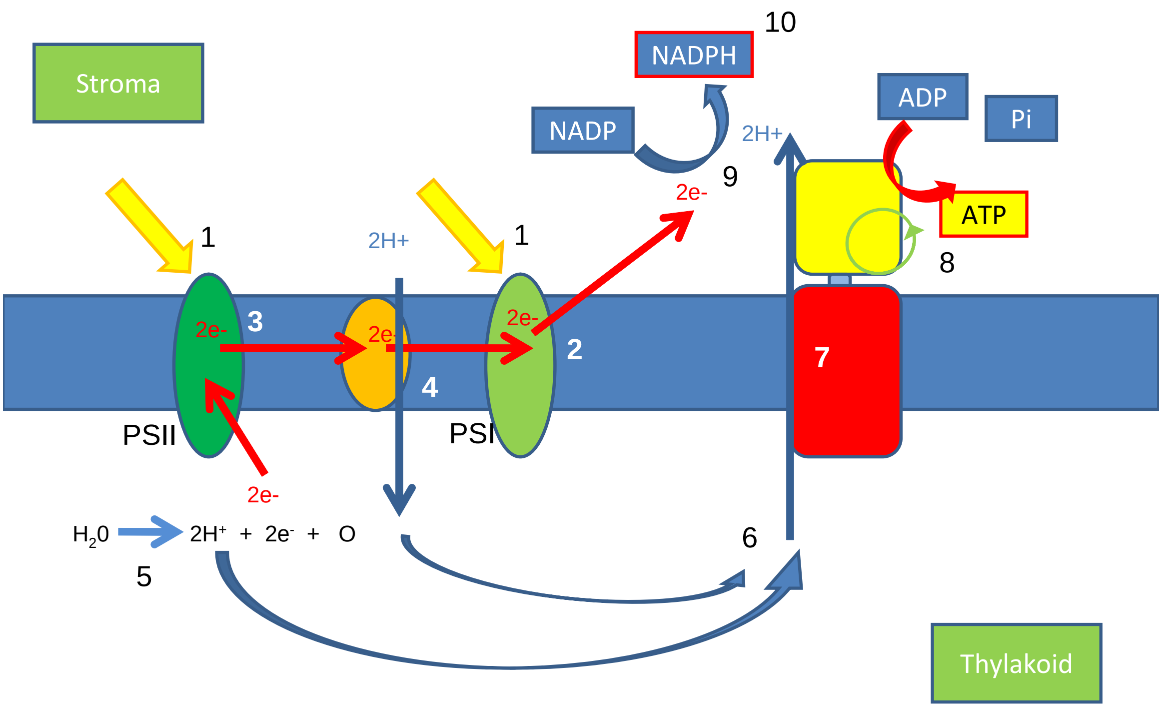
State that the light-dependent stage takes place in thylakoid membranes and that the light-independent stage takes place in the stroma.

- In plants photosynthesis is a two stage process which takes place in organelles called Chloroplasts
  - The light dependent stage
    - Takes place in the thylakoid and inter-granal lamellae membranes of chloroplasts
    - Requires photosystems containing the photosynthetic pigments
    - Utilises light energy and water and produces ATP and NADPH which are used in the light dependent stage
  - The Light independent stage (The Calvin cycle)
    - Takes place in the stroma of chloroplasts
    - Requires enzymes including RUBISCO in particular
    - Utilises Carbon Dioxide and produces Glucose

Outline how light energy is converted to chemical energy (ATP and reduced NADP) in the light-dependent stage.

- **Photophosphorylation**
  - The phosphorylation of ADP to ATP using light energy
  - Occurs in the membranes of thylakoids and intergranal lamellae
  - Involves photosystems

- **Non-cyclic Photophosphorylation**
  - Involves both PSI and PSII
  - Creates a lot of ATP
  - Creates reduced NADP (NADPH)
  - Involves the photolysis of water



1 Photons (light particles) strike photosystems I and II
2 Energy is transferred from the photons to electrons in the primary pigment reaction centre (Chlorophyll a P700) which become excited
Electrons leave the chlorophyll a and pass through into the stroma of the chloroplast.
3 Energy is transferred from the photons to electrons in the primary pigment reaction centre (Chlorophyll a P680) which become excited
Electrons leave the chlorophyll a and pass onto an electron carrier protein.
4 The electron carrier protein in turn becomes excited as it receives the electrons. As it becomes excited it pumps protons (H^+) across the thylakoid membrane into the thylakoid lumen from the stroma.

5 Photolysis of water in the thylakoid lumen. Enzymes in photosystem II split water into protons (H^+), electrons (e^-) and oxygen. The electrons replace those lost from photosystem II chlorophyll a in the primary pigment reaction centre.

6 The protons (H^+) from photolysis of water along with those pumped into the thylakoid lumen accumulate. This creates a proton gradient across the thylakoid membrane. The thylakoid lumen is acidic as a result of this build up.

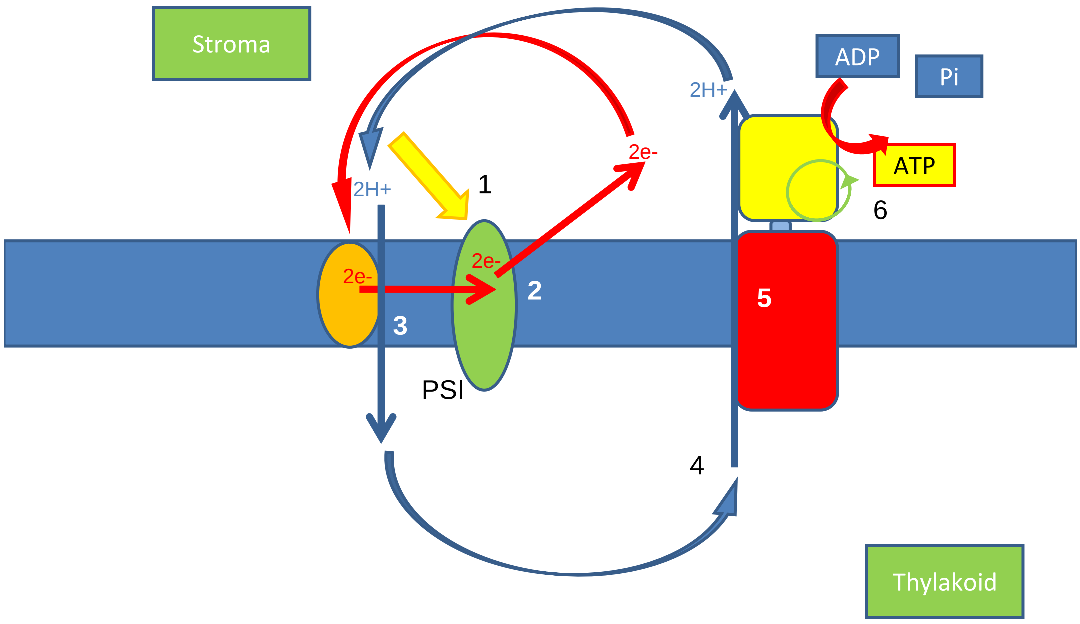
7 Protons cannot pass out of the thylakoid lumen as the inner membrane is impermeable to them. There is however places where they can pass out of the lumen into the stroma – through an enzyme called ATPsynth(et)ase. The protons flow down their concentration gradient by a process known as chemiosmosis.

8 This flow of protons through ATPsynth(et)ase generates a proton motive force. This proton motive force is used to turn the head unit of the ATPsynth(et)ase enzyme which physically combines a phosphate to ADP creating ATP. This is known as photophosphorylation.

9 The protons now in the stroma combine with the electrons lost from photosystem I to make hydrogen. This happens on a NADP coenzyme reducing it to NADPH.

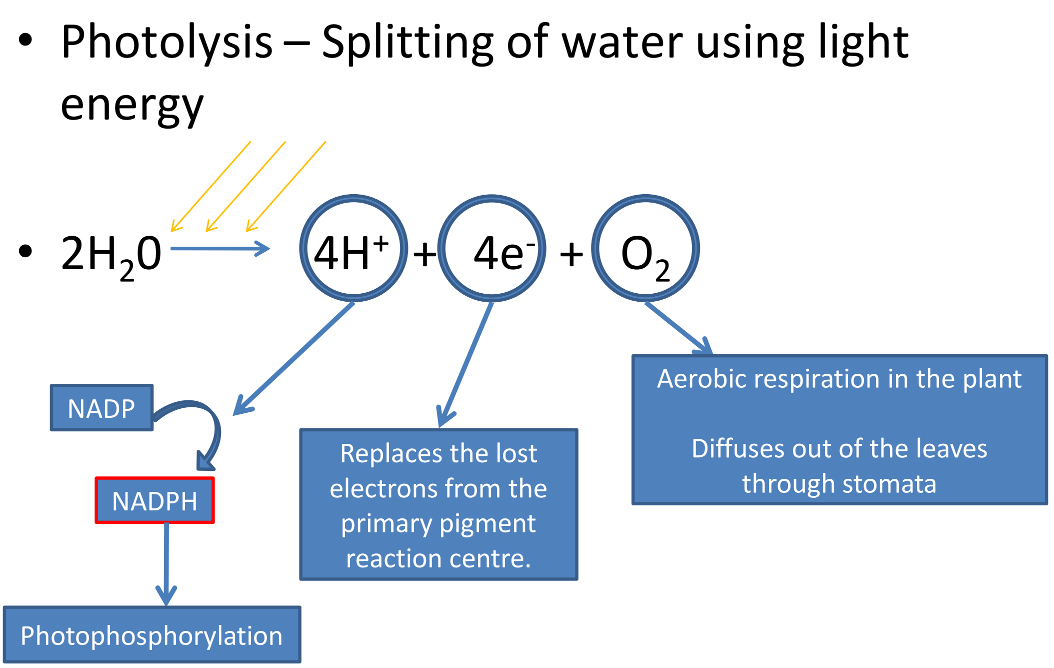
10 Both ATP and NADPH are in the stroma and are used here in the light independent stage of photosynthesis.

- **Cyclic Phosphorylation**
  - Involves only PSI
  - Creates a little ATP
  - Does not create reduced NADP (NADPH)
  - Does not involve the photolysis of water
  - Used to generate a little ATP to pump ions into guard cells so they open through turgor pressure.



1 Photons (light particles) strike photosystems I
2 Energy is transferred from the photons to electrons in the primary pigment reaction centre (Chlorophyll a P700) which become excited
Electrons leave the chlorophyll a and pass through into the stroma of the chloroplast.
3 The electrons move to the electron carrier protein which in turn becomes excited as it receives the electrons. As it becomes excited it pumps protons (H^+) across the thylakoid membrane into the thylakoid lumen from the stroma. The electrons then pass back to the chlorophyll a molecule of the primary pigment reaction centre. Completing a cycle, hence the name cyclic photophosphorylation
4 The protons pumped into the thylakoid lumen accumulate. This creates a proton gradient across the thylakoid membrane. The thylakoid lumen is acidic as a result of this build up.
5 Protons cannot pass out of the thylakoid lumen as the inner membrane is impermeable to them. There is however places where they can pass out of the lumen into the stroma – through an enzyme called ATPsynth(et)ase. The protons flow down their concentration gradient by a process known as chemiosmosis.
6 This flow of protons through ATPsynth(et)ase generates a proton motive force. This proton motive force is used to turn the head unit of the ATPsynth(et)ase enzyme which physically combines a phosphate to ADP creating ATP. This is known as photophosphorylation.
7 The protons now in the stroma are available to be pumped by the electron carrier protein again when it is excited by another electron.

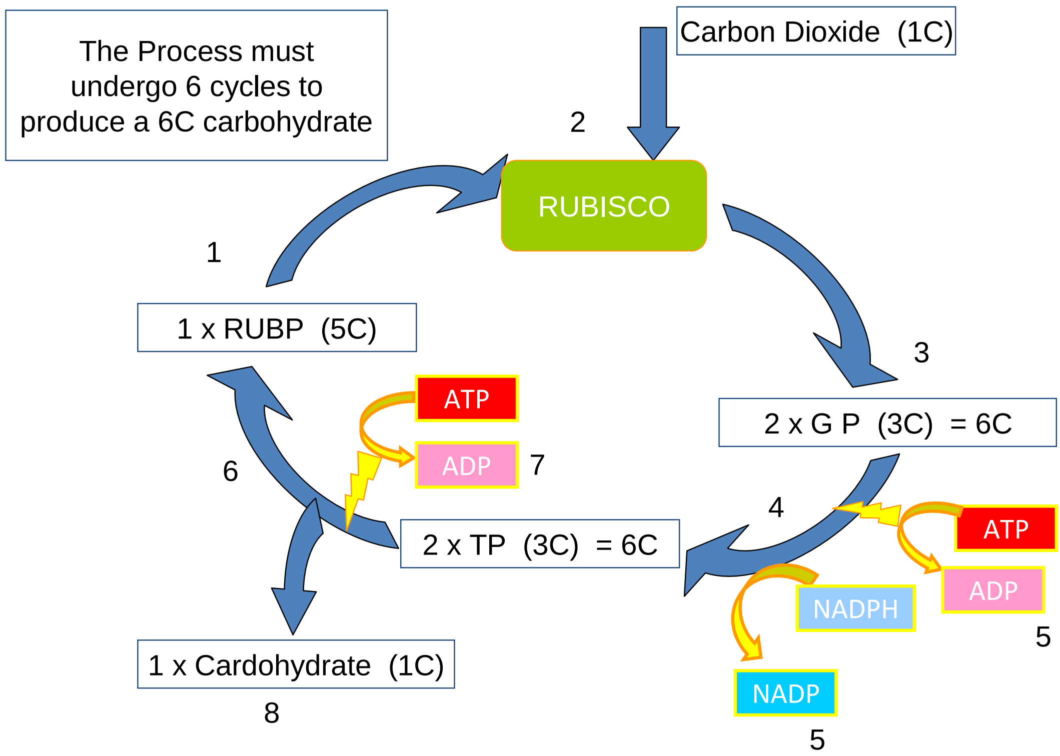
Explain the role of water in the light-dependent stage.



- **Photolysis of Water**
- Photosystem II contains an enzyme that, in the presence of light can split water into H^+ ions (protons), electrons and oxygen.
- Water is the source of H^+ ions which are used in chemiosmosis to produce ATP
- These protons are accepted by a coenzyme NADP, which becomes reduced NADP (NADPH) and is used in the light independent stage.

Outline how the products of the light-dependent stage are used in the light-independent stage (Calvin cycle) to produce triose phosphate (TP).
&
Explain the role of carbon dioxide in the light-independent stage (Calvin cycle).
&
State that TP can be used to make carbohydrates, lipids and amino acids.
&
State that most TP is recycled to RuBP.

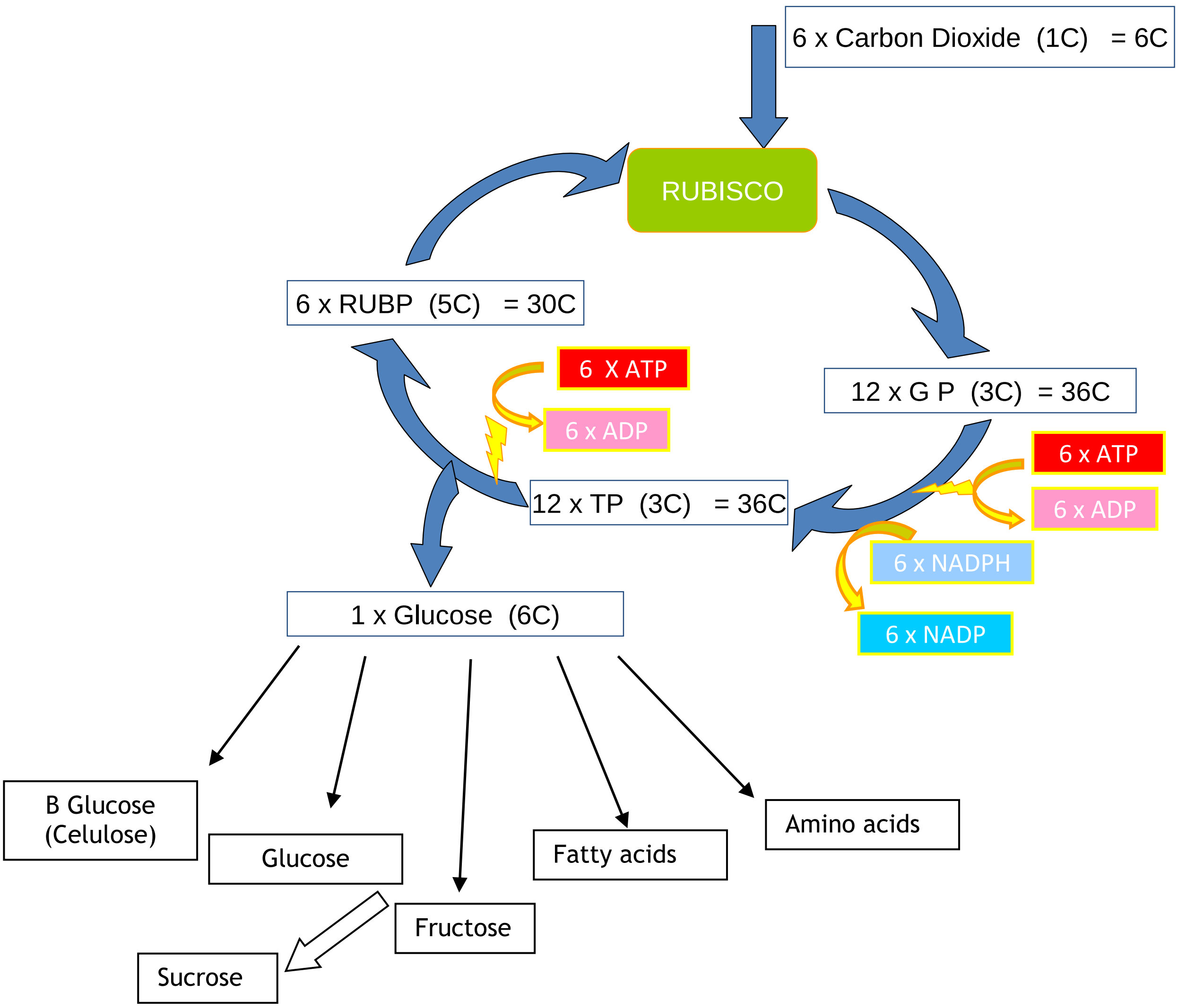
- **The light independent stage – The Calvin cycle**
    - Takes places in the stroma of chloroplasts



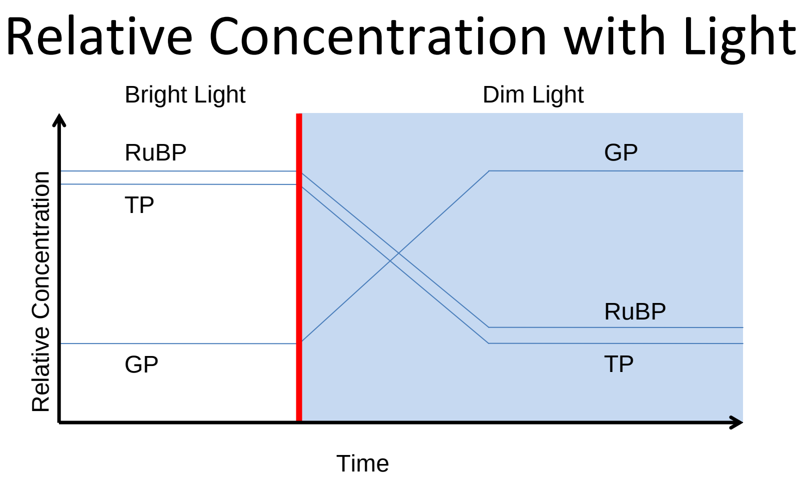
1. Ribulose bisphosphate (RUBP) is a 5 carbon molecule found in the stroma of chloroplasts.
2. RUBP binds to the active site of an enzyme RUBISCO (ribulose bisphosphate carboxylase oxygenase) along with carbon dioxide (1 carbon molecule).

3. RUBP (5C) and carbon dioxide (1C) are fixed to produce two molecules of GP (Glycerate-3-phosphate) each with 3 carbons (6C in total). If carbon dioxide is in short supply then RUBP is not converted to GP. This keeps RUBP levels high and GP levels low.
4. GP is stable and will remain as GP unless ATP and NADPH are produced from the light dependent reaction. If NADPH and ATP have been produced then the two molecules of GP are converted to two molecules of TP (a triose phosphate), both of which are also 3 carbon molecules.
5. NADPH will become oxidised to NADP and ATP will be hydrolysed to ADP releasing energy. Both NADP and ADP are now available to be recycled in the light dependent stage of photosynthesis.
6. TP is stable and will remain as TP unless ATP is produced from the light dependent reaction. If ATP has been produced then most of the two molecules of TP are recycled back into the 5 carbon molecule of RUBP. ADP are now available to be recycled in the light dependent stage of photosynthesis.
7. ADP are now available to be recycled in the light dependent stage of photosynthesis.
8. One carbon of TP per cycle is not recycled back to RUBP but in fact will make 1/6 of a glucose molecule. The cycle happens 6 times to produce a 6 carbon hexose sugar = Glucose.

So it looks like this



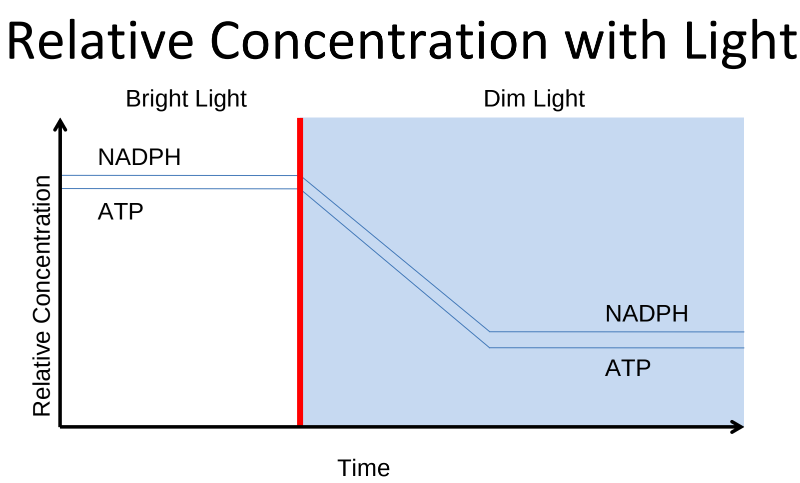
Describe the effect on the rate of photosynthesis, and on levels of GP, RuBP and TP, of changing carbon dioxide concentration, light intensity and temperature.

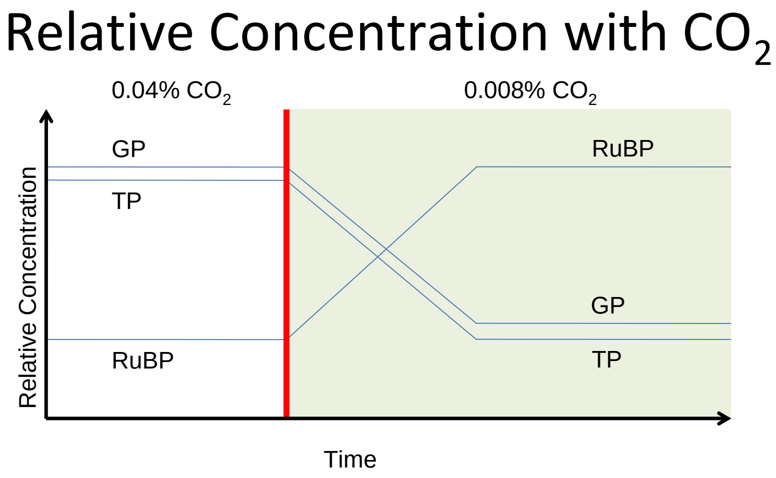


- **In bright light**
  - GP levels are low because, a lot of ATP and NADPH are being made in the light dependent stage of photosynthesis
  - This means that GP is quickly converted to TP and also RUBP keeping these molecules in higher concentrations.

- **In dim light**
  - GP levels rise as it is not able to be converted to TP and RUBP as there is less ATP and NADPH.
  - This results in TP and RUBP levels decreasing.

- Below shows the relative concentrations of ATP and NADPH with light levels.





- **In high concentrations of Carbon dioxide**
    - RUBP levels are low as Carbon dioxide is not a limiting factor.
    - Carbon dioxide is constantly binding to the active site of RUBISCO and so whatever RUBP molecules there are, are being fixed to the carbon dioxide and converted to GP.
    - This results in low RUBP levels and high GP and TP levels.

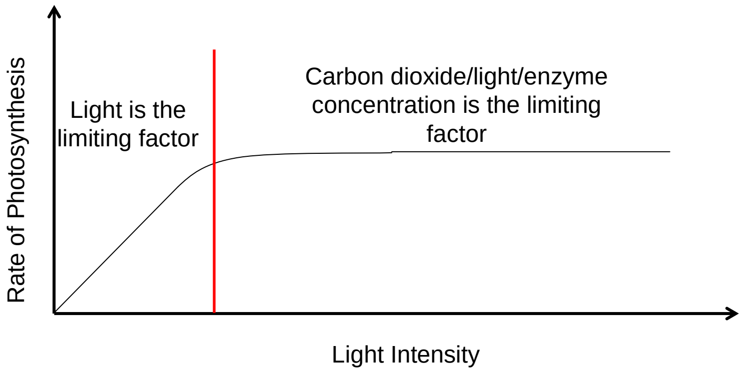
- **In low concentrations of Carbon dioxide**
    - RUBP levels start to increase as Carbon dioxide becomes the limiting factor.
    - Carbon dioxide is not available to bind to the active site of RUBISCO and so regardless of the level of RUBP molecules there is not enough carbon dioxide to fix to it and convert it to GP.
    - This results in high RUBP levels and low GP and TP levels.

- **Temperature levels**
- Temperature levels will affect several aspects of photosynthesis
- Increasing temperature will increase the rate of enzyme activity in the light independent stage, in particular RUBISCO in the light independent stage and ATPsynth(et)ase in the light dependent stage.
- However too much temperature will denature these enzymes and stop photosynthesis entirely.
- Above 25°C oxygenase activity of Rubisco increases faster than its carboxylase activity
- So ATP and reduced NADP dissipated and wasted
- Reduces overall rate of photosynthesis
- Increasing temperature will increase water loss and closure of stomata
- Increasing temperature will increase diffusion rate and hence chemiosmosis in the light dependent stage at the thylakoid and intergranal lamellae membranes.

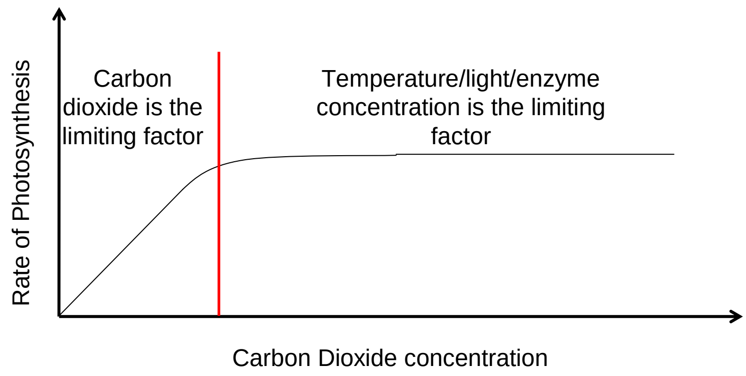
Discuss limiting factors in photosynthesis, with reference to carbon dioxide concentration, light intensity and temperature.

- **Limiting Factor**
    - A variable that limits the rate of a particular process (in this case photosynthesis).
    - If the factor is increased then the process will take place at a higher rate.
    - Where the process is affected by a number of different factors the limiting factor is the one whose magnitude limits the rate of the process.

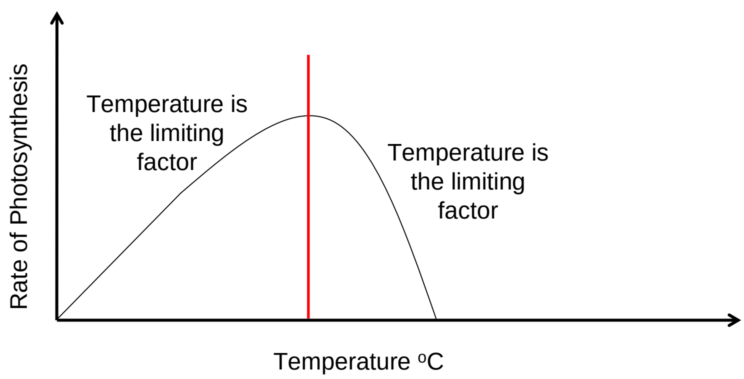
- **Limiting factors for photosynthesis will be**
- Light intensity
    - Light intensity limits photosynthesis in the light dependent stage
    - Low light intensity means less photons strike the photosystems
    - Less excitation of electrons and so less NADP reduced to NADPH and less ATP produced.



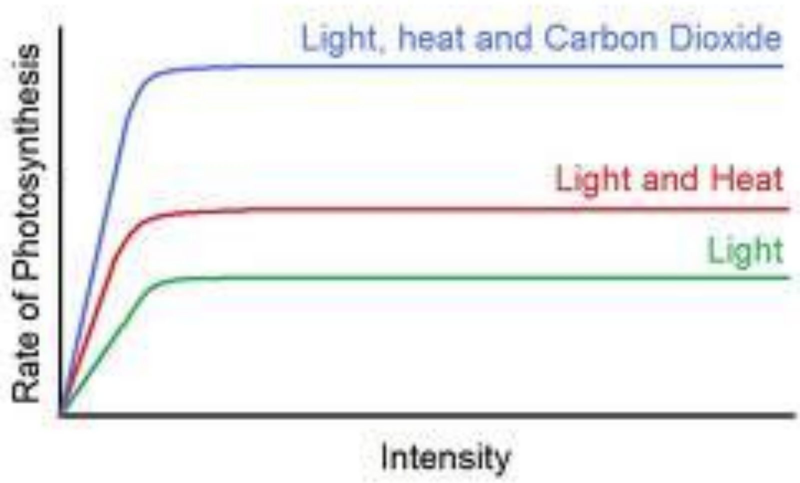
- Carbon dioxide concentration in the air
    - Carbon dioxide concentration limits photosynthesis in the light independent stage
    - Low carbon dioxide concentration means less action of the enzyme RUBISCO
    - Less RUBP is fixed to carbon dioxide producing less GP and hence less TP.
    - Less glucose is produced.

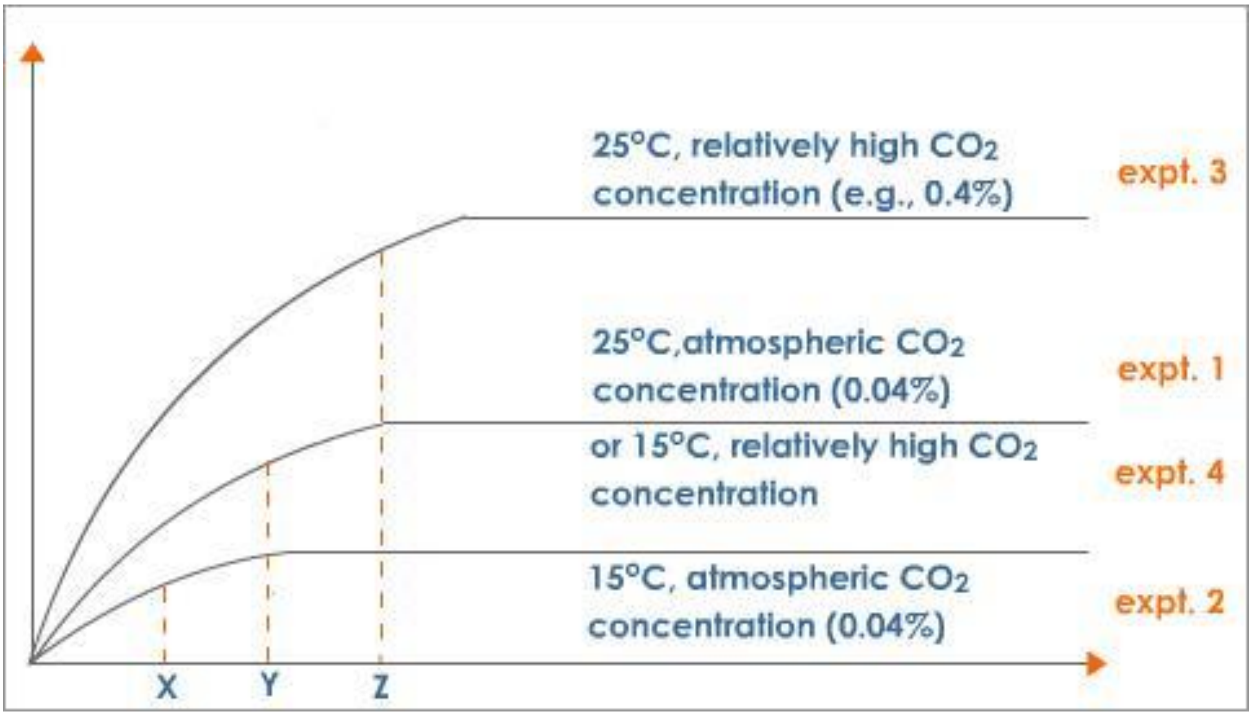


- Temperature
  - temperature limits photosynthesis in the light independent stage
  - Low temperatures means less action of the enzyme RUBISCO and ATPsynth(et)ase
  - High temperatures would lead to denaturation of RUBISCO and ATPsynth(et)ase
  - Less RUBP is fixed to carbon dioxide producing less GP and hence less TP.
  - Less glucose is produced.
  - less ATP produced.



- Water availability
  - water limits photosynthesis in the light independent stage
  - Low water levels no photolysis of water and hence a shortage of electrons.
  - fewer electrons means less NADP reduced to NADPH and less ATP produced.
  - Less water leads to stomatal closure and so less gas exchange (i.e. less carbon dioxide available)
  - Less RUBP is fixed to carbon dioxide producing less GP and hence less TP.
  - Less glucose is produced.





Describe how to investigate experimentally the factors that affect the rate of photosynthesis.

- There are many ways to measure photosynthesis including the uptake of substrates or the appearence of products

- We could measure
    - Volume of oxygen produced
    - Amount of carbon dioxide used
    - Increase in dry mass of plant

    - It is usually measured using the volume of oxygen produced per minute by an aquatic plant
    - Although this has some limitations
    - Some of the oxygen that is produced will be used by the plant in respiration
    - There could be some dissolved nitrogen in the gas collected
    - Some oxygen could be trapped in the leaves

    - The apparatus used is a Photpsynthometer (audus microburette)
    - It is set up so it is air tight with no air bubbles

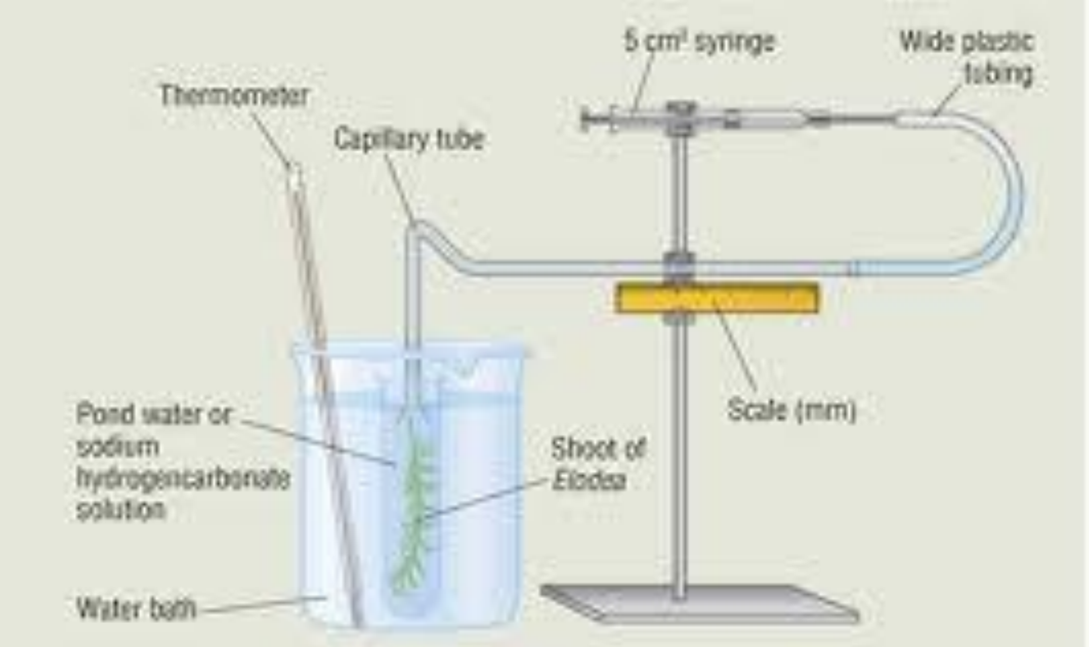
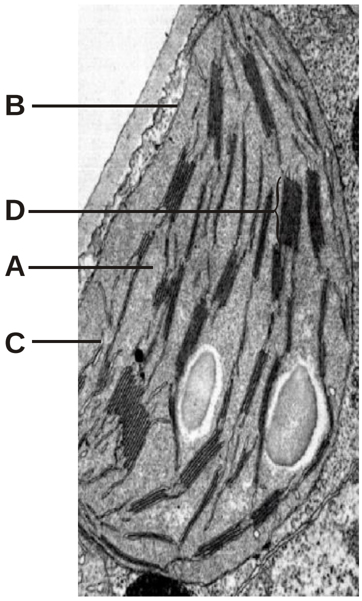


Figure 1 A photosynthometer – apparatus used to measure the rate of photosynthesis under various conditions

- **Setting up the experiment**
  - Fill the apparatus with water, including the syringe until it is completely full with no air bubbles
  - Cut a piece of well illuminated Elodea (Canadian pondweed) about 7cm long and make sure that bubbles of gas are emerging from the cut end
  - Place the elodea cut end up into a test tube containing the same waster the pondweed is kept in
  - Add two drops of Hydrogencarbonate solution
  - Stand the test tube in a beaker full of water at 20ºC
  - Place a light source as close to the beaker as possible
  - Measure the distance (d) from the piece of pondweed to the light source
  - Light intensity (*I) can* be calculated using the following formula
    - **$I = 1/d^2$**
  - Leave apparatus for 5-10 minutes to allow the plant to acclimatise
  - Position the elodea under the flared end of the tube for a set period of time (i.e. 5 minutes)
  - Gently pull on the syringe and draw the gas bubble out of the elbow bend into the main body of the capillary tube so the length of the bubble can be read from the scale.
  - Read and record the length of the bubble.
  - Rest the apparatus and repeat
  - Conduct the same again under different light intensities, temperatures, or carbon dioxide concentrations using water baths.

- Photosynthesis rate could also be calculated using the changes in density of leaf discs.

1. The figure below is an electronmicrograph of a chloroplast.



Identify the structures labelled **A** to **D**.

A ....

B ....

C ....

D ....

[Total 4 marks]

2. Photosynthetic pigments fall into two categories: primary pigments and accessory pigments.

Explain the difference between primary and accessory pigments.

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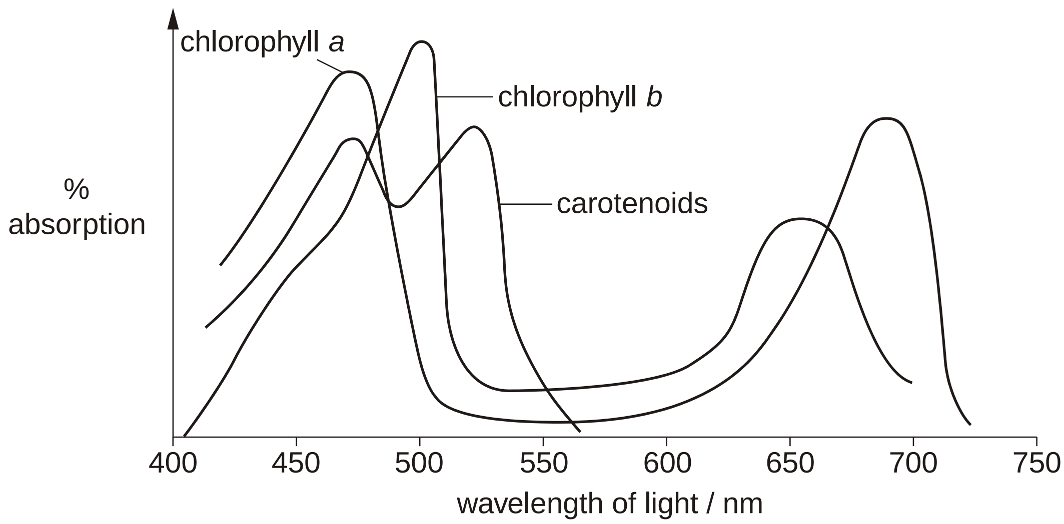
[Total: 2 marks]

3. The figure below shows the absorption spectra for three different photosynthetic pigments.



(i) Explain what is meant by the term *photosynthetic pigment*.

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[3]

(ii) Using the figure above, describe the pattern shown by chlorophyll *a*.

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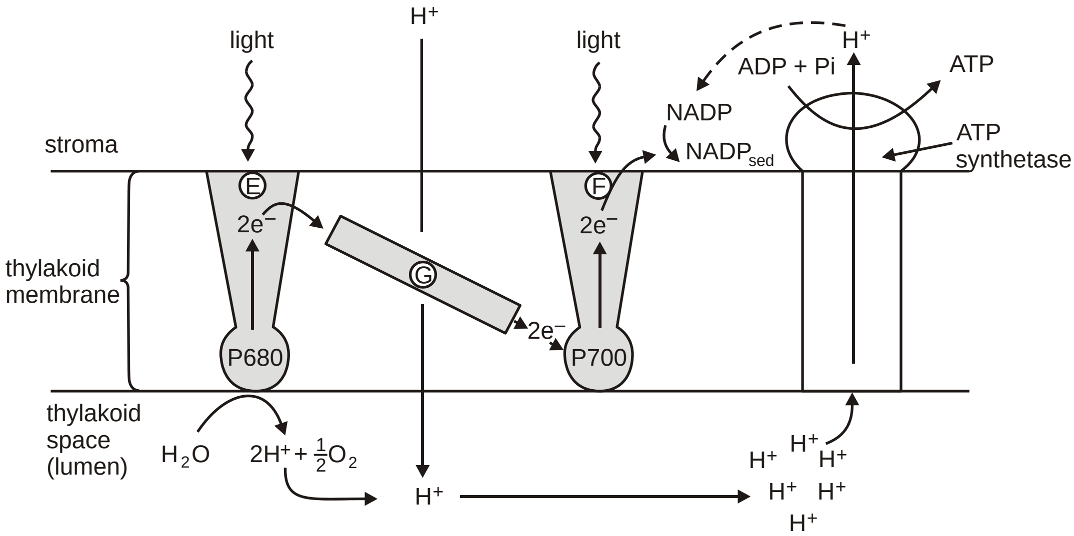
[2]

[Total 5 marks]

4. The light-dependent stage of photosynthesis takes place on thylakoid membranes in chloroplasts. These membranes surround the thylakoid space (lumen) and are arranged into stacks known as grana. Below is a diagram showing the arrangement of photosystems in the thylakoid membrane, and summarising the processes that take place there.



(a) (i) Name the pigment represented by P680 and P700.

.... [1]

(ii) Name the **type** of molecule represented by **G**.

.... [1]

(b) Explain, **using the information in the diagram**, why the pH of the thylakoid space (lumen) is lower than that of the stroma **and** what significance this has for ATP production.

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[4]

[Total 6 marks]

5. In this question, one mark is available for the quality of the use and organisation of scientific terms.

Photosynthetic pigments are arranged in light-harvesting clusters called photosystems.

Describe how the light energy absorbed by these photosystems is converted into chemical energy in the **light dependent stage** of photosynthesis.

[8]

4.3.1

Quality of Written Communication [1]

[Total: 9 marks]

6. In this question, one mark is available for the quality of spelling, punctuation and grammar.

In the palisade cells of a leaf, the fixation of carbon dioxide occurs in the Calvin cycle.

Describe the main features of this cycle. **No credit will be given for a flow diagram of the cycle**.

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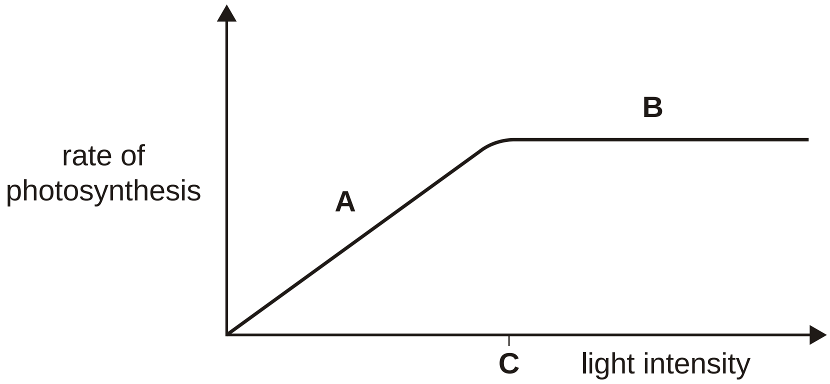
[7]

Quality of Written Communication [1]

[Total 8 marks]

7. The rate of photosynthesis is affected by a number of environmental factors. The figure below shows the effect of light intensity on the rate of photosynthesis.



(i) State the limiting factor in region **A** of the graph.

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[1]

(ii) Explain why there is no further increase in the rate of photosynthesis beyond point **C**.

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[2]

[Total 3 marks]

8. For many plants living in temperate regions the optimum temperature for photosynthesis is approximately 25°C.

Explain why the rate of photosynthesis decreases at temperatures above 25°C.

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[Total 4 marks]