Bio Factsheet

Number 2

The essential guide to photosynthesis

Photosynthesis is the use of light energy from the sun to fix carbon dioxide i.e. turn it into sugars. These sugars can then be converted into other essential substances - fats and proteins etc. - which plants need to live and grow. At GCSE level the process of photosynthesis is represented by the following equation:

$6CO_2$ +	$6H_2O$	Light energy →	$C_6H_{12}O_6$ +	$6O_2$
Carbon dioxide, a colourless gas which makes up 0.04% (by volume) of the atmosphere. Enters through microscopic pores (stomata) on leaves.	Root hairs absorb water passively i.e. no energy is required. Water is needed to: 1. Keep plant tissues turgid eg. to maximise leaf surface area for light absorption. 2. As a source of electrons in non-cyclic photophosphorylation (Fig 2). 3. As a solvent (all chemical reactions must occur in solution).	The reaction is catalysed by light energy absorbed by chlorophyll contained in chloroplasts in leaves and green stems.	Glucose, which can be used to make other substances such as fats and proteins etc.	Oxygen, which may be used by the plant in respiration or which may diffuse out of the leaves via the stomata.

The equation is an over-simplification. 1. There is clear evidence that photosynthesis occurs in two stages - one which is light dependant (the LDS) and one which is light independent (the LIS). 2. Glucose is not the first or only useful product. 3. Only visible light - a small part of the electromagnetic spectrum - is used. 4. Certain wavelengths are much more important than others

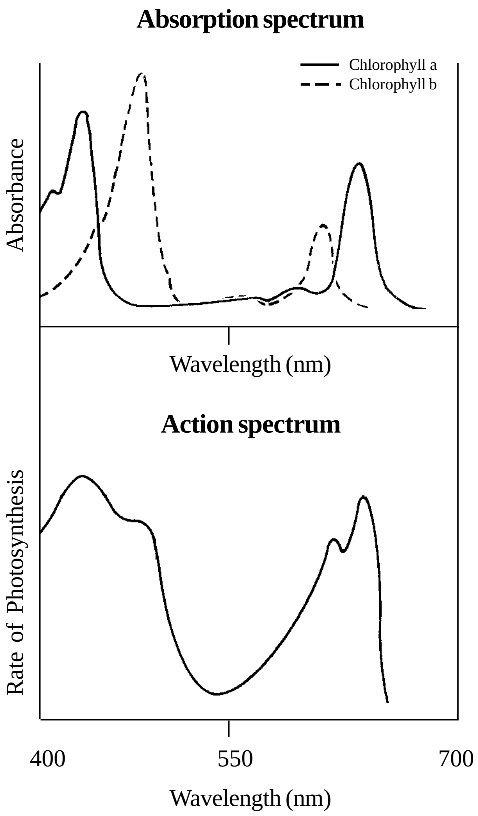
Chlorophyll and light absorption
Chlorophyll absorbs light from the visible part of the electromagnetic spectrum. Chlorophyll is made up of a number of different pigments: chlorophyll a, chlorophyll b, chlorophyll c along with other pigments such as carotenoids. Each of these absorb different wavelengths of light so that the total amount of light absorbed is greater than if a single pigment were involved.

Not all wavelengths of light are absorbed equally. An **absorption spectrum** is a graph showing the percentage absorption plotted against wavelength of light (Fig 1).

An **action spectrum** is a graph showing the rate of photosynthesis plotted against wavelength of light (Fig 1).

The similarity between the absorption spectrum and the action spectrum shows that red (650-700nm) and blue (400-450nm) wavelengths, which are absorbed most strongly, are also the wavelengths which stimulate photosynthesis the most. Green light (550mm) is mostly reflected.

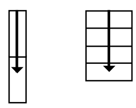
Fig 1. The absorption and action spectra



Typical Exam Question
Why do leaves appear green?

Structure to function: chloroplast
1. *Internal compartmentalisation. LDS and LIS effectively separated, thus allowing rate-determining factors such as pH and enzyme concentrations to be optimized.*
2. *DNA and ribosomes means chloroplast can code for and produce its own proteins eg. enzymes such as RuBPC.*
3. *Double membrane provides control of substances entering/ leaving the organelle.*
4. *Thylakoid membranes provide large surface area for light absorption.*

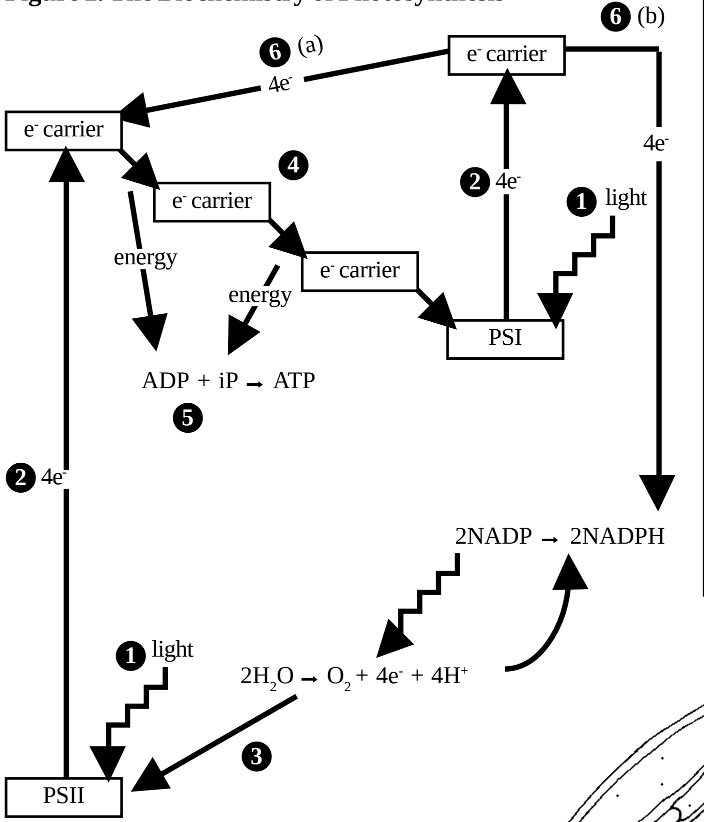
Structure to function: the leaf
1. *Thin, therefore rapid light penetration.*
2. *Waxy cuticle reduces water loss.*
3. *Upper epidermis transparent to light.*
4. *Palisade mesophyll arranged at 90° to surface of leaf minimising amount of light absorbed by cell walls before it reaches chloroplasts.*



5. *Chloroplasts in palisade mesophyll are capable of being moved to optimise light absorption.*
6. *Spongy mesophyll has many air spaces therefore rapid gaseous diffusion.*

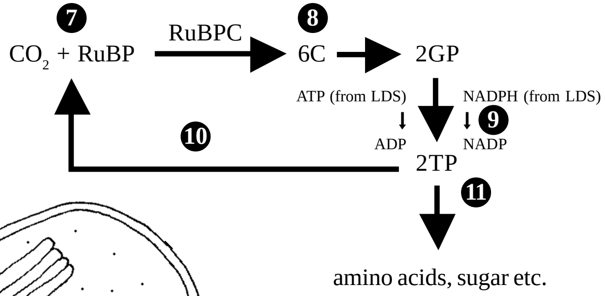
Exam Hint *- Structure: function is a key concept on all syllabuses. The strongest candidates will demonstrate a clear understanding of the adaptations of photosynthetic organs, tissues, cells and organelles.*

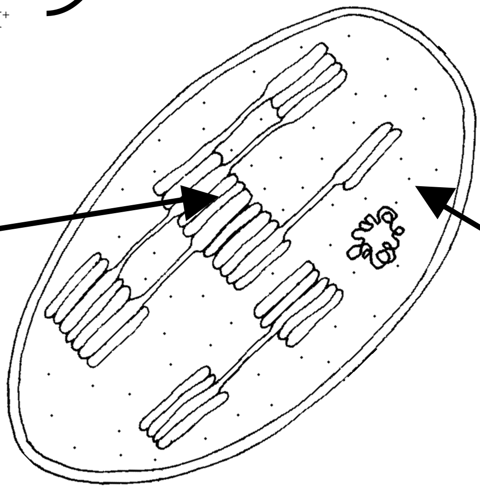
Figure 2. The Biochemistry of Photosynthesis



Key

PSI:	Photosystem 1
PSII:	Photosystem 2
e^-:	Electrons
e^- carrier	Electron carrier eg. ferredoxin
ADP:	Adenosine diphosphate
ATP:	Adenosine triphosphate
iP:	Inorganic phosphate
NADP:	Nicotinamide adenine dinucleotide phosphate
RuBP:	Ribulose bisphosphate
RuBPC:	Ribulose bisphosphate carboxylase
GP:	Glycerate-3-phosphate
TP:	Triose phosphate





Light Dependent Stage (1-6)
Occurs in thylakoids

NCP products
1. Oxygen
2. Hydrogen ions
3. ATP.

CPP products
1. ATP

Light Independent Stage (7-11)
Occurs in Stroma
Products; sugar - which can be converted into fats, amino acids etc.

Typical exam question
Differentiate cyclic photophosphorylation and non-cyclic photophosphorylation.

Exam Hint *- Able candidates should demonstrate their understanding that the LIS is dependant on two of the products of the LDS. Often however, candidates confuse the two stages or suggest that they are independent of each other.*

1. Light energy is absorbed by chlorophyll molecules in PSI and PSII.
2. The electrons in the chlorophyll molecules are boosted to a higher energy level and are emitted.
3. The loss of electrons from PSII stimulates the loss of electrons from water i.e. it stimulates the splitting or photolysis of water. O_2 is given off.
4. The electron from PSII passes through a series of electron carriers. At each transfer some energy is released.
5. This energy is used by cytochromes to pump protons (H^+ ions) from the stroma across the thylakoid membranes. This sets up an electrochemical or H^+ gradient. The H^+ ions then diffuse back through a protein which spans the thylakoid membrane. Part of this protein acts as an enzyme - ATP synthetase - which uses the diffusion of H^+ to synthesise ATP.
6. The electrons emitted from PSI may:

a) Pass down through the same carrier molecules as the electrons from PSII, again generating ATP. Before returning to PSI. Thus electrons are **cycled** (PSI → carriers → PSI → carriers etc. The energy to begin this **cycle** came from light (**photo**) and is used to convert ADP to ATP i.e. to **phosphorylate** ADP (add a phosphate). Hence this process is called **cyclic photophosphorylation (CPP)**.

or

b) Combine with the hydrogen ions (protons) released from the photolysis of water to reduce nicotinamide adenine dinucleotide phosphate (NADP), forming NADPH.

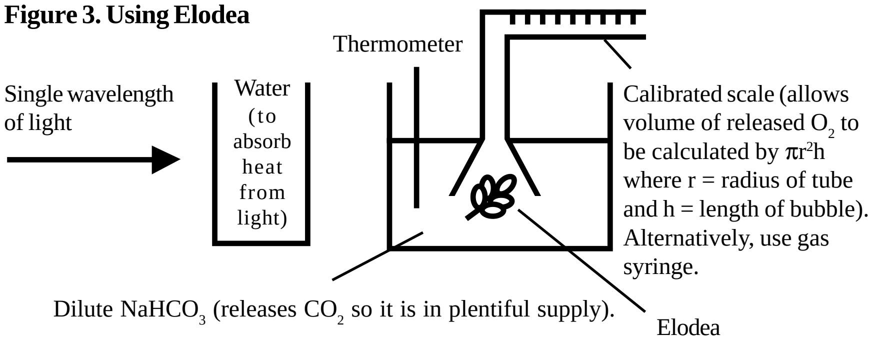
Non cyclic photophosphorylation (NCP) occurs when electrons are emitted from water and then pass to PSII → carrier (with ATP production) → PSI → carriers → NADPH.

Reactions 1-6 make up the **Light Dependent Stage**. The ATP and NADPH produced diffuse into the stroma where the **Light Independent Stage** occurs (7-11).

7. CO_2 combines with a 5C compound called ribulose bisphosphate. This reaction is catalysed by the enzyme RuBPC.
8. The 6C compound formed immediately splits into two molecules of glycerate-3-phosphate (GP).
9. The GP molecules are converted into molecules of triose phosphate (TP) using energy from ATP and the hydrogen atom from NADPH i.e. the two useful products of the LDS are now used up in the LIS.
10. Some of the TP is used to regenerate RuBP.
11. The rest of the TP is used to produce other essential substances which the plant needs - fats, proteins etc.

Photosynthesis investigations

Figure 3. Using Elodea



1. Constructing an action spectrum

Individual wavelengths of light are projected onto Elodea and the amount of oxygen (No. of bubbles/minute or volume/minute) given off from each wavelength is measured.

Precautions

1. *Each wavelength must be of similar intensity and be shone for the same length of time.*
2. *Temperature of solution surrounding Elodea must not change.*
3. *All light, other than wavelength being tested, must be excluded.*

Limitations

1. *Bubbles may become trapped and therefore not be measured.*
2. *If No. of bubbles is used, there is an assumption that all bubbles are of the same volume - this is unlikely.*
3. *Temperature/rate of release of CO_2 from $NaHCO_3$ may vary.*

2. Investigating the factors which affect the rate of photosynthesis

This apparatus can also be used to investigate the effect of changing light intensity (LI), carbon dioxide concentration [CO_2]and temperature (T°) on the rate of photosynthesis. In each, the volume of oxygen released over a certain time period is taken as an index of the rate of photosynthesis

• Light Intensity (LI).

A light is placed at different distances from the Elodea. A graph of volume of oxygen/ distance of LI is plotted (light intensity is proportional to $1/d^2$ where d = distance of light from plant).

Precautions

1. *Exclude background light*
2. *Keep T°,* [$NaHCO_3$] *and wavelength constant and time period for each LI equal.*

• *Carbon Dioxide Concentration* [CO_2]

[CO_2] *is varied by using different concentrations of $NaHCO_3$*

Precautions

1. *Keep LI, T° and wavelength constant and time period for each* [CO_2] *equal.*

• Temperature (T°)

T° is varied by adding ice, cold or warm water as appropriate.

Precautions

1. *Keep LI,* [$NaHCO_3$] *and wavelength constant and time period for each T° equal.*

Typical Exam Questions

1. ***Plot a graph of O_2 evolution against T°, LI or* [$NaHCO_3$].**
2. ***Suggest possible sources of error in the above investigations.***

Separating Chlorophyll Pigments

1. *Cut up green leaves and macerate with a solvent eg. acetone. Maceration breaks cell walls, releasing chlorophyll, which dissolves.*
2. *Use a micro-pipette to build up a concentrated spot of chlorophyll solution on the bottom of a piece of chromatography paper. Allow a spot to dry before each new application.*
3. *Suspend bottom edge of paper* ***but not the chlorophyll spot in solvent****. Seal with a bung. Solvent diffuses up paper and the individual chlorophyll pigments dissolve and are carried up the paper. Since they are differentially soluble, they move different distances.*
4. *Cut out the individual pigments and redissolve to obtain individual pigment solutions.*

Investigating the LIS

The biochemical pathway of the Light Independent Stage can be investigated by using radioactively-labelled carbon dioxide ($^{14}CO_2$), as follows:

1. *A suspension of green algae are fed a radioactive sodium hydrogen carbonate solution ($NaH^{14}CO_3$).*
2. *The algae immediately began to fix the carbon dioxide. The radioactivity will then be present in any compounds formed during the Light Independent Stage. At 5 second time intervals a sample of the algae are removed and killed using hot alcohol.*
3. *The biochemical contents of the algal chloroplasts are then separated using chromatography.*
4. *The chromatogram is then dried and a piece of x-ray film is placed over it. Any radioactive compounds - formed from the $^{14}CO_2$ - cause the film above them to fog. By identifying these substances and analysing the sequence in which they formed, Calvin unravelled the biochemical pathway of the LIS.*

Practice Questions

1. Define the term **action spectrum** (2 marks)

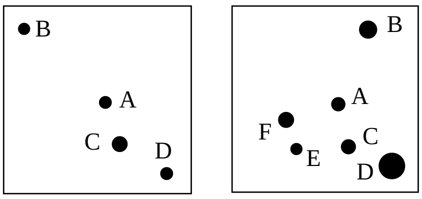
2. Distinguish between cyclic and non-cyclic photophosphorylation (4 marks)

3. Outline the role of each of the following in photosynthesis:
   (a) light (2 marks)
   (b) ATP (1 mark)

4. Explain how structure and function are related in each of the following:
   (a) a palisade mesophyll cell (3 marks)
   (b) a chloroplast (2 marks)

5. Describe, in outline, an experiment which you could use to investigate the effect of temperature on the rate of photosynthesis

6. In a photosynthesis investigation, a solution of $NaH^{14}CO_3$ was supplied to a well-lit suspension of green algae. At five second intervals, samples of the algae were treated with hot alcohol and analysed by chromatography. A photographic film was placed over the chromatograms. The distribution of spots on two chromatograms is shown below.



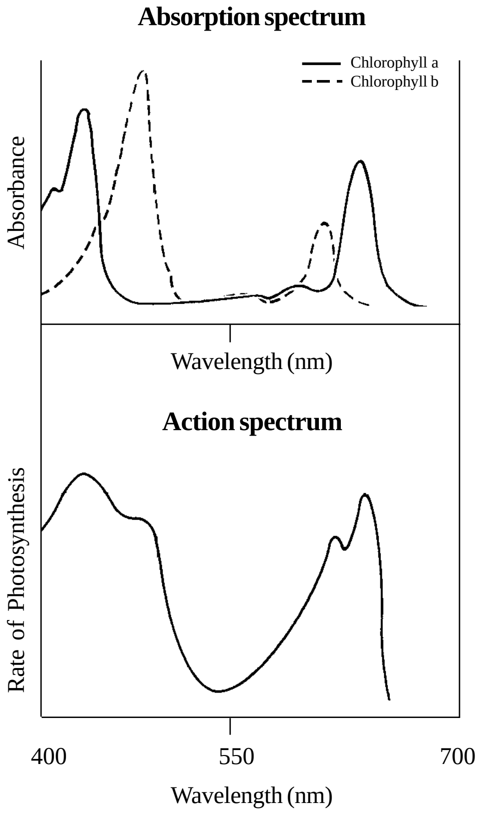
5 seconds 20 seconds

   (a) Suggest why each of the following were used:

   (i) $NaH^{14}CO_3$
   (ii) Hot alcohol
   (iii) Photographic film

   (b) What stage of photosynthesis is being investigated?

7. The diagram below shows the absorption and action spectra for some chloroplast pigments.



   (a) State which wavelength of light is best absorbed by chlorophyll a (1 mark)

   (b) Comment on the relationship between the absorption spectrum and the action spectrum (2 marks)

   (c) Explain why most plants appear green in colour. (1 mark)

Answers
(semicolons indicate marking points)

1. A graph;
   which shows the effectiveness of different wavelengths in stimulating photosynthesis;

2. Cyclic photophosphorylation - the process in which electrons are emitted from PSI;
   Electrons pass through carriers with the production of ATP;
   and back to PSI;
   Non-cyclic photophosphorylation - the process in which electrons are emitted from PSII;
   pass through carriers with the production of ATP;
   pass to PSI;
   loss of electrons from PSII stimulates photolysis;

3. (a) Provides energy for excitation of electrons in PSI and PSII;
   Provides energy for photolysis;

   (b) Provides energy to convert GP to TP;

4. (a) Oriented at 90° to leaf surface;
   therefore minimising the amount of light absorbed by cross walls;
   Chloroplasts are arranged around the inner edges of the cell;
   increases light absorption;
   chloroplasts can be moved to optimise light absorption;

   (b) Show internal compartmentalisation;
   Light independent stage and light dependent stage reactions are kept separate;
   increases efficiency;
   Thylakoids provide a large surface area for pigments;
   increases efficiency of light absorption;

5. Draw apparatus (see Figure 3);
   Vary temperature by adding ice/cold/hot water;
   ensure mixing and equilibration;
   use four different temperatures;
   plot graph of oxygen emitted/temperature.

6. (a)
   (i) Provides a source of CO_2;
   (ii) Immediately kills algae;
   (iii) Detects radioactivity and therefore fixation of carbon atoms;

   (b) Light independent stage;

7. (a) red;

   (b) close correlation;
   wavelengths absorbed are those used;

   (c) green light is reflected;

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