Bio Factsheet

Number 63

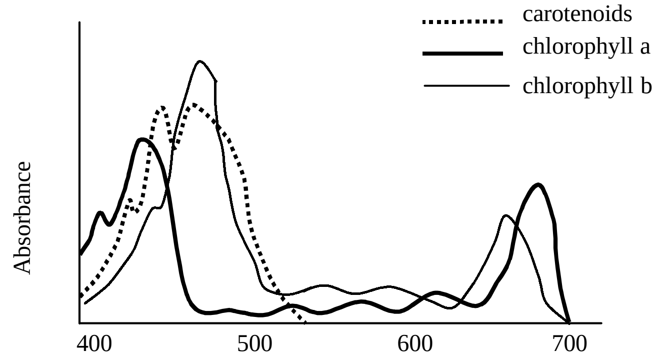
Pigments in Plants

Pigments in plants have the following roles:
- **the photosynthetic pigments trap solar energy and change it into chemical energy which enables the plant to fix carbon dioxide and so synthesise food substances.**
- **pigments are used to colour flowers to make them attractive to pollinating insects, and to colour fruits to make them attractive to animals enabling seed dispersal.**
- **pigments are used to control the photoperiod of plants which regulates when they flower.**

The photosynthetic pigments

In plants these fall into two chemical classes, the **chlorophylls** and the **carotenoids**. They are located on the chloroplast thylakoid membranes (grana) and the disc-shaped chloroplasts are arranged in cells so that the membranes are at right angles to the source of light, enabling maximum absorption. The chloroplasts of higher plants contain chlorophyll a, chlorophyll b, β-carotene and sometimes the carotenoid, xanthophyll. These pigments all absorb light but over slightly different wavelength ranges. Thus, by containing several pigments the plant can absorb a wider range of light. Generally green wavelengths are reflected rather than absorbed – which is why plants are green in colour. The light absorption spectra of these pigments is shown in Fig 1. Note that it is mainly red and blue wavelengths that are absorbed.

Fig 1. Absorption spectra of chlorophylls and carotenoids

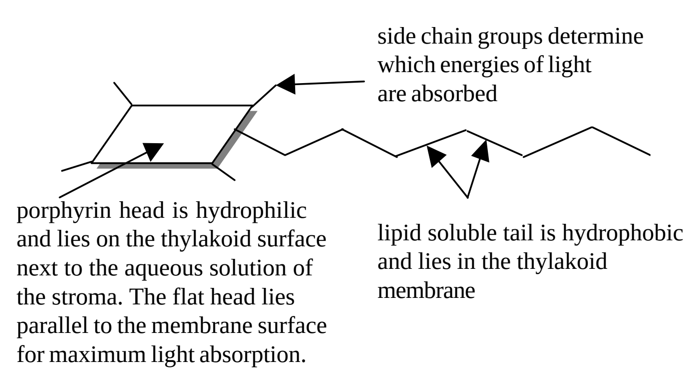


Structurally, chlorophyll molecules contain a porphyrin ring which is a flat square structure containing four smaller rings each possessing a nitrogen atom which will bond with a magnesium atom. (A similar structure is found in haemoglobin but the metal atom in this case is iron). The head is joined to a long hydrocarbon tail. Different chlorophylls bear different side chains on the head and this modifies their light absorption characteristics. Fig 2. shows the structure of a chlorophyll molecule and Fig 3. shows the structure of a chloroplast.

***Exam hint** – questions are often asked about chloroplast structure and about the nature, positioning and absorption spectra of the photosynthetic pigments.*

Note- it is not necessary to know the detailed chemical structure of the porphyrin ring.

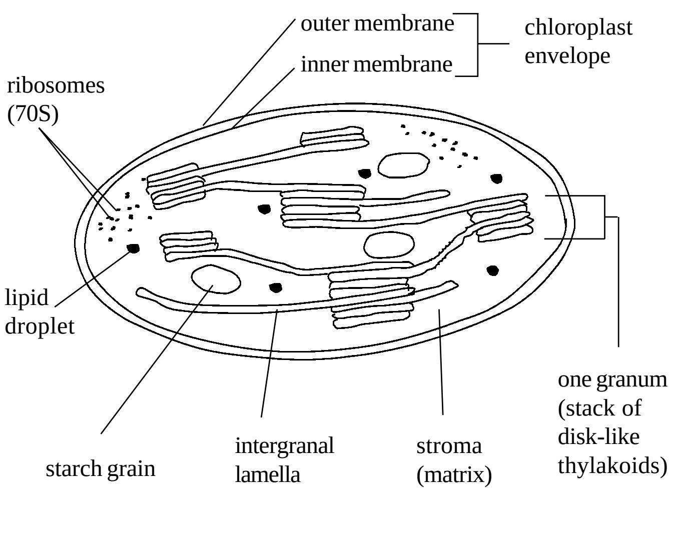
Fig 2. Structure of a chlorophyll molecule



***Remember** - hydrophilic means 'water loving' and hydrophobic means 'water hating'*

Absorption of light energy by the porphyrin head causes emission of electrons from it.

Fig 3. Structure of a chloroplast (electron microscope detail)



Excitation of pigments by light

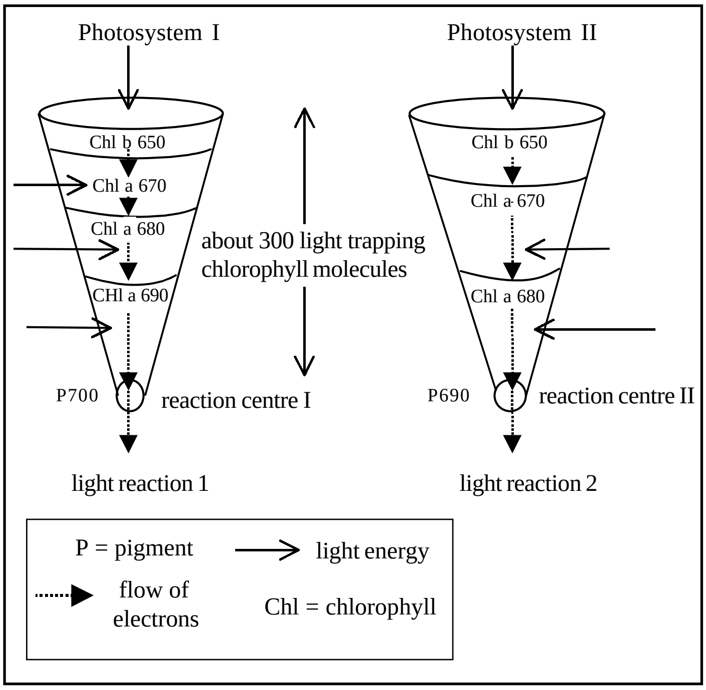
The absorption of visible light by the pigments causes the excitation of electrons to '**excited states**' as they absorb energy. This 'excited state' is unstable and the electrons return to their '**ground state**' (which is the original low energy state), losing their energy of excitation as they do so. It is this energy that is trapped during the photosynthetic process.

$$\text{chlorophyll (reduced form)} \xrightarrow{\text{light energy}} \text{chlorophyll}^{+} \text{ (oxidised form)} + e^{-} \text{ (excited electron)}$$

Each lost electron is accepted by another molecule, called an '**electron acceptor**'. Thus the chlorophyll is oxidised and the electron acceptor is reduced. The chlorophyll is thus an '**electron donor**'.

The photosynthetic pigments are of two types, **primary pigments** and **accessory pigments**. The accessory pigments pass the emitted electrons to the primary pigments. Electrons are then emitted from the primary pigments and it is these that drive the photosynthetic process. The two primary pigments are both forms of chlorophyll a, called P690 and P700 (absorbing light best at 690 and 700 nm wavelengths, respectively). The accessory pigments include other forms of chlorophyll a, chlorophyll b and carotenoids. The light energy trapping systems of the plant are called photosystem I and photosystem II and are illustrated in Fig 4.

Fig 4. Energy capture traps of photosystems I and II (in the quantosomes)



> ***Remember** – losing an electron is oxidation and gaining an electron is reduction. Gaining a proton (hydrogen ion) or hydrogen atom is reduction, losing a proton or hydrogen atom is oxidation.*

The **quantosomes** are regularly spaced particles embedded in the thylakoids, and are either large or small. It is probable that the large quantosomes contain photosystem II and reaction centre II and the small quantosomes contain photosystem I and reaction centre I.

The role of the light reactions is to produce ATP for use in the dark (light independent) reactions, by the processes of cyclic and non-cyclic photophosphorylation. In addition, the non-cyclic pathway produces $NADPH_2$.

> ***Exam Hint** – questions are often asked about the roles of pigments in photosynthesis. Candidates should know about the excitation of electrons in the light traps and their links to photosystems I and II, resulting in ATP and $NADPH_2$ production.*

> The roles of pigments in photosynthesis ends with the presentation of excited electrons to the photosystems. For details of the photosystems (light reaction) and the dark (light independent) reaction of photosynthesis Factshheet No 2, The essential guide to photosynthesis, September 1997, could be consulted. There is not enough space in this factsheet to cover the whole photosynthetic process.

Colouring pigments in plants

The red, blue and purple colours of flower petals and many fruits are due to the presence of different **anthocyanin** pigments. Unlike chlorophylls and carotenoids, these do not lie in plastids but are usually situated in the vacuoles, dissolved in the cell sap, mainly in epidermal cells. Ivory, yellow and orange colourings are due to carotenoid pigments which lie in plastids.

> ***Remember** – prior to leaf fall in deciduous trees the chlorophyll pigments break down. Leaves then turn yellow due to the carotenoid pigments which remain in the chloroplasts and which are no longer masked by the chlorophylls. In many species, the leaves at this time also synthesise anthocyanins, which give the red tints. Similar changes, which are induced by the plant growth substance, **ethene**, occur in many fruits as they ripen*

Anthocyanins are indicators, showing blue in alkaline media and red in acid ones. Thus changes in pH (of the soil or the cell sap) during the life of the plant may cause changes in flower colour. Chemically anthocyanins are derivatives of glucose (glycosides).

Phytochrome

Phytochrome is a pale-blue pigment which is important in plant growth and development. It exists in two interconvertible forms. P_{660} has a maximum light absorption peak in the red end at 660 nm, whereas P_{730} has maximum absorption in the far red at 730 nm. When P_{660} is exposed to light at 660 nm, it is converted to P_{730}. When P_{730} is exposed to light at 730 nm, it is converted to P_{660}, and it slowly decays to P_{660} in the absence of light.

Thus during daylight the plant accumulates P_{730} since daylight contains more red light. P_{730} is believed to be enzymatically active and influences a number of light-related processes, for example, **photoperiodism,** leaf lamina unfolding and **seed germination.** During the night the P_{730} slowly converts back to P_{660}, which is then ready to respond to the daylight again.

Thus, in summary:

- Red light is absorbed by P_{660} which converts it to P_{730}.
- Far red light is absorbed by P_{730} which converts it to P_{660}.
- P_{730} in the dark slowly converts to P_{660} and it is this slow conversion that is the 'clock' by which the plant measures night length.

Flowering in long day plants (henbane, snapdragon, cabbage, spring wheat and barley) is stimulated only if the level of P_{730} stays above a critical value. Flowering in short day plants (cocklebur, chrysanthemum, soya bean, strawberry and tobacco) is stimulated only if the level of P_{730} falls below a critical value. The levels of P_{730} are governed by the duration of dark periods (night).

Practice questions

1. (a) (i) Name the plant pigment that occurs in the forms P_{660} and P_{730}. 1

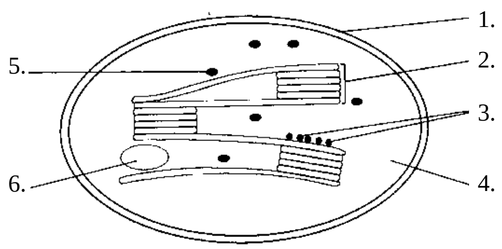
(ii) Draw a simple flow chart to show the interconversion between P_{660} and P_{730}. 2

(b) A number of Poinsettia plants were subjected to three different patterns of illumination (blank spaces) and darkness (black spaces). The following results were obtained:

Using this information deduce whether Poinsettias are long day plants, short day plants or day neutral plants. 2

Total 5

2. The diagram shows the electron microscope features of a chloroplast.



(a) Name structures 1 to 6. 6

(b) Where are the photosynthetic pigments situated in the chloroplast? 1

(c) Name three pigments usually present in chloroplasts. 3

(d) Why do leaves change to shades of yellow and red just prior to leaf fall? 2

Total 12

3. Suggest reasons for the following:
(a) Chloroplasts contain a number of different pigments. 3

(b) Red seaweeds can live at greater depths in the sea than green seaweeds. 3

(c) Hydrangeas have blue flowers when growing on basic soils and pink flowers when growing on acid soils. 2

Total 8

Answers

Semicolons indicate marking points

1. (a) (i) phytochrome;

(ii) far red light/night ;
$\mathbf{P_{660}} \rightleftharpoons \mathbf{P_{730}}$
red light/day ;

(b) short day plants;
require a dark period longer than a critical length;

2. (a) 1 = <u>double</u> envelope/outer membrane;
2 = grana/stack of thylakoids;
3 = quantosomes;
4 = stroma;
5 = oil droplet;
6 = starch grain;

(b) in the quantosomes;

(c) chlorophyll a; chlorophyll b; β-carotene/xanthophyll;

(d) as chlorophyll breaks down it no longer masks the yellow β-carotene;
anthocyanins which are red are made (from unwanted metabolites);

3. (a) different pigments trap different wavelengths of energy;
thus a wider spectrum of light energy can be used to generate excited electrons;
accessory pigments all transfer excited electrons/energy to the primary pigment;

(b) green seaweeds need to absorb blue and red wavelengths in order to flourish;
red seaweeds absorb blue but reflect red;
blue light penetrates deeper under water than red light/all wavelengths available near surface but only blue available at depth;

(c) blue and pink colours are due to anthocyanins;
these are pH sensitive;
blue in alkaline/basic conditions, pink/red in acid conditions;

Acknowledgements;
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