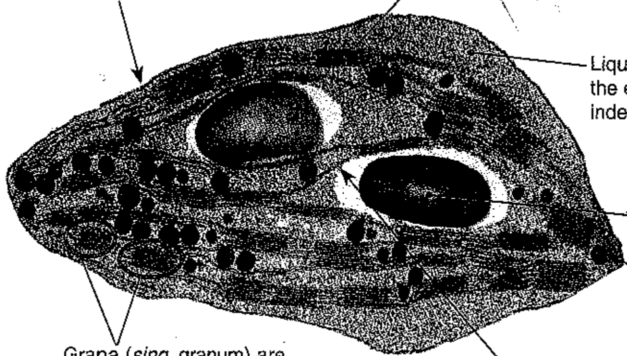
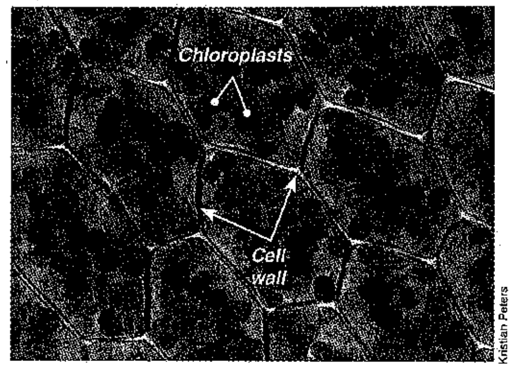
Chloroplasts

Chloroplasts are specialized plastids where photosynthesis occurs. A mesophyll leaf cell will contain between 50-100 chloroplasts. The chloroplasts are generally aligned so that their broad surface runs parallel to the cell wall to maximize the surface area available for light absorption. Chloroplasts have an internal structure characterized by a system of membranous structures called **thylakoids** arranged into stacks called **grana**. Special pigments, called **chlorophylls** and **carotenoids**, are bound to the membranes as part of light-capturing photosystems. They absorb light of specific wavelengths (mostly reds and blues) and thereby capture the light energy. Chlorophylls give leaves their green color (green light is reflected and not absorbed).

The Structure of a Chloroplast



TEM image of a single chloroplast



Chloroplasts visible in plant cells

1. Label the transmission electron microscope image of a chloroplast below:

Image: Dartmouth College

2. (a) Describe where chlorophyll is found in a chloroplast: ______________________

   (b) Explain why chlorophyll is found there: ______________________

3. Explain how the internal structure of chloroplasts helps absorb the maximum amount of light: ______________________

4. Explain why plant leaves appear green: ______________________

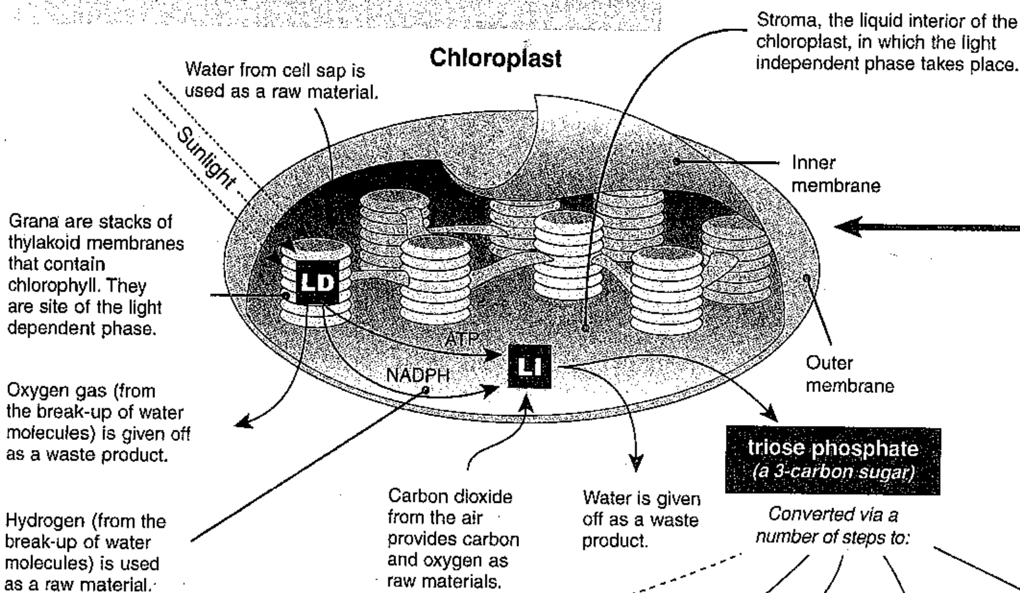
Photosynthesis

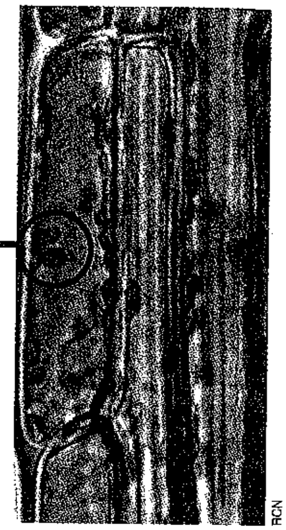
Photosynthesis is of fundamental importance to living things because it transforms sunlight energy into chemical energy stored in molecules, releases free oxygen gas, and absorbs carbon dioxide (a waste product of cellular metabolism). Photosynthetic organisms use special pigments, called **chlorophylls**, to absorb light of specific wavelengths and thereby capture the light energy.

Visible light is a small fraction of the total **electromagnetic radiation** reaching Earth from the sun. Of the visible spectrum, only certain wavelengths (red and blue) are absorbed for photosynthesis. Other wavelengths, particularly green, are reflected or transmitted. Photosynthesis is summarized in the chemical equation and diagram (below).

$$6CO_2 + 12H_2O \xrightarrow[\text{Chlorophyll}]{\text{Light}} C_6H_{12}O_6 + 6O_2 + 6H_2O$$

Photosynthesis equation





Plant cells (*Elodea*)

triose phosphate *(a 3-carbon sugar)*

Converted via a number of steps to:

Lipids and amino acids

LD = **Light dependent phase**
Process: *Energy capture* via photosystems I and II

LI = **Light independent phase**
Process: *Carbon fixation* via the Calvin cycle

Monosaccharides	**Cellulose**	**Starch**	**Disaccharides**
Glucose is the fuel for cellular respiration and supplies energy for metabolism. Glucose can be converted to fructose.	Glucose is used as a building block for creating cellulose, a component of plant cell walls.	Stored as a reserve supply of energy in starch granules, to be converted back into glucose when required.	Monosaccharides join to form disaccharides, e.g. fructose and glucose form sucrose, found in sugar cane.

1. Describe the three things of fundamental biological importance provided by photosynthesis:

(a) ______

(b) ______

(c) ______

2. Describe the role of the following in photosynthesis:

(a) The carrier molecule NADP: ______

(b) ATP: ______

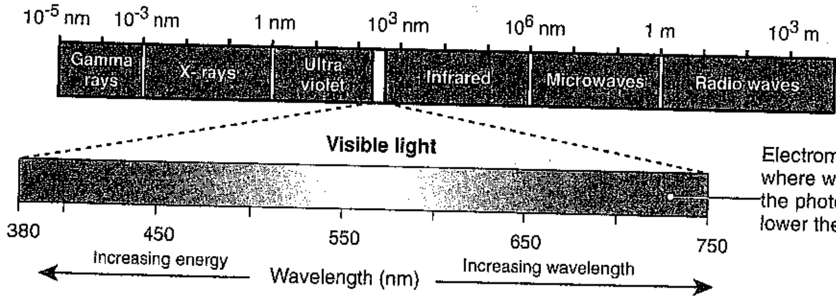
(c) Chlorophyll molecules: ______

(d) Light: ______

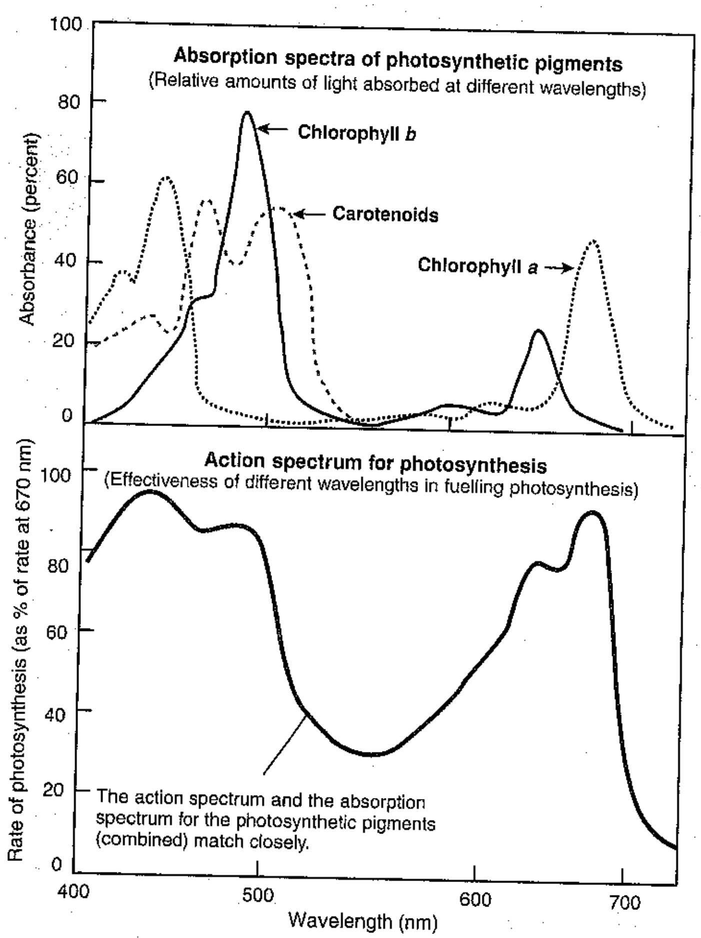
As light meets matter, it may be reflected, transmitted, or absorbed. Substances that absorb visible light are called **pigments**, and different pigments absorb light of different wavelengths. The ability of a pigment to absorb particular wavelengths of light can be measured with a spectrophotometer. The light absorption vs the wavelength is called the **absorption spectrum** of that pigment. The absorption spectrum of different photosynthetic pigments provides clues to their role in photosynthesis, since light can only perform work if it is absorbed. An **action spectrum** profiles the effectiveness of different wavelength light in fuelling photosynthesis. It is obtained by plotting wavelength against some measure of photosynthetic rate (e.g. CO_2 production). Some features of photosynthetic pigments and their light absorbing properties are outlined below.

The Electromagnetic Spectrum

Light is a form of energy known as electromagnetic radiation. The segment of the electromagnetic spectrum most important to life is the narrow band between about 380 nm and 750 nm. This radiation is known as visible light because it is detected as colors by the human eye (although some other animals, such as insects, can see in the UV range). It is the visible light that drives photosynthesis.

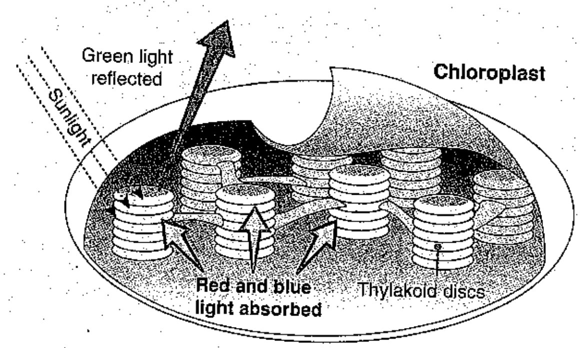


Electromagnetic radiation (EMR) travels in waves, where wavelength provides a guide to the energy of the photons; the greater the wavelength of EMR, the lower the energy of the photons in that radiation.



The photosynthetic pigments of plants

The photosynthetic pigments of plants fall into two categories: chlorophylls (which absorb red and blue-violet light) and carotenoids (which absorb strongly in the blue-violet and appear orange, yellow, or red). The pigments are located on the chloroplast membranes (the thylakoids) and are associated with membrane transport systems.



The pigments of chloroplasts in higher plants (above) absorb blue and red light, and the leaves therefore appear green (which is reflected). Each photosynthetic pigment has its own characteristic absorption spectrum (left, top graph). Although only chlorophyll a can participate directly in the light reactions of photosynthesis, the accessory pigments (chlorophyll *b* and carotenoids) can absorb wavelengths of light that chlorophyll *a* cannot. The accessory pigments pass the energy (photons) to chlorophyll a, thus broadening the spectrum that can effectively drive photosynthesis.

Left: Graphs comparing absorption spectra of photosynthetic pigments compared with the action spectrum for photosynthesis.

1. What is meant by the absorption spectrum of a pigment? ______________________________

____

2. Why doesn't the **action spectrum** for photosynthesis exactly match the absorption spectrum of chlorophyll *a*?

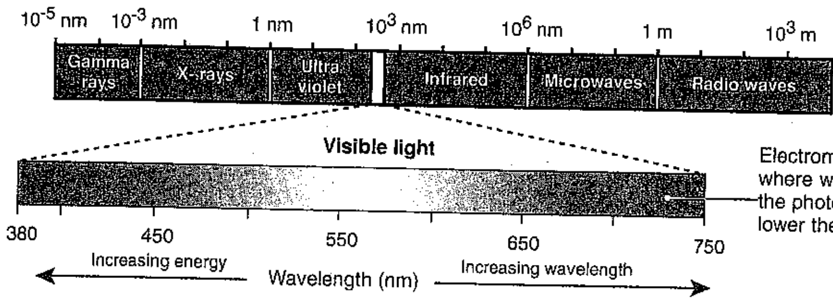
____

ISBN: 978-1-927173-12-1

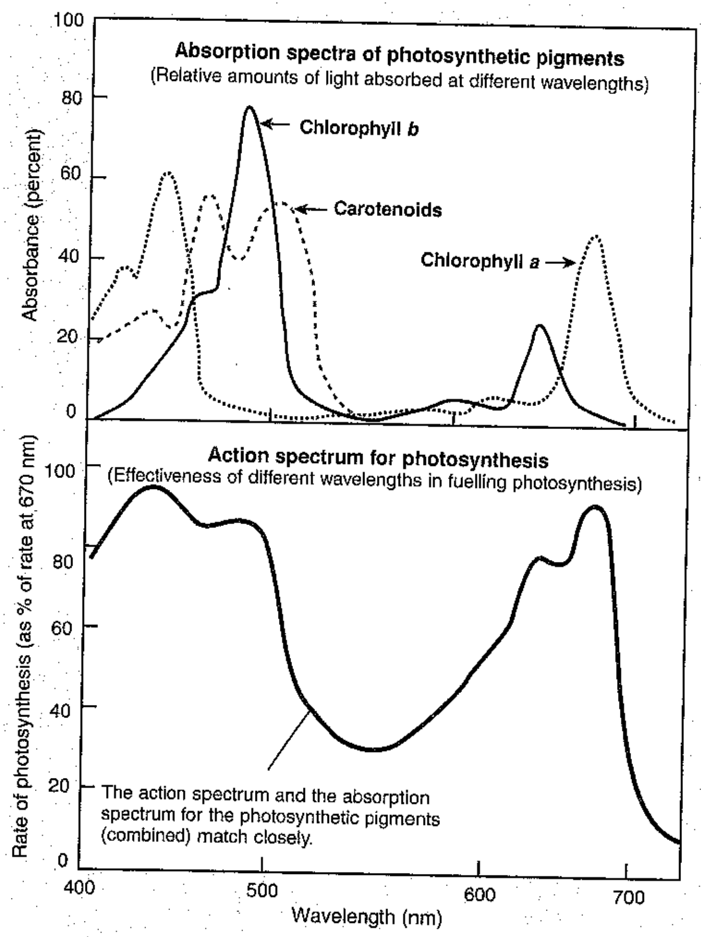
As light meets matter, it may be reflected, transmitted, or absorbed. Substances that absorb visible light are called **pigments**, and different pigments absorb light of different wavelengths. The ability of a pigment to absorb particular wavelengths of light can be measured with a spectrophotometer. The light absorption vs the wavelength is called the **absorption spectrum** of that pigment. The absorption spectrum of different photosynthetic pigments provides clues to their role in photosynthesis, since light can only perform work if it is absorbed. An **action spectrum** profiles the effectiveness of different wavelength light in fuelling photosynthesis. It is obtained by plotting wavelength against some measure of photosynthetic rate (e.g. CO_2 production). Some features of photosynthetic pigments and their light absorbing properties are outlined below.

The Electromagnetic Spectrum

Light is a form of energy known as electromagnetic radiation. The segment of the electromagnetic spectrum most important to life is the narrow band between about 380 nm and 750 nm. This radiation is known as visible light because it is detected as colors by the human eye (although some other animals, such as insects, can see in the UV range). It is the visible light that drives photosynthesis.

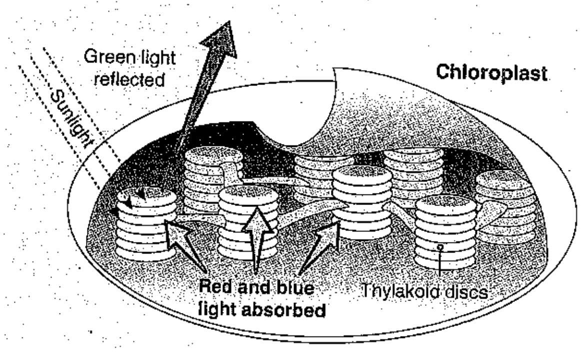


Electromagnetic radiation (EMR) travels in waves, where wavelength provides a guide to the energy of the photons; the greater the wavelength of EMR, the lower the energy of the photons in that radiation.



The photosynthetic pigments of plants

The photosynthetic pigments of plants fall into two categories: chlorophylls (which absorb red and blue-violet light) and carotenoids (which absorb strongly in the blue-violet and appear orange, yellow, or red). The pigments are located on the chloroplast membranes (the thylakoids) and are associated with membrane transport systems.



The pigments of chloroplasts in higher plants (above) absorb blue and red light, and the leaves therefore appear green (which is reflected). Each photosynthetic pigment has its own characteristic absorption spectrum (left, top graph). Although only chlorophyll a can participate directly in the light reactions of photosynthesis, the accessory pigments (chlorophyll *b* and carotenoids) can absorb wavelengths of light that chlorophyll *a* cannot. The accessory pigments pass the energy (photons) to chlorophyll a, thus broadening the spectrum that can effectively drive photosynthesis.

Left: Graphs comparing absorption spectra of photosynthetic pigments compared with the action spectrum for photosynthesis.

1. What is meant by the absorption spectrum of a pigment? ______________________

____

2. Why doesn't the **action spectrum** for photosynthesis exactly match the absorption spectrum of chlorophyll *a*?

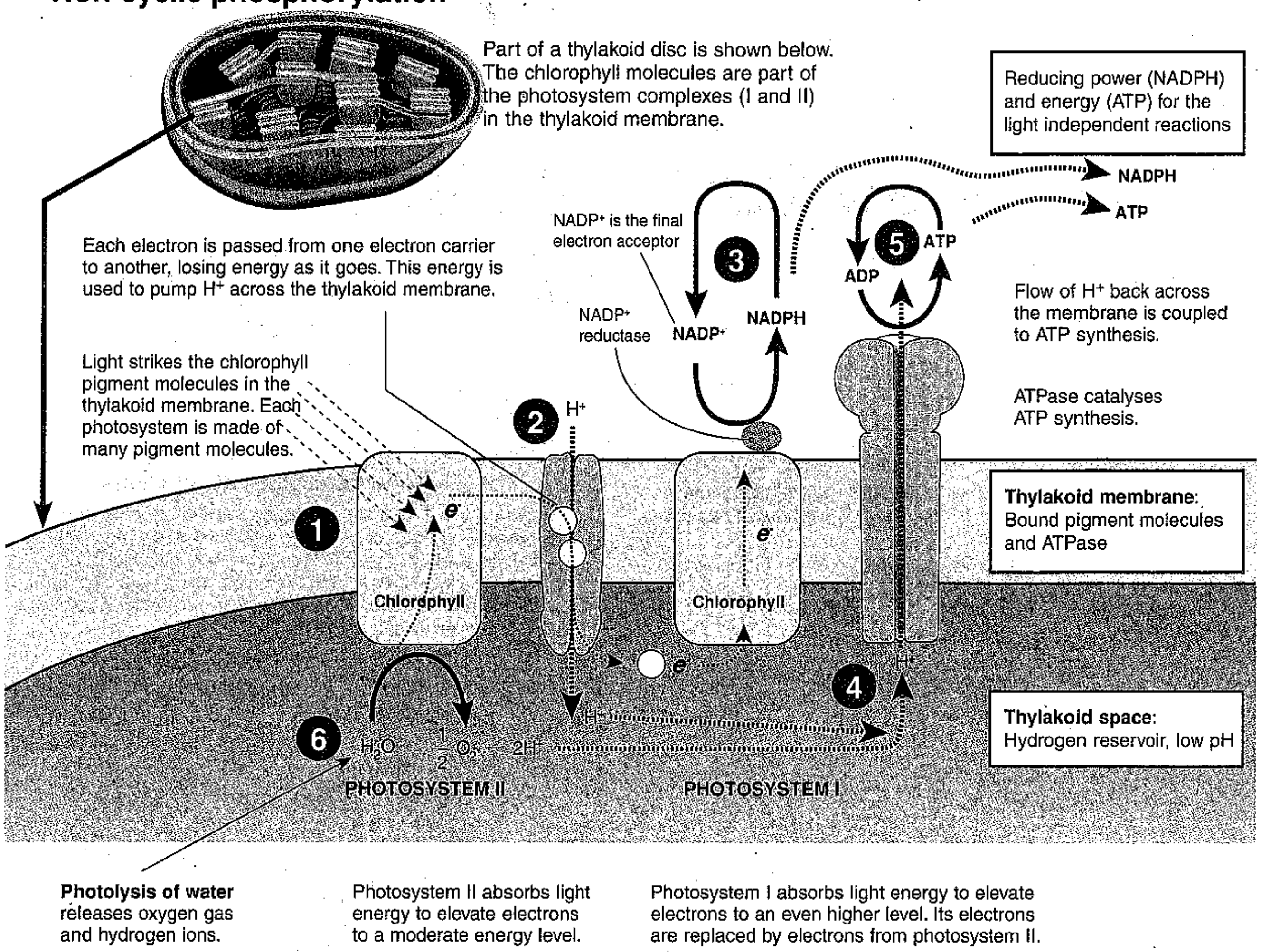
____

ISBN: 978-1-927173-12-1

Light Dependent Reactions

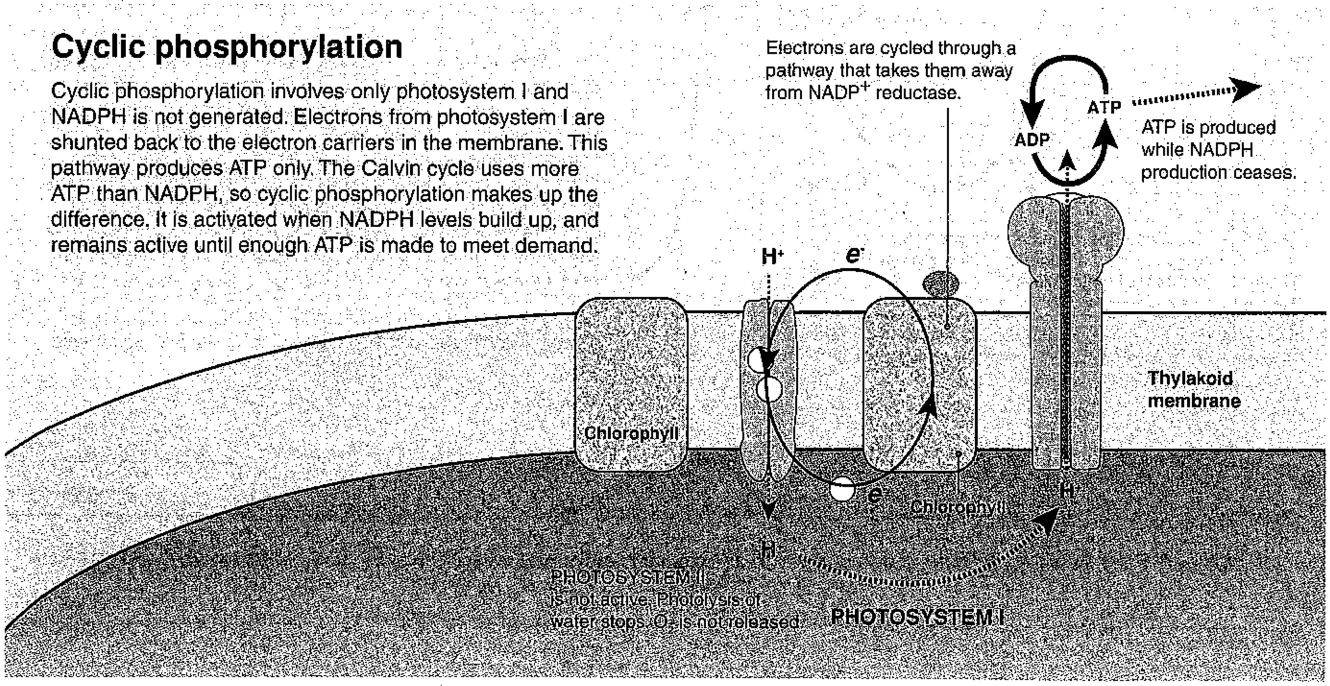
Like cellular respiration, photosynthesis is a redox process, but in photosynthesis, water is split, and electrons and hydrogen ions, are transferred from water to CO_2, reducing it to sugar. The electrons increase in potential energy as they move from water to sugar. The energy to do this is provided by light. Photosynthesis has two phases. In the **light dependent reactions**, light energy is converted to chemical energy (ATP and NADPH). In the **light independent reactions**, the chemical energy is used to synthesize carbohydrate. The light dependent reactions most commonly involve **non-cyclic phosphorylation**, which produces ATP and NADPH in roughly equal quantities. The electrons lost are replaced from water. In **cyclic phosphorylation**, the electrons lost from photosystem II are replaced by those from photosystem I. ATP is generated, but not NADPH.

Non-cyclic phosphorylation



Cyclic phosphorylation

Cyclic phosphorylation involves only photosystem I and NADPH is not generated. Electrons from photosystem I are shunted back to the electron carriers in the membrane. This pathway produces ATP only. The Calvin cycle uses more ATP than NADPH, so cyclic phosphorylation makes up the difference. It is activated when NADPH levels build up, and remains active until enough ATP is made to meet demand.



photosynthesis: ___

2. Explain the role of chlorophyll molecules in photosynthesis: ___

3. Summarize the events of the light dependent reactions: ___

4. Describe how ATP is produced as a result of light striking chlorophyll molecules during the light dependent phase:

5. (a) Explain what you understand by the term **non-cyclic phosphorylation**: ___

   (b) Suggest why this process is also known as non-cyclic **photo**phosphorylation: ___

6. (a) Describe how **cyclic photophosphorylation** differs from non-cyclic photophosphorylation: ___

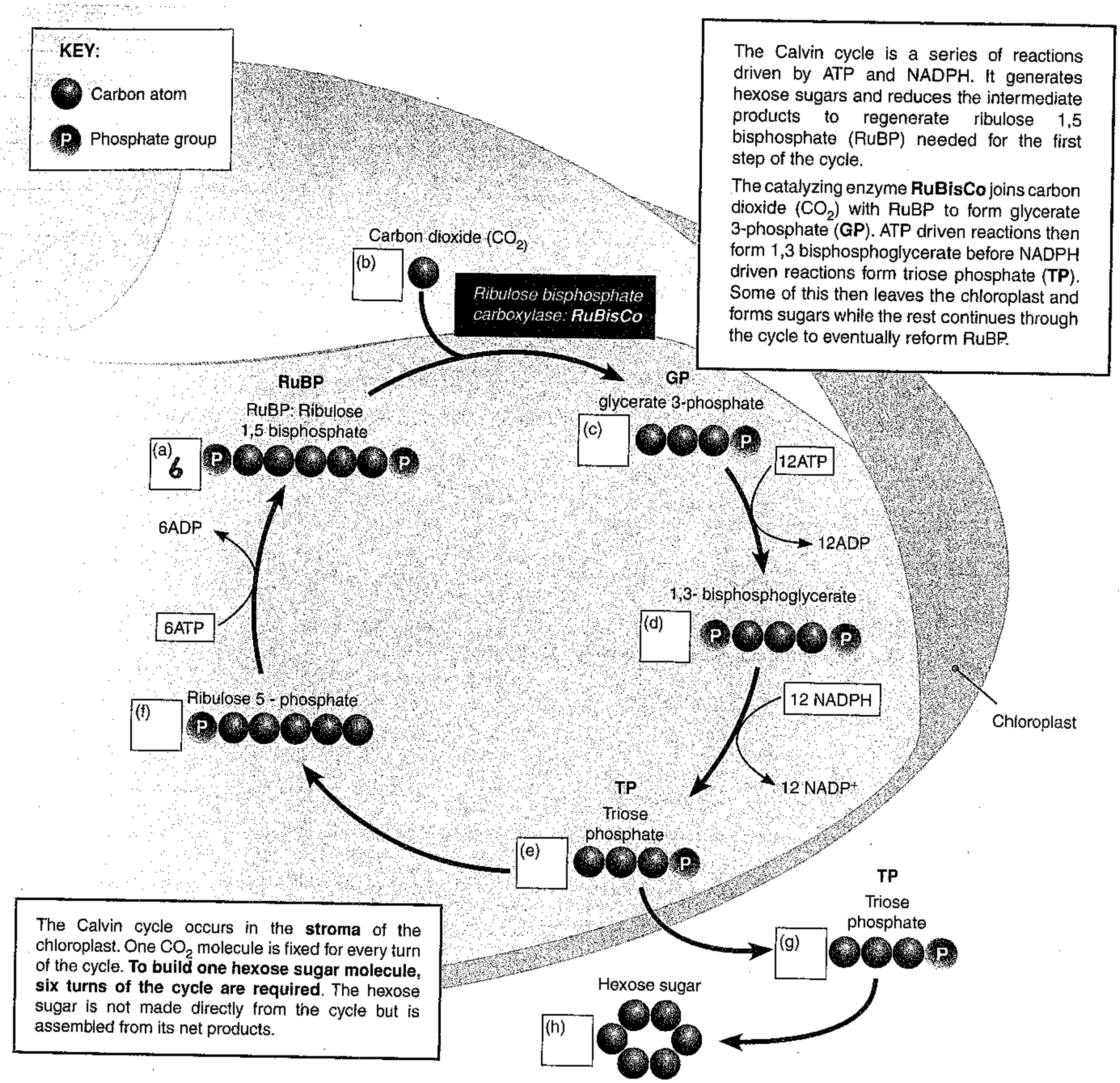
   (b) Both cyclic and noncyclic pathways operate to varying degrees during photosynthesis. Since the non-cyclic pathway produces both ATP and NAPH, explain the purpose of the cyclic pathway of electron flow:

7. Explain how the independence of photosystem I gives a mechanism for evolution of the photosynthetic pathway:

ISBN: 978-1-927173-12-1

Light Independent Reactions

The **light independent reactions** of photosynthesis (the **Calvin cycle**) take place in the stroma of the chloroplast, and do not require light to proceed. Here, hydrogen (H^+) is added to CO_2 and a 5C intermediate to make carbohydrate. The H^+ and ATP are supplied by the light dependent reactions. The Calvin cycle uses more ATP than NADPH, but the cell uses cyclic phosphorylation (which does not produce NADPH) when it runs low on ATP to make up the difference.



1. In the boxes on the diagram above, write the number of molecules formed at each step during the formation of **one hexose sugar molecule.** The first one has been done for you:

2. Explain the importance of RuBisCo in the Calvin cycle: ______________________________

____

3. Identify the actual end product on the Calvin cycle: ______________________________

4. Write the equation for the production of one hexose sugar molecule from carbon dioxide: ______________________________

____

5. Explain why the Calvin cycle is likely to cease in the dark for most plants, even though it is independent of light:

____