

13.1 Photosynthesis as an energy transfer process

Name: _____ Class: _____ Date: _____ Total: 36 marks

KEY WORDS chloroplast • calvin cycle • pigment
• chromatography • chlorophyll

Objective

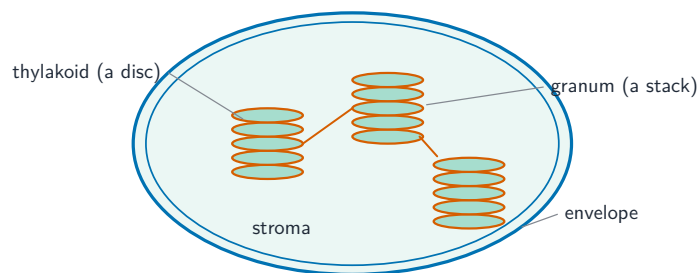
Build the skills to answer exam questions on **photosynthesis as an energy transfer process** – the **chloroplast**, the two stages, pigments, **photophosphorylation** and the **Calvin cycle**.

You must be able to:

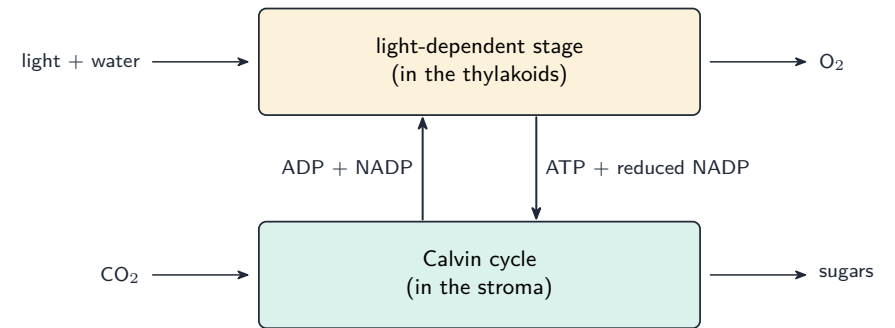
- relate chloroplast structure to function and explain the two linked stages
- describe the roles of pigments, interpret spectra, and use **Rf values**
- explain cyclic and non-cyclic photophosphorylation and the Calvin cycle

1 Key knowledge and worked examples

■ Chloroplast and the two stages

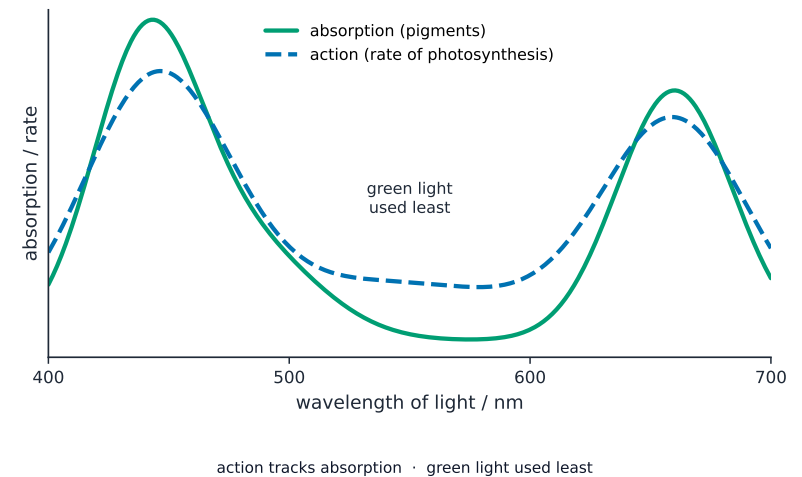


Thylakoids stack into grana (light-dependent stage); the stroma is where the Calvin cycle runs

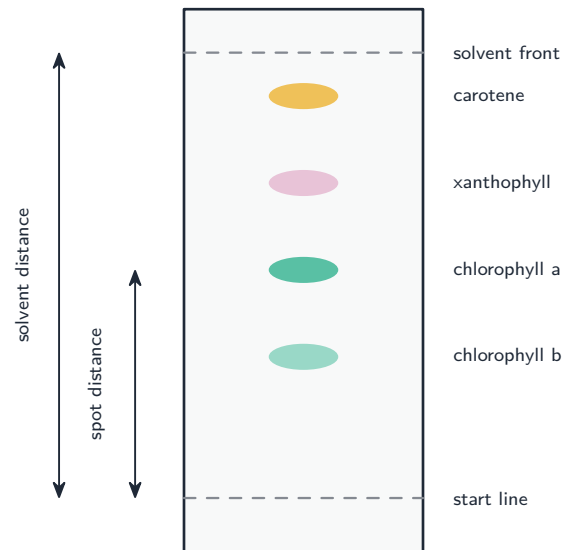


The first stage makes the ATP and reduced NADP that the second spends to turn CO₂ into sugars

■ Pigments, spectra and chromatography

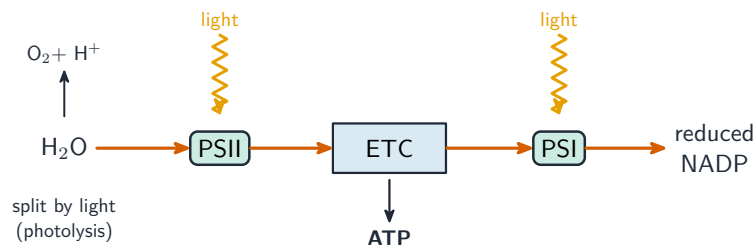


The absorption and action spectra match – blue and red light are used most



$$R_f = \text{distance moved by the pigment} \div \text{distance moved by the solvent}$$

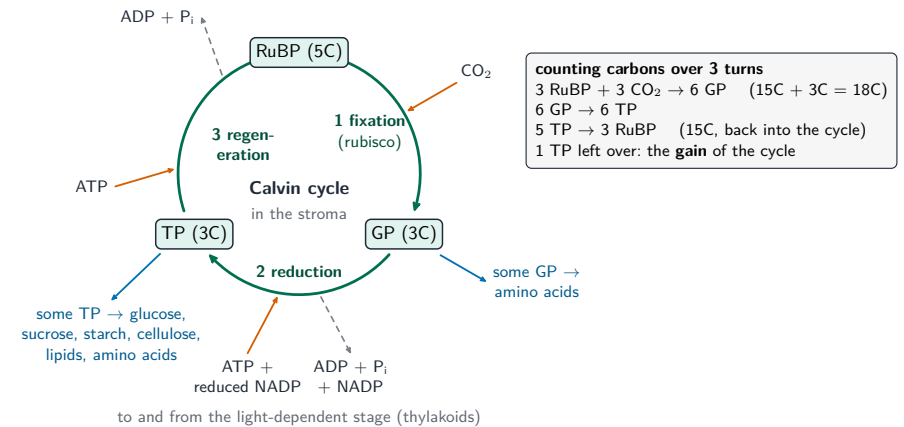
■ Photophosphorylation



Non-cyclic: both photosystems, photolysis of water, makes ATP and reduced NADP.

Cyclic: PSI only, makes ATP only

■ The Calvin cycle



Fixation (rubisco) → reduction (uses ATP + reduced NADP) → regeneration of RuBP; some TP becomes sugars

■ The chloroplast, mapped onto the two stages

Structure	What happens there
thylakoid membranes, stacked into grana	the light-dependent stage: photosystems, the electron transport chain, ATP and reduced NADP made, water photolysed
stroma	the light-independent stage (Calvin cycle): CO ₂ fixed into carbohydrate using that ATP and reduced NADP

The **grana** give a very large surface area for the pigments and electron carriers; the **stroma** holds the enzymes, and also DNA and 70S ribosomes so the chloroplast makes some of its own proteins.

The light-dependent stage, in the order marks are given: light excites electrons in **chlorophyll**; the excited electrons pass along the **electron transport chain**, releasing energy that pumps protons and drives ATP synthesis (**photophosphorylation**); **photolysis** splits water, $2\text{H}_2\text{O} \rightarrow 4\text{H}^+ + 4\text{e}^- + \text{O}_2$, replacing the lost electrons and releasing oxygen as the **by-product**; NADP is reduced.

The Calvin cycle, the three steps you must name:

1. **Fixation** – CO₂ combines with **RuBP** (5C) catalysed by **rubisco**, giving two molecules of **GP** (3C).
2. **Reduction** – GP is reduced to **TP** using reduced NADP and ATP from the light stage.

3. **Regeneration** – most TP is used, with more ATP, to regenerate RuBP; the rest leaves to make carbohydrate.

Reading a “what happens if” question – this is where the marks concentrate. Removing the **light** stops ATP and reduced NADP reaching the stroma, so GP cannot be reduced: **GP rises, TP and RuBP fall**. Removing **CO₂** stops fixation, so RuBP is not used up: **RuBP rises, GP and TP fall**. Learn the pair as a mirror image and you can answer either version.

Worked example. A plant photosynthesising steadily is put into darkness. Predict what happens to the concentrations of GP and RuBP in the next few seconds, and explain.

1. In the dark no ATP or reduced NADP is produced.
2. GP therefore cannot be reduced to TP, so GP **accumulates**.
3. RuBP is still being consumed by fixation for a short time but is no longer regenerated, so RuBP **falls**.

2 Practice

- 2.1 State what is made in the light-dependent stage and passed to the Calvin cycle. [2]

- 2.2 Name the enzyme that fixes carbon dioxide onto RuBP in the Calvin cycle. [1]

- 2.3 State where in the chloroplast each stage of photosynthesis occurs. [2]

- 2.4 Name the enzyme that catalyses the fixation of carbon dioxide, and the two molecules involved. [3]

- 2.5 State the source of the oxygen released in photosynthesis, and name the process. [2]

3 Exam-style questions

- 3.1 In which part of the chloroplast does the Calvin cycle take place? [1]

- ☐ **A** the thylakoid membrane
B the stroma
C the grana
D the outer envelope

- 3.2 Which is produced **only** in non-cyclic (not cyclic) photophosphorylation? [1]

- ☐ **A** ATP
B reduced NADP and oxygen
C carbon dioxide
D RuBP

- 3.3 In a chromatography experiment a pigment moved 4.8 cm while the solvent moved 12.0 cm.

- (a) Calculate the R_f value of the pigment. [2]

- (b) State **one** reason the chloroplast contains several different pigments. [1]

- 3.4 Describe the three main steps of the Calvin cycle. [4]

3.5 A plant is photosynthesising at a steady rate in the light with a normal carbon dioxide supply.

(a) Describe the light-dependent stage, naming the site and the two products passed to the Calvin cycle. [4]

(b) Name the three stages of the Calvin cycle and the number of carbon atoms in RuBP, GP and TP. [4]

(c) The plant is suddenly placed in darkness. Predict and explain what happens to the concentrations of GP and RuBP. [4]

(d) In a separate experiment the carbon dioxide supply is removed instead, with the light left on. Predict and explain the effect on GP and RuBP. [3]

(e) Explain why the grana are arranged as stacks of membranes. [2]

Solutions

Each answer shows the steps, then the **result**.

2.1

- ATP and reduced NADP

2.2

- rubisco

2.3

- Light-dependent: the thylakoid membranes of the grana; light-independent: the stroma

2.4

- Rubisco; carbon dioxide combines with RuBP to give two molecules of GP

2.5

- Water; photolysis

3.1 B

- The Calvin cycle takes place in the stroma

3.2 B

- Only non-cyclic photophosphorylation makes reduced NADP and releases oxygen (from photolysis)

3.3

(a)

- $R_f = \frac{4.8}{12.0} = 0.40$

(b)

- different pigments absorb different wavelengths, so more of the light energy is trapped

3.4

- fixation – rubisco joins CO₂ to RuBP (5C) to make two GP (3C); reduction – GP is reduced to TP using ATP and reduced NADP; regeneration – most TP is used (with ATP) to remake RuBP

3.5

(a)

- It takes place in the thylakoid membranes; light excites electrons in chlorophyll, which pass along an electron transport chain releasing energy to make ATP; photolysis of

water replaces the lost electrons and releases oxygen; the products passed on are ATP and reduced NADP

(b)

- Fixation, reduction and regeneration; RuBP has 5 carbons, GP has 3 and TP has 3

(c)

- GP rises, because no ATP or reduced NADP is available to reduce it to TP; RuBP falls, because it continues to be used in fixation for a short time but is no longer regenerated

(d)

- RuBP rises, because it is no longer used up in fixation; GP and TP fall, because no new GP is being formed

(e)

- Stacking gives a very large surface area within a small volume, so many more photo-systems and electron carriers can be held, increasing the rate of the light-dependent stage