A-LEVEL BIOLOGY • EXERCISE SHEET

13.1 Photosynthesis as an energy transfer process

Name: ____________ Class: ________ Date: __________ **Total: 36 marks**

KEY WORDS chloroplast 叶绿体 • calvin cycle 卡尔文循环 • pigment 色素 • chromatography 色谱法 • chlorophyll 叶绿素

Objective

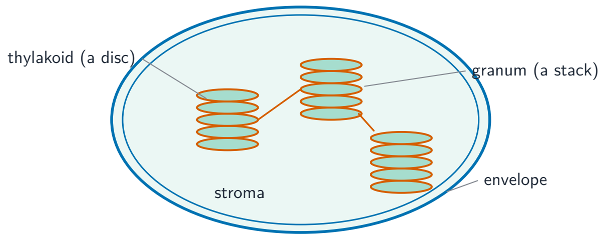
Build the skills to answer exam questions on **photosynthesis as an energy transfer process** — the **chloroplast** 叶绿体, the two stages, pigments, **photophosphorylation** 光合磷酸化 and the **Calvin cycle** 卡尔文循环.

You must be able to:

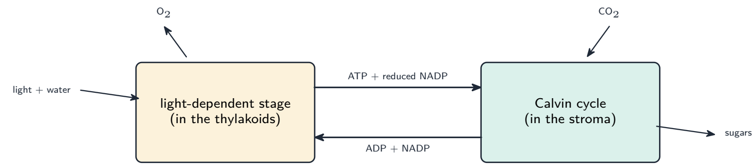
- relate chloroplast structure to function and explain the two linked stages
- describe the roles of pigments, interpret spectra, and use **Rf values** 比移值
- explain cyclic and non-cyclic photophosphorylation and the Calvin cycle

1 Worked examples

Chloroplast and the two stages

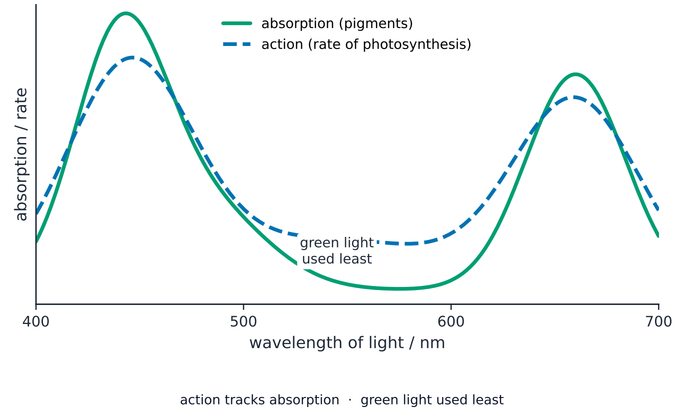


Thylakoids stack into grana (light-dependent stage); the stroma is where the Calvin cycle runs

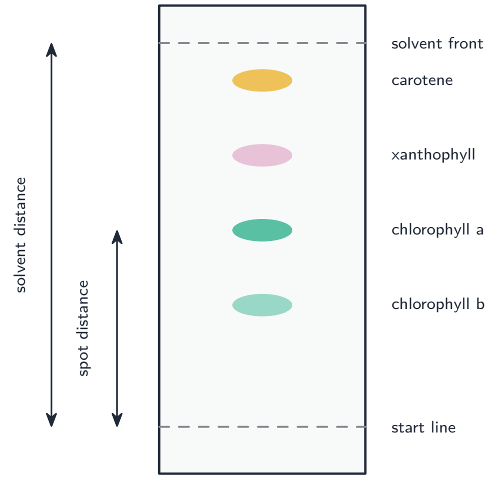


The first stage makes the ATP and reduced NADP that the second spends to turn CO_2 into sugars

Pigments, spectra and chromatography

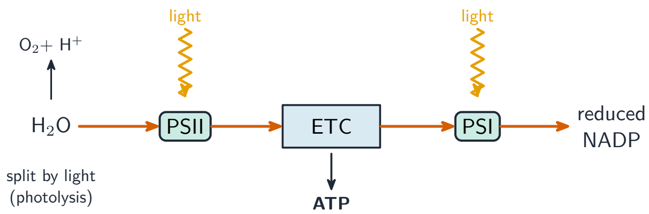


The absorption and action spectra match — blue and red light are used most



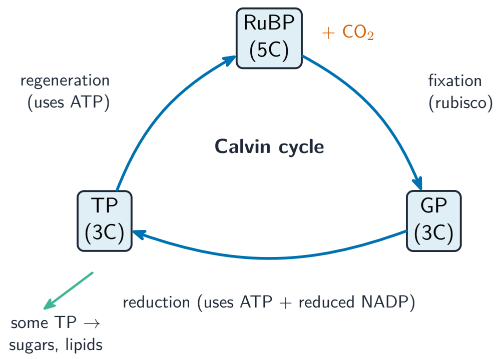
Rf = distance moved by the pigment ÷ distance moved by the solvent

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 类囊体膜, stacked into grana	the **light-dependent** stage: photosystems, the electron transport chain, ATP and reduced NADP made, water photolysed
stroma 基质	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, $2H_2O \rightarrow 4H^+ + 4e^- + O_2$, 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** — CO_2 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 CO_2 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 Rf 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

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) $R_f = \dfrac{4.8}{12.0} = 0.40$.
(b) different pigments absorb different wavelengths, so more of the light energy is trapped.

3.4 fixation — rubisco joins CO_2 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 photosystems and electron carriers can be held, increasing the rate of the light-dependent stage.