DP Biology – C1.3 (HL extension)

Inside photosynthesis

- How does photosynthesis capture and use the energy in sunlight?
- How do non-living factors affect photosynthesis?

HL statements C1.3.9–19. Textbook pp. 439–449.

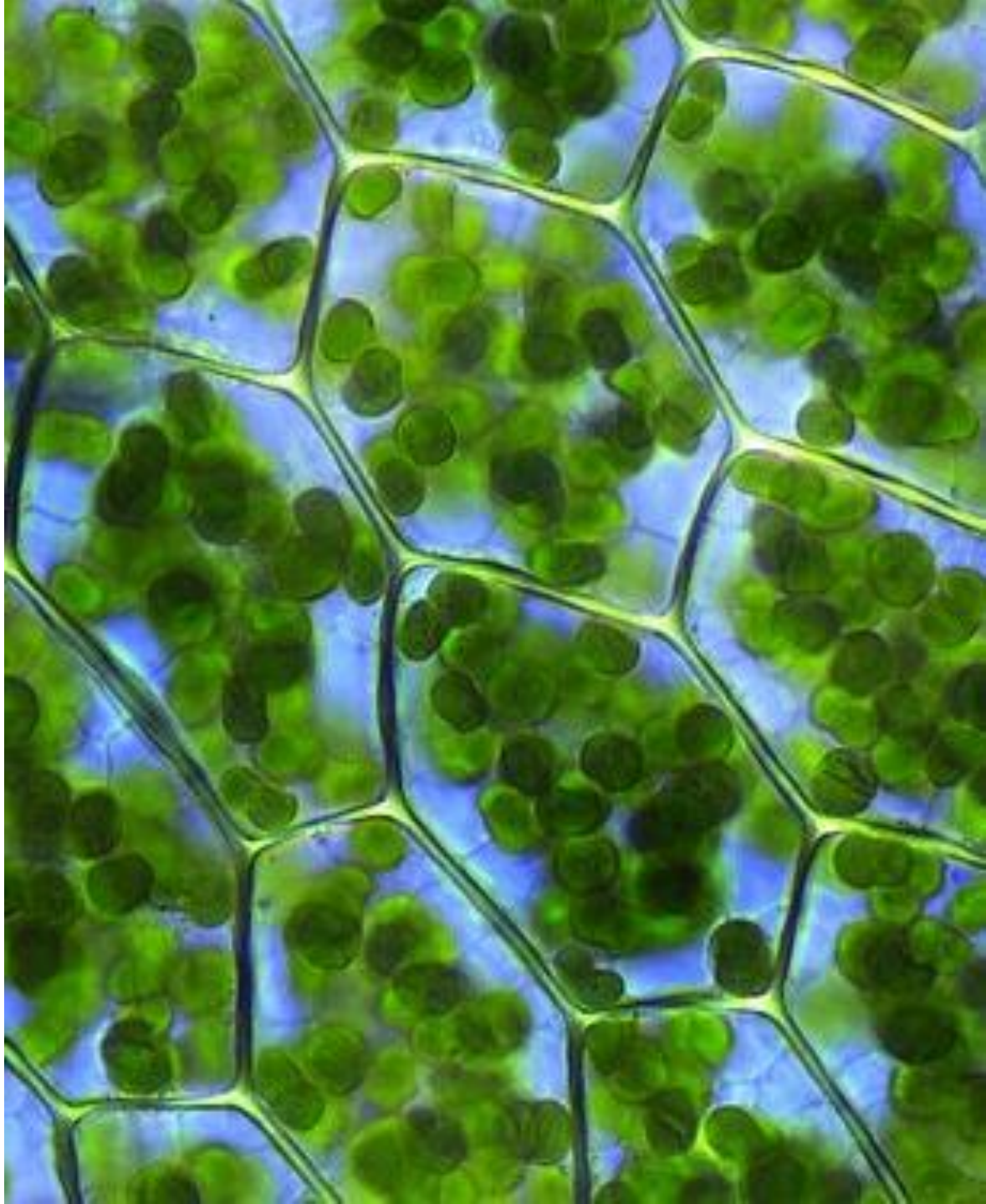


Image: chloroplasts in moss leaf cells. Kristian Peters, CC BY-SA 3.0.

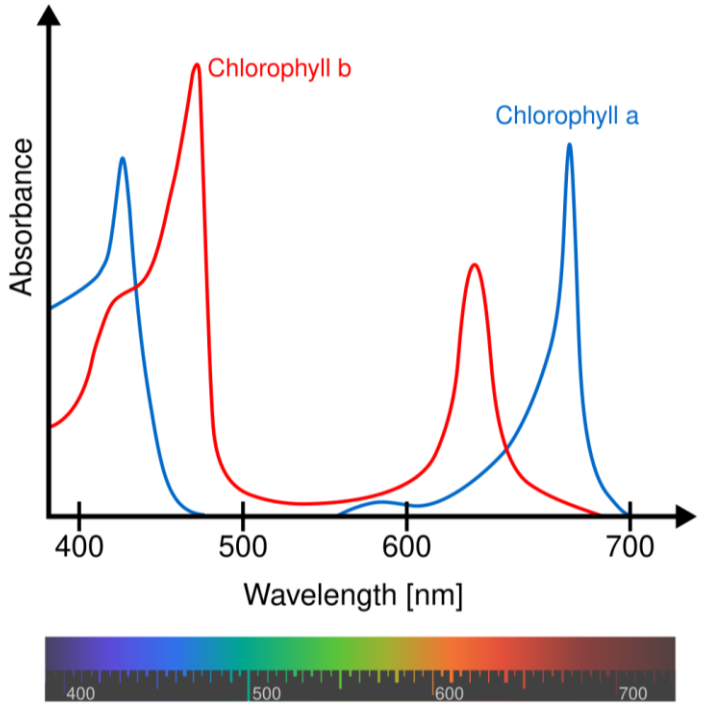
Objectives for each class

Class	Statements	By the end of the class, you can...
1	C1.3.9–10	Describe photosystems and explain why pigments work as a structured array
2	C1.3.11	Explain how photosystem II splits water, and the effects of oxygen on early Earth
3	C1.3.12–14	Explain ATP production by chemiosmosis, reduction of NADP, and where each happens in a thylakoid
4	C1.3.15–16	Explain carbon fixation by rubisco and the reduction of glycerate 3-phosphate to triose phosphate
5	C1.3.17–18	Explain regeneration of RuBP and how other carbon compounds are made from Calvin cycle products
6	C1.3.19	Explain why the two stages of photosynthesis need each other

Photosystems

C1.3.9

- A photosystem is an array of chlorophyll and **accessory pigments** held by proteins in a membrane
- Found in thylakoid membranes of chloroplasts, and in the membranes of cyanobacteria
- Pigments absorb light and pass the energy from molecule to molecule
- At the centre, a **reaction centre** chlorophyll uses the energy to emit an excited electron
- There are two kinds: photosystem II (P680) and photosystem I (P700)



Absorption spectra of chlorophylls a and b. CC BY-SA 3.0.

Key idea

Light energy becomes the energy of an excited electron. Losing that electron oxidizes the reaction centre chlorophyll.

Why pigments work together

C1.3.10

Feature of the array	Advantage
Several kinds of pigment	Absorbs a wider range of wavelengths
Hundreds of pigment molecules	More chance of capturing scattered photons
Precise spacing and orientation	Energy passes quickly to the reaction centre, like a funnel
Reaction centre linked to an electron acceptor	The excited electron is captured before its energy is lost as heat or light

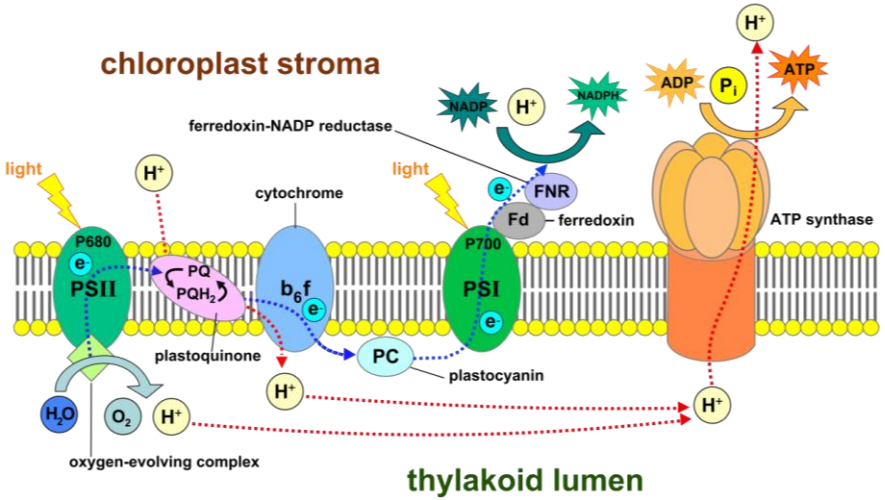
A single molecule is not enough

Isolated chlorophyll in solution absorbs light but just re-emits it as red light and heat (fluorescence). Only the organized array can pass energy on and release an electron.

Photolysis in photosystem II

$$2\ H_2O \rightarrow 4\ H^+ + 4\ \text{electrons} + O_2$$

- Photosystem II loses excited electrons; electrons from water replace them
- Water is split, releasing protons into the thylakoid space
- The electrons and protons are used in photosynthesis
- **Oxygen is a waste product**, released through stomata



Thylakoid membrane, light-dependent reactions. Somepics, CC BY-SA 4.0.

Oxygen changed the Earth

C1.3.11



Banded iron formation, Australia. G. Churchard, CC BY 2.0.



Stromatolites, Shark Bay. CC BY-SA 2.0.

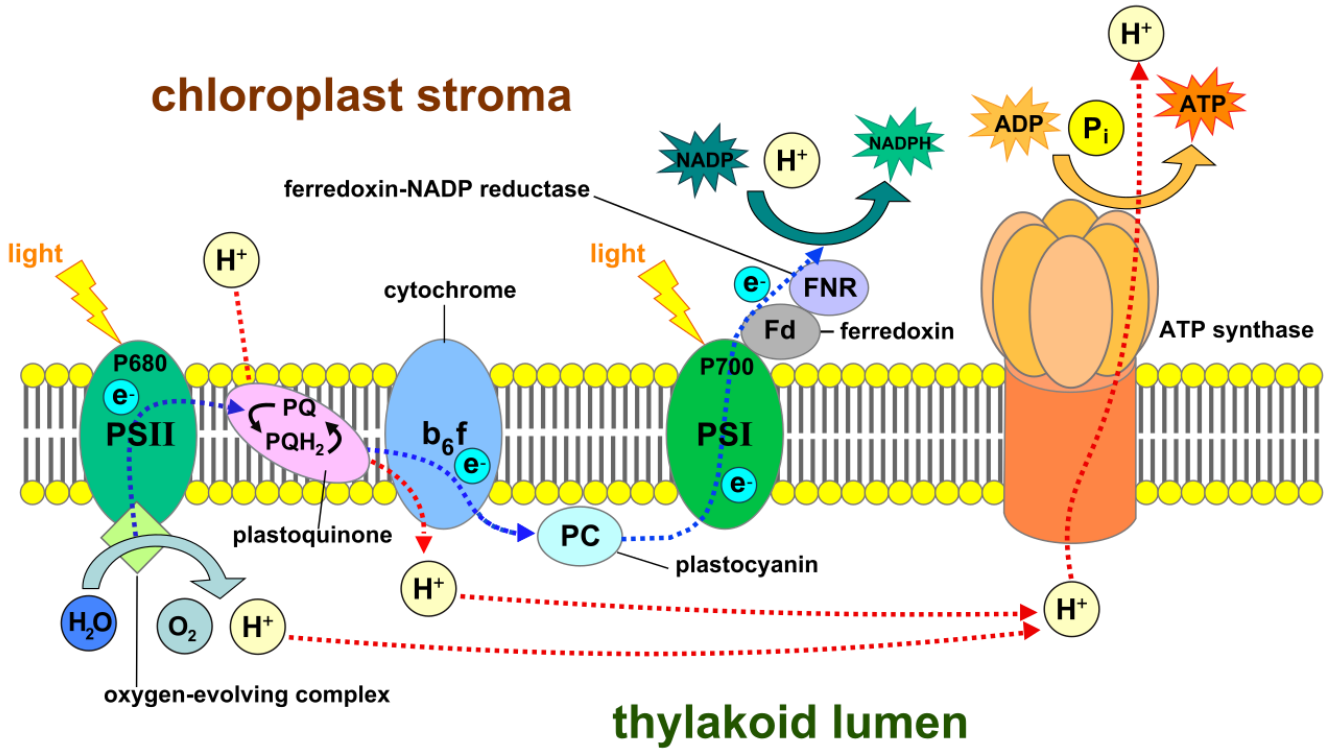
When	Event
About 3.5 billion years ago	Cyanobacteria-like organisms begin photosynthesis
About 2.4 billion years ago	Great Oxidation Event: oxygen builds up in the air
2.4 to 1.8 billion years ago	Iron dissolved in seas is oxidized and settles as banded iron
Later	Ozone layer forms; aerobic respiration and complex life become possible

Also

Many anaerobic organisms were poisoned by oxygen.

ATP by chemiosmosis in thylakoids

C1.3.12



- Excited electrons from photosystem II pass along a chain of carriers
- Energy released pumps protons from the stroma into the thylakoid space
- Photolysis adds more protons inside
- Protons flow back through **ATP synthase**, making ATP: **photophosphorylation**

Electron carriers, proton pumping and ATP synthase. Somepics, CC BY-SA 4.0.

	Non-cyclic	Cyclic
Electrons from	Photosystem II (water)	Photosystem I, returned to the chain
Products	ATP, reduced NADP, oxygen	ATP only

Photosystem I reduces NADP

C1.3.13

- Photosystem I absorbs light and emits excited electrons
- Its vacancies are filled by electrons from the chain after photosystem II
- The excited electrons pass, two at a time, to **NADP**
- NADP also takes a proton from the stroma: NADP + 2 electrons + H+ → reduced NADP
- Use the pair "NADP and reduced NADP" or "NADP+ and NADPH" consistently

Compare

In respiration, NAD carries hydrogen away from food to make ATP. In photosynthesis, NADP carries hydrogen to carbon dioxide to make sugar.

The thylakoid as a system

C1.3.14

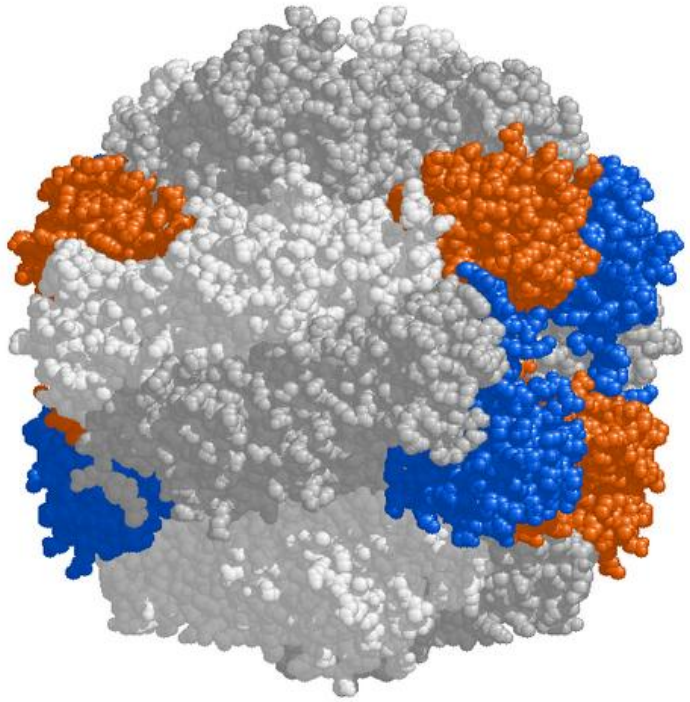
Process	Where in the thylakoid
Light absorption	Photosystems in the membrane
Photolysis of water	Photosystem II, on the side facing the thylakoid space
Proton pumping	Electron carriers in the membrane, into the thylakoid space
ATP synthesis	ATP synthase, releasing ATP into the stroma
Reduction of NADP	Photosystem I side, releasing reduced NADP into the stroma

So

ATP and reduced NADP are made on the stroma side, right where the Calvin cycle uses them.

Carbon fixation by rubisco

C1.3.15



Rubisco. ARP, public domain.

RuBP (5C) + CO_2 → 2 glycerate 3-phosphate (3C)

- Catalysed by **rubisco** in the stroma
- Rubisco is the most abundant enzyme on Earth
- It works slowly and is not effective at low CO_2 concentrations, so chloroplasts need a lot of it
- This step fixes inorganic carbon into an organic compound

Think about it

Why might plants in hot, dry places, which close their stomata, be limited by the properties of rubisco?

Making triose phosphate

C1.3.16

Glycerate 3-phosphate + reduced NADP + ATP → triose phosphate + NADP + ADP

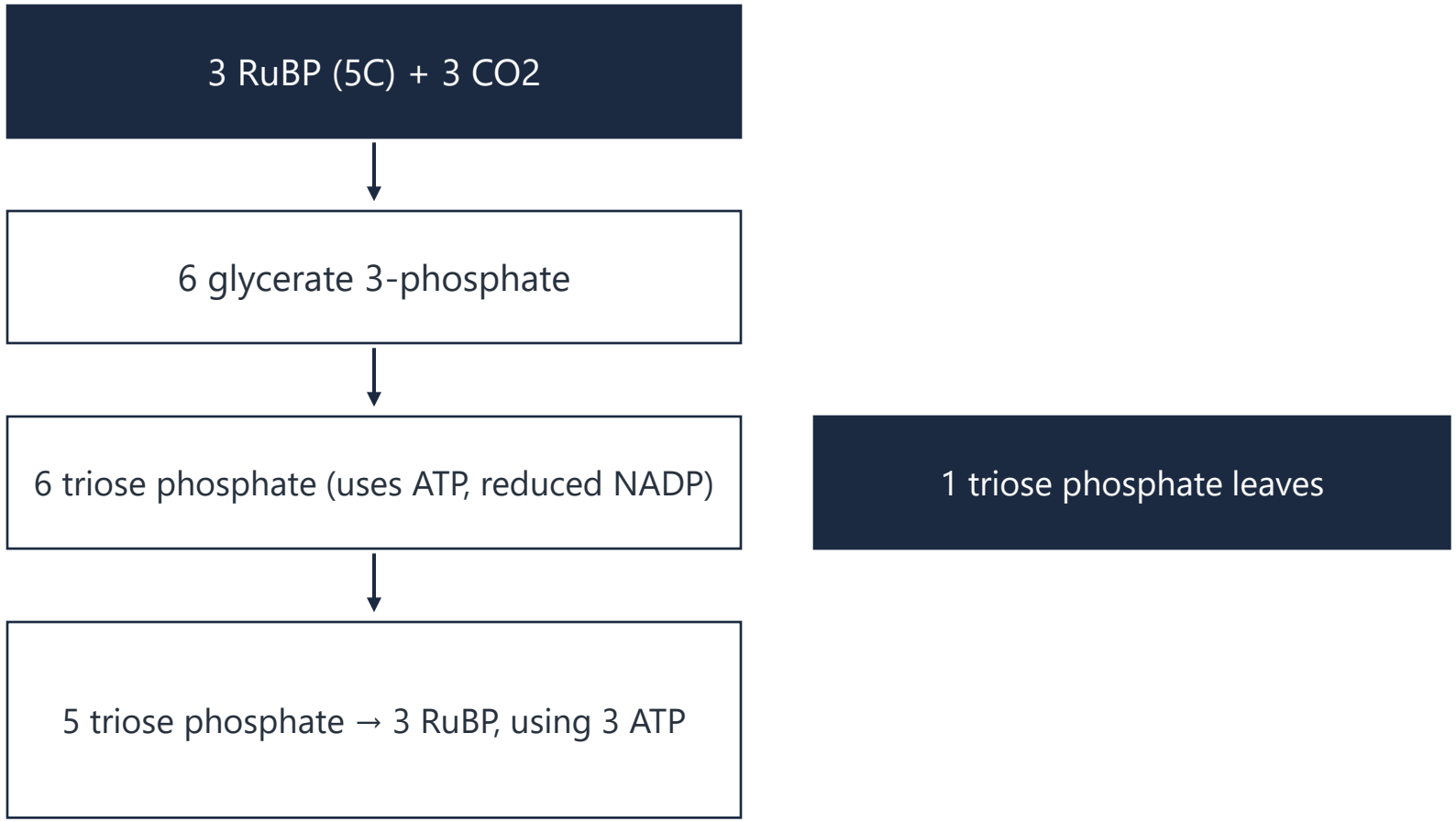
- Reduced NADP supplies the hydrogen that reduces glycerate 3-phosphate
- ATP supplies the energy
- Triose phosphate is a 3C sugar, the first carbohydrate made
- This is a reduction, the reverse of what happens in glycolysis

Activity

Write the equation for one turn of the Calvin cycle. For each CO_2 fixed, how many ATP and reduced NADP are used? (3 ATP and 2 reduced NADP.) Explain where each is used.

Regenerating RuBP

- Five triose phosphates (15C) are rearranged into three RuBP (15C)
- Uses ATP
- Three turns fix 3 CO_2 and release one triose phosphate
- For one glucose, 5/6 of all triose phosphate must go back to RuBP



From triose phosphate to everything else

C1.3.18

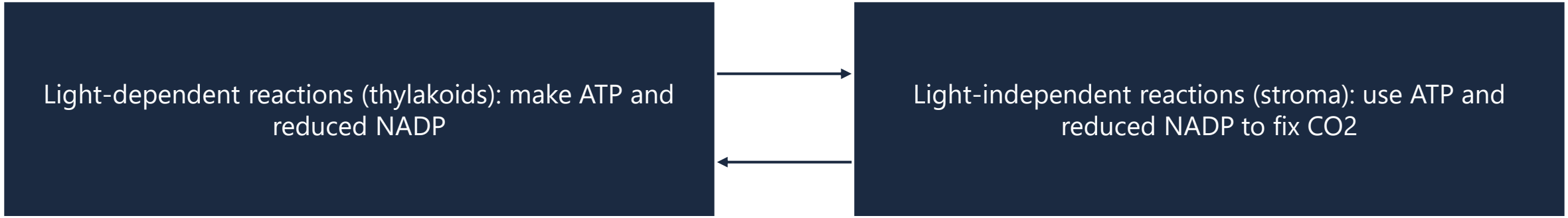
Product	How it is made
Glucose, sucrose, starch, cellulose	Triose phosphates joined, then sugars linked
Amino acids	Calvin cycle intermediates plus nitrogen (from nitrate or ammonium)
Lipids	Fatty acids and glycerol made from triose phosphate
Nucleotides	Sugars plus nitrogen and phosphate

Key idea

Every carbon atom in a plant was fixed by rubisco in the Calvin cycle. Other compounds come from pathways that start at cycle intermediates.

Two stages, one process

C1.3.19



If...	Then...
Light stops	No ATP or reduced NADP are made, so the Calvin cycle stops within seconds
CO2 runs out	ATP and reduced NADP are not used, so NADP runs out; photosystem I cannot pass on electrons, the chain backs up and photosystem II stops

Link

This connects to limiting factors in C1.3 (SL).

Check that you can explain

1. What a photosystem is, and why the pigments work as an array
2. Photolysis of water, and why oxygen changed the Earth
3. How ATP is made by chemiosmosis, and cyclic versus non-cyclic
4. How photosystem I reduces NADP
5. Where each light-dependent process happens in a thylakoid
6. Carbon fixation by rubisco and the reduction to triose phosphate
7. How RuBP is regenerated and other compounds are made
8. How each stage depends on the other

Exit activity: 5 minutes

On your own and without notes. Hand this in as you leave.

1. State the substrates and product of the reaction catalysed by rubisco.
2. Explain why photosynthesis releases oxygen.
3. Explain why the Calvin cycle stops in the dark.

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