

Photosynthesis

Three one-hour lesson plans, and three more at higher level

Six one-hour lessons: three at standard level and three more at higher level (the guide gives C1.3 three hours at SL and three more at HL). They follow Adam's teaching order: the equation and the colours of light, pigments and spectra with the chromatography practical, then limiting factors with the leaf disc lab and the dry lab; at higher level, photosystems and water, the thylakoid at work, and the Calvin cycle with the whole system. Every figure and film plays on a projector: step through it with the arrow keys and stop on each caption. The wet practicals (chromatography, leaf discs) have dry-lab stand-ins for a class without a lab.

LESSON	COVERS	FOCUS	CHAPTERS
1 Light into sugar	C1.3.1, C1.3.2, C1.3.3 and C1.3.5	Where the energy and the atoms of glucose come from, why the oxygen is from water, and why leaves absorb red and blue light	1, 2, 4
2 Pigments and spectra	C1.3.4 and C1.3.6	Separating leaf pigments by chromatography, working out R _f , and comparing absorption and action spectra	3, 5
3 Limiting factors, and tomorrow's air	C1.3.7 and C1.3.8	Light, carbon dioxide and temperature as limiting factors, how to vary each, and greenhouse against FACE experiments	6, 7, lab
4 Photosystems and water HL	C1.3.9, C1.3.10 and C1.3.11	Pigments in arrays round a reaction centre, why one pigment alone is useless, and photolysis at photosystem II and its consequences for Earth	8, 9
5 The thylakoid at work HL	C1.3.12, C1.3.13 and C1.3.14	Chemiosmosis in the thylakoid, cyclic and non-cyclic photophosphorylation, NADP reduced at photosystem I, and where each step happens	10, 11
6 The Calvin cycle, and the whole system HL	C1.3.15 to C1.3.19	Rubisco and carbon fixation, GP to TP, RuBP remade, every compound from the Calvin cycle, and why each half needs the other	12, 13, 14, 15

The guide, for the class to read and play: biologybybradford.com/guides/ib-biology-c1-3-photosynthesis

Light into sugar

60 minutes • C1.3.1, C1.3.2, C1.3.3 and C1.3.5 • Chapters 1, 2, 4

Where the energy and the atoms of glucose come from, why the oxygen is from water, and why leaves absorb red and blue light

BY THE END, STUDENTS CAN

- ☐ Explain how photosynthesis turns light energy into the chemical energy of carbon compounds, and why ecosystems depend on it C1.3.1
- ☐ Write the word equation, say where each atom of glucose comes from, and explain why the oxygen given off comes from water C1.3.2, C1.3.3
- ☐ Explain why pigments absorb only some wavelengths, and read and sketch an absorption spectrum with wavelengths and colours C1.3.5

TIMING

0-6	6 min	Do now: sketch the equation	
6-14	8 min	Where the energy comes from	
14-28	14 min	Where the atoms go	
28-38	10 min	Two processes compared	
38-54	16 min	Why leaves are green	
54-60	6 min	Exit	
	60 min	One lesson	

STARTER

- 6 min** **Do now: sketch the equation**
- Students draw photosynthesis as a picture with its inputs, outputs and conditions, from memory (activity below), then share it with a partner.

ON THE BOARD, FROM THE GUIDE

Open the guide on the projector at each chapter (the links work in this PDF). Every figure plays from its own buttons, and the lesson's slides have the same figures, step by step, in the order of this plan.

01 Sunlight in, chemical energy out

CHAPTER 01 IN THE SLIDES

Step through the figure (4 steps, the arrow keys on a projector). Stop on each caption and ask what changed before you go on.

- Light energy** from the Sun reaches a leaf.
- Photosynthesis turns it into **chemical energy** in the bonds of sugar.
- The cow lives on that energy, and stores some of it in milk.
- You release it in **respiration**, as ATP, and every step loses some as **heat**.

Predict box: The chemical energy in a slice of cheese: where did it first come from? Hands up or mini whiteboards first.

Answer B: Light caught by the grass it ate

02 Carbon from the air, hydrogen from water

CHAPTER 02 IN THE SLIDES

Step through the figure (4 steps, the arrow keys on a projector). Stop on each caption and ask what changed before you go on.

1. What goes in: **carbon dioxide** from the air, **water** from the soil.
2. Light energy **splits water**. The oxygen leaves as a by-product.
3. The **hydrogen** is added to carbon dioxide, building **glucose**.
4. carbon dioxide + water → glucose + oxygen. The bars show where each atom came from: green, carbon dioxide; pink, water.

Show the figure: Six atoms or molecules and two bins. Which molecule going in had the atom at all, and what tells you?

Play the animation, From light to sugar. It loops; pause it on each moment below and ask what is happening (in the lesson slides it is a video).

1. Into a **leaf**, a **palisade cell**, a **chloroplast** and the **thylakoids** where its pigments sit.
2. Chlorophyll absorbs **red** and **blue** light and reflects **green**.
3. Energy absorbed by chlorophyll **splits water**. The **oxygen** is given off as a by-product.
4. **Carbon dioxide** diffuses in from the air.
5. Hydrogen from water is added to carbon dioxide, building **glucose**, which can be stored as **starch**.
6. **carbon dioxide + water → glucose + oxygen**

Predict box: Where does the oxygen gas a leaf gives off come from? Hands up or mini whiteboards first.

Answer D: From the water it splits

04 Why some colours and not others

CHAPTER 04 IN THE SLIDES

Step through the figure (4 steps, the arrow keys on a projector). Stop on each caption and ask what changed before you go on.

1. **White light** is every colour together.
2. Chlorophyll absorbs **blue** and **red** and reflects most **green**.
3. An **absorption spectrum**: how much of each wavelength a pigment absorbs. These are for pigments dissolved in a solvent.
4. **Accessory pigments** absorb where chlorophyll a absorbs least.

Show the figure: Sketch chlorophyll's absorption spectrum: seven handles, one for each colour band. Chlorophyll a is the pigment to draw.

Predict box: Why does chlorophyll absorb red and blue light but very little green? Hands up or mini whiteboards first.

Answer D: Red and blue photons match jumps its electrons can make

Remember it: Richard Of York Gave Battle In Vain (Red, Orange, Yellow, Green, Blue, Indigo, Violet).

THE LESSON

8 min Where the energy comes from

Chapter 1: the predict (the cheese) as a vote, then the figure. Pairs draw the Energy flowchart (below).

14 min Where the atoms go

Chapter 2: the predict, then the figure step by step. Then Where does each atom go? (the card sort below, or the chapter's sorter on the board). Then play the photosynthesis film, SL, whole: "Light in, water split, oxygen out, sugar made."

10 min Two processes compared

The Venn below: respiration, met in C1.2, against photosynthesis.

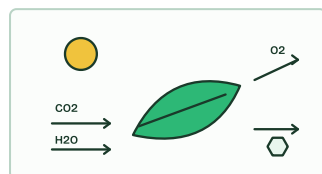
16

min

Why leaves are green

Chapter 4: the predict. Students sketch the spectrum on paper (Draw the spectrum, below), then set chapter 4's handles on the board. Play the figure, then turn over the Richard Of York tiles.

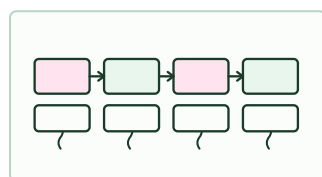
ACTIVITIES

**DO NOW**

Sketch the equation

Students draw photosynthesis as a picture: what goes in, what comes out, where, and what it needs. Shared with a partner, then compared with chapter 2's figure.

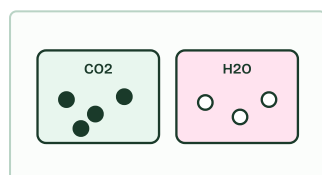
Needs: mini whiteboards.

**PAIRS**

Energy flowchart

Eight cards (Sun, light energy, leaf, chemical energy in glucose, a rabbit, chemical energy in ATP, muscle contraction, heat) laid as a flowchart (chapter 1). Then pairs add where heat leaves at every step.

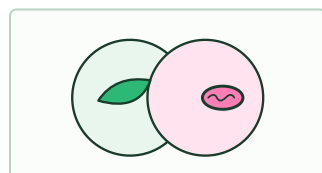
Needs: card sets.

**CARD SORT**

Where does each atom go?

Ten small cards (each a coloured atom: the carbon, hydrogen and oxygen atoms of glucose, the oxygen gas, the carbon in starch, the hydrogen in a fat, the oxygen atoms in the carbon dioxide, and so on) sorted onto two mats, "from carbon dioxide" and "from water" (chapter 2). The class then hears the heavy-oxygen story.

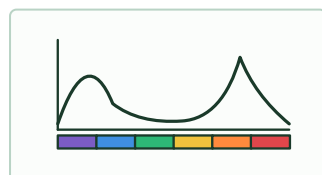
Needs: card sets and two mats per pair.

**VENN**

Two processes compared

A two-circle Venn: photosynthesis and respiration. Where it happens, inputs, outputs, energy in or out, and which organisms. At least three things go in the overlap (ATP made, membranes, enzymes, both in plant cells).

Needs: an A4 Venn sheet.

**SKETCH**

Draw the spectrum

On axes with wavelengths and a coloured strip of the visible spectrum, students sketch chlorophyll's absorption spectrum in pencil, then chlorophyll b's in another colour, and check against chapter 4's figure.

Needs: printed axes and coloured pencils.

PLENARY

6

min

Exit

Label where each atom of glucose came from, and say in one sentence why a leaf looks green.

WHAT STUDENTS GET WRONG

The oxygen comes from carbon dioxide. It comes from water ([chapter 2](#)).

Plants get their mass from the soil. Most of it is carbon and oxygen from the air.

Plants photosynthesise by day and respire by night. They respire all the time.

Leaves are green because chlorophyll makes green light. Green is what is not absorbed.

Light splits water directly. Chlorophyll absorbs the light, and its energy is used to split the water; light falling on water does not split it.

STRETCH AND SUPPORT

Support: chapter captions as cut-up cards to put in order; the dotted key terms as a glossary; a writing frame for "explain the effect of light intensity" (rise, why, plateau, why).

Stretch: if all the oxygen given off comes from water, the equation needs 12 water molecules in and 6 out. Write that equation and say why.

IN THE GUIDE

- 1** [Sunlight in, chemical energy out](#)
- 2** [Carbon from the air, hydrogen from water](#)
- 4** [Why some colours and not others](#)
- A11** [The whole guide, with the figures that play](#)
- PPTX** [This lesson's slides, in the order of this plan](#)

PRACTISE AND REVISE

BUILD FOR YOUR CLASS

- [Tarsia puzzle](#), [dominoes](#) and [picture reveal](#) on C1.3, built from its key terms and ready to print
- A [pub quiz](#) with rounds on C1.3, to present or run with no projector
- An [escape room](#) built from the [question bank](#) on C1.3

ALREADY ON THE SITE FOR C1.3

- [Quiz: Photosynthesis](#)
- [Quiz: Photosynthesis \(HL\)](#)
- Revision map: [C1.3 Photosynthesis](#), to fill in
- Exam questions: [C1.3 in the exam maker](#), a paper with its markscheme

CARD SETS ON SPLYCR

Open a set to host it as a class game, or make a copy to edit.

- [C1.3 Photosynthesis \(SL\)](#)
- [C1.3 Photosynthesis \(HL\)](#)

EXAM PRACTICE

Check yourself

Set it for homework: a fresh paper of exam-bank questions on C1.3 at standard level each time, marked as students go and saved to their Exam practice when they are signed in.

biologybybradford.com/exam-maker/sit?topics=C1.3&level=SL&paper=quiz&marks=15&src=ep



Pigments and spectra

60 minutes • C1.3.4 and C1.3.6 • Chapters 3, 5

Separating leaf pigments by chromatography, working out R_f, and comparing absorption and action spectra

BY THE END, STUDENTS CAN

- ☐ Separate leaf pigments by chromatography, work out R_f values and identify each pigment by colour and R_f C1.3.4
- ☐ Compare absorption and action spectra, and plot an action spectrum from oxygen or carbon dioxide data C1.3.6

TIMING

0–5	5 min	Do now: one green or several?	
5–35	30 min	Separate the greens	
35–43	8 min	Measure and identify	
43–55	12 min	Engelmann's bacteria	
55–60	5 min	Exit	
	60 min	One lesson	

STARTER

5 min Do now: one green or several?

"Is the green of a leaf one pigment or several? Which would travel furthest in a solvent, and why?"
Students write a sentence each. Do not correct yet.

ON THE BOARD, FROM THE GUIDE

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03 More than one green

CHAPTER 03 IN THE SLIDES

Slide the figure through Time 0 and Time 100, and have the class say what will change before each.

Step through the figure (3 steps, the arrow keys on a projector). Stop on each caption and ask what changed before you go on.

- Grind a leaf with a little sand and a few drops of propanone. Spot the extract on a pencil line 2 cm from the bottom of the strip, then stand the strip in propanone, below the line, with the lid on.
- Take the strip out before the solvent reaches the top and mark the front in pencil at once. The pigments have separated into bands. The table beside it lists known values for this solvent.
- Measure from the origin line to the middle of each band and to the front. Work out R_f for each band, then name each pigment from its colour and its R_f.

Predict box: The solvent front has moved 8.0 cm from the origin and a yellow band 5.7 cm. What is the band's R_f?
Hands up or mini whiteboards first.

Answer B: 0.71

05 Absorbed is not the same as used

CHAPTER 05 IN THE SLIDES

Show the figure: Seven wavelengths of light, the oxygen a sprig gave off in 10 minutes in each, and empty axes. Rate = volume of oxygen ÷ time.

Play the animation, Engelmann's bacteria. It loops; pause it on each moment below and ask what is happening (in the lesson slides it is a video).

1. A strand of green alga, and bacteria that swim towards **oxygen**.
2. In white light the whole strand gives off oxygen. The bacteria gather evenly.
3. Engelmann put a **prism** under the slide. What will the bacteria do?
4. The bacteria crowd where **red** and **blue** light fall. Counted, they draw an **action spectrum**.

Predict box: Engelmann shone a spectrum along a strand of alga and added bacteria that swim towards oxygen. Where did the bacteria gather? Hands up or mini whiteboards first.

Answer A: Under the red and the blue light

THE LESSON

30

min

Separate the greens

The practical below: grind, spot, run. While the solvent climbs, [chapter 3's](#) figure is on the board (slide the time), then the Rf predict.

8

min

Measure and identify

Measure the strip, work out each Rf and identify the pigments from the table. Pairs answer the four Chromatography questions (below). No lab: use the chromatography bench instead, in pairs.

12

min

Engelmann's bacteria

[Chapter 5:](#) the predict (Engelmann), then Engelmann's experiment: split the light, count, compare. Then Plot it, done as a class on the board.

ACTIVITIES

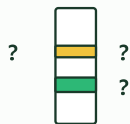


PRACTICAL

Separate the greens

Paper chromatography of spinach ([chapter 3](#)). Grind 4 or 5 leaves with a little sand and 1 cm³ of propanone to a paste. Draw a pencil origin 2 cm from the bottom of a strip of chromatography paper. Spot the extract with a fine pipette, drying between spots, until there is a small dark spot (under 2 mm). Stand the strip in solvent below the origin in a stoppered boiling tube. Take it out before the front reaches the top and mark the front at once. Measure and work out each Rf, and identify from the table for that solvent. Safety: propanone is highly flammable and an irritant: no flames, good ventilation, eye protection.

Needs: spinach, sand, mortar and pestle, propanone, chromatography paper or TLC strips, boiling tubes with bungs, fine pipettes, pencils, rulers, eye protection.



DISCUSS

Chromatography questions

Four questions. A pigment that clings to the paper: does it move faster or slower? One that dissolves well in the solvent? What makes one pigment outrun another? How do you identify one? Pairs answer in one sentence each, then the class agrees model answers.

Needs: the questions on the board.

PLENARY

5

min

Exit

Work out an Rf from two distances, and give one similarity and one difference between the absorption and action spectra.

WHAT STUDENTS GET WRONG

Rf can be more than 1, or is measured from the bottom of the paper. It is measured from the origin, and is always under 1.

The action spectrum is the same as the absorption spectrum. It is the rate at each wavelength: it follows absorption but is not identical.

STRETCH AND SUPPORT

Support: chapter captions as cut-up cards to put in order; the dotted key terms as a glossary; a writing frame for "explain the effect of light intensity" (rise, why, plateau, why).

Stretch: why might a red seaweed's pigments not show up at all in this solvent? (Its main extra pigments dissolve in water, not propanone.)

Stretch: compare chlorophyll with haemoglobin and melanin: what does each absorb, and what is it for?

IN THE GUIDE

- 3** [More than one green](#)
- 5** [Absorbed is not the same as used](#)
- A11** [The whole guide, with the figures that play](#)
- PPTX** [This lesson's slides, in the order of this plan](#)

EXAM PRACTICE

Check yourself

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biologybybradford.com/exam-maker/sit?topics=C1.3&level=SL&paper=quiz&marks=15&src=ep



PRACTISE AND REVISE

BUILD FOR YOUR CLASS

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CARD SETS ON SPLYCR

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- [C1.3 Photosynthesis \(SL\)](#)
- [C1.3 Photosynthesis \(HL\)](#)

Limiting factors, and tomorrow's air

60 minutes • C1.3.7 and C1.3.8 • Chapters 6, 7 • The dry lab

Light, carbon dioxide and temperature as limiting factors, how to vary each, and greenhouse against FACE experiments

BY THE END, STUDENTS CAN

- ☐ Suggest and test hypotheses about light, carbon dioxide and temperature as limiting factors, naming the variables C1.3.7
- ☐ Compare greenhouse and FACE experiments as ways of predicting how plants will grow in tomorrow's air C1.3.8

TIMING

0-5	5 min	Do now: sketch it	
5-17	12 min	Leaf discs, set going	
17-27	10 min	Sketch, then check	
27-35	8 min	Which question is better?	
35-47	12 min	Greenhouse against FACE	
47-55	8 min	Leaf discs: the last counts	
55-60	5 min	Exit	
	60 min	One lesson	

STARTER

5
min

Do now: sketch it

Rate of photosynthesis against light intensity, with no help (the first stage of [chapter 6's](#) sketches).

ON THE BOARD, FROM THE GUIDE

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06 Whatever runs short sets the pace

CHAPTER 06 IN THE SLIDES

Show the figure: Sketch a hypothesis as a graph, then check it. Three stages: light, then temperature, then carbon dioxide at high and low light.

Predict box: A plant at 15 °C is given more and more light until its rate levels off. Then it is warmed to 25 °C. What happens to the rate? Hands up or mini whiteboards first.

Answer B: It rises to a higher plateau

Remember it: Lazy Cats Toast (Light intensity, Carbon dioxide concentration, Temperature).

07 Tomorrow's air, today

CHAPTER 07 IN THE SLIDES

Step through the figure (3 steps, the arrow keys on a projector). Stop on each caption and ask what changed before you go on.

- Two ways to grow plants in **tomorrow's air**.
- A greenhouse **controls** more variables; a **FACE** ring keeps real field conditions.
- In the field, the gain in yield was smaller.

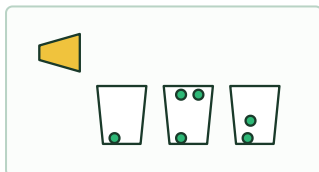
Predict box: Crops given extra carbon dioxide gained less yield in FACE rings than in enclosures. What is the most likely reason? Hands up or mini whiteboards first.

Answer C: In fields, another factor soon limits

THE LESSON

- 12 min** **Leaf discs, set going**
The leaf disc practical below, set going in groups at three hydrogencarbonate concentrations. One student in each group counts the floating discs every minute through the next steps.
- 10 min** **Sketch, then check**
Chapter 6: Sketch, then check, stages 2 and 3 on the board against the students' own sketches. Then the predict, then the Lazy Cats Toast tiles.
- 8 min** **Which question is better?**
The activity below, then the leaf disc lab's variables: how is each varied, why, and in what units?
- 12 min** **Greenhouse against FACE**
Chapter 7: the predict, then the figure. Students fill a two-column table, greenhouse and FACE, with one controlled variable for each.
- 8 min** **Leaf discs: the last counts**
Last counts, then each group's time for half the discs to float goes on the board. The dry lab (the pondweed bench) is shown on the board with one distance series, and set for homework, written up with the coach.

ACTIVITIES

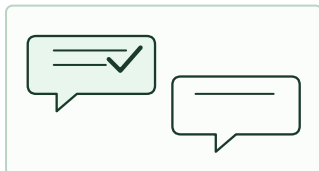


PRACTICAL

Leaf discs

Punch ten discs from a spinach leaf (avoiding veins) for each cup (chapter 6). Draw the air out of them in a 10 cm³ plastic syringe of the cup's solution with a drop of washing-up liquid (a finger on the nozzle, pull the plunger, release, repeat until they sink). Tip them into a cup of the same solution: 0 %, 0.2 % and 0.5 % sodium hydrogencarbonate (1 g in 100 cm³ is 1 %). Stand each cup the same distance from a lamp. Count the discs floating every minute for 15 to 20 minutes, and find the time for half to float.

Needs: spinach, a hole punch, 10 cm³ plastic syringes, sodium hydrogencarbonate, washing-up liquid, clear cups, a lamp, a metre rule, timers.



WRITE

Which question is better?

Two research questions for the leaf disc lab: one names the independent variable with its range and units, the dependent variable and how it is measured, and the organism; the other does not. Students say which is better and why, then write their own for the dry lab.

Needs: the two questions on the board.

○	_____
→	_____
⊥	_____

TABLE

Three ways to measure it

A three-row table: oxygen given off, carbon dioxide taken up, gain in mass. For each, how it is measured and the theory behind the method. If there is time, or set it with the dry lab homework: lesson 3's minutes have no slot for it.

Needs: a printed table.



PRACTICAL

Algal balls

An alternative to the leaf discs, if there is time or in another lesson. Algae trapped in alginate beads sit in bottles of red hydrogencarbonate indicator, the bottles along a metre rule from a lamp. After an hour or so the indicator turns purple where carbon dioxide is taken up (photosynthesis faster than respiration) and yellow where it is added. Make the beads with sodium alginate and calcium chloride, by the SAPS method; compare with a colour chart or a colorimeter at 550 nm.

Needs: concentrated algae, 2 % sodium alginate, 2 % calcium chloride, hydrogencarbonate indicator, small bottles with lids, a lamp, a metre rule.

PLENARY

5
min

Exit

Name the limiting factor at three points on a sketch graph.

WHAT STUDENTS GET WRONG

A limiting factor stops photosynthesis. It sets the rate; it is the one in shortest supply.

More light always means a faster rate. Only while light is limiting.

The plateau means the plant is "full". It means another factor now limits.

Lamp distance is the light intensity. Intensity falls about as $1 \div \text{distance}^2$: measure it, and watch for heat.

STRETCH AND SUPPORT

Support: chapter captions as cut-up cards to put in order; the dotted key terms as a glossary; a writing frame for "explain the effect of light intensity" (rise, why, plateau, why).

Stretch: in the dry lab, plot rate against $1 \div \text{distance}^2$ and find where the straight line ends. What does that point tell you?

Stretch: a greenhouse grower can add carbon dioxide, light or heat. Using a sketch graph, which should she add first on a dull winter day, and why?

IN THE GUIDE

- 6** [Whatever runs short sets the pace](#)
- 7** [Tomorrow's air, today](#)
- Lab** [Dry lab: Pondweed and the lamp](#)
- A11** [The whole guide, with the figures that play](#)
- PPTX** [This lesson's slides, in the order of this plan](#)

PRACTISE AND REVISE

BUILD FOR YOUR CLASS

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- [Quiz: Photosynthesis \(HL\)](#)
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CARD SETS ON SPLYCR

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- [C1.3 Photosynthesis \(HL\)](#)

EXAM PRACTICE

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Photosystems and water HL

60 minutes • C1.3.9, C1.3.10 and C1.3.11 • Chapters 8, 9

Pigments in arrays round a reaction centre, why one pigment alone is useless, and photolysis at photosystem II and its consequences for Earth

BY THE END, STUDENTS CAN

- ☐ Describe a photosystem and explain why pigments work only as an array round a reaction centre C1.3.9, C1.3.10
- ☐ Explain how photolysis at photosystem II supplies electrons and protons, and what its waste oxygen did to the Earth C1.3.11

TIMING

0-6	6 min	Do now: annotate it	
6-14	8 min	Redox again	
14-20	6 min	The glowing chlorophyll demonstration	
20-32	12 min	An array and a reaction centre	
32-46	14 min	Water split	
46-54	8 min	A written question	
54-60	6 min	Exit	
	60 min	One lesson	

STARTER

6
min

Do now: annotate it

Annotate it (below): an unlabelled drawing of a chloroplast with the two stages, from SL memory.

ON THE BOARD, FROM THE GUIDE

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08 Pigments in an array

CHAPTER 08 IN THE SLIDES

Step through the figure (5 steps, the arrow keys on a projector). Stop on each caption and ask what changed before you go on.

1. On its own, chlorophyll gives the energy straight back, as **red light**.
2. A **photosystem**: hundreds of pigments around a **reaction centre**, in a membrane.
3. The **energy** hops from pigment to pigment, inwards.
4. The reaction centre emits an **excited electron**.
5. Many pigments, many colours, all feeding one reaction centre.

Predict box: Chlorophyll dissolved in propanone glows red under a bright light. Chlorophyll in a leaf hardly glows at all. Why? Hands up or mini whiteboards first.

Answer D: In a leaf the energy is passed on and used

Step through the figure (4 steps, the arrow keys on a projector). Stop on each caption and ask what changed before you go on.

1. Photosystem II has lost electrons.
2. It takes more from **water**.
3. **Photolysis**: electrons refill the reaction centre; **protons** stay in the lumen.
4. The **oxygen** is a waste product.

Show the figure: The shape of the rise is known better than the numbers, so only 0 and today's level are marked. Banded iron formations are mostly older than about 1.8 billion years.

Predict box: Cyanobacteria were splitting water for a long time before oxygen built up in the air. Where did their oxygen go at first? Hands up or mini whiteboards first.

Answer A: Into iron dissolved in the oceans

Remember it: Please Eat Oranges (Protons, Electrons, Oxygen).

THE LESSON

8
min

Redox again

Oxidation is loss of electrons or hydrogen, reduction is gain (a C1.2 recap). Which molecule in photosynthesis is reduced?

6
min

The glowing chlorophyll demonstration

The demonstration below, with [chapter 8's](#) predict made first.

12
min

An array and a reaction centre

[Chapter 8's](#) figure step by step. Then Pass the energy (below).

14
min

Water split

[Chapter 9](#): the predict, the figure, then the Please Eat Oranges tiles. The Great Oxidation figure follows, with the banded iron story told in two minutes.

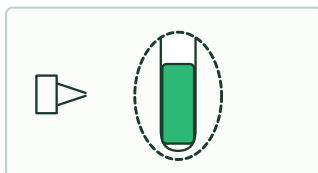
8
min

A written question

A short written question on C1.3.9 to C1.3.11 from the exam maker (in Practise and revise), timed and marked.

A teacher's mnemonic for the order: **Two before One**. Photosystem II goes first, and splits water; photosystem I reduces NADP.

ACTIVITIES



DEMO

Glowing chlorophyll

A boiling tube of spinach extract in propanone, in a dark room, lit from the side by a bright white torch (or a blue LED): it glows deep red. A whole leaf under the same light does not. Ask: where did the energy go in the leaf? ([chapter 8's](#) predict). Safety: propanone, as in Separate the greens.

Needs: extract, a boiling tube, a bright torch, a dark corner.



MODEL

Pass the energy

Students stand as a photosystem: eight to ten “pigments” in a ring round one “reaction centre”, with an “acceptor” beside them. A light card (a photon) handed to any outer pigment is passed inwards hand to hand (the energy moves, not the card’s owner) to the reaction centre, who hands a yellow “electron” token to the acceptor and is left short. Who refills it? (Photolysis, [chapter 9](#).) Then one student alone with a light card can only drop it (heat, or red light).

Needs: light cards and a few yellow tokens.



DO NOW

Annotate it

A chloroplast outline with the two stages shown as boxes, unlabelled. Students label photolysis, waste, reduced NADP, ATP, the thylakoid and the stroma.

Needs: the printed outline.

PLENARY

6

min

Exit

Why can a single chlorophyll molecule not do any part of photosynthesis?

WHAT STUDENTS GET WRONG

Every pigment in a photosystem gives off electrons.

They pass on energy; only the reaction centre emits an electron.

Oxygen from photolysis is used in the Calvin cycle. It is waste; the protons and electrons are used.

STRETCH AND SUPPORT

Stretch: the reaction centres of photosystems II and I absorb best at about 680 and 700 nm (their names, P680 and P700, are beyond the guide). Why might two photosystems in series be needed to lift electrons from water all the way to NADP? (The Z scheme, for discussion.)

Stretch: make a respiration and photosynthesis Tarsia puzzle in the Tarsia builder, ticking C1.2 and C1.3 together.

IN THE GUIDE

8 [Pigments in an array](#)

9 [Water split, oxygen spare](#)

A11 [The whole guide, with the figures that play](#)

PPTX [This lesson's slides, in the order of this plan](#)

EXAM PRACTICE

Check yourself

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biologybybradford.com/exam-maker/sit?topics=C1.3&level=HL&paper=quiz&marks=15&src=ep



PRACTISE AND REVISE

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- A [pub quiz](#) with rounds on C1.3, to present or run with no projector
- An [escape room built from the question bank](#) on C1.3

ALREADY ON THE SITE FOR C1.3

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- Quiz: [Photosynthesis \(HL\)](#)
- Revision map: [C1.3 Photosynthesis](#), to fill in
- Exam questions: [C1.3 in the exam maker](#), a paper with its markscheme

CARD SETS ON SPLYCR

Open a set to host it as a class game, or make a copy to edit.

- [C1.3 Photosynthesis \(SL\)](#)
- [C1.3 Photosynthesis \(HL\)](#)

The thylakoid at work HL

60 minutes • C1.3.12, C1.3.13 and C1.3.14 • Chapters 10, 11

Chemiosmosis in the thylakoid, cyclic and non-cyclic photophosphorylation, NADP reduced at photosystem I, and where each step happens

BY THE END, STUDENTS CAN

- ☐ Explain how a proton gradient and ATP synthase make ATP in the thylakoid, by cyclic and non-cyclic photophosphorylation C1.3.12
- ☐ Explain how photosystem I reduces NADP, and where in a thylakoid each light-dependent step happens C1.3.13, C1.3.14

TIMING

0-5	5 min	Do now: where do protons collect?	
5-17	12 min	The thylakoid, step by step	
17-32	15 min	Act it out	
32-42	10 min	NADP and the map	
42-55	13 min	Plan a 7-mark answer	
55-60	5 min	Exit	
60 min		One lesson	

STARTER

5
min

Do now: where do protons collect?

In a mitochondrion, where do protons collect, and where is ATP made? Now guess for a chloroplast ([chapter 10's](#) predict).

ON THE BOARD, FROM THE GUIDE

Open the guide on the projector at each chapter (the links work in this PDF). Every figure plays from its own buttons, and the lesson's slides have the same figures, step by step, in the order of this plan.

10 Protons downhill make ATP

CHAPTER 10 IN THE SLIDES

Step through the figure (5 steps, the arrow keys on a projector). Stop on each caption and ask what changed before you go on.

1. The thylakoid membrane: **photosystems**, a **chain of carriers** and **ATP synthase**.
2. Electrons give up energy along the chain, which **pumps protons** into the lumen.
3. Protons pile up in the small lumen: a **proton gradient**.
4. They flow back through **ATP synthase**, which makes **ATP** in the stroma: **chemiosmosis**.
5. **Non-cyclic**: on to NADP. **Cyclic**: back round the chain, for more ATP.

Predict box: In a working chloroplast, where do protons build up? Hands up or mini whiteboards first.

Answer C: In the lumen, inside each thylakoid

11 NADP reduced, and the thylakoid as a system

CHAPTER 11 IN THE SLIDES

Tap the parts of the figure in turn: Stroma, Envelope, Granum, Granum, Granum, Thylakoid lumen, Stroma, Photosystem II, Chain of carriers, Photosystem I, NADP and ATP synthase.

Play the animation, The thylakoid at work. It loops; pause it on each moment below and ask what is happening (in the lesson slides it is a video).

1. Light energy is passed through an **array of pigments** to the **reaction centre**, a special chlorophyll, which gives off an **excited electron**.
2. The reaction centre replaces its lost electrons by **splitting water** (photolysis). The protons stay in the lumen; the **oxygen** is a waste product.
3. The electron passes along a **chain of carriers**, which uses its energy to **pump protons** from the stroma into the lumen.
4. At **photosystem I** light lifts the electron again. Two electrons and a proton from the stroma **reduce NADP**.
5. Protons flow out of the lumen through **ATP synthase**, making **ATP** in the stroma, where the Calvin cycle will use it.
6. The thylakoid as a system: water split on the lumen side, **ATP** and **reduced NADP** made on the stroma side.

Predict box: On which side of the thylakoid membrane is NADP reduced, and why does that side make sense? Hands up or mini whiteboards first.

Answer A: The stroma side, where the Calvin cycle uses it

Remember it: Loads Spends (Lumen, Stroma).

THE LESSON

12
min

The thylakoid, step by step

Chapter 10's figure step by step. Switch to Cyclic: what stops?

15
min

Act it out

Act it out (below): the light-dependent reactions modelled in plasticine on an A3 thylakoid.

10
min

NADP and the map

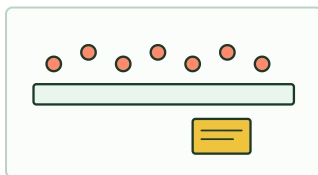
Chapter 11: the predict, then Map the thylakoid with the labels hidden and the Loads and Spends tiles. Then the chemiosmosis film (thylakoid), with the light off.

13
min

Plan a 7-mark answer

Plan a 7-mark answer (below) on the light-dependent reactions, then write it.

ACTIVITIES

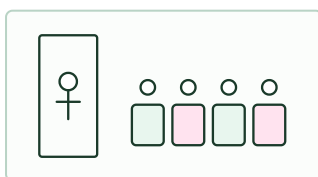


MODEL

Act it out

On an A3 drawing of a thylakoid membrane (stroma below, lumen above), pairs model the light-dependent reactions (chapters 10 and 11). Plasticine balls are protons. A sticky note stands for NADP, which turns into reduced NADP only once it holds two electron tokens and one proton. ADP and phosphate balls are joined at ATP synthase only as protons pass through it. Then one partner narrates while the other moves the pieces, using a markscheme's points as the script.

Needs: A3 thylakoid drawings, plasticine in two colours, sticky notes and tokens.



ROLE PLAY

Meet the membrane

If there is time. One student is the host at the door of the thylakoid; each other student is a part (photosystem II, photosystem I, a carrier, ATP synthase, ATP, ADP, NADP, reduced NADP, a proton, an electron, water, the lumen, the stroma) and introduces themselves to the host: where they live and who they work with.

Needs: name cards.



WRITE

Plan a 7-mark answer

The C1.3 exam maker's higher level extended question on how the light-dependent reactions produce ATP and NADPH (7 marks; the question says NADPH where this guide says reduced NADP). Students list the points they will make (photosystems, photolysis, chain, pumping, gradient, ATP synthase, photosystem I, NADP, cyclic), then write. Peer mark against the exam maker's markscheme.

Needs: lined paper.

PLENARY

5
min

Exit

Where in a thylakoid are water split, ATP made and NADP reduced?

WHAT STUDENTS GET WRONG

Protons collect in the stroma, or in the "intermembrane space". They collect in the lumen.

Cyclic photophosphorylation makes reduced NADP. It makes ATP only.

ATP and reduced NADP "move to the stroma". They are made on the stroma side.

STRETCH AND SUPPORT

Stretch: compare a mitochondrion's chain with the thylakoid's in a table: source of electrons, last acceptor, where protons collect, where ATP is made.

Stretch: make a respiration and photosynthesis Tarsia puzzle in the Tarsia builder, ticking C1.2 and C1.3 together.

IN THE GUIDE

- 10** [Protons downhill make ATP](#)
- 11** [NADP reduced, and the thylakoid as a system](#)
- A11** [The whole guide, with the figures that play](#)
- PPTX** [This lesson's slides, in the order of this plan](#)

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biologybybradford.com/exam-maker/sit?topics=C1.3&level=HL&paper=quiz&marks=15&src=ep



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CARD SETS ON SPLYCR

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- [C1.3 Photosynthesis \(SL\)](#)
- [C1.3 Photosynthesis \(HL\)](#)

The Calvin cycle, and the whole system HL

60 minutes • C1.3.15 to C1.3.19 • Chapters 12, 13, 14, 15

Rubisco and carbon fixation, GP to TP, RuBP remade, every compound from the Calvin cycle, and why each half needs the other

BY THE END, STUDENTS CAN

- ☐ Explain how Rubisco fixes carbon dioxide onto RuBP, and why the stroma needs so much of it C1.3.15
- ☐ Follow the carbon through the Calvin cycle: GP reduced to TP, and five TP in six remade into RuBP C1.3.16, C1.3.17
- ☐ Explain how every carbon compound in a plant is made from the Calvin cycle's products with mineral nutrients C1.3.18
- ☐ Explain why the light-dependent and light-independent reactions stop without each other C1.3.19

TIMING

0-5	5 min	Do now: true or false?	
5-17	12 min	Rubisco	
17-29	12 min	Count the carbons	
29-35	6 min	Where the carbon goes	
35-45	10 min	Each half needs the other	
45-55	10 min	Hexagons	
55-60	5 min	Exit	
	60 min	One lesson	

STARTER

5
min

Do now: true or false?

True or false, with a reason: "The light-independent reactions happen at night."

ON THE BOARD, FROM THE GUIDE

Open the guide on the projector at each chapter (the links work in this PDF). Every figure plays from its own buttons, and the lesson's slides have the same figures, step by step, in the order of this plan.

12 Fixing carbon, slowly

CHAPTER 12 IN THE SLIDES

Step through the figure (4 steps, the arrow keys on a projector). Stop on each caption and ask what changed before you go on.

1. **RuBP**, a five-carbon sugar, waits in **Rubisco's** active site.
2. **Carbon dioxide** joins it: **carbon fixation**.
3. The six carbons split into two **GP**.
4. Rubisco is slow, so a leaf makes **a lot** of it.

Step through the figure (4 steps, the arrow keys on a projector). Stop on each caption and ask what changed before you go on.

1. One Rubisco cannot keep up.
2. Eleven keep pace with bright light.
3. With little carbon dioxide, each does less and fumbles more.
4. More Rubisco helps until light is the limit.

Predict box: A leaf cell could save a lot of protein by making less Rubisco. Why doesn't it? Hands up or mini whiteboards first.

Answer D: Each Rubisco fixes only a few CO₂ a second

13 GP to TP, and RuBP made again

CHAPTER 13 IN THE SLIDES

Step through the figure (6 steps, the arrow keys on a projector). Stop on each caption and ask what changed before you go on.

1. Three **RuBP** wait for three **carbon dioxide**.
2. **Rubisco** fixes them: six **GP**.
3. **Reduced NADP** and **ATP** turn GP into **TP**.
4. One TP in six leaves the cycle.
5. Five **TP** are remade into three **RuBP**, using ATP.
6. Six turns, six carbon dioxide: one **glucose**.

Predict box: Of every six TP the Calvin cycle makes, how many must be used to remake RuBP? Hands up or mini whiteboards first.

Answer C: Five

Remember it: Fresh Rolls Rise (Fix, Reduce, Regenerate).

14 Every carbon came this way

CHAPTER 14 IN THE SLIDES

Step through the figure (4 steps, the arrow keys on a projector). Stop on each caption and ask what changed before you go on.

1. From TP: **sugars, starch** and **cellulose**.
2. **Lipids**.
3. **Amino acids**, with nitrogen from **nitrate**.
4. **Nucleotides**, with nitrogen and **phosphate**.

Play the animation, Follow one carbon atom. It loops; pause it on each moment below and ask what is happening (in the lesson slides it is a video).

1. One **carbon atom**, in a molecule of **carbon dioxide** in the air.
2. It **diffuses** in through a stoma and into a chloroplast.
3. **Rubisco** joins the CO₂ to **RuBP**; the product splits into two molecules of **GP**.
4. GP is reduced to **TP** with ATP and reduced NADP. One TP in six leaves the cycle; the rest remake RuBP.
5. Every carbon compound in the plant is made from the **Calvin cycle's** products. Here, with nitrogen from **nitrate** in the soil, an **amino acid**.
6. Joined into a **protein**, the atom stays in the plant until the plant, or whatever eats it, respires it.

Predict box: A plant has plenty of light, water and carbon dioxide, but its soil has no nitrate. Which will it fail to make? Hands up or mini whiteboards first.

Answer A: Proteins

15 Each half needs the other

CHAPTER 15 IN THE SLIDES

Switch the figure through Light and carbon dioxide, Lights off and No carbon dioxide, and have the class say what will change before each.

Play the animation, Photosynthesis, the whole system. It loops; pause it on each moment below and ask what is happening (in the lesson slides it is a video).

1. Into a leaf, a palisade cell, a **chloroplast**, and one **thylakoid** membrane.
2. Light energy passes through an **array of pigments** to the **reaction centre**, which emits an **excited electron**.
3. **Photolysis**: water is split. Its electrons refill photosystem II, its **protons** stay in the lumen, and its **oxygen** is a waste product.
4. Electrons passing along the chain pump protons into the lumen; protons flowing back through **ATP synthase** make **ATP**.
5. At **photosystem I** the electrons are lifted again and **reduce NADP**, with a proton from the stroma.
6. Sometimes the electron from photosystem I goes **back round** the chain (**cyclic**): more ATP, and no NADP reduced.
7. **Rubisco** fixes 3 **CO₂** onto 3 **RuBP**: 6 **GP**.
8. **ATP** and **reduced NADP** turn 6 GP into 6 **TP**; ADP and NADP go back to the thylakoid.
9. 1 **TP** leaves the cycle; the other 5 are remade into 3 **RuBP**, using ATP.
10. Two halves, each running on what the other makes: **ATP** and **reduced NADP** one way, **ADP** and **NADP** the other.

Play the animation, Respiration and photosynthesis on one map. It loops; pause it on each moment below and ask what is happening (in the lesson slides it is a video).

1. **The link reaction**, in the matrix: each pyruvate loses carbon dioxide and is oxidised, making reduced NAD, and coenzyme A carries the acetyl group on.
2. Reduced NAD from glycolysis, the link reaction and the Krebs cycle hands its electrons to the **electron transport chain**, and goes back as NAD.
3. ATP and reduced NADP from the thylakoid reduce GP to TP. One TP in six leaves; the other five, with more ATP, remake RuBP.
4. Follow **ATP**: made in glycolysis, the Krebs cycle, at the electron transport chain and in the thylakoid; used in glycolysis, the Calvin cycle and all over the cell.

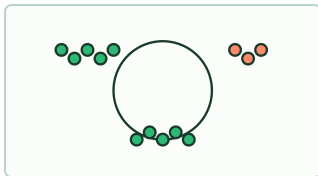
Predict box: A leaf in bright light is suddenly given no carbon dioxide. What happens to photosystem II? Hands up or mini whiteboards first.

Answer C: It stops, as NADP runs out further on

THE LESSON

12 min	Rubisco <u>Chapter 12</u> : the predict, the figure, then rounds 1 and 2 of the Rubisco race in pairs.
12 min	Count the carbons <u>Chapter 13</u> : the predict, then Count the carbons (below) in plasticine alongside the figure. Then the Fresh Rolls Rise tiles.
6 min	Where the carbon goes <u>Chapter 14</u> : the predict, then the carbon trail on its Built into the plant route.
10 min	Each half needs the other <u>Chapter 15</u> : the predict, the figure's three states, then the photosynthesis film, HL, with the light off and then the carbon dioxide off. The metabolism map's Follow a molecule, on ATP.
10 min	Hexagons Hexagons (below), in groups, telling the whole story.

ACTIVITIES

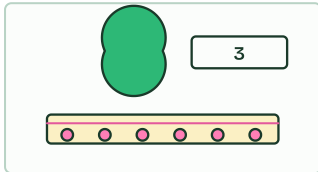


MODEL

Count the carbons

Plasticine balls as carbon atoms ([chapter 13](#)). Three RuBP of five balls each and three carbon dioxide of one: fix them into six GP of three; turn them into TP (an ATP card and a reduced NADP card each); take one TP out; remake three RuBP from the five left. Count the balls at every stage: fifteen plus three in, fifteen plus three out.

Needs: plasticine in two colours, and ATP and reduced NADP cards.

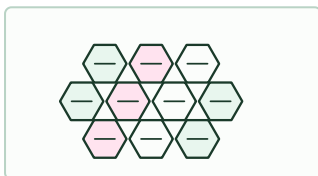


GAME

The Rubisco race

Pairs play rounds 1 and 2 on one device ([chapter 12](#)): how many Rubisco to keep up, and how many on the hot day?

Needs: a device per pair.

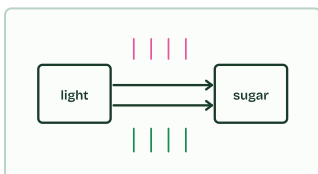


CARD SORT

Hexagons

Our own set of 24 hexagon cards (terms from both stages: photon, photosystem II, photolysis, oxygen, chain of carriers, proton gradient, ATP synthase, photosystem I, NADP, reduced NADP, stroma, lumen, Rubisco, RuBP, GP, TP, carbon dioxide, ATP, ADP, Calvin cycle, glucose, nitrate, starch, light). Groups join hexagons edge to edge only where they can say the link aloud, then tell the whole story in order.

Needs: printed hexagons for each group.



DIAGRAM

Improve the diagram

If there is time. A deliberately thin diagram of photosynthesis (two boxes, "light" in, "sugar" out). Students add every detail they now know, in two colours: one for SL and one for HL.

Needs: the printed diagram.

PLENARY

5
min

Exit

With no carbon dioxide, why does photosystem II stop?

WHAT STUDENTS GET WRONG

The light-independent reactions happen in the dark. They need the light reactions' products, so they run in the light.

The light-dependent reactions make glucose. The Calvin cycle does.

Glyceraldehyde 3-phosphate is reduced in the Calvin cycle. GP (glycerate 3-phosphate) is reduced to TP.

Rubisco is abundant because it is used up. It is abundant because it is slow.

No carbon dioxide only stops the Calvin cycle. It stops photosystem II too ([chapter 15](#)).

STRETCH AND SUPPORT

Stretch: in the 1950s Calvin's group switched the light off on algae and measured the cycle's molecules: GP rose and RuBP fell. Explain both from the cycle.

Support: leave the Count the carbons balls on the bench while students write; use the Fresh Rolls Rise tiles as a frame.

Stretch: make a respiration and photosynthesis Tarsia puzzle in the Tarsia builder, ticking C1.2 and C1.3 together.

IN THE GUIDE

- 12** [Fixing carbon, slowly](#)
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biologybybradford.com/exam-maker/sit?topics=C1.3&level=HL&paper=quiz&marks=15&src=ep



How this was made. The course structure, the activities and the teaching choices come from my own classroom, my presentations and my years of teaching IB and AP Biology. I use Claude, an AI, to help write and build the interactive guides, lesson plans, slides and practice questions, and to draw the diagrams and code the interactives. I direct the work and review it against the IB and AP specifications before it goes live.