

Cell respiration

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

Five one-hour lessons follow the guide in Adam's teaching order: two at standard level (ATP and the two routes, then measuring the rate, with the dough practical running beside [the dry lab](#)) and three at higher level (hydrogen and glycolysis, the matrix and the fuels, then the chain and the whole journey). The guide gives C1.2 two hours at SL and three more at HL. The plan follows the chapters, so a class can read them for homework and use the lesson for the activities. Every figure and both films play on a projector: step through each one with the arrow keys and stop on each caption.

LESSON	COVERS	FOCUS	CHAPTERS
1 ATP, and two ways to make it	C1.2.1 to C1.2.5	ATP as the cell's energy currency, what it pays for, respiration against gas exchange, and aerobic against anaerobic respiration	1, 2, 3, 4
2 Measuring a rate you cannot see	C1.2.6	Measuring respiration rate: the dough lab, the respirometer, the control, and the rate per gram per minute	5, 1ab
3 Hydrogen off, and glycolysis HL	C1.2.7 to C1.2.10	Oxidation as hydrogen removal and NAD as its carrier, the four stages of glycolysis, and lactate and ethanol as ways to give NAD back	6, 7, 8
4 Inside the matrix, and which fuel HL	C1.2.11, C1.2.12 and C1.2.17	The link reaction and the Krebs cycle, counting carbons and carriers, and fat against sugar as fuels	9, 12
5 The chain, the turbine and the whole journey HL	C1.2.13 to C1.2.16	Reduced NAD and the electron transport chain, the proton gradient, ATP synthase and oxygen as the last acceptor	10, 11

The guide, for the class to read and play: biologybybradford.com/guides/ib-biology-c1-2-cell-respiration

ATP, and two ways to make it

60 minutes • C1.2.1 to C1.2.5 • Chapters 1, 2, 3, 4

ATP as the cell's energy currency, what it pays for, respiration against gas exchange, and aerobic against anaerobic respiration

BY THE END, STUDENTS CAN

- ☐ Describe ATP as a nucleotide and explain what makes it suit the job of moving energy around a cell C1.2.1
- ☐ Explain how hydrolysis of ATP releases energy for active transport, building molecules and movement, and why remaking it takes energy C1.2.2, C1.2.3
- ☐ Explain respiration as the cell's way of making ATP from carbon compounds, and tell it apart from gas exchange C1.2.4
- ☐ Compare aerobic and anaerobic respiration in humans, with word equations for both C1.2.5

TIMING

0-5	5 min	Do now: which need energy?	
5-15	10 min	ATP, spent and remade	
15-23	8 min	Burning or respiring?	
23-35	12 min	Compare the two routes	
35-43	8 min	The respiration film	
43-55	12 min	The ATP budget	
55-60	5 min	Exit: true or false	
	60 min	One lesson	

STARTER

- 5 min** **Do now: which need energy?**
- Pairs list the functions of life they remember and star every one that needs energy (activity below). Land on: all of them. Students then say which kind of job each is.

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 The cell's small change

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.

1. A **nucleotide**: adenine, ribose and one phosphate.
2. Add a phosphate: **ADP**.
3. Add another: **ATP**, adenosine triphosphate.
4. What makes it the cell's **energy currency**.

Predict box: Removing one phosphate from ATP releases only a modest amount of energy. Why does that suit a cell? Hands up or mini whiteboards first.

Answer B: A job can take what it needs, with little wasted

02 Spend it, remake it

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. ATP, ADP and phosphate: the same molecules, used again and again.
2. **Hydrolysis**: water splits off the last phosphate. Energy is **released** for pumps, building and movement.
3. Remaking ATP **needs energy**: from respiration.
4. Spent and remade, over and over: the energy flows through, and some is lost as heat.

Predict box: Remaking ATP from ADP and phosphate needs energy. Where does a muscle cell get it? Hands up or mini whiteboards first.

Answer A: From respiring glucose or fat

Remember it: B A M (Building, Active transport, Movement).

03 Fuel in, ATP out

CHAPTER 03 IN THE SLIDES

Switch the figure through Burning, Cell respiration and Gas exchange, and have the class say what will change before each.

Predict box: A leaf in bright light takes in carbon dioxide and gives out oxygen. Is it respiring? Hands up or mini whiteboards first.

Answer C: Yes: all its living cells respire all the time

04 With oxygen and without

CHAPTER 04 IN THE SLIDES

Switch the figure through Plenty of oxygen and Not enough oxygen, and have the class say what will change before each.

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

1. One **mitochondrion**. Its inner membrane is deeply folded.
2. Splitting glucose into two pyruvate in the **cytoplasm** gives a little ATP: **2**.
3. With oxygen, pyruvate goes into a **mitochondrion**. Its carbon leaves as **carbon dioxide**; its hydrogen goes to the folds of the inner membrane.
4. **Oxygen** joins the hydrogen to make **water**. Here, at the folds, most of the ATP is made: about 30 to 32 from one glucose.
5. **Aerobic respiration**: glucose + oxygen → carbon dioxide + water. The energy released remakes ATP for the cell's work.

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. Rest: the mitochondria keep up easily.
2. A sprint: demand outruns the oxygen supply.
3. No oxygen: what happens to the ATP from each glucose?
4. Play the rounds to fill in the record.

Predict box: A sprinter's leg muscles run short of oxygen. Per glucose, how much ATP does anaerobic respiration make compared with aerobic? Hands up or mini whiteboards first.

Answer C: About one fifteenth as much

Remember it: L O W (Lactate, Only 2 ATP, Without oxygen).

THE LESSON

10
min

ATP, spent and remade

Students build ATP on mini whiteboards from a nucleotide (activity below), then play [chapter 1's](#) figure and make its predict. Then [chapter 2's](#) figure step by step, stopping on each caption, and the BAM tiles. Ask: "Where does the energy to remake ATP come from?" before step 3.

8 min **Burning or respiring?**
 Chapter 3: the predict about the leaf as a vote with hands up. Run the demonstration (below), then play the figure's three settings: burning, cell respiration and gas exchange. Students decide which of the three releases energy and which makes ATP.

12 min **Compare the two routes**
 Chapter 4: the predict, then students fill in the comparison table in pairs (below) and check it against the figure's two settings. Write both word equations on the board from memory. Turn over the LOW tiles.

8 min **The respiration film**
 Play the SL respiration film once through. Then turn the oxygen off at the end: students call out what will change before you press it.

12 min **The ATP budget**
 In pairs, rounds 1 to 4 (the game after [chapter 4](#)). Collect each pair's ATP per glucose for the sprint and the blocked blood supply on the board.

ACTIVITIES



DISCUSSION

Which need energy?

Pairs list the functions of life (nutrition, metabolism, growth, response, excretion, homeostasis, reproduction, and movement where it applies) and star the ones that need energy. Every one does: which kind of ATP job is each one (building, active transport, movement)?

Needs: mini whiteboards.



MODEL

Build ATP

On mini whiteboards, draw three shapes for a nucleotide (a rectangle, a pentagon and a circle), then add two more circles: ADP, then ATP. Label the base, the sugar and the phosphates, and circle the part removed by hydrolysis.

Needs: mini whiteboards and pens.



DEMONSTRATION

Burning or respiring?

Set a corn puff or a crisp alight on a mounted needle under a boiling tube of water (no nuts: allergies), beside a stoppered flask of soaked seeds with a thermometer that warms slowly over a day (set it up the day before). Same fuel and the same products; one fast and uncontrolled, the other a step at a time and making ATP. Safety: eye protection, a heat-proof mat, a fire blanket to hand, and the teacher holds the needle.

Needs: corn snacks, a mounted needle, a Bunsen burner, a boiling tube in a clamp, a vacuum flask of soaked seeds with a thermometer.

with	without

TABLE

Compare the two routes

A table to fill in pairs: substrates, oxygen needed, ATP per glucose, waste products, where in the cell, mitochondria needed, and the word equation. Check it against [chapter 4](#)'s figure.

Needs: the printed table.



QUIZ

True or false

Ten statements, five set as the exit: "Glycolysis happens in the cytoplasm" (true); "Chloroplasts are where a plant cell respire aerobically" (false: mitochondria, after glycolysis in the cytoplasm); "Anaerobic respiration in muscle makes carbon dioxide" (false); "Aerobic respiration gives about 30 to 32 ATP per glucose" (true); "The oxygen you breathe in ends up in the carbon dioxide you breathe out" (false: it ends up in water); "Plants respire only at night" (false); "ATP is the cell's long-term energy store" (false); "Lactate is made from pyruvate when oxygen is short" (true); "Anaerobic respiration in muscle makes a net 2 ATP per glucose" (true); "Respiration makes energy" (false: it releases it).

Needs: the statements on the board, or on cards.

GAME

The ATP budget

Pairs at one device, rounds 1 to 4 after [chapter 4](#). Collect each pair's ATP per glucose for rounds 3 and 4 on the board and compare: what did a sprint cost in glucose, and what happened with the blood supply blocked?

Needs: one device per pair.

PLENARY

5
min

Exit: true or false

Five statements from the set below, a reason for each false one.

WHAT STUDENTS GET WRONG

Respiration is breathing. Respiration is chemistry in every cell; breathing moves air and gas exchange moves gases.

Respiration makes energy. It releases energy from the fuel and transfers it to ATP.

Energy is stored in the bond between phosphates, and breaking it releases energy. Breaking bonds takes energy; hydrolysis releases energy overall, because ADP and phosphate hold less than ATP and water did. Check the slides you borrow for this.

ATP is an energy store. A cell holds only a little and remakes it all the time.

Plants photosynthesise instead of respiring. Every living cell respire all the time.

All of aerobic respiration happens in the mitochondria. Glycolysis is in the cytoplasm.

Anaerobic respiration in humans makes carbon dioxide. The product in human muscle is lactate only.

Muscles switch from aerobic to anaerobic. Anaerobic respiration adds to aerobic respiration when oxygen cannot keep up.

STRETCH AND SUPPORT

Support: give the captions of [chapter 4](#)'s figure as cut-up cards to sort into "with oxygen" and "without", the dotted key terms as a glossary, and a writing frame for "compare aerobic and anaerobic respiration" (one row of the table, one sentence each).

Support: use the BAM and LOW tiles as sentence starters.

Stretch: a resting adult remakes roughly their own body mass of ATP each day, from a stock of well under a kilogram. How many times a day is each ATP molecule remade?

Stretch: compare each sprint round's ATP per glucose with the aerobic figure: how many times more glucose does the sprint need for the same ATP?

IN THE GUIDE

- 1 [The cell's small change](#)
- 2 [Spend it, remake it](#)
- 3 [Fuel in, ATP out](#)
- 4 [With oxygen and without](#)
- 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 C1.2, built from its key terms and ready to print
- A [pub quiz](#) with rounds on C1.2, to present or run with no projector
- An [escape room](#) built from the [question bank](#) on C1.2

ALREADY ON THE SITE FOR C1.2

- Lesson: [Cell Respiration HL \(HL\)](#)
- Lesson: [Cell Respiration](#)
- Quiz: [Cell Respiration](#)
- Quiz: [Cell Respiration \(HL\)](#)
- Revision map: [C1.2 Cell respiration](#), to fill in
- Exam questions: [C1.2 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.

- [C1.2 Cell Respiration](#)
- [B3.2–C2.2 Plant Transport, Respiration & Neural Signalling](#)

EXAM PRACTICE

Check yourself

Set it for homework: a fresh paper of exam-bank questions on C1.2 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=C1.2&level=SL&paper=quiz&marks=15&src=ep



Measuring a rate you cannot see

60 minutes • C1.2.6 • Chapter 5 • The dry lab

Measuring respiration rate: the dough lab, the respirometer, the control, and the rate per gram per minute

BY THE END, STUDENTS CAN

☐ Measure the rate of respiration with a respirometer and work it out from raw or secondary data C1.2.6

TIMING

0-5	5 min	Do now: how fast is a seed respiring?	
5-15	10 min	Rising dough	
15-25	10 min	How a respirometer works	
25-45	20 min	The dry lab with the IA coach	
45-55	10 min	Back to the dough	
55-60	5 min	Exit: work out a rate	
	60 min	One lesson	

STARTER

5 min Do now: how fast is a seed respiring?

"How could you tell how fast a seed is respiring without opening it?" Students write three ideas each. Collect them: oxygen in, carbon dioxide out, fuel used.

ON THE BOARD, FROM THE GUIDE

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05 A rate you cannot see

CHAPTER 05 IN THE SLIDES

Tap the parts of the figure in turn: Water bath and thermometer, Potassium hydroxide, Wire gauze, Germinating seeds, Glass bead tube, Bung and screw clip, Capillary and coloured drop and Scale.

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. Read both drops at the start and the end.
2. Take off the control's movement.
3. Turn distance into volume with the bore.
4. Divide by time and by mass.

Predict box: In the respirometer the seeds respire and the potassium hydroxide absorbs their carbon dioxide. Which way does the drop move? Hands up or mini whiteboards first.

Answer B: Towards the seeds, as they take in oxygen

THE LESSON

10 min Rising dough

Pairs make the dough, set up five tubes and take the first reading (the practical below). Readings every 5 minutes through the lesson, one student a pair keeping time.

10

min

How a respirometer works

Chapter 5: the predict about the drop, then the explore figure part by part: why the potassium hydroxide, why the beads, why the clip. Then figure 5.2's worked rate, one step at a time. Ask: "What would a negative control tell you?"

20

min

The dry lab with the IA coach

In pairs on the dry lab. First How? Why? Units? in the coach (below), then a temperature series of three trials at five temperatures, with means and standard deviations. Download the results as a CSV for a class graph.

10

min

Back to the dough

Final readings. Each pair works out its rate over 5 to 20 minutes and adds it to a class table. Compare it with the dry lab's dough mode and ask why sucrose is nearly as fast as glucose.

ACTIVITIES



PRACTICAL

Rising dough

Make one dough: stir 4 g of dried yeast into 75 cm³ of warm water (about 35 °C), then add plain flour until it is a thick batter that just drops from a spatula (about 20 spatulas). Divide it into five equal portions in small beakers and stir 2 g of one sugar into each (glucose, fructose, sucrose, starch, and none): weigh the sugar rather than using "two spatulas". Spoon each into a boiling tube to a height of 30 mm, mark the level, stand the tubes in a water bath at 30 °C (or record the room temperature), and read the height of the top every 5 minutes for 30 minutes.

Students then design their own results table (time, height in mm with its uncertainty, a column for each sugar), graph height against time with a line for each sugar, and write a conclusion and an evaluation: which sugar was fastest and why, which variables were not controlled (the consistency of the dough, the temperature), and two specific improvements.

Needs: dried yeast, plain flour, glucose, fructose, sucrose and starch, a balance, spatulas, small beakers, five boiling tubes and a rack per pair, rulers, a water bath or a thermometer, a timer.

How	Why	Units
✓		
✓		

PLANNING

How? Why? Units?

Before running the dry lab, pairs fill in the coach's variables table: for each variable, how it is set or measured, why it matters and its unit. Then they use the planning questions as a checklist: the range of values, the time for the run, the controlled variables, a negative control, the precision of the measurement, and safety.

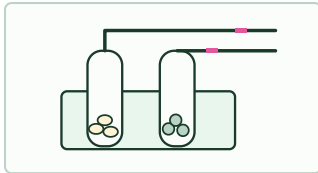
Needs: a device per pair.

DRY LAB

The dry lab

One device per pair. Results go to a CSV for a class graph, and the coach's write-up is copied into notes. Start with temperature; pairs who finish run the dough mode.

Needs: one device per pair.



DEMONSTRATION (OPTIONAL)

A real respirometer

Two boiling tubes in a beaker of water at room temperature: 3-day mung beans on a gauze over potassium hydroxide solution in one, and glass beads of the same volume over the same in the other. Fit bungs with a bent capillary and a drop of coloured water, and a screw clip on a side arm. Run it alongside the dough while students work. Safety: potassium hydroxide is corrosive; use eye protection and gloves, and the teacher sets it up.

Needs: as listed, and a mm scale behind each capillary.

PLENARY

5

min

Exit: work out a rate

A drop moved 18 mm in 5 minutes in a bore of 1 mm; the control moved 1 mm; there was 2.5 g of seeds. Work out the rate. (Students show every step and the unit.)

WHAT STUDENTS GET WRONG

The drop moves because the seeds give out carbon dioxide. It is absorbed; the drop moves because oxygen is taken up.

The control is “to compare”. The bead tube shows what moves the drop that is not respiration, so it can be subtracted.

A disaccharide must be slower than glucose for yeast. Yeast split sucrose outside the cell with an enzyme, so it is nearly as fast.

STRETCH AND SUPPORT

Support: give the captions of [chapter 4](#)'s figure as cut-up cards to sort into “with oxygen” and “without”, the dotted key terms as a glossary, and a writing frame for “compare aerobic and anaerobic respiration” (one row of the table, one sentence each).

Stretch: in the [dry lab](#), find the time with the clip open below which the control matters most, and explain from the gas law why a cold bath fakes respiration.

Stretch: design a dough experiment to separate the flour's own sugars from the added starch (hint: a flour that has been heated to destroy its enzymes).

Stretch: shadow puppets: in groups, answer two written questions from the C1.2 exam maker as shadow puppets, so the class has to explain each step aloud.

IN THE GUIDE

5 [A rate you cannot see](#)

Lab [Dry lab: Respirometer: seeds and dough](#)

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

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

EXAM PRACTICE

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biologybybradford.com/exam-maker/sit?topics=C1.2&level=SL&paper=quiz&marks=15&src=ep



PRACTISE AND REVISE

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- [B3.2–C2.2 Plant Transport, Respiration & Neural Signalling](#)

Hydrogen off, and glycolysis HL

60 minutes • C1.2.7 to C1.2.10 • Chapters 6, 7, 8

Oxidation as hydrogen removal and NAD as its carrier, the four stages of glycolysis, and lactate and ethanol as ways to give NAD back

BY THE END, STUDENTS CAN

- ☐ Explain oxidation as the removal of hydrogen, and NAD as the carrier that is reduced when it accepts it C1.2.7
- ☐ Outline glycolysis: phosphorylation, lysis, oxidation and ATP formation, with its net yield C1.2.8
- ☐ Explain how making lactate, or ethanol and carbon dioxide in yeast, gives NAD back so glycolysis can go on, and how bakers and brewers use yeast C1.2.9, C1.2.10

TIMING

0-5	5 min	Do now: OIL RIG	
5-15	10 min	Hydrogen and NAD	
15-30	15 min	Glycolysis stepping stones	
30-42	12 min	Giving NAD back	
42-55	13 min	A written question	
55-60	5 min	Exit	
	60 min	One lesson	

STARTER

- 5 min** **Do now: OIL RIG**
- Three reactions on the board. Students label each molecule oxidised or reduced and say what moved. Then turn over the OIL RIG tiles.

ON THE BOARD, FROM THE GUIDE

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06 Taking hydrogen away

CHAPTER 06 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. A substrate, an enzyme, and NAD.
2. Hydrogen is removed: **dehydrogenation**. Each hydrogen is a proton and an electron.
3. The substrate is **oxidised**; NAD is **reduced**. A **redox** reaction.
4. Reduced NAD carries the hydrogen away and comes back as NAD.

Predict box: A dehydrogenase takes two hydrogens off a molecule of fuel. What has happened to that molecule? Hands up or mini whiteboards first.

Answer D: It is oxidised: it has lost electrons

Remember it: Oil Rig (Oxidation Is Loss, Reduction Is Gain).

07 Two ATP in, four out

CHAPTER 07 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. One glucose, in the cytoplasm.
2. **Phosphorylation:** 2 ATP spent, the sugar made reactive.
3. **Lysis:** split into two 3-carbon sugars.
4. **Oxidation:** hydrogen to NAD, making 2 reduced NAD.
5. **ATP formation:** 4 ATP made, so 2 gained.
6. Ten steps, ten enzymes, two pyruvate.

Predict box: Glycolysis spends 2 ATP at the start. How many does it make by the end, from one glucose? Hands up or mini whiteboards first.

Answer A: 4, so the cell gains 2

Remember it: Penguins Love Orange Anchovies (Phosphorylation, Lysis, Oxidation, ATP formation).

08 Giving NAD back

CHAPTER 08 IN THE SLIDES

Switch the figure through Glycolysis alone, Muscle and Yeast, and have the class say what will change before each.

Predict box: Without oxygen, why does a muscle cell turn pyruvate into lactate instead of leaving it as pyruvate? Hands up or mini whiteboards first.

Answer D: It gives NAD back, so glycolysis can go on

THE LESSON

10

min

Hydrogen and NAD

Chapter 6: the predict, then the figure one step at a time. NAD is a carrier that must be emptied to be used again: ask students why a cell cannot just make a lot more of it.

15

min

Glycolysis stepping stones

Pairs order the seven cards (activity below), then check against chapter 7's figure and make its predict. Turn over the Penguins tiles.

12

min

Giving NAD back

Chapter 8: the predict, then the figure's three settings: glycolysis alone, muscle and yeast. Then the ATP budget's round 5 on the board: tick and untick Lactate made and watch the NAD.

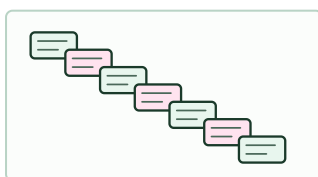
13

min

A written question

A written question on glycolysis or fermentation from the C1.2 exam maker (in Practise and revise), timed at 9 minutes and peer-marked against the markscheme. Each pair then writes one line on bread and one on beer.

ACTIVITIES



CARD ORDER · HL

Glycolysis stepping stones

Seven cards, each a half sentence, to put in order and complete: what glycolysis is; where it happens; phosphorylation by 2 ATP; the split into two 3-carbon sugars; oxidation by NAD; ATP formation; the end products and the net yield. Then a second set with gaps, for homework.

Needs: card sets, one per pair.

5
min**Exit**

Why can glycolysis go on without oxygen in a muscle, and what would stop it?

WHAT STUDENTS GET WRONG

Oxidation means adding oxygen. In respiration it is mostly removing hydrogen, and so electrons.

Glycolysis needs oxygen, or happens in the mitochondrion. Neither.

Lactate is made to get rid of pyruvate. It is made to give NAD back.

Lactic acid makes muscles sore the next day. It does not: the acid of hard exercise is not lactate itself, and next-day soreness is something else.

STRETCH AND SUPPORT

Stretch: some yeasts ferment even with oxygen when sugar is plentiful. What would that do to a dough, and to the yield of ATP per glucose?

Stretch: make a Tarsia puzzle on C1.2 that is better than the site's own, in the Tarsia builder.

Consequences for ecosystems: respiration returns carbon dioxide to the air and releases heat at every transfer. Use both to start the energy flow of C4.2: where does the energy of a food chain go?

IN THE GUIDE

6 [Taking hydrogen away](#)

7 [Two ATP in, four out](#)

8 [Giving NAD back](#)

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=C1.2&level=HL&paper=quiz&marks=15&src=ep

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- [B3.2–C2.2 Plant Transport, Respiration & Neural Signalling](#)

Inside the matrix, and which fuel HL

60 minutes • C1.2.11, C1.2.12 and C1.2.17 • Chapters 9, 12

The link reaction and the Krebs cycle, counting carbons and carriers, and fat against sugar as fuels

BY THE END, STUDENTS CAN

- ☐ Outline the link reaction and the Krebs cycle: where the carbon dioxide and the reduced NAD come from C1.2.11, C1.2.12
- ☐ Compare lipids and carbohydrates as fuels: energy per gram, and which routes each can take C1.2.17

TIMING

0-5	5 min	Do now: draw a mitochondrion	
5-15	10 min	The link reaction	
15-30	15 min	Build the Krebs cycle	
30-38	8 min	Name the reaction	
38-55	17 min	Fat or sugar?	
55-60	5 min	Exit	
	60 min	One lesson	

STARTER

- 5 min** **Do now: draw a mitochondrion**
- From memory, with no notes (activity below), and label it. Keep the drawings: they are used again in lesson 5.

ON THE BOARD, FROM THE GUIDE

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09 The carbon leaves as carbon dioxide

CHAPTER 09 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. Pyruvate goes into the **matrix**.
2. **Link reaction**: a carbon off as CO₂ (**decarboxylation**), hydrogen to NAD (**oxidation**). The **acetyl group** goes on with **coenzyme A**.
3. Acetyl (2C) + **oxaloacetate** (4C) → **citrate** (6C).
4. Two decarboxylations, four oxidations, one ATP.
5. Oxaloacetate is **remade**: a cycle.
6. Two turns per glucose: all six carbons gone as CO₂.

Show the figure: Name the reaction: eight steps of respiration and four kinds of reaction. Which bin does each belong in, and what tells you?

Predict box: Each turn of the Krebs cycle takes in a 2-carbon acetyl group. Why does the cycle not fill up with carbon? Hands up or mini whiteboards first.

Answer B: Two carbons leave as carbon dioxide each turn

12 Fat or sugar?

CHAPTER 12 IN THE SLIDES

Switch the figure through What is in them and How they are respired, and have the class say what will change before each.

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

1. Inside a muscle fibre, one **mitochondrion**: the folded inner membrane (**cristae**), the **matrix** inside it.
2. Net from one glucose: **2 ATP**, **2 reduced NAD** and **2 pyruvate**.
3. The **link reaction**, in the **matrix**: pyruvate loses a carbon as CO_2 (**decarboxylation**) and hydrogen to NAD (**oxidation**).
4. One **ATP** is made, and a fourth oxidation passes hydrogen to another carrier.
5. Protons flow back through **ATP synthase**, turning it: most of the ATP is made here. **Oxygen** takes the electrons at the end, making water.
6. From one glucose: **6 CO_2** , water, and **about 30 to 32 ATP**, nearly all of it from the chain.

Predict box: Gram for gram, fat releases about twice the energy of carbohydrate when respired. Why? Hands up or mini whiteboards first.

Answer C: Fat holds less oxygen and more hydrogen to oxidise

THE LESSON

10

min

The link reaction

Chapter 9: students draw the link reaction from a written summary (activity below), then play the first two steps of the figure to check it.

15

min

Build the Krebs cycle

Pairs build the cycle with hexagon cards (below), then play the rest of [chapter 9's](#) figure and make its predict. Count the carbons out loud.

8

min

Name the reaction

Chapter 9's sorter in pairs, then on the board for the two cards most argued over.

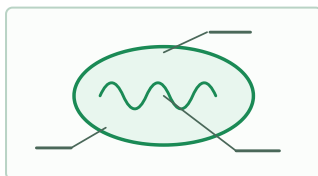
17

min

Fat or sugar?

Chapter 12: the predict, then Count the oxygen (below), then the figure's two settings. The chain is lesson 5, so here say only that fat enters at the Krebs cycle, which runs only while oxygen is there; the chapter's watch-out is read again in lesson 5.

ACTIVITIES

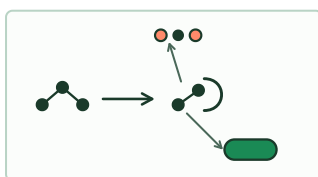


DRAWING · HL

Draw a mitochondrion

From memory: the outer membrane, the inner membrane folded into cristae, the matrix, the intermembrane space, and ribosomes and DNA. Then add where the link reaction, the Krebs cycle and the chain happen.

Needs: paper.

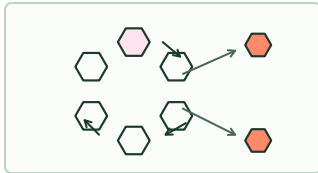


DRAWING · HL

The link reaction as a diagram

From a written summary, draw the link reaction: pyruvate in, carbon dioxide out, hydrogen to NAD, and the acetyl group onto coenzyme A.

Needs: paper.

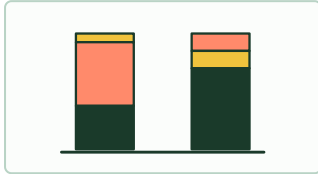


CARD MODEL · HL

Build the Krebs cycle

Hexagon cards to arrange in a ring: acetyl group (2C), oxaloacetate (4C), citrate (6C), decarboxylation (twice), oxidation (four times) and ATP, with arrows drawn between them. The rule: only citrate and oxaloacetate are named.

Needs: printed hexagon sets, A3 paper.



CALCULATION · HL

Count the oxygen

From the formulae $C_6H_{12}O_6$ and $C_{16}H_{32}O_2$, work out the percentage of each that is oxygen by mass, and the oxygen needed to respire one of each (6 and 23 O_2). Then: which gives more energy per gram, and why?

Needs: calculators.

PLENARY

5
min

Exit

One reason fat gives more energy per gram, and one thing fat cannot do that glucose can.

WHAT STUDENTS GET WRONG

The Krebs cycle makes most of the ATP. It makes reduced NAD; the chain makes most of the ATP.

The carbon dioxide breathed out comes from the oxygen breathed in. It comes from the fuel's carbon, in the link reaction and the Krebs cycle.

Fat gives more energy because its molecules are bigger. A fatty acid holds less oxygen and more oxidisable hydrogen and carbon per gram.

Fat can be respired anaerobically. It enters at the Krebs cycle, so it needs oxygen.

STRETCH AND SUPPORT

Stretch: the respiratory quotient (carbon dioxide given out divided by oxygen taken up) for glucose is 1.0 and for palmitic acid 16 divided by 23. Work out what an athlete's breath would show as they switch from fat to carbohydrate.

Stretch: make a Tarsia puzzle on C1.2 that is better than the site's own, in the Tarsia builder.

Consequences for ecosystems: respiration returns carbon dioxide to the air and releases heat at every transfer. Use both to start the energy flow of C4.2: where does the energy of a food chain go?

IN THE GUIDE

9 [The carbon leaves as carbon dioxide](#)

12 [Fat or sugar?](#)

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

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

EXAM PRACTICE

Check yourself

Set it for homework: a fresh paper of exam-bank questions on C1.2 at higher level each time, marked as students go and saved to their Exam practice when they are signed in.

biologybybradford.com/exam-maker/sit?topics=C1.2&level=HL&paper=quiz&marks=15&src=ep



PRACTISE AND REVISE

BUILD FOR YOUR CLASS

- [Tarsia puzzle, dominoes and picture reveal](#) on C1.2, built from its key terms and ready to print
- A [pub quiz](#) with rounds on C1.2, to present or run with no projector
- An escape room built from the [question bank](#) on C1.2

ALREADY ON THE SITE FOR C1.2

- Lesson: [Cell Respiration HL \(HL\)](#)
- Lesson: [Cell Respiration](#)
- Quiz: [Cell Respiration](#)
- Quiz: [Cell Respiration \(HL\)](#)
- Revision map: [C1.2 Cell respiration](#), to fill in
- Exam questions: [C1.2 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.

- [C1.2 Cell Respiration](#)
- [B3.2–C2.2 Plant Transport, Respiration & Neural Signalling](#)

The chain, the turbine and the whole journey HL

60 minutes • C1.2.13 to C1.2.16 • Chapters 10, 11

Reduced NAD and the electron transport chain, the proton gradient, ATP synthase and oxygen as the last acceptor

BY THE END, STUDENTS CAN

- ☐ Explain how electrons passed along the chain build a proton gradient across the inner membrane C1.2.13, C1.2.14
- ☐ Explain how ATP synthase uses the proton gradient to make ATP, and why oxygen is needed at the end of the chain C1.2.15, C1.2.16

TIMING

0–5	5 min	Do now: what does oxygen do?	
5–17	12 min	The chain	
17–30	13 min	The turbine	
30–38	8 min	The whole journey	
38–48	10 min	The loop game	
48–55	7 min	Plan an 8-mark answer	
55–60	5 min	Exit	
	60 min	One lesson	

STARTER

5
min

Do now: what does oxygen do?

In one sentence, what does oxygen do in respiration? Keep the answer for the exit.

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 Down the chain

CHAPTER 10 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.

- Reduced NAD from all three stages arrives at the inner membrane.
- It hands a **pair of electrons** to the first carrier, and becomes NAD again.
- Each step down releases a little energy, used to **pump protons**.
- Protons pile up in the intermembrane space: a **proton gradient**.

Predict box: Electrons pass along the chain of carriers, releasing a little energy at each step. What is that energy used for? Hands up or mini whiteboards first.

Answer D: Pumping protons across the inner membrane

11 Protons through the turbine

CHAPTER 11 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. One way back for the protons: **ATP synthase**.
2. Protons flowing down the gradient turn it, and their energy joins **ADP and phosphate**: ATP.
3. **Oxygen** takes the electrons and protons at the end, making **water**.
4. **Chemiosmosis**: the gradient makes ATP, and oxygen keeps the chain flowing.

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

1. **Reduced NAD** from glycolysis, the link reaction and the Krebs cycle hands a **pair of electrons** to the first carrier, and becomes NAD again.
2. As the electrons pass along the chain they give up energy, which the carriers use to **pump protons** into the intermembrane space.
3. Protons pile up in the narrow space: a **proton gradient**. The membrane will not let them back through, except at one place.
4. Protons flow back down their gradient through **ATP synthase**, turning it. The energy joins **ADP and phosphate**: ATP.
5. **Oxygen** takes the electrons at the end of the chain, with protons from the matrix, making **water**. That keeps the electrons flowing.

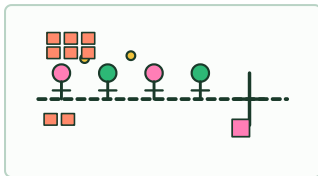
Predict box: A cell's mitochondria run out of oxygen. What happens to the electron transport chain? Hands up or mini whiteboards first.

Answer A: Electrons back up and the pumping stops

THE LESSON

12 min	The chain <u>Chapter 10</u> : the predict, then Be the chain (the role play below), then the figure, stopping on each caption.
13 min	The turbine <u>Chapter 11</u> : the predict, then the figure, then the chemiosmosis film: turn the oxygen off and watch what stops first.
8 min	The whole journey The HL respiration film from start to end. Switch the fuel to a fatty acid, then the cell to yeast. Grandma Likes Knitting Everything for the order: Glycolysis, Link reaction, Krebs cycle, Electron transport chain.
10 min	The loop game One card each (below), corrected: students read their answer and the next question until the loop is closed.
7 min	Plan an 8-mark answer Plan "Explain how ATP is made in the mitochondrion by chemiosmosis" in keywords (activity below). Write it for homework, then check it with <u>the Check step</u> .

ACTIVITIES

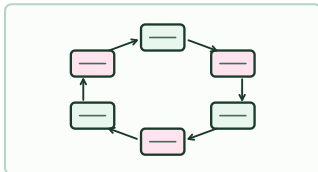


ROLE PLAY · HL

Be the chain

A rope on the floor is the inner membrane. Three students are pumps and two are carriers, standing on it; one is ATP synthase, a turnstile in the rope. "Reduced NAD" brings a pair of tennis balls (electrons) to the first pump; each time the balls are passed on, that pump moves one bean bag (a proton) across the rope into the "intermembrane space". When the space is crowded, bean bags may go back only through the turnstile, and each one that goes through hands an "ATP" card to the matrix. "Oxygen" at the end takes the balls and two bean bags. Then oxygen sits down: what happens?

Needs: a rope, two tennis balls, ten bean bags, ATP cards, labels on lanyards.

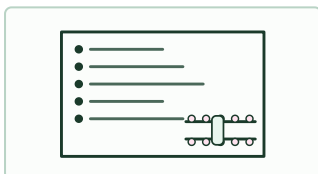


LOOP GAME · HL

The loop game

Eighteen cards, each an answer and a question, that loop back to the start. Each student reads their answer and the next question until the loop closes. The corrections to look for: aerobic respiration gives about 30 to 32 ATP (not 36 to 38); the Krebs cycle's main product is reduced NAD (no FADH_2 at IB); the product in humans is lactate (not "lactic acid"); and hydrolysis of ATP releases energy.

Needs: a printed set, one card per student.

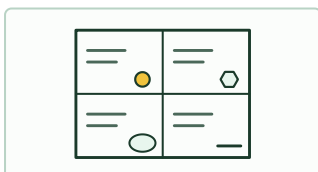


WRITING · HL

Plan an 8-mark answer

"Explain how ATP is made in the mitochondrion by chemiosmosis." Plan it in keywords first: reduced NAD from three stages, a pair of electrons to the first carrier, energy released along the chain, protons pumped into the intermembrane space, a gradient, ATP synthase, protons flow back, ADP and phosphate joined, oxygen as terminal acceptor, water, which keeps the chain flowing, and cristae for area. Then write it.

Needs: lined paper.



SUMMARY · HL (OPTIONAL)

Four corners

Divide a page into four: glycolysis, link reaction, Krebs cycle, and chain and chemiosmosis. In each corner, ten keywords and a small picture: where, what, why and how.

Needs: A3 paper.

PLENARY

5
min

Exit

Rewrite your Do now sentence so that it would earn two marks.

WHAT STUDENTS GET WRONG

The chain makes ATP. It makes a proton gradient; ATP synthase makes the ATP.

ATP synthase pumps protons. Protons flow down through it and turn it.

Oxygen turns into carbon dioxide. It ends up in water.

Aerobic respiration gives 36 to 38 ATP. About 30 to 32 is the figure now used. Many older sources and papers give 36 to 38.

STRETCH AND SUPPORT

Stretch: cyanide stops the last carrier passing electrons to oxygen. Predict, stage by stage, what stops in a cell, and why the blood leaving the tissues is still rich in oxygen while the cells run short of ATP (breathing and gas exchange are not respiration).

Stretch: make a Tarsia puzzle on C1.2 that is better than the site's own, in the Tarsia builder.

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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.