

Cambridge AS & A Level · Biology 9700 · Notes

Energy and respiration A2

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Read first: [Biological molecules](#), [Enzymes](#), [Cell structure](#), [Cell membranes and transport](#)

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What you need to know

By the end of this topic you should be able to:

Energy (12.1)

1. **Explain why organisms need energy:** active transport, movement, and anabolic reactions such as DNA replication and protein synthesis.
2. **Describe the features of ATP** that make it the universal energy currency.
3. **State the two ways ATP is made:** **substrate-linked** reactions (a phosphate moved straight onto ADP) and **chemiosmosis** in the membranes of mitochondria and chloroplasts.
4. **Explain the different energy values** of carbohydrates, lipids and proteins as respiratory substrates.
5. **State what the respiratory quotient (RQ) is:** molecules of carbon dioxide given out ÷ molecules of oxygen taken in.
6. **Calculate RQ values** from respiration equations.
7. **Use simple respirometers** to find the RQ of germinating seeds or small invertebrates (such as blowfly larvae).

Respiration (12.2)

8. **State where each stage of aerobic respiration happens:** glycolysis in the cytoplasm, the link reaction and Krebs cycle in the mitochondrial matrix, oxidative phosphorylation on the inner mitochondrial membrane.
9. **Outline glycolysis:** glucose phosphorylated, fructose 1,6-bisphosphate (6C) split into two triose phosphates (3C), oxidised to pyruvate (3C), making ATP and reduced NAD.
10. **Explain that pyruvate enters mitochondria** for the link reaction when oxygen is available.
11. **Describe the link reaction**, including coenzyme A carrying the acetyl (2C) group.
12. **Outline the Krebs cycle:** oxaloacetate (4C) accepts the acetyl group to form citrate (6C), which is turned back into oxaloacetate in small steps.
13. **Explain that the Krebs cycle involves decarboxylation and dehydrogenation** and reduces NAD and FAD.
14. **Describe how NAD and FAD carry hydrogen** to the carriers in the inner mitochondrial membrane.

15. **Explain oxidative phosphorylation:** hydrogen atoms split into protons and electrons; electrons release energy along the electron transport chain; the energy moves protons across the inner membrane; protons return through ATP synthase by facilitated diffusion, providing energy for ATP synthesis; oxygen is the final electron acceptor, forming water. (No names of carriers or details of ATP synthase.)
16. **Relate mitochondrial structure to function,** from diagrams and electron micrographs.
17. **Outline respiration without oxygen:** lactate fermentation in mammals, ethanol fermentation in yeast.
18. **Explain why aerobic respiration yields far more energy** than anaerobic (no full ATP count needed).
19. **Explain how rice grows with its roots under water:** aerenchyma, ethanol fermentation in the roots, faster stem growth.
20. **Use redox indicators** (DCPIP, methylene blue) to find how temperature and substrate concentration affect the rate of respiration of yeast.
21. **Use simple respirometers** to find how temperature affects the rate of respiration.

Photosynthesis is a separate topic: here you only need to know that chemiosmosis also happens in chloroplasts.

Understand it

Why cells need energy

Every cell does work, and work needs energy:

- **Active transport:** moving ions or molecules against their concentration gradient, such as the sodium–potassium pump.
- **Movement:** muscle fibres contracting, cilia beating, vesicles moving through the cytoplasm, chromosomes separating in mitosis and meiosis, exocytosis and endocytosis.
- **Anabolic reactions:** building large molecules from small ones, such as DNA replication and protein synthesis (making mRNA, attaching amino acids to tRNA, forming peptide bonds).

Energy not captured as ATP is released as **heat**, which helps mammals and birds keep a constant body temperature.

ATP: the energy currency

ATP (adenosine triphosphate) is a nucleotide: the base **adenine**, the sugar **ribose**, and a chain of **three phosphate groups**.

Hydrolysis of the last phosphate (by ATPase) gives **ADP** and inorganic phosphate (**P_i**) and **releases 30.5 kJ** per mole. ADP can lose another phosphate to become AMP.



Why ATP suits its job:

- It releases energy in **small, manageable amounts**, so little is wasted as heat.
- It releases energy **quickly**, in one hydrolysis step.
- It is **small and water-soluble**, so it moves easily **within the cell** (it is not carried around the body).
- It is **easily regenerated** from ADP and Pi, so it has a **high turnover**: a cell holds little ATP and remakes it constantly.
- It is used by **every organism**, linking energy-releasing reactions with energy-using ones: hence "universal".

GTP can do the same job in some reactions, because it is hydrolysed in the same way.

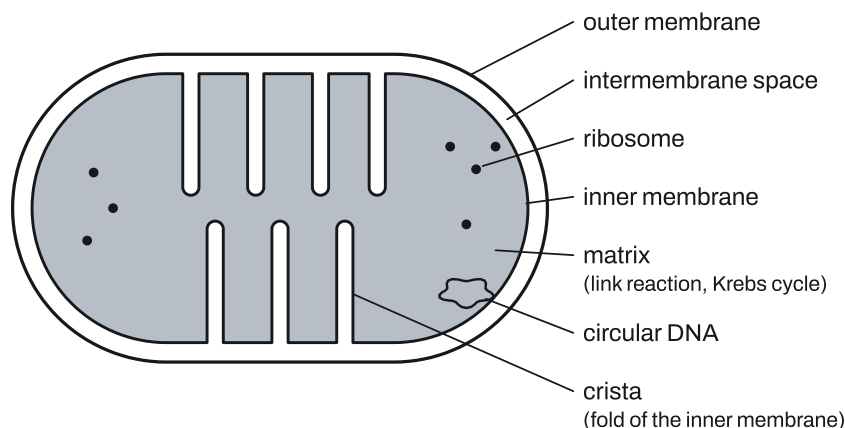
Two ways to make ATP

Adding a phosphate to ADP (**phosphorylation**) happens in two ways:

- **Substrate-linked phosphorylation**: an enzyme moves a phosphate group directly from a respiratory intermediate onto ADP. This happens in **glycolysis** (cytoplasm) and the **Krebs cycle** (mitochondrial matrix). It needs no membrane and no oxygen.
- **Chemiosmosis**: energy from electrons builds up protons on one side of a membrane; they flow back through ATP synthase, which makes ATP. In respiration this is **oxidative phosphorylation**, on the **inner mitochondrial membrane**. In photosynthesis it is **photophosphorylation**, on the thylakoid membranes of chloroplasts.

The mitochondrion

The link reaction, Krebs cycle and oxidative phosphorylation all happen in mitochondria.



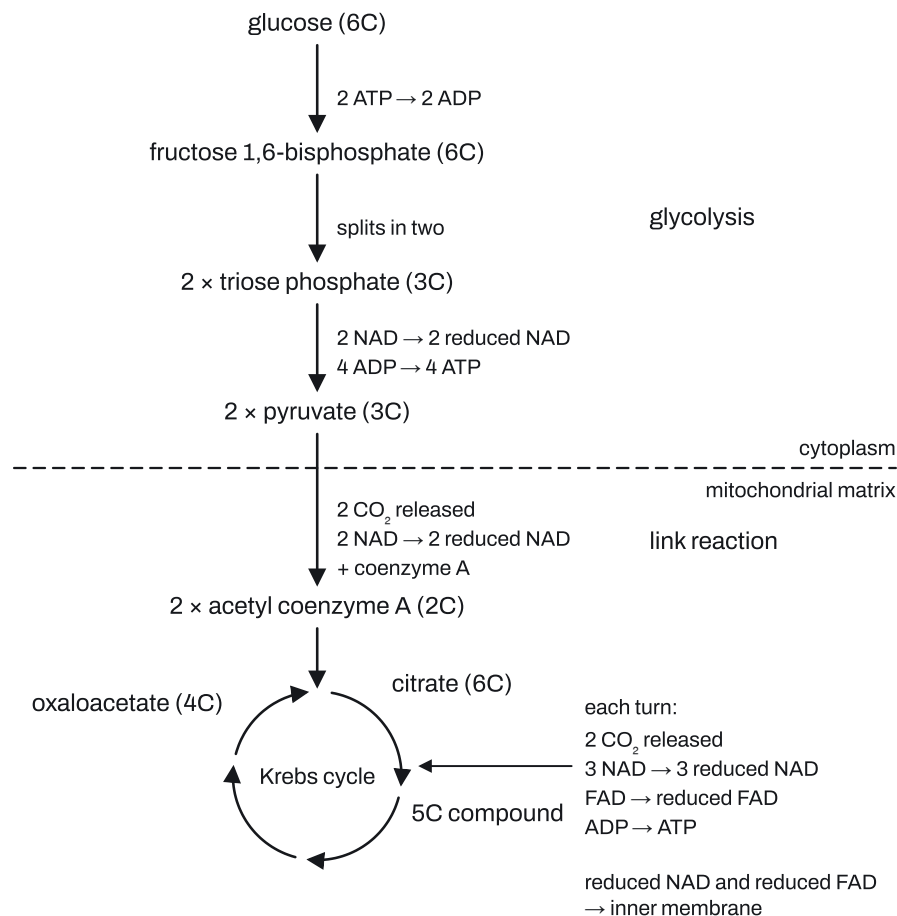
Part	Feature	How it helps
Outer membrane	Permeable to small molecules	Lets pyruvate, oxygen and ADP in, and CO ₂ and ATP out
Intermembrane space	Small volume between the two membranes	Protons pumped into it build up to a high concentration (low pH) quickly

Part	Feature	How it helps
Inner membrane	Holds the electron transport chains and ATP synthase	Site of oxidative phosphorylation
	Folded into cristae	Large surface area for many electron transport chains and ATP synthases, so more ATP can be made
	Impermeable to protons	Protons can only get back to the matrix through ATP synthase, so the proton gradient is kept
Matrix	Enzymes and coenzymes (NAD, FAD, coenzyme A) of the link reaction and Krebs cycle	Site of the link reaction and Krebs cycle
	Circular DNA and (70S) ribosomes	Makes some of its own proteins (ETC parts, ATP synthase, enzymes)

Very active cells (such as cardiac muscle) have **more mitochondria** with **more cristae**. In an electron micrograph the matrix looks dark and grainy, with the cristae as folded shelves reaching into it. Mitochondria can divide (fission) when a cell needs more.

Stage 1: glycolysis (cytoplasm)

Glycolysis splits one glucose (6C) into two pyruvates (3C). It needs no oxygen.



1. **Phosphorylation.** Two ATP each give a phosphate, making **fructose 1,6-bisphosphate** (6C). This **activates** the sugar (less stable, so it splits more easily) and stops it leaving the cell.
2. **Splitting (lysis).** Fructose 1,6-bisphosphate splits into two **triose phosphate** molecules (3C).
3. **Oxidation.** Each triose phosphate is **dehydrogenated**: the hydrogen removed reduces NAD.
4. **ATP made.** Each triose phosphate becomes **pyruvate** (3C), making 2 ATP by **substrate-linked phosphorylation**.

Per glucose: 2 ATP used, 4 ATP made, so a **net gain of 2 ATP**; also **2 reduced NAD** and **2 pyruvate**. Glucose enters the cell by facilitated diffusion through a carrier (GLUT).

Stage 2: the link reaction (matrix)

When **oxygen is available**, pyruvate enters the matrix by **active transport** through a carrier protein. Each pyruvate is:

- **decarboxylated** (CO₂ removed) and **dehydrogenated** (hydrogen removed, **reducing NAD**);
- the remaining **acetyl group (2C)** joins **coenzyme A**, forming **acetyl CoA**, which carries it into the Krebs cycle.

Per glucose: 2 CO₂ and 2 reduced NAD. Oxygen isn't used in the link reaction, but it needs **NAD**, which is only regenerated when the electron transport chain runs, and that needs oxygen at its end.

Stage 3: the Krebs cycle (matrix)

1. The **acetyl group (2C)** joins **oxaloacetate (4C)** to form **citrate (6C)**; coenzyme A is released for reuse.
2. Citrate is changed back to oxaloacetate in **small enzyme-catalysed steps**:
 - **decarboxylation** removes 2 CO₂ (6C → 5C → 4C);
 - **dehydrogenation** removes hydrogen, which reduces **3 NAD** and **1 FAD**;
 - **1 ATP** is made by **substrate-linked phosphorylation**.
3. The regenerated oxaloacetate accepts another acetyl group.

The cycle turns **twice per glucose**: 4 CO₂, 6 reduced NAD, 2 reduced FAD, 2 ATP. With the link reaction's 2 CO₂, all six carbons of glucose leave as CO₂. The cycle's main product is **hydrogen**, carried to the inner membrane.

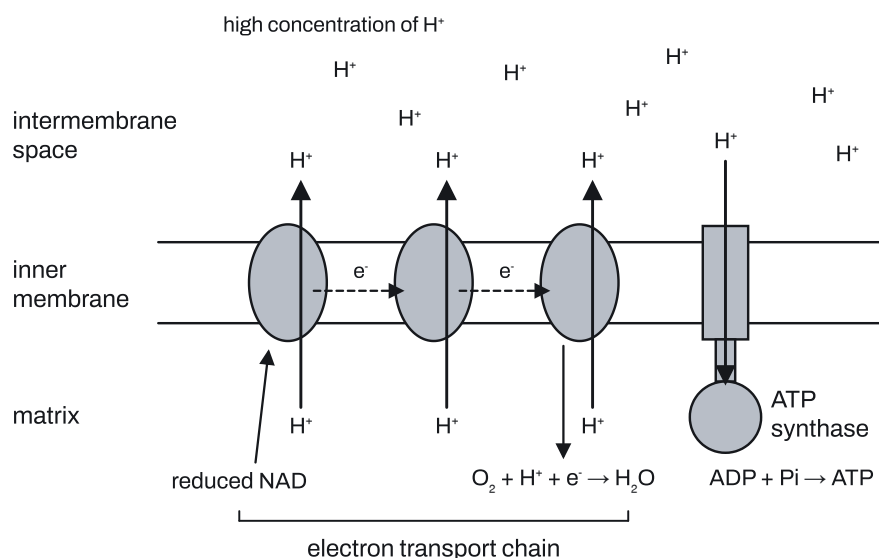
NAD, FAD and coenzyme A

These are **coenzymes** (non-protein helpers of enzymes).

- **NAD** and **FAD** are **hydrogen carriers**: they help **dehydrogenase** enzymes by accepting the **hydrogen atoms** removed (becoming **reduced**), carry them to the electron transport chain, give them up (are **oxidised**) and return for more.
- **NAD** is reduced in **glycolysis, the link reaction and the Krebs cycle**. **FAD** is reduced **only in the Krebs cycle**.
- **Coenzyme A** carries **acetyl groups** from the link reaction into the Krebs cycle.

They carry whole hydrogen atoms (a proton plus an electron), never hydrogen ions alone. If reduced NAD can't be oxidised, the cell runs out of NAD and the reactions that need it stop.

Stage 4: oxidative phosphorylation (inner membrane)



1. **Reduced NAD and reduced FAD** give hydrogen atoms to the carriers of the **electron transport chain** (ETC) and become NAD and FAD again.
2. Each **hydrogen atom splits** into a **proton** (H^+) and an energetic **electron**.
3. The **electrons pass along the carriers, releasing energy**.
4. The carriers use this energy to **pump protons** by active transport **from the matrix into the intermembrane space**.
5. A **proton gradient** (electrochemical gradient) builds up across the inner membrane, which is impermeable to protons.
6. Protons **diffuse back into the matrix** through **ATP synthase** (facilitated diffusion), providing the energy to make **ATP from ADP and Pi: chemiosmosis**.
7. At the end of the chain, **oxygen** is the **final electron acceptor**: it combines with electrons and protons to form **water**.

Reduced FAD feeds a **later carrier** than reduced NAD, so fewer protons are pumped and less ATP is made. The ETC **pumps** protons out of the matrix; ATP synthase lets them **flow back in**.

Why aerobic respiration yields much more energy

With oxygen, glucose is broken down completely to CO_2 and water, and most ATP comes from oxidative phosphorylation, driven by the hydrogen collected earlier.

Without oxygen, there is no final electron acceptor: the ETC stops, NAD runs out, and the link reaction and Krebs cycle stop. Only **glycolysis** continues (with NAD regenerated by fermentation), giving a **net 2 ATP** per glucose. Most of the energy stays in the lactate or ethanol.

Respiration without oxygen: fermentation

Without oxygen, the cell regenerates NAD by using **reduced NAD to reduce pyruvate** (or a product of it), so glycolysis can continue.

	Lactate fermentation (mammals, e.g. muscle)	Ethanol fermentation (yeast, and plants such as rice)
Where	Cytoplasm	Cytoplasm
Starts from	Pyruvate	Pyruvate
Steps	One: pyruvate is reduced to lactate by lactate dehydrogenase	Two: pyruvate is decarboxylated to ethanal (CO_2 released, pyruvate decarboxylase); ethanal is reduced to ethanol by ethanol (alcohol) dehydrogenase
Hydrogen acceptor	Pyruvate	Ethanal
Carbon dioxide	Not made	Made

	Lactate fermentation (mammals, e.g. muscle)	Ethanol fermentation (yeast, and plants such as rice)
NAD regenerated	Yes	Yes
Reversible?	Yes: lactate can be turned back into pyruvate	No: the CO ₂ is lost
ATP	Net 2 per glucose, from glycolysis only	Net 2 per glucose, from glycolysis only

After exercise (the oxygen debt). In hard exercise some respiration is anaerobic and **lactate** builds up. Afterwards, extra oxygen is needed, so breathing stays deep and fast: lactate is carried to the **liver** and **oxidised back to pyruvate**; some pyruvate is respired aerobically for ATP, which turns the rest into **glucose** and **glycogen**; haemoglobin and myoglobin are reloaded. Diving mammals show the same pattern: blood lactate rises during a dive and falls afterwards.

Rice: growing with roots under water

Flooded soil water holds very little oxygen. Three adaptations help rice:

- **Aerenchyma.** In flooded, low-oxygen conditions, rice roots (and stems) **develop** aerenchyma: tissue with many **large air spaces**. It forms in response to low oxygen: roots in oxygenated water make very little. The air spaces let **oxygen diffuse from the parts above water down to the roots**, so root cells can keep respiring **aerobically**.
- **Ethanol fermentation in the roots.** When oxygen still runs short, root cells use ethanol fermentation to keep making some ATP. Rice root cells **tolerate higher concentrations of ethanol** than most plants and have **more ethanol dehydrogenase**. This enzyme keeps reducing ethanal to ethanol, regenerating NAD so fermentation continues; the ethanal $\rightleftharpoons$ ethanol step it catalyses is reversible (unlike the whole pathway, which can't go back to pyruvate once CO₂ is lost), so the enzyme can also convert ethanol back to ethanal, keeping ethanol from building up to toxic levels.
- **Faster stem growth.** The stems (internodes) grow faster, keeping **leaves and flowers above the water** for gas exchange, **photosynthesis** and pollination.

Respiratory substrates and their energy values

Other **respiratory substrates** include fructose, **fatty acids** and glycerol (from lipids) and **amino acids** (usually only when carbohydrate and fat run short). Glycerol joins glycolysis as triose phosphate; fatty acids are cut into acetyl groups; amino acids lose their nitrogen and enter as pyruvate, acetyl CoA or a Krebs intermediate, depending on their number of carbons.

Substrate	Energy value (approximately)
Carbohydrate	16–17 kJ g ⁻¹
Protein	17 kJ g ⁻¹

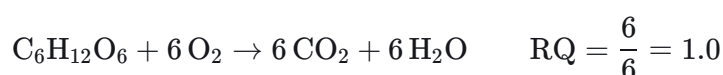
Substrate	Energy value (approximately)
Lipid	37–39 kJ g ⁻¹

Why lipids release over twice as much per gram: most of the energy comes from **hydrogen** passed to the ETC. Lipids have **many more hydrogen atoms** (C–H bonds) and little oxygen, so a gram of lipid reduces **more NAD and FAD**, **more protons** are pumped and pass through **ATP synthase**, and **more ATP** is made.

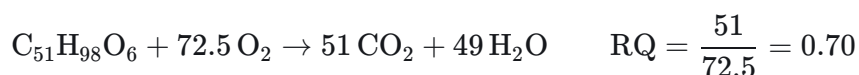
The respiratory quotient (RQ)

$$RQ = \frac{\text{molecules (or volume) of CO}_2 \text{ given out}}{\text{molecules (or volume) of O}_2 \text{ taken in}}$$

Volumes or moles can replace molecules. From an equation, count the molecules. For glucose:



For a typical fat, tripalmitin:

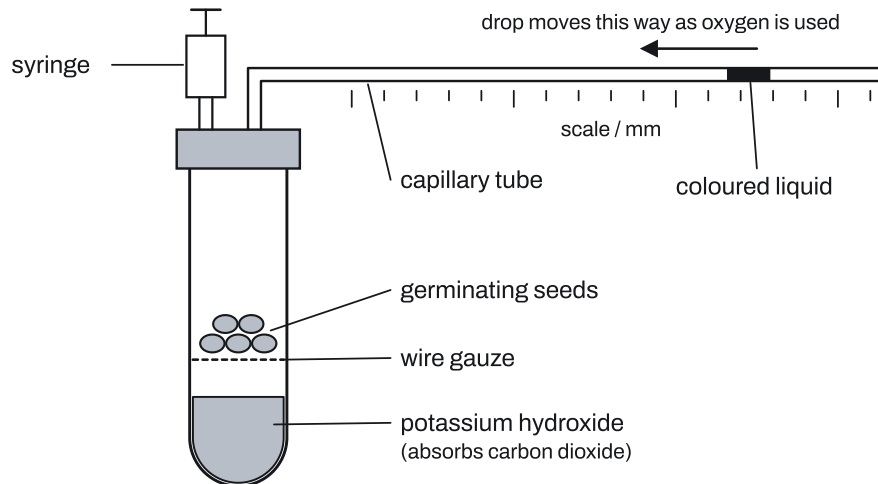


Lipids have little oxygen of their own, so they need more O₂ to turn their hydrogen into water: RQ below 1.

Substrate respired	Typical RQ
Carbohydrate	1.0
Protein	about 0.8 (0.8–0.9)
Lipid	0.7
A mixture (e.g. at rest on a normal diet)	between 0.7 and 1.0, often about 0.8
Some anaerobic respiration as well	above 1.0 (CO ₂ is given out without the matching O ₂ being taken in)

An RQ that **falls** over time (fasting, a long flight) shows a switch from **carbohydrate** to **lipid**. Oxygen-rich organic acids can have an RQ **above 1**.

Measuring respiration with a respirometer



A **respirometer** measures how fast organisms (germinating seeds, blowfly larvae, woodlice) take in oxygen.

- **Potassium hydroxide solution** (or soda lime) **absorbs carbon dioxide** as it is given out.
- So the only change in gas volume is the **oxygen taken in**: the pressure inside **falls**, and the coloured liquid moves **towards the organisms**.
- Measure the **distance moved in a set time**. The volume of oxygen is the volume of capillary the drop moved along:

$$\text{volume} = \pi r^2 \times \text{distance moved}, \quad \text{rate} = \frac{\text{volume}}{\text{time}}$$

where r is the radius of the capillary's bore.

Good practice: stand it in a **water bath** and let it **equilibrate** for a few minutes before starting; set up a **control** with glass beads (or dead seeds) of the same volume, so movement caused by temperature or pressure changes shows up; reset the liquid with the **syringe**; keep the mass of organisms and volume of potassium hydroxide the same; **repeat** and find the mean (the standard deviation shows how consistent the results are).

Finding the RQ. Run it twice with the same organisms: **with potassium hydroxide** the distance x is the **oxygen taken in**; **with water instead**, the distance y is **oxygen taken in minus carbon dioxide given out**. So the carbon dioxide is $x - y$ and

$$\text{RQ} = \frac{x - y}{x}.$$

If the liquid doesn't move in the second run, the RQ is 1.

Effect of temperature. As temperature rises, molecules have more **kinetic energy**, so more **enzyme-substrate complexes** form and respiration speeds up. Above the **optimum**, the respiratory enzymes **denature** (the active site changes shape) and the rate falls.

Measuring respiration with a redox indicator

DCPIP and **methylene blue** are **redox indicators**: **blue when oxidised, colourless when reduced**. In yeast, the dehydrogenase enzymes of respiration remove hydrogen from their substrates; the indicator accepts some of it and is reduced. **The faster the yeast respire, the sooner the blue disappears.**

To find the effect of **glucose concentration** (or temperature):

1. Use the **same volumes of yeast suspension and glucose solution**, changing only the **glucose concentration** (or only the **temperature**, in a water bath).
2. Keep the **volume and concentration of indicator** and everything else the same.
3. Add the indicator, mix, and cover with a **layer of oil**, because oxygen from the air would turn the indicator blue again.
4. Time how long the blue takes to disappear (against a colour standard, or with a colorimeter).
5. Repeat and find means. **Rate** = $\frac{1}{\text{time}}$: **a shorter time means a faster rate.**

Key facts and formulas

None of these are in the syllabus's list of mathematical formulae, so they are all "Learn it". When a question needs an area or volume formula, it usually gives it.

Formula	Status
$\text{ATP} + \text{H}_2\text{O} \rightarrow \text{ADP} + \text{P}_i$, releasing 30.5 kJ mol^{-1}	Learn it
$\text{RQ} = \frac{\text{CO}_2 \text{ given out}}{\text{O}_2 \text{ taken in}}$	Learn it
RQ: carbohydrate 1.0, protein about 0.8, lipid 0.7; above 1.0 means some anaerobic respiration	Learn it
Energy values: carbohydrate and protein about 17 kJ g^{-1} , lipid about $37\text{--}39 \text{ kJ g}^{-1}$	Learn it
Respirometer: volume = $\pi r^2 \times \text{distance}$; $\text{RQ} = \frac{x - y}{x}$	Learn it
Redox indicator: rate = $\frac{1}{\text{time}}$	Learn it
Efficiency = $\frac{\text{energy captured in ATP}}{\text{energy released by the substrate}} \times 100$	Learn it
Glycolysis per glucose: 2 ATP used, 4 made (net 2), 2 reduced NAD, 2 pyruvate	Learn it
Link reaction per pyruvate: 1 CO_2 , 1 reduced NAD, 1 acetyl CoA	Learn it
Krebs cycle per turn (two per glucose): 2 CO_2 , 3 reduced NAD, 1 reduced FAD, 1 ATP	Learn it
Without oxygen: net 2 ATP per glucose (glycolysis only)	Learn it

How to do it

We have tagged 48 questions on this topic (2021–2025), all structured questions from Paper 4. The types came up this often. 35 of the 48 questions mix more than one type, so the counts add up to more than 48.

Question type	Questions
Explain the effect of an inhibitor, uncoupler or lack of oxygen on ATP production	13
Identify stages, locations or substances on a diagram or table	13
Outline oxidative phosphorylation and chemiosmosis	11
Describe glycolysis and substrate-linked phosphorylation	10
Explain the features of ATP and why cells need energy	10
Describe and compare anaerobic respiration (lactate, ethanol, oxygen debt)	9
Define, calculate and interpret RQ	7
Describe and explain a respirometer or redox-indicator investigation	7
Relate the structure of a mitochondrion to its function	7
Describe the link reaction and the Krebs cycle	6
Calculate from respiration data	6
Describe the roles of NAD, FAD and coenzyme A	5
Explain the relative energy values of respiratory substrates	5
Describe and explain how rice is adapted to flooding	5
Describe and explain data on respiratory enzymes or rates	4

1. Explain the effect of an inhibitor, uncoupler or lack of oxygen on ATP production (13 questions)

Worth 3–6 marks. Find where the problem acts, then follow the chain, saying what happens **less** at each step:

1. ETC electron flow slows or stops → **less energy released**.
2. **Fewer protons pumped** into the intermembrane space → smaller **proton gradient**.
3. **Fewer protons through ATP synthase** → **less ATP** (less chemiosmosis).
4. Fewer electrons reach **oxygen** → less **water**, less oxygen used.
5. Reduced NAD/FAD not oxidised → **NAD and FAD not regenerated** → link reaction and Krebs cycle slow or stop.
6. The cell falls back on **glycolysis** (substrate-linked ATP only) and makes **lactate** (yeast: ethanol) to regenerate NAD.

Variations you will meet:

- **No oxygen:** oxygen is the **final electron acceptor**, so the ETC stops and the chain follows. Say "NAD is not regenerated", not "reduced NAD".
- **A poison blocking a carrier** (cyanide on the last carrier, an insecticide on the first): exactly the chain above.
- **Why the link reaction needs oxygen:** not used in it, but it needs **NAD**, which is only regenerated when the ETC runs.
- **An uncoupler** (a chemical that makes the inner membrane leaky to protons, or the protein channel in brown fat): protons return **without passing through ATP synthase**, so **less ATP** and the energy is **released as heat**. The cell respire **more substrate** (fat used, weight lost) and more glycolysis gives more pyruvate and lactate ([9700/41/M/J/21 Q2](#)).
- **No mitochondria**, or **pyruvate can't enter the matrix**: no link reaction, Krebs cycle or oxidative phosphorylation; **ATP only from glycolysis**; pyruvate → lactate (or ethanol).
- **Lactate dehydrogenase inhibited**: less pyruvate → lactate, so **less NAD regenerated**, less triose phosphate oxidised, **less substrate-linked ATP** in glycolysis.

2. Identify stages, locations or substances on a diagram or table (13 questions)

1. **Locations:** glycolysis → cytoplasm; link reaction and Krebs cycle → matrix; oxidative phosphorylation → inner membrane / cristae. Nothing happens "in the outer membrane".
2. **Substances:** use carbon numbers (diagram 2). 6C → glucose, fructose 1,6-bisphosphate or citrate; 3C → triose phosphate or pyruvate; 2C → acetyl CoA; 4C → oxaloacetate; lost where carbons fall → **CO₂**. A coenzyme going in and coming out "reduced" → NAD (FAD only in the Krebs cycle).
3. **Fermentation:** yeast pyruvate → **ethanal** (+ **CO₂**) → **ethanol**, reduced NAD → NAD at the second step; mammals pyruvate → **lactate**.

Variations you will meet:

- **Tick-and-cross tables** of which stage does what, as in [9700/43/O/N/24 Q3](#):

Event	Glycolysis	Link	Krebs	Oxidative phosphorylation
Breaks the substrate into smaller molecules (catabolism)	✓	✓	✓	✗
A coenzyme is reduced or oxidised	✓	✓	✓	✓ (reduced NAD and FAD are oxidised)
A coenzyme bonds covalently to an intermediate	✗	✓ (acetyl CoA)	✗	✗
Carbon dioxide released	✗	✓	✓	✗
ATP made by substrate-linked phosphorylation	✓	✗	✓	✗

- **The link reaction's coenzymes:** **NAD** and **coenzyme A**.

- **Membrane transport:** glucose enters through a **carrier** (GLUT, facilitated diffusion), not a channel; pyruvate enters the matrix through a carrier (active transport).
- **Name the space** between the membranes: **intermembrane space** (not "inner membrane space").
- **Drawing arrows:** oxygen goes straight **through the phospholipid bilayers** of both membranes (not through proteins); protons are pumped **from the matrix into the intermembrane space**; carbon dioxide is made in the matrix, so it diffuses out through **both** membranes.

3. Outline oxidative phosphorylation and chemiosmosis (11 questions)

Worth 4–7 marks, one per step. Write the seven steps in "Stage 4" in order, using the key words: **hydrogen atoms** from reduced NAD/FAD → **protons and electrons** → electrons along the **ETC** release energy → **protons pumped into the intermembrane space** → **proton gradient** → protons **diffuse through ATP synthase** → **ADP + Pi** → **ATP (chemiosmosis)** → **oxygen, the final electron acceptor**, forms **water**.

Variations you will meet:

- **Given the first steps:** start where they stop and give the rest.
- **Reduced FAD** feeds a **later carrier** than reduced NAD: on a diagram of four carriers, the second.
- **Membrane potential:** pumping protons out leaves the intermembrane side positive and the matrix negative.
- **Compare with chloroplasts:** mitochondria — electrons from **reduced NAD/FAD**, protons into the **intermembrane space** across the **inner membrane**, **oxygen** the final acceptor (water); chloroplasts — electrons from **chlorophyll** (replaced by photolysis of **water**), protons into the **thylakoid space** across the **thylakoid membrane**, **NADP** the final acceptor.
- **Name the stage** with chemiosmosis: oxidative phosphorylation (respiration), photophosphorylation (photosynthesis); not "the electron transport chain", which is a structure.
- **Why the real ATP yield is below the theoretical value:** protons leak across the inner membrane; energy lost as heat; ATP used to move pyruvate and ADP into the mitochondrion; intermediates and reduced NAD used in other reactions.

4. Describe glycolysis and substrate-linked phosphorylation (10 questions)

Give the four steps in "Stage 1" in order, with the key words: **cytoplasm**; glucose **phosphorylated** (2 ATP) → **fructose 1,6-bisphosphate** → **2 triose phosphate** → **oxidised (dehydrogenated)**, **NAD reduced** → **pyruvate**; 4 ATP by **substrate-linked phosphorylation**, **net 2 ATP**, **2 reduced NAD**.

Variations you will meet:

- **Why phosphorylate glucose first?** It **activates** glucose (less stable, splits more easily) and **can't leave the cell**. Not "lowers the activation energy of glucose": activation energy belongs to a reaction.
- **How does a diagram show glycolysis involves oxidation?** Reduced NAD is made, so **triose phosphate** was dehydrogenated. Don't mention FAD.
- **The two ways ATP is made:** **substrate-linked** and **oxidative** phosphorylation.
- **Where is substrate-linked phosphorylation?** **Both** the **cytoplasm** and the **mitochondrial matrix**.

- **How ATP is made in the Krebs cycle:** an **enzyme** transfers a **phosphate** from an intermediate to ADP (**substrate-linked**, not ATP synthase).
- **A use of reduced NAD from glycolysis:** carries hydrogen to the ETC; or, without oxygen, reduces pyruvate (to lactate) or ethanal (to ethanol).

5. Explain the features of ATP and why cells need energy (10 questions)

Give each feature from "ATP: the energy currency" **with its consequence** (hydrolysed in **one step** → quick release; **30.5 kJ mol⁻¹**, small manageable amounts; **small, water-soluble** → moves within the cell; **regenerated**, high turnover). For uses: **active transport, movement, anabolic reactions**.

Variations you will meet:

- **"Two examples of movement in cells":** two **different** ideas, at cell level (a **muscle fibre** contracting, not "the arm"). For exocytosis, name what is released, not "vesicles".
- **Why protein synthesis needs ATP:** unwinding DNA, activating nucleotides, attaching amino acids to tRNA, peptide bonds, moving the ribosome. (DNA is transcribed; "transcription of mRNA" is wrong.)
- **Why GTP can be used:** similar structure (purine base, ribose, three phosphates), hydrolysed the same way.
- **Heat:** energy not captured in ATP is used in **thermoregulation** (maintaining body temperature).
- **Energy-rich molecules** entering respiration: glucose, fructose, fatty acids, glycerol, amino acids.

6. Describe and compare anaerobic respiration (lactate, ethanol, oxygen debt) (9 questions)

1. **"Compare":** similarities **and** differences, straight from the fermentation table (a table in your answer works well). Similarities: cytoplasm, pyruvate, **NAD regenerated**, redox, net 2 ATP.
2. **"Outline ethanol fermentation":** glycolysis → pyruvate **decarboxylated** to ethanal → ethanal **reduced** to ethanol → **NAD regenerated**. (Removing CO₂ is decarboxylation only.)

Variations you will meet:

- **"How does fermentation let cells work without oxygen?"** **NAD regenerated** → **glycolysis** continues → **ATP** by substrate-linked phosphorylation.
- **"Why is it an advantage to yeast?"** It survives without oxygen, still making ATP. Answer for the yeast, not for bakers.
- **Oxygen use stays high after exercise:** the **oxygen debt** (see "After exercise"): lactate → **liver, oxidised to pyruvate**, respired for ATP, which makes the rest into **glucose / glycogen**.
- **Blood lactate data** (a diving mammal): during the dive, less oxygen → **anaerobic respiration, pyruvate reduced to lactate**; after, oxygen returns, lactate **oxidised to pyruvate** (much in the **liver**). Quote values with units.
- **Inhibiting lactate dehydrogenase:** see type 1.

7. Define, calculate and interpret RQ (7 questions)

1. **Define:** molecules (or volume) of **CO₂ produced** ÷ molecules (or volume) of **O₂ taken in**.
2. **Find the oxygen:** oxygen atoms in the products ($2 \times \text{CO}_2 + \text{H}_2\text{O}$), minus the substrate's own, halved.
3. **Divide** to the decimal places asked. **Interpret:** 1.0 carbohydrate, about 0.8 protein or a mixture, 0.7 lipid, above 1 some anaerobic respiration.

For butanoic acid, $\text{C}_4\text{H}_8\text{O}_2$: products $4 \text{CO}_2 + 4 \text{H}_2\text{O}$ contain $8 + 4 = 12$ oxygen atoms; the acid supplies 2, so $10 \text{ atoms} = 5 \text{ O}_2$. $\text{RQ} = \frac{4}{5} = 0.80$.

Variations you will meet:

- **"Highest or lowest RQ?"** from a table: work out each. Oxygen-rich organic acids are **highest** (often above 1); long-chain fatty acids **lowest**.
- **RQ against time** (fasting, torpor, a long flight): **near 1.0** (carbohydrate), **falls** as carbohydrate runs out (a mixture), **levels near 0.7** (lipid). Trend, then **two data points**, then explanation.
- **Exercise intensity:** rest about 0.8 (mixture); moderate 1.0 (carbohydrate); very high **above 1.0** (some anaerobic respiration).
- **A breath analyser:** measures **O₂ taken in** (air flow) and **CO₂ breathed out** (CO₂ sensor), divides; near 1 carbohydrate, near 0.7 lipid.

8. Describe and explain a respirometer or redox-indicator investigation (7 questions)

- **Respirometer** (see "Measuring respiration with a respirometer"): KOH **absorbs CO₂** → O₂ uptake **lowers the pressure** → liquid moves **towards the organisms** → **distance in a set time**, volume = $\pi r^2 \times \text{distance}$ → controls (water bath, equilibration, glass-bead control, repeats).
- **Redox indicator** (see "Measuring respiration with a redox indicator"): **redox** indicator, **blue** → **colourless** when **reduced** by hydrogen from **dehydrogenase** reactions; time the change, rate = $\frac{1}{t}$; control yeast, glucose and indicator volumes, temperature (about 20–45 °C for yeast), oil layer.

Variations you will meet:

- **Explain a temperature graph:** rate rises to an optimum (**kinetic energy**, more **enzyme–substrate complexes**), then falls (enzymes **denature**). For "time for DCPIP to change colour", **shortest time = fastest rate**.
- **Plot a graph:** rate against temperature, points exact, **smooth curve**, no extrapolation.
- **Plan an 8-mark investigation:** independent variable with a range, variables kept the same, how to measure, repeats and means, what to plot. Vary **glucose concentration**, not the amount of yeast.
- **Predict the rate at 5 °C vs 20 °C:** **lower**; less kinetic energy, fewer enzyme–substrate collisions.
- **Bromothymol blue or hydrogencarbonate indicator** with a plant or snail: **respiration** CO₂ (link reaction, Krebs cycle) lowers the pH; photosynthesis in light uses it; a tube with no organism is the **control**.

9. Relate the structure of a mitochondrion to its function (7 questions)

Use the table in "The mitochondrion", one **structure + function** pair per mark, working outer membrane → intermembrane space → inner membrane and cristae (surface area, ETC, ATP synthase, impermeable to protons) → matrix (enzymes, DNA, ribosomes).

Variations you will meet:

- **9-mark essay:** that same order, one pair per sentence.
- **Cardiac muscle cells have many cristae:** more ETCs and ATP synthases → **more oxidative phosphorylation**, for **continuous contraction**.
- **What mitochondrial genes code for:** ETC proteins, ATP synthase, link and Krebs enzymes, transport proteins, tRNA and rRNA. Not ancestry tracing.
- **Molecules in the matrix** other than coenzymes: pyruvate, oxaloacetate, citrate, enzymes, oxygen, DNA. (ATP synthase is in the membrane.)
- **Unfamiliar structures** (a lipid making the inner membrane impermeable to ions; an ATP/ADP swap carrier): link to keeping the **proton gradient** or a **supply of ADP**.
- **Fission:** for **higher energy needs**, before **cell division**, or to replace damaged mitochondria, which **lysosomes** break down for reuse.

10. Describe the link reaction and the Krebs cycle (6 questions)

Link reaction (4 marks): **matrix**; pyruvate **decarboxylated** and **dehydrogenated**; **NAD reduced**; **acetyl (2C) + coenzyme A → acetyl CoA**. **Krebs cycle:** acetyl + **oxaloacetate (4C) → citrate (6C)**; **decarboxylation** and **dehydrogenation** back to oxaloacetate; **NAD and FAD reduced**; **1 ATP per turn** (substrate-linked).

Variations you will meet:

- **"Name the two chemical changes"** in the link reaction: **decarboxylation** and **dehydrogenation**.
- The **acetyl group**, not pyruvate, joins coenzyme A. Write "coenzyme A" in full.
- **Conditions for pyruvate to enter by active transport:** a **carrier protein** (the membrane is otherwise impermeable to it), **ATP**, **oxygen**; it moves **against** its gradient.
- **Control of the link reaction:** a build-up of acetyl CoA (little free coenzyme A) inhibits its enzyme: **end-product inhibition**, matching acetyl CoA supply to the Krebs cycle and freeing coenzyme A.

11. Calculate from respiration data (6 questions)

Show working, give **units**, round at the end. Usually one mark for method, one for the answer.

- **Theoretical ATP per glucose:** substrate-linked ATP + ATP from each reduced coenzyme – **2 ATP used**. With 3 per reduced NAD and 2 per reduced FAD: $(4 - 2) + 2 + 10 \times 3 + 2 \times 2 = 38$. Forgetting the -2 gives 40; leaving out glycolysis's 4 ATP gives 34.
- **Percentage efficiency:**
$$\frac{\text{moles of ATP} \times 30.5}{\text{energy per mole of glucose}} \times 100.$$

- **ATP turnover per hour** = $\frac{\text{moles used per day}}{\text{moles in the body} \times 24}$: do both steps.
- **Surface area of a mitochondrion** as a cylinder (formula given): **radius = diameter ÷ 2**, and **square** it.
- **Gross photosynthesis** = net CO₂ uptake + respiration CO₂, both read at the same temperature, with units.
- **Rates**: volume ÷ time (respirometer) or $\frac{1}{t}$ (redox indicator).

12. Describe the roles of NAD, FAD and coenzyme A (5 questions)

Give the points in "NAD, FAD and coenzyme A" in order: **coenzymes** helping **dehydrogenases** → **accept hydrogen atoms** (reduced) → NAD in glycolysis, link reaction and Krebs, FAD in Krebs only → **carry hydrogen to the inner membrane / ETC** → oxidative phosphorylation, ATP → **oxidised and recycled**. **Coenzyme A** carries the **acetyl group** into the Krebs cycle.

Variations you will meet:

- **"In the mitochondrion" only**: NAD in the link reaction and Krebs cycle, not glycolysis.
- **What NAD carries**: hydrogen atoms (protons **and** electrons together), not "hydrogen ions" or "hydrogen molecules".
- NAD and FAD don't dehydrogenate anything themselves: they **assist** dehydrogenases.

13. Explain the relative energy values of respiratory substrates (5 questions)

State the values (lipid about 37–39 kJ g⁻¹, over twice carbohydrate and protein at about 17), then **explain** the chain: **more H atoms / C–H bonds** → **more reduced NAD and FAD** → **more protons pumped** → **more through ATP synthase** → **more ATP**.

Variations you will meet:

- **Tick the right value** in a table: carbohydrate about 17, lipid about 37, protein about 17.
- **Which amino acid could become pyruvate or oxaloacetate?** Count the carbons in its skeleton: 3C → pyruvate, 4C → oxaloacetate.

14. Describe and explain how rice is adapted to flooding (5 questions)

Give each of the three adaptations in "Rice" **with its explanation**: **aerenchyma** → O₂ **diffuses** to the roots → **aerobic respiration**; **ethanol fermentation** with **ethanol tolerance** and **more ethanol dehydrogenase** → ATP without oxygen; **fast stem growth** → **leaves and flowers above water** → photosynthesis, gas exchange, reproduction.

Variations you will meet:

- **Data on aerenchyma development**: in deoxygenated water it rises slowly, then quickly, then levels off; in oxygenated water it stays low. Describe, **quote two times and two percentages**, explain: it forms in **response to low oxygen**.

- **"How do root cells respond to a high ethanol concentration?"**: more **ethanol dehydrogenase**. Mark schemes credit both of its jobs, making ethanol so fermentation continues and breaking ethanol down (9700/42/O/N/25 Q1, 9700/44/M/J/25 Q7).
- **Naming from a flow chart**: the gas lacking is **oxygen**, the root waste product **ethanol**, the tissue **aerenchyma**.
- Also credited: leaf ridges that **trap air** under water. Hormones controlling stem growth belong to control and coordination.

15. Describe and explain data on respiratory enzymes or rates (4 questions)

1. **Describe** each trend, then **compare** the lines.
2. **Quote paired data**: both x and y values, with units.
3. **Explain** with this topic: inhibition, temperature, mitochondria or need for ATP.

Variations you will meet:

- **A molecule shaped like the substrate** lowers activity, overcome by more substrate: **competitive inhibition**; binds the active site, so the Krebs cycle **slows** and intermediates don't build up (**regulation**).
- **Activity falls over time, faster at a higher concentration of a chemical**: it is an **inhibitor**; compare both at the same time.
- **Muscle respire faster than liver**: greater need for **ATP** (contraction, shivering).
- **GM yeast makes more ethanol**: compare maxima and when they level off; explain with its extra enzymes.

Worked examples

The bold codes show where marks are earned, as in Cambridge mark schemes. The number is how many marks.

- **M1** method mark: for a correct method, even if the numbers slip.
- **A1** accuracy mark: for a correct answer; it needs the M mark before it.
- **B1** mark for a correct result on its own, with no method needed.

Example 1

(a) State where in a eukaryotic cell (i) glycolysis and (ii) oxidative phosphorylation take place. **[2]**

(b) Outline glycolysis. **[4]**

(c) Name the type of phosphorylation that makes ATP in glycolysis, and state the net number of ATP molecules made from one molecule of glucose. **[2]**

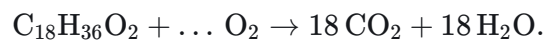
(a) (i) The **cytoplasm**. **B1** (ii) The **inner mitochondrial membrane** (the cristae). **B1**

(b) Any four of: glucose is **phosphorylated** using ATP; to **fructose 1,6-bisphosphate**; which **splits into two triose phosphates**; triose phosphate is **oxidised (dehydrogenated)** to **pyruvate**; **NAD is reduced**; ATP is made. **B1 B1 B1 B1**

(c) **Substrate-linked** phosphorylation. **B1** Net **2** ATP (4 made, 2 used). **B1**

Example 2

Stearic acid, $C_{18}H_{36}O_2$, is a fatty acid. When it is respired aerobically,



(a) Calculate the number of oxygen molecules used, and the RQ of stearic acid to 2 decimal places. **[2]**

(b) A student put germinating sunflower seeds in a respirometer containing potassium hydroxide solution. The coloured liquid in the capillary tube, radius 0.5 mm, moved 36 mm towards the seeds in 15 minutes. Calculate the rate of oxygen uptake in $mm^3 \text{ min}^{-1}$. **[2]**

(c) She repeated the experiment with water instead of potassium hydroxide solution. The liquid moved 9 mm towards the seeds in 15 minutes. Calculate the RQ of the seeds, and suggest what they were respiring. **[3]**

(a) The products contain $18 \times 2 + 18 = 54$ oxygen atoms; the acid supplies 2, so 52 atoms = $26 O_2$. **B1** RQ = $\frac{18}{26} = 0.69$. **B1**

(b) Volume = $\pi r^2 \times \text{distance} = \pi \times 0.5^2 \times 36 = 28.27 \text{ mm}^3$. **M1** Rate = $28.27 \div 15 = 1.88 \text{ mm}^3 \text{ min}^{-1}$. **A1**

(c) With potassium hydroxide the movement (36 mm) is the oxygen taken in. With water it is oxygen taken in minus carbon dioxide given out, so the carbon dioxide is $36 - 9 = 27 \text{ mm}$. **M1** RQ = $\frac{27}{36} = 0.75$. **A1** Close to 0.7, so the seeds were respiring **mainly lipid** (their stored oil). **B1**

Example 3

A textbook value for the energy released by the complete oxidation of glucose is 2870 kJ mol^{-1} . The hydrolysis of ATP releases 30.5 kJ mol^{-1} . Assume that each reduced NAD gives 2.5 ATP and each reduced FAD gives 1.5 ATP in oxidative phosphorylation.

(a) Calculate the net number of ATP molecules made per molecule of glucose in aerobic respiration. Show your working. **[2]**

(b) Calculate the percentage efficiency of aerobic respiration, and of respiration in anaerobic conditions. **[3]**

(c) Explain why aerobic respiration releases much more energy than respiration in anaerobic conditions. **[3]**

(a) Substrate-linked: glycolysis net $4 - 2 = 2$, Krebs cycle 2. Reduced NAD: $2 + 2 + 6 = 10$, giving $10 \times 2.5 = 25$. Reduced FAD: $2 \times 1.5 = 3$. **M1**

Total = $2 + 2 + 25 + 3 = 32 \text{ ATP}$. **A1**

(b) Aerobic: $\frac{32 \times 30.5}{2870} \times 100 = 34.0\%$. **M1 A1** Anaerobic (net 2 ATP): $\frac{2 \times 30.5}{2870} \times 100 = 2.1\%$. **A1** (Aerobic respiration makes $32 \div 2 = 16$ times as much ATP.)

(c) No **final electron acceptor**, so the **ETC** and **oxidative phosphorylation** stop. **B1** No **NAD** is regenerated, so the **link reaction** and **Krebs cycle** stop. **B1** Only **glycolysis** runs, giving **2 ATP**; most energy stays in **lactate** or **ethanol**. **B1**

Example 4

Oligomycin is an antibiotic that blocks the channel in ATP synthase, so that protons cannot pass through it.

(a) Explain why oligomycin reduces ATP production by mitochondria. **[3]**

(b) Scientists treated animal cells with oligomycin in the presence of oxygen. The cells took in less oxygen, and the concentration of lactate around them rose. Suggest explanations for these results. **[4]**

(a) Protons **cannot diffuse from the intermembrane space back into the matrix** through ATP synthase. **B1** So there is **no chemiosmosis**: the energy of the proton gradient is not used. **B1** **ADP and Pi are not joined** to make ATP by **oxidative phosphorylation**. **B1**

(b) Protons build up, the **gradient becomes too steep** to pump against, so **electron flow along the ETC slows**. **B1** Fewer electrons pass to **oxygen**, the final acceptor, so **less oxygen is used** (and less water made). **B1** Reduced NAD is not oxidised, so **NAD is not regenerated** for the link reaction and Krebs cycle. **B1** The cells rely on **glycolysis**; to regenerate NAD they **reduce pyruvate to lactate** (lactate dehydrogenase), so lactate is released. **B1**

Common mistakes

- **Saying energy is "produced"**. Energy is **released** (along the ETC, or when ATP is hydrolysed). Examiners penalise this year after year.
- **Saying NAD carries hydrogen ions, or electrons alone**. NAD and FAD carry **hydrogen atoms** (protons and electrons); the atom splits only at the inner membrane.
- **Mixing up "NAD" and "reduced NAD"**. Without oxygen, **NAD** is not regenerated; "reduced NAD not regenerated" is wrong.
- **Saying ATP synthase pumps protons**, or calling it "ATPase". The **ETC** pumps protons **from the matrix into the intermembrane space** (not the "inner membrane space"); they **diffuse back** through **ATP synthase**.
- **Putting stages in the wrong place**: glycolysis in the matrix, the Krebs cycle on the inner membrane, or oxidative phosphorylation on the outer membrane.
- **Forgetting substrate-linked phosphorylation in the matrix**, or calling the Krebs cycle's ATP "oxidative phosphorylation".
- **Saying oxygen is used in the link reaction**. Oxygen is needed at the end of the ETC; without it NAD isn't regenerated, and that stops the link reaction.

- **Putting FAD in glycolysis or the link reaction**, or saying **pyruvate** (rather than the **acetyl group**) joins coenzyme A.
- **Saying ATP is carried around the body**. It moves **within the cell**; say "**water-soluble**".
- **Not knowing that lipid has the highest energy value**, and missing the key RQ mark: a **falling RQ** means a switch **from carbohydrate to lipid**.
- **Ethanol fermentation steps**: pyruvate → ethanal is **decarboxylation** only; ethanal → ethanol is **reduction**. Don't describe lactate fermentation when the question is about yeast.
- **Redox indicators**: naming a pH indicator, not saying it is **reduced** (blue → colourless), or changing the yeast concentration when asked about **substrate** concentration.
- **Data and calculations**: single-point quotes instead of **paired** data with units; describing when asked to explain; using the diameter instead of the radius; doing only one step of a two-step calculation.

How to get the marks

- **"State" / "name"**: one precise term ("substrate-linked phosphorylation", "intermembrane space", "decarboxylation"). A wrong second answer can cancel a right one.
- **"Outline"**: the main steps in order, one mark each, with the key words (phosphorylation, triose phosphate, dehydrogenation, proton gradient, ATP synthase, final electron acceptor, chemiosmosis).
- **"Explain"** and **"suggest and explain"**: start where the change acts and link each step to the next with "so", saying what happens **less**, not only what normally happens.
- **"Compare"**: similarities **and** differences, with both halves of each difference ("CO₂ is made in yeast but not in mammals").
- **"Describe the results"**: overall trend, then changes in gradient, then a **paired data quote** with units. "Explain" then needs the biology, not the data again.
- **Calculations**: show every step, give units, round at the end to the decimal places asked. Marks can follow from your own earlier wrong value.
- **Stay in context**: "in the mitochondrion" leaves out glycolysis; "in yeast" means ethanol; "movement in cells" means cell-level examples.

Quick check

1. Calculate the RQ of glycerol, C₃H₈O₃, when it is respired aerobically to carbon dioxide and water. Give your answer to 2 decimal places.
2. A resting person contains 0.1 moles of ATP at any time and hydrolyses 60 moles of ATP in a day. How many times per hour is the whole pool of ATP remade?
3. Explain why a gram of lipid releases more energy in respiration than a gram of carbohydrate.
4. Give two differences between ethanol fermentation in yeast and lactate fermentation in mammals.
5. In a methylene blue experiment, the blue colour disappeared in 4 minutes with 5% glucose and in 10 minutes with 1% glucose. Calculate the rate ($\frac{1}{t}$) for each, and explain the difference.

Answers

1. $\text{C}_3\text{H}_8\text{O}_3 + 3.5 \text{O}_2 \rightarrow 3 \text{CO}_2 + 4 \text{H}_2\text{O}$ (products contain $6 + 4 = 10$ oxygen atoms; glycerol gives 3, so 7 atoms are needed $= 3.5 \text{O}_2$). $\text{RQ} = \frac{3}{3.5} = 0.86$.
2. Per day: $60 \div 0.1 = 600$ times. Per hour: $600 \div 24 = 25$ times.
3. Lipids have more **hydrogen atoms** (C–H bonds) per gram $\rightarrow$ more reduced **NAD and FAD** $\rightarrow$ **more protons pumped** $\rightarrow$ more through **ATP synthase** $\rightarrow$ more ATP.
4. Any two: yeast makes **ethanol**, mammals make **lactate**; yeast **releases CO_2** , mammals don't; yeast uses **two steps** (pyruvate $\rightarrow$ ethanal $\rightarrow$ ethanol), mammals **one** (pyruvate $\rightarrow$ lactate); in yeast the hydrogen acceptor is **ethanal**, in mammals **pyruvate**; lactate fermentation is **reversible**, ethanol fermentation is not.
5. $\frac{1}{4} = 0.25 \text{ min}^{-1}$ and $\frac{1}{10} = 0.1 \text{ min}^{-1}$; the rate with 5% glucose is 2.5 times faster. More glucose $\rightarrow$ more enzyme–substrate complexes $\rightarrow$ more **dehydrogenation** per minute, so the methylene blue is **reduced** (decolourised) sooner.

Past questions to try

- [9700/42/M/J/25 Q1](#): the carriers of the ETC, ATP synthase, and the effect of cyanide.
- [9700/42/F/M/25 Q1](#): energy values, the respirometer, calculating an RQ and interpreting an RQ graph.
- [9700/43/O/N/23 Q5](#): comparing the RQs of four substrates and comparing fermentation in yeast and mammals.
- [9700/42/F/M/24 Q6](#): a respirometer experiment on germinating peas, with a graph to plot.