Energy and respiration

A-Level Biology

Why living things need energy

Cells need a steady supply of **energy** 能量, which they get from **respiration** 呼吸作用. Energy is needed for:

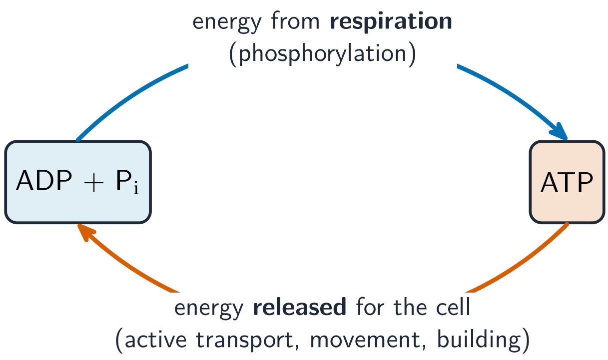
- **active transport** 主动运输 (moving substances against a gradient),
- movement (for example muscle contraction),
- **anabolic** 合成代谢 reactions — the building of large molecules, such as in DNA replication and protein synthesis.

During exercise, muscles need a constant supply of energy released by respiration

ATP — the energy currency

ATP is the molecule that carries energy to where it is needed. It is made from ADP and a phosphate group; when it loses that phosphate again, it releases a small, usable burst of energy. ATP suits this job well, so we call it the **universal energy currency**:

- it releases energy quickly, in small amounts that match a cell's needs.
- it is easily made and re-made, again and again.
- it is small and soluble, so it moves easily around the cell.

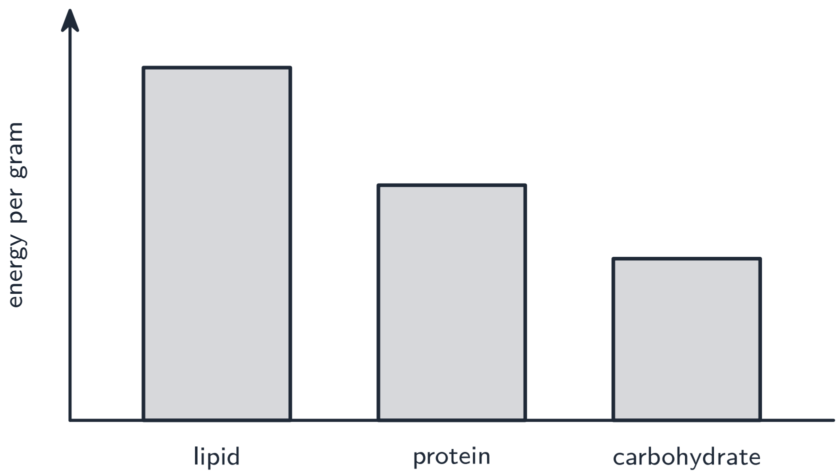


Respiration adds a phosphate to make ATP; the cell breaks it off again to release energy

ATP is made in two ways: by direct transfer of a phosphate group in **phosphorylation** 磷酸化 reactions, and by **chemiosmosis** 化学渗透 across the membranes of **mitochondria** 线粒体 and chloroplasts.

Respiratory substrates and RQ

A **respiratory substrate** 呼吸底物 is a molecule that is broken down to release energy. Per gram, **lipids** release the most energy (they have the most hydrogen), proteins are next, and carbohydrates the least.



Lipids release the most energy per gram, then proteins, then carbohydrates

The **respiratory quotient** 呼吸商 (RQ) compares the gases exchanged:

$$RQ = \frac{\text{molecules of carbon dioxide produced}}{\text{molecules of oxygen taken in}}$$

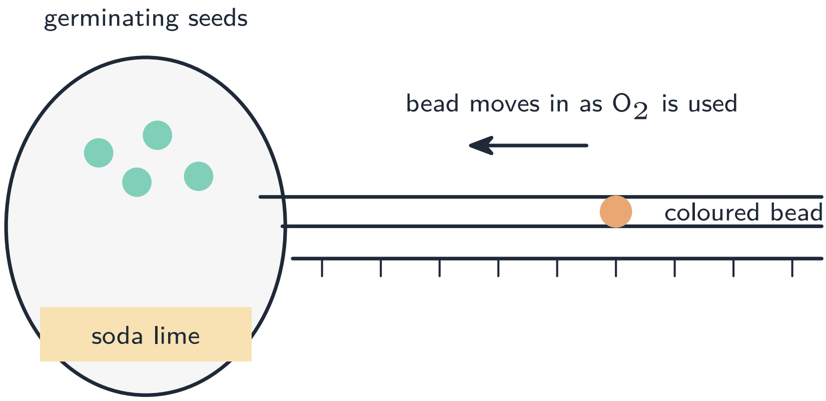
You can work out the RQ from a respiration equation. Carbohydrates give an RQ of about 1.0, lipids about 0.7 and proteins about 0.9.

Worked example. Find the RQ for the aerobic respiration of glucose: $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$.

$$RQ = \frac{CO_2 \text{ produced}}{O_2 \text{ taken in}} = \frac{6}{6} = 1.0.$$

This is why an RQ near 1.0 suggests the organism is respiring carbohydrate; a lower RQ (about 0.7) suggests it is using lipid, which needs more oxygen per molecule of CO_2.

A **respirometer** 呼吸计 measures the **oxygen** 氧气 taken in by living things, such as **germinating** 萌发 seeds or small **invertebrates** 无脊椎动物, and is used to find their RQ.

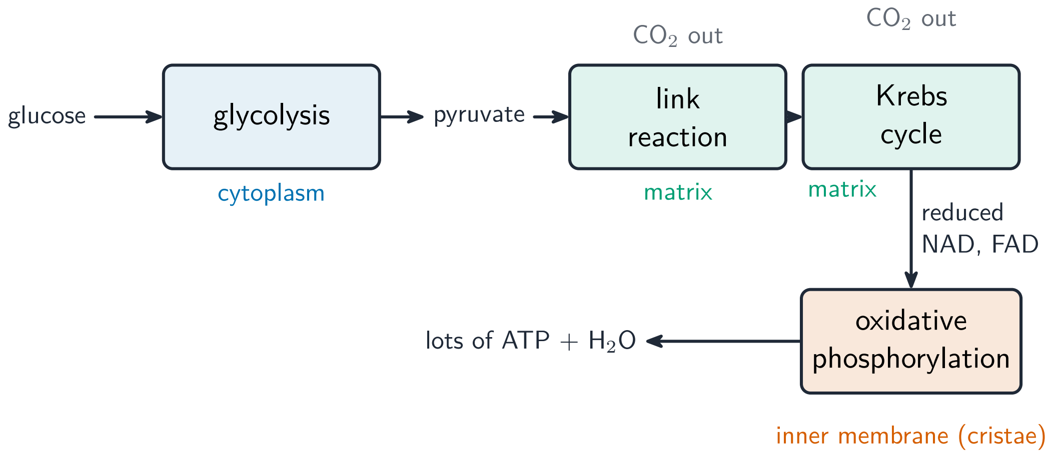


The soda lime absorbs the CO_2 given off, so the gas volume falls only by the oxygen used — and the bead moves in by that amount

Aerobic respiration: the four stages

Aerobic 有氧 respiration (with oxygen) has four stages, each in a set place in the cell:

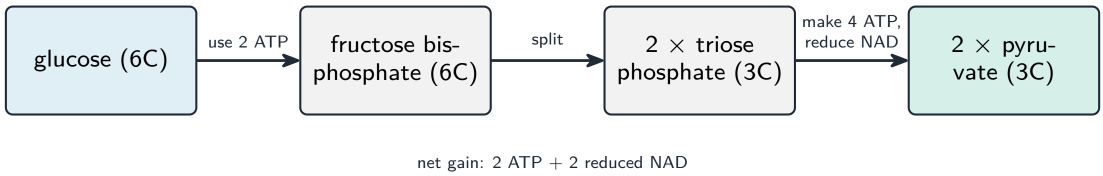
Stage	Where it happens
glycolysis 糖酵解	the **cytoplasm** 细胞质
link reaction 连接反应	the **matrix** 基质 of the mitochondria
Krebs cycle 克雷布斯循环	the matrix of the mitochondria
oxidative phosphorylation 氧化磷酸化	the inner membrane of the mitochondria



The four stages and where each happens; reduced NAD and FAD carry hydrogen to the inner membrane where most ATP is made

Glycolysis

Glucose 葡萄糖 (6 carbons) is first phosphorylated, using 2 ATP, to form fructose bisphosphate (6C). This 6C molecule is split into two triose phosphate molecules (3C each). These are then **oxidised** 氧化 to **pyruvate** 丙酮酸 (3C). Glycolysis makes a net gain of 2 ATP and some **reduced** 还原 NAD (NAD is a **coenzyme** 辅酶, a helper molecule).



Glycolysis spends 2 ATP to start but makes 4, so the net gain is 2 ATP (plus reduced NAD) — and it needs no oxygen

The link reaction

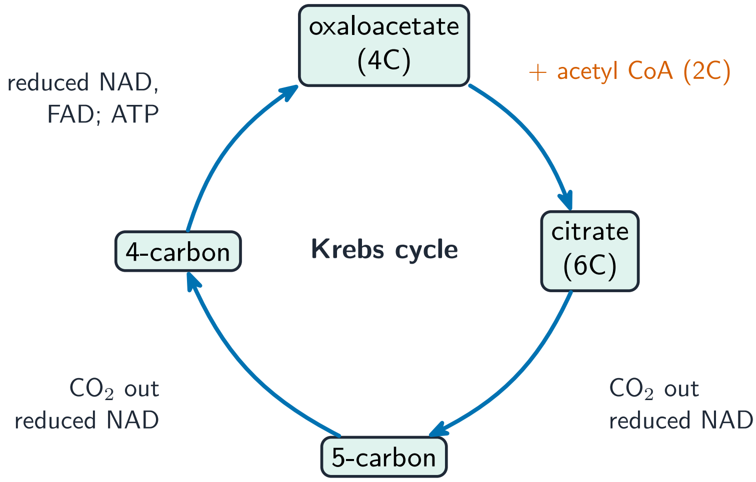
When oxygen is available, pyruvate enters the mitochondria. There each pyruvate loses a **carbon dioxide** 二氧化碳 and is turned into a 2-carbon **acetyl** 乙酰基 group. This group is carried by **coenzyme A** 辅酶 A to form acetyl coenzyme A. Some carbon dioxide is released and NAD is reduced.

The Krebs cycle

The 2C acetyl group joins a 4-carbon molecule, **oxaloacetate** 草酰乙酸, to make a 6-carbon molecule, **citrate** 柠檬酸. Citrate is then changed back to oxaloacetate in a series of small steps, ready to accept the next acetyl group. During these steps:

- **decarboxylation** 脱羧 removes carbon as carbon dioxide.
- **dehydrogenation** 脱氢 removes hydrogen, which **reduces** the coenzymes NAD and FAD.

The reduced NAD and FAD then carry the hydrogen to the carriers in the inner mitochondrial membrane.

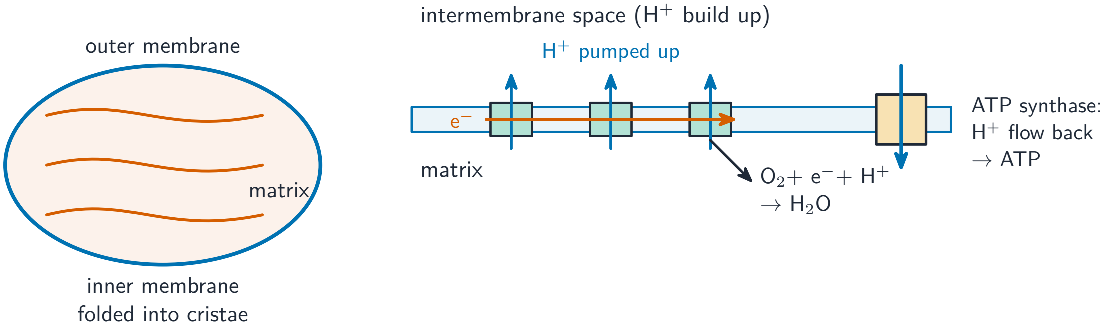


Each turn releases carbon dioxide (decarboxylation) and reduced NAD and FAD (dehydrogenation)

Oxidative phosphorylation

This stage makes most of the ATP:

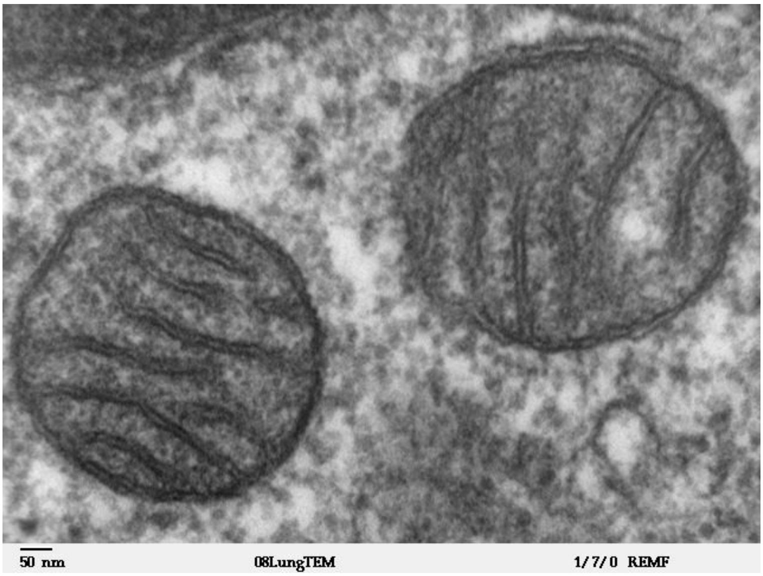
1. the hydrogen atoms split into **protons** 质子 and energetic **electrons** 电子.
2. the electrons pass along the **electron transport chain** 电子传递链, releasing energy as they go.
3. this energy is used to pump protons across the inner membrane.
4. the protons flow back into the matrix through a channel called **ATP synthase** ATP 合酶. This flow provides the energy to make ATP (this is chemiosmosis).
5. **oxygen** is the final electron acceptor: it joins with electrons and protons to form water.



Electrons pump protons (H^+) into the intermembrane space; they flow back through ATP synthase to make ATP (chemiosmosis)

The structure of mitochondria

The inner membrane is folded into **cristae 嵴**, giving a large surface for the electron transport chain and ATP synthase. The matrix inside holds the substances and helpers for the link reaction and the Krebs cycle.

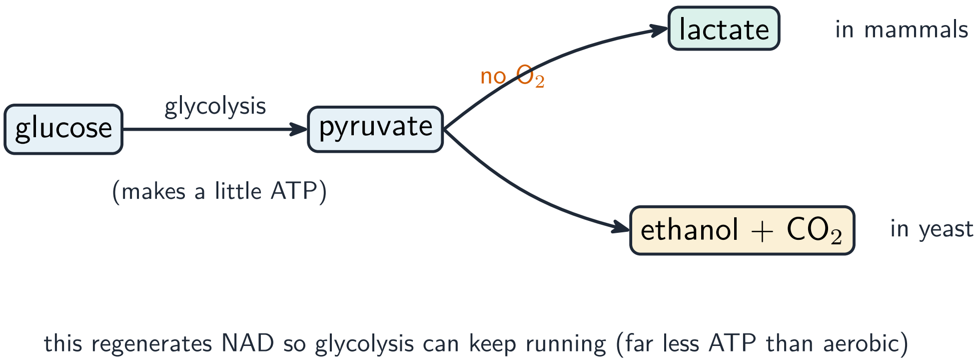


Two real mitochondria, photographed with an electron microscope. The dark stripes crossing the inside are the cristae — all that folding is what makes the surface for the electron transport chain so large

Anaerobic respiration

When there is no oxygen, only glycolysis can run. To keep glycolysis going, the cell must use up the reduced NAD. This happens by **fermentation** 发酵:

- in mammals, pyruvate is turned into **lactate** 乳酸 (lactate fermentation). The lactate is later broken down when oxygen returns.
- in **yeast** 酵母, pyruvate is turned into **ethanol** 乙醇 and carbon dioxide (ethanol fermentation).

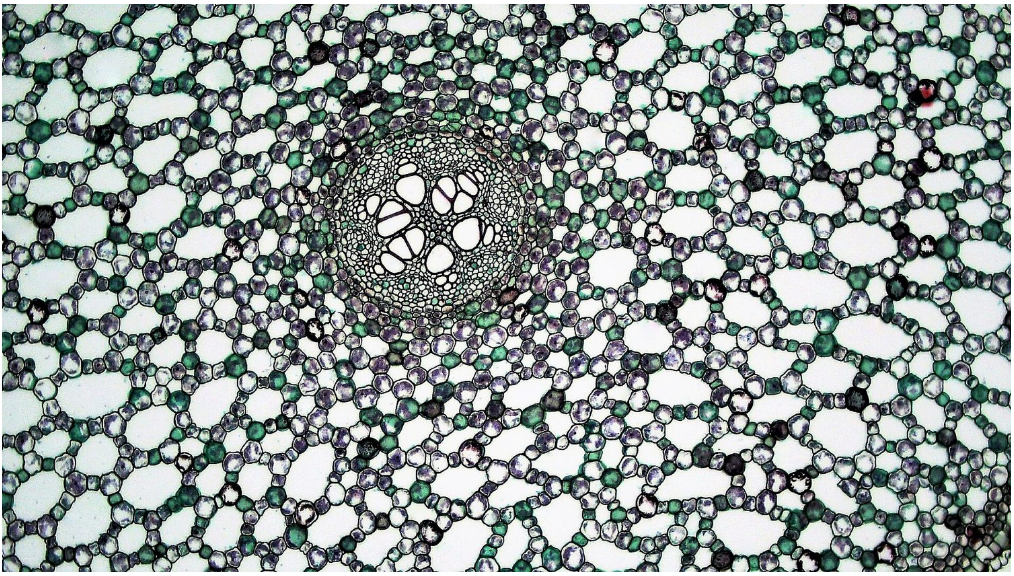


Without oxygen, pyruvate becomes lactate (mammals) or ethanol (yeast); this regenerates NAD for glycolysis

Anaerobic 无氧 respiration gives far less energy than aerobic respiration. Aerobic respiration also runs the Krebs cycle and oxidative phosphorylation, which release a lot more ATP, while anaerobic respiration gains only the small amount from glycolysis.

Rice and waterlogged roots

Rice can grow with its roots under water, where there is little oxygen. It is adapted in three ways: it develops **aerenchyma** 通气组织 (air-filled spaces) in the roots to carry air down; the roots use ethanol fermentation to keep making some ATP; and the stems grow faster to reach the air above the water.



A root of a plant that grows in water, seen in cross-section. The big white gaps are the aerenchyma — connected air channels that let oxygen diffuse all the way down to roots sitting in oxygen-poor mud

Investigating the rate of respiration

A redox **indicator** 指示剂 such as DCPIP or methylene blue loses its colour when it gains hydrogen from respiring cells. The faster the colour is lost, the faster the yeast is respiring, so you can test the effect of temperature or substrate concentration. A respirometer can also be used to measure how temperature changes the rate of oxygen uptake.

Exam tips

- State **where** each stage happens and its ATP yield: glycolysis (cytoplasm), link reaction + Krebs (matrix), oxidative phosphorylation (inner membrane, most ATP).
- Explain the roles of **NAD/FAD** (carry hydrogen to the electron transport chain) and of oxygen (the final electron acceptor).

- **RQ** = CO2 produced ÷ O2 used (≈ 1.0 carbohydrate, 0.7 lipid); know how a respirometer measures it.
- Anaerobic respiration gives lactate (animals) or ethanol + CO2 (yeast/plants) and far less ATP (glycolysis only).