Energy & Respiration

A-Level Biology ▪ Topic 12

A-Level Biology

What we will cover

1. ATP – the energy currency
2. Substrates & RQ
3. The four stages
4. Glycolysis
5. Krebs & oxidative phosphorylation
6. Anaerobic respiration

muscles need energy

1 ATP and substrates

ATP – the energy currency

ATP 三磷酸腺苷 stores energy in its terminal phosphate bond. Hydrolysis to ADP + P_i releases a small, usable amount; respiration (and photosynthesis) rebuilds it. It works as a currency because it is small and soluble, so it moves easily around the cell, and because it is easily made and re-made, again and again. The energy pays for **active transport** 主动运输 against a gradient and for **anabolic** 合成代谢 reactions – building large molecules such as in DNA replication and protein synthesis.

> ATP is a short-term, mobile energy currency – not a store. Cells make it as they need it.

Substrates and RQ

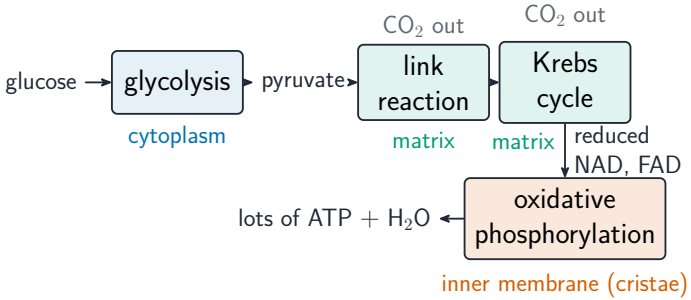
Respiratory quotient 呼吸商 $\mathrm{RQ} = \mathrm{CO_2}$ produced / $\mathrm{O_2}$ used. Carbohydrate ≈ 1.0; lipid ≈ 0.7; protein ≈ 0.9. An RQ above 1 suggests anaerobic respiration as well.

2 Aerobic respiration

The four stages

- **glycolysis** 糖酵解 – in the **cytoplasm** 细胞质
- **link reaction** 连接反应 & **Krebs cycle** 克雷布斯循环 – the **matrix** 基质
- **oxidative phosphorylation** 氧化磷酸化 – the inner membrane

Reduced NAD & FAD carry hydrogen to the membrane.

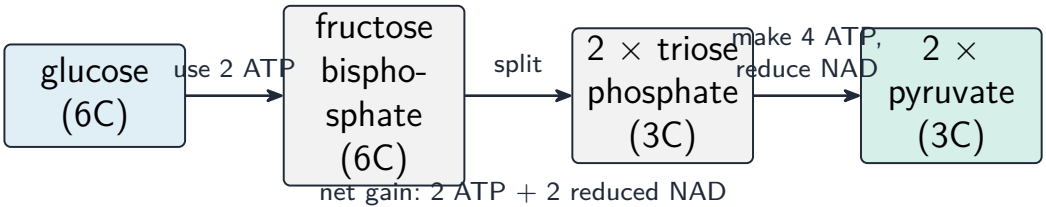


Glycolysis

Glucose 葡萄糖 (6C) is split into two **pyruvate** 丙酮酸 (3C).

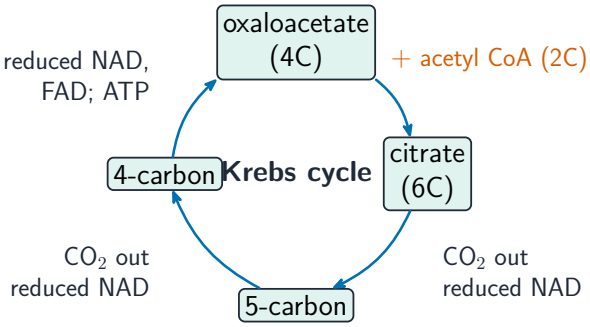
> It spends 2 ATP but makes 4 – a net 2 ATP (plus reduced NAD) – and needs no oxygen.

Glycolysis, in detail



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

Krebs cycle



The link reaction makes **acetyl CoA** 乙酰辅酶 A, which joins the cycle. Each turn:

- **decarboxylation** 脱羧 – releases CO_2
- **dehydrogenation** 脱氢 – reduces NAD & FAD

The link reaction and the Krebs cycle

the link reaction	pyruvate enters the mitochondrion, loses a **carbon dioxide** 二氧化碳, and is joined to **coenzyme A** 辅酶 A
the product	acetyl coenzyme A – two carbons, entering the cycle
the cycle starts	acetyl CoA joins **oxaloacetate** 草酰乙酸 (4C) to form **citrate** 柠檬酸 (6C)
decarboxylation 脱羧	removes carbon as carbon dioxide – twice per turn
dehydrogenation	removes hydrogen onto the **coenzymes** 辅酶 NAD and FAD
per turn	2 CO_2, 3 NADH, 1 $FADH_2$, 1 ATP – and the cycle turns twice per glucose

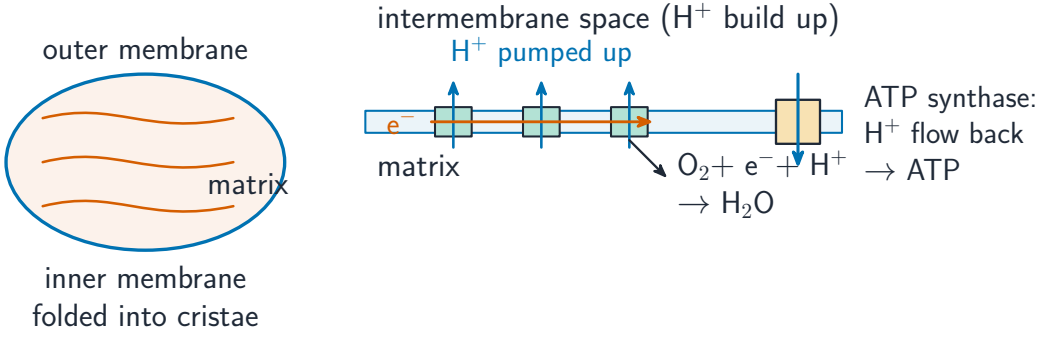
A redox **indicator** 指示剂 such as DCPIP or methylene blue loses its colour as it gains hydrogen from respiring cells. The faster it decolourises, the faster respiration is.

Oxidative phosphorylation

Makes most of the ATP:

- electrons pass the **electron transport chain** 电子传递链, pumping protons
- protons flow back through **ATP synthase** ATP 合酶 (**chemiosmosis** 化学渗透)
- **oxygen** 氧气 is the final electron acceptor → water

Oxidative phosphorylation, in detail



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

3 Anaerobic respiration

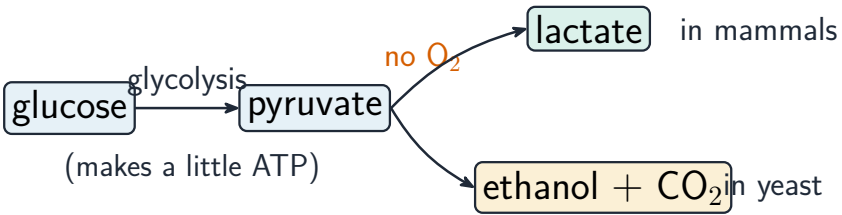
Anaerobic respiration

Without oxygen, only glycolysis runs. **Fermentation** 发酵 regenerates NAD:

- mammals → **lactate** 乳酸
- **yeast** 酵母 → **ethanol** 乙醇 + CO_2

Far less ATP than aerobic respiration.

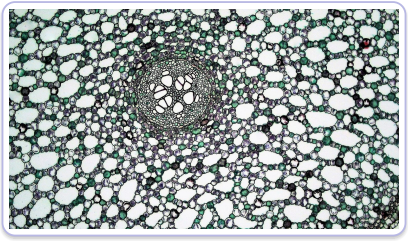
Anaerobic respiration, in detail



this regenerates NAD so glycolysis can keep running (far less ATP than aerobic)

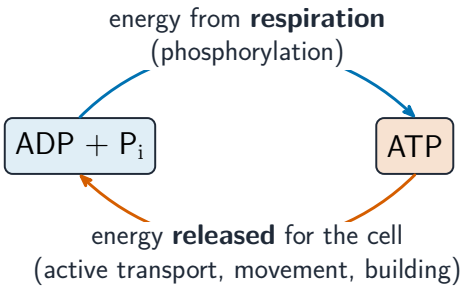
> Without oxygen, only glycolysis runs.

Rice and waterlogged roots



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

ATP – the energy currency, continued



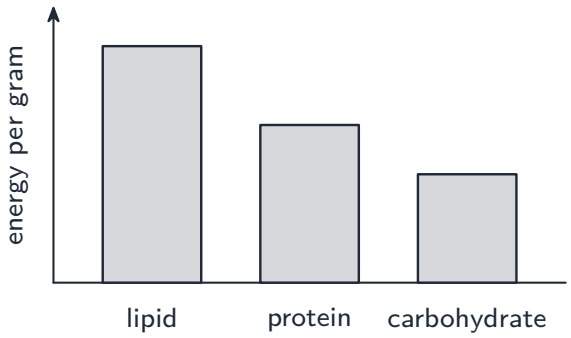
Respiration adds a phosphate to make ATP; the cell breaks it off again to release energy

How ATP is made, and what RQ tells you

phosphorylation 磷酸化	direct transfer of a phosphate group to ADP – substrate-level phosphorylation
chemiosmosis 化学渗透	protons pumped across a membrane flow back through ATP synthase, which makes the ATP
the respiratory quotient 呼吸商	$\text{RQ} = \dfrac{\text{CO}_2 \text{ produced}}{\text{O}_2 \text{ used}}$
the values	carbohydrate 1.0, protein about 0.9, lipid about 0.7
why lipid is lowest	it is the most reduced substrate, so it needs the most oxygen per carbon
above 1.0	means some respiration is anaerobic – CO_2 released with no oxygen used

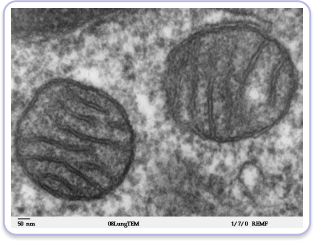
RQ identifies the substrate being respired. Measuring it on **germinating** 萌发 seeds or **invertebrates** 无脊椎动物 in a respirometer is the standard practical.

Respiratory substrates and RQ



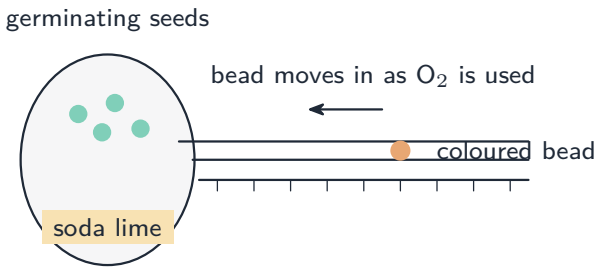
Lipids release the most energy per gram, then proteins, then carbohydrates

The structure of mitochondria



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

Respiratory substrates and RQ, continued



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

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).

4 Recap

Worked example – respiratory quotient

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

- RQ $= \dfrac{CO_2 \text{ produced}}{O_2 \text{ used}}$
- $= \dfrac{6}{6} = 1.0$
- Lipids are less oxidised, so they need more oxygen $\Rightarrow$ RQ ≈ 0.7.
- An RQ above 1.0 means some anaerobic respiration is also happening.

RQ identifies the substrate: carbohydrate 1.0, protein ≈ 0.9, lipid ≈ 0.7. Above $1.0 \Rightarrow$ extra CO_2 from anaerobic respiration.

Topic 12 – key takeaways

1 ATP

the cell's energy currency; ADP + P_i

2 Glycolysis

glucose to pyruvate; net 2 ATP, no O_2

3 Krebs cycle

decarboxylation & dehydrogenation

4 Chemiosmosis

ATP synthase makes most ATP; O_2 accepts e^-

Check yourself

1. Where in the cell does glycolysis happen?
2. What is the net ATP gain from glycolysis?
3. What is the final electron acceptor?
4. What does yeast make in anaerobic respiration?

Answers **1.** the cytoplasm **2.** 2 ATP **3.** oxygen **4.** ethanol and CO_2