

# Energy and respiration

A-Level Biology 9700 · Topic 12 revision notes

Everything from the 4 lessons of this topic on a few pages: the key idea of each lesson, the diagram to remember, the points to learn and the traps examiners set. Read it, cover it, test yourself.

1. Energy, ATP and respiratory quotients

2. Mitochondria, glycolysis and the Krebs cycle

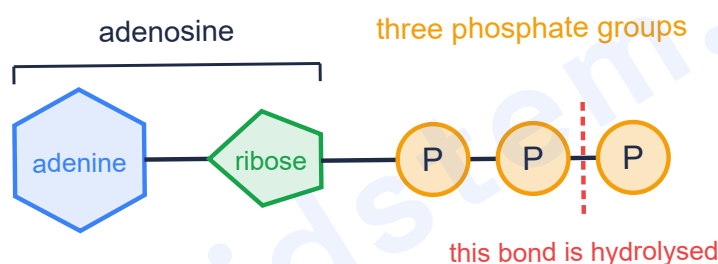
3. Oxidative phosphorylation and chemiosmosis

4. Anaerobic respiration, rice and measuring respiration rate

# 1 Energy, ATP and respiratory quotients

## Syllabus 12.1

Living organisms need energy for **active transport**, **movement** and **anabolic reactions** such as DNA replication and protein synthesis. Respiration transfers energy from substrates to **ATP**, the universal energy currency: its hydrolysis to ADP and phosphate releases energy in small, usable amounts, in one step, wherever it is needed. ATP is made by **substrate-linked phosphorylation** and by **chemiosmosis** in the membranes of mitochondria and chloroplasts. Lipids release about twice as much energy per gram as carbohydrates or proteins because they contain more hydrogen. The **respiratory quotient** (RQ) is the number of molecules of  $\text{CO}_2$  produced divided by the number of molecules of  $\text{O}_2$  taken in: about 1.0 for carbohydrate, 0.7 for lipid and 0.9 for protein, and it can be measured with a **respirometer**.



one step, one enzyme: about  $30.5 \text{ kJ mol}^{-1}$  released

used for active transport, movement and anabolic reactions

remade by substrate-linked phosphorylation and chemiosmosis

Fig. 1: ATP is a phosphorylated nucleotide; hydrolysis of the last phosphate releases energy in one small step

## Energy, currency, fuel.

- ✓ **Energy for:** active transport, movement, anabolic reactions.
- ✓ **ATP:** small amounts, one step, soluble, quickly remade, universal.
- ✓ **RQ** =  $\text{CO}_2 \text{ produced} \div \text{O}_2 \text{ taken in}$ : 1.0 carbohydrate, 0.7 lipid, 0.9 protein.
- ✓ **Respirometer:** KOH tube =  $\text{O}_2$  uptake; water tube =  $\text{O}_2 - \text{CO}_2$ .

## Watch out!

Energy is not "stored in the bond" and released by breaking it.

Breaking any bond needs energy. Energy is released by the whole hydrolysis reaction, because the products (ADP and phosphate) are more stable than ATP and water. Write "hydrolysis of ATP releases energy".

RQ is  $\text{CO}_2$  divided by  $\text{O}_2$ , never the other way up. A quick check: lipids must come out below 1, because they need extra oxygen to oxidise all that hydrogen to water.

A gauze platform keeps the organisms off the KOH, which is corrosive. And in tube B a liquid that does not move does not mean no respiration: it means the volume of  $\text{CO}_2$  given out equals the volume of  $\text{O}_2$  taken in (RQ = 1).

## 2 Mitochondria, glycolysis and the Krebs cycle

### Syllabus 12.2

Aerobic respiration has four stages: **glycolysis** in the cytoplasm, the **link reaction** and **Krebs cycle** in the mitochondrial matrix, and **oxidative phosphorylation** on the inner mitochondrial membrane. In glycolysis, glucose is phosphorylated using 2 ATP to fructose 1,6-bisphosphate (6C), which splits into two triose phosphates (3C); these are oxidised to pyruvate (3C), giving a net 2 ATP and 2 reduced NAD. If oxygen is available, pyruvate enters the mitochondrion. In the link reaction it is **decarboxylated** and **dehydrogenated**, and the 2C acetyl group is carried by **coenzyme A**. In the Krebs cycle, **oxaloacetate** (4C) accepts the acetyl group to form **citrate** (6C), which is converted back to oxaloacetate in small steps, releasing  $\text{CO}_2$  and reducing NAD and FAD.

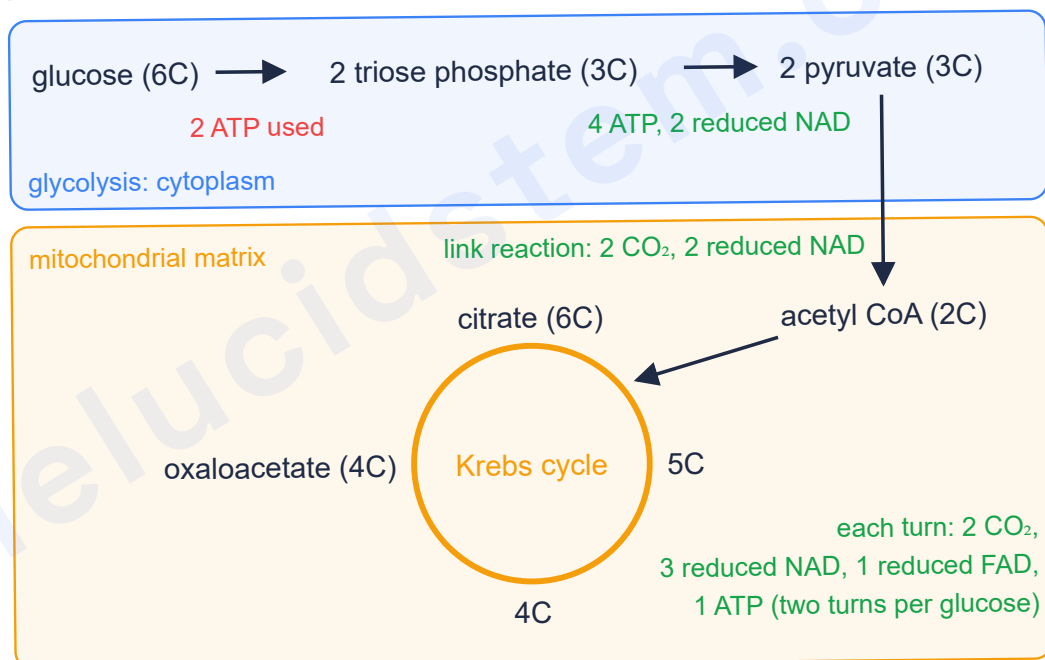


Fig. 1: glycolysis in the cytoplasm feeds the link reaction and Krebs cycle in the matrix (numbers per glucose unless stated)

### Place, carbon, hydrogen.

- ✓ **Cytoplasm:** glycolysis. **Matrix:** link reaction and Krebs cycle. **Inner membrane:** oxidative phosphorylation.
- ✓ **Glycolysis:** phosphorylation, lysis, oxidation to pyruvate; net 2 ATP, 2 reduced NAD.
- ✓ **Link:** decarboxylation + dehydrogenation; coenzyme A carries the acetyl group.
- ✓ **Krebs:**  $4C + 2C \rightarrow 6C$ , back to  $4C$ ; per turn 2  $CO_2$ , 3 reduced NAD, 1 reduced FAD, 1 ATP.

### Watch out!

Glycolysis does not happen in the mitochondrion. Glucose never enters it: only pyruvate does, and only when oxygen is available.

Glycolysis makes 4 ATP but uses 2, so the **net** yield is 2 ATP per glucose. Questions that ask for the net yield expect 2, not 4.

The Krebs cycle itself makes very little ATP. Its main job is to supply reduced NAD and reduced FAD, whose hydrogen drives oxidative phosphorylation on the inner membrane.

### 3 Oxidative phosphorylation and chemiosmosis

#### Syllabus 12.2

Reduced NAD and reduced FAD carry hydrogen from glycolysis, the link reaction and the Krebs cycle to carriers in the **inner mitochondrial membrane**. There each hydrogen atom splits into a **proton** and an **energetic electron**. The electrons pass along the **electron transport chain**, releasing energy that is used to transfer protons from the matrix into the **intermembrane space**. The protons return to the matrix by **facilitated diffusion through ATP synthase**, providing the energy to make ATP from ADP and phosphate: this is **chemiosmosis**. **Oxygen is the final electron acceptor**; it combines with electrons and protons to form water. Without oxygen the chain stops, and so do the Krebs cycle and link reaction.

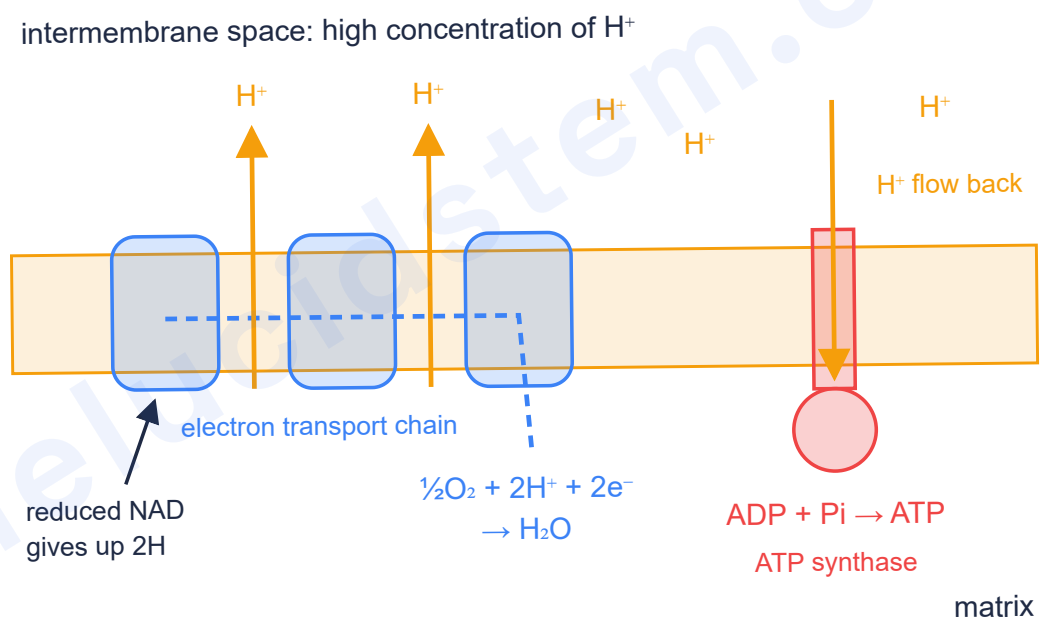


Fig. 1: the electron transport chain pumps protons into the intermembrane space; they flow back through ATP synthase

### *Carry, split, pump, flow.*

- ✓ **NAD and FAD** carry hydrogen to the inner membrane.
- ✓ **H splits:** protons and energetic electrons; electrons go along the chain.
- ✓ **Energy released** pumps protons into the intermembrane space.
- ✓ **Protons flow back** through ATP synthase; **oxygen** accepts the electrons, forming water.

### *Watch out!*

Electrons move along the chain; protons are pumped across the membrane. Do not write that electrons pass through ATP synthase: it is protons that flow through it.

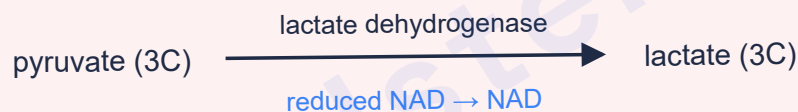
Oxygen accepts **electrons** (and protons) to form water. It does not "make ATP" or "react with glucose" directly, and the  $\text{CO}_2$  released in respiration does not come from this oxygen.

## 4 Anaerobic respiration, rice and measuring respiration rate

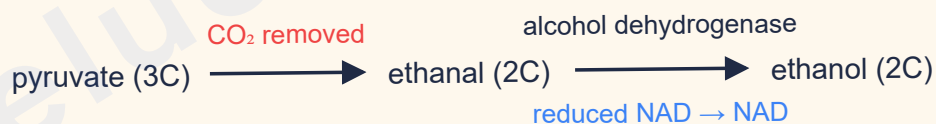
### Syllabus 12.2

In anaerobic conditions there is no final electron acceptor, so oxidative phosphorylation, the Krebs cycle and the link reaction stop. Glycolysis can continue only if reduced NAD is reoxidised another way. In mammals, pyruvate accepts the hydrogen and becomes **lactate** (**lactate fermentation**); in yeast and plant roots, pyruvate is decarboxylated to ethanal, which accepts the hydrogen and becomes **ethanol** (**ethanol fermentation**). Either way only the **2 ATP** from glycolysis are made per glucose, against about 30 or more aerobically, because most of the energy stays in lactate or ethanol. **Rice** copes with flooded roots through aerenchyma, ethanol fermentation and fast stem growth. **Redox indicators** such as methylene blue and DCPIP are decolourised as they accept hydrogen from respiring yeast, so the time taken measures the rate of respiration.

#### lactate fermentation (mammals)



#### ethanol fermentation (yeast, plant roots)



NAD returns to glycolysis: 2 ATP per glucose  
aerobic respiration: about 30 or more ATP per glucose

Fig. 1: lactate and ethanol fermentation both reoxidise reduced NAD so that glycolysis can continue

## Regenerate NAD, measure the rate.

- ✓ **Lactate:** pyruvate + reduced NAD → lactate + NAD (mammals).
- ✓ **Ethanol:** pyruvate → ethanal + CO<sub>2</sub> → ethanol (yeast, rice roots).
- ✓ **Yield:** 2 ATP anaerobic, about 30 or more aerobic.
- ✓ **Redox indicator** decolourises when reduced; rate =  $1 \div \text{time}$ .

## Watch out!

Anaerobic respiration does not "make lactate to release energy".

The ATP comes only from glycolysis; making lactate or ethanol just reoxidises NAD. Say so in your answer.

Aerenchyma lets oxygen diffuse to the roots; it is not a tissue that makes oxygen, and rice roots do not take oxygen from the water by active transport.

A decolourised indicator has been **reduced**, not oxidised: it has gained hydrogen. And use a comparison of rates ( $1 \div \text{time}$ ), not times, when you describe the effect of temperature.