Respiration

Glycolysis, the link reaction, the Krebs cycle, oxidative phosphorylation and chemiosmosis, anaerobic respiration, lactate, respiratory quotient, and the related core practicals.

Overview

Aerobic respiration splits the **respiratory substrate** (glucose), releasing **carbon dioxide** as a waste product, and reunites the **hydrogen** with **atmospheric oxygen** to form **water**, releasing large amounts of energy, which is used to make **ATP**.

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O \qquad \text{(about 30 ATP per glucose)}$$

Respiration is a **stepped process**: each step is controlled by a specific **intracellular enzyme**, so energy is released gradually and **less is lost as heat**.

Stage	Site	Needs oxygen?
Glycolysis	Cytoplasm	No
Link reaction	Mitochondrial matrix	Indirectly (aerobic)
Krebs cycle	Mitochondrial matrix	Indirectly (aerobic)
Oxidative phosphorylation	Inner mitochondrial membrane (cristae)	Yes

Glycolysis

In the **cytoplasm**, one **glucose** (6C) is converted to two **pyruvate** (3C).

1. **Phosphorylation**: glucose is phosphorylated using **2 ATP**, making it more reactive and trapping it in the cell, to give **hexose bisphosphate**.
2. The hexose bisphosphate splits into two **triose phosphate** molecules.
3. Each triose phosphate is **oxidised** (loses hydrogen), and the hydrogen is picked up by **NAD**, making **reduced NAD**.
4. ATP is made by **substrate-level phosphorylation** (4 ATP made, so a **net gain of 2 ATP**), and **2 pyruvate** form.

Net products per glucose: **2 ATP, 2 reduced NAD, 2 pyruvate**.

The link reaction

Pyruvate enters the **mitochondrial matrix** by active transport. Each pyruvate is **decarboxylated** (loses CO_2) and **dehydrogenated** (loses hydrogen to **NAD**) and joined to **coenzyme A**, forming **acetyl**

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coenzyme A (2C). Per glucose: **2 acetyl CoA, 2 CO_2, 2 reduced NAD**.

The Krebs cycle

In the **matrix**, **acetyl CoA** (2C) combines with a 4C compound to form a **6C** compound. Through a cycle of reactions:

- **Decarboxylation** releases **2** CO_2 per turn,
- **Dehydrogenation** produces **3 reduced NAD** and **1 reduced FAD**,
- **1 ATP** is made by **substrate-level phosphorylation**,
- The 4C compound is **regenerated**.

Per glucose (two turns): **6 reduced NAD, 2 reduced FAD, 2 ATP, 4** CO_2.

Oxidative phosphorylation

Occurs on the **inner mitochondrial membrane (cristae)**, which has a large surface area.

1. **Reduced NAD and FAD** deliver their hydrogen atoms to the **electron transport chain**, splitting into protons (H^+) and **electrons**.
2. Electrons pass along a chain of **carriers**, releasing **energy** at each step.
3. The energy is used to **pump protons** from the matrix into the **intermembrane space**, creating a **proton gradient**.
4. Protons flow back **down their gradient** through **ATP synthase** (**chemiosmosis**), which **catalyses the synthesis of ATP** from ADP and P_i.
5. At the end of the chain, **oxygen** is the **final electron acceptor**. It combines with electrons and protons to form **water**.

> **Without oxygen, the electron transport chain stops, the carriers stay reduced, NAD and FAD are not regenerated, so the Krebs cycle and link reaction stop. Only glycolysis can continue, by using anaerobic pathways.**

Anaerobic respiration

Without oxygen, glycolysis is the only source of ATP. **NAD must be regenerated** for glycolysis to continue.

- **In animals**: pyruvate is **reduced to lactate** using the hydrogen from reduced NAD (catalysed by lactate dehydrogenase), regenerating NAD. Only **2 ATP** per glucose.
- **In yeast** (and plants): pyruvate is **decarboxylated** to **ethanal**, which is reduced to **ethanol**, regenerating NAD.

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What happens to lactate

Lactate builds up during exercise and can cause muscle fatigue. After exercise, it is carried to the **liver**, where it is **converted back to pyruvate** and then to glucose or oxidised to CO_2 and water in aerobic respiration. This needs extra oxygen, the **oxygen debt**, which is why breathing stays fast after exercise.

Respiratory quotient (RQ)

$$RQ = \frac{\text{volume (or moles) of } CO_2 \text{ produced}}{\text{volume (or moles) of } O_2 \text{ consumed}}$$

Substrate	RQ
Carbohydrate (glucose)	**1.0**
Lipid	About **0.7**
Protein	About 0.9
Anaerobic respiration in yeast	Greater than 1 (producing CO_2 with no O_2)

The RQ shows which substrate is being respired and whether anaerobic respiration occurs.

Core practicals

Core Practical 15: redox indicator in yeast

An artificial hydrogen carrier (**methylene blue** or **DCPIP** or **TTC**) replaces NAD in the dehydrogenation reactions, and changes colour when it **accepts hydrogen** (e.g. methylene blue goes from blue to colourless). Mix yeast with glucose and the indicator, and measure the **time** to the colour change at different temperatures or with different substrates. A **shorter time** shows a **faster rate** of respiration. Include a control with boiled yeast.

Core Practical 16: respirometer and RQ

A **simple respirometer** (a sealed tube with germinating seeds or small invertebrates and a **capillary tube** with a drop of coloured liquid) measures **oxygen uptake**.

- **Potassium hydroxide (or soda lime)** absorbs the CO_2, so the movement of the fluid shows the volume of O_2 **used**.
- Without the absorber, the net change shows O_2 used minus CO_2 produced, from which the **RQ** is calculated.
- **Control**: keep the temperature constant (a water bath), and use a **control tube** with an inert material (glass beads) to correct for changes in air pressure and temperature.
- Rate of O_2 uptake = volume change / time (and per gram of mass).

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