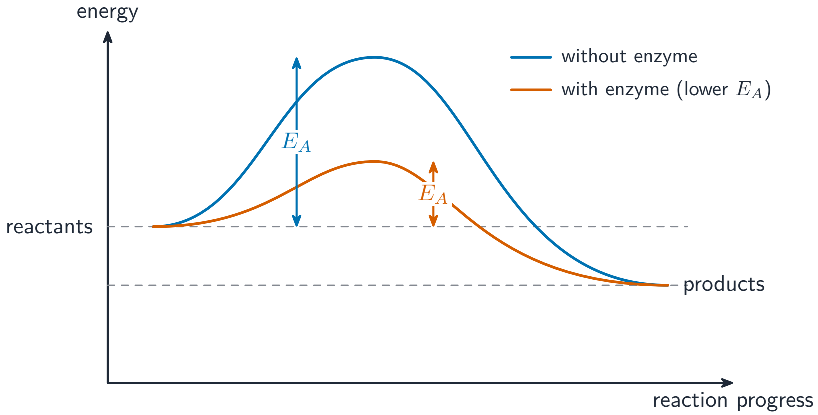
Cellular Energetics

AP Biology

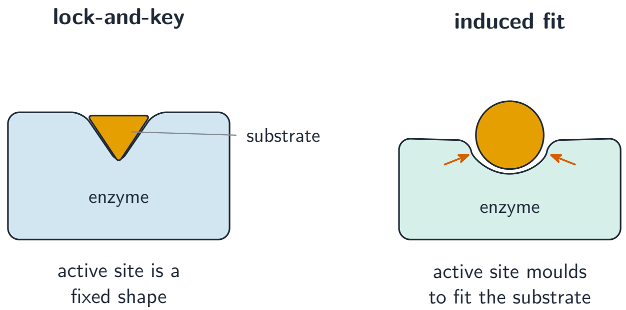
Enzymes as Biological Catalysts

Biological washing powder uses enzymes that work at moderate temperature and pH

An **enzyme** 酶 is a protein **catalyst** 催化剂 that speeds a reaction by lowering its **activation energy** 活化能, without being used up. Each enzyme has an **active site** 活性位点 that binds a specific **substrate** 底物 (the "lock and key" or induced fit), so enzymes are highly specific. They do not change whether a reaction is favorable – only how fast it goes.



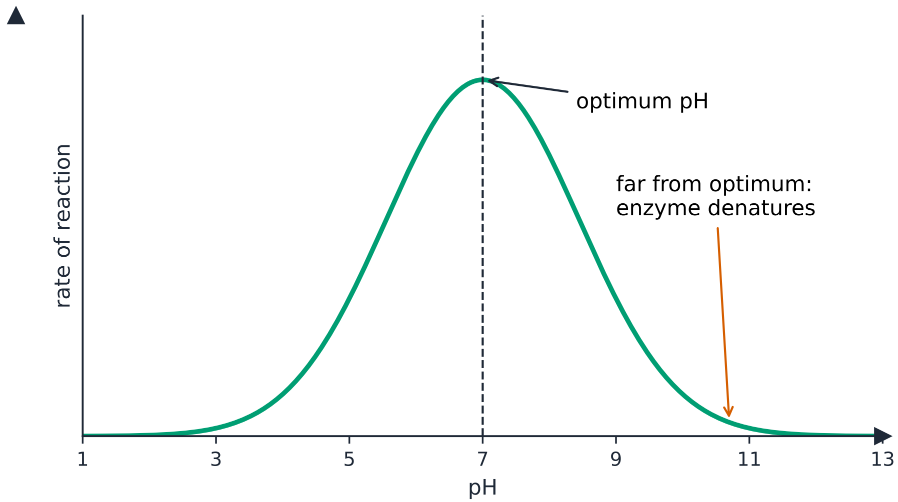
An enzyme lowers the activation energy of a reaction



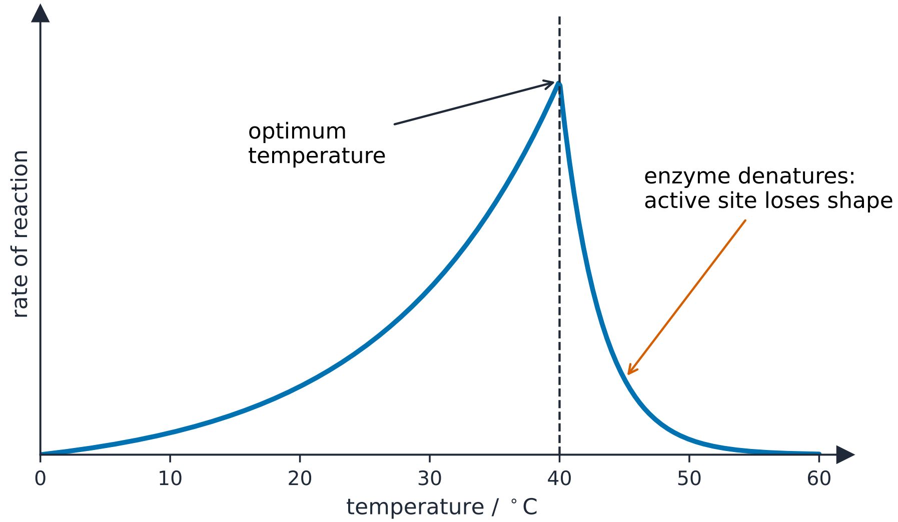
The lock-and-key and induced-fit models of enzyme action

Environmental Impacts on Enzyme Function

Enzyme activity depends on conditions. Each enzyme has an **optimal** temperature and pH; beyond it, the protein **denatures** 变性 (loses shape) and stops working. **Substrate concentration** raises the rate until the enzyme saturates. **Inhibitors** 抑制剂 slow enzymes – **competitive** ones block the active site, **noncompetitive** ones bind elsewhere and change the shape.



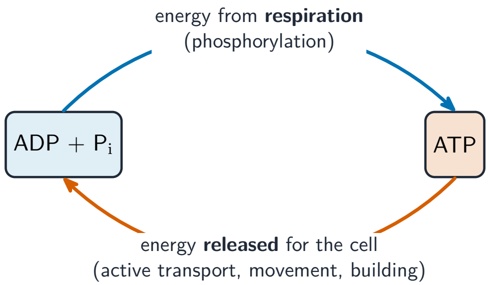
Each enzyme has an optimum pH



Rate rises to an optimum temperature, then falls as the enzyme denatures

Cellular Energy and ATP

ATP (adenosine triphosphate) is the cell's energy currency. Energy is stored in its phosphate bonds; breaking off a phosphate (ATP → ADP) **releases** energy to power cellular work, and reattaching one stores energy. Cells constantly recycle ATP, coupling energy-releasing reactions to energy-requiring ones.



The ATP-ADP cycle stores and releases energy

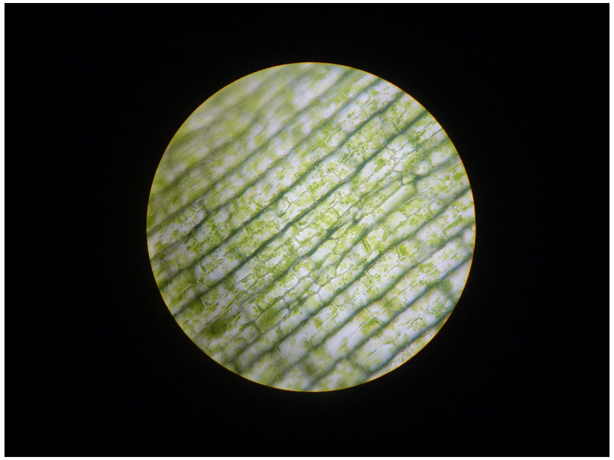
Life and the laws of thermodynamics

A living cell is highly ordered, and that order is often mistaken for a violation of physics. It is not.

- **The first law** 热力学第一定律 says energy is conserved: it changes form but is never created or destroyed. A cell does not make energy — it *transforms* the chemical energy of glucose, or the light energy of the Sun, into the chemical energy of ATP.
- **The second law** 热力学第二定律 says that in any energy transfer, some energy is lost as heat and the **entropy** 熵 of the universe increases. A cell builds order inside itself, but only by releasing more disorder to its surroundings, mostly as heat.

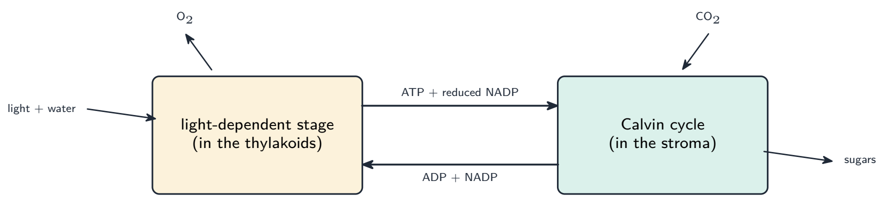
So life requires a **constant input of free energy** 自由能 from outside. This is why an organism cut off from its energy source dies: maintaining order is not free, and the moment the input stops, the ordered system runs down.

Photosynthesis



Chloroplasts fill plant mesophyll cells — the organelles of photosynthesis

Photosynthesis 光合作用 captures light energy to build sugar from CO_2 and water, releasing O_2. It has two stages:



The two stages of photosynthesis are linked by ATP and NADPH

- The **light reactions** (in the thylakoid membranes) use light to make ATP and NADPH and split water, releasing oxygen.
- The **Calvin cycle** 卡尔文循环 (in the stroma) uses that ATP and NADPH to fix CO_2 into sugar.

So light energy becomes chemical energy stored in glucose.

Where the oxygen in the air came from

Photosynthesis did not only feed the first organisms; it changed the planet. Scientific evidence supports the claim that photosynthesis by **prokaryotes** 原核生物 — specifically **cyanobacteria** 蓝细菌 — produced the oxygen that built Earth's **oxygenated atmosphere** 含氧大气.

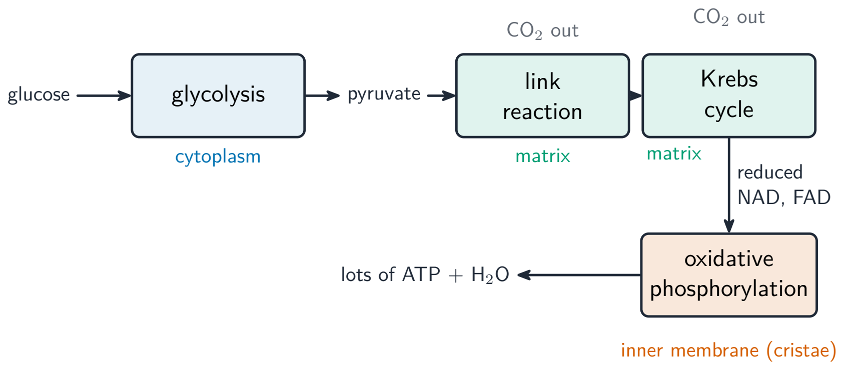
The evidence is physical: **banded iron formations** 条带状铁建造 in rocks about 2.4 billion years old record iron dissolved in the ocean being oxidised and precipitating out, which needs free oxygen. Before that event, called the Great Oxidation Event, the atmosphere held almost none.

Two consequences matter for the rest of the course. Free oxygen made **aerobic respiration** possible, which releases far more ATP per glucose than anaerobic pathways do. And it was lethal to much of the anaerobic life already present, so it counts as one of the largest extinction events in Earth's history — an early example of organisms changing their own environment.

Cellular Respiration

TEM of a mitochondrion: folded inner membrane (cristae) multiplies surface for respiration

Cellular respiration 细胞呼吸 releases the energy in glucose to make ATP, mostly using oxygen. Its stages:



The stages of aerobic respiration and where in the cell they happen

- **Glycolysis** 糖酵解 (in the cytoplasm) splits glucose, making a little ATP.
- The **Krebs cycle** 克雷布斯循环 (mitochondrial matrix) releases CO_2 and loads electron carriers.
- The **electron transport chain** 电子传递链 (inner membrane) uses those electrons to pump protons and make most of the ATP, with oxygen as the final electron acceptor.

Without oxygen, cells use **fermentation** 发酵 to keep glycolysis running, making far less ATP. Photosynthesis and respiration are complementary – the products of one are the reactants of the other.

Worked example. Aerobic respiration of one glucose nets about **2 ATP** from glycolysis, **2 ATP** from the Krebs cycle, and about **28 ATP** from oxidative phosphorylation, for $\approx$ **32 ATP** total. With no oxygen only glycolysis runs, so fermentation nets just **2 ATP** per glucose — roughly 16 times less energy, which is why aerobic pathways dominate in oxygen-rich cells.

Exam tips

- An **enzyme lowers the activation energy** and is not used up; its **active site** is specific to one substrate (lock and key).
- Rate rises with temperature only up to the **optimum** — beyond it the enzyme **denatures** and the rate falls (unlike an ordinary reaction).
- Know the ATP$\leftrightarrow$ADP cycle: breaking a phosphate **releases** energy to power the cell.
- Write the overall equations: photosynthesis **stores** energy (builds glucose); respiration **releases** it (breaks glucose down) — they are opposites.

- Match each stage to its location and whether it needs oxygen.