

5 · Respiration, Internal Environment, Coordination and Gene Technology

Pearson Edexcel · International A-Level · Biology

Inside the body: energy, balance and control

Sprint for a bus and your body performs a symphony: muscles burn glucose faster, the heart doubles its output, ventilation deepens, sweat starts, and the kidney re-tunes its water recovery – all controlled without a conscious thought. This unit follows that machinery: respiration at molecular scale, muscle and heart at tissue scale, nerves and hormones as the controllers, and gene technology as the modern window onto it.

WBI15 Respiration, Internal Environment, Coordination and Gene Technology is the second IA2 unit: 1 hour 45 minutes, 90 marks. It assesses Topic 7 (Respiration, Muscles and the Internal Environment) and Topic 8 (Coordination, Response and Gene Technology), and one 20-mark question is built on a **pre-released scientific article** – you will have studied it in advance.

Respiration: four stages, one purpose

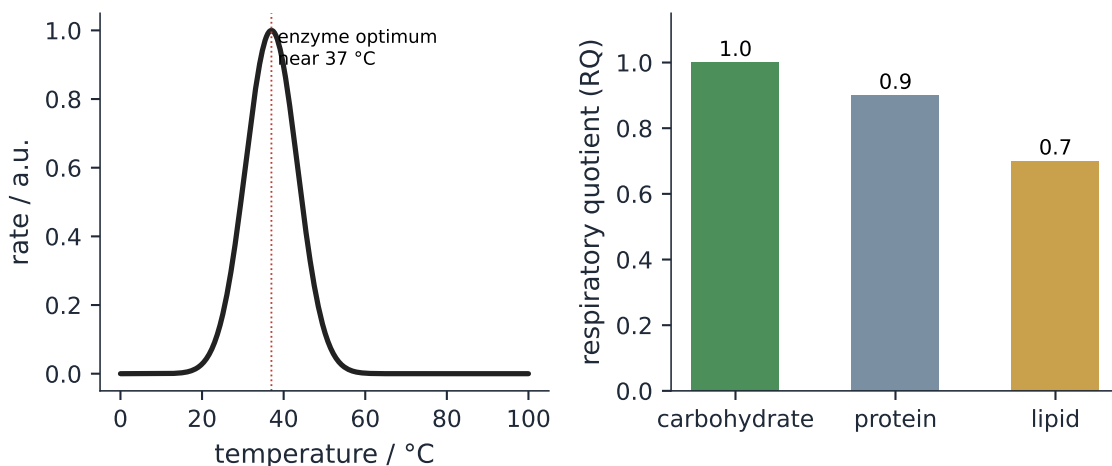
Respiration releases energy in steps, each catalysed by a specific enzyme. Aerobic respiration's summary:



Stage	Where	What happens	Net yield
Glycolysis	cytoplasm	hexose phosphorylated then split; pyruvate formed	2 ATP, 2 reduced NAD
Link reaction	mitochondrial matrix	pyruvate oxidised and decarboxylated to acetyl	1 CO ₂ , 1 reduced NAD per pyruvate
Krebs cycle	matrix	acetyl fully oxidised; substrates regenerate	CO ₂ , ATP, reduced NAD, reduced FAD
Oxidative phosphorylation	cristae	electron transport chain pumps H ⁺ ; chemiosmosis through ATP synthase; O ₂ the final acceptor	most ATP

Anaerobic conditions stop the chain – reduced NAD cannot be recycled – so pyruvate accepts its hydrogen and becomes **lactate** in muscle. After exercise, lactate is carried to the liver and rebuilt into glucose (needing oxygen: the **oxygen debt**).

Respiratory quotient : $RQ = \text{CO}_2 \text{ produced} / \text{O}_2 \text{ consumed}$. Carbohydrate 1.0, protein 0.9, lipid ≈ 0.7 – an organism's RQ reveals what it is burning.



Left, respiration rate peaks at the enzyme optimum near body temperature and collapses as proteins denature. Right, respiratory quotient by substrate.

Worked check. A respirometer shows 60 cm³ CO₂ produced and 60 cm³ O₂ consumed in the same interval: $RQ = 1.0$ – carbohydrate. A germinating seed with RQ 0.7 is burning lipid reserves.

Muscles: the sliding filament

A **tendon** joins muscle to bone; a **ligament** joins bone to bone across a joint; muscles work in antagonistic pairs. A skeletal muscle fibre is a fused, multinucleate cell packed with **myofibrils** of **actin** and **myosin**.

Contraction is the sliding filament cycle: an action potential releases Ca²⁺; calcium exposes actin's binding sites; the energised myosin head (its ATP split) attaches, pulls the actin, then detaches when new ATP binds – thousands of heads per second, each stroke a few nanometres.

Fast-twitch fibres: thick, few mitochondria, quick and powerful, fatigue fast (sprinting). Slow-twitch: many mitochondria, rich blood supply, myoglobin – endurance.

The heart's own clock and the medulla's override

Cardiac muscle is **myogenic** : it beats without nerve input. The **sino-atrial node** sets the pace; the wave spreads over the atria to the **atrio-ventricular node**, then along Purkyne fibres to the ventricles – atria contract first, ventricles a fraction later.

The cardiovascular control centre and the ventilation centre in the **medulla oblongata** adjust both systems to demand: chemical receptors sense CO₂ and pH, baroreceptors pressure.

$$\text{cardiac output} = \text{stroke volume} \times \text{heart rate}$$

Worked check. At rest: $70 \text{ cm}^3 \times 72 \text{ min}^{-1} \approx 5.0 \text{ dm}^3 \text{ min}^{-1}$. During exercise: $120 \text{ cm}^3 \times 150 \text{ min}^{-1} = 18 \text{ dm}^3 \text{ min}^{-1}$ – the table the exam loves. Ventilation rises in step, read from spirometer traces (tidal volume $\times$ breathing rate = **minute ventilation**).

Homeostasis and feedback

Homeostasis holds the internal environment in dynamic equilibrium – not stillness, but variables oscillating inside narrow limits. **Negative feedback** corrects deviations in either direction (the thermostat pattern); **positive feedback** amplifies them (a self-reinforcing loop, as voltage-gated sodium channels open during an action potential).

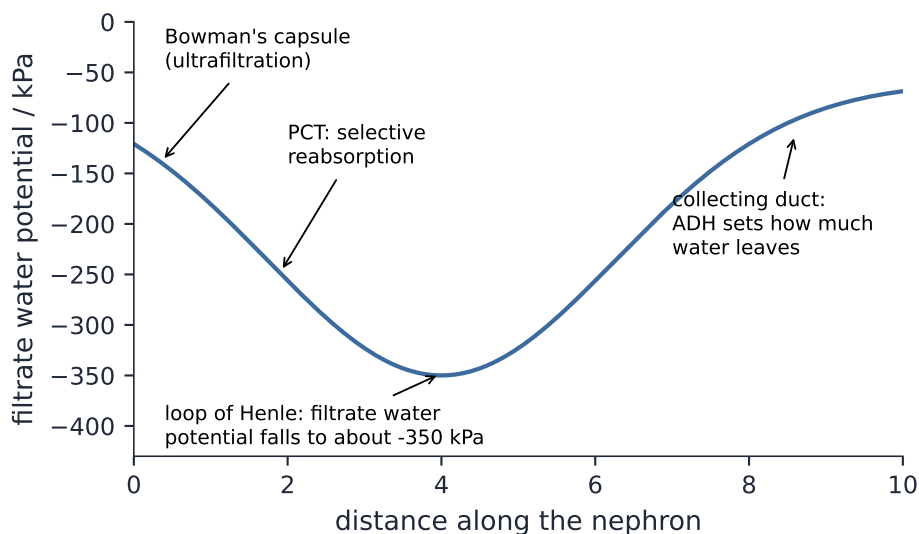
Thermoregulation runs through the **hypothalamus** : heat loss by vasodilation and sweating; heat conservation by vasoconstriction, shivering and hair erection.

Adrenaline prepares the fight-or-flight response – heart rate, blood glucose and airways all respond together.

The kidney: filter, reabsorb, fine-tune

Blood enters the **nephron** 's glomerulus at high pressure – the afferent arteriole is wider than the efferent – and small molecules are forced through podocytes and the basement membrane into **Bowman's capsule** (ultrafiltration: everything except cells and large proteins). The **proximal convoluted tubule**

reabsorbs all glucose and amino acids plus most salts and water (active transport then osmosis). The **loop of Henle** builds a water-potential gradient down the medulla by countercurrent multiplication. The **collecting duct** makes the final decision: **ADH** is made in the hypothalamus and released by the posterior pituitary; it promotes aquaporin insertion so more water is reabsorbed – concentrated urine when dehydrated, dilute when not.



Water potential of the filtrate falls steeply through the loop of Henle; the collecting duct's permeability, set by ADH, decides the final urine concentration.

Excess amino acids are **deaminated** in the liver; the toxic ammonia becomes **urea** for excretion.

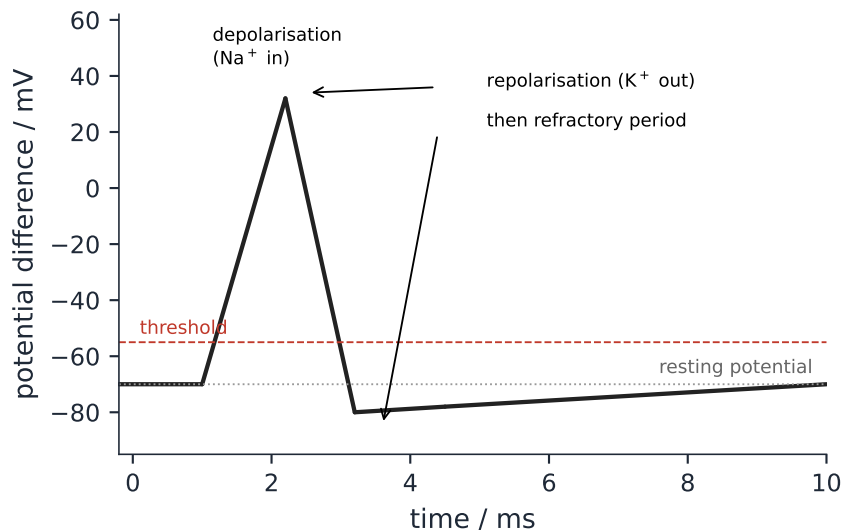
Worked check. ADH present → collecting duct walls permeable → water leaves down the gradient into the medullary blood → small volume, concentrated urine. Alcohol suppresses ADH – large volume, dilute.

Switching genes: transcription factors and epigenetics

A **transcription factor** binds a gene's promoter and switches transcription on or off. Steroid hormones enter target cells and bind intracellular receptor proteins. The activated receptors can act as transcription factors; the hormone molecule itself does not bind DNA as a transcription factor. **Epigenetics** concerns changes in gene activity without changing the DNA base sequence. Promoter DNA **methylation** can reduce transcription. Histone acetylation usually makes chromatin more accessible, whereas deacetylation can make it less accessible. Methylation at a tumour-suppressor promoter can reduce protective gene expression. Imprinting errors can disrupt development, including some cases of Prader–Willi syndrome.

Nerve impulses and synapses

The resting neurone pumps Na^+ out and K^+ in (the **sodium-potassium pump**), holding an interior at about -70 mV. A stimulus past **threshold** (about -55 mV) opens sodium channels: an **all-or-nothing** action potential spikes to $+30$ mV, then potassium channels repolarise; the **refractory period** prevents backward travel and sets a maximum frequency.



The action potential – depolarisation as sodium enters, repolarisation as potassium leaves, then the refractory period.

In **myelinated** neurones the impulse jumps node to node (**saltatory conduction**) – far faster. At the **synapse**, calcium entry triggers vesicles of neurotransmitter to fuse with the presynaptic membrane; the transmitter diffuses and binds postsynaptic receptors; enzymes then clear the gap. Drugs act here: SSRIs block serotonin re-uptake, so the signal persists; lidocaine blocks sodium channels; ecstasy (MDMA) floods the cleft with serotonin then depletes it.

The nervous system divides: CNS (brain, spinal cord) and PNS – **somatic** (voluntary) and **autonomic** (involuntary; sympathetic accelerates, parasympathetic calms). Receptors are transducers: rods (dim light, many per bipolar cell – sensitivity), cones (colour, one-to-one – acuity), plus thermoreceptors, chemoreceptors, baroreceptors, **nociceptors** (pain). The spinal **reflex arc** passes sensory → relay → motor neurone in the cord's grey matter – fast, involuntary, protective. **Habituation** is a decreasing response to a repeated harmless stimulus.

Plants: light and growth switches

Phytochrome flips between Pr (absorbs red) and Pfr (absorbs far-red); sunlight's red bias leaves Pfr dominant, controlling germination and flowering by day length. **Auxin** elongates cells by acidifying walls; **gibberellins** induce enzymes (amylase in the aleurone layer) that mobilise starch in germination.

The brain and its chemistry

Landmarks and jobs: **cerebral hemispheres** (voluntary, thought), **cerebellum** (coordination, balance), **hypothalamus** and **pituitary** below them (homeostasis, hormones), **medulla oblongata** (heart, breathing). **MRI** shows structure; **fMRI** shows activity via oxygenated-blood flow; **CT** fast structural scans; **PET** metabolism with radioactive tracers.

Chemistry first: Parkinson's is a **dopamine** deficit – treated with **L-Dopa**, which crosses the blood-brain barrier and is converted to dopamine in the brain. Low serotonin links to depression – the target of SSRIs.

Gene technology

Recombinant DNA DNA: a **restriction enzyme** cuts DNA at its recognition sequence, leaving **sticky ends**; the human gene (made without introns from mRNA) is spliced into a **plasmid** with **DNA ligase**; the plasmid transforms host bacteria; **marker genes** (antibiotic resistance or fluorescence) select the cells that took it up. Scale up in a fermenter and the bacteria secrete human **insulin** – cleaner and safer than extracting from pigs. GM animals make human proteins in milk; risks and benefits of GM crops (resistance, yields versus gene flow to wild relatives) are the standard evaluation.

Microarrays identify active genes: sample mRNA hybridises to complementary probes on the chip; spots that fluoresce mark genes being transcribed. **Bioinformatics** compares sequences across species and individuals – how relatedness is now measured.

Check yourself

1. Name the stage of respiration occurring in the mitochondrial matrix and one of its inputs.
2. A runner's muscles produce lactate. Explain why, and what happens to the lactate afterwards.
3. Myosin heads cannot detach without ATP. Explain what this means for muscles after death.
4. Calculate cardiac output for stroke volume 85 cm^3 and heart rate 140 min^{-1} .
5. Explain why the afferent arteriole is wider than the efferent arteriole.
6. State two differences between negative and positive feedback, with one example of each.
7. Why does myelination increase conduction speed?
8. An axon's threshold is -55 mV . A stimulus moves it to -60 mV . What happens, and why?
9. Red light converts phytochrome to which form?

10. Explain why L-Dopa is given instead of dopamine itself.
11. A microarray spot fluoresces strongly. What does that show?
12. Why must the human insulin gene be made from mRNA rather than from genomic DNA when inserting into bacteria?

Answers: 1 the link reaction (or Krebs cycle) – input pyruvate (or acetyl); 2 oxygen is short so reduced NAD is recycled by reducing pyruvate to lactate; afterwards lactate goes to the liver and is converted back to glucose, using oxygen; 3 without ATP the myosin stays bound to actin – rigor mortis; 4 $85 \times 140 = 11\,900 \text{ cm}^3 \text{ min}^{-1} = 11.9 \text{ dm}^3 \text{ min}^{-1}$; 5 the pressure difference drives ultrafiltration of plasma into Bowman's capsule; 6 negative returns a variable toward its set point (thermoregulation); positive pushes it further away (fever rising); 7 the impulse jumps between nodes of Ranvier instead of depolarising the whole membrane – fewer, bigger steps; 8 nothing – threshold is not reached, so no action potential (all-or-nothing); 9 Pfr; 10 dopamine cannot cross the blood-brain barrier but L-Dopa can, and is converted to dopamine inside the brain; 11 that gene was being actively transcribed – its mRNA was present and hybridised; 12 bacteria cannot splice introns, so the gene must come from mature mRNA that already lacks them.