

Cambridge AS & A Level · Biology 9700 · Notes

Homeostasis A2

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Read first: [Biological molecules](#), [Cell membranes and transport](#), [Transport in plants](#), [Transport in mammals](#)

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What you need to know

By the end of this topic you should be able to:

Homeostasis in mammals (14.1)

1. **Say what homeostasis is and why it matters:** keeping the internal environment within narrow limits so cells work efficiently (core temperature, blood glucose, blood water potential).
2. **Explain how homeostasis works:** a stimulus (internal or external) is detected by receptors; a coordination system (the nervous system or the endocrine system) passes the information on; effectors (muscles and glands) respond; and negative feedback returns the factor to its set point.
3. **State that urea is made in the liver** by deamination of excess amino acids.
4. **Describe the structure of the kidney:** fibrous capsule, cortex, medulla, renal pelvis, ureter, and the branches of the renal artery and renal vein.
5. **Identify the parts of a nephron** in diagrams, photomicrographs and electron micrographs: glomerulus, Bowman's capsule, proximal convoluted tubule, loop of Henle, distal convoluted tubule and collecting duct, with their blood vessels.
6. **Describe and explain how urine is formed**, limited to ultrafiltration in the Bowman's capsule (making glomerular filtrate) and selective reabsorption in the proximal convoluted tubule.
7. **Relate the detailed structure** of the Bowman's capsule and the proximal convoluted tubule to their jobs.
8. **Describe osmoregulation:** the roles of the hypothalamus, the posterior pituitary gland, antidiuretic hormone (ADH), aquaporins and the collecting ducts.
9. **Describe cell signalling using glucagon:** receptor and its change of shape, G protein, adenylyl cyclase, the second messenger cAMP, protein kinase A, the amplifying enzyme cascade, and glycogen breakdown.
10. **Explain negative feedback control of blood glucose:** what insulin does to muscle cells and liver cells, and what glucagon does to liver cells.
11. **Explain how test strips and biosensors measure glucose** in blood and urine, using glucose oxidase and peroxidase.

Homeostasis in plants (14.2)

12. **Explain that stomata open and close** as conditions change, balancing carbon dioxide uptake by diffusion (for photosynthesis) against water loss by transpiration.
13. **Explain that stomata have daily rhythms** of opening and closing.
14. **Describe the structure and function of guard cells** and explain how they open and close stomata.
15. **Describe the role of abscisic acid (ABA)** in closing stomata during water stress, including calcium ions as a second messenger.

The loop of Henle's mechanism, the distal convoluted tubule's own work and details of the insulin receptor are **not** needed. You only need to know that the medulla's tissue fluid has a very low water potential, which the collecting ducts use.

Understand it

What homeostasis is for

Your cells sit in **tissue fluid**, which is made from blood plasma (see Transport in mammals). If that fluid changes, cells stop working well:

- **Core temperature** (about 37 °C in humans). Enzymes have an optimum temperature. Colder, and molecules have less kinetic energy, so there are fewer enzyme–substrate complexes and metabolism slows. Much hotter, and enzymes denature.
- **Blood glucose concentration** (about 4–6 mmol dm⁻³). Glucose is the main respiratory substrate, and brain cells depend on it. Too little and cells run short of ATP. Too much lowers the water potential of the blood, so water leaves cells by osmosis.
- **Blood water potential**. Animal cells have no cell wall. If the tissue fluid's water potential falls, cells lose water by osmosis and shrink; if it rises, cells take in water and can burst.

Homeostasis is keeping the internal environment within narrow limits, close to a **set point**, whatever happens outside.

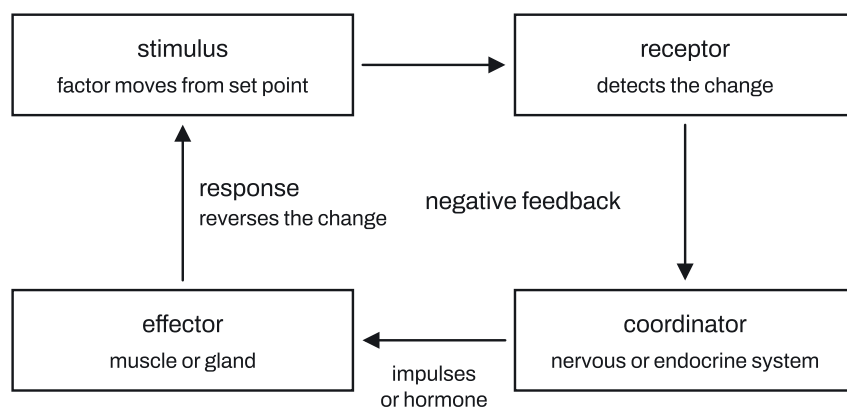
How homeostasis works

Every homeostatic mechanism has the same parts:

Part	What it does	Example: body too hot	Example: blood glucose too high
Stimulus	A change in a factor. Internal (inside the body) or external (outside)	Core temperature rises	Glucose absorbed after a meal
Receptor	Detects the change	Thermoreceptors in the hypothalamus	Beta cells in the pancreas

Part	What it does	Example: body too hot	Example: blood glucose too high
Coordinator	Passes on the information: the nervous system (impulses) or the endocrine system (hormones in the blood)	Hypothalamus, nerve impulses	Pancreas, the hormone insulin
Effector	A muscle or gland that responds	Sweat glands; muscles in arteriole walls	Liver and muscle cells
Response	Brings the factor back	Sweating, vasodilation	Glucose taken up and stored

The response **reverses the change** that started it: a rise causes a fall, and a fall causes a rise. This is **negative feedback**. Once the factor is back at the set point, the receptors stop being stimulated and the response switches off, so the factor wobbles only slightly around the set point.



Two hormones pulling in opposite directions (insulin and glucagon) give finer control than one.

Thermoregulation is a good example of the nervous route. In the cold: arterioles near the skin surface **constrict** (vasoconstriction), so less blood flows near the surface and less heat is lost by radiation; **shivering** (muscle contraction) releases heat from respiration; hairs are raised to trap an insulating layer of air; less sweat is made, so less heat is lost by evaporation. Animals also use behaviour: curling up reduces the surface area exposed to cold air.

Nervous and endocrine systems

The **endocrine system** is made of glands (such as the pancreas and pituitary) that secrete **hormones** straight into the blood. A hormone is a cell-signalling molecule: it reaches every part of the body, but it only affects **target cells** that have receptors complementary to it.

Nervous system

Electrical impulses (action potentials), with neurotransmitters at synapses

Endocrine system

Chemical: hormones

Nervous system

Carried along neurones

Very fast

Effect is localised (one muscle or gland)

Response is short-lived

Endocrine system

Carried in the blood

Slower

Effect can be widespread (every cell with the receptor)

Response usually lasts longer

The three hormones in this topic compared:

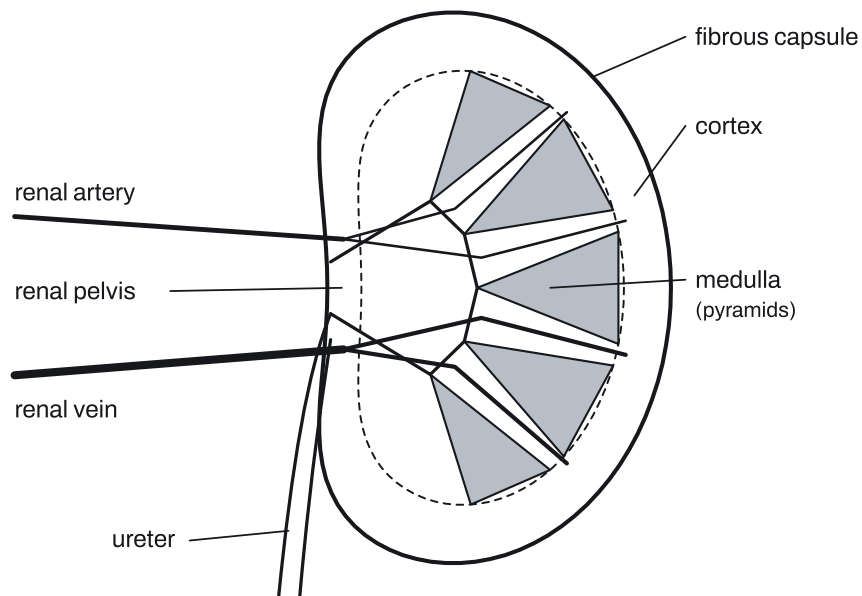
Hormone	Made or released by	Released when	Target cells	Main effect
ADH	Made in the hypothalamus, released from the posterior pituitary	Osmoreceptors detect a low blood water potential	Collecting duct cells	More water moves from the filtrate into the blood
Insulin	Beta cells of the islets of Langerhans (pancreas)	Blood glucose rises	Liver, muscle (and fat) cells	Glucose moves from the blood into cells
Glucagon	Alpha cells of the islets of Langerhans	Blood glucose falls	Liver cells	Glucose moves from liver cells into the blood

All three bind to receptors on the **cell surface membrane** of their target cells.

Urea: where the kidney's waste comes from

The body cannot store excess amino acids. In the **liver**, the amino group is removed (**deamination**) and becomes **ammonia**, which is very toxic and very soluble. The rest of the molecule is respired or converted to glucose or fat. The ammonia is combined with carbon dioxide to make **urea** (in the ornithine cycle), which is much less toxic. Urea travels in the blood plasma to the kidneys and is excreted in urine.

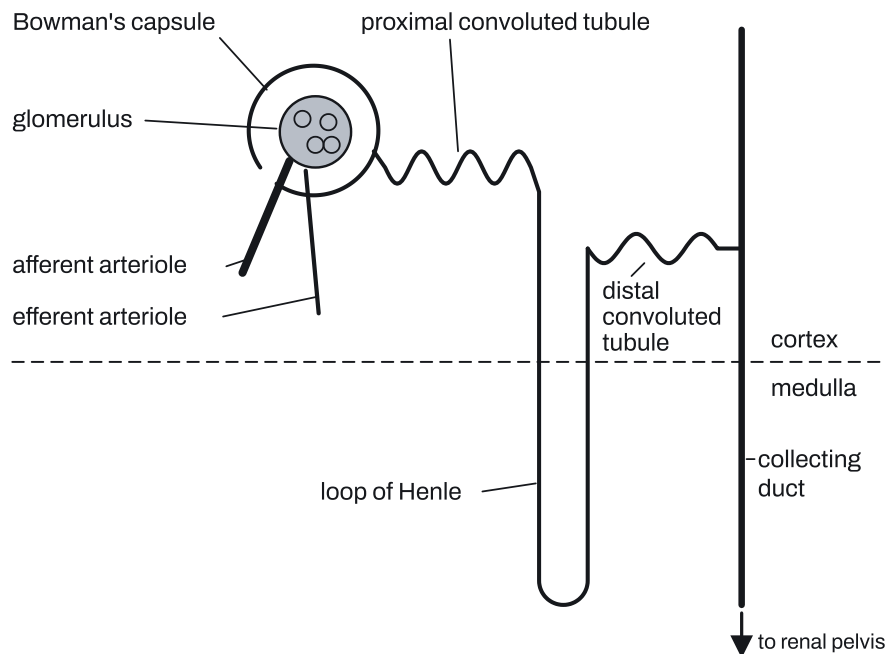
The kidney



- **Fibrous capsule**: a tough outer layer that protects the kidney.
- **Cortex**: the outer region. It holds the glomeruli, the Bowman's capsules and the convoluted tubules, so it looks grainy.
- **Medulla**: the inner region, in cone-shaped pyramids. It holds the loops of Henle and the collecting ducts, which run in parallel, so it looks striped.
- **Renal pelvis**: the funnel-shaped space where urine from the collecting ducts collects.
- **Ureter**: carries urine from the renal pelvis to the bladder.
- **Renal artery** (from the aorta) brings blood in; **renal vein** takes blood back towards the vena cava. Both branch inside the kidney.

Each kidney has about a million **nephrons**, the tubules that make urine.

The nephron



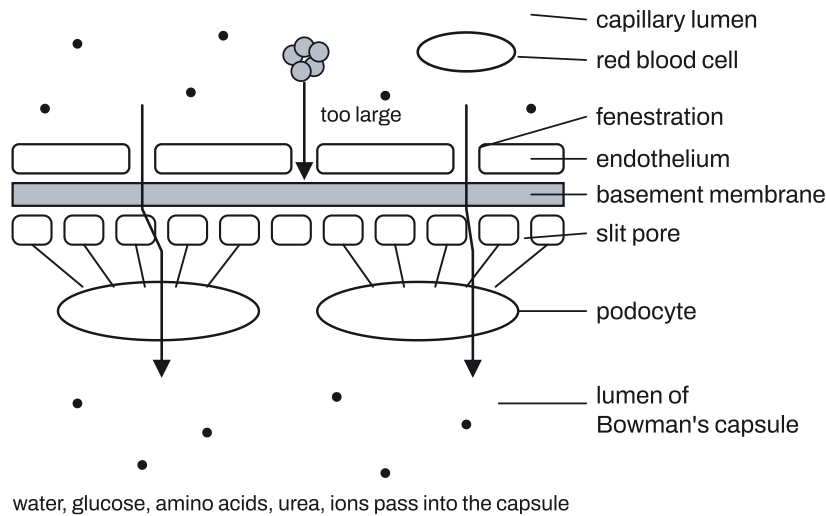
Blood flows **afferent arteriole** → **glomerulus** → **efferent arteriole** → capillaries around the tubules → renal vein. Fluid in the nephron flows **Bowman's capsule** → **proximal convoluted tubule (PCT)** → **loop of Henle** → **distal convoluted tubule (DCT)** → **collecting duct** → **renal pelvis**.

In a photomicrograph: glomeruli look like round knots of cells inside a clear ring (the capsule space); PCT cells are cube-shaped with a fuzzy brush border of microvilli facing a small lumen; collecting ducts have wider lumens and paler cells.

Ultrafiltration in the Bowman's capsule

The **afferent arteriole is wider than the efferent arteriole**, so blood enters the glomerulus faster than it can leave. This builds up a **high hydrostatic (blood) pressure** in the glomerular capillaries. The pressure forces fluid out of the blood into the capsule, even though the plasma has a slightly lower water potential than the filtrate (because of its proteins): the pressure gradient is bigger than that water potential gradient.

The fluid passes through three layers:

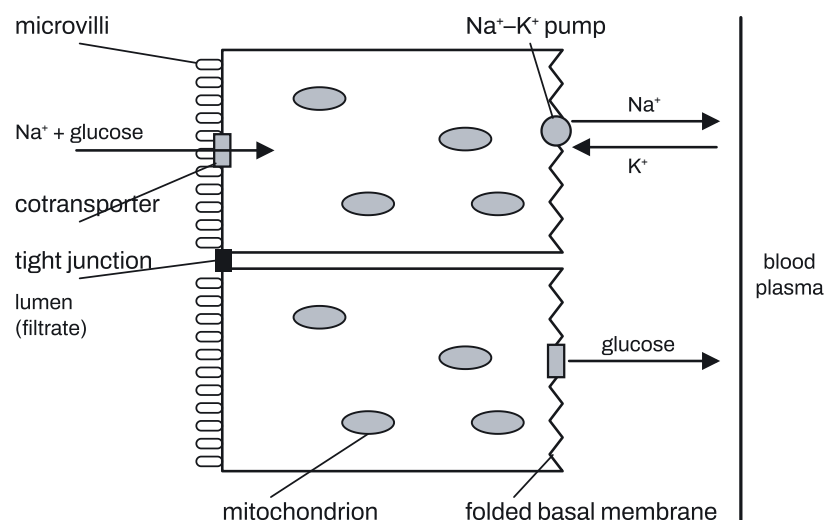


1. **Capillary endothelium with fenestrations** (gaps): plasma passes, blood cells don't.
2. **Basement membrane**: a mesh of collagen and glycoproteins. This is the **filter**: it stops molecules with a relative molecular mass above about **68 000–70 000**, so most plasma proteins stay in the blood.
3. **Podocytes**: cells of the capsule's inner wall with foot-like processes; the gaps between them (**slit pores**, filtration slits) let the filtrate through into the capsule.

Glomerular filtrate therefore has water, glucose, amino acids, urea and mineral ions **at the same concentration as plasma**, but **no** blood cells and almost no proteins. It forms fast: about **125 cm³ per minute**, which is $125 \times 60 \times 24 = 180\,000 \text{ cm}^3$, or **180 dm³ a day**. Less than 2 dm³ of urine leaves the body, so about 99% of the water is reabsorbed.

Selective reabsorption in the proximal convoluted tubule

The PCT takes back **all** the glucose and amino acids, and most of the water and ions, leaving urea and other wastes behind. Its cells are built for it:



1. **Sodium–potassium pumps** in the **basal membrane** (the side next to the blood) actively transport Na⁺ out of the cell, using ATP (3 Na⁺ out for every 2 K⁺ in), keeping the Na⁺ concentration **inside the cell low**.

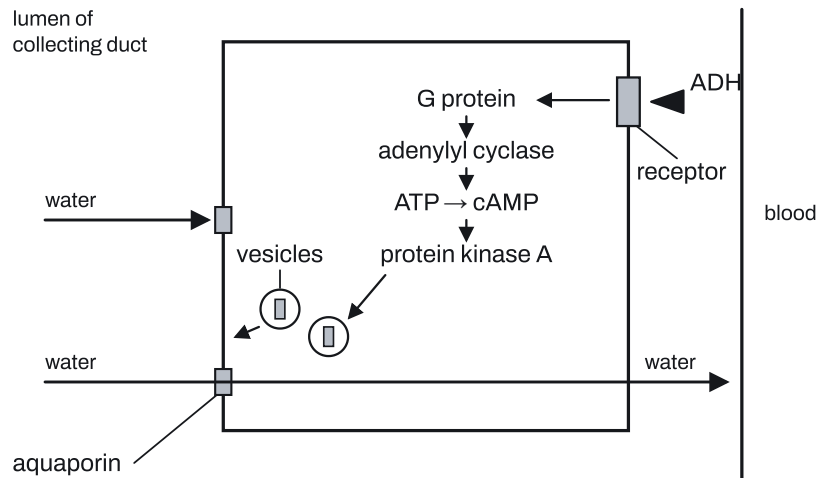
2. So Na^+ **diffuses** from the filtrate into the cell through **cotransporter proteins** in the membrane facing the lumen. Each carries a **glucose** (or amino acid) molecule in **with** the Na^+ , even **against** its concentration gradient: **cotransport**, powered by the Na^+ gradient.
3. Glucose and amino acids leave on the blood side by **facilitated diffusion**.
4. **Water follows by osmosis**. Much urea stays in the filtrate, so its concentration rises along the nephron.

Feature of PCT cells	Why it helps
Microvilli on the lumen side	Large surface area for cotransporter proteins
Many cotransporter proteins	Glucose and amino acids taken up quickly
Many mitochondria	ATP for the sodium–potassium pumps
Folded basal membrane	More room for pumps and transport proteins
Tight junctions between cells	Fluid can't leak between cells; everything passes through the cells, where it is controlled
Close to capillaries , one thin cell layer	Short distance to the blood

Osmoregulation and ADH

Osmoregulation is control of the water potential of the blood. The receptor, coordinator and effector are:

1. **Osmoreceptors in the hypothalamus** detect a **fall** in the water potential of the blood (for example after sweating, eating salty food or not drinking). They lose water by osmosis and shrink.
2. **Neurosecretory cells in the hypothalamus** make more **ADH**. It passes down their axons to the **posterior pituitary gland**, which **releases** it into the blood.
3. ADH reaches the **collecting duct cells** (the target cells) and binds to receptors on their cell surface membrane (the blood side).
4. This activates a **G protein**, then **adenylyl cyclase**, which makes the second messenger **cAMP**. cAMP activates a **protein kinase**, which phosphorylates proteins.
5. **Vesicles** holding **aquaporins** (water channel proteins) move to the membrane facing the lumen and **fuse** with it, so more aquaporins are in that membrane.
6. The membrane is now **more permeable to water**. The tissue fluid of the medulla has a very **low water potential** (the loop of Henle keeps it salty), so **water moves by osmosis** from the filtrate, **through the aquaporins into the cells, and on into the tissue fluid and blood**.
7. A **smaller volume of more concentrated urine** is made, and the blood's water potential rises back towards the set point.

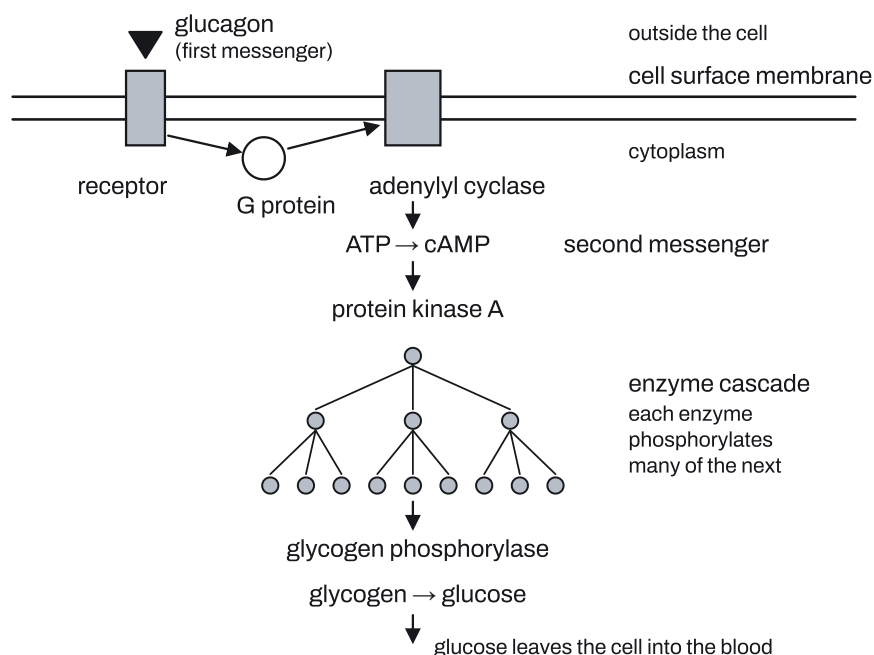


Negative feedback: as the water potential rises (or after drinking a lot), less ADH is released, aquaporins are taken back into the cell, less water is reabsorbed and a **large volume of dilute urine** is made.

Why desert mammals have thick medullas. Longer loops of Henle make a **thicker medulla** with an **even lower water potential**, so more water is reabsorbed from the collecting ducts and the urine is more concentrated (a high urine : plasma solute ratio, $U : P$). Kangaroo rats (desert) have very thick medullas; beavers (rivers) have thin ones.

Cell signalling by glucagon

When blood glucose falls, **alpha cells** in the pancreas secrete **glucagon**. Glucagon cannot enter cells. Instead it works through a chain of signals inside the **liver cell**:



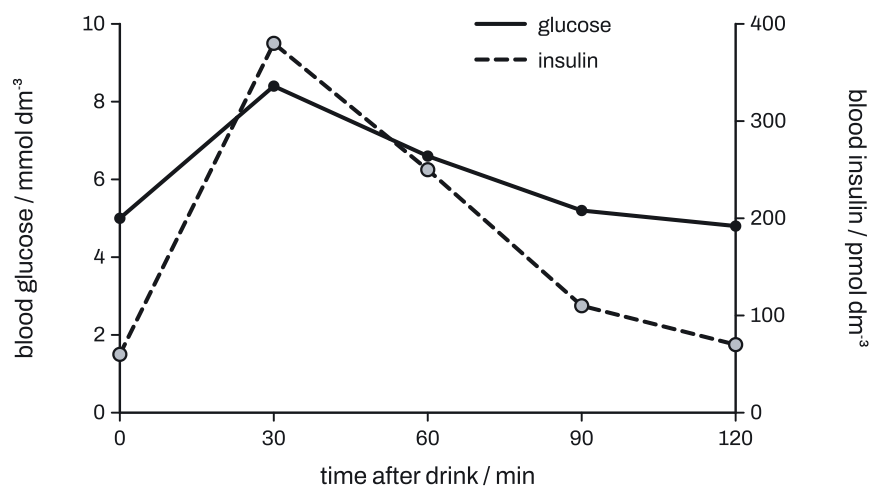
1. Glucagon (the **first messenger**) binds to a **receptor** on the liver cell's **cell surface membrane**. The shapes are complementary. Binding causes a **conformational change** (change of shape) in the receptor.

2. The receptor activates a **G protein**, which activates the enzyme **adenylyl cyclase** in the membrane.
3. Adenylyl cyclase converts **ATP to cyclic AMP (cAMP)**, the **second messenger**, inside the cell.
4. cAMP activates **protein kinase A**, which starts an **enzyme cascade**: each enzyme activates the next by **phosphorylating** it (adding a phosphate group from ATP).
5. **Amplification**: each activated enzyme activates many molecules of the next, so one glucagon molecule leads to thousands of active enzymes at the end. A tiny amount of hormone gives a large, fast response.
6. The last enzyme, **glycogen phosphorylase**, is activated and breaks **glycogen into glucose** (**glycogenolysis**).

Glucagon also increases **gluconeogenesis** (making glucose from amino acids and glycerol) and reduces glycogen synthesis. The glucose moves out of the liver cells into the blood by facilitated diffusion, so blood glucose **rises**.

ADH uses the same kind of pathway (receptor, G protein, adenylyl cyclase, cAMP, kinase) in collecting duct cells.

Negative feedback of blood glucose



When blood glucose rises (after a meal):

1. **Beta cells** in the islets of Langerhans detect the rise and secrete **insulin**; alpha cells secrete less glucagon.
2. Insulin binds to receptors on **muscle cells and liver cells** (and fat cells).
3. **Muscle cells**: vesicles holding **GLUT4** glucose transporter proteins move to the cell surface membrane and fuse with it, so the membrane becomes **more permeable to glucose**; more glucose enters by **facilitated diffusion**. Insulin also increases the use of glucose in **respiration** and its conversion to **glycogen**.
4. **Liver cells**: insulin activates the enzymes that turn glucose into **glycogen** (**glycogenesis**; glycogen synthase is one of them). Keeping the glucose concentration inside the cell low means more glucose diffuses in. Insulin also increases fat synthesis.

5. Blood glucose **falls** back towards the set point; the beta cells are stimulated less, so insulin secretion falls.

When blood glucose falls (between meals, during exercise, when glucose is being respired quickly):

1. **Alpha cells** detect the fall and secrete **glucagon**; insulin secretion falls.
2. Glucagon acts only on **liver** cells (muscle cells have no glucagon receptors): glycogenolysis and gluconeogenesis increase, as above.
3. Glucose passes into the blood; blood glucose **rises** back to the set point, and glucagon secretion falls.

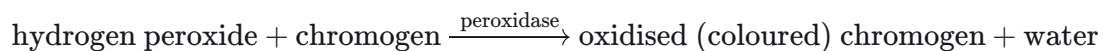
When control fails. In **type 1 diabetes** the pancreas makes too little insulin; in **type 2 diabetes** target cells respond poorly to it (fewer GLUT4 reach the membrane), or too little is made. Blood glucose stays high after a meal, and glucose the PCT cannot all reabsorb appears in the urine.

Measuring glucose: test strips and biosensors

Both use the enzyme **glucose oxidase**, which is specific to glucose:



Test strip (dip stick): a pad holds **glucose oxidase**, **peroxidase** and a colourless **chromogen**. Peroxidase uses the hydrogen peroxide to **oxidise the chromogen**, which becomes coloured:



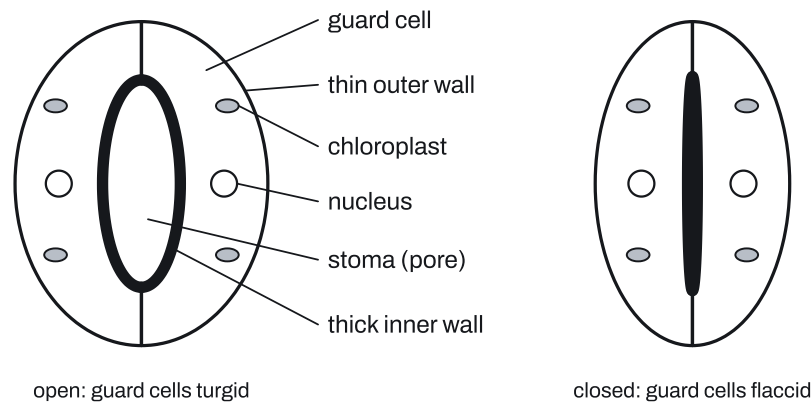
The more glucose, the darker the colour. You compare it with a **colour chart**, which gives only a **range** of concentrations. Test strips are cheap and are often used on **urine**; urine glucose shows only that blood glucose has been high enough for some to escape reabsorption, some time earlier.

Biosensor: glucose oxidase is **immobilised** on an electrode, behind a partially permeable membrane. A drop of **blood** is added; glucose passes through and is oxidised. The reaction produces a small **electric current** (electrons are transferred to the electrode). A **transducer** converts the chemical change into this electrical signal, which is **amplified** and shown as a **digital reading**. The current is **proportional to the glucose concentration**.

Advantages of a biosensor: it gives an **exact number** (quantitative), it is **accurate**, the result is **quick**, it measures the **blood glucose now** (not past levels in urine), the sensor can be **reused** and the readings can be stored.

Guard cells and stomata

A stoma is the **pore** between **two guard cells**. The plant has a problem: it needs the stomata **open** so that **carbon dioxide diffuses in** for photosynthesis, but water vapour then **diffuses out** (transpiration). So stomata open when photosynthesis is possible and close when water loss would be dangerous.



Structure and function of guard cells:

- The **cell wall is thicker on the inner side** (next to the pore) than on the outer side, and **cellulose microfibrils** run around the cell in hoops. When the cell swells, the thin outer wall stretches more, and the hoops stop it getting fatter, so it gets longer and **bends outwards**, opening the pore.
- **Chloroplasts** (the only epidermal cells with them; they have few grana) and many **mitochondria** supply ATP.
- Many **proton pumps** and **K⁺ channels** in the cell surface membrane.
- **No plasmodesmata** to the neighbouring epidermal cells, so each guard cell controls its own ion content.

Opening (in light):

1. **Proton pumps** use **ATP** to actively transport **H⁺ out** of the guard cells.
2. The inside of the cell becomes **more negative** (and there is a proton gradient).
3. **K⁺ channels open** and **K⁺ ions diffuse in**; Cl⁻ ions also enter.
4. The **water potential** of the guard cells **decreases** (becomes more negative).
5. **Water enters by osmosis** from the neighbouring epidermal cells.
6. The guard cells become **turgid** and swell; because the inner wall is thicker, they **curve apart** and the stoma **opens**.

Closing, and abscisic acid (ABA) in water stress. When the plant is short of water (drought, high temperature, low humidity, high wind), it makes **ABA**. Closing runs in this order:

1. ABA binds to **receptors** on the **cell surface membrane** of guard cells.
2. The **proton pumps stop** pumping H⁺ out.
3. **Calcium ions (Ca²⁺) move into the cytoplasm** (through channels in the cell surface membrane, and from the vacuole). Ca²⁺ is the **second messenger**.
4. Ca²⁺ opens channels so **K⁺ ions (and Cl⁻) leave** the guard cells; it also keeps the proton pumps and the inward K⁺ channels shut.
5. The **water potential** of the guard cells **increases**.
6. **Water leaves by osmosis**; the guard cells become **flaccid**.
7. The stoma **closes**, cutting water loss by transpiration.

Daily rhythms. Stomata are usually **open during the day** (light, so CO₂ is needed for the Calvin cycle) and **closed at night** (no photosynthesis, so opening would only waste water). They often start to open before dawn. If plants are kept in constant darkness the rhythm carries on for a while, which shows it is controlled partly by the plant's **genes** (an internal clock); light keeps the rhythm in time and the opening full. Stomata can also close in the middle of a hot, dry day.

Key facts and formulas

No formula for this topic is in the syllabus's list of mathematical formulae, so learn them all.

Formula	Status
Percentage change = $\frac{\text{new} - \text{original}}{\text{original}} \times 100$ (a fall gives a negative value: state it as a decrease)	Learn it
Percentage reabsorbed = $\frac{\text{volume filtered} - \text{volume in urine}}{\text{volume filtered}} \times 100$	Learn it
Rate of change = $\frac{\text{change in quantity}}{\text{time taken}}$, with units such as pmol dm ⁻³ min ⁻¹	Learn it
"How many times" = $\frac{\text{later value}}{\text{earlier value}}$ (no units)	Learn it
cm ³ min ⁻¹ to dm ³ per day: $\times 60 \times 24 \div 1000$	Learn it
glucose + O ₂ $\xrightarrow{\text{glucose oxidase}}$ gluconic acid + H ₂ O ₂	Learn it
H ₂ O ₂ + chromogen $\xrightarrow{\text{peroxidase}}$ coloured oxidised chromogen + H ₂ O	Learn it
ATP $\xrightarrow{\text{adenylyl cyclase}}$ cAMP (the second messenger)	Learn it
Useful values: GFR about 125 cm ³ min ⁻¹ (180 dm ³ a day); filter cut-off about 68 000–70 000 relative molecular mass; blood glucose about 4–6 mmol dm ⁻³ ; core temperature about 37 °C	Learn it

Word pairs that examiners separate:

- **Glucagon** (the hormone) and **glycogen** (the stored polysaccharide).
- **Glycogenolysis** (glycogen → glucose), **glycogenesis** (glucose → glycogen), **gluconeogenesis** (new glucose from amino acids or glycerol).
- **Hypothalamus** makes ADH; the **posterior pituitary** releases (secretes) it.
- **Afferent** arteriole in (wider); **efferent** arteriole out (narrower).

How to do it

In the Paper 4 questions we have tagged for this topic (60 questions, 2021–2025), the types came up this often. 46 of the 60 questions mix more than one type, so the counts add up to more than 60.

Question type	Questions
Explain ADH and osmoregulation	16
Identify kidney and nephron structures	16
Describe how guard cells open and close stomata	11
Explain homeostasis and negative feedback	11
Explain blood glucose control by insulin and glucagon	10
Describe ultrafiltration	9
Describe the glucagon signalling pathway	8
Describe selective reabsorption in the PCT	8
Predict the effects of a disorder	8
Explain glucose test strips and biosensors	7
Compare the endocrine and nervous systems	7
Explain why stomata open and close, and their rhythms	6
Calculate from kidney or glucose data	6
Relate medulla thickness or urine concentration to habitat	5
State how and where urea is made	3
Explain thermoregulation responses	3

1. Explain ADH and osmoregulation (16 questions)

Write the seven-step chain from "Osmoregulation and ADH" in Understand it, in order: osmoreceptors in the hypothalamus → ADH released from the posterior pituitary → receptors on collecting duct cells → cAMP → aquaporins fuse with the luminal membrane → more water reabsorbed by osmosis into the blood → smaller volume of concentrated urine. Each link is usually a mark.

Variations you will meet:

- **Name the stimulus** osmoreceptors detect: a change in the **water potential of the blood** (not "water level").
- **Label a diagram** of a collecting duct cell: often G protein, cAMP, aquaporin, or draw arrows for water: **lumen** → **cell** → **capillary**.
- **Reasons the blood water potential falls**: sweating, not drinking, salty food, more solutes (such as glucose) in the blood.

- **A graph of ADH against urine flow:** as ADH rises, urine flow falls. Explain with aquaporins and osmosis, and quote figures from the graph.
- **The reverse:** after drinking a lot, less ADH, aquaporins removed from the membrane, large volume of dilute urine.
- **Name the parts:** receptors (osmoreceptors, hypothalamus), effector (posterior pituitary and collecting duct), target cells (collecting duct cells).

2. Identify kidney and nephron structures (16 questions)

1. Use the kidney and nephron diagrams in Understand it: capsule outside, grainy cortex, striped medulla, renal pelvis leading to the ureter; fluid runs Bowman's capsule → PCT → loop of Henle → DCT → collecting duct.
2. The vessel entering the glomerulus is the wider **afferent arteriole**; the one leaving is the **efferent arteriole**.

Variations you will meet:

- **A letter table** (a letter can be used more than once): ultrafiltration, **Bowman's capsule**; glucose reabsorbed, **PCT**; ADH acts, **collecting duct**; loops of Henle, **medulla**; urine collects, **renal pelvis**.
- **The process at each region:** ultrafiltration, selective reabsorption, osmoregulation.
- **The Bowman's capsule close up:** podocyte, endothelial cell, basement membrane; filtrate is inside the capsule, plasma inside the capillary.
- **A kidney section:** pelvis, medulla and cortex are the usual answers, as in [9700/43/O/N/25 Q9](#).

3. Describe how guard cells open and close stomata (11 questions)

Use the numbered opening and ABA closing sequences from "Guard cells and stomata" in Understand it. Keep them in order, name the **guard cells** (not the stomata) as where ions and water move, and say **osmosis** and **water potential**.

Variations you will meet:

- **Put the closure events in order** from a table: environmental change, ABA released, then the seven ABA steps in Understand it.
- **Identify an ion** on a diagram: the ion that leaves when Ca^{2+} rises is **K⁺**.
- **Describe the structure of guard cells:** uneven wall thickness, radial microfibrils, chloroplasts (few grana), many mitochondria, no plasmodesmata, many transport proteins in the membrane.
- **Label a diagram** of guard cells: thick inner wall, chloroplast, nucleus, vacuole, stoma.
- If you are asked for **opening**, don't describe closing (and the reverse): examiners cap the marks.

4. Explain homeostasis and negative feedback (11 questions)

1. **Name the mechanism:** often just "**negative feedback**" for 1 mark.

2. **Explain the principles** (4 marks): go round the loop in the first diagram (set point, receptor, coordinator, effector, response, back to the set point) and name it **negative feedback**.
3. **Why homeostasis matters**: enzymes, glucose for respiration, osmosis in cells.

Variations you will meet:

- **Complete a passage**: typical words are **internal**, **negative feedback**, **receptors**, **endocrine**, **glycogen**.
- **Essay** on what homeostasis is and why it matters: define it, name the three factors, give the reason for each.

5. Explain blood glucose control by insulin and glucagon (10 questions)

1. **Describe** the graph first if asked: the rise, the peak (time and value), the fall, and whether it returns to the start, with units.
2. **Explain** with the chains in "Negative feedback of blood glucose": a rise → beta cells → insulin → GLUT4, glycogenesis, respiration → back to the set point → less insulin; a fall → alpha cells → glucagon → glycogenolysis and gluconeogenesis in the liver.

Variations you will meet:

- **Flow chart with gaps**: typical answers are **insulin**, **muscle** (or liver) cells, **glycogen**, **negative feedback**.
- **Which processes speed up when blood glucose falls**: glycogenolysis **increases**; glycogenesis, glycolysis and fatty acid synthesis **decrease**.
- **Two meals compared**: a high-carbohydrate meal gives a sharp glucose peak and a big insulin peak; a high-fat, low-carbohydrate meal gives little change, and a gradual fall as glucose is respired and glucagon then restores it.
- **Starch vs glucose drink**: starch has to be digested first, so the peak is later and lower.

6. Describe ultrafiltration (9 questions)

Give the chain from "Ultrafiltration in the Bowman's capsule": wide afferent, narrow efferent arteriole → high hydrostatic pressure → through fenestrations, basement membrane (the filter) and slit pores → what passes and what stays. Say it is driven by **pressure**, not diffusion.

Variations you will meet:

- **"Why is the afferent arteriole wider?"**: to build the high pressure needed to force fluid through the filter.
- **Role of one named layer**, such as the basement membrane (acts as the filter) or podocytes (slits let filtrate through, and hold the capillaries).
- **Table of filtrate vs urine**: glucose **same** in filtrate, **not present** in urine; large proteins **not present** in either; urea **same** in filtrate, **increased** in urine.
- **Factors that change GFR**: blood pressure, dehydration, kidney damage, age.
- **Conditions for ultrafiltration** (2 marks): high hydrostatic pressure, and a filter (the basement membrane) that only lets small molecules through.

7. Describe the glucagon signalling pathway (8 questions)

Write the six steps from "Cell signalling by glucagon" in order, one mark each (up to 7), then finish with gluconeogenesis and glucose leaving the cell into the blood. Name the **liver cell** and the **cell surface membrane**.

Variations you will meet:

- **Label a diagram** of the pathway: the enzyme in the membrane (adenylyl cyclase), the molecule it makes (cAMP), the enzyme cascade.
- **"What is the role of the enzyme cascade?"**: amplification.
- **A faulty last enzyme** (such as glycogen phosphorylase): glucagon still binds and cAMP is still made; signalling works, but glycogen can't be broken down, so blood glucose stays low.

8. Describe selective reabsorption in the PCT (8 questions)

Use the four steps and the adaptations table from "Selective reabsorption" in Understand it: pump on the blood side lowers Na^+ in the cell, Na^+ cotransports glucose in from the lumen, glucose diffuses out into the blood, water follows by osmosis. For "explain how the cells are adapted", pair each feature with its reason.

Variations you will meet:

- **Label where** the cotransporters are (membrane facing the lumen, on the microvilli) and where the Na^+/K^+ pumps are (basal membrane, next to the blood).
- **The role of Na^+** in selective reabsorption: it drives cotransport of glucose.

9. Predict the effects of a disorder (8 questions)

Say where the normal mechanism breaks, then what follows for the blood and urine.

- **ADH not made, or cannot bind** (diabetes insipidus): few aquaporins added, membrane **less permeable** (not "impermeable"), **less water reabsorbed**, **large volume of dilute urine**, **thirst**.
- **Low PI3K** (an enzyme in the insulin pathway of muscle cells) or type 2 diabetes: **fewer GLUT4** vesicles fuse with the membrane, **less glucose uptake**, blood glucose **stays high**.
- **Faulty glycogen synthase**: glucose can't be stored as glycogen, blood glucose **stays high**, glucose may appear in the **urine**.
- **Managing type 2 diabetes**: less carbohydrate, more exercise, weight loss, medication or insulin.
- A receptor gene on the **X chromosome**: a son gets his X from his **mother**, so he can't inherit it from his father.

10. Explain glucose test strips and biosensors (7 questions)

For up to 7 marks, give the biosensor chain from "Measuring glucose" in order, ending with a current **proportional** to the glucose concentration and a **digital reading**. For a test strip, it is glucose oxidase, then peroxidase, then the chromogen's colour compared with a chart.

Variations you will meet:

- **Name the products:** A = gluconic acid (not "glutamic acid"), B = a **chromogen**.
- **Advantages of a biosensor:** quantitative, accurate, quick, blood glucose at the moment of testing, reusable, stores readings.
- Don't mix the two: a biosensor gives a current, not a colour.

11. Compare the endocrine and nervous systems (7 questions)

1. Write **matched pairs**, each with "whereas": hormones vs impulses; chemical vs electrical; blood vs neurones; widespread vs localised; slow vs fast; long-lasting vs short-lived.

Variations you will meet:

- **Why insulin is a cell-signalling molecule of the endocrine system:** it is a **hormone**; **secreted** by an endocrine gland (beta cells in the pancreas) in response to a stimulus; **travels in the blood**; binds **receptors on target cells**; causes a response.
- **Tick table** for ADH, glucagon and insulin: all bind cell surface receptors; ADH and glucagon make molecules move **into the blood** (insulin makes glucose move out of it); only ADH is released after detection by **osmoreceptors**.
- **Passage:** endocrine **glands**, **receptors**, **second messenger**, **collecting duct**.

12. Explain why stomata open and close, and their rhythms (6 questions)

1. **Open** in light for **CO₂ diffusion** into the leaf for **photosynthesis**; **close** at night or in water stress to cut **water loss by transpiration**.
2. **Describe a rhythm graph:** most open around midday, fewest around midnight, with **two paired values** (time and percentage).

Variations you will meet:

- **Rhythm continues in constant darkness:** shows control by **genes** (an internal rhythm); the lower peak shows **light** is also needed.
- **Factors that close stomata apart from time of day:** water stress (drought), high temperature, low humidity, high wind speed, high CO₂ concentration in the leaf, low light intensity.
- **An ABA graph:** as ABA in the xylem sap increases, stomatal conductance (water vapour loss) decreases steeply, then levels off; quote two pairs of values with units.
- **Why this homeostasis matters to the plant:** CO₂ for photosynthesis, water kept for turgidity and reactions, cooling by transpiration.

13. Calculate from kidney or glucose data (6 questions)

1. Pick the formula: **percentage change**, **percentage reabsorbed**, **rate** (change ÷ time), or **how many times** (ratio).
2. Read the graph carefully (to half a small square), and write the values you read.
3. Show the working and give the **decimal places** and **units** asked for. Missing units on a rate costs a mark.

Variations you will meet:

- **Percentage of filtrate water reabsorbed**, for example $\frac{150-1.2}{150} \times 100 = 99.2\%$.
- **Rate per year from age groups**: use the difference between the **midpoints** of the groups (20–29 to 80–89 is 60 years).
- **Rate of change of insulin** from a graph, in $\text{pmol dm}^{-3} \text{ min}^{-1}$.
- **How many times** the urea concentration increases from filtrate to urine: divide, round as asked, no units.

14. Relate medulla thickness or urine concentration to habitat (5 questions)

1. **Describe** the trend: thicker medulla, more concentrated urine (a positive correlation).
2. **Explain** with "Why desert mammals have thick medullas": longer loops, lower water potential in the medulla, more water reabsorbed from the collecting ducts, water conserved; high U : P means the animal tolerates water shortage.

Variations you will meet:

- **A frozen kidney**: the salty medulla freezes less hard than the cortex.
- **An animal that survives without drinking**: water from food, metabolic water from respiration, little sweating, concentrated urine.

15. State how and where urea is made (3 questions)

1. **Where**: the liver.
2. **How**: **deamination** of **excess amino acids** (the amino group is removed as ammonia, which is converted to urea).

16. Explain thermoregulation responses (3 questions)

Thermoregulation is not a separate learning outcome, but it is the classic example of the principles (outcome 2). For each response in "How homeostasis works", say what it does **and how**: vasoconstriction means less blood near the surface, so less heat is lost; shivering releases heat from respiration; raised hairs trap insulating air; less sweat means less evaporation.

Variations you will meet:

- **Countercurrent exchange** (arteries surrounded by veins in a flipper): heat passes from warm arterial blood to the cooler venous blood returning to the body, so less heat is lost from the flipper.

- **A mammal and a reptile** on one graph: the mammal's core temperature stays **constant** as the environment warms; the reptile's **rises** with it.

Worked examples

The bold codes show where marks are earned, as in Cambridge mark schemes. The number is how many marks.

- **M1** method mark: for a correct method, even if the numbers slip.
- **A1** accuracy mark: for a correct answer; it needs the M mark before it.
- **B1** mark for a correct result on its own, with no method needed.

Example 1

(a) State where urea is made in the body, and from what. **[2]**

(b) Describe how the structure of the glomerulus and the Bowman's capsule results in the formation of glomerular filtrate. **[5]**

(c) In one person the glomerular filtration rate is $120 \text{ cm}^3 \text{ min}^{-1}$, and 1.5 dm^3 of urine is produced each day. Calculate the percentage of the filtrate volume that is reabsorbed. Give your answer to one decimal place. **[2]**

(a) In the **liver B1**, from the **deamination of excess amino acids B1**.

(b) Any five of:

- the **afferent arteriole** is **wider** than the **efferent arteriole B1**;
- so there is a **high hydrostatic pressure** in the glomerular capillaries **B1**;
- fluid is forced through the **fenestrations** (gaps) in the capillary **endothelium B1**;
- the **basement membrane** acts as the **filter B1**;
- it stops **blood cells** and **large proteins** (above about 68 000 relative molecular mass) **B1**;
- the filtrate passes through the **slit pores** between **podocytes** into the capsule **B1**;
- water, glucose, amino acids, urea and ions pass through **B1**.

(c) Filtrate per day = $120 \times 60 \times 24 = 172\,800 \text{ cm}^3 = 172.8 \text{ dm}^3$. **M1** for converting both volumes to the same units per day.

$$\text{Percentage reabsorbed} = \frac{172.8 - 1.5}{172.8} \times 100 = 99.1\%. \text{ **A1**}$$

Example 2

A long-distance runner sweats heavily on a hot day and drinks very little.

- (a) Explain how the runner's hypothalamus and pituitary gland respond. [3]
- (b) Describe how ADH increases the reabsorption of water in the kidney. [5]
- (c) After ADH was injected into a volunteer, the rate of urine production fell from $4.8 \text{ cm}^3 \text{ min}^{-1}$ to $1.1 \text{ cm}^3 \text{ min}^{-1}$. Calculate the percentage decrease, to one decimal place. [2]
- (a) Sweating **lowers the water potential** of the blood. **Osmoreceptors** in the **hypothalamus** detect this **B1**. The hypothalamus **makes more ADH B1**, and the **posterior pituitary gland releases** it into the blood **B1**.
- (b) Any five of: ADH binds to **receptors** on the **collecting duct cells B1**; a G protein and adenylyl cyclase are activated and **cAMP** (a **second messenger**) is made **B1**; a **protein kinase** is activated **B1**; **vesicles** containing **aquaporins** move to and **fuse with the cell surface membrane facing the lumen B1**; the membrane becomes **more permeable to water B1**; **more water** moves **by osmosis** from the filtrate **into the blood** (down the water potential gradient to the medulla) **B1**; a **small volume of concentrated urine** is produced **B1**.
- (c) $\frac{1.1 - 4.8}{4.8} \times 100 = -77.1\%$ **M1**, so a decrease of **77.1% A1**.

Example 3

A volunteer drank a glucose solution at time 0. The table shows the concentrations of glucose and insulin in the volunteer's blood.

Time / min	0	30	60	90	120
Blood glucose / mmol dm^{-3}	5.0	8.4	6.6	5.2	4.8
Blood insulin / pmol dm^{-3}	60	380	250	110	70

- (a) Calculate the percentage increase in blood glucose concentration between 0 and 30 minutes. [2]
- (b) Calculate the mean rate of decrease in blood insulin concentration between 30 and 90 minutes. Give units. [2]
- (c) Explain how negative feedback returns the blood glucose concentration to its set point after 30 minutes. [4]
- (a) $\frac{8.4 - 5.0}{5.0} \times 100$ **M1** = 68.0% **A1**.
- (b) $\frac{380 - 110}{90 - 30} = \frac{270}{60}$ **M1** = 4.5 $\text{pmol dm}^{-3} \text{ min}^{-1}$ **A1** (the unit is needed for the mark).
- (c) Any four of: the **rise** is **detected by the pancreas** (beta cells) **B1**; **insulin** rises to **380 pmol dm^{-3} at 30 min B1**; more **GLUT4** in muscle cell membranes, so **more glucose uptake B1**; **glycogenesis** in liver and muscle cells **B1**; glucose **falls to 5.2 mmol dm^{-3} by 90 min**, near the set point **B1**; then **less insulin** is secreted (**70 pmol dm^{-3}) B1**.

Example 4

The percentage of open stomata on the leaves of a plant was 90% at 12:00 (midday) and 12% at 24:00 (midnight).

(a) Calculate the percentage decrease in open stomata from 12:00 to 24:00. Give your answer to one decimal place. [2]

(b) Explain why it is an advantage to the plant to open its stomata in the day and close them at night. [3]

(c) Describe the mechanism in guard cells that opens a stoma in the morning. [5]

(a) $\frac{90 - 12}{90} \times 100$ **M1** = 86.7% **A1**.

(b) Open in light to let **CO₂ diffuse in** for **photosynthesis** (the Calvin cycle) **B1**; closed at night, when there is **no photosynthesis B1**, to **reduce water loss by transpiration B1**.

(c) Any five of: **proton pumps** in the guard cell membrane use **ATP** to pump **H⁺ out B1**; the inside of the cell becomes **more negative B1**; **K⁺ channels open** and **K⁺ enters** the guard cells **B1**; the **water potential** of the guard cells **decreases B1**; **water enters by osmosis B1**; the cells become **turgid B1**; the **thicker inner wall** stretches less, so the cells **bend apart** and the pore opens **B1**.

Common mistakes

- **Writing "glucagon" for "glycogen"** (or the reverse). Glucagon is the hormone; glycogen is the store it breaks down.
- **Saying glucagon itself is broken down to glucose**, or that glucagon "directly" breaks glycogen down. Glucagon is a **signal**: it binds a receptor, and enzymes inside the liver cell do the work.
- **Saying the hypothalamus "secretes" ADH or the pituitary "produces" it**. The hypothalamus **makes** it; the **posterior** pituitary **releases** it.
- **Water moving the wrong way in the collecting duct**. Under ADH, water is **reabsorbed** from the filtrate **into the blood**. Say "by **osmosis**, down a **water potential** gradient", not "down a concentration gradient", and never "by active transport through aquaporins".
- **Saying the membrane becomes "impermeable"** when ADH can't bind, or that aquaporins "close" or "stop binding". Fewer aquaporins are **added**, so it is **less permeable**.
- **Explaining ultrafiltration with diffusion or osmosis**. It is driven by **hydrostatic pressure**. The filter is the **basement membrane**.
- **Missing out "cell surface membrane"** for where receptors are, or saying glucagon binding "produces" a G protein. It **activates** a G protein.
- **Writing "negative feedback" when the answer is "homeostasis"** (or the reverse). Homeostasis is the overall process of keeping conditions constant; negative feedback is the mechanism.
- **Describing ions and water moving into "stomata"**. A stoma is a hole. Everything moves into and out of the **guard cells**.

- **"Glutamic acid"** instead of **gluconic acid**, and confusing a biosensor (a current) with a test strip (a colour).

How to get the marks

- **"Name" / "state" / "identify"**: one precise term ("posterior pituitary", "podocyte", "cAMP", "negative feedback"). Don't give two answers.
- **"Describe" a process**: the steps **in order**, one mark each. The 6–7 mark parts reward a full chain, so don't stop after three steps.
- **"Explain"**: link each step with "so": high pressure **so** fluid is forced out; more aquaporins **so** more permeable **so** more water reabsorbed.
- **"Describe" a graph**, or **"with reference to Fig. ..."**: the trend and turning points, with **times, values and units** quoted from the figure.
- **"Suggest"**: apply the normal mechanism to the new situation, then say what goes wrong and the effect on the blood or urine.
- **Compare**: matched pairs with "whereas".
- **Calculations**: show the working, give the decimal places asked for, and units for rates. State a percentage **decrease** as a positive number with the word "decrease".
- **Say where things move from and to**: "from the filtrate into the blood", "out of the guard cells".

Quick check

1. Name (a) the receptors that detect a change in blood water potential and where they are, (b) the structure that releases ADH, (c) the second messenger in the glucagon pathway.
2. In a desert rodent, urea makes up 0.05% of the blood plasma and 3.60% of the urine. Calculate how many times more concentrated the urea is in the urine, and suggest what this shows about the rodent's kidneys.
3. Give three features of proximal convoluted tubule cells and say how each helps selective reabsorption.
4. A dog's kidneys form 60 dm^3 of glomerular filtrate in a day, and the dog produces 0.9 dm^3 of urine. Calculate the percentage of the filtrate volume that is reabsorbed, to one decimal place. Then state which part of the nephron reabsorbs all of the glucose.
5. Explain why a urine test strip that contains glucose oxidase, peroxidase and a chromogen changes colour when glucose is present.

Answers

1. (a) **Osmoreceptors** in the **hypothalamus**. (b) The **posterior pituitary gland**. (c) **Cyclic AMP (cAMP)**.
2. $\frac{3.60}{0.05} = 72$ times. The kidneys reabsorb a great deal of water (long loops of Henle, a thick medulla), so the urine is very concentrated: an adaptation to conserve water.
3. Any three rows of the PCT table in Understand it, for example: **microvilli**, a large surface area for cotransporters; **many mitochondria**, ATP for the Na^+/K^+ pumps; **tight junctions**, so everything passes through the cells.
4. $\frac{60 - 0.9}{60} \times 100 = 98.5\%$. All the glucose is reabsorbed in the **proximal convoluted tubule**.
5. **Glucose oxidase** oxidises glucose to **gluconic acid and hydrogen peroxide**. **Peroxidase** uses the hydrogen peroxide to **oxidise the chromogen**, which is coloured when oxidised. More glucose makes more hydrogen peroxide, so a darker colour, which is compared with a colour chart.

Past questions to try

- **9700/42/O/N/24 Q1**: parts of the Bowman's capsule, conditions for ultrafiltration, a filtrate and urine table, and the response to sweating.
- **9700/43/M/J/23 Q6**: the basement membrane, the percentage of filtrate water reabsorbed, and ADH on the collecting duct.
- **9700/43/M/J/24 Q6**: why stomata open and close, and the full opening mechanism.
- **9700/42/O/N/23 Q6**: the glucagon pathway on a diagram, liver processes when blood glucose falls, and test strips vs biosensors.