

Homeostasis

A-Level Biology 9700 · Topic 14 revision notes

Everything from the 5 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.

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|--|---|
| 1. <u>Principles of homeostasis</u> | 3. <u>Osmoregulation and ADH</u> |
| 2. <u>The kidney: filtering and reclaiming</u> | 4. <u>Cell signalling and blood glucose</u> |
| | 5. <u>Stomata: homeostasis in plants</u> |

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1 Principles of homeostasis

Syllabus 14.1

Homeostasis is the maintenance of a constant internal environment: **core temperature**, **blood glucose concentration** and **blood water potential** are all kept within narrow limits around a **set point**. This matters because enzymes work best within a narrow range of temperature and pH, and cells shrink or swell if the water potential of the tissue fluid changes. A change away from the set point is a **stimulus**, which may be **internal** (more heat from respiration during exercise) or **external** (a cold day). **Receptors** detect it; a **coordination system**, either the **nervous system** (fast, short-lived, impulses along neurones) or the **endocrine system** (slower, longer-lasting, hormones in the blood), sends instructions; **effectors**, which are **muscles or glands**, bring about a response. In **negative feedback** the response reverses the original change, so the value returns towards the set point.

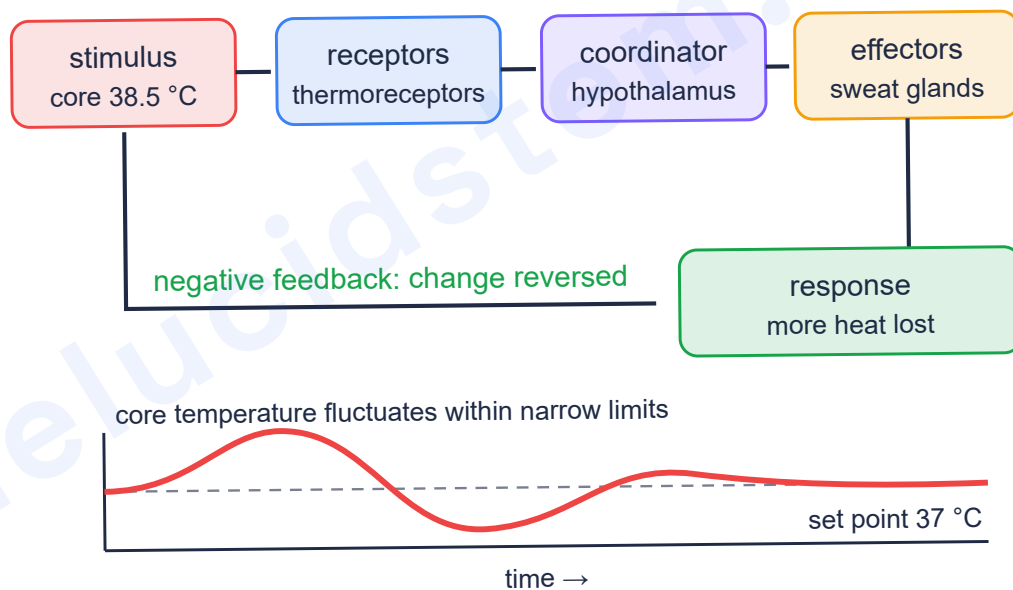


Fig. 1: the components of a negative feedback loop, using a rise in core temperature as the stimulus

Detect, coordinate, respond.

- ✓ **Homeostasis** = keeping the internal environment within narrow limits.
- ✓ **Receptor** detects; **coordinator** sends instructions; **effector** (muscle or gland) responds.
- ✓ **Negative feedback:** the response reverses the change.
- ✓ **Nervous** = fast and brief; **endocrine** = slower and longer-lasting.

Watch out!

Negative feedback does not mean that something bad happens. It means the response is in the **opposite direction** to the change: a rise causes responses that lower the value, a fall causes responses that raise it.

Arterioles do not move up and down in the skin. Vasodilation and vasoconstriction change the **diameter** of arterioles, which changes how much blood flows through the surface capillaries.

2 The kidney: filtering and reclaiming

Syllabus 14.1

Excess amino acids cannot be stored, so in the **liver** they are **deaminated**: the amine group is removed as ammonia and converted into **urea**, which the kidneys excrete. Each kidney has a **fibrous capsule**, an outer **cortex**, an inner **medulla** and a **renal pelvis** that drains into the **ureter**; it is supplied by branches of the **renal artery** and drained by the **renal vein**. Its functional units are about a million **nephrons**: **glomerulus** and **Bowman's capsule**, **proximal convoluted tubule**, **loop of Henle**, **distal convoluted tubule** and **collecting duct**. In **ultrafiltration**, high hydrostatic pressure in the glomerulus (the afferent arteriole is wider than the efferent) forces water and small solutes through the endothelium, the **basement membrane** and the gaps between **podocytes**; cells and large proteins stay in the blood. In **selective reabsorption** in the PCT, Na^+/K^+ pumps and cotransporters, with microvilli and many mitochondria, return all the glucose and amino acids, most ions and much water to the blood.

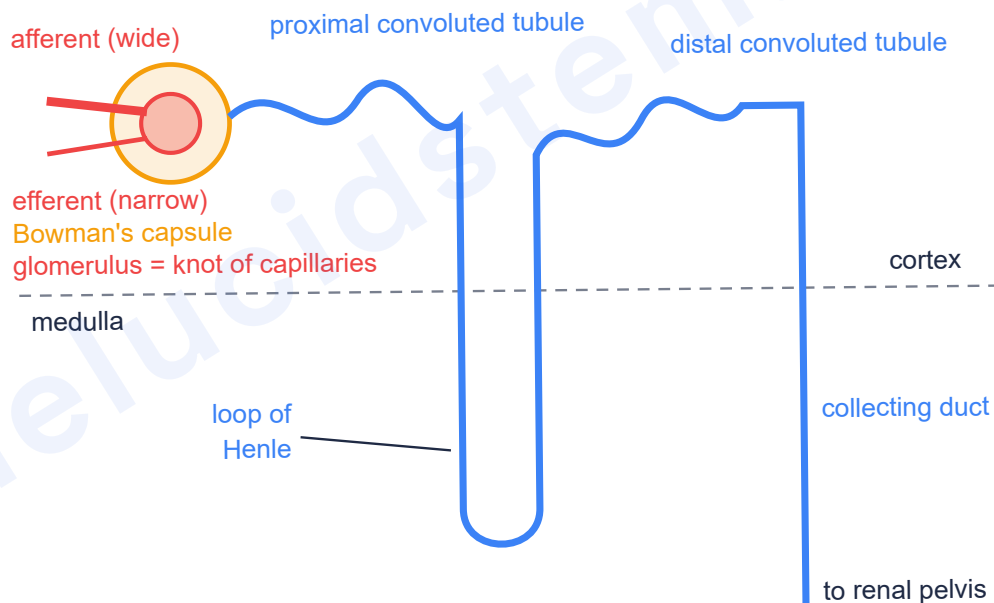


Fig. 1: a nephron and its blood supply; the Bowman's capsule and convoluted tubules lie in the cortex, the loop of Henle and collecting duct in the medulla

Liver, filter, reclaim.

- ✓ **Urea** is made in the liver by deamination of excess amino acids.
- ✓ **Afferent wider than efferent** = high pressure in the glomerulus.
- ✓ **Basement membrane** is the filter; cells and large proteins stay in the blood.
- ✓ **PCT:** Na^+ pumped out basally, cotransport in apically; microvilli and mitochondria.

Watch out!

Urea is made in the **liver**, not in the kidney. The kidney only removes urea that the blood brings to it.

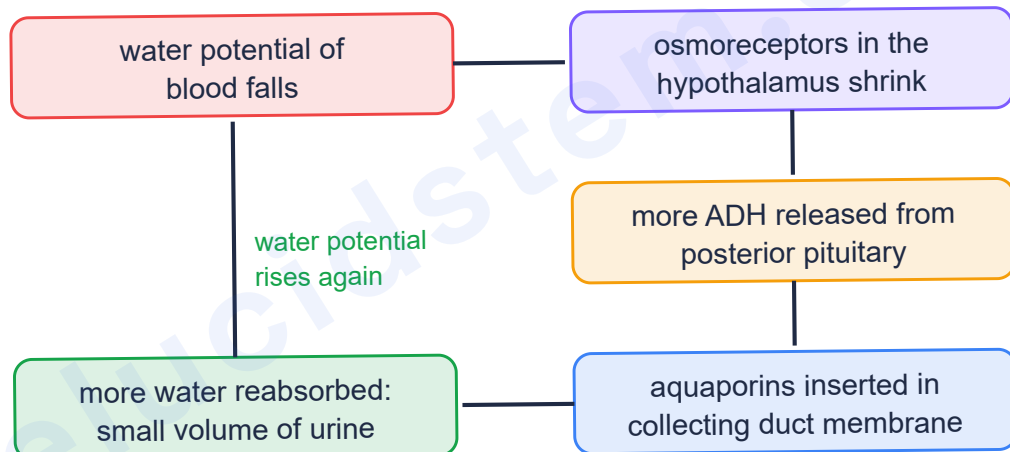
Ultrafiltration is not selective: everything small enough passes through, including glucose and amino acids. The selecting is done afterwards, by reabsorption in the PCT.

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3 Osmoregulation and ADH

Syllabus 14.1

Osmoregulation is the control of the **water potential of the blood**. **Osmoreceptors** in the **hypothalamus** detect it. When the water potential falls (after sweating, or eating salty food), they lose water by osmosis and shrink, stimulating neurosecretory cells; these make **ADH** (antidiuretic hormone) in the hypothalamus and it is released from their endings in the **posterior pituitary gland** into the blood. ADH binds to receptors on the cells of the **collecting ducts**, triggering vesicles containing **aquaporins** (water channel proteins) to fuse with the membrane facing the lumen. The duct wall becomes more permeable, more water moves by **osmosis** into the concentrated tissue fluid of the medulla and then the blood, and a **small volume of concentrated urine** is made. When the water potential rises, less ADH is released, aquaporins are taken back into vesicles and a **large volume of dilute urine** results. This is **negative feedback**.



the reverse happens when the water potential of the blood rises:
less ADH, aquaporins removed, large volume of dilute urine

Fig. 1: negative feedback control of the water potential of the blood by ADH

Detect, release, insert.

- ✓ **Receptors:** osmoreceptors in the hypothalamus.
- ✓ **ADH** made in the hypothalamus, released from the **posterior** pituitary.
- ✓ **ADH** → aquaporins inserted in the collecting duct luminal membrane.
- ✓ **Water moves by osmosis**; ADH only changes permeability.

Watch out!

ADH does not pump water. It only changes the **permeability** of the collecting duct to water; the water moves passively by **osmosis** into the concentrated medulla.

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4 Cell signalling and blood glucose

Syllabus 14.1

Blood glucose is kept near 5 mmol dm^{-3} by **negative feedback**. The α and β cells of the **islets of Langerhans** in the pancreas are both receptors and the source of the hormones. When glucose is high, **β cells** secrete **insulin**: in **muscle cells** vesicles with **GLUT4** transporters fuse with the cell surface membrane, so more glucose enters by facilitated diffusion; in **liver cells** (and muscle) enzymes for **glycogenesis** are activated, and glucose is respired faster. When glucose is low, **α cells** secrete **glucagon**, which acts on **liver cells**: it binds to a **cell surface receptor**, causing a **conformational change** that activates a **G protein**, which stimulates **adenylyl cyclase** to make **cyclic AMP** (the **second messenger**). cAMP activates **protein kinase A**, starting an **enzyme cascade** of phosphorylations that **amplifies** the signal until **glycogen phosphorylase** breaks down glycogen to glucose. **Test strips** and **biosensors** measure glucose using **glucose oxidase** (glucose to gluconic acid and hydrogen peroxide) and, on strips, **peroxidase** with a colourless chromogen that becomes coloured.

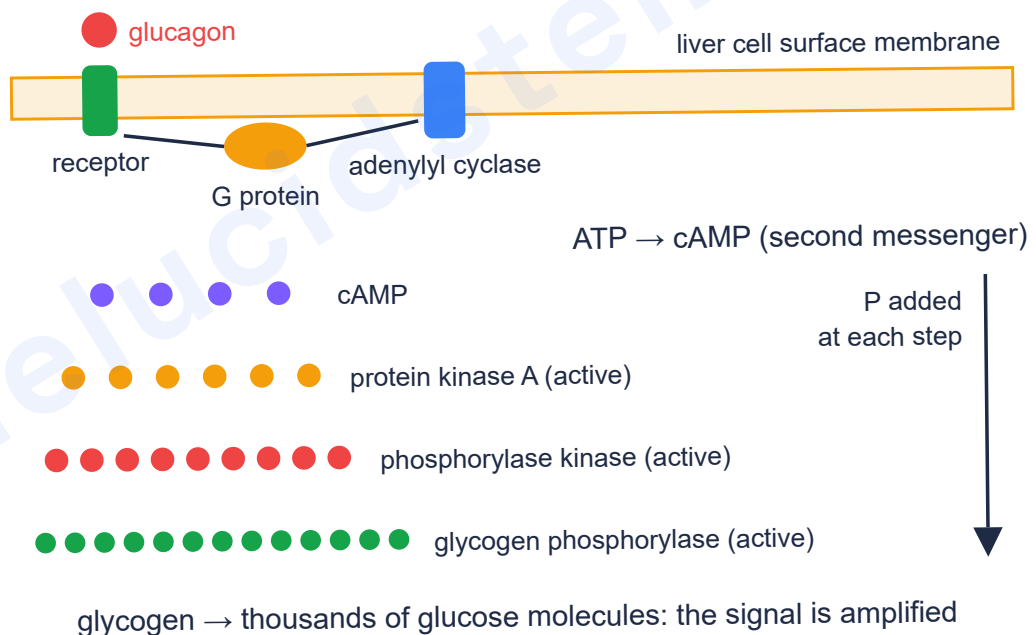


Fig. 1: the glucagon signalling pathway in a liver cell; each active enzyme activates many molecules of the next, so the signal is amplified

First, second, cascade.

- ✓ **Glucagon** (first messenger) → receptor → G protein → adenylyl cyclase.
- ✓ **cAMP** (second messenger) → protein kinase A → phosphorylation cascade.
- ✓ **Insulin:** GLUT4 in muscle, glycogenesis in liver. **Glucagon:** liver only.
- ✓ **Strip:** glucose oxidase + peroxidase + chromogen. **Biosensor:** current.

Watch out!

The hormone is the **first messenger**; it never enters the cell. **cAMP** is the **second messenger** that carries the signal through the cytoplasm.

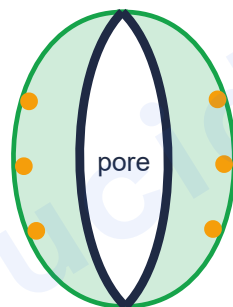
Glycogen, glucagon and glycogenesis are easy to confuse. **Glucagon** is the hormone; **glycogen** is the storage polysaccharide; **glycogenesis** makes glycogen; **glycogenolysis** breaks it down.

5 Stomata: homeostasis in plants

Syllabus 14.2

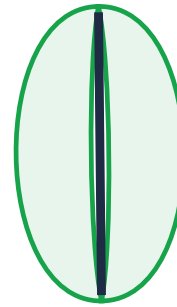
Stomata **open and close in response to environmental conditions**. Opening lets **carbon dioxide** diffuse in for photosynthesis; closing reduces **water loss by transpiration**, so the size of the aperture is a balance between the two. Stomata usually open in light and close in darkness, and they also follow a **daily (circadian) rhythm** that continues even in constant conditions. Each stoma is bordered by two **guard cells** with chloroplasts and **unevenly thickened walls**; the inner wall next to the pore is thicker and cellulose microfibrils run around the cell. To open, ATP-driven proton pumps move H^+ out, K^+ ions flow in, the **water potential** of the guard cells falls, water enters by **osmosis** and the turgid cells bow apart. To close, K^+ leaves, water follows and the cells become flaccid. In **water stress** the plant makes **abscisic acid (ABA)**, which binds to guard cell receptors and causes Ca^{2+} ions to enter the cytoplasm as a **second messenger**; this opens channels so K^+ and anions leave and the stomata close.

open (turgid guard cells)



K^+ in, water in by osmosis
thick inner walls: cells bow apart

closed (flaccid guard cells)



K^+ out, water out by osmosis
night, or ABA in water stress

open: CO_2 in for photosynthesis, but water lost

closed: water conserved, but little CO_2 uptake

Fig. 1: an open stoma with turgid guard cells and a closed stoma with flaccid guard cells, seen from above

Ions, osmosis, shape.

- ✓ **Opening:** H^+ pumped out, K^+ in, water potential falls, water in.
- ✓ **Thick inner wall** makes turgid guard cells bow apart.
- ✓ **ABA** (water stress) $\rightarrow Ca^{2+}$ second messenger $\rightarrow K^+$ out $\rightarrow$ close.
- ✓ **Trade-off:** CO_2 in versus water vapour out.

Watch out!

Stomata do not open because the plant needs to transpire. They open to let **carbon dioxide in**; water loss is the unavoidable cost, which is why they close when water is short.

When K^+ enters, the guard cell's water potential becomes **lower** (more negative), so water moves **in**. Do not say the water potential rises as ions enter.