

Homeostasis, hormones and the kidney

Revision notes · Negative and positive feedback, homeostasis and thermoregulation, hormones switching genes, and the kidney's role in excretion and osmoregulation.

For Pearson Edexcel International AS Biology XBI11 and International A Level Biology YBI11. **A Level only** is IA2 content (Units 4 to 6), not needed for the International AS.

Homeostasis, hormones and the kidney **Spec 7.16-7.22** **A Level only**

Negative and positive feedback **Spec 7.16**

Most control systems in the body contain the same components: a **receptor** detects a change in a factor, a coordination centre (for example the hypothalamus) processes the information, and an **effector** (a muscle or gland) brings about a response.

Negative feedback

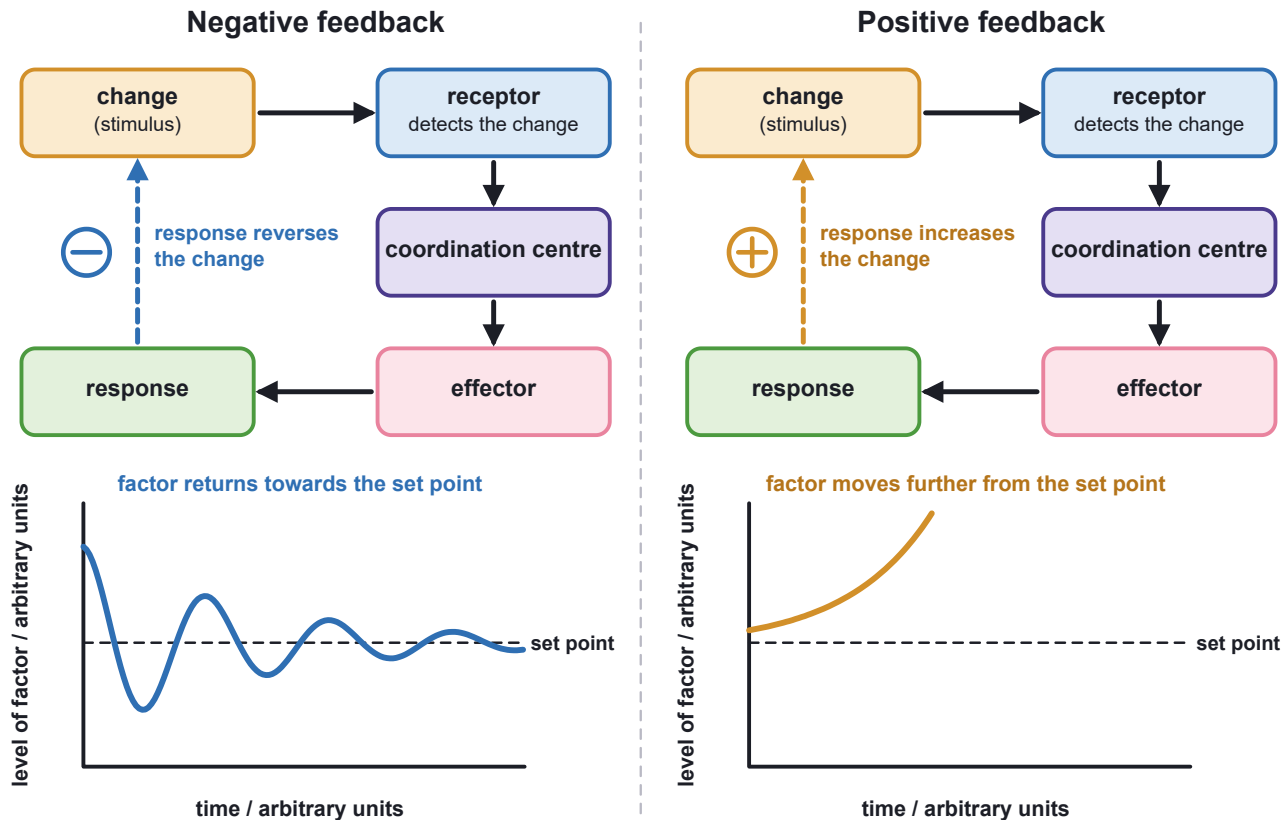
In **negative feedback**, the response reverses the original change. If the factor rises above the set point, the response makes it fall; if it falls below, the response makes it rise. The factor therefore fluctuates around the set point within narrow limits. Having receptors and effectors that work in opposite directions (for example vasoconstriction and vasodilation) gives control in both directions.

1. A factor changes from its set point (the stimulus).
2. Receptors detect the change and send information to the coordination centre.
3. The coordination centre sends signals (nerve impulses or hormones) to effectors.
4. Effectors produce a response that reverses the change.
5. The factor returns to its set point and the stimulus is removed, so the response is switched off.

Positive feedback

In **positive feedback**, the response increases the change away from the set point. It is not used to maintain a steady state. It is useful when a rapid, complete change is needed, for example the stimulation of uterine contractions by oxytocin during birth, and the opening of voltage-gated sodium channels in an action potential. If it is not stopped it can be harmful.

Common mistake: 'Negative' does not mean the effect is bad or that the response decreases the factor. Negative feedback reverses whichever change occurred. Positive feedback amplifies it.



Negative feedback reverses a change; positive feedback amplifies it.

Homeostasis and thermoregulation Spec 7.17

Homeostasis is the maintenance of a stable internal environment (for example body temperature, blood glucose concentration, blood water potential and pH) within narrow limits, by negative feedback. It is a state of **dynamic equilibrium**: conditions continually change slightly and are continually corrected, so they fluctuate around a set point.

It is important because enzymes work best at a particular temperature and pH, and cells need a stable water potential and a constant supply of glucose and oxygen for respiration. During exercise, muscle respiration increases heat production, CO₂ concentration and the demand for glucose and oxygen, so conditions must be corrected to prevent damage.

Thermoregulation and the hypothalamus

The **hypothalamus** contains thermoreceptors that detect the temperature of the blood flowing through it (core temperature). Thermoreceptors in the skin also send information to the hypothalamus. The hypothalamus acts as the coordination centre and sends impulses to the effectors.

Responses to a change in core temperature		
Response	If core temperature rises (e.g. exercise)	If core temperature falls
Skin arterioles	Vasodilation: more blood flows near the surface, so more heat is lost by radiation	Vasoconstriction: less blood flows near the surface, so less heat is lost
Sweat glands	Sweat secreted: evaporation of water takes heat from the skin	Little or no sweat
Skeletal muscles	No shivering	Shivering: rapid involuntary contractions release heat from respiration
Hair erector muscles	Relax: hairs lie flat (little effect in humans)	Contract: hairs stand up, trapping an insulating layer of air
Metabolic rate	Reduced	Increased (e.g. by hormones such as adrenaline and thyroxine)
Behaviour	Seek shade, remove clothing	Seek warmth, add clothing

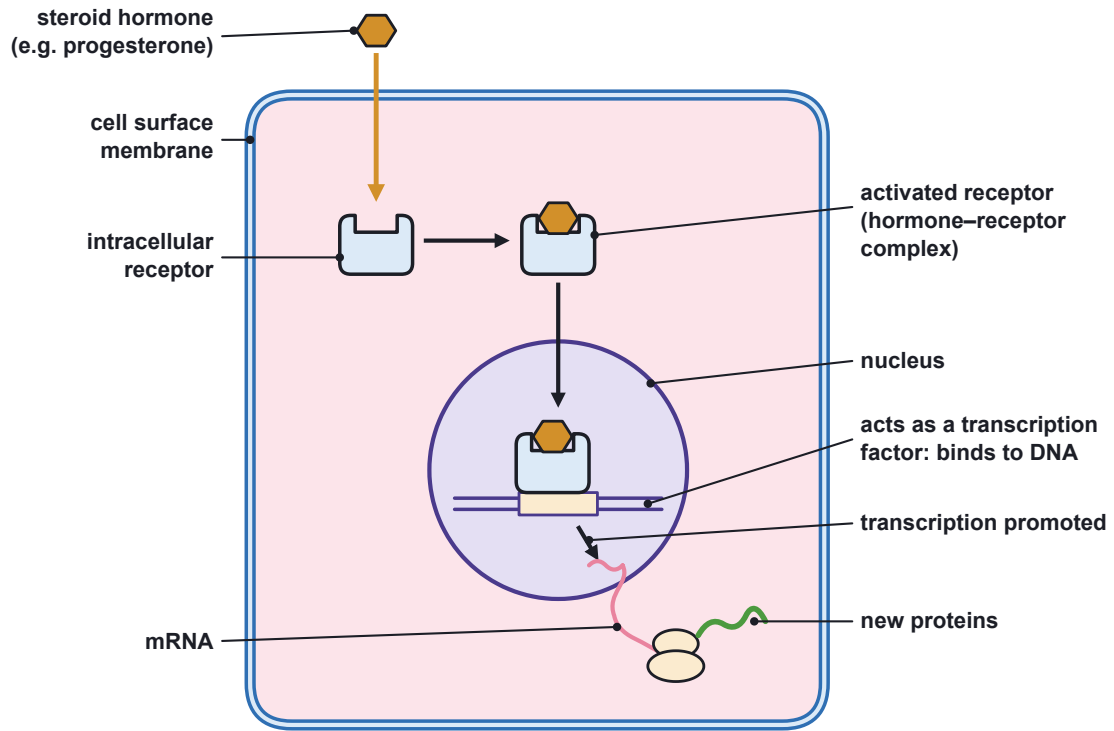
Exam tip: In exercise, say that heat released by respiration in muscle raises core temperature, the hypothalamus detects it, and effectors such as sweat glands and skin arterioles lower it again (negative feedback).

Hormones and transcription factors Spec 7.22

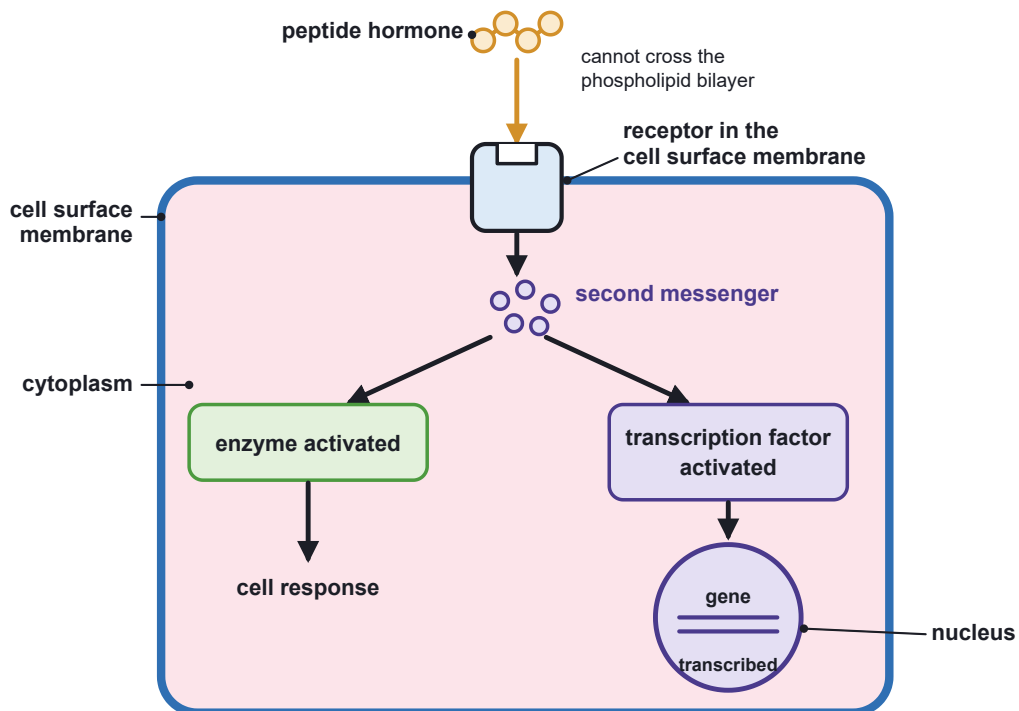
Transcription factors are proteins that bind to specific base sequences on DNA, near a gene. Some (activators) help RNA polymerase bind and so switch the gene on; others (repressors) block transcription and switch the gene off. Whether a gene is expressed, and how much protein is made, depends on which transcription factors are active in a cell.

Two ways in which hormones affect gene expression		
Feature	Steroid hormones (e.g. oestrogen)	Peptide hormones (e.g. insulin, glucagon)
Solubility	Lipid-soluble	Water-soluble
Entry to the cell	Pass through the phospholipid bilayer by diffusion	Cannot pass through the membrane
Receptor	Inside the cell (cytoplasm or nucleus): acts intracellularly	On the cell surface membrane: acts extracellularly
How gene expression changes	The hormone-receptor complex acts as a transcription factor: it binds to DNA, switching a gene on (or off), so mRNA and a protein are made	Binding activates a second messenger (e.g. cyclic AMP) inside the cell, which triggers a cascade that activates or inactivates transcription factors and enzymes
Speed of response	Slower: protein must be made	Often quicker, because enzymes already present are altered

Exam tip: Peptide hormones act without entering the cell because they cannot cross the phospholipid bilayer. Steroid hormones can, so their receptor is inside the cell.



Steroid hormones enter the cell and act as **transcription factors**.



Peptide hormones cannot cross the membrane, so they work through a **second messenger**.

Structure of the mammalian kidney Spec 7.18

Gross structure

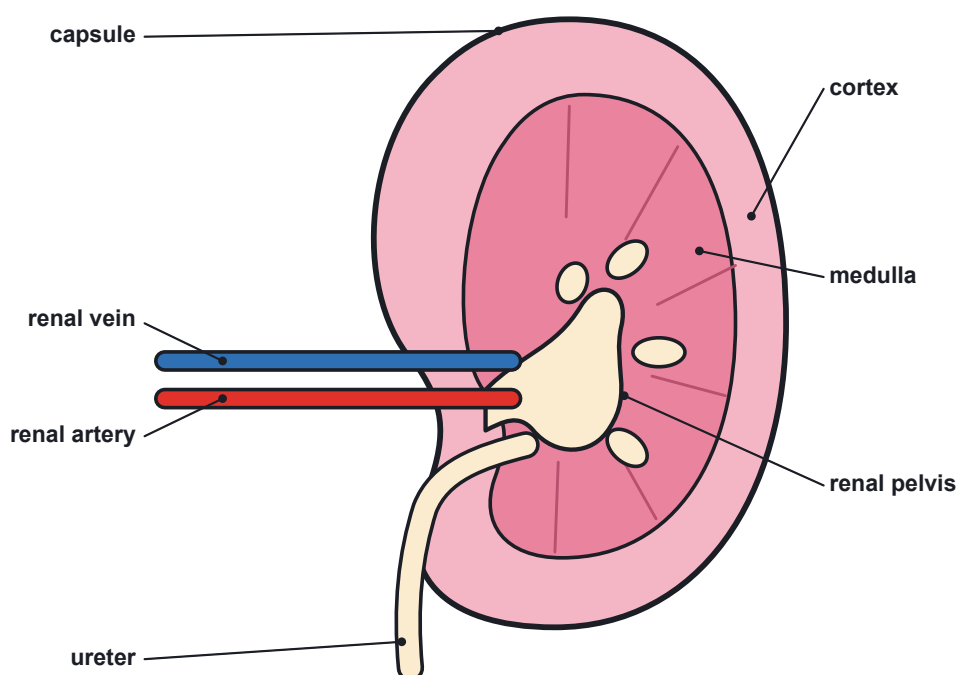
- Renal artery brings oxygenated blood with urea; renal vein carries blood away.
- Fibrous capsule around the outside.
- Cortex: outer region, containing the glomeruli, Bowman's capsules and convoluted tubules.
- Medulla: inner region, containing the loops of Henle and collecting ducts.

- Renal pelvis: the funnel-shaped cavity that collects urine and drains into the ureter, which leads to the bladder.

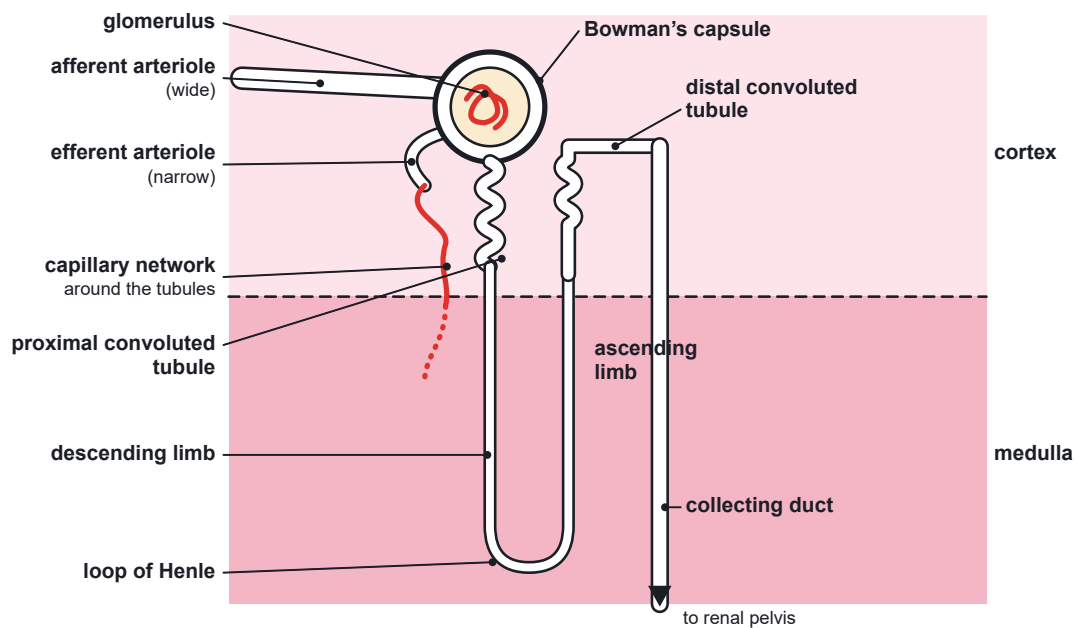
Microscopic structure: the nephron

Parts of a nephron		
Part	Position	Structure and role
Glomerulus	Cortex (inside Bowman's capsule)	Knot of capillaries; the afferent arteriole is wider than the efferent arteriole, which creates high pressure
Bowman's capsule	Cortex	Cup-shaped; the inner layer has podocytes; collects the filtrate
Proximal convoluted tubule	Cortex	Cuboidal epithelium with microvilli and many mitochondria; reabsorbs most of the filtrate
Loop of Henle	Medulla (descends and ascends)	Creates a high solute concentration (low water potential) in the medulla
Distal convoluted tubule	Cortex	Adjusts the ion content of the filtrate
Collecting duct	Cortex to medulla to pelvis	Collects urine from many nephrons; water reabsorbed under the control of ADH

Blood flows from the renal artery to the afferent arteriole, glomerulus and efferent arteriole, then through a capillary network around the tubules (where substances are reabsorbed), and leaves in the renal vein.



Structure of the kidney in section.



A nephron, with the cortex / medulla boundary marked.

Urea production and ultrafiltration Spec 7.19

Making urea in the liver

1. Amino acids not needed for protein synthesis cannot be stored. In the liver, the amino group is removed from each excess amino acid (deamination), forming ammonia and a keto acid.
2. The keto acid can be respired or converted to carbohydrate or fat.
3. Ammonia is toxic and very soluble, so it is combined with carbon dioxide in the ornithine cycle (details are not required) to make urea, using ATP.
4. Urea is soluble and much less toxic. It is carried in the blood plasma to the kidneys.

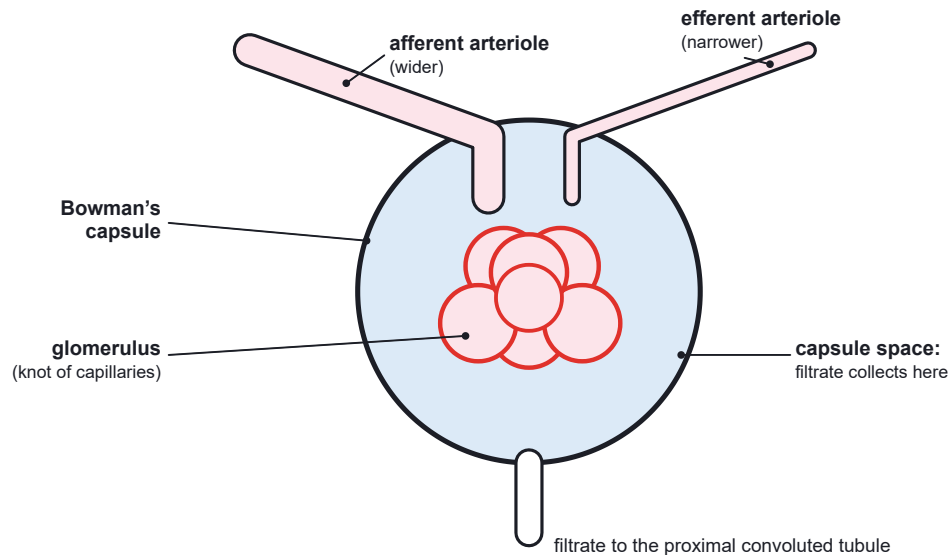
Ultrafiltration

Ultrafiltration is filtration at the molecular level. Blood in the glomerulus is at high hydrostatic pressure, because the afferent arteriole is wider than the efferent arteriole. This forces water and small solutes out of the capillaries into the Bowman's capsule, through three layers:

- the fenestrated capillary endothelium, whose cells have many small pores (fenestrations) through them;
- the basement membrane, a mesh of collagen and glycoproteins that acts as the filter and stops large proteins;
- the podocytes of the Bowman's capsule, which have filtration slits between their feet-like extensions.

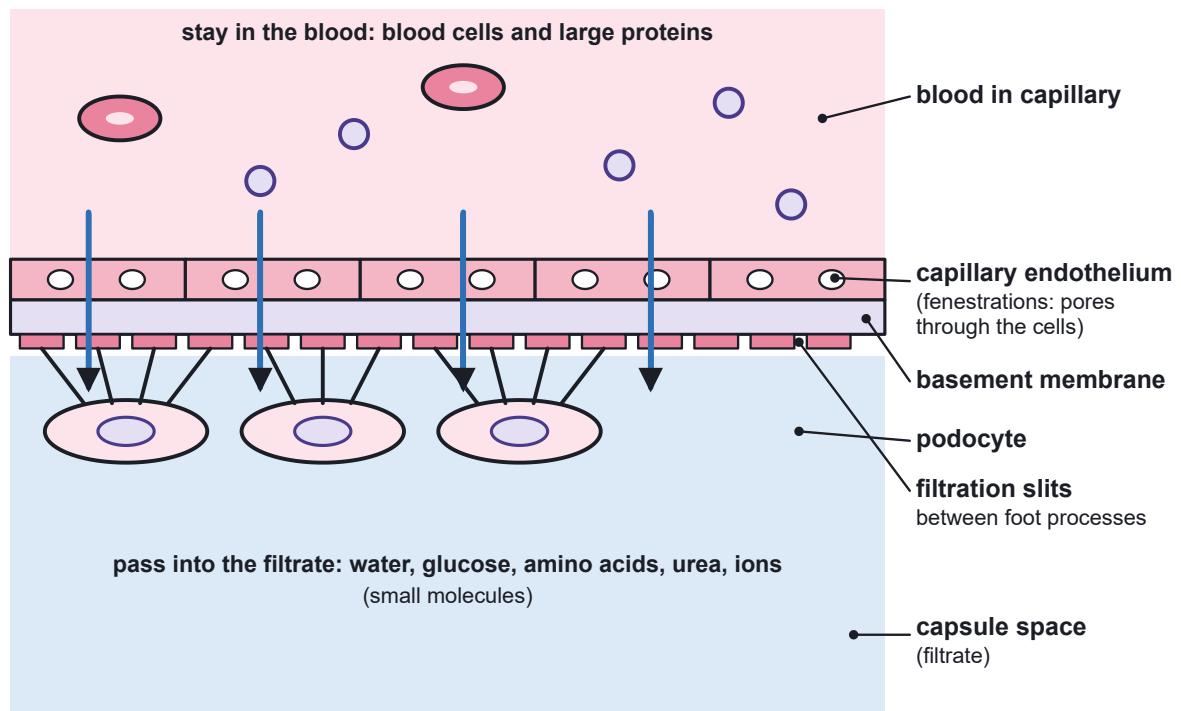
The **glomerular filtrate** contains water, glucose, amino acids, urea and inorganic ions. It does not contain blood cells or large plasma proteins, which are too large to pass through. The pressure is opposed by the water potential of the blood (which is lowered by the plasma proteins) and the pressure of fluid in the capsule. The volume filtered is about 125 cm³ per minute in humans.

Exam tip: State all three layers and the reason for the high pressure (wide afferent, narrow efferent arteriole). 'Ultrafiltration' needs a high pressure, not just a membrane.



wide afferent and narrow efferent arteriole: high blood pressure in the glomerulus

The wide afferent and narrow efferent arteriole keep the **pressure high** in the glomerulus.



Three layers filter the blood: **endothelium, basement membrane and podocytes**.

Selective reabsorption and the loop of Henle Spec 7.20

The proximal convoluted tubule

The cells lining the proximal tubule have microvilli (a large surface area) and many mitochondria (to supply ATP for active transport). They carry out **selective reabsorption**:

- Sodium ions are actively transported out of the cell into the blood side by sodium-potassium pumps, lowering the sodium concentration in the cell.
- Sodium ions then move into the cell from the filtrate down their concentration gradient through co-transporter proteins, carrying glucose or amino acids with them (co-transport). Glucose and amino acids then pass into the blood by facilitated diffusion.

- All of the glucose and amino acids are normally reabsorbed, as well as much of the sodium and chloride ions.
- Water follows by osmosis, because the water potential of the cells and blood is now lower. Most of the filtrate (about 80%) is reabsorbed here, and some urea diffuses out.

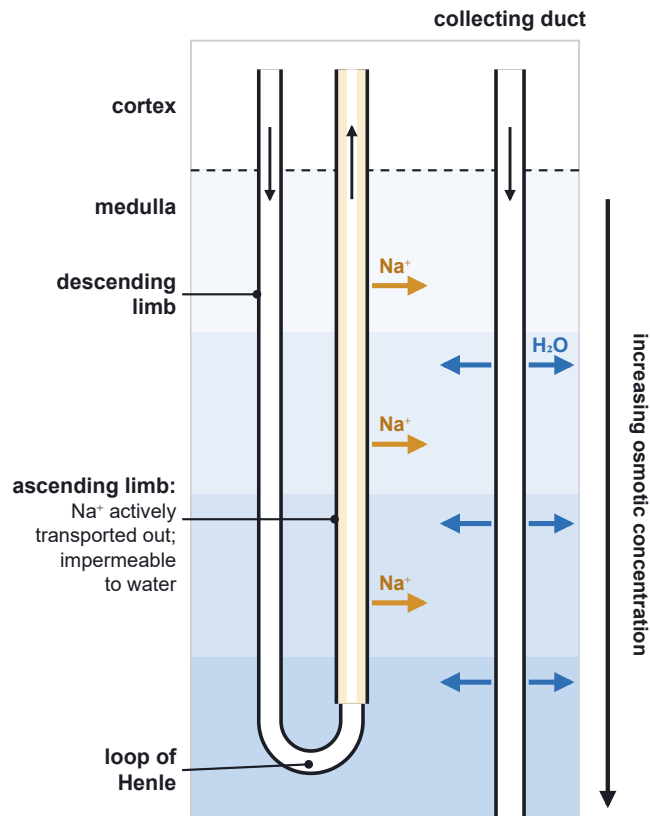
The loop of Henle as a countercurrent multiplier

The loop creates a high concentration of solutes (a low water potential) in the tissue fluid of the medulla, which increases the reabsorption of water from the filtrate in the collecting duct. It does this by using a **countercurrent multiplier** mechanism: the fluid flows in opposite directions in the two limbs, and a small difference at each level is multiplied into a large gradient along the whole loop.

1. In the ascending limb, which is impermeable to water, sodium and chloride ions are actively pumped out into the medulla. This lowers the water potential of the medulla tissue fluid.
2. In the descending limb, which is permeable to water but not to ions, water leaves the filtrate by osmosis into the medulla. The filtrate becomes more concentrated as it descends, so it is most concentrated at the bottom of the loop.
3. As the filtrate rises in the ascending limb, ions move out (they diffuse out from the lower part and are actively pumped out in the upper part), so the filtrate becomes more dilute again.
4. The concentration gradient in the medulla is kept steep, with the lowest water potential deepest in the medulla.
5. Blood capillaries (the vasa recta) carry away the reabsorbed water.

The filtrate then flows through the distal tubule and the collecting duct, which pass back down through the medulla. If the collecting duct is permeable to water, water moves out by osmosis down the water potential gradient, producing concentrated urine. Animals with long loops of Henle (such as desert mammals) have a steeper gradient and can produce a more concentrated urine.

Common mistake: The descending limb is permeable to water, while the ascending limb is not. Do not say that water is reabsorbed from the ascending limb.



The loop of Henle builds up a **high solute concentration in the medulla**, so water can be reabsorbed.

ADH and the control of plasma concentration Spec 7.21

The concentration of the blood plasma (its water potential) and the blood volume must be kept within narrow limits. This is **osmoregulation**, and it is controlled by negative feedback involving the hypothalamus, the pituitary gland and the hormone **ADH** (antidiuretic hormone).

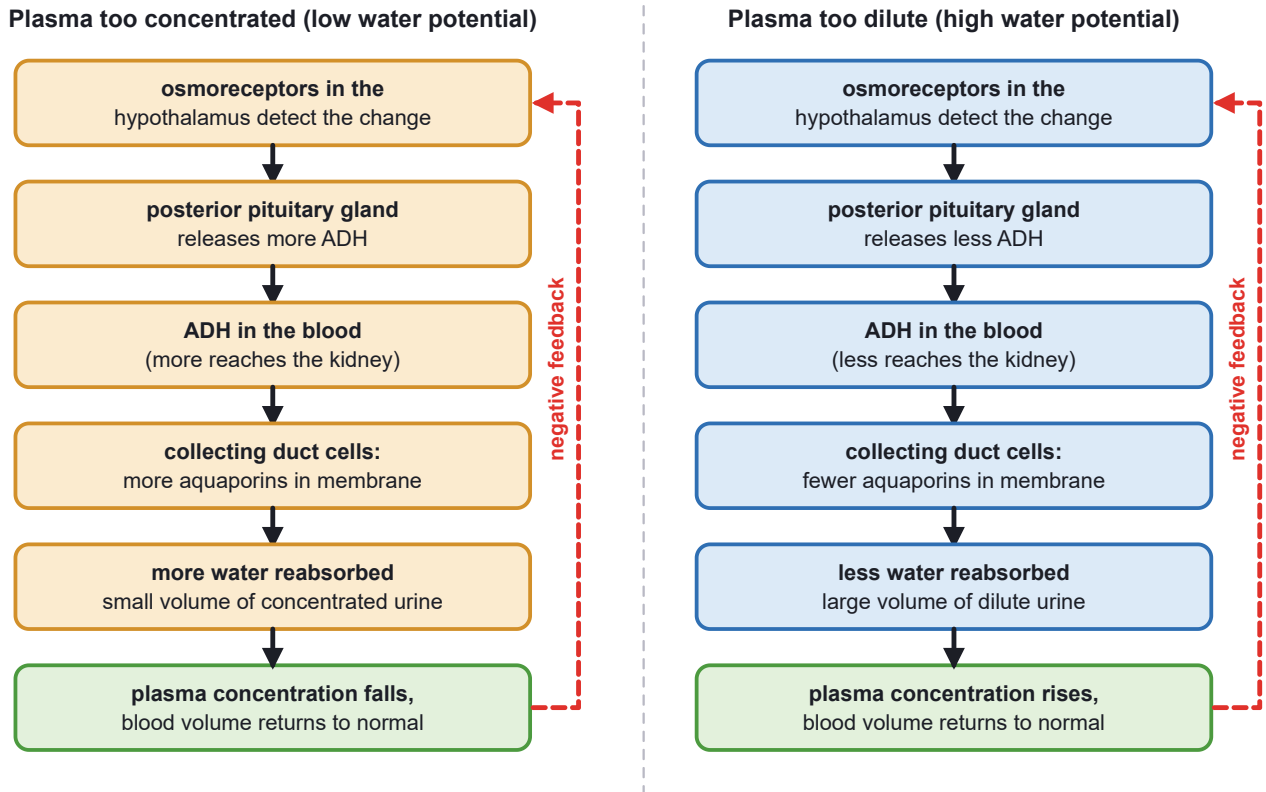
If the blood plasma becomes too concentrated (for example after sweating, or little water)

1. Osmoreceptors in the hypothalamus detect the low water potential of the blood: they lose water by osmosis and shrink.
2. The hypothalamus stimulates neurosecretory cells that make ADH. ADH passes down their axons to the posterior pituitary gland and is released into the blood.
3. ADH travels in the blood to the kidney and binds to receptors on the cell surface membranes of the collecting duct (and distal convoluted tubule) cells.
4. This activates a second messenger system that causes vesicles containing aquaporins (water channels) to fuse with the cell surface membrane. The walls therefore become more permeable to water.
5. More water leaves the collecting duct by osmosis into the concentrated medulla and returns to the blood. A small volume of concentrated urine is produced.
6. Plasma water potential and blood volume rise back to normal, so osmoreceptors are no longer stimulated and less ADH is released: negative feedback.

If the blood plasma is too dilute

The osmoreceptors are not stimulated, so less ADH is released. Fewer aquaporins are in the membrane of the collecting duct, so it is less permeable to water. Less water is reabsorbed and a large volume of dilute urine is produced. This lowers the blood volume and raises the concentration of the plasma.

Exam tip: Describe the whole loop: stimulus, receptor, hormone, target cells, response, then the effect that reverses the change. Mention the pituitary gland and aquaporins.



ADH adjusts **water reabsorption** in the collecting duct by negative feedback.

Quick check

1. What is negative feedback?
2. Which part of the brain contains the thermoreceptors that detect core temperature?
3. What forces fluid out of the glomerulus?
4. Which limb of the loop of Henle is impermeable to water?
5. What is the effect of ADH on the collecting duct?

Quick check answers

Homeostasis, hormones and the kidney

1. A change is detected and the response reverses it, returning the factor towards its set point.
2. The hypothalamus.
3. High hydrostatic pressure, caused by the afferent arteriole being wider than the efferent arteriole.
4. The ascending limb.
5. It makes the walls more permeable to water by inserting aquaporins, so more water is reabsorbed.