REVISION GUIDE

Keeping the inside *steady*

Homeostasis

Your body temperature, blood sugar and the saltiness of your blood hardly change, whatever you eat or wherever you are. Sensors, a control centre and effectors correct every drift, and the kidney balances water and waste.

12 chapters · a dry lab

The interactive guide, with every animation:

biologybybradford.com/guides/ib-biology-d3-3-homeostasis

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By the end you can

- [ ] Define homeostasis and name four variables that humans keep within limits D3.3.1
- [ ] Explain how negative feedback keeps a variable at its set point, from above and from below D3.3.2
- [ ] Explain how insulin and glucagon control blood glucose D3.3.3
- [ ] Describe the changes in type 1 and type 2 diabetes, with risk factors, prevention and treatment D3.3.4
- [ ] Explain thermoregulation as negative feedback, naming receptors, control centre and effectors D3.3.5
- [ ] Describe how humans lose and conserve heat, including brown adipose tissue D3.3.6
- [ ] Distinguish excretion from osmoregulation and say what the kidney does for each D3.3.7
- [ ] Explain ultrafiltration in the glomerulus and reabsorption in the proximal convoluted tubule D3.3.8
- [ ] Explain how the loop of Henle keeps the medulla salty D3.3.9
- [ ] Explain how ADH and aquaporins in the collecting duct control the water the body keeps D3.3.10
- [ ] Explain how blood supply to organs changes with sleep, rest and exercise D3.3.11

Tick each one when you can do it without the book.

D3.3.1 HOMEOSTASIS AS MAINTENANCE OF THE INTERNAL ENVIRONMENT

01 Holding *the inside* steady

You live in air that swings from freezing to scorching and eat meals hours apart, yet your cells sit in conditions that hardly change. **Homeostasis** is that steadiness. A variable is kept within preset limits around a **set point**, whatever happens outside.

Four variables matter most in humans: body temperature, blood pH, blood glucose concentration and blood osmotic concentration. Each is held steady because cells run on enzymes and membranes that only work well in a narrow range of conditions. The green band on each scale is its normal range; tap one to see why it matters.

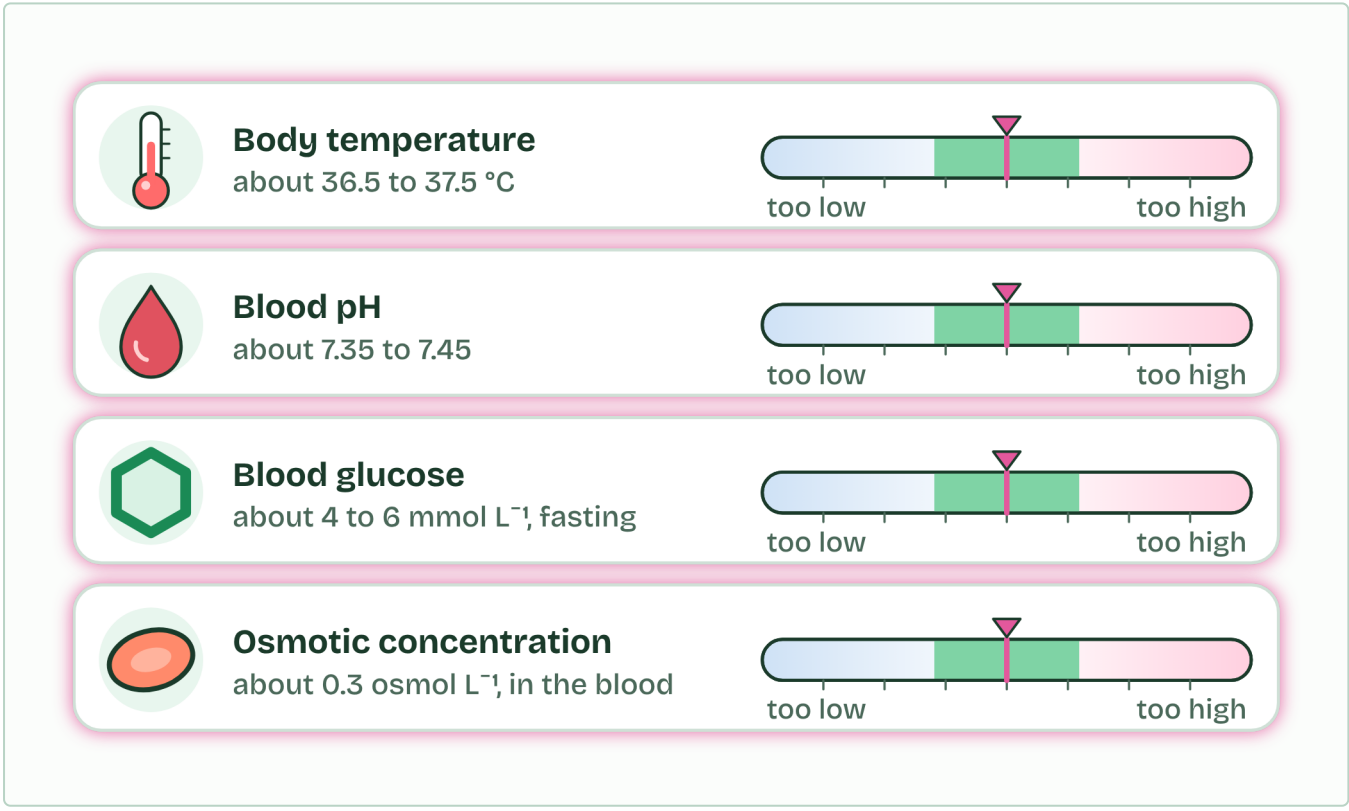
KEY POINTS

- A homeostatic variable is held within **preset limits**, not at an exact value.
- The four to know are **body temperature**, **blood pH**, **blood glucose** and **blood osmotic concentration**.
- The internal environment stays steady **even when the outside changes**.

KEY TERMS

homeostasis
The maintenance of the internal environment of an organism, keeping variables within preset limits despite changes in the external environment.

set point
The value of a homeostatic variable that the control system works to restore.



Body temperature about 37 °C. Enzymes work best in a narrow range: colder and reactions slow, hotter and proteins start to lose their shape. Sensors are thermoreceptors, and the control centre is the hypothalamus.

Blood pH about 7.4. A change in pH changes the shape of enzymes and other proteins. Carbon dioxide from respiration forms an acid in water, so the rate of breathing helps to hold the pH steady.

Blood glucose about 4 to 6 mmol L^{-1} before a meal. The brain depends on a steady supply of glucose. Too much damages blood vessels and draws water out of cells by osmosis.

Blood osmotic concentration the total concentration of dissolved particles, about 0.3 osmol L^{-1}. Too low and cells take in water and swell; too high and they lose water and shrink. The kidney controls it (chapters 8 to 11).

PREDICT

The air temperature drops from 20 °C to 5 °C. What happens to the temperature of the blood in a healthy person?

(A) It falls by about the same amount, because the body loses heat to the cold air

(B) It stays within a degree or so of 37 °C, because the body works to keep it there

(C) It rises, because the body speeds up to make heat and cannot slow down again

(D) It stays exactly the same, to many decimal places, because the body is a perfect thermostat

Decide before you look. Answer on page 34.

D3.3.2 NEGATIVE FEEDBACK LOOPS IN HOMEOSTASIS

02 A change that *switches itself off*

Every homeostatic system has the same four parts. A **receptor** detects the variable, a **control centre** compares it with the set point, and an **effector** changes something that pushes the variable back. The response is the opposite of the change, so it is **negative feedback**.

It works in both directions. If the variable rises above the set point the loop pushes it down, and if it falls below, the same kind of loop pushes it up, so it hovers around the set point. The loop switches itself off, because once the change has been reversed there is nothing left to trigger a response.

Positive feedback is the opposite: the response makes the change bigger, so the variable runs away from its set point. That is why it is not used for homeostasis. A rising temperature that caused more heat would not stop until the body was damaged. Positive feedback is used where a quick, all-or-nothing change is needed, as in childbirth or blood clotting.

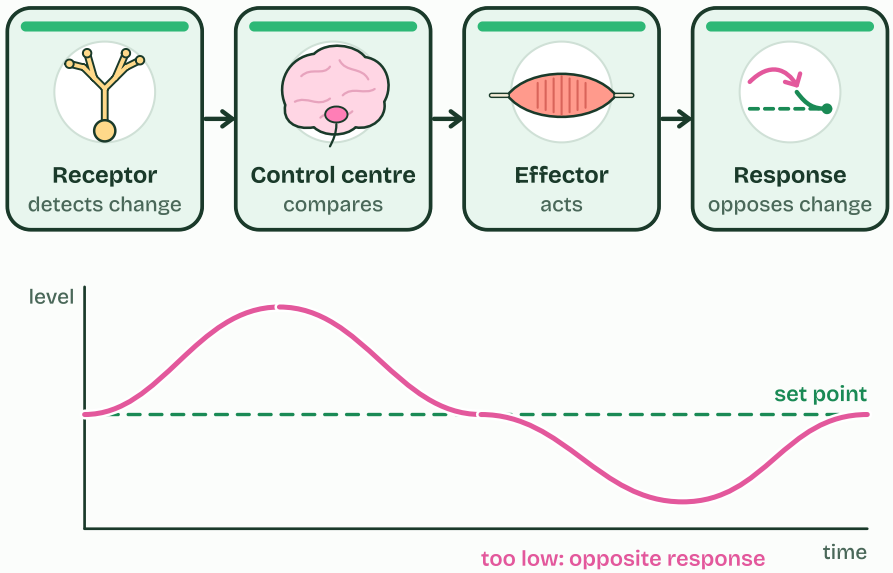
KEY TERMS

receptor
A cell or sense organ that detects a change in a variable.

control centre
The part of a control system, such as the hypothalamus or the pancreas, that compares the variable with its set point and sends instructions.

effector
A cell, tissue or organ, such as a muscle or a gland, that carries out the response.

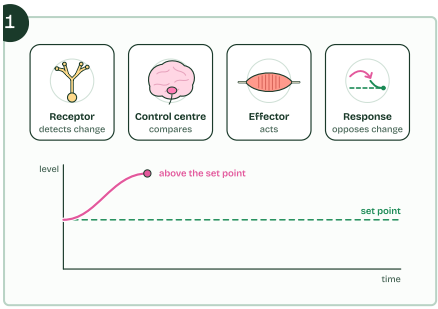
negative feedback
A control system in which the response reverses the change that triggered it, returning the variable to its set point.



STEP BY STEP

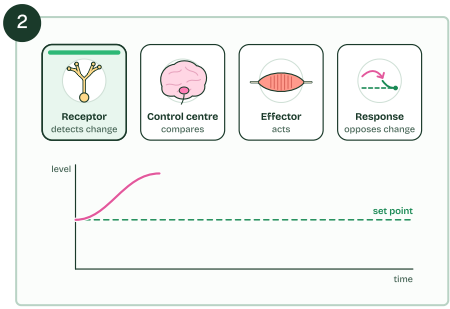
6 STEPS

1



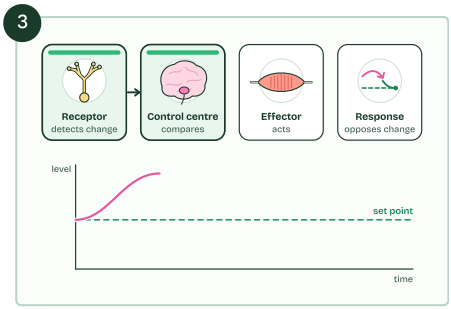
A change pushes the variable **above** its set point.

2



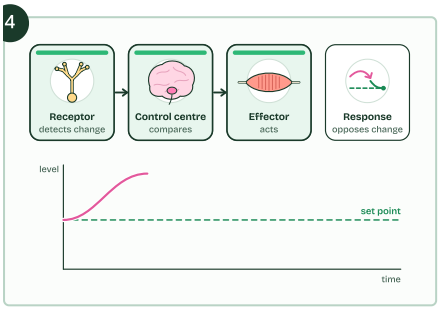
A **receptor** detects the change.

3



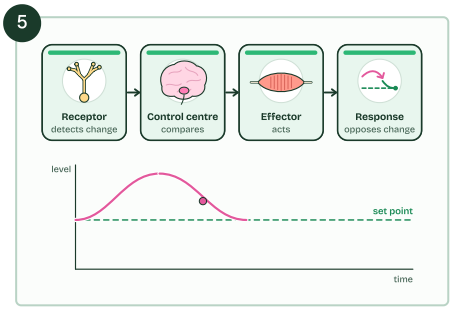
The **control centre** compares it with the set point and sends a signal.

4



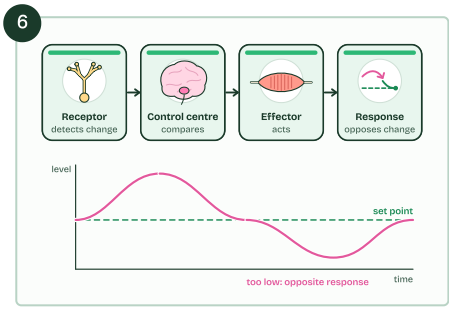
An **effector** acts on the signal.

5



The **response** opposes the change, so the level **falls back** to the set point.

6



If it falls **too low**, the same loop works the other way, and it returns to the set point.

PREDICT

A thermostat turns the heating on when a room is cold and off when it is warm enough. Why is this negative feedback?

(A) The heating always runs, but more slowly when the room is warm

(B) The response, heating, reverses the change that triggered it, a fall in temperature

(C) The response makes the room even colder, which is a bad outcome

(D) The thermostat is a machine and so cannot be feedback

Decide before you look. Answer on page 34.

IN THE EXAM

Why negative feedback keeps a variable steady, in four points:

1. A receptor detects a change from the set point.
2. A control centre sends a signal to an effector.
3. The effector produces a response that **reverses** the change.
4. The variable returns to the set point, and the response stops. It works for a rise or a fall.

03

D3.3.3 REGULATION OF BLOOD GLUCOSE, A ROLE OF HORMONES IN HOMEOSTASIS

Two hormones, *one set point*

Glucose is the fuel your cells burn, and blood glucose is held at about 4 to 6 mmol L^{-1} when you have not eaten recently. The control centre is the pancreas, which has two kinds of endocrine cell in clusters called islets. **Beta cells** secrete **insulin**, and **alpha cells** secrete **glucagon**. A hormone is a chemical messenger carried in the blood to its target cells, and only cells with the right receptor respond.

After a meal glucose enters the blood and its concentration rises. Beta cells detect it and secrete insulin. Insulin travels in the blood to target cells, mostly in the liver, muscle and fat. They take up more glucose, and the liver and muscle convert it to **glycogen**. Blood glucose falls back to the set point and insulin secretion falls.

Between meals or in exercise the level falls. Alpha cells secrete glucagon, which acts mainly on liver cells. They break glycogen down to glucose and release it into the blood, so the level rises again.

Try the dry lab: give a healthy volunteer a glucose drink and watch the peak and the fall.

KEY TERMS

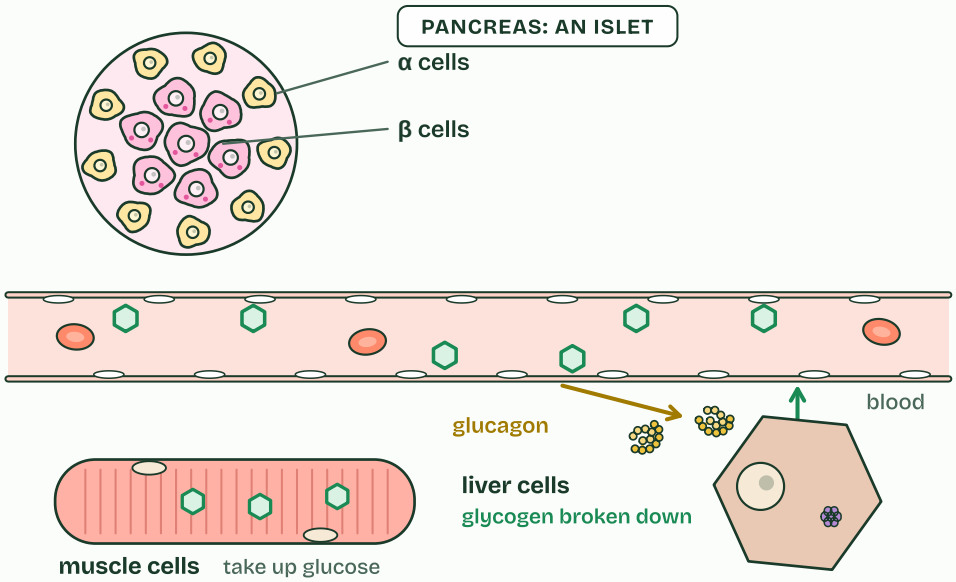
beta cells
Cells in the pancreatic islets that secrete insulin when blood glucose is high.

insulin
A hormone made by beta cells in the pancreas. It lowers blood glucose by making target cells take up glucose and the liver store it as glycogen.

alpha cells
Cells in the pancreatic islets that secrete glucagon when blood glucose is low.

glucagon
A hormone made by alpha cells in the pancreas. It raises blood glucose by making the liver break glycogen down to glucose.

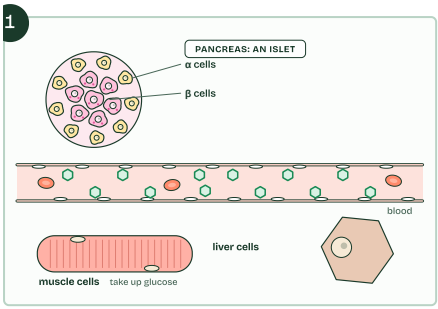
glycogen
A branched polymer of glucose stored in liver and muscle cells.



STEP BY STEP

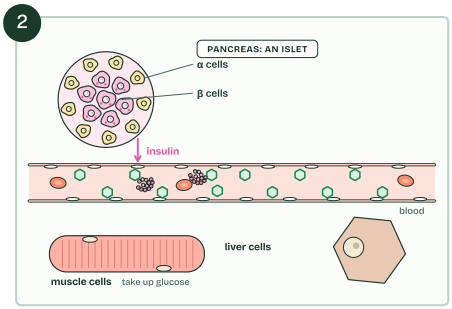
6 STEPS

1



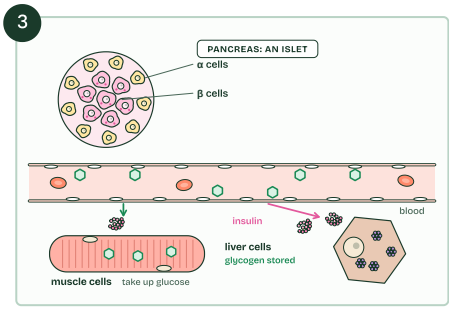
After a meal **glucose** in the blood is high.

2



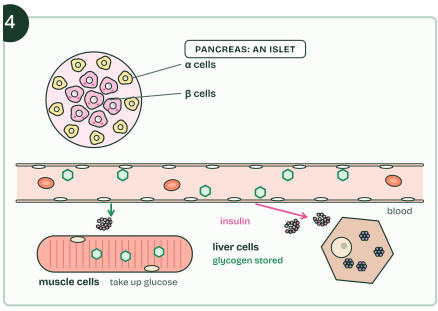
Beta cells secrete **insulin** into the blood.

3



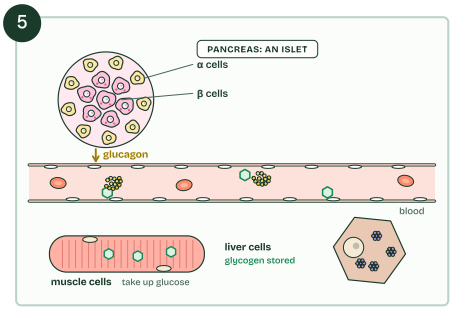
Insulin reaches the **target cells**. They take up glucose and the liver stores it as **glycogen**.

4



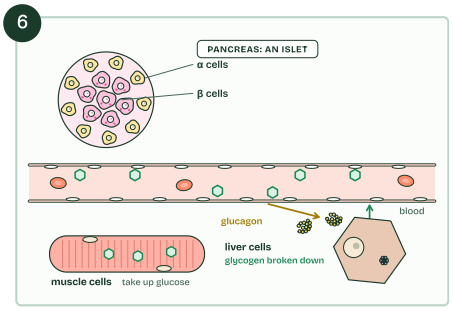
Blood glucose **falls back** to the set point.

5



Later the level is **low**. **Alpha cells** secrete **glucagon**.

6



Glucagon makes the liver **break down glycogen** and release glucose, so the level **rises** to the set point.

PREDICT

A person skips lunch and their blood glucose starts to fall. Which change comes next?

(A) Beta cells secrete more insulin, so the liver stores glycogen

(B) Alpha cells secrete glucagon, so the liver breaks glycogen down and releases glucose

(C) The pancreas stops making any hormone until the person eats again

(D) The kidneys remove all the remaining glucose from the blood

Decide before you look. Answer on page 34.

REMEMBER IT

The insulin response, in four letters

B	I	T	S
B	I	T	S
Beta cells	**Insulin**	**Target cells**	**Store**
detect high glucose	is secreted into the blood	take up glucose	the extra as glycogen

IN THE EXAM

Control of blood glucose in short points:

1. **High:** beta cells in the pancreas detect it and secrete insulin into the blood.
2. Insulin makes liver and muscle cells take up glucose and convert it to glycogen, so the level falls.
3. **Low:** alpha cells secrete glucagon.
4. Glucagon makes the liver break glycogen down to glucose and release it, so the level rises. Each response reverses the change: negative feedback.

04 When the control *breaks*

D3.3.4 PHYSIOLOGICAL CHANGES THAT FORM THE BASIS OF TYPE 1 AND TYPE 2 DIABETES

Diabetes mellitus is the long-term failure to control blood glucose. There are two main kinds, and they fail at different points in the loop.

Type 1 diabetes is the loss of the beta cells. The immune system attacks them, so little or no insulin is made. It usually begins in childhood or youth, and it cannot yet be prevented. It is treated by monitoring blood glucose and injecting insulin (or using a pump), matched to food and exercise.

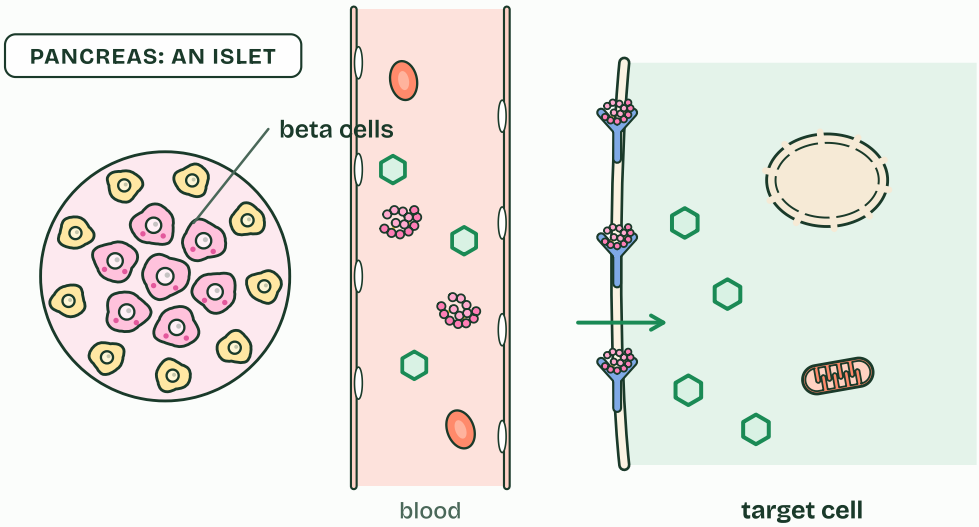
Type 2 diabetes is **insulin resistance**: beta cells make insulin, but target cells respond to it poorly. Later the beta cells may tire. Risk factors include overweight and obesity, little physical activity, a diet high in refined sugar and fat, increasing age and a family history. It can be prevented or delayed by a healthy diet, exercise and keeping a healthy body mass, and treated first by the same changes, then by drugs and sometimes insulin.

Switch between the three people to compare them, then use the glucose tolerance lab to see what each curve looks like.

KEY TERMS

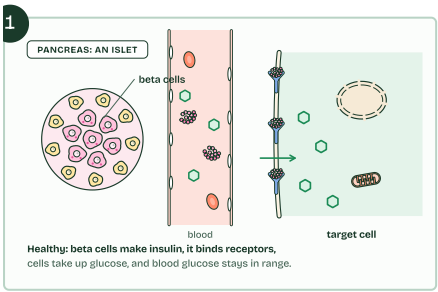
diabetes mellitus
A condition in which blood glucose stays too high because insulin is missing or the body does not respond to it.

insulin resistance
A condition in which target cells respond less to insulin, so more is needed to take up the same amount of glucose.

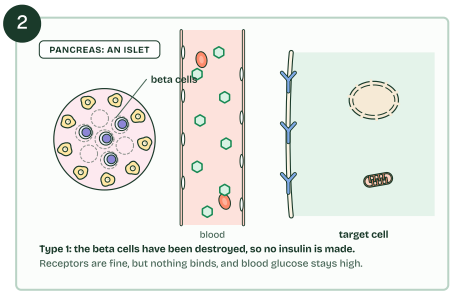


Healthy: beta cells make insulin, it binds receptors, cells take up glucose, and blood glucose stays in range.

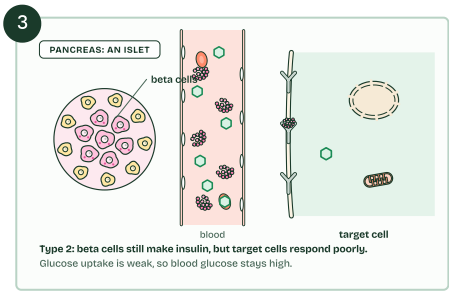
SWITCH IT 3 SETTINGS



Healthy



Type 1



Type 2

PREDICT

A person with diabetes has plenty of insulin in the blood but a high blood glucose level. Which is the most likely kind?

(A) Type 1, because the beta cells have been destroyed

(B) Type 2, because the target cells respond poorly to the insulin that is there

(C) Neither, because insulin is always low in diabetes

(D) Type 1, because the pancreas makes too much insulin

Decide before you look. Answer on page 34.

WATCH OUT

Type 2 diabetes is not caused by sugar alone, and type 1 is not caused by eating too much of it. Type 1 is an immune attack on beta cells. Type 2 has many risk factors, including body mass, activity, age and genes.

05 A thermostat *in the brain*

D3.3.5 THERMOREGULATION AS AN EXAMPLE OF NEGATIVE FEEDBACK CONTROL

Humans keep the core temperature close to 37 °C by negative feedback. There are two sets of sensors. **Peripheral thermoreceptors** in the skin report the temperature of the outside, and cells in the **hypothalamus** sense the temperature of the blood passing through it. The hypothalamus compares them with the set point and sends instructions.

It uses two routes. Nerve impulses are fast: they go to effectors such as skeletal muscle and the blood vessels of the skin (next chapter). The slower route is hormonal. In the cold the hypothalamus signals the **pituitary gland**, which releases thyroid stimulating hormone (TSH) into the blood. TSH makes the thyroid gland release **thyroxin**, which raises the metabolic rate of most cells, so they release more heat from respiration.

KEY POINTS

- **Receptors:** peripheral thermoreceptors in the skin, and the hypothalamus itself.
- **Control centre:** the hypothalamus.
- **Effectors:** skeletal muscle and adipose tissue, with skin arterioles and sweat glands (next chapter).
- **Hormone route:** pituitary gland (TSH), then thyroid gland (thyroxin), then a higher metabolic rate.

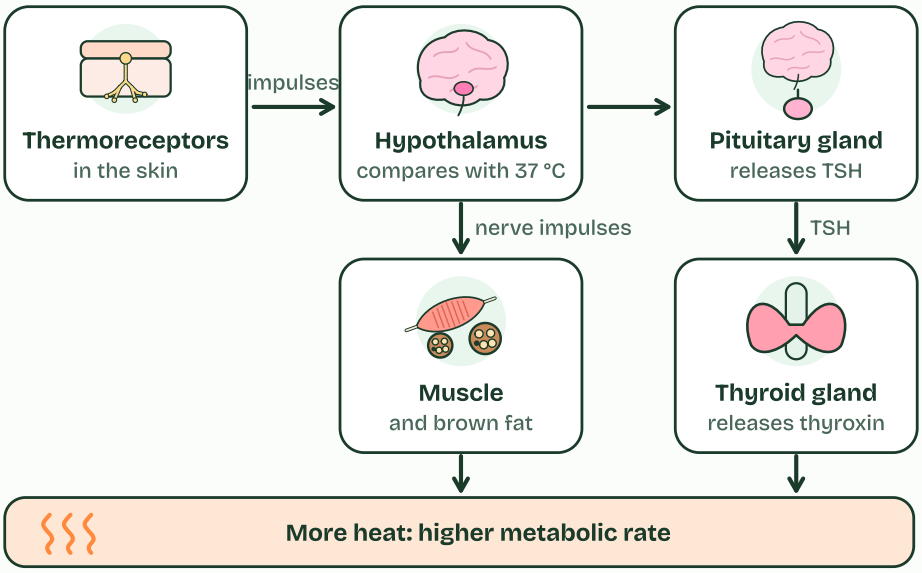
KEY TERMS

peripheral thermoreceptors
Temperature sensors in the skin that send nerve impulses to the hypothalamus.

hypothalamus
The part of the brain that links the nervous and endocrine systems. It is the control centre for body temperature and for blood osmotic concentration.

pituitary gland
A small gland beneath the hypothalamus. Its hormones control other glands, and it releases ADH made in the hypothalamus.

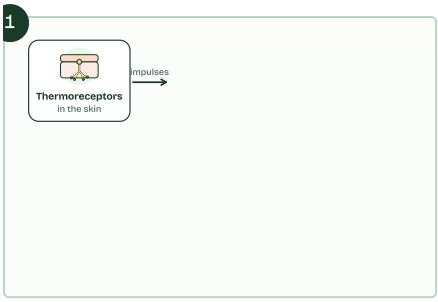
thyroxin
A hormone made by the thyroid gland that raises the metabolic rate of most body cells, so more heat is made.



STEP BY STEP

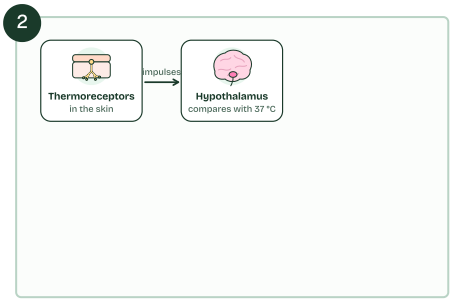
5 STEPS

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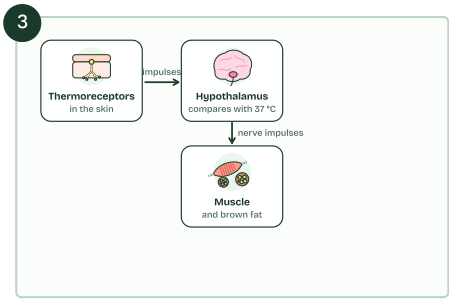
The body is losing heat. **Thermoreceptors** in the skin report it.

2



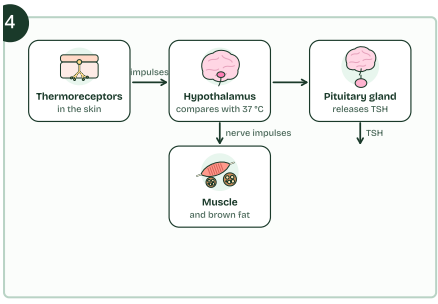
The **hypothalamus** compares the temperature with the set point of about 37 °C.

3



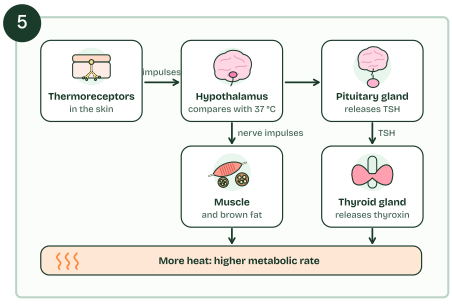
Nerve impulses go to **effectors**: skeletal muscle and adipose tissue.

4



The hypothalamus also signals the **pituitary**, which releases TSH.

5



TSH makes the **thyroid** release **thyroxin**. Cells use more energy and release more heat, and the temperature rises to the set point.

PREDICT

Which cells or organs detect the change when you step out into cold air?

(A) Only the muscles, which shiver when they are cold

(B) Thermoreceptors in the skin and cells in the hypothalamus, which report to the hypothalamus

(C) The thyroid gland, which is the control centre for heat

(D) The pituitary gland, which makes the heat

Decide before you look. Answer on page 34.

06 Keeping heat in, *letting it out*

D3.3.6 THERMOREGULATION MECHANISMS IN HUMANS

Birds and mammals regulate body temperature by **physiological** means, changes inside the body, and by **behaviour** such as seeking shade or putting on a coat. For humans you need the physiology of the skin and muscles.

When you are too cold, the hypothalamus triggers **vasoconstriction** of the arterioles that supply the skin. Less warm blood reaches the surface, so less heat is lost to the air. Muscles contract and relax rapidly: **shivering** uses ATP and releases heat. Erector muscles raise the hairs, which traps a layer of air in animals with thick fur but does little for a person. Adipose tissue can make heat too (next chapter).

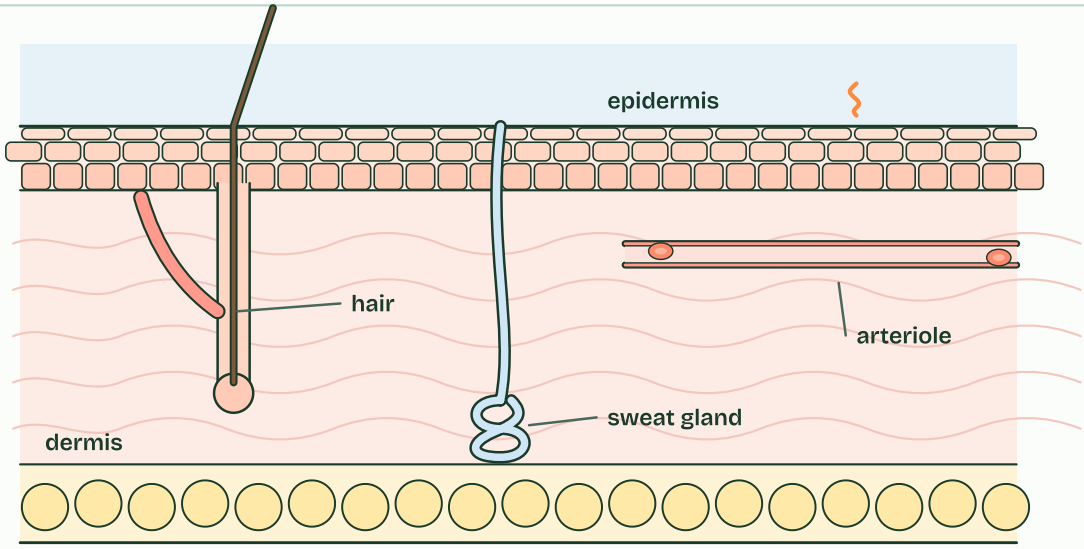
When you are too hot, the arterioles widen, called **vasodilation**. More blood flows near the surface and heat is lost by radiation. Sweat glands secrete sweat, which takes heat from the skin as it evaporates. The hairs lie flat.

KEY TERMS

vasoconstriction
The narrowing of arterioles, so that less blood flows through them.

shivering
Rapid, involuntary contractions of skeletal muscles that release heat from respiration.

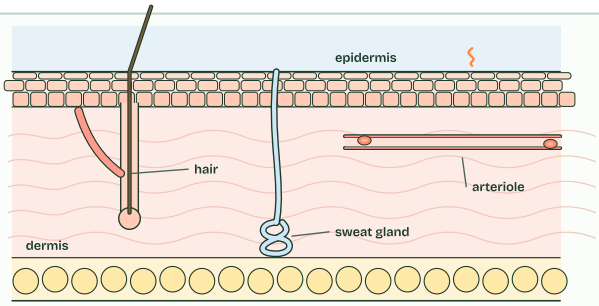
vasodilation
The widening of arterioles, so that more blood flows through them.



Cold: arterioles narrow (vasoconstriction), less blood reaches the skin, hairs are raised, and muscles shiver. Less heat is lost.

SWITCH IT 2 SETTINGS

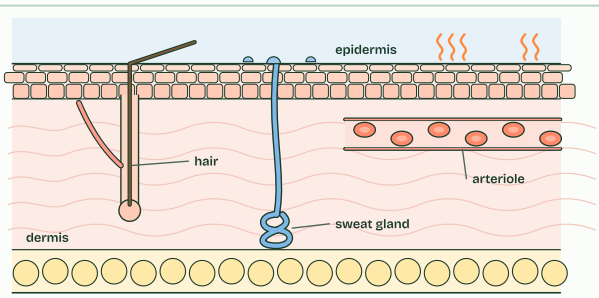
1



Cold: arterioles narrow (vasoconstriction), less blood reaches the skin, hairs are raised, and muscles shiver. Less heat is lost.

Cold

2



Hot: arterioles widen (vasodilation), more blood reaches the skin, sweat evaporates from the skin, hairs lie flat. More heat is lost.

Hot

PREDICT

A runner finishes a race on a warm day and their skin looks flushed and red. What is happening?

(A) Vasoconstriction of skin arterioles, which holds heat in the body

(B) Vasodilation of skin arterioles, which brings more blood to the surface so heat is lost

(C) The skin is getting more oxygen, so the runner is cooling down because of the oxygen

(D) The thyroid is releasing more thyroxin, which cools the skin

Decide before you look. Answer on page 34.

WATCH OUT

The blood vessels do not move closer to the skin, and a capillary does not get wider. It is the **arterioles** that change width, which changes how much blood flows to the surface.

07 A *furnace* that makes no ATP

D3.3.6 THERMOREGULATION MECHANISMS IN HUMANS: BROWN ADIPOSE TISSUE

Most of the body's fat, **white adipose tissue**, stores energy and insulates. **Brown adipose tissue** is different: its cells are packed with mitochondria, which give it a brown colour, and its job is to make heat.

In a normal mitochondrion the electron transport chain pumps protons across the inner membrane, and the protons flow back through ATP synthase, which makes ATP (chapter C1.2). In brown fat the inner membrane has a protein that lets protons flow back *without* passing through ATP synthase. This is **uncoupled respiration**. The energy of the proton gradient is released as heat rather than stored in ATP, and the cell keeps oxidising fuel to restore the gradient. The result is a lot of heat from a lot of fuel.

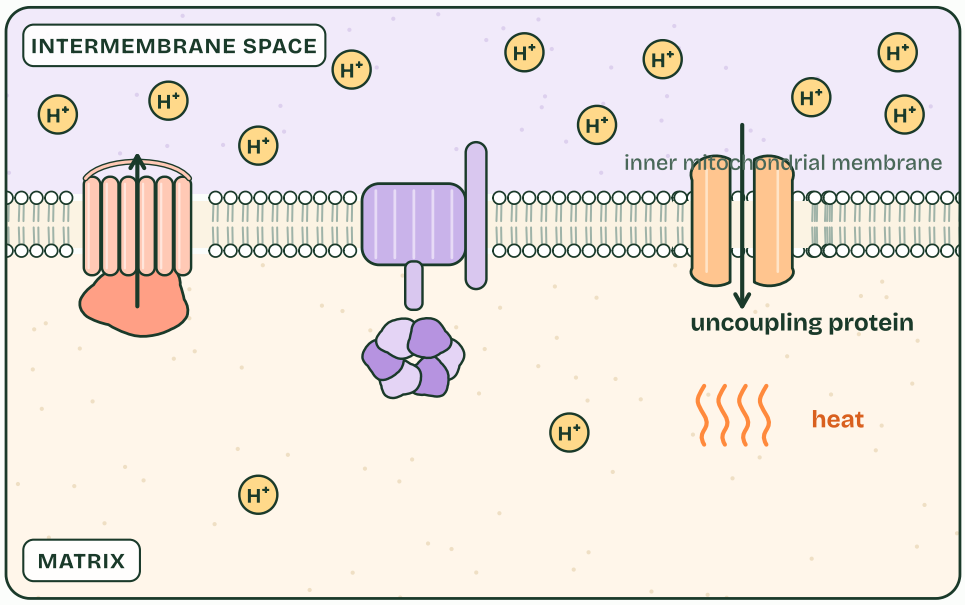
KEY POINTS

- In **uncoupled respiration** protons return through an uncoupling protein, not ATP synthase.
- The energy is released as **heat**, and no ATP is made by that route.
- Brown adipose tissue and **skeletal muscle** (shivering) are the **effectors** that make heat.

KEY TERMS

brown adipose tissue
A tissue with many mitochondria and little stored fat, in which uncoupled respiration releases the energy of the proton gradient as heat. It is most abundant in newborn babies and hibernating mammals.

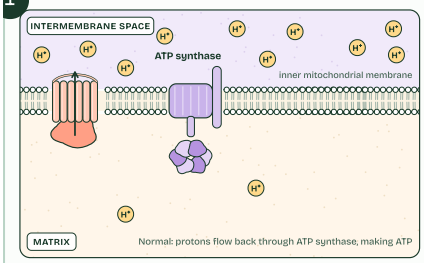
uncoupled respiration
Respiration in which protons cross the inner mitochondrial membrane through an uncoupling protein instead of ATP synthase, so the energy of the gradient is released as heat instead of making ATP.



STEP BY STEP

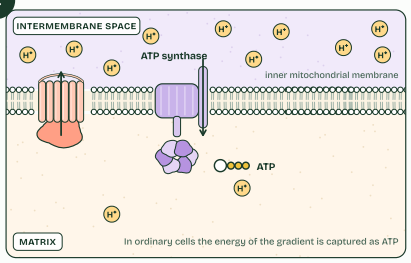
4 STEPS

1



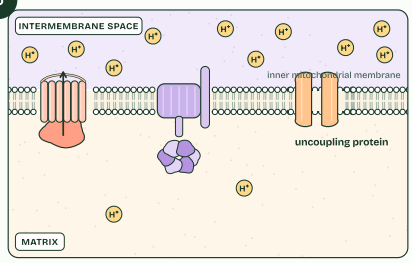
Protons are pumped to the **intermembrane space**, making a gradient.

2



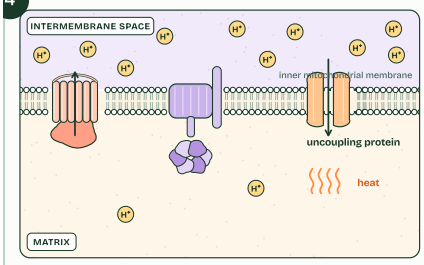
In most cells they flow back through **ATP synthase**, which makes ATP.

3



In **brown fat** the membrane also has an **uncoupling protein**, a second way back.

4



Protons pass through it with **no ATP** made. The energy of the gradient is released as **heat**.

PREDICT

Brown adipose tissue is most abundant in newborn babies. Why is a baby more in need of it than an adult?

(A) A baby has less surface area, so it loses heat more slowly than an adult

(B) A baby has a large surface area for its volume and cannot shiver well, so it loses heat fast and needs another way to warm up

(C) Babies use brown fat to store extra energy for growing

(D) Babies do not have a hypothalamus, so brown fat does their temperature control

Decide before you look. Answer on page 34.

08 Clearing waste and *balancing water*

D3.3.7 HL ROLE OF THE KIDNEY IN OSMOREGULATION AND EXCRETION

The kidney does two different jobs, and the exam asks you to tell them apart. **Excretion** is the removal of the waste products of metabolism. The kidney excretes **urea**, which the liver makes from excess amino acids. **Osmoregulation** is a separate job: keeping the total concentration of dissolved solutes, the **osmotic concentration**, within narrow limits. The kidney does both at once, by making urine.

Osmotic concentration is measured in **osmoles per litre** (osmol L^{-1}), the number of solute particles in a litre of solution. Human blood is about 0.3 osmol L^{-1}. If it differs from that, water moves in or out of cells by osmosis and they change volume, so the kidney changes how much water it keeps (chapters 9 to 11).

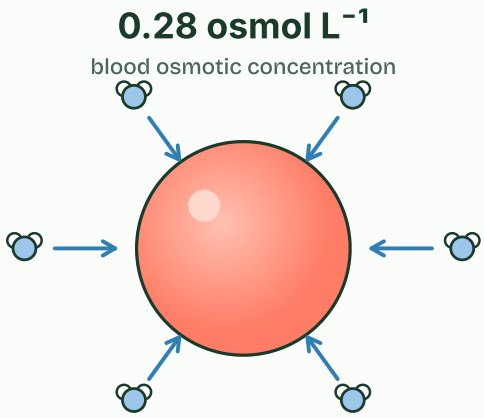
KEY TERMS

excretion
The removal from the body of the waste products of metabolism, such as urea and carbon dioxide.

urea
A nitrogenous waste made in the liver from amino acids that are not needed, and excreted in urine.

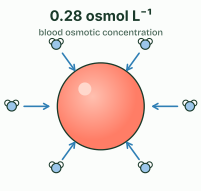
osmoregulation
The control of the osmotic concentration of the blood and tissue fluid, by regulating the balance of water and solutes.

osmotic concentration
The total concentration of solute particles dissolved in a solution, measured in osmoles per litre (osmol L^{-1}).

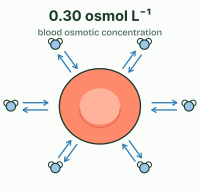


Cells swell
Blood is too dilute: water enters cells by osmosis.

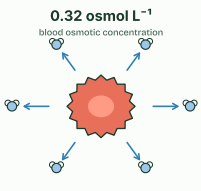
SWITCH IT 3 SETTINGS

1


Too dilute

2


Set point

3


Too concentrated

PREDICT

A person eats a very salty meal and drinks no water. Which change will happen in the blood?

(A) Its osmotic concentration rises, because there is the same water but more solute

(B) Its osmotic concentration falls, because salt draws water into the blood

(C) Its osmotic concentration stays the same, because osmosis is not involved

(D) Its pH falls to 0 because salt is acidic

Decide before you look. Answer on page 34.

WATCH OUT

Osmoregulation and excretion are not the same thing. Removing urea is **excretion**. Controlling how much water the body keeps is **osmoregulation**.

D3.3.8 HL ROLE OF THE GLOMERULUS, BOWMAN'S CAPSULE AND PROXIMAL CONVOLUTED TUBULE IN EXCRETION

09 Filter everything small, *take back what you need*

Each kidney has about a million tiny filtering tubes, **nephrons**. The first part is the **glomerulus**, a knot of capillaries enclosed by the cup-shaped **Bowman's capsule**.

Ultrafiltration happens here. Blood arrives at high pressure because the arteriole going in is wider than the one leaving. Water and small solutes, such as ions, glucose, amino acids and urea, are forced through the pores of the capillary wall and the basement membrane into the capsule. Blood cells and large proteins are too big to pass. The fluid in the capsule is the **filtrate**.

The filtrate contains useful things, so the next part, the **proximal convoluted tubule**, takes them back. Its cells have microvilli to give a large surface area and many mitochondria for active transport. All the glucose and most of the sodium and other ions are reabsorbed by active transport, and water follows by osmosis. Urea is mostly left behind. What stays is mostly waste, which is how the kidney excretes it.

Watch the film from the glomerulus to the urine. Pay attention to what happens to each kind of particle.

KEY TERMS

nephrons
The functional units of the kidney: each has a glomerulus, a Bowman's capsule and a long tubule that ends in a collecting duct.

glomerulus
A knot of capillaries inside the Bowman's capsule, where blood plasma is filtered under high pressure.

Bowman's capsule
The cup-shaped end of a nephron that surrounds the glomerulus and collects the filtrate.

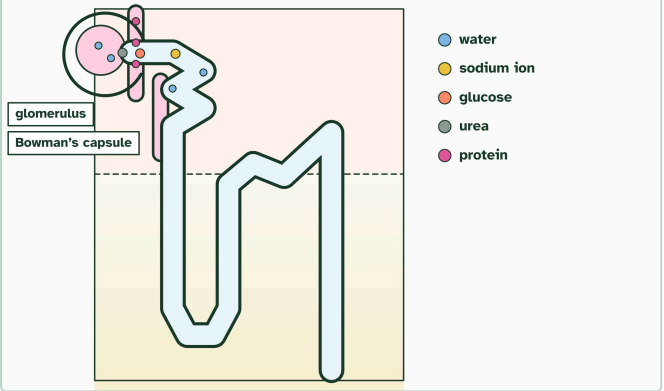
ultrafiltration
Filtration under pressure through a very fine filter. In the kidney, plasma without its large proteins is forced from the glomerulus into the Bowman's capsule.

proximal convoluted tubule
The first coiled part of the nephron after the Bowman's capsule, where most reabsorption of glucose, ions and water happens.

ANIMATION · MAKING URINE IN A NEPHRON

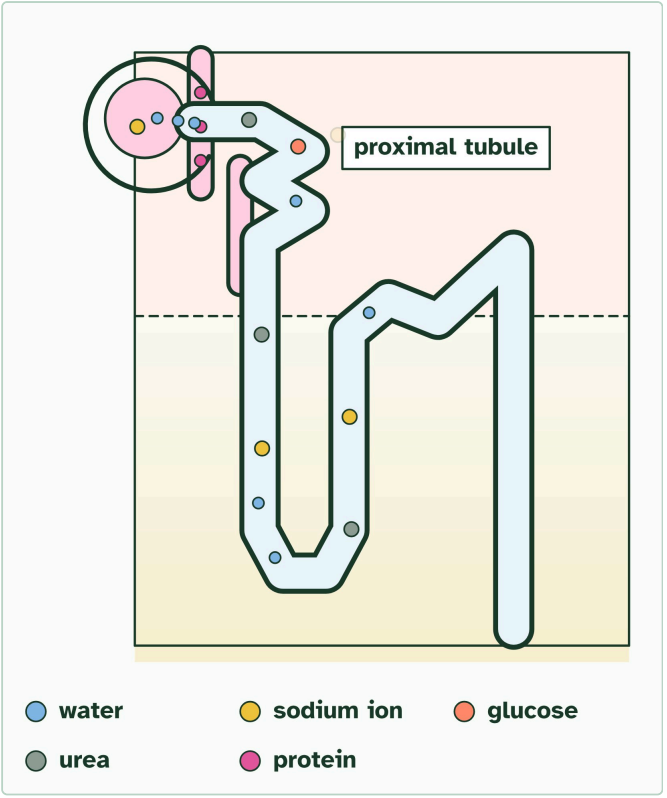
5 MOMENTS

1 ULTRAFILTRATION



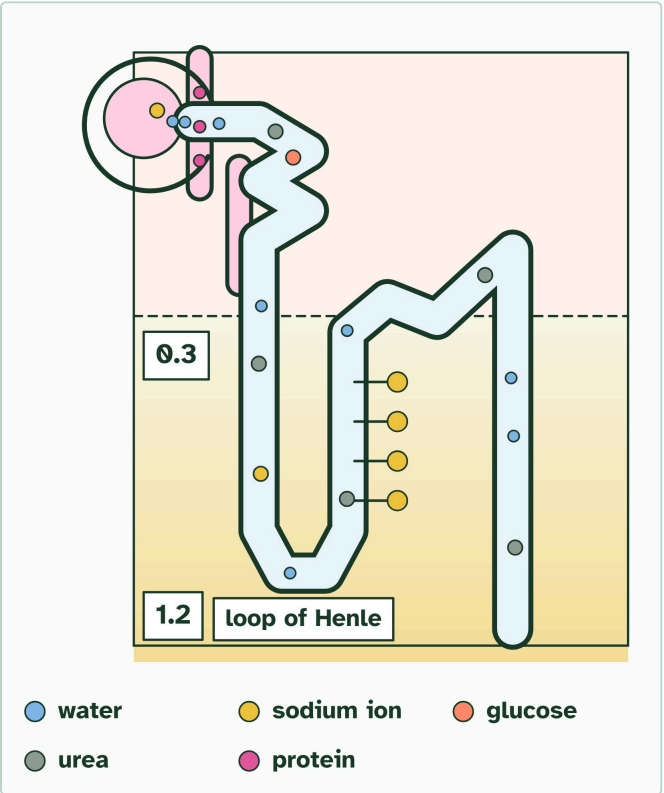
Blood is forced through the **glomerulus** at high pressure. Water, ions, glucose and urea pass through the filter into the Bowman's capsule: **ultrafiltration**. Blood cells and big proteins stay in the blood.

2 REABSORPTION



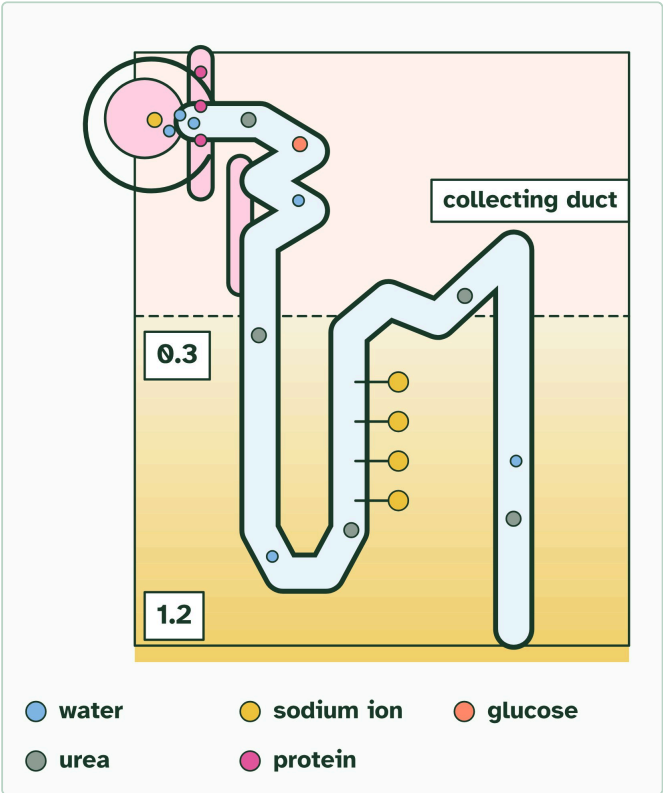
In the **proximal convoluted tubule** all the glucose and most of the ions are taken back into the blood by active transport, and water follows by osmosis: **selective reabsorption**.

3 LOOP OF HENLE



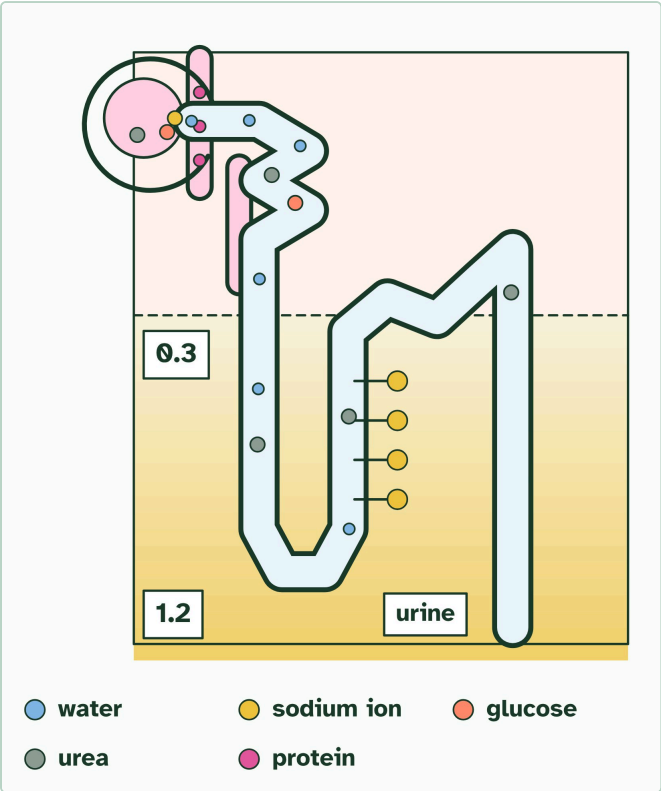
In the **loop of Henle** the ascending limb pumps Na^+ out by active transport. This makes the fluid of the medulla very salty, from about 0.3 osmol/L near the top to 1.2 at the tip, and the descending limb loses water to it.

4 COLLECTING DUCT



In the **collecting duct** water leaves by osmosis through **aquaporins**. **ADH** decides how many there are, so how much water is kept.

5 URINE



What is left is **urine**: water, urea and some ions. Move the ADH slider and run it again: more ADH, less water in a more concentrated urine.

Watch it move, and change it as it runs: biologybybradford.com/guides/ib-biology-d3-3-homeostasis#nephron

PREDICT

A person's urine contains protein, which is not normally found in it. Which part of the nephron is most likely to be damaged?

(A) The proximal tubule, because it reabsorbs all the protein

(B) The filter in the glomerulus and capsule, which should hold large proteins back

(C) The collecting duct, because it makes protein

(D) The loop of Henle, because it pumps proteins out of the medulla

Decide before you look. Answer on page 35.

IN THE EXAM

Making urine so far, in four points:

1. **Ultrafiltration:** high pressure forces water and small solutes out of the glomerulus into the Bowman's capsule; blood cells and proteins stay in the blood.
2. The filtrate contains useful substances as well as waste.
3. **Reabsorption** in the proximal tubule: all the glucose and most ions go back to the blood by active transport.
4. Water follows by osmosis, and urea and other wastes are left in the filtrate to be excreted.

D3.3.9 HL ROLE OF THE LOOP OF HENLE

10 Making the medulla *salty*

Water cannot be pumped. It only moves by osmosis, from a region of lower solute concentration to a higher one. To take water back from the filtrate, the kidney therefore needs somewhere very salty to move it to. The **loop of Henle** makes it.

Cells in the wall of the **ascending limb** use active transport to pump sodium ions out of the filtrate into the tissue fluid of the **medulla**. The ascending limb is impermeable to water, so the water cannot follow the ions out. The tissue fluid of the medulla ends up with a high osmotic concentration, saltiest near the tip of the loop at about 1.2 osmol L^{-1}, against 0.3 in the blood.

This salty medulla is what lets the **collecting duct**, which runs down through it, take back water by osmosis. The more concentrated the medulla, the more concentrated the urine can be, and desert animals such as the kangaroo rat have very long loops.

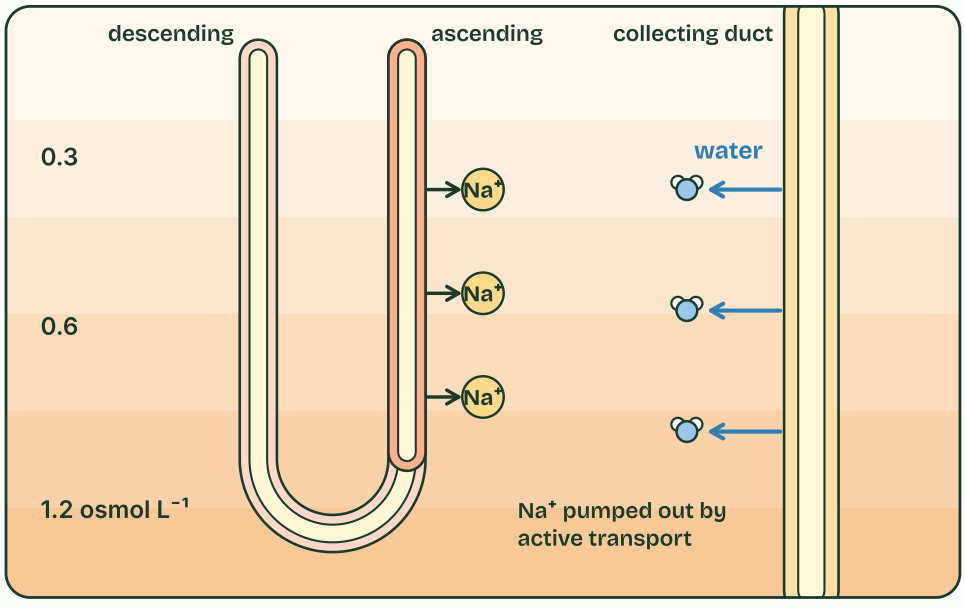
KEY POINTS

- The ascending limb **pumps Na^+ out** by active transport and is **impermeable to water**.
- This keeps the medulla at a **high osmotic concentration**.
- Water leaves the **collecting duct** by osmosis into the salty medulla.

KEY TERMS

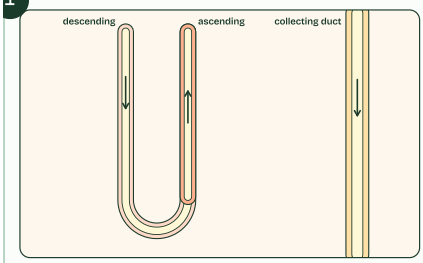
loop of Henle
The U-shaped part of the nephron that runs into the medulla. Its ascending limb pumps sodium ions out and so makes the medulla salty.

medulla
The inner part of the kidney, below the cortex, where the loops of Henle and collecting ducts run.



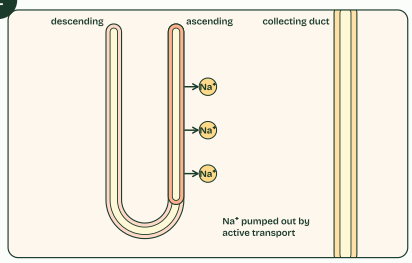
STEP BY STEP
4 STEPS

1



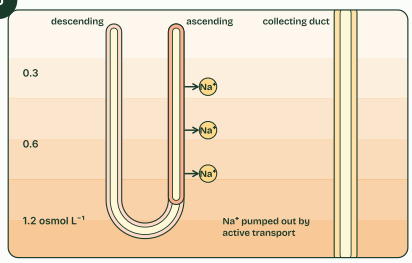
Filtrate flows **down** the descending limb and **up** the ascending limb.

2



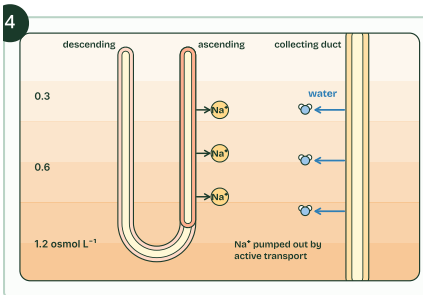
The ascending limb **pumps sodium ions out** by active transport. It is watertight.

3



The medulla becomes **very salty**, saltiest at the bottom.

4



Water leaves the **collecting duct** by osmosis into the salty medulla and is carried away by the blood.

PREDICT

What would happen to the concentration of the medulla if the sodium pumps in the ascending limb stopped working?

(A) The medulla would become even saltier, because sodium could not leave the filtrate

(B) The medulla would become less concentrated, so less water could be reabsorbed from the collecting duct

(C) Nothing, because the collecting duct controls the medulla

(D) The filtrate would become more concentrated, so more urine would be made

Decide before you look. Answer on page 35.

11 A hormone that *opens the taps*

D3.3.10 HL OSMOREGULATION BY WATER REABSORPTION IN THE COLLECTING DUCTS

The medulla is salty all the time. What changes from hour to hour is how *watertight* the collecting duct is. If you have not drunk for a while, the blood becomes more concentrated. **Osmoreceptors** in the hypothalamus detect it and signal the pituitary gland, which releases more **antidiuretic hormone (ADH)** into the blood.

ADH travels to the kidney and binds to receptors on the cells of the collecting duct. This makes vesicles inside the cells fuse with the cell membrane, which adds **aquaporins**, channels that let water through. Water moves by osmosis from the filtrate into the salty medulla, so less is lost and the urine is small in volume and concentrated.

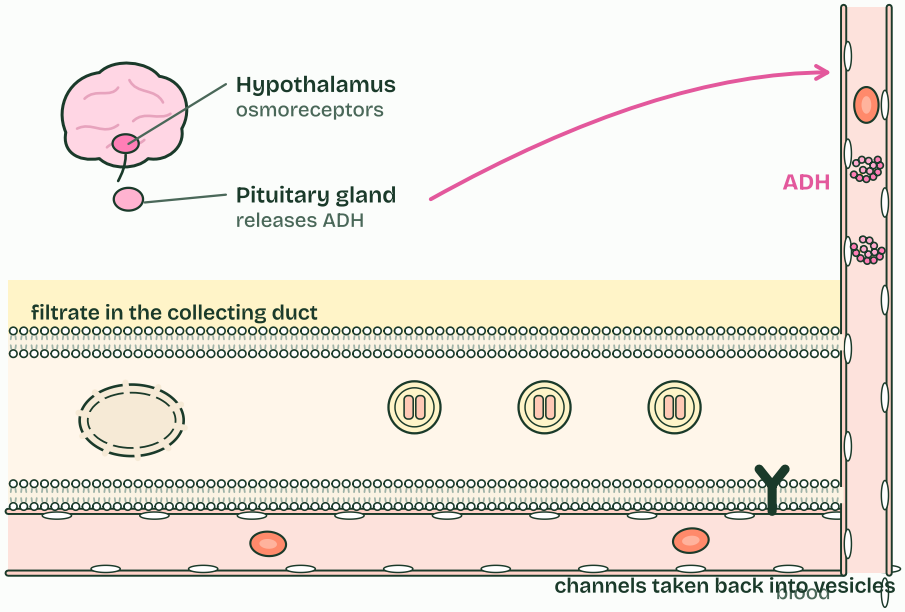
If you have drunk a lot, ADH falls. The aquaporins are taken back into vesicles by endocytosis, the membrane becomes much less permeable, and a large volume of dilute urine is made. The blood returns to its set point either way. So the aquaporins **switch location** between the cell membrane and vesicles inside the cell.

KEY TERMS

osmoreceptors
Sensory cells, in the hypothalamus, that detect the osmotic concentration of the blood.

antidiuretic hormone (ADH)
A hormone made in the hypothalamus and released by the pituitary gland. It makes the collecting ducts of the kidney reabsorb more water.

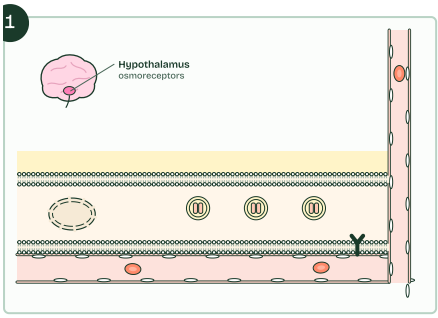
aquaporins
Channel proteins in a membrane that let water molecules pass by osmosis.



STEP BY STEP

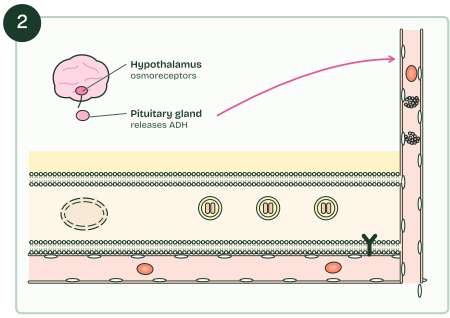
6 STEPS

1



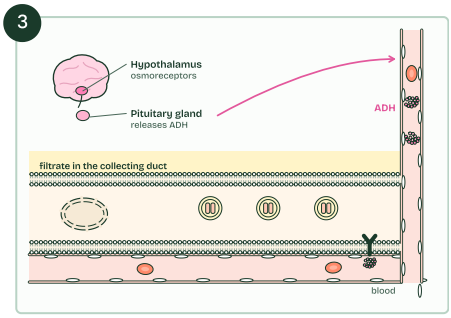
The blood is too **concentrated**. **Osmoreceptors** in the hypothalamus detect it.

2



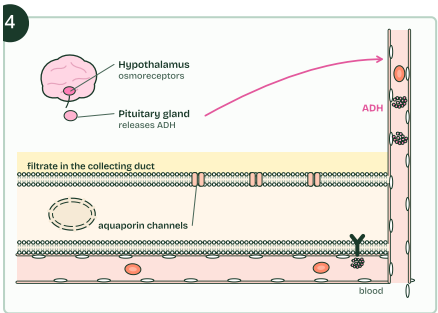
The **pituitary gland** releases more **ADH**.

3



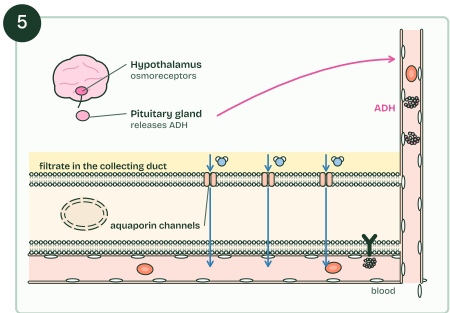
ADH travels in the blood and **binds to receptors** on the collecting duct cells.

4



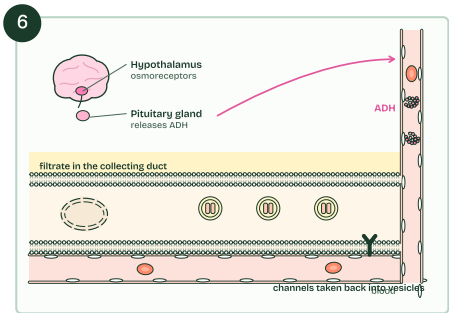
Vesicles **fuse with the membrane**, adding **aquaporins** to it.

5



Water leaves the filtrate through the aquaporins by **osmosis** and enters the blood.

6



When the blood is back to normal ADH falls, and the aquaporins are **taken back into vesicles**.

PREDICT

After running a long way in the heat, an athlete makes only a little dark urine. Which change in the collecting duct cells explains it?

(A) Vesicles carrying aquaporins fuse with the cell membrane, so more water is reabsorbed

(B) Aquaporins are moved into vesicles, so more water is reabsorbed

(C) The cells make less ADH

(D) The cells pump water out against the concentration gradient, using ATP

Decide before you look. Answer on page 35.

REMEMBER IT

Osmoregulation when the blood is too concentrated

O	A	A	R	S
O	A	A	R	S
Osmoreceptors in the hypothalamus detect it	**ADH** released by the pituitary	**Aquaporins** move into the duct membrane	**Reabsorb** more water by osmosis	**Small** volume of concentrated urine

IN THE EXAM

How the body responds to a loss of water, in short points:

1. Osmoreceptors in the hypothalamus detect a rise in the blood's osmotic concentration.
2. The pituitary gland releases more ADH.
3. ADH makes vesicles with aquaporins fuse with the membrane of the collecting duct cells.
4. More water is reabsorbed by osmosis into the salty medulla, so the urine is concentrated and the blood returns to its set point. The reverse happens when there is too much water.

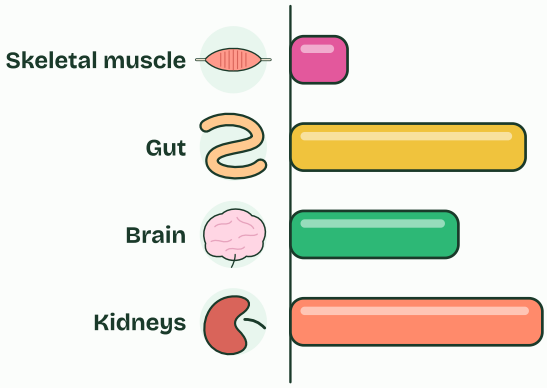
12 Sending blood *where it is needed*

D3.3.11 HL CHANGES IN BLOOD SUPPLY TO ORGANS IN RESPONSE TO CHANGES IN ACTIVITY

The heart cannot supply every organ at its maximum all the time, so blood is **shared out** according to need. The amount reaching an organ is changed by the arterioles that supply it. When smooth muscle in an arteriole wall relaxes it widens (vasodilation) and more blood flows through. When it contracts the arteriole narrows (vasoconstriction) and less does. Signals from the nervous system and hormones, and chemicals released by working tissue, control which.

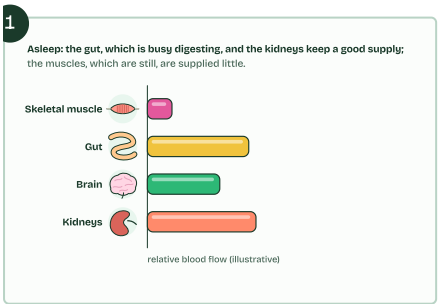
In **vigorous exercise** the muscles need much more oxygen and glucose, and must lose heat. Their arterioles dilate and they receive most of the blood. Arterioles to the gut and kidneys constrict, so they receive much less, as they are not urgent in the next few minutes. In **wakeful rest** the blood is shared more evenly, with a good share to the gut and the kidneys. During **sleep** the muscles are still and need little. The brain needs a steady supply at all times, as it cannot store energy and is damaged quickly if starved of oxygen.

Asleep: the gut, which is busy digesting, and the kidneys keep a good supply; the muscles, which are still, are supplied little.



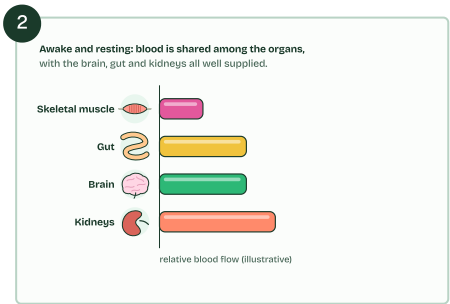
SWITCH IT 3 SETTINGS

1



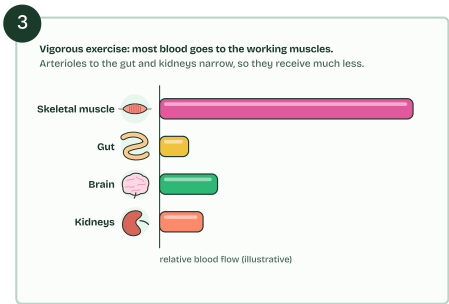
Sleep

2



Wakeful rest

3



Vigorous exercise

PREDICT

A person goes for a hard run straight after a large meal and gets a stitch and indigestion. What is the likeliest reason?

(A) The muscles are asking for blood, so blood flow to the gut is reduced and digestion is disturbed

(B) The gut has taken all of the blood, so the muscles cannot work

(C) The kidneys are taking all the blood from the gut

(D) The brain has diverted all the blood to the heart

Decide before you look. Answer on page 35.

WATCH OUT

The brain's blood supply is kept up in almost every situation. It is the **share** that falls in exercise, because the total blood flow is much bigger, not the brain being starved.

Key terms

Every term this guide defines, A to Z, with the chapter it is in. Cover the right-hand side and test yourself.

alpha cells 03
Cells in the pancreatic islets that secrete glucagon when blood glucose is low.

antidiuretic hormone (ADH) 11
A hormone made in the hypothalamus and released by the pituitary gland. It makes the collecting ducts of the kidney reabsorb more water.

aquaporins 11
Channel proteins in a membrane that let water molecules pass by osmosis.

beta cells 03
Cells in the pancreatic islets that secrete insulin when blood glucose is high.

Bowman's capsule 09
The cup-shaped end of a nephron that surrounds the glomerulus and collects the filtrate.

brown adipose tissue 07
A tissue with many mitochondria and little stored fat, in which uncoupled respiration releases the energy of the proton gradient as heat. It is most abundant in newborn babies and hibernating mammals.

control centre 02
The part of a control system, such as the hypothalamus or the pancreas, that compares the variable with its set point and sends instructions.

diabetes mellitus 04
A condition in which blood glucose stays too high because insulin is missing or the body does not respond to it.

effector 02
A cell, tissue or organ, such as a muscle or a gland, that carries out the response.

excretion 08
The removal from the body of the waste products of metabolism, such as urea and carbon dioxide.

glomerulus 09
A knot of capillaries inside the Bowman's capsule, where blood plasma is filtered under high pressure.

glucagon 03
A hormone made by alpha cells in the pancreas. It raises blood glucose by making the liver break glycogen down to glucose.

glycogen 03
A branched polymer of glucose stored in liver and muscle cells.

homeostasis 01
The maintenance of the internal environment of an organism, keeping variables within preset limits despite changes in the external environment.

hypothalamus 05
The part of the brain that links the nervous and endocrine systems. It is the control centre for body temperature and for blood osmotic concentration.

insulin 03
A hormone made by beta cells in the pancreas. It lowers blood glucose by making target cells take up glucose and the liver store it as glycogen.

insulin resistance 04
A condition in which target cells respond less to insulin, so more is needed to take up the same amount of glucose.

loop of Henle 10
The U-shaped part of the nephron that runs into the medulla. Its ascending limb pumps sodium ions out and so makes the medulla salty.

medulla 10
The inner part of the kidney, below the cortex, where the loops of Henle and collecting ducts run.

negative feedback 02
A control system in which the response reverses the change that triggered it, returning the variable to its set point.

nephrons 09
The functional units of the kidney: each has a glomerulus, a Bowman's capsule and a long tubule that ends in a collecting duct.

osmoreceptors 11
Sensory cells, in the hypothalamus, that detect the osmotic concentration of the blood.

osmoregulation 08
The control of the osmotic concentration of the blood and tissue fluid, by regulating the balance of water and solutes.

osmotic concentration 08
The total concentration of solute particles dissolved in a solution, measured in osmoles per litre (osmol L^{-1}).

peripheral thermoreceptors 05
Temperature sensors in the skin that send nerve impulses to the hypothalamus.

pituitary gland 05
A small gland beneath the hypothalamus. Its hormones control other glands, and it releases ADH made in the hypothalamus.

proximal convoluted tubule 09
The first coiled part of the nephron after the Bowman's capsule, where most reabsorption of glucose, ions and water happens.

receptor 02
A cell or sense organ that detects a change in a variable.

set point 01
The value of a homeostatic variable that the control system works to restore.

shivering 06
Rapid, involuntary contractions of skeletal muscles that release heat from respiration.

thyroxin 05
A hormone made by the thyroid gland that raises the metabolic rate of most body cells, so more heat is made.

ultrafiltration 09
Filtration under pressure through a very fine filter. In the kidney, plasma without its large proteins is forced from the glomerulus into the Bowman's capsule.

uncoupled respiration 07
Respiration in which protons cross the inner mitochondrial membrane through an uncoupling protein instead of ATP synthase, so the energy of the gradient is released as heat instead of making ATP.

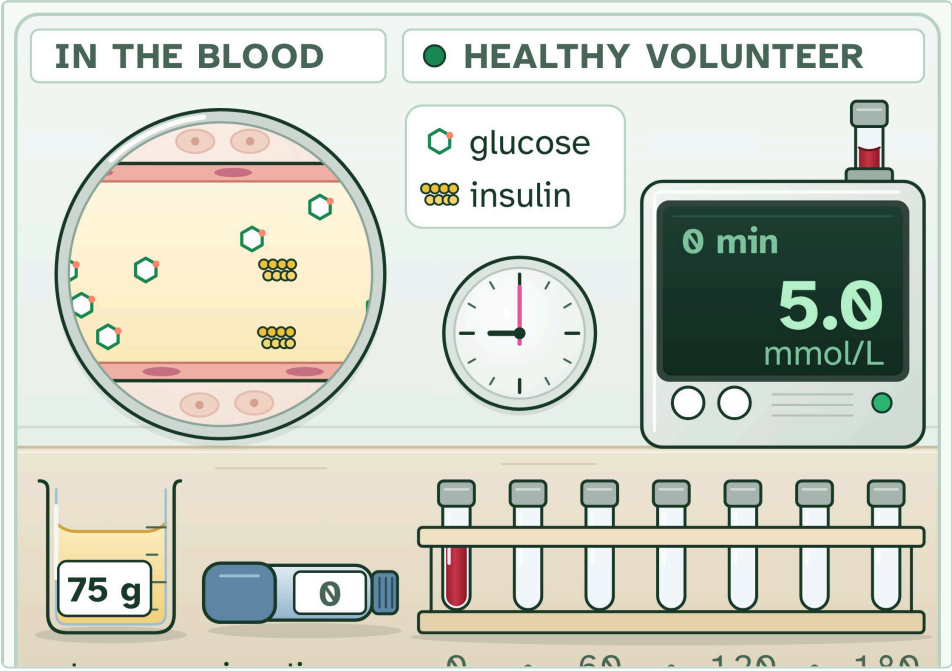
urea 08
A nitrogenous waste made in the liver from amino acids that are not needed, and excreted in urine.

vasoconstriction 06
The narrowing of arterioles, so that less blood flows through them.

vasodilation 06
The widening of arterioles, so that more blood flows through them.

Dry lab: *Glucose tolerance*

A volunteer drinks glucose and a sample of blood is taken every half hour. Test a healthy person and someone with each kind of diabetes, and see which part of the control loop has failed.



Run it online: change the variables, run the trials, and the table and graph fill in as you go. `biologybybradford.com/guides/ib-biology-d3-3-homeostasis#lab`

Your question

How does blood glucose change after a glucose drink in a healthy person, and how are the curves different in type 1 and type 2 diabetes?

What you can change

The person, the drink (glucose or water as the control) and, for type 1 diabetes, a dose of insulin before the drink. Everything else is the same: a fast of ten hours first, 75 g of glucose, and a blood sample every 30 minutes for three hours.

What to record

For each test, the fasting level, the peak, the time of the peak and the level at two hours. Compare them with the dashed thresholds on the graph. Repeat a test to see the measurement wobble. Download the CSV to plot your own.

Find out

- **What does a healthy person do?** Run the glucose drink and then the water control. How high does the level rise, when does it peak, and how long does it take to return?
- **How is type 1 diabetes different?** Run it with no insulin. Compare the fasting level, the peak and the level at two hours with the healthy person.
- **Can insulin fix it?** Run type 1 with 4, 8 and then 12 units of insulin before the drink. Which setting brings the level closest to a healthy curve, and what might go wrong with too much?
- **And type 2?** Run it. The curve looks a bit like type 1, but the cause is different. What would you measure in the blood to tell them apart?

Record

- For each test: the person, the drink, the insulin, and the six readings in the table.
- The fasting level, the peak and its time, and the level at two hours, compared with the dashed thresholds of 7.0 and 11.1 mmol/L.
- A repeat of one test, to see how much of the difference between two curves could be measurement error.
- Download the CSV to plot your own graph.

Your question How does blood glucose change after a glucose drink in a healthy person, and how are the curves different in type 1 and type 2 diabetes?**What you can change**The person, the drink (glucose or water as the control) and, for type 1 diabetes, a dose of insulin before the drink. Everything else is the same: a fast of ten hours first, 75 g of glucose, and a blood sample every 30 minutes for three hours.**What to record**For each test, the fasting level, the peak, the time of the peak and the level at two hours. Compare them with the dashed thresholds on the graph. Repeat a test to see the measurement wobble. Download the CSV to plot your own.

Back to the feedback loop

Use your curves to explain how negative feedback brings blood glucose back to its set point after the drink, and where the loop is broken in type 1 and in type 2 diabetes.

QUESTIONS ON THE LAB

QUESTION 1

You give the healthy volunteer plain water instead of the glucose drink. What does the blood glucose do over the three hours?

(A) It rises to about 8 mmol/L and then falls, because the body reacts to any drink

(B) It stays close to the fasting level, because nothing has been added to the blood

(C) It falls steadily, because the water dilutes the blood glucose

Answer on page 35.

QUESTION 2

Type 1 diabetes without insulin, and then with 10 units. Which part of the curve changes most?

(A) The fasting level at time 0, because the injection is given just before the drink

(B) The size of the peak and the level at two hours, because the insulin takes effect over the next hour or two

(C) Nothing, because the beta cells are still missing

Answer on page 35.

Check yourself

The check for this guide is online: a fresh paper of past-paper style questions from the exam bank on D3.3 each time, marked as you go, and saved to your Exam practice progress when you are signed in. Scan the code, or type the link.

biologybybradford.com/exam-maker/sit?topics=D3.3&level=HL&paper=quiz&marks=15&src=ep

Answers

PREDICTIONS IN THE CHAPTERS

01 The air temperature drops from 20 °C to 5 °C. What happens to the temperature of the blood in a healthy person?

B **It stays within a degree or so of 37 °C, because the body works to keep it there**

Core body temperature stays close to 37 °C. The body adjusts how much heat it makes and loses, so the internal temperature changes by only a small fraction of the change outside. It is kept within limits rather than held at an exact value.

02 A thermostat turns the heating on when a room is cold and off when it is warm enough. Why is this negative feedback?

B **The response, heating, reverses the change that triggered it, a fall in temperature**

Negative feedback means the response opposes the change. A fall in temperature switches the heating on, which warms the room, and once it is warm the heating switches off. Negative does not mean bad.

03 A person skips lunch and their blood glucose starts to fall. Which change comes next?

B **Alpha cells secrete glucagon, so the liver breaks glycogen down and releases glucose**

A fall in blood glucose is the signal for alpha cells to secrete glucagon. It makes liver cells break glycogen down to glucose and release it, which raises the level. This is negative feedback working from below the set point.

04 A person with diabetes has plenty of insulin in the blood but a high blood glucose level. Which is the most likely kind?

B **Type 2, because the target cells respond poorly to the insulin that is there**

Plenty of insulin and a high glucose level points to insulin resistance, which is type 2. In type 1 the beta cells are gone, so insulin is low or missing.

05 Which cells or organs detect the change when you step out into cold air?

B **Thermoreceptors in the skin and cells in the hypothalamus, which report to the hypothalamus**

Peripheral thermoreceptors in the skin, and thermoreceptors in the hypothalamus that monitor the blood, are the receptors. The hypothalamus is the control centre. Muscle and adipose tissue are effectors, and the pituitary and thyroid are part of the hormonal route.

06 A runner finishes a race on a warm day and their skin looks flushed and red. What is happening?

B **Vasodilation of skin arterioles, which brings more blood to the surface so heat is lost**

Flushed skin is vasodilation. The arterioles widen so more warm blood flows near the surface and loses heat to the air. Sweat then evaporates and cools the skin further.

07 Brown adipose tissue is most abundant in newborn babies. Why is a baby more in need of it than an adult?

B **A baby has a large surface area for its volume and cannot shiver well, so it loses heat fast and needs another way to warm up**

Small bodies have a large surface area for their volume and lose heat quickly, and newborns shiver poorly. Brown fat warms them without shivering. The hypothalamus still controls it.

08 A person eats a very salty meal and drinks no water. Which change will happen in the blood?

A **Its osmotic concentration rises, because there is the same water but more solute**

More solute with the same volume of water makes the blood more concentrated. Water would leave cells by osmosis, and the person feels thirsty. The kidney responds by reabsorbing more water.

09 A person's urine contains protein, which is not normally found in it. Which part of the nephron is most likely to be damaged?

B **The filter in the glomerulus and capsule, which should hold large proteins back**

Proteins are too large to pass through a healthy filter, so they stay in the blood. Protein in the urine points to damage to the filter. The proximal tubule reabsorbs glucose, ions and water, but not protein, as there is none in the filtrate.

10 What would happen to the concentration of the medulla if the sodium pumps in the ascending limb stopped working?

B **The medulla would become less concentrated, so less water could be reabsorbed from the collecting duct**

The pumps are what build the high concentration in the medulla. Without them the gradient would fade and the collecting duct would have little draw on its water, so a larger volume of more dilute urine would be made.

11 After running a long way in the heat, an athlete makes only a little dark urine. Which change in the collecting duct cells explains it?

A **Vesicles carrying aquaporins fuse with the cell membrane, so more water is reabsorbed**

A sweating athlete loses water, so the blood becomes more concentrated and ADH rises. ADH makes aquaporins move into the membrane, so more water leaves the duct by osmosis. Water is never pumped.

12 A person goes for a hard run straight after a large meal and gets a stitch and indigestion. What is the likeliest reason?

A **The muscles are asking for blood, so blood flow to the gut is reduced and digestion is disturbed**

In vigorous exercise arterioles to the gut constrict and arterioles to the muscles dilate. The gut then gets a much smaller share of the blood, and digestion is less efficient, so eating a big meal before hard exercise is uncomfortable.

QUESTIONS ON THE DRY LAB

Q1 You give the healthy volunteer plain water instead of the glucose drink. What does the blood glucose do over the three hours?

B **It stays close to the fasting level, because nothing has been added to the blood**

It stays near the fasting level of about 5 mmol/L. The control shows that the rise in the other tests is caused by the glucose, and that taking samples does not change the result.

Q2 Type 1 diabetes without insulin, and then with 10 units. Which part of the curve changes most?

B **The size of the peak and the level at two hours, because the insulin takes effect over the next hour or two**

Insulin acts over the next hour or two, so the peak is lower and the level falls back faster. The beta cells are still missing, which is why the injection has to be repeated, matched to food and exercise.

How this was made. The course structure, the activities and the teaching choices come from my own classroom, my presentations and my years of teaching IB and AP Biology. I use Claude, an AI, to help write and build the interactive guides, lesson plans, slides and practice questions, and to draw the diagrams and code the interactives. I direct the work and review it against the IB and AP specifications before it goes live.

Written and drawn for Biology by Bradford, biologybybradford.com. Free to print and share with a class.