Homeostasis (chapter 14):

- **Homeostasis**: to maintain a constant/stable internal environment in the body
- The importance of homeostasis in a mammal:
  - To maintain a constant internal environment of blood and tissue fluids within narrow limits / set point, effects:
  - Low temperature, consequence: slowed metabolism / enzymes less active
  - High temperature, consequence: enzymes denatured
  - Low water potential, consequence: water leaving cells / cells shrink
  - High water potential, consequence: water enters cells / cells burst
  - Low blood glucose, consequence: effect on respiration
  - High blood glucose, consequence: water leaving cells / cells shrink
  - Control of pH, consequence: enzymes become less active
- Control mechanisms use a negative feedback loop involving:
  - **Receptor** (sensor) detects changes in both **internal and external stimuli** (any change in a physiological factor being regulated) away from the set-point; nerve impulse sent to a **central control** or hormone released, which then reaches the **effectors** (muscles and glands) / target organs; effector performs corrective action, hence factor returns to set-point
- Continuous monitoring of the factor by receptors produces a steady stream of information to the control centre that makes continuous adjustments to the output, hence the factor fluctuates around a particular **set point**
- Negative feedback: the mechanism to keep changes in the factor within narrow limits, by increasing or decreasing accordingly during a change in the factor
- Two **coordination systems** in mammals:
  - Nervous system, by electrical impulses transmitted along neurones
  - Endocrine system, by hormones (chemical messengers) travel in the blood

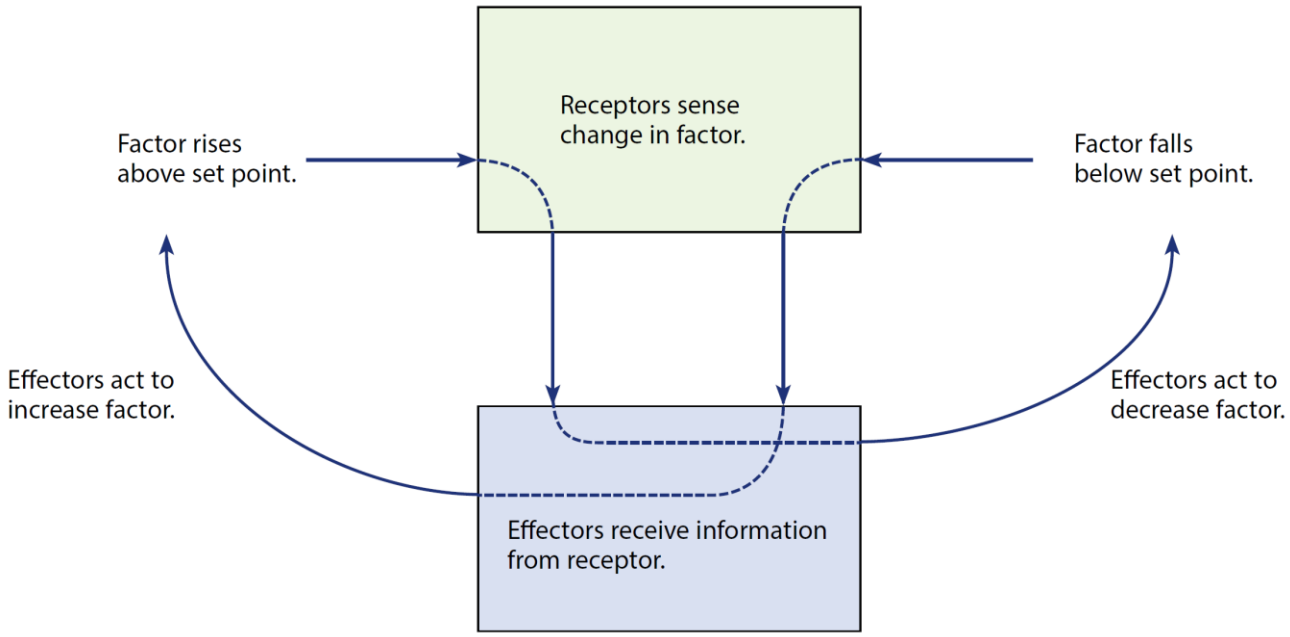


Figure 14.2 A negative feedback control loop.

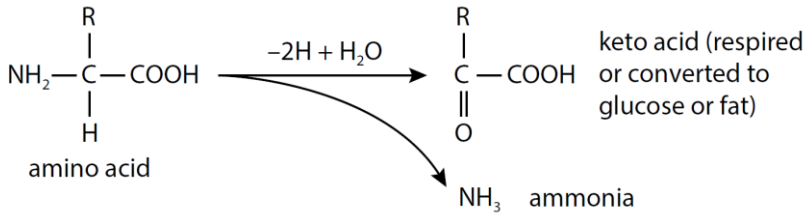
- **Thermoregulation** is the control of body temperature involving both coordination systems, controlled by the hypothalamus – receives constant input of sensory information about

temperature of the blood (by the themorecepter cells monitoring the core temperature) and the surroundings (skin receptors)

- If there is a decrease in temperature, hypothalamus sends impulses that activate several physiological responses which decreases the loss of heat from the body and increases heat production:
  - Vasoconstriction – contraction of the muscles in the walls of the arterioles in skin surface, narrowing the lumens, reducing the supply of blood, hence less heat lost from the blood
  - Shivering – involuntary contraction of the skeletal muscles generate heat, absorbed by the blood
  - Raising body hairs – contraction of the muscles attached to the hairs, increasing the depth of fur and the layer of insulation, trapping air close to the skin
  - Decrease in sweat production – reduces heat loss by evaporation from skin surface
  - Increase secretion of adrenaline – increases the rate of heat production in the liver
- A decrease in temperature gradually (e.g. winter), the hypothalamus releases a hormone which activates the **anterior pituitary gland** to release **thyroid stimulating hormone** (TSH)
  - TSH stimulates the thyroid gland to secrete **thyroxine** hormone into the blood, increases the metabolic rate, increases the heat production
  - When temperature starts to increase again, the hypothalamus responds by reducing the release of TSH by the anterior pituitary gland, hence less thyroxine released from the thyroid gland
- If there is a increase in temperature, hypothalamus increases the loss of heat from the body and reduces heat production:
  - Vasodilation – relaxation of the arterioles in skin, hence it widens, more blood flows to the capillaries, heat energy lost
  - Increasing sweat production – sweat glands increase production of sweat which evaporates on the surface of the skin, removing heat from the body
  - Lowering body hairs – relaxation of the muscles attached to the hairs, hence they lie flat, reducing the depth of fur and layer of insulation

- Excretion: the removal of unwanted products (e.g. ammonia – toxic) of metabolism
  - Urea is produced in the liver from excess amino acids, transported to the kidney in solution in the blood plasma through diffusion from liver cells, which will then be removed from the blood, dissolved in water and excreted as urine
- The formation of urea from excess amino acids by liver cells:
  - Deamination / removal of amine group and ammonia (NH_3) formed, which is then combined with carbon dioxide forming the urea cycle
  - Ammonia is a soluble and toxic compound, hence needed to be converted into urea (main nitrogenous excretory product) – less soluble and less toxic

a



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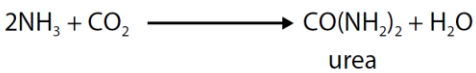


Figure 14.4 **a** Deamination and **b** urea formation.

- Structure of kidney:
  - Each kidney receives blood from a **renal artery**; return blood via a **renal vein**
  - Narrow tube – **ureter** – carries urine from kidney to bladder
  - **Urethra** – single tube – carries urine to the outside of the body

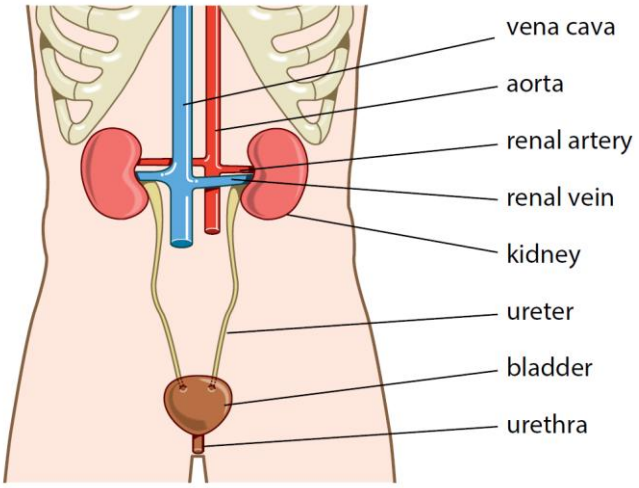


Figure 14.5 Position of the kidneys and associated structures in the human body.

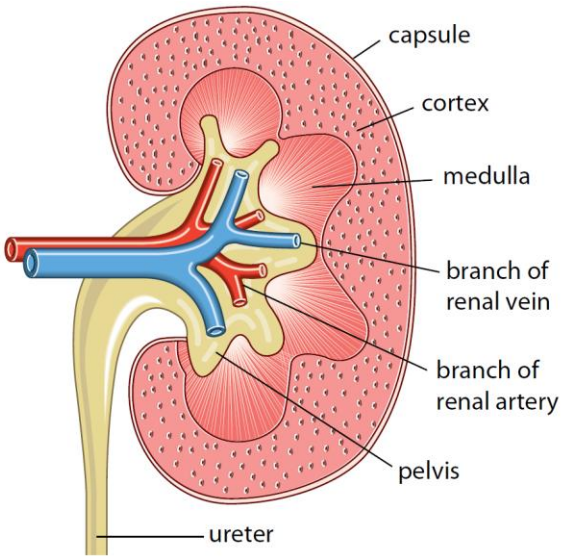


Figure 14.6 A kidney cut in half vertically.

  - A longitudinal section through a kidney (Fig 14.6) shows its main areas:
    - **Capsule** covering the whole kidney
    - **Cortex** lying beneath the capsule
    - **Medulla** – central area of kidney
    - **Pelvis** – where ureter joins

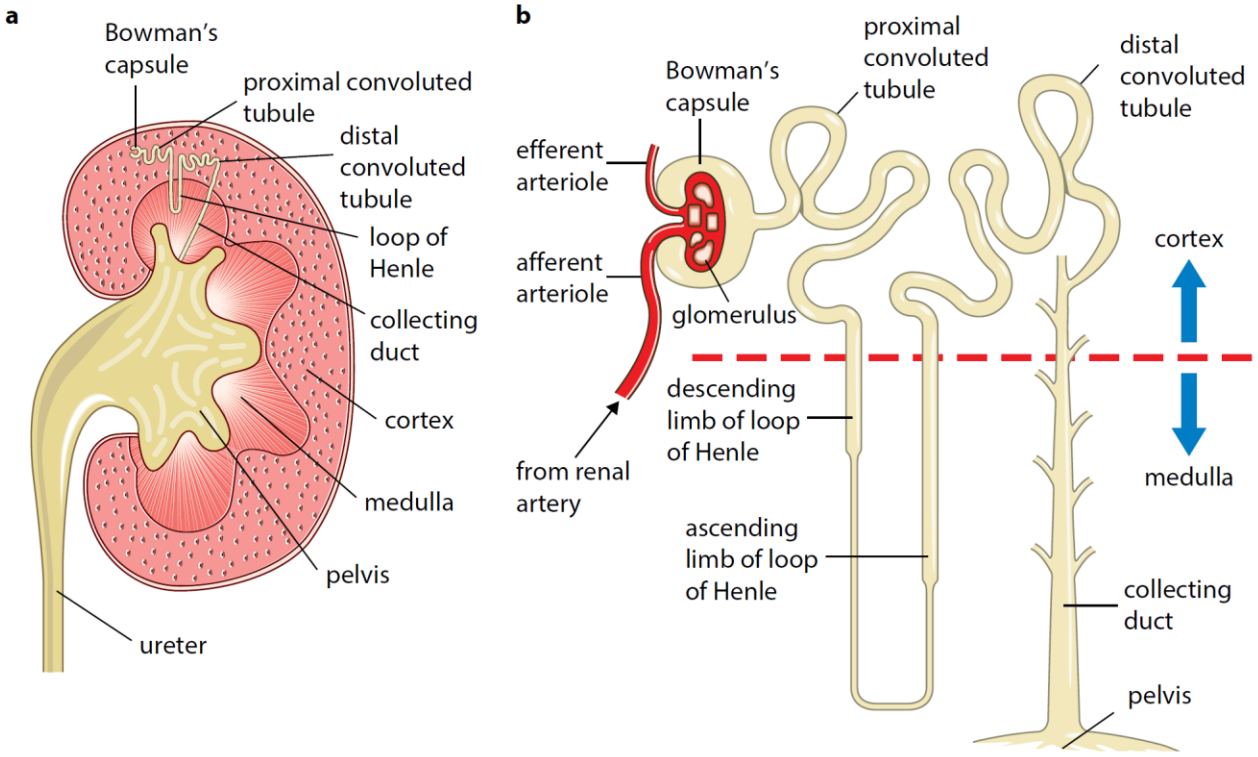


Figure 14.8 **a** Section through the kidney to show the position of a nephron; **b** a nephron.

- A kidney is made up of thousands of tiny tubes called **nephrons** and many blood vessels
- One end of the nephron forms a cup-shaped structure called **Bowman's capsule**, surrounding a tight network of capillaries called a **glomerulus** (both located on the cortex)
- The tube then forms a twisted region called the **proximal convoluted tubule**
- Which then runs down towards the centre of the kidney (medulla) forming the **loop of Henle**
- It then runs back upwards into the cortex forming another twisted region called **distal convoluted tubule**
- Before finally joining a **collecting duct** that leads down through the medulla and into the pelvis of the kidney

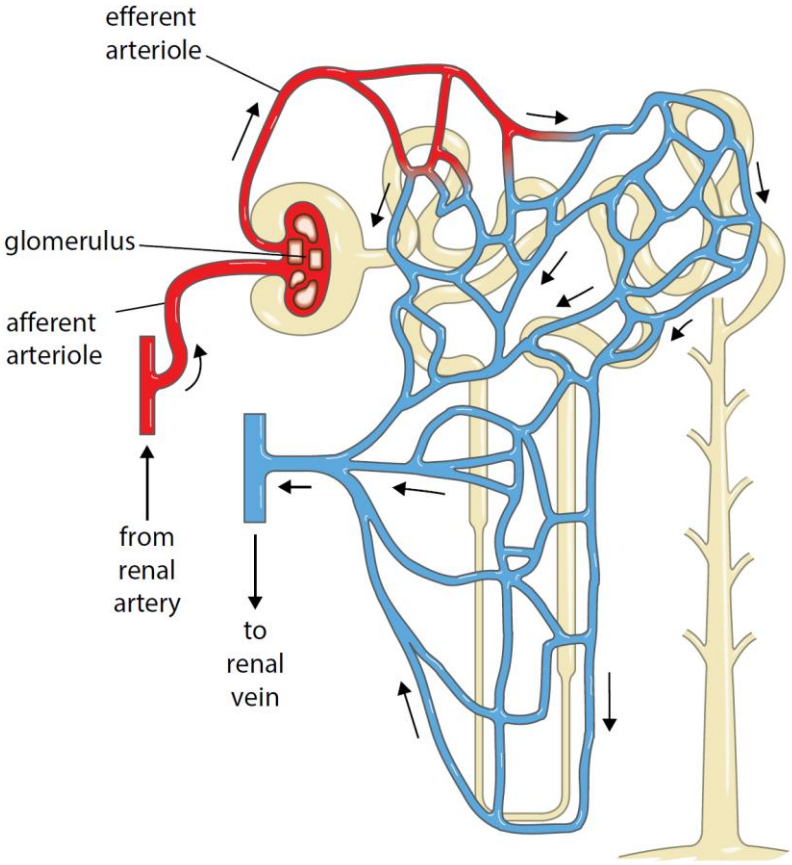


Figure 14.9 The blood supply associated with a nephron.

- Each glomerulus is supplied with blood from a branch of renal artery called an **afferent arteriole**
- The capillaries of the glomerulus rejoins to form an **efferent arteriole**, which leads off to form a network of capillaries running closely alongside the rest of the nephron, where it then flows into a branch of the renal vein

- The kidney makes urine in a two-stage process:
  - Ultrafiltration – filtering of small molecules including urea into the Bownman's capsule from the blood
  - Selective reabsorption – taking back useful molecules from the fluid in the nephron as it flows along
- **Water potential**: tendency of water molecules to move from one region to another
- **Ultrafiltration**

- The blood in the glomerular capillaries is separated from the lumen of the Bowman's capsule by two cell layers (endothelium of the capillary and epithelial cells (podocytes – having finger-like projections with gaps in between them) making the inner lining of the Bowman's capsule) and a basement membrane

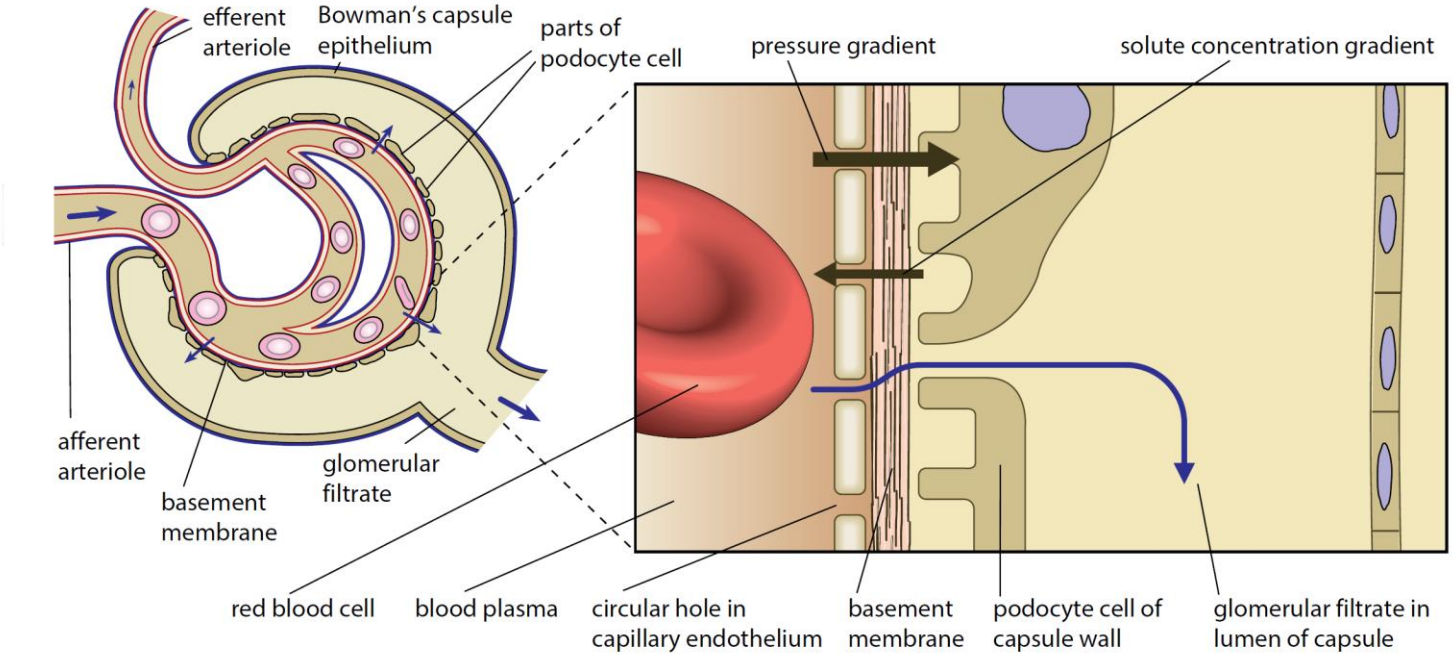


Figure 14.10 Detail of the endothelium of a glomerular capillary and Bowman's capsule. The arrows show how the net effect of higher pressure in the capillary and lower solute concentration in the Bowman's capsule is that fluid moves out of the capillary and into the lumen of the capsule. The basement membrane acts as a molecular filter.

- The diameter of lumen of the afferent arteriole is wider than efferent arteriole, which leads to high blood pressure (hydrostatic pressure) and low pressure in the Bowman's capsule, hence plasma/fluid passes through the fenestrations between the endothelial cells of the capillaries; however, red and white blood cells / large proteins (plasma proteins) / molecules greater than 68 000(MM), cannot pass through due to the basement membrane which acts as a selective barrier; filtrate through the basement membrane can freely pass through the podocytes due to its fenestrations and forced into the Bowman's capsule (renal capsule)

- **Reabsorption in the proximal convoluted tubule**
  - Process called selective reabsorption (above 180 mg, no further absorption, as carriers in the PCT are saturated)
  - Lining of the proximal convoluted tubule is made of a single layer of cuboidal epithelial cells which are adapted to their function of reabsorption by having:
    - Microvilli to increase the surface area of the inner surface facing the lumen to increase absorption of Na^+ / glucose / amino acids
    - Tight junctions to hold adjacent cells together so that fluid cannot pass between the cells (all reabsorbed substances must go through the cells)
    - Many mitochondria to provide ATP for sodium-potassium (Na^+-K^+) pump proteins in the outer membranes of the cells
    - Many co-transporter proteins in the membrane facing the lumen
    - Folded basal membrane to increase surface area to increase sodium-potassium pumps to move Na^+ into the blood
    - More ER for increase in protein synthesis

- The folded basal membranes of the cells lining the proximal convoluted tubule are those nearest the blood capillaries; sodium–potassium pumps in these membranes move sodium ions out of the cells; the sodium ions are carried away in the blood, lowering the concentration of sodium ions inside the cell, so that they passively diffuse into it, down their concentration gradient, from the fluid in the lumen of the tubule; however, sodium ions do not diffuse freely through the membrane – only enter through special co-transporter proteins in the membrane, each of which transports something else, such as a glucose molecule or an amino acid, at the same time as the sodium ion (the passive movement of sodium ions into the cell down their concentration gradient provides the energy to move glucose molecules, against a concentration gradient – indirect or secondary active transport, since the energy (as ATP) is used in the pumping of sodium
- All of the glucose, amino acids, vitamins and many Na^+ and Cl^- ions, some urea and most water are reabsorbed from the glomerular filtrate into the blood, which increases the water potential in the filtrate, hence water moves down this gradient through the cells into the blood

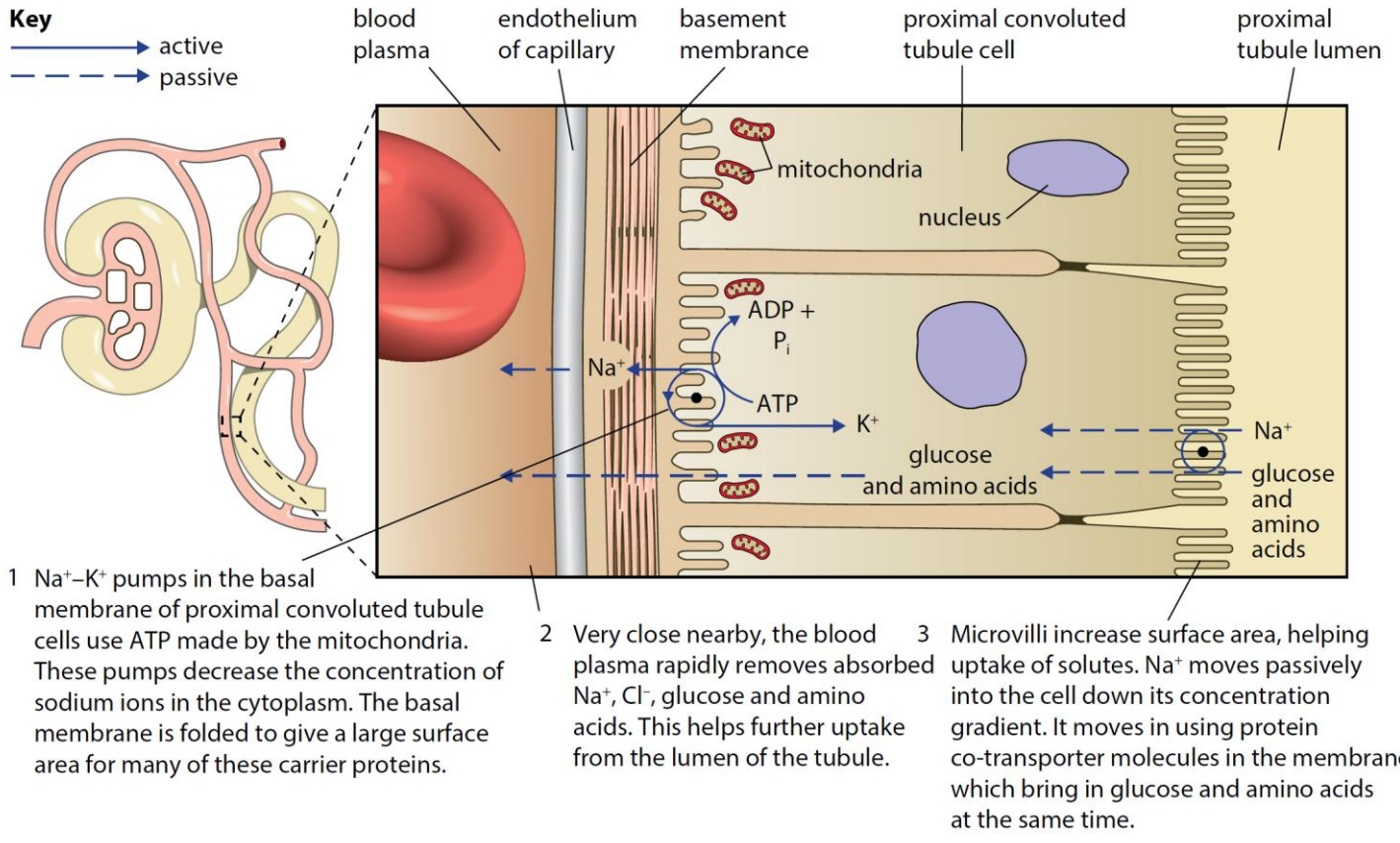


Figure 14.12 Reabsorption in the proximal convoluted tubule.

- **Reabsorption in the loop of Henle and collecting duct**
  - Descending limb is permeable to water, ascending limb does not
  - In the ascending limb, active transport of Na^+ and Cl^- ions out of loop into the tissue fluid, which decreases the water potential in the tissue fluid and increases the water potential of the ascending limb's water potential
  - Descending limb permeable to both water and Na^+ and Cl^- ions, hence as fluid moves down the loop, water from filtrate moves down a water potential gradient into the tissue fluid by osmosis, while Na^+ and Cl^- ions diffuse into the loop, down

their potential gradient, thus the fluid becomes more concentrated towards the bottom of the loop; the longer the loop, the more concentrated the fluid can become

- Concentrated fluid flows up the ascending limb where Na^+ and Cl^- ions diffuse out in the lower part of ascending limb; and active transported out on the upper part of ascending limb

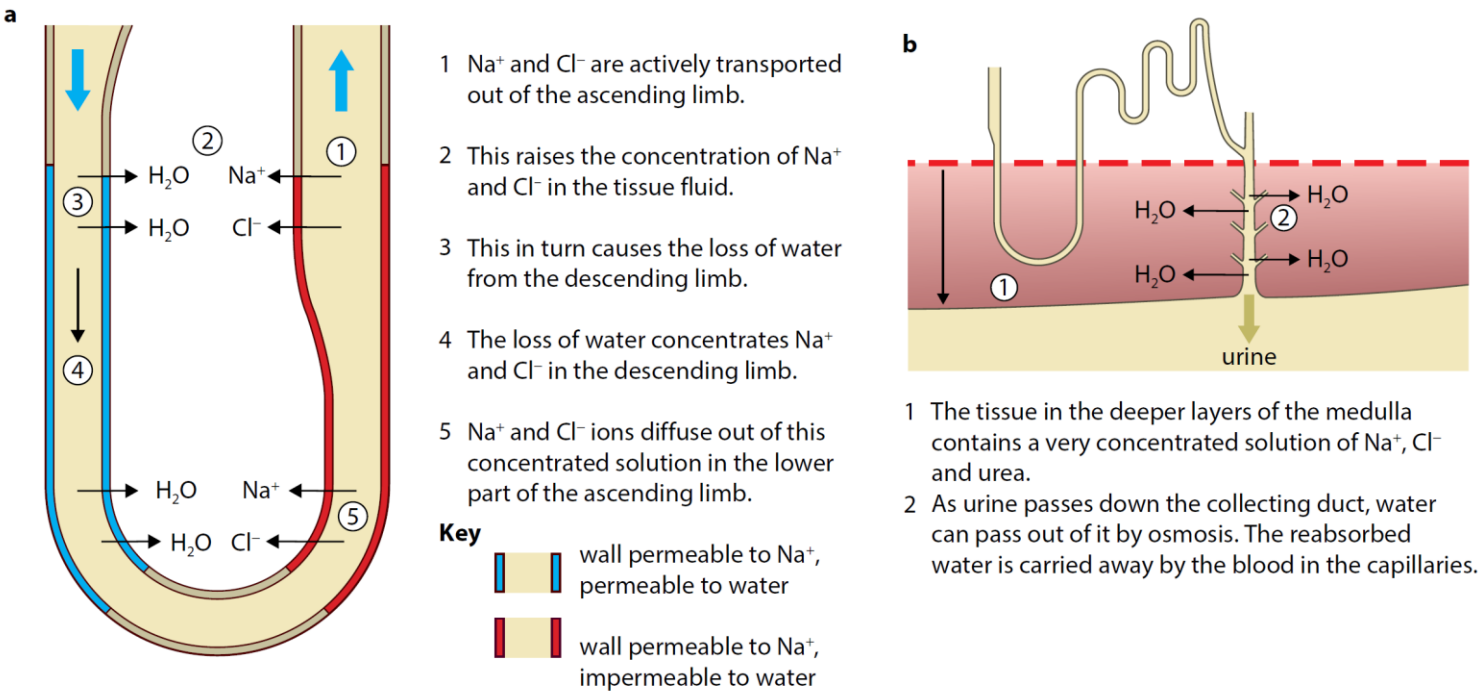
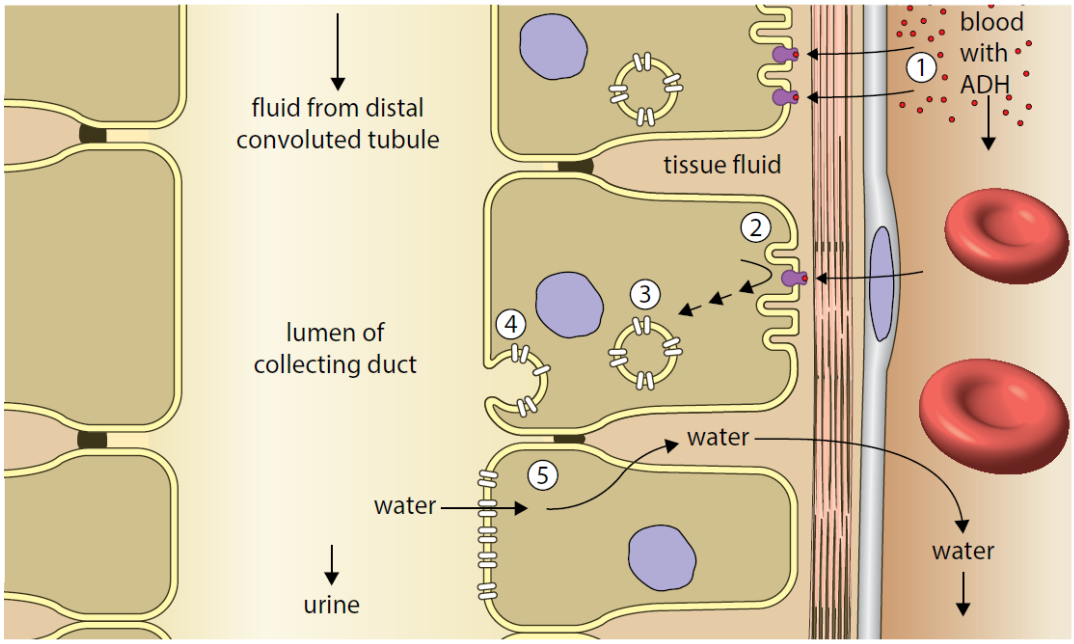


Figure 14.13 How the loop of Henle allows the production of concentrated urine. **a** The counter-current mechanism in the loop of Henle builds up high concentrations of sodium ions and chloride ions in the tissue fluid of the medulla. **b** Water can pass out of the fluid in the collecting duct by osmosis, as the surrounding tissue fluid has a lower water potential.

- Counter-current multiplier mechanism used – fluid flowing in vertically opposite directions to maximise the concentration built up of solutes both inside and outside the tube at the bottom of the loop
- As fluid flows up the ascending limb of the loop of Henle, it loses sodium and chloride ions as it goes, so becoming more dilute and having a higher water potential; cells of the ascending limb of the loop of Henle and the cells lining the collecting ducts are permeable to urea which diffuses into the tissue fluid, hence urea is also concentrated in the tissue fluid in the medulla, so water can move out of the collecting duct by osmosis, due to the tissue fluid's high solute concentration and low water potential

- **Reabsorption in the distal convoluted tubule and collecting duct**
  - Na^+ ions are actively pumped from the fluid in the tubule into the tissue fluid, into the blood
  - K^+ ions are actively transported into the tubule, where the rate of transfer of the two ions are variable, helps regulate the concentration of these ions in the blood
- **Osmoregulation**: the control of the water potential of body fluids
- Roles of hypothalamus, posterior pituitary, collecting ducts and ADH in osmoregulation:
  - Hypothalamus detects changes in water potential of the blood, as osmoreceptors (in the hypothalamus) shrink when there is a low water potential (ADH produced in hypothalamus), and released into the blood via the posterior pituitary gland
  - Nerve impulses are sent from the hypothalamus to posterior pituitary gland

- ADH bind to receptor proteins on the collecting duct cell surface membranes and affects the collecting duct by activating series of enzyme controlled reactions, activating vesicles containing aquaporins in their membranes to move to cell surface membrane on lumen side; fuses with the cell surface membrane, hence increases water permeability of collecting duct cells, causing more water reabsorption / more concentrated urine, as water moves through the aquaporins, out of the tubule into the tissue fluid down water potential gradient



1 ADH binds to receptors in the cell surface membrane of the cells lining the collecting duct.
2 This activates a series of enzyme-controlled reactions, ending with the production of an active phosphorylase enzyme.
3 The phosphorylase causes vesicles, surrounded by membrane containing water-permeable channels (aquaporins), to move to the cell surface membrane.
4 The vesicles fuse with the cell surface membrane.
5 Water can now move freely through the membrane, down its water potential gradient, into the concentrated tissue fluid and blood plasma in the medulla of the kidney.

Figure 14.18 How ADH increases water reabsorption in the collecting duct.

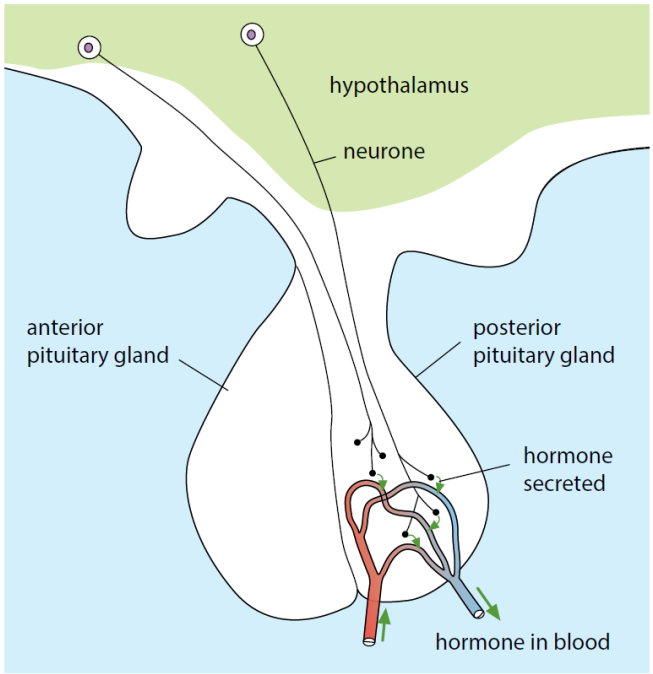


Figure 14.16 ADH is produced by neurones in the hypothalamus and is released into the blood where the neurones terminate in the posterior pituitary gland.

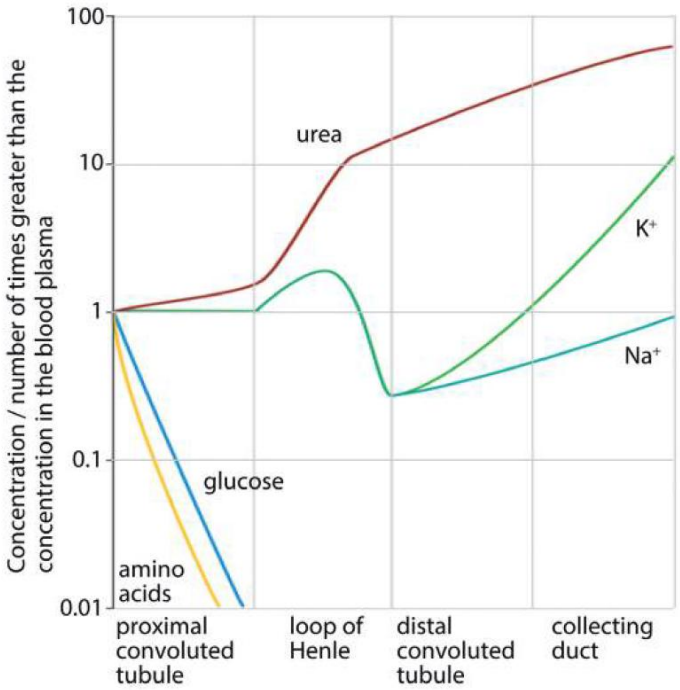


Figure 14.15 Relative concentrations of five substances in different parts of a nephron.

- Homeostatic control of blood glucose concentration is carried out by two hormones secreted by endocrine tissue – consisting of groups of cells known as **islets of Langerhans** (containing α cells secreting glucagon; β cells secreting insulin) in the pancreas

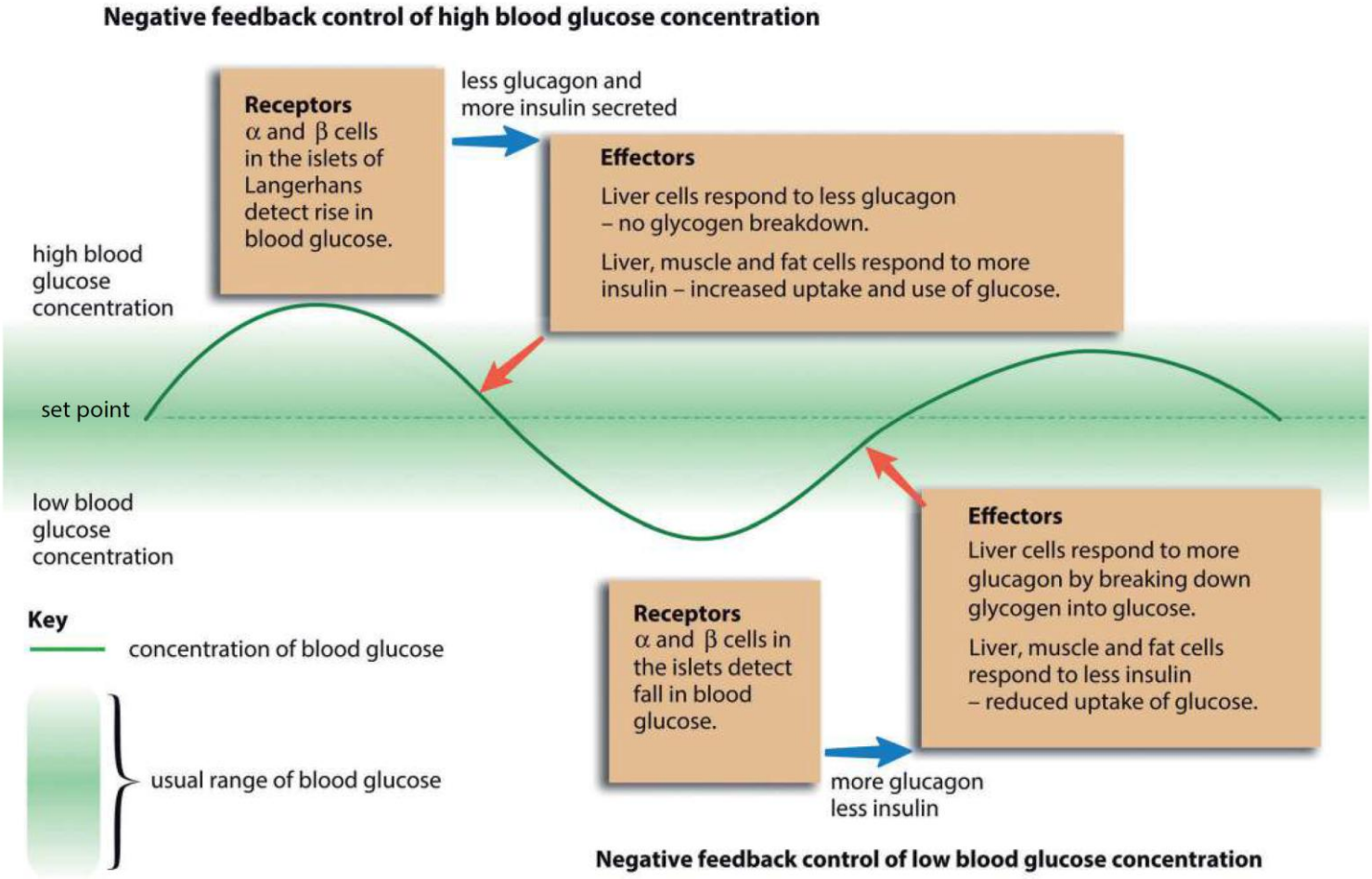


Figure 14.21 The control mechanism for the concentration of glucose in the blood.

- Insulin is a signalling molecule which binds to a receptor in the cell surface membrane and affects the cell indirectly through the mediation of intracellular messengers, following these steps:
  - Increase in blood glucose concentration detected by β cells in the islets of Langerhans, hence more insulin secreted into the blood
  - Resulting to increase in glucose absorption in the liver by phosphorylating glucose – traps glucose inside cells as phosphorylated glucose cannot pass through the transporters in the cell surface membrane; increases the permeability of glucose in muscle / fat cells by addition of GLUT 4 proteins to cell surface membranes of these cells; increases the rate of respiration of glucose; conversion of glucose to glycogen; inhibits secretion of glucagon; process called negative feedback
- The action of glucagon on liver cells in the regulation of blood glucose concentration:
  - Decrease in blood glucose concentration detected by α cells and responds by secreting glucagon
  - Glucagon binds to receptors in cell surface membrane of liver cell
  - Receptor changes conformation and G-protein activated
  - Adenylate cyclase activated causing ATP to be converted to cyclic AMP which is a second messenger

- Cyclic AMP activates kinase protein which activate enzymes through phosphorylation resulting to enzyme cascade
- Glycogen phosphorylase activated catalysing the breakdown of glycogen to glucose
- Glucose diffuses out of liver cell through GLUT2 transporter proteins into the blood
- Gluconeogenesis – glucose made from amino acids and lipids
- Increase in blood glucose concentration

- The main stages of cell signalling in the control of blood glucose concentration by adrenaline:
  - Adrenaline binds to receptors in the cell surface membrane
  - Receptor changes conformation and G proteins activated
  - Adenylyl cyclase activated resulting to ATP converted to cyclic AMP which is a second messenger
  - Cyclic AMP activates kinase protein which activates enzymes through phosphorylation resulting to enzyme cascade
  - Glycogen phosphorylase activated catalysing the breakdown of glycogen to glucose
  - Glucose diffuses out of liver cell through GLUT2 transporter proteins into the blood
  - Increase in blood glucose concentration
- Diabetes mellitus are of two forms:
  - Type 1 diabetes: insulin-dependent diabetes, where pancreas is incapable of secreting sufficient insulin, early onset
  - Type 2 diabetes: non-insulin-dependent diabetes, where pancreas does secrete insulin, but liver and muscle cells do not respond properly to it, late onset – associated with diet and obesity
- The symptoms of diabetes mellitus include the tendency to drink a lot of water and a loss of body mass because:
  - High blood glucose concentration causes decrease in water potential of the blood, which is detected by osmoreceptors resulting to the feelings of thirst
  - Less glucose converted to glycogen, as glucose lost in urine (above the renal threshold), hence glucose is not taken up by cells, hence fats are metabolised, resulting to build up in ketones which decreases the blood pH causing come
- Dip stick can be used to measure glucose concentration by:
  - Immobilised glucose oxidase enzyme stuck onto pad at the end of the stick
  - Dip stick lowered into urine and if it contains glucose, glucose oxidase oxidises glucose into gluconic acid (gluconolactone) and hydrogen peroxide
  - Peroxide reacts with chromogen (using peroxidase enzyme) on pad to form a brown compound, due to the oxygen produced resulting to the oxidation of chromogen by oxygen, which produces a range of colour
  - Darkness of colour / range of colours is matched against a colour chart and is proportional to concentration of glucose (the darker the colour, the more glucose present)
  - Does not give the current blood glucose concentration (only that it is higher than the renal threshold
  - Important to keep a fixed time in observing colour changes
- Biosensor can be used to measure glucose concentration by:
  - The pad contains glucose oxidase enzyme reacts with glucose in the blood to produce gluconolactone and oxygen
  - Oxygen is detected and an electric current is generated which is detected by an electrode, amplified and gives numerical value of blood glucose concentration

  - The greater the current, the greater the reading from the biosensor, the greater the glucose present
- Advantages of biosensor over dip stick:
  - Gives the actual reading of blood glucose concentration
  - Re-usable
  - Quantitative, hence more precise reading
- Stomata have daily rhythms of opening and closing (opens during the day to maintain the inward diffusion of carbon dioxide and the outward diffusion of oxygen and water vapour in transpiration; the closure of stomata at night when photosynthesis does not occur to reduce rates of transpiration and conserve water) and also respond to changes in environmental conditions to allow diffusion of carbon dioxide and regulate water loss by transpiration
  - Open in response to:
    - Increase in light intensity to gain CO2 for photosynthesis, allowing oxygen to diffuse out
    - Allows transpiration to occur for which brings water / mineral ions in for photosynthesis
  - Close in response to:
    - Decrease in light intensity as CO_2 is not required (no photosynthesis)
    - Low humidity, high temperature, high wind speed and water stress
    - To prevent water loss by transpiration (maintains cell turgidity)
- Guard cells open when they gain water to become turgid and close when they lose water to become flaccid, by osmosis
- Mechanism by which guard cells open stomata:
  - Proton pumps in cell surface membranes of guard cells actively pump H^+ out of the cells, which causes a lower H^+ concentration inside the cell, hence inside of cell is more negatively charged than the outside
  - K^+ channels open to move K^+ into the cell by facilitated diffusion down an electrochemical gradient
  - Water potential of cell decreases, due to increase in solute potential, hence water moves into the cell by osmosis down a water potential gradient through the aquaporins in the membrane
  - Volume of the guard cells increases becoming turgid opening the stoma
  - Unequal thickness of the cell wall of the guard cells (thicker wall adjacent to the pore

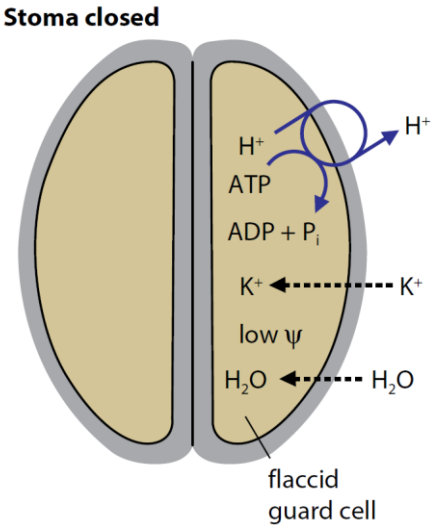


Figure 14.32 How a stoma is opened. Guard cells do not have plasmodesmata, so all exchanges of water and ions must occur across the cell surface membranes through the pump and channel proteins.

- Stomata close when proton pumps in cell surface membranes of guard cells stop and K^+ ions diffuses out of the guard cells through K^+ channels to enter the neighbouring cells, creating a water potential gradient in the opposite direction, hence water leaves the guard cells so it becomes flaccid and stoma closes, reducing the CO_2 uptake for photosynthesis and reduces rate of transpiration; in conditions of water stress, abscisic acid (ABA) hormone stimulates stomatal closure
- The role of abscisic acid in the closure of stomata:
  - Plant secretes abscisic acid during times of water stress
  - Abscisic acid is a stress hormone which binds to receptors on the cell surface membranes of guard cells, and inhibits proton pump (H^+ not pumped out of cell)
  - High H^+ concentration inside cell, resulting to change in charge, stimulating Ca^{2+} influx into the cytoplasm which acts as second messenger, and encourages K+ efflux (K^+ channels open)
  - Water potential of the cell increases, hence water moves out of cell by osmosis
  - Volume of guard cells decreases, becoming flaccid
  - The response is very fast