DP IB Biology: HL

Your notes

11.3 The Kidney & Osmoregulation

Contents

11.3.1 Osmoregulation in Organisms

Your notes

Organisms & Osmolarity in the Environment

- Living organisms need to maintain a **safe balance of water and** solutes in their cells
- Failure to maintain this balance will mean that an organism's cells could either **take on water and burst**, or **lose water and shrink** due to the effects of **osmosis**
  - Cells with a **higher** osmolarity **than their surrounding environment** will **gain water by osmosis** and the resulting internal pressure increase could cause the cell to **burst**
    - Note that plant cells are protected from bursting by their **strong cell walls**
  - Cells with a **lower osmolarity than their surrounding environment** will **lose water by osmosis** and the resulting drop in internal pressure will cause the cell to **shrink**
- Organisms avoid the cell damage that can result from water gain or loss by either **osmoconforming** or **osmoregulating**
  - Osmoconforming means that the **osmolarity of an organism's body fluids matches that of its surroundings**
    - Examples of osmoconformers include **marine invertebrates** such as mussels, lobsters, and jellyfish, as well as some **unusual groups of fish** such as sharks and hagfish
    - Osmoconforming is achieved by **retaining ions from the environment in the body fluids**, or in the case of sharks by retaining the urea produced in metabolism
    - Some osmoconformers have the ability to **change their internal osmolarity over a large range** when their environment changes
  - Osmoregulation means **maintaining a constant body fluid osmolarity regardless of the osmolarity of the external environment**
    - Examples of osmoregulators include **land animals**, **marine mammals**, **most fish**, and **amoebas** (singled-celled eukaryotes)
      - Amoebas use an organelle called a contractile vacuole to carry out osmoregulation; as the cell takes on water by osmosis, the water moves into the contractile vacuole, which then moves to cell surface membrane, fuses with it, and releases its contents outside the cell
    - Osmoregulators must **balance retention of water** with the **concentration of other molecules** in their body fluids, such as **sugars, salts**, and **amino acids**

The Malpighian Tubule System

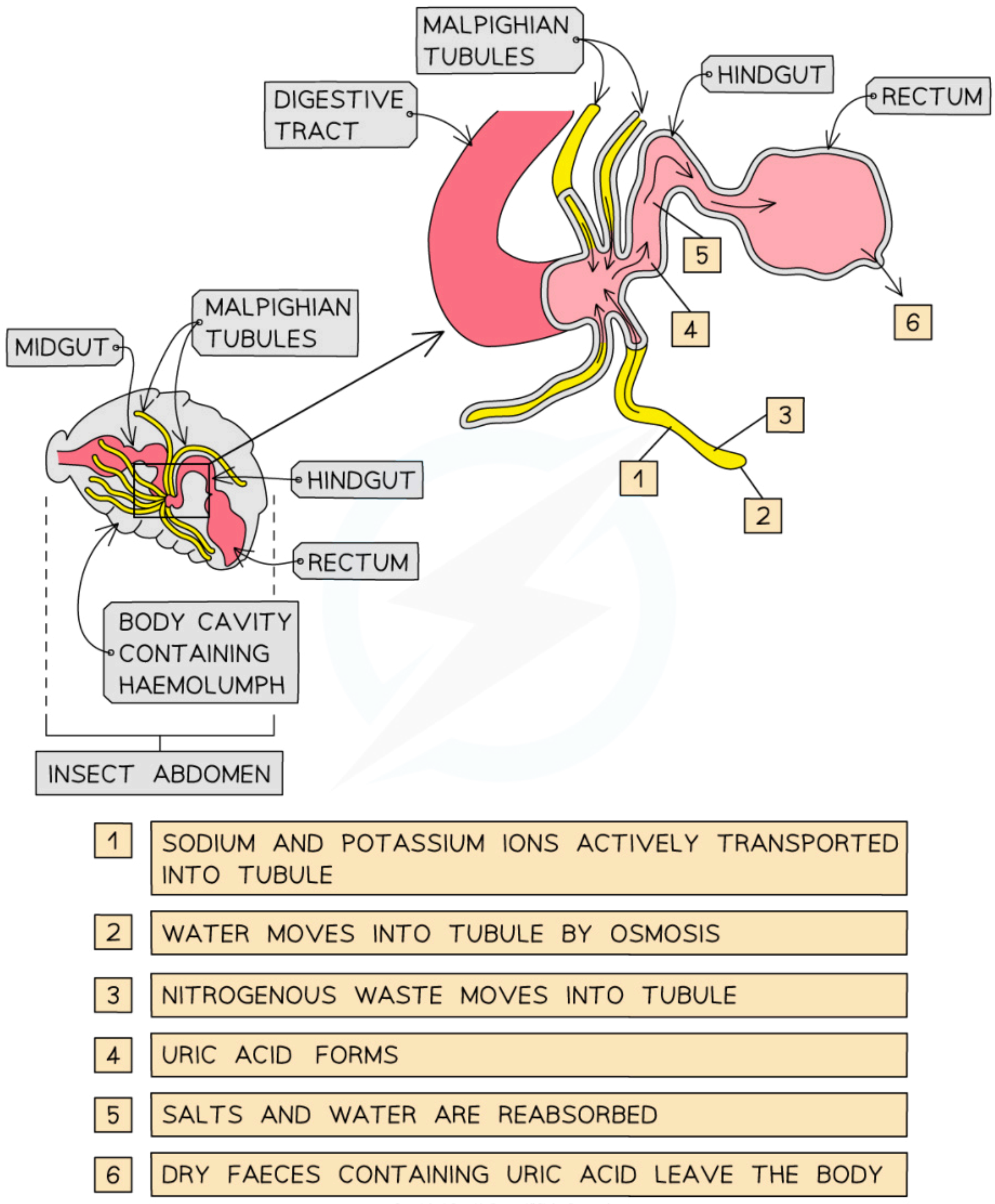
Your notes

- **Osmoregulation** is the process by which the **balance of water and solutes in the body fluids** of an organism is **maintained**
- In vertebrates osmoregulation is carried out by **kidneys**
  - Kidneys remove **nitrogenous waste** as well as any unwanted **sugars** and **salts** from the blood
    - Nitrogenous waste is produced when there are **excess amino acids** present after the digestion of dietary **protein**
    - Amino acids **cannot be stored**, so are converted first to toxic ammonia, then to a less toxic form; in humans this is **urea**, while some other animals e.g. birds and insects produce **uric acid**
    - The urea or uric acid can then be safely excreted from the body

Osmoregulation in insects

- Insects that live on land osmoregulate using a specialised system of **malpighian tubules**
  - Malpighian tubules are **a series of small tubes** that extend **from the body cavity** and drain **into the insect's digestive system**
- Insects do not technically have blood but instead have a fluid known as **haemolymph within the body cavity** which **surrounds the internal organs**
- The malpighian tubule system removes **nitrogenous waste**, **salts,** and **water** from the haemolymph, enabling the excretion of nitrogenous waste in the form of **uric acid**
  - The tubules are lined with cells that **actively transport ions** such as sodium (Na^+) and potassium (K^+) from the haemolymph into the tubule lumen, **raising the osmolarity** and **altering the charge** of the lumen contents
  - **Water moves** into the lumen from the haemolymph by **osmosis**
  - **Nitrogenous waste enters the tubules** from the haemolymph along an electrical gradient
  - The ions, water, and nitrogenous waste drain from the malpighian tubules into the digestive system
  - Nitrogenous waste is converted into **uric acid**
  - **Useful salts and water are reabsorbed** from the hindgut into the haemolymph
  - Uric acid remains in the digestive system, from which it later leaves the body **along with faeces**

Your notes



Terrestrial insects use the malpighian tubule system to remove nitrogenous waste from their bodies in the form of uric acid

Examiner Tip

Don't get too bogged down in the exact details of the processes taking place inside the Malpighian tubules, just make sure that you can outline the events e.g.

- Small molecules such as salts and nitrogenous waste are actively transported from the haemolymph into the malpighian tubules
- Water follows by osmosis
- The malpighian tubules drain into the insect's digestive tract
- Useful substances such as salts and water are reabsorbed from the gut, while uric acid is excreted

Your notes

Blood Composition in the Renal Blood Vessels

- The kidneys have two important roles in the human body
  - They **remove the toxic products of metabolism** from the blood
  - They **maintain the balance of water and solutes** in the blood
- Blood enters the kidney from the body through the **renal artery** and leaves the kidney to return to the body in the **renal vein**
- The **composition of the blood changes** as it passes through the kidneys due to
  - The removal of waste
  - The adjustment of the balance of solutes and water
  - Respiration taking place in the cells of the kidney
- The blood **entering the kidney via the renal artery** therefore has a **different composition** to the blood **leaving the kidney via the renal vein**

Blood composition in the renal blood vessels table

Substance	Renal artery in comparison to renal vein	Explanation
Urea	Higher	Product of the breakdown of excess amino acids that is excreted by the kidneys
Water	Higher	Product of respiration in the cells and of digestion. Excess water is removed from the blood by the kidneys
Salt	Higher	Product of digestion. Excess salt is removed from the blood by the kidneys
Oxygen	Higher	Carried in the blood from the lungs and used up by the aerobically respiring cells within the kidney itself
Carbon dioxide	Lower	Produced by the respiring cells of the kidney and released into the blood
Glucose	Slightly higher	Product of digestion that is partially used up by the respiring cells of the kidney. Note that most sugar filtered by the kidneys is reabsorbed back into the blood

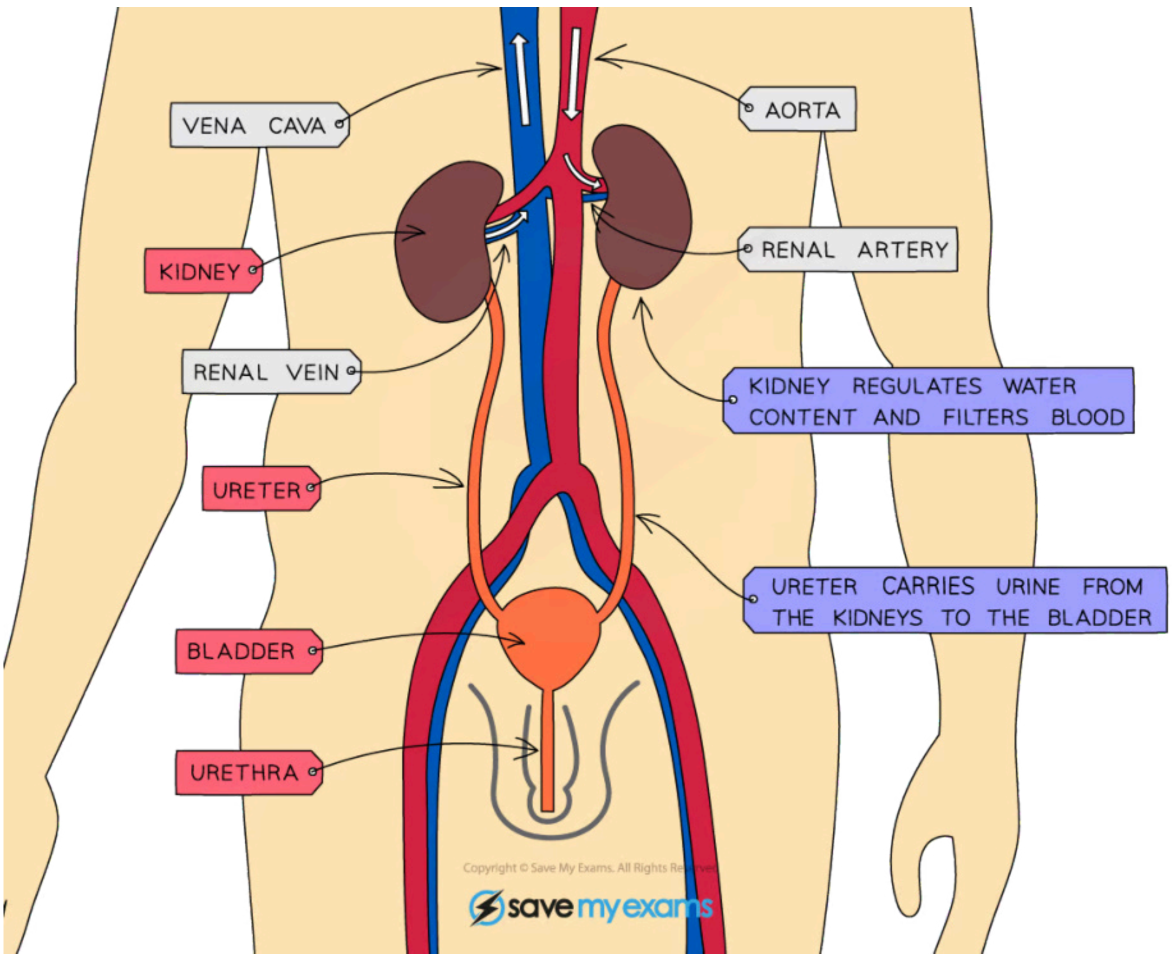
11.3.2 Kidney: Structure & Function

Your notes

Ultrastructure of the Glomerulus and Bowman's Capsule

Introduction to kidney structure

- Humans have **two kidneys**, which remove waste products from the blood and maintain the blood's balance of water and solutes
- The **renal artery** supplies blood to the kidneys, while the **renal vein** carries blood away
- The filtrate produced by the kidneys forms **urine** which is **transferred to the bladder via a tube called the ureter**



The kidneys are supplied with blood by the renal artery, while the renal vein carries blood away. A ureter carries urine from each kidney to the bladder.

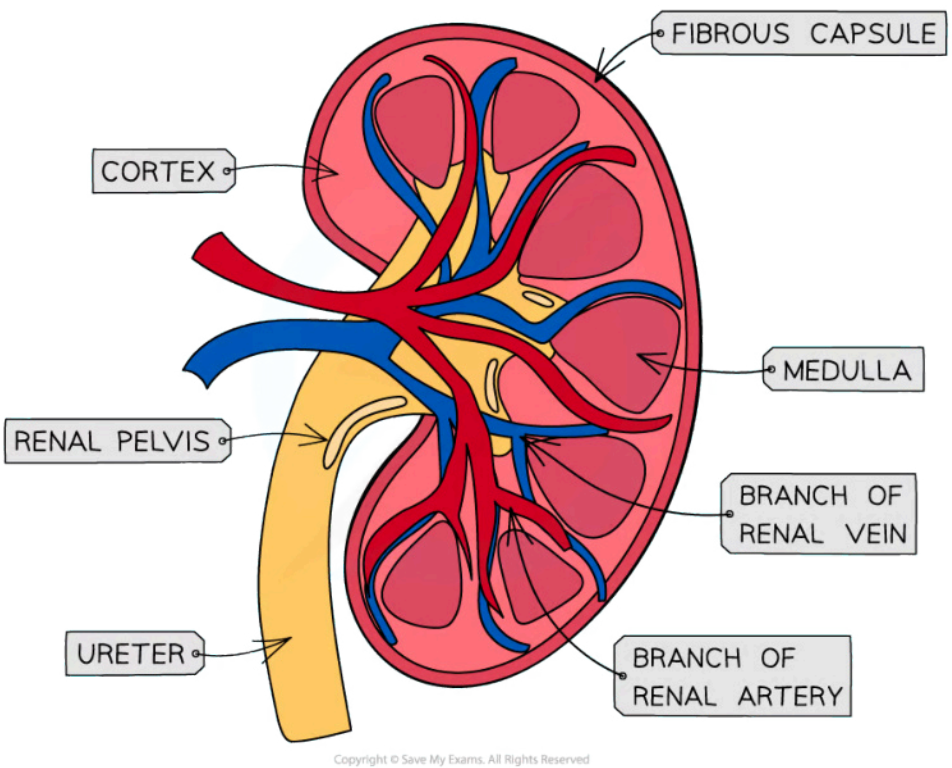
Kidney Structure & Function Table

Your notes

Structure	Function
Renal artery	Carries oxygenated blood (containing urea and salts) to kidneys
Renal vein	Carries deoxygenated blood (that has had urea and excess salts removed) away from kidneys
Kidney	Regulates water content of blood and filters blood
Ureter	Carries urine from kidneys to bladder
Bladder	Stores urine (temporarily)
Urethra	Releases urine outside of the body

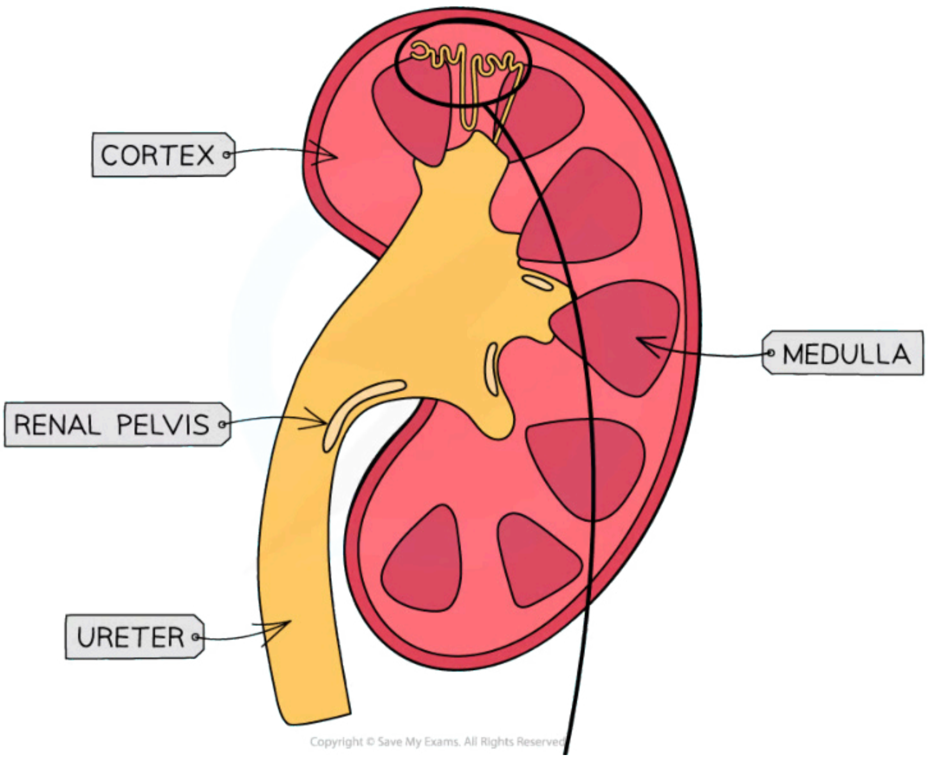
- The kidney itself is surrounded by an outer layer known as the **fibrous capsule**
- Beneath the fibrous capsule, the kidney has **three main regions**
  - The **cortex**
  - The **medulla**
  - The **renal pelvis**

Your notes



The kidney has three main regions; the cortex, the medulla, and the renal pelvis.

- Each kidney contains **thousands** of **tiny tubes**, or **tubules**, known as **nephrons**
- Nephrons are the **functional unit** of the kidney and are responsible for the **formation of urine**
- Different parts of the nephron are found in different regions of the kidney
  - The **cortex**
    - Location of the glomerulus, Bowman's capsule, proximal convoluted tubule, and distal convoluted tubule
  - The **medulla**
    - Location of the loop of Henle and collecting duct
  - The **renal pelvis**
    - All kidney nephrons drain into this structure, which connects to the ureter


CORTEX
MEDULLA
RENAL PELVIS
URETER
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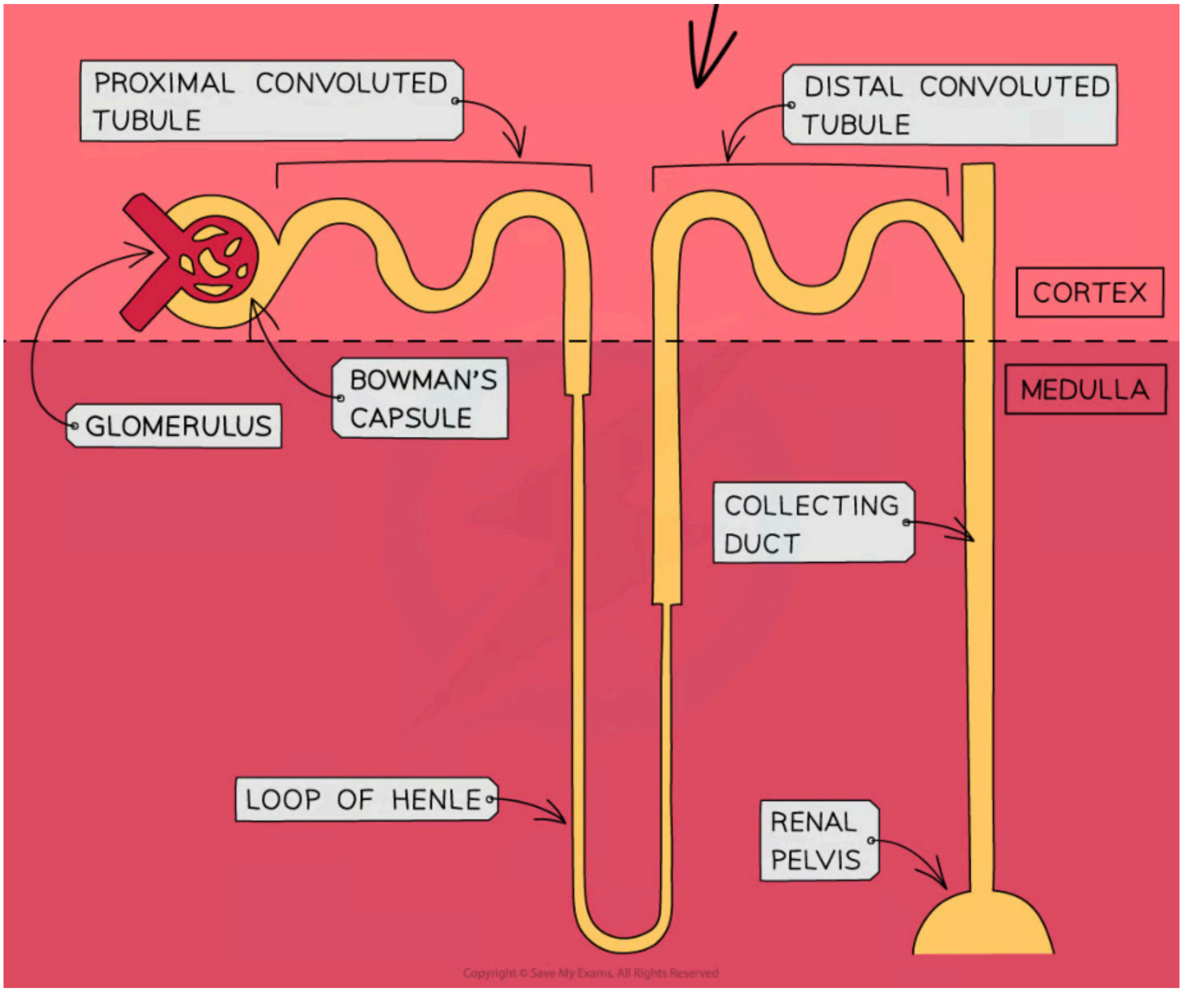
Your notes

Your notes

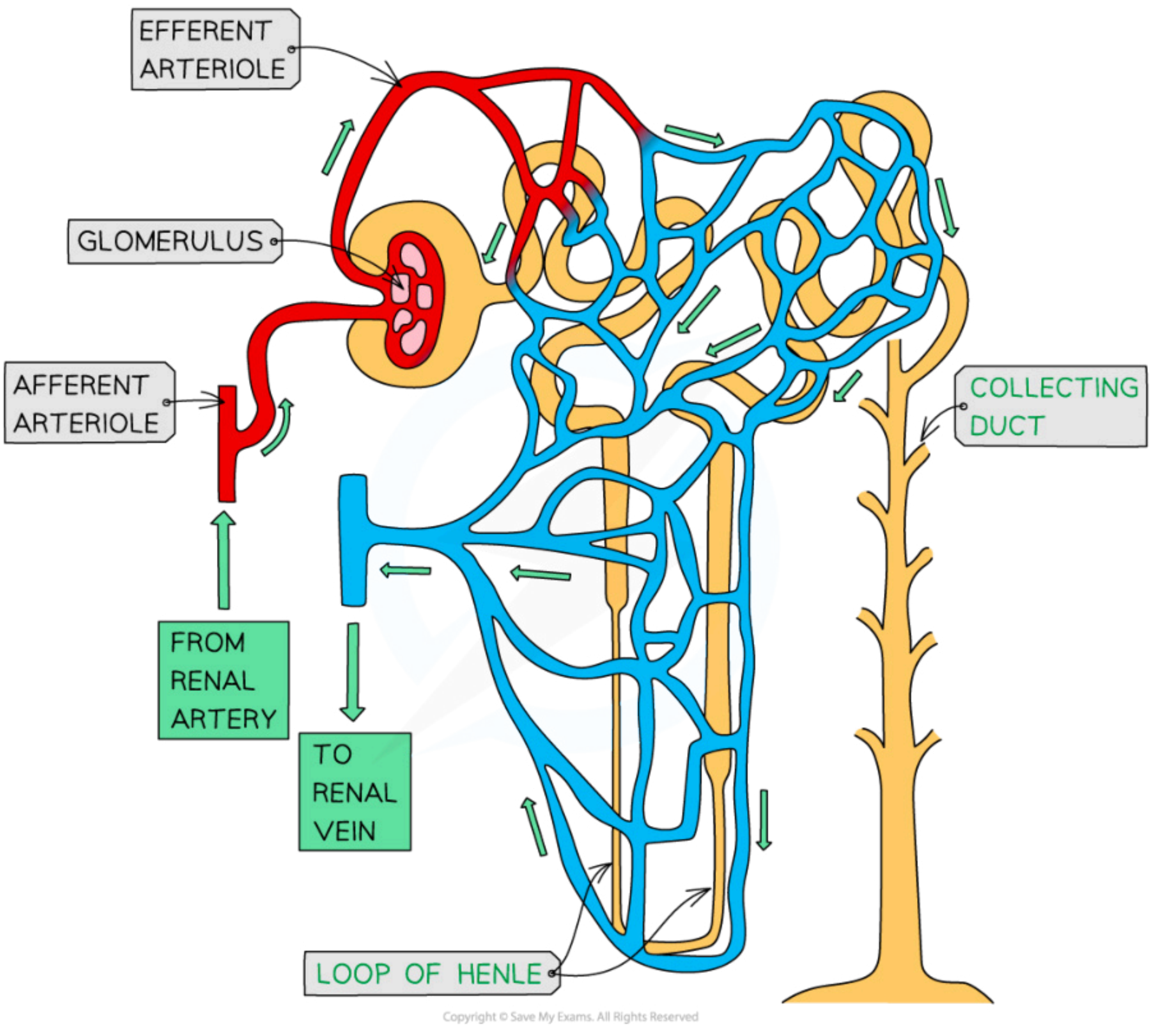


The nephron spans the three regions of the kidney.

The Glomerulus and Bowmans Capsule

- Within the **Bowman's capsule** of each nephron is a structure known as the **glomerulus**
  - Each glomerulus is supplied with blood by an **afferent arteriole** which carries blood from the **renal artery**
  - The afferent arteriole splits into a **ball of capillaries** that forms the **glomerulus** itself
  - The capillaries of the glomerulus rejoin to form the **efferent arteriole**
- Blood flows from the glomerulus into a network of capillaries that run closely **alongside the rest of the nephron** and eventually into the **renal vein**

Your notes

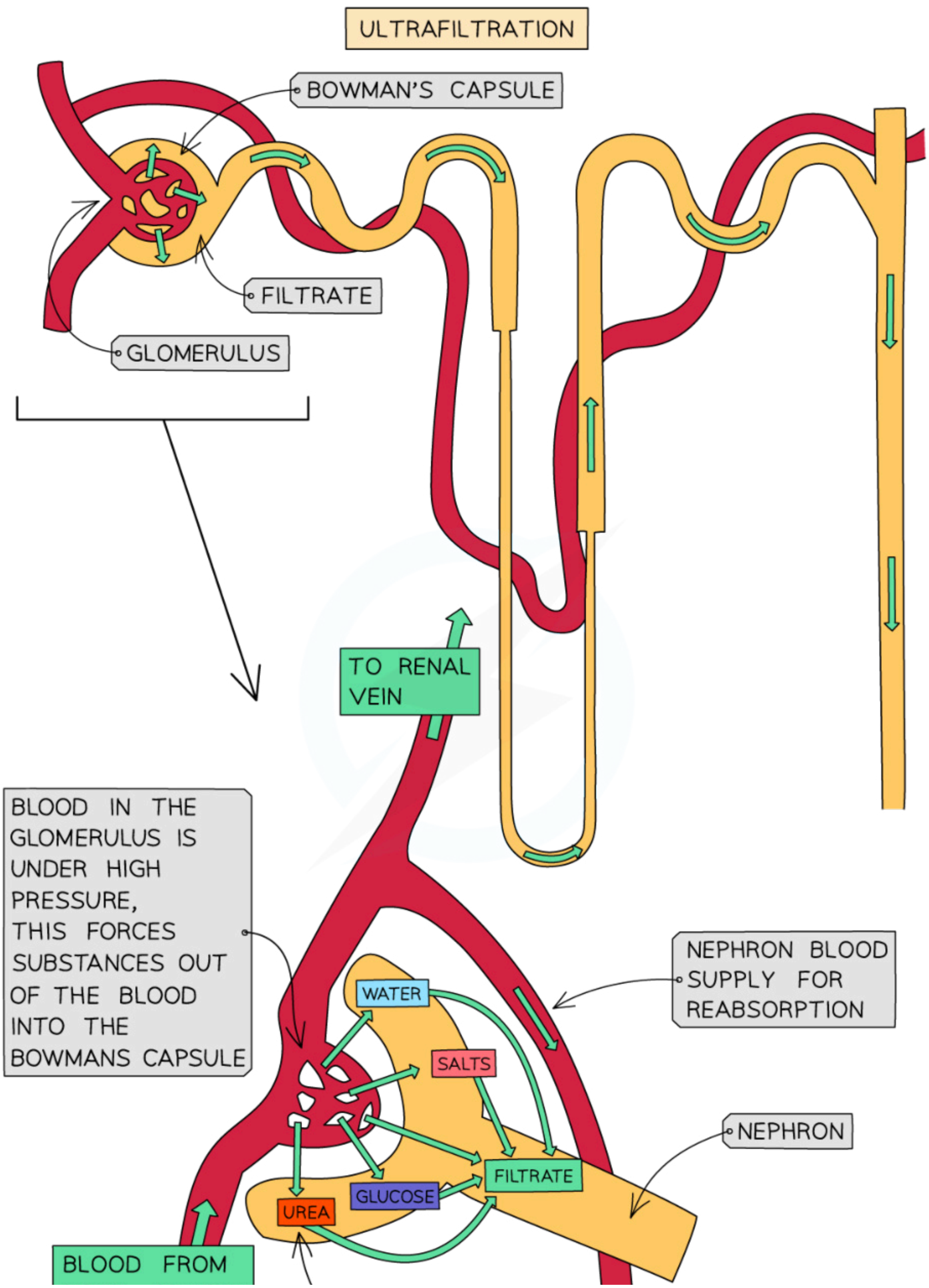


The afferent arteriole supplies the capillaries of the glomerulus, which rejoin to form the efferent arteriole.

- The **glomerulus sits within** the **Bowman's capsule**; these two structures together carry out the process of **ultrafiltration**
- The blood in the glomerulus is at **high pressure**
  - The **afferent arteriole is wider than the efferent arteriole**, increasing the blood pressure as the blood flows through the glomerulus
  - Note that while all capillaries exert outward pressure, forcing tissue fluid out towards the surrounding cells, the **outward pressure in the glomerulus is much higher than in other capillaries**
- This high pressure forces small molecules in the blood **out of the capillaries of the glomerulus and into the Bowman's capsule**
  - These small molecules include
    - Chloride ions
    - Sodium ions

    - Glucose
    - Urea
    - Amino acids
- The resulting fluid in the Bowman's capsule is called the **glomerular filtrate**
- **Large molecules such as proteins remain in the blood** and do not pass into the filtrate

Your notes


ULTRAFILTRATION
BOWMAN'S CAPSULE
FILTRATE
GLOMERULUS
TO RENAL VEIN
BLOOD IN THE GLOMERULUS IS UNDER HIGH PRESSURE, THIS FORCES SUBSTANCES OUT OF THE BLOOD INTO THE BOWMANS CAPSULE
WATER
SALTS
NEPHRON BLOOD SUPPLY FOR REABSORPTION
NEPHRON
FILTRATE
GLUCOSE
UREA
BLOOD FROM

High blood pressure in the glomerulus forces small molecules into the Bowman's capsule, forming glomerular filtrate; this is ultrafiltration

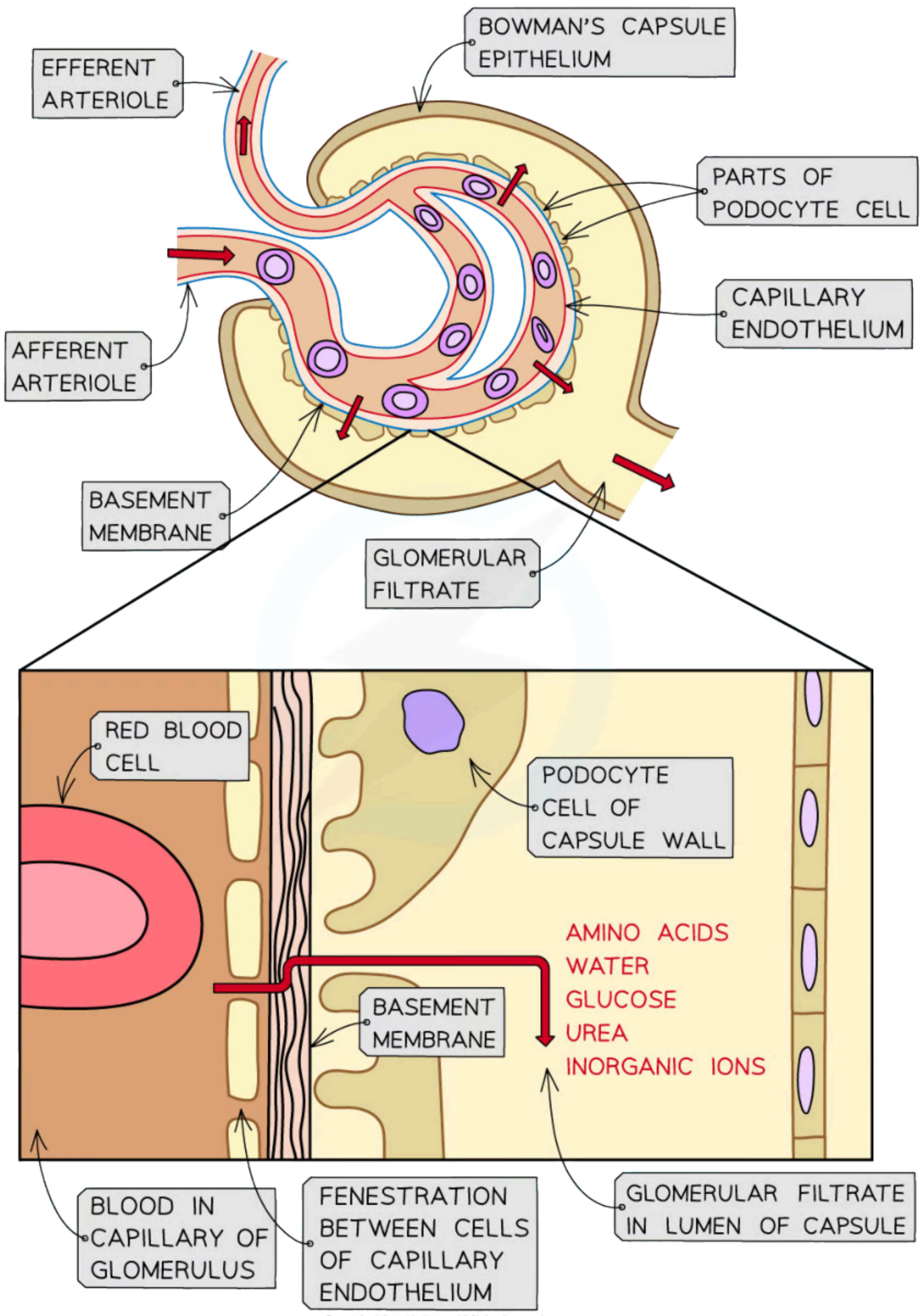
Composition of the blood plasma compared to glomerular filtrate table

	Concentration / mol dm^{-3} OR *mg dm^{-3}	
	Blood plasma	Glomerular filtrate
Urea	5	5
Na^+ ions	150	145
Cl^- ions	110	115
Glucose	5	5
Protein*	740	5

- The **structures** within the glomerulus and Bowman's capsule are especially **well adapted for ultrafiltration**
- The blood in the **glomerular capillaries** is **separated** from the **lumen** of the **Bowman's capsule** by **two cell layers** with a **basement membrane** in between them:
  - The first **cell layer** is the endothelium **of the capillary**
    - There are gaps between the cells of the capillary endothelium known as **fenestrations**; fluid can pass through these gaps but not blood cells
  - The next layer is the **basement membrane**
    - The basement membrane is made up of a **network of collagen protein** and **glycoproteins**
    - This **mesh-like structure** acts as a sieve, allowing small molecules through but **preventing passage of large proteins** from the blood plasma
  - The second cell layer is the epithelium **of the Bowman's capsule**
    - The epithelial cells have many **foot-like projections** which wrap around the capillary; these cells are known as **podocytes** and the **gaps between the projections** allow the passage of small molecules
- As blood passes through the glomerular capillaries the **fenestrations between the capillary endothelial cells**, the **mesh-like basement membrane**, and the **gaps between the podocyte projections** allow substances dissolved in the blood plasma to **pass into the Bowman's capsule**
  - The substances that pass into the Bowman's capsule make up the **glomerular filtrate**

Your notes

    - The main substances that form the glomerular filtrate are **amino acids, water, glucose, urea and salts** (Na^+ and Cl^- ions)
- **Red and white blood cells** and **platelets** remain in the blood as they are **too large** to pass through the fenestrations between the capillary endothelial cells
- The **basement membrane stops large protein molecules** from getting through


BOWMAN'S CAPSULE EPITHELIUM
EFFERENT ARTERIOLE
PARTS OF PODOCYTE CELL
CAPILLARY ENDOTHELIUM
AFFERENT ARTERIOLE
BASEMENT MEMBRANE
GLOMERULAR FILTRATE
RED BLOOD CELL
PODOCYTE CELL OF CAPSULE WALL
AMINO ACIDS
WATER
GLUCOSE
UREA
INORGANIC IONS
BASEMENT MEMBRANE
BLOOD IN CAPILLARY OF GLOMERULUS
FENESTRATION BETWEEN CELLS OF CAPILLARY ENDOTHELIUM
GLOMERULAR FILTRATE IN LUMEN OF CAPSULE
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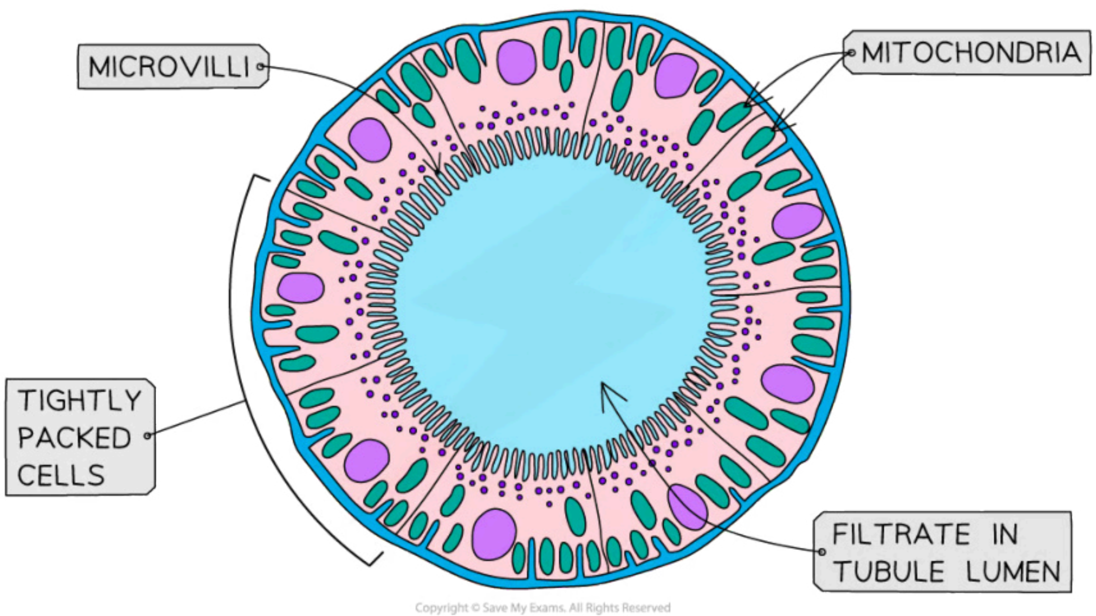
The glomerular filtrate must pass through three layers during ultrafiltration; the capillary endothelium, the basement membrane, and the Bowman's capsule epithelium

Role of the Proximal Convoluted Tubule

Your notes

- Many of the substances that pass into the **glomerular filtrate** are useful to the body
- These substances are therefore **reabsorbed** into the blood as the filtrate passes along the nephron
- This process is known as **selective reabsorption** since not all substances are reabsorbed
  - Reabsorbed substances include **water, salts, glucose,** and **amino acids**
- Most of this reabsorption occurs in the **proximal convoluted tubule**
  - Note that while **most water and salts** are reabsorbed in the proximal convoluted tubule, the **loop of Henle** and **collecting duct** are also involved in the reabsorption of these substances
- The lining of the proximal convoluted tubule is composed of a **single layer of epithelial cells** which are **adapted to carry out reabsorption** in several ways:



The proximal convoluted tubule, seen here in cross section, has several adaptive features to aid selective reabsorption

- Microvilli
  - **Microvilli** are tiny finger-like projections on the surface of epithelial cells which increase the surface area for diffusion
- Co-transporter proteins
- Many mitochondria
- Tightly packed cells

Adaptations for Selective Reabsorption Table

Your notes

Adaptation of proximal convoluted tubule epithelial cell	How adaptation aids reabsorption
Many microvilli present on the luminal membrane (the cell surface membrane that faces the lumen).	This increases the surface area for reabsorption.
Many co-transporter proteins in the luminal membrane.	Each type of co-transporter protein transports a specific solute (eg. glucose or a particular amino acid) across the luminal membrane.
Many mitochondria.	These provide energy for sodium-potassium ($Na^+ - K^+$) pump proteins in the basal membranes of the cells.
Cells tightly packed together.	This means that no fluid can pass between the cells (all substances reabsorbed must pass through the cells).

The process of selective reabsorption

- **Sodium ions** (Na+) are transported from the proximal convoluted tubule into the surrounding tissues by **active transport**
- The positively charged sodium ions creates an electrical gradient, causing **chloride ions** (Cl-) to follow by **diffusion**
- **Sugars** and **amino acids** are transported into the surrounding tissues by **co-transporter proteins**, which also transport sodium ions
- The movement of ions, sugars, and amino acids into the surrounding tissues **raises the** osmolarity **of the tissues**, so **water leaves the proximal convoluted tubule** by osmosis
- **Urea** moves out of the proximal convoluted tubule by **diffusion**
- All of the substances that leave the proximal convoluted tubule for the surrounding tissues **eventually make their way into nearby capillaries** down their concentration gradients

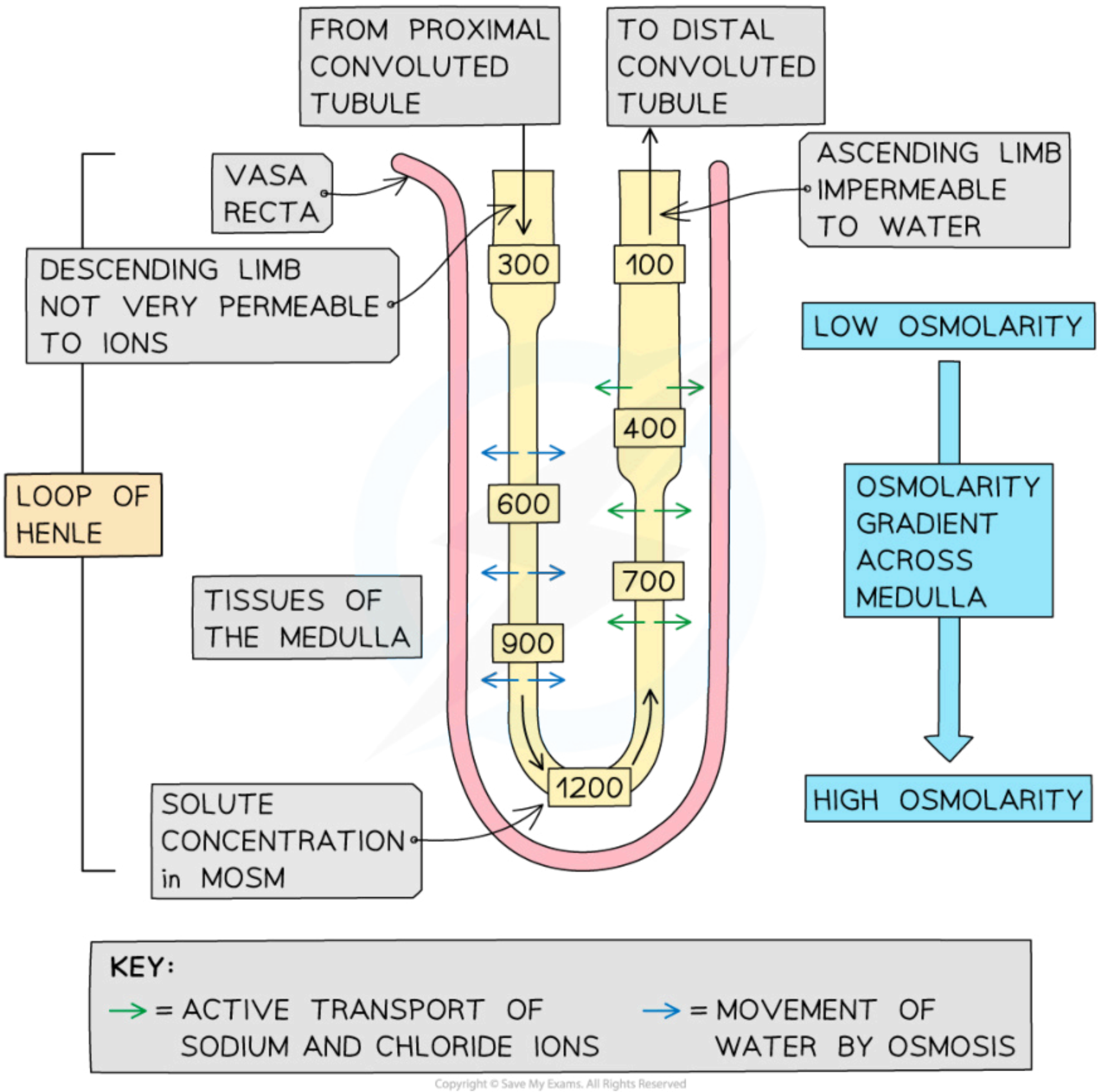
Your notes

Role of the Loop of Henlé

- Many animals deal with the excretion of the toxic waste product **urea** by **dissolving it in water** and **excreting** it
- While this method of excretion works well, it brings with it the **problem of water loss**
- The role of the loop of Henle is to **enable the production of urine that is more concentrated than the blood**, and to therefore **conserve water**
  - Note that it is also possible to produce urine that is less concentrated than the blood; this is important when water intake is high to prevent blood becoming too dilute
- The loop of Henle achieves this by the use of a **countercurrent multiplier system**
  - ***Countercurrent*** refers to the opposite directions of filtrate flow in the descending and ascending limbs of the loop of Henle
  - ***Multiplier*** refers to the steep concentration gradient that the loop of Henle is able to generate across the medulla

The process in the loop of Henle

- **Sodium** and **chloride** ions are pumped **out of the filtrate in the ascending limb** of the loop of Henle into the **surrounding medulla** region, raising its osmolarity
  - The ascending limb of the loop of Henle is **impermeable to water**, so water is **unable to leave the loop here by osmosis**
  - The **osmolarity of the ascending limb decreases as it rises** back into the cortex due to the **removal of solutes** and **retention of water**
- The neighbouring **descending limb is permeable to water**, so water moves **out of the descending limb by osmosis** due to the high osmolarity of the medulla created by the ascending limb
  - The descending limb has few transport proteins in the membranes of its cells, so **has low permeability to ions**
  - The **osmolarity of the filtrate increases as the descending limb moves down** into the medulla due to the **loss of water** and **retention of ions**
- The water and ions that leave the loop of Henle for the medulla make their way **into nearby capillaries**
  - The capillary that flows directly alongside the loop of Henle is known as the **vasa recta**
  - The vasa recta also supplies oxygen to and removes carbon dioxide from the **respiring cells of the loop of Henle**



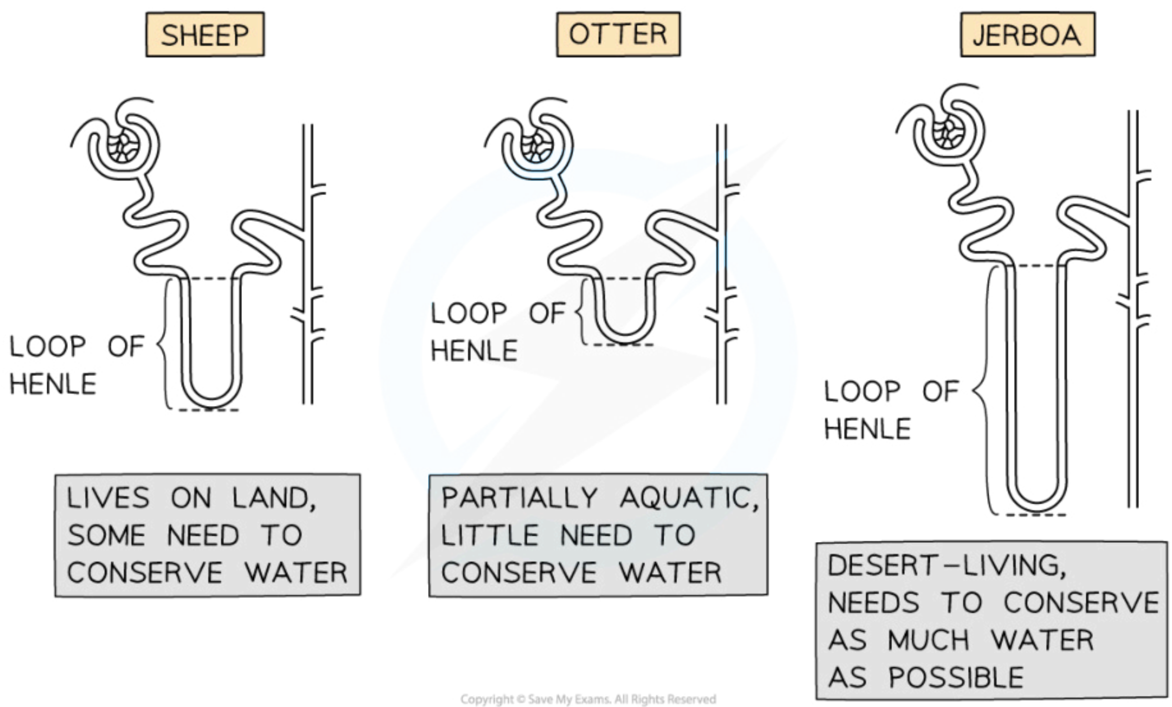
The loop of Henle generates a steep osmolarity gradient across the medulla, maximising the reabsorption of water

11.3.3 Conserving Water

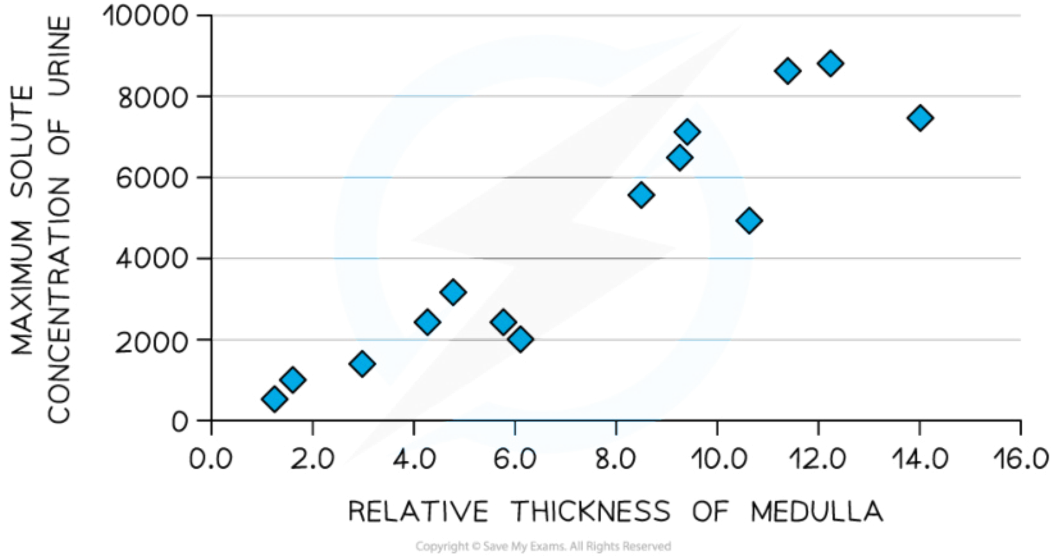
Your notes

Conserving Water & the Loop of Henlé

- Animals that live in dry environments such as deserts depend on their ability to **conserve water** for survival
- Such animals often have **very long loops of Henle**
  - The **longer** the loop of Henle, the **greater** an animal's ability to **conserve water**
    - A longer loop of Henle is able to generate steeper concentration gradients and so more water can be reabsorbed by osmosis
  - The **collecting ducts** of such animals are also **very long**
- Animals that need to conserve water have **thicker medulla regions** in their kidneys to provide additional space for their long loops of Henle
- This means that both **loop of Henle length** and **medulla thickness** can be indicators of an animal's ability to conserve water



The length of the loop of Henle differs depending on an organism's need to conserve water; the longer the loop of Henle, the more water can be reabsorbed



The thicker the medulla region of the kidney, the more concentrated urine can become, meaning that more water is reabsorbed in animals with a thicker medulla. A thicker medulla is needed to allow space for a longer loop of Henle.

Your notes

Consequences of Dehydration & Overhydration

- If the balance of water and solutes in the body are not maintained correctly, the result may be **dehydration** or **overhydration**
- Dehydration results if water is **lost from the body and not replaced**
- e.g.
  - After **excessive sweating**
  - After **diarrhoea**
- In dehydration the **osmolarity of the body fluids rises above that of the surrounding cells**, leading to **cell water loss** and **shrinkage** as water moves out of the cells by **osmosis**
- Symptoms of dehydration include
  - **Low volume** of **dark, concentrated urine**
  - Not being able to sweat, leading to a **reduced ability to regulate body temperature**
  - A **drop in blood pressure** due to reduced blood volume
  - An **elevated heart rate** as the heart attempts to compensate for the drop in blood pressure
  - Feeling **tired** due to increased exposure of the tissues to **metabolic waste**
    - Metabolic waste is usually removed from the body by being dissolved in water and excreted in the urine; this cannot happen quickly enough if there is a lack of water available
- Overhydration can result if there is **too much water in the body fluids in relation to solutes** such as sugars and salts; this can result from
  - **Overconsumption of water**
  - **Not replacing sugars and salts** after excessive sweating
  - **Kidney problems**
  - The **side effects** of certain **drugs**
- In overhydration the **osmolarity of the body fluids drops below that of the surrounding cells**, causing water to move into the cells by osmosis
  - This leads to **swelling of the body's cells**
- Overhydration can lead to symptoms such as
  - **Excessive urination** as the body produces **large volumes** of **colourless, dilute urine**
  - **Headaches** resulting from swelling of cells in the brain
  - **High blood pressure** due to increased blood volume
  - **Low heart rate** as the heart attempts to compensate for the increase in blood pressure
  - **Neurological problems** due to low concentrations of important ions such as sodium ions

NOS: Curiosity about particular phenomena; investigations were carried out to determine how desert animals prevent water loss in their wastes

- Scientists **observe events**, or **phenomena**, in the natural world, noticing when phenomena **cannot be explained using existing understanding**
- When a phenomenon cannot be explained using existing knowledge, scientists come up with **hypotheses** that might explain such phenomena, and **design investigations** to allow them to **test these hypotheses**
- When scientists studying **desert rodents** such as kangaroo rats (genus *Dipodomys*) noticed that they were able to survive on a diet of dry seeds with little or no separate water intake, they became **curious** as to how the rats' physiology enabled them to do this

- **Analysis** of the kangaroo rats' water intake from food and their water losses due to breathing, excretion, and egestion, showed that water intake and water losses were equal
- **Studying kangaroo rat anatomy** and **behaviour**, scientists were able to **conclude** that they balanced their water intake and losses by
  - Having a very long loop of Henle and a thick medulla region
  - Producing urine many times more concentrated than their body fluids
  - Producing very small quantities of urine
  - Producing very dry faeces which they then consume to reabsorb any remaining water
- **Curiosity** about the extent of kangaroo rat water conservation abilities led scientists to **investigate** whether or not they could survive when given seawater to drink; they found that the kangaroo rats were able to fully excrete the excess salt from seawater with very little increased loss of water!

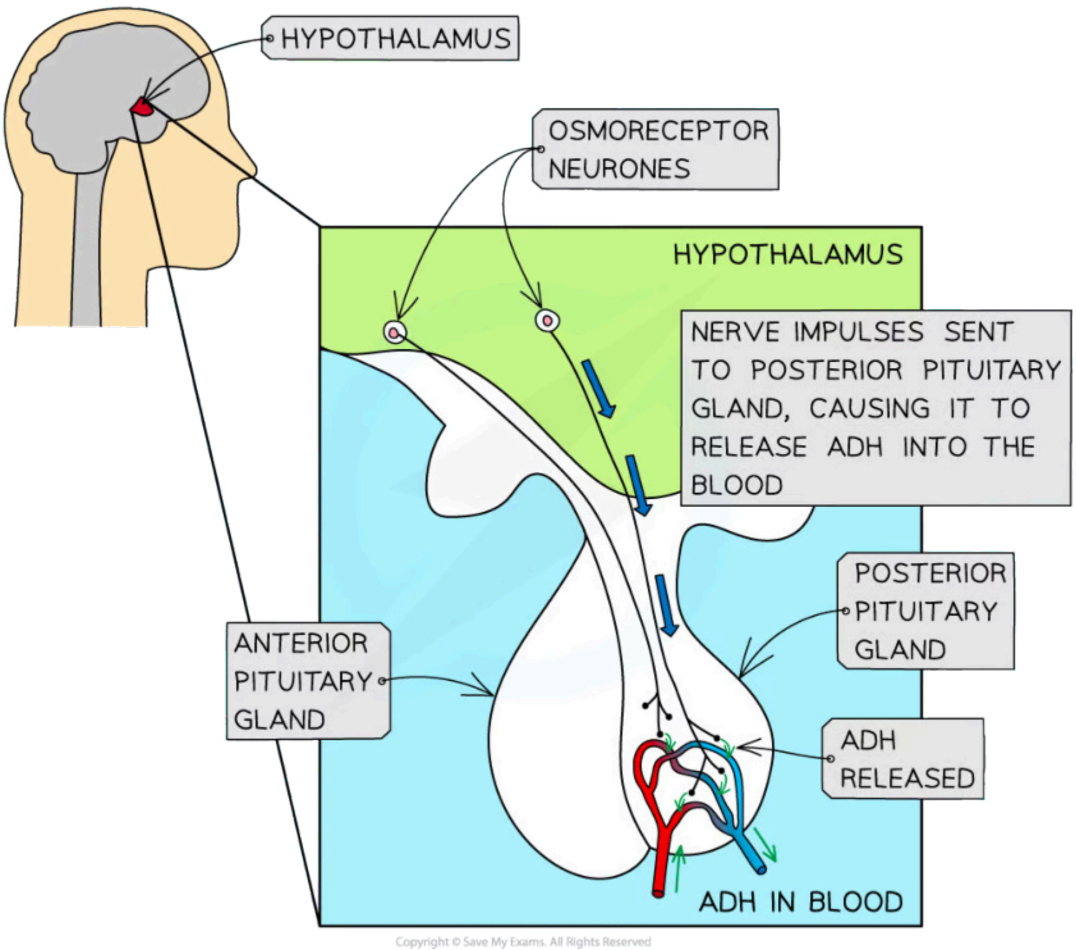
Your notes

11.3.4 The Role of ADH

Your notes

ADH

- Living organisms can maintain a **safe balance of water and solutes** in their bodies by **osmoregulation**
  - **Osmoregulation** is an example of homeostasis
- The kidneys play an important role in osmoregulation by altering the **amount of water reabsorbed** from the glomerular filtrate into the blood
- The amount of water reabsorbed by the kidneys can be regulated by changing the **permeability of the walls of the distal convoluted tubule** and **collecting duct** to water
- The permeability of these parts of the nephron is regulated by a hormone called **antidiuretic hormone**, or **ADH**
- ADH is released from the posterior section of the **pituitary gland** in the brain, which is regulated by a region of the brain called the **hypothalamus**
  - The hypothalamus **monitors the composition of the blood** as it flows past osmoreceptor cells in the brain, as well as **receiving signals from receptors** elsewhere in the body



Blood water content is monitored by osmoreceptor cells in the hypothalamus, which then regulates the release of ADH from the posterior pituitary gland into the blood.

Low blood water content

- Blood water content might drop as a result of **reduced water intake**, **sweating**, or **diarrhoea**
  - Low blood water content can also be referred to as **high blood solute concentration**, or **high blood osmolarity**
  - If blood water content gets too low it can lead to **dehydration**
- A reduction of blood water content is **detected by the hypothalamus** in the brain
- The hypothalamus **causes the pituitary gland to secrete ADH** into the blood
  - The target cells of ADH are in the distal convoluted tubule and collecting duct in the kidneys
- ADH **increases the permeability of the walls of the distal convoluted tubule** and **collecting duct** in the kidneys to water
  - The permeability of the walls of the distal convoluted tubule and collecting duct are increased by increasing the number of **channel proteins called aquaporins** in the cell surface membranes of the cells lining the nephron lumen

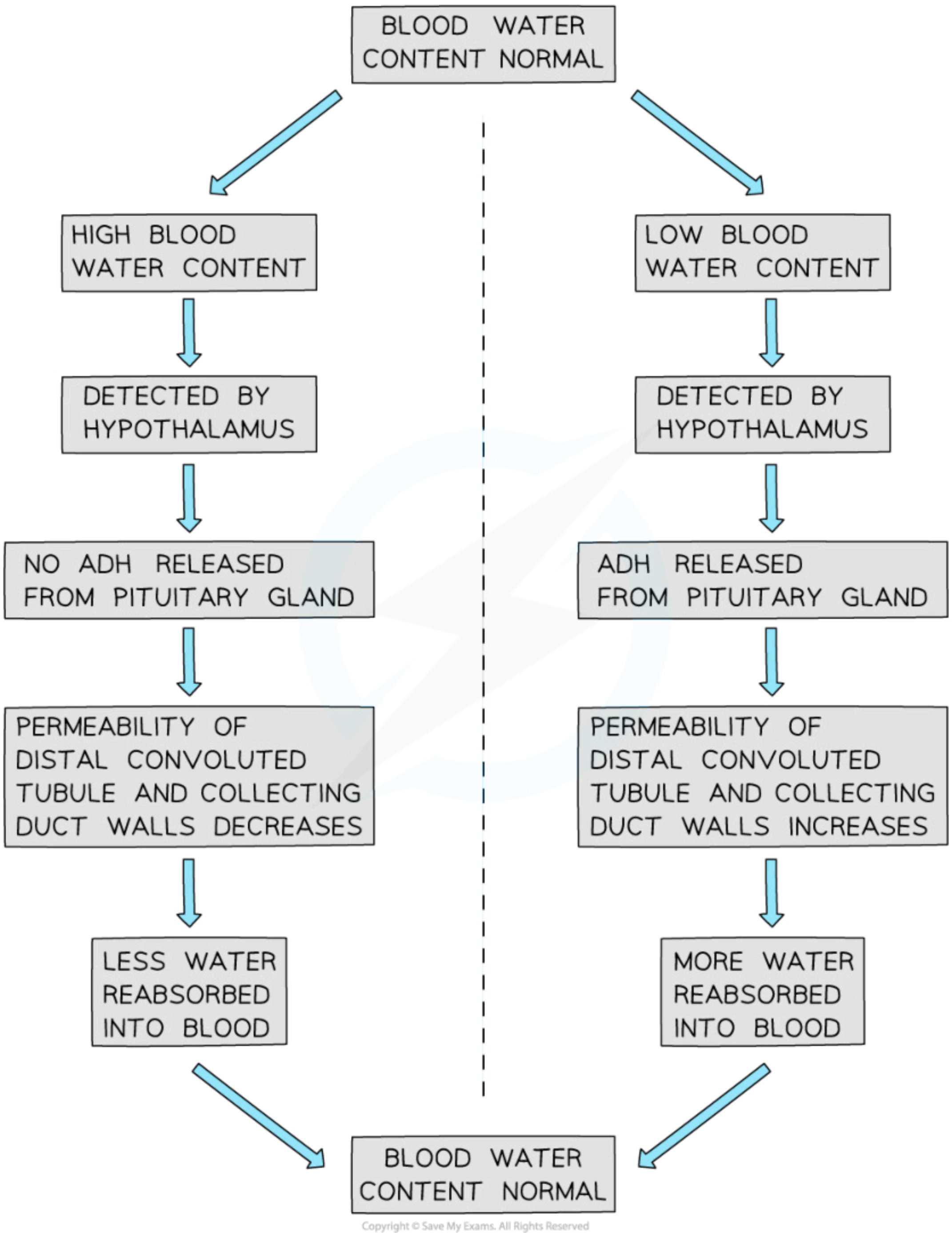
- **More water is reabsorbed into the blood** via the distal convoluted tubule and collecting duct
  - The activity of the loop of Henle generates a **concentration gradient across the medulla**, meaning that as the collecting duct descends into the medulla the **osmolarity of the tissues of the medulla increases**; this means that **water is reabsorbed by osmosis** all the way down the length of the collecting duct
- The reabsorption of water leaves a **concentrated filtrate** that passes through the collecting duct and into the renal pelvis
  - This remaining filtrate is the **urine**; from the renal pelvis it passes along the ureter to the **bladder**
- The **blood water content increases** and a **small quantity** of **concentrated urine** is produced

High blood water content

- Blood water content might increase due to increased water intake or loss of salts during sweating
  - High blood water content can also be referred to as **low blood solute concentration**, or **low blood osmolarity**
  - If blood water content gets too high it can lead to **overhydration**
- High blood water content is detected by the hypothalamus
- The hypothalamus **no longer stimulates the pituitary gland to release ADH** and ADH levels in the blood drop
- The **distal convoluted tubule and collecting duct walls become less permeable to water**
  - Fewer aquaporins are present
- **Less water is reabsorbed** from these regions of the nephron into the blood, and the water instead passes down the collecting duct into the renal pelvis along with the rest of the filtrate
- **Blood water content decreases** and a **large quantity** of **dilute urine** is produced

Your notes

Your notes



Osmoregulation is an example of homeostasis; the amount of water reabsorbed by the kidneys into the blood is regulated

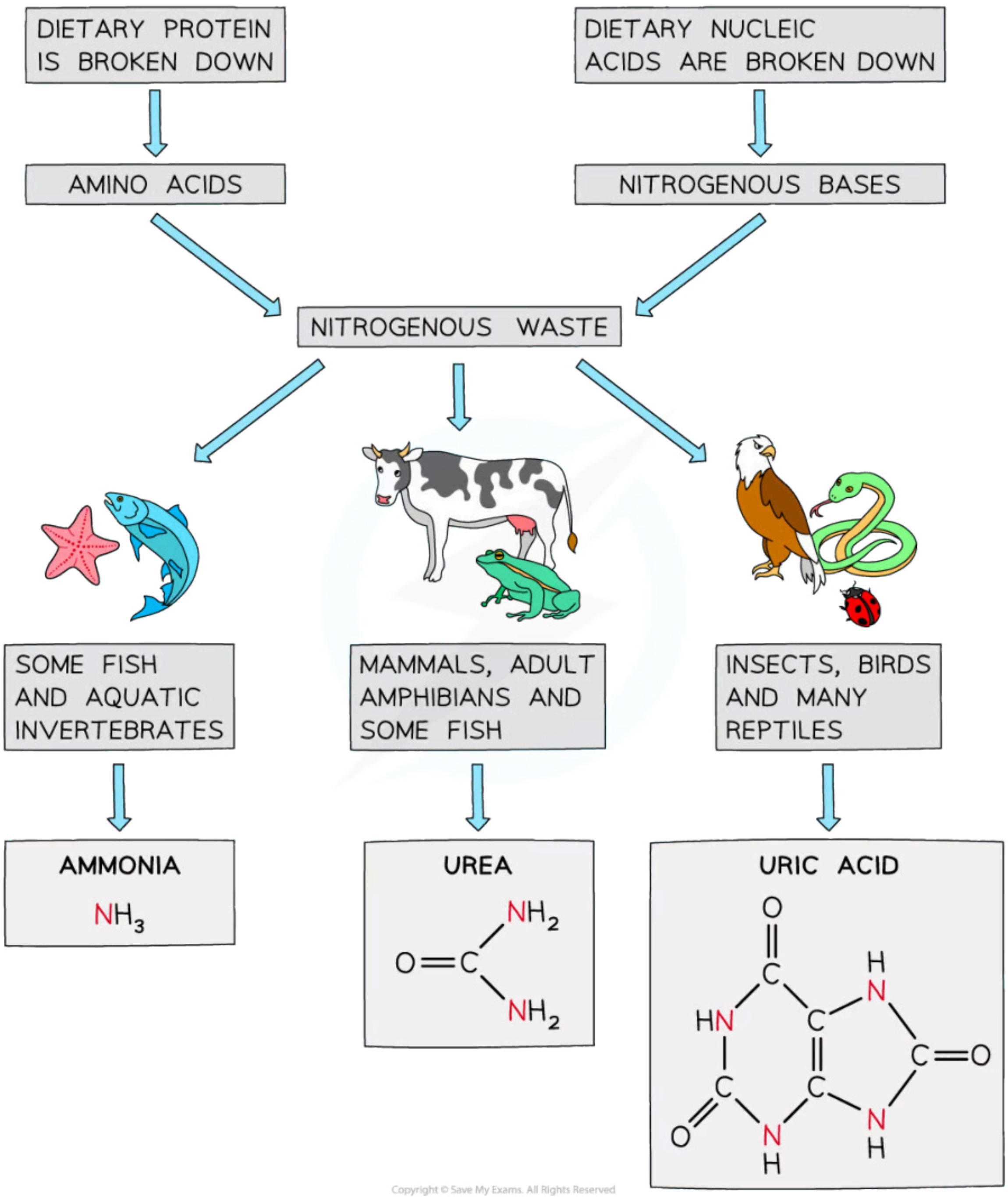
11.3.5 Types of Nitrogenous Waste

Your notes

Types of Nitrogenous Waste

- **Nitrogenous waste** comes from the **breakdown of excess dietary amino acids** and **nucleic acids**
  - The waste is first converted into **ammonia**; some organisms excrete it in this form
  - Ammonia is **highly toxic**, so some organisms **convert it into urea** before **excretion**, while others convert it into **uric acid**
- The way that this nitrogenous waste is excreted differs depending on the requirements of an organism and its environment
- Ammonia is highly toxic; it cannot be stored in the body and must therefore be removed quickly from the body
  - Aquatic organisms live in a watery environment so they can **excrete ammonia directly into their surroundings** where it is diluted to a safe level
  - Organisms that excrete ammonia directly include some types of fish and aquatic invertebrates
- Some organisms **convert highly toxic ammonia into less toxic urea**; urea can remain in the body at low concentrations, but needs to be excreted before it builds up to a harmful level
  - Organisms that excrete urea need to **dilute it with water** to form **urine** before it is excreted, so **some spare water availability is necessary**
  - Urea is excreted by mammals, adult amphibians, and some fish
    - Despite living in an aquatic environment, marine mammals still release urea rather than ammonia; this is due to their shared evolutionary ancestry with the land mammals
- Ammonia can also be **converted into uric acid**; this requires **more energy** than converting to urea but comes with other advantages
  - Uric acid **does not dissolve in water**, instead forming crystals in solution; this means that **less water is needed** to excrete uric acid than urea
    - This is useful for organisms such as birds and insects, for whom carrying water in their bodies could be problematic; carrying water would make their bodies heavier and flying would be less energy efficient
  - Uric acid **aids the survival of animals that develop inside an impermeable egg** shell; if they produced water soluble urea they might poison themselves with their own waste before hatching, but the crystal-forming uric acid does not affect development
  - Uric acid excreting animals include birds, arthropods such as insects, and reptiles
- Some animals excrete their nitrogenous waste in different forms at different stages of their life cycle e.g. amphibians excrete ammonia during their aquatic larval stage and urea when they develop into adults

Your notes



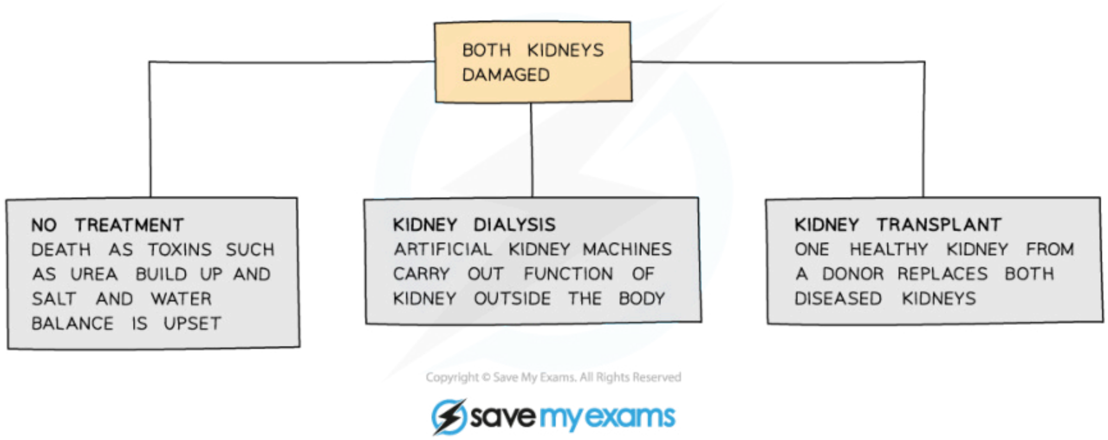
Nitrogenous waste can be excreted as ammonia, urea, or uric acid

Your notes

11.3.6 Kidney Failure & Urinalysis

Treatment of Kidney Failure

- **Kidney failure** can occur in one or both kidneys for a variety of reasons, such as
  - Physical damage from an injury
  - High blood pressure
  - Diabetes
  - Overuse of certain drugs (e.g. aspirin)
  - Infection
- Kidney failure is **dangerous** and **can be fatal** within a relatively short time period
  - Humans can survive with **one functioning kidney**
- If the kidneys fail **urea is not excreted**; this leads to a **build-up of urea** in the blood which **can become toxic at high concentrations**
- Kidney failure can also lead to **disruption in the balance of water and solutes** in the blood
  - This can lead to problems relating to **osmosis and cell damage** as well as more specific problems relating to **excess quantities of certain mineral ions**
- There are two forms of treatment for kidney failure
  - **Dialysis**
    - Toxins, metabolic waste products and excess substances are removed from the blood by **diffusion through a dialysis membrane**
  - **Kidney transplant**
    - The non-functioning kidneys are **replaced with a functioning kidney from a donor**
    - Note that the non-functioning kidneys are **usually left in place** while the new kidney is attached to the blood supply elsewhere in the abdomen

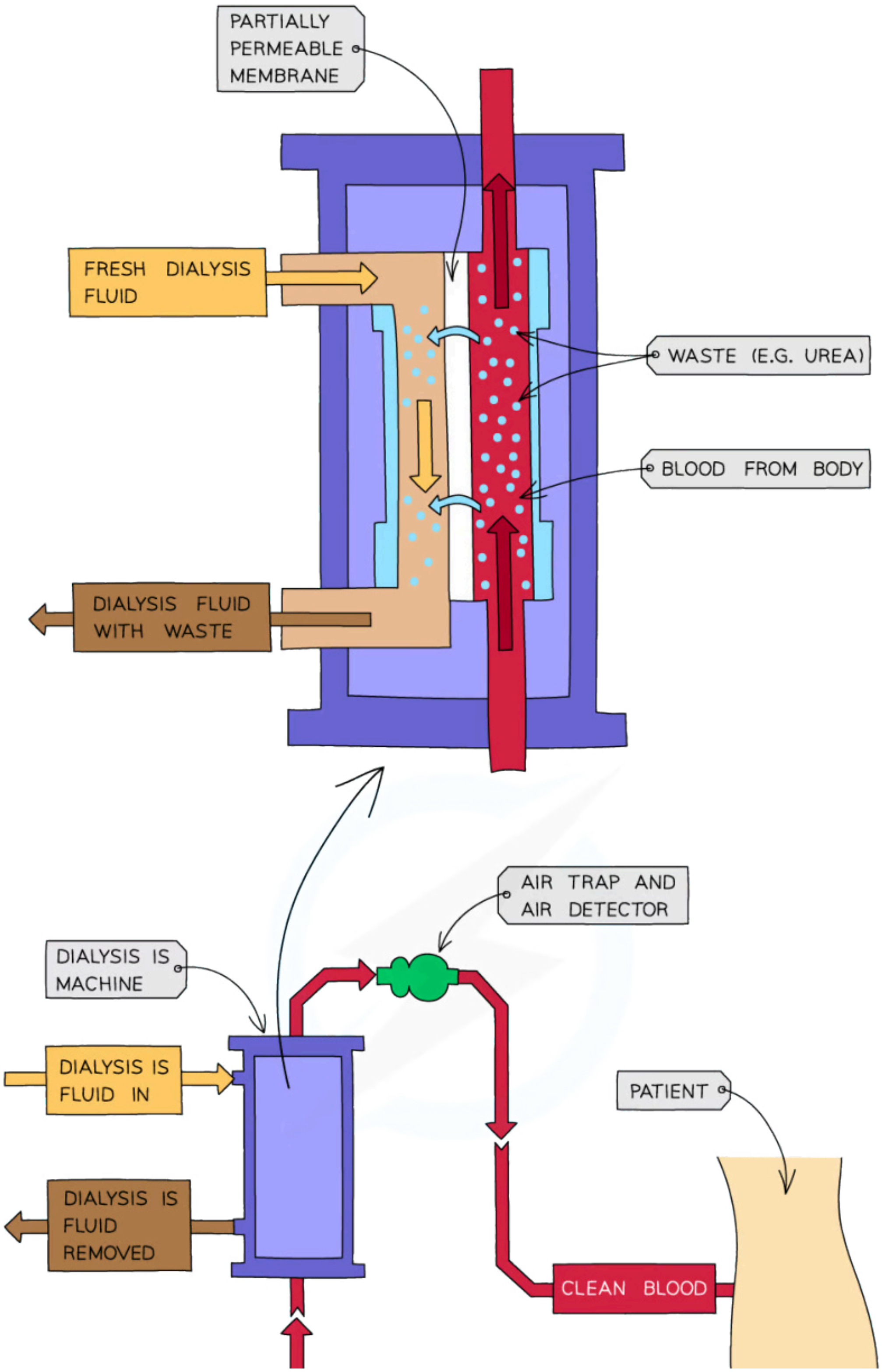


If both kidneys fail it can be fatal, but there are treatment options.

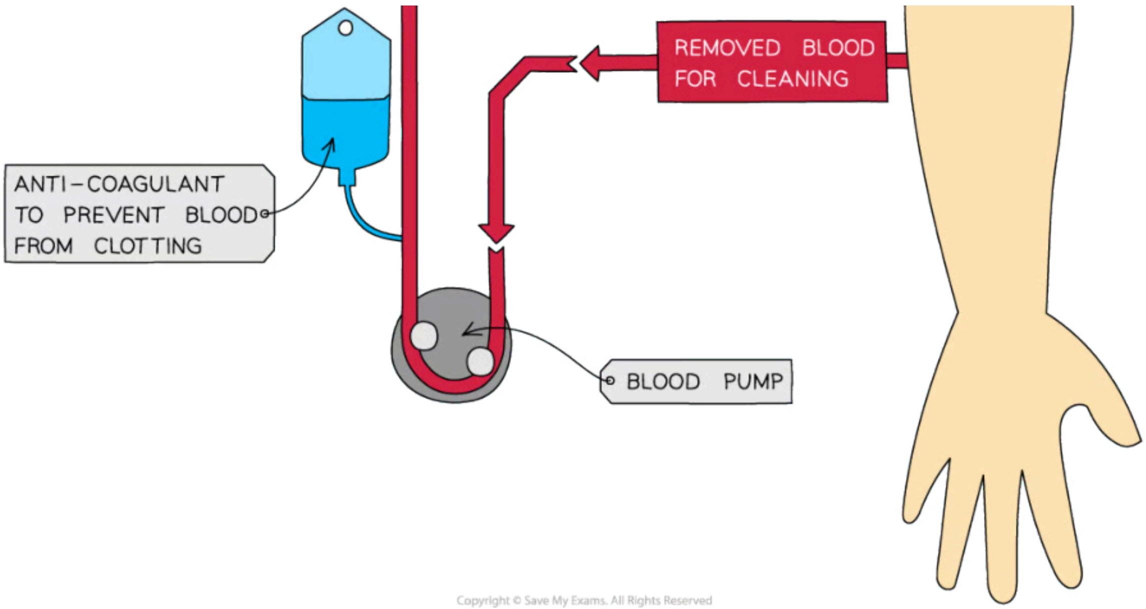
Haemodialysis

Your notes

- **Dialysis** is a process used to **separate small and large molecules** with a **partially permeable membrane**
- **Haemodialysis**, also spelled hemodialysis, is a form of dialysis treatment that needs to be carried out **several times a week** and that requires a **dialysis machine**
  - Another form of dialysis is known as peritoneal dialysis and involves use of the patient's own internal membranes rather than a machine
- Blood flows via a tube from the patient to the dialysis machine
- Inside the dialysis machine **partially permeable dialysis membranes** separate the patient's blood from dialysis fluid
- **Small molecules** such as urea and salts **can fit through pores** in the dialysis membrane so **exchange of substances** can take place
  - The dialysis fluid contains **no urea**, so there is always a **urea diffusion gradient** causing **urea to diffuse out of the blood** and into the fluid
  - The dialysis fluid contains a salt concentration **similar to the ideal blood concentration**, so diffusion of salts across the membrane **only occurs when there is an imbalance**
    - If the blood is too high in salts they will diffuse out of the blood and if the blood is too low in salts they will diffuse in
  - The fluid contains a **glucose concentration equal to normal blood sugar** levels, preventing the outward diffusion of glucose across the membrane when blood glucose levels are normal
    - If blood sugar levels are elevated the glucose will diffuse out of the blood into the fluid
- The blood and fluid flow in **opposite directions** to **ensure a concentration gradient along the whole length** of the membrane
- The fluid in the machine is also **continually refreshed** so that **concentration gradients are maintained** between the dialysis fluids and the blood
  - This means that each time blood circulates through the machine some more of the urea it contains passes into the dialysis fluid, until almost all of it is removed
  - Each haemodialysis session takes 3–4 hours to complete
- Patients are given a drug that **prevents the formation of blood clots** during dialysis
  - Such drugs are known as anticoagulants


PARTIALLY PERMEABLE MEMBRANE
FRESH DIALYSIS FLUID
WASTE (E.G. UREA)
BLOOD FROM BODY
DIALYSIS FLUID WITH WASTE
AIR TRAP AND AIR DETECTOR
DIALYSIS IS MACHINE
DIALYSIS IS FLUID IN
PATIENT
DIALYSIS IS FLUID REMOVED
CLEAN BLOOD

Your notes



Haemodialysis involves passing blood through a dialysis machine, which enables removal of toxic urea and a rebalancing of water and solutes.

Your notes

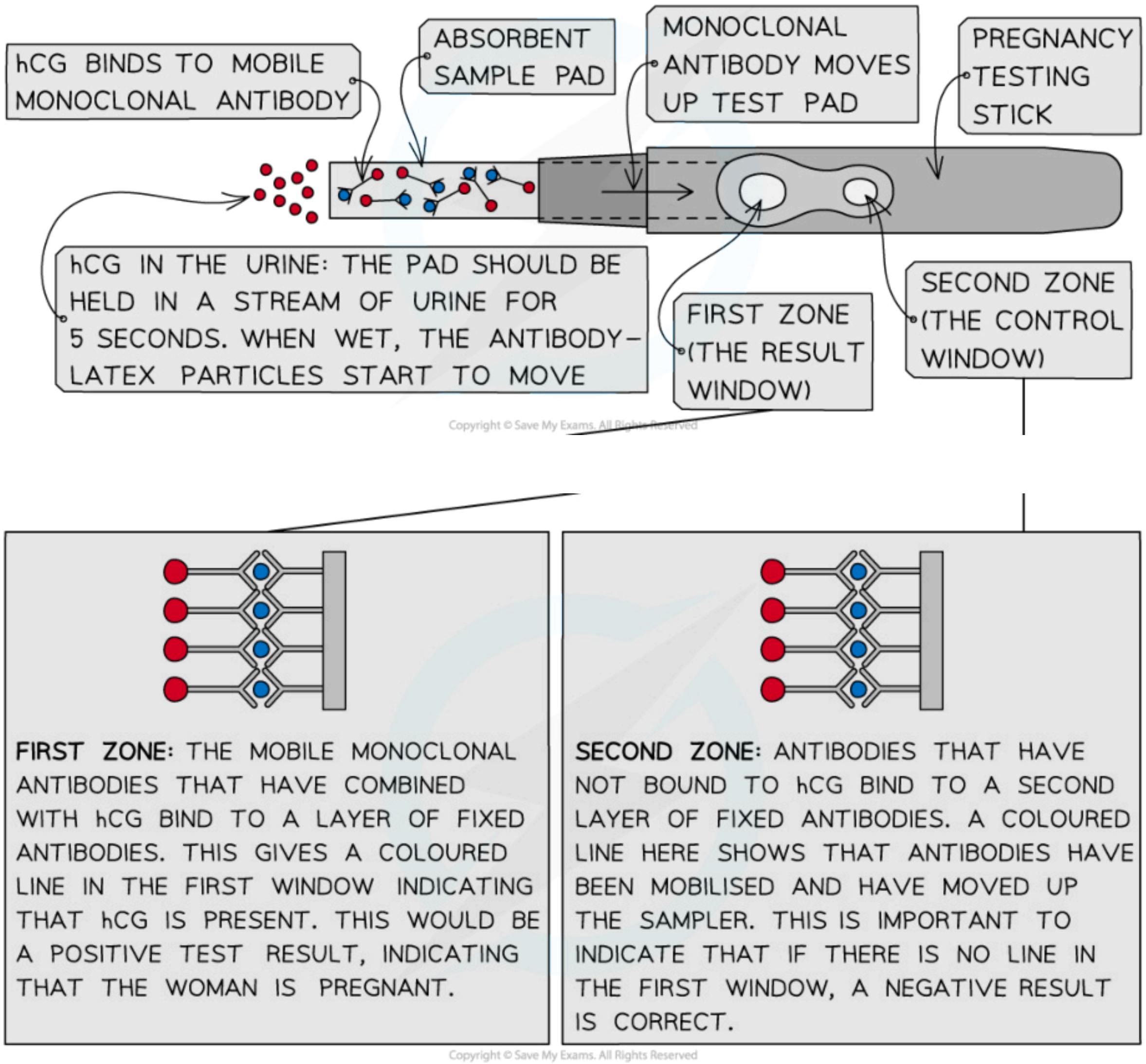
Kidney transplant

- An alternative to potentially restricting dialysis treatments is to have a **kidney transplant**
- This involves taking a **single, healthy kidney from a donor** and **transplanting** it into a patient with kidney failure
- Kidney transplants are considered to be a **better long term solution** to kidney failure than dialysis
  - The patient has more freedom as they **no longer need to have dialysis several times a week**
  - Patients often feel ill after dialysis and again as toxins start to accumulate a few days later; **a transplant enables a patient to be healthy** for an extended period
  - **Diet can be much less restricted** than it needs to be when a patient is on dialysis
- There are still some risks associated with kidney transplants
  - Donors won't have the same antigens on their cell surface membranes as the patient so there will be some **immune response to the new kidney**
  - **Immunosuppressant drugs need to be taken** for the rest of a patient's life to reduce the risk of organ rejection; these can leave the patient **vulnerable to infections**
  - A kidney will often be rejected over time, so **a new kidney transplant is often needed** after several years
  - There are **not enough donors** to cope with the demand, and waiting lists are long

Urinalysis

Your notes

- Analysing the composition of urine by carrying out **urinalysis** can tell us a great deal about the health of an individual; urine contains
  - The **products of metabolism**
  - **Molecules that are present in the blood** in high concentrations and that fit through the membranes in the glomerulus and Bowman's capsule
  - **Drugs** that may have been taken into the body
- Urinalysis shows up any **deviations from normal urine composition**, aiding with **medical diagnoses** or **detecting drug use**
- Tests that can be carried out during urinalysis include
  - **pH testing**
    - The pH of urine may influence the development of kidney stones
    - **Test strips** containing indicator chemicals may change colour when dipped in a urine sample
  - Testing for **glucose concentration**
    - High glucose levels in the urine can be a sign of **diabetes**
    - Test strips similar to those used in pH testing can change colour to indicate the **glucose concentration** of a urine sample
  - Testing for the **presence of proteins**
    - In normal circumstances proteins are too large to filter through from the glomerulus, so if they are present in the urine this can be a sign of high blood pressure, kidney damage, or diabetes
  - **Drugs** testing
    - Drugs can be tested for using monoclonal antibodies which bind to specific drugs due to their complementary structure, showing up as a line on a test strip
      - This kind of test works in a similar way to the lateral flow tests or rapid antigen tests that you may have come across when testing for COVID19
    - This is important when testing for e.g. doping in sport
  - Testing for the **presence of white blood cells**
    - This can be a sign of infection in the urinary tract
  - **Pregnancy** testing
    - The hormones that circulate in the blood during pregnancy can be detected in the urine using complementary monoclonal antibodies
- An example of a type of urinalysis that involves a **test strip** and the use of **monoclonal antibodies** is the pregnancy test
  - Pregnancy testing sticks contain antibodies that are specific to **human chorionic gonadotropin** (**hCG**), a hormone produced during pregnancy



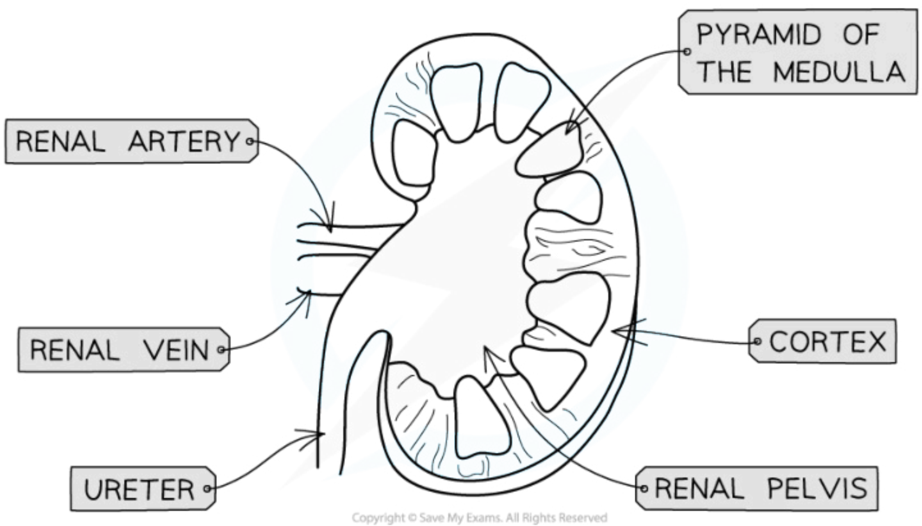
Monoclonal antibodies are used to detect the presence of the hormone hCG in the urine of pregnant women.

Your notes

11.3.7 Skills: Drawing & Annotating the Kidney

Drawing the Human Kidney

- The following elements should be included in a drawing of the human kidney
  - The kidney should be **roughly oval in shape** with an **inward curve on the side** where it is **connected** to the **blood vessels and ureter**
  - The **renal vein should be wider in diameter** than the **renal artery**
  - All three kidney regions should be clearly shown
    - An **outer cortex** that takes up **roughly a fifth** of the kidney's diameter
    - The **medulla within the cortex**
      - The medulla has regions called '**pyramids**' **which should be visible**
    - The **renal pelvis on the inward curve** of the kidney's side, and **draining into the ureter**
  - Lines should be drawn in **clear, dark pencil** with **no sketching**
  - Label lines should **not cross each other** and should **cross as little of the drawing as possible**
  - No shading or colour is required



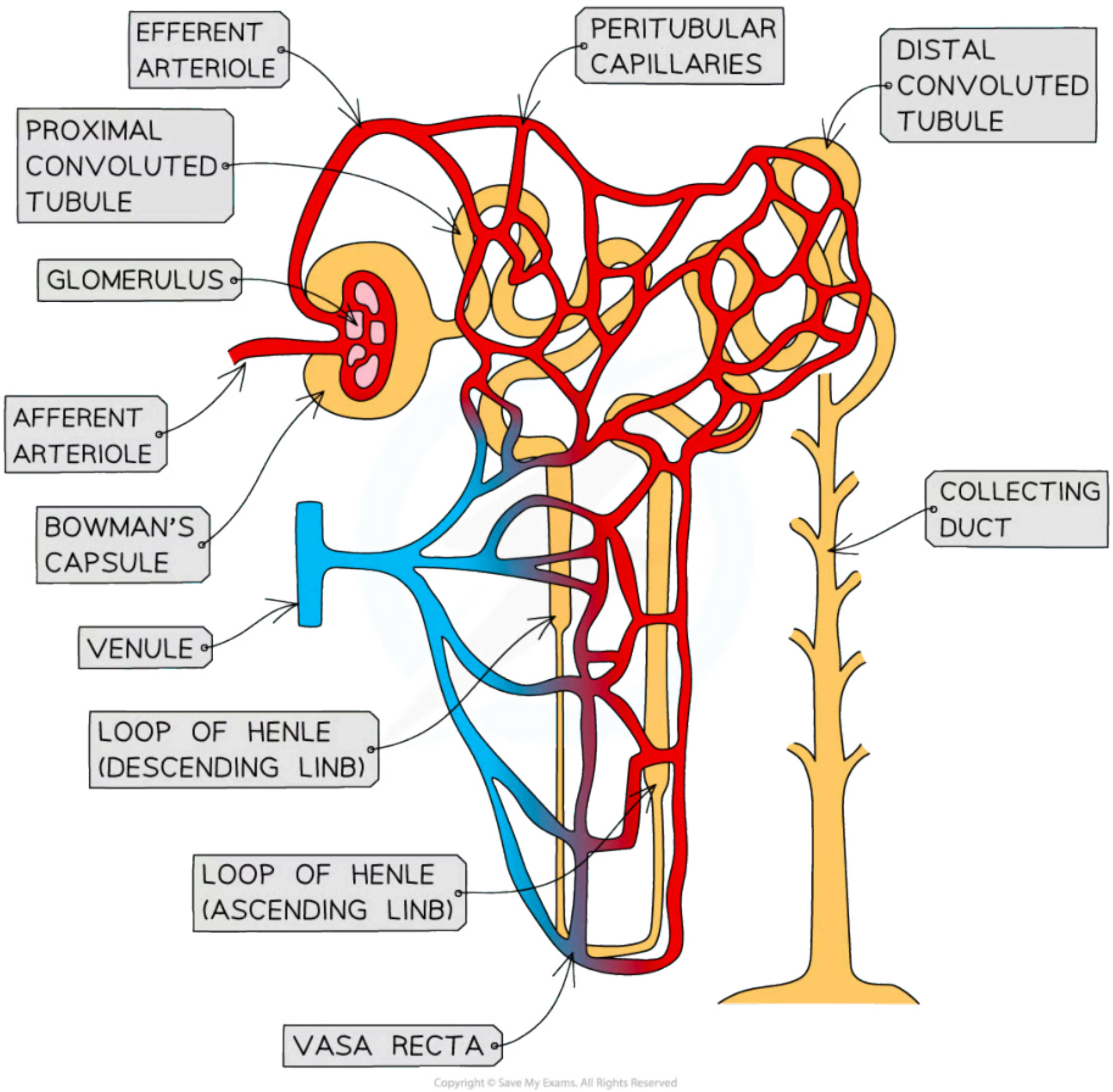
A drawing of the kidney should be an accurate representation of the kidney's shape, show the three main regions of the kidney, and show the kidney's connections to blood vessels and the ureter

Annotating the Nephron

Your notes

- Each kidney contains **thousands of tiny tubes**, or **tubules**, known as **nephrons**
- Nephrons are the **functional unit of the kidney** and are responsible for the **formation of urine**
- An annotated diagram of the nephron should include the following elements
- The **glomerulus**
  - A **ball of capillaries** inside which blood flows at **high pressure** to bring about **ultrafiltration**
- The **afferent** and **efferent arterioles** of the glomerulus
  - The afferent arteriole **brings blood into the glomerulus** from the renal artery and the efferent arteriole **carries blood away from the glomerulus** and into the peritubular capillaries
  - The **afferent arteriole is wider than the efferent arteriole** to generate high blood pressure in the glomerulus
  - Remember, **a** comes before **e** in the alphabet, and **a**fferent comes before **e**fferent in the blood flow through the kidney
- The **Bowman's capsule**
  - A cup-like structure into which the **blood of the glomerulus is filtered**
- The **proximal convoluted tubule**
  - The section of the kidney tubule in which **most reabsorption of sugars, water, and salts** occurs
  - It is lined with **tightly packed cells** that have **microvilli** and **many mitochondria** to aid the reabsorption process
  - Remember, **prox**imity means that something is **close by**, so the **prox**imal convoluted tubule is **closest** to the glomerulus
- The **loop of Henle**
  - A hairpin-like structure that **concentrates the filtrate** and **creates a concentration gradient** across the medulla in order to **maximise water reabsorption**
  - The **descending** limb **descends** into the medulla, while the **ascending** limb **ascends** back up into the cortex
- The **distal convoluted tubule**
  - The section of tubule that connects the loop of Henle with the collecting duct; **more water is reabsorbed here**
  - The amount of water reabsorbed **depends on the amount of ADH** in the blood
  - Remember, **dis**tant refers to something that is **far away**, so the **dis**tal convoluted tubule is **furthest away** from the glomerulus
- The **collecting duct**
  - This tube **descends back into the medulla** and **drains into the renal pelvis**
  - **More water is reabsorbed** here
  - The amount of water reabsorbed **depends on the amount of ADH** in the blood
- The **vasa recta**
  - The **capillary that flows alongside the loop of Henle** and into which water and salts are reabsorbed
- Peritubular capillaries and venules
  - Peritubular capillaries are a network of blood vessels in close proximity to the nephron into which substances are reabsorbed
  - Venules carry blood back towards the renal vein

Your notes



Nephrons are the functional unit of the kidney