5.2 Excretion

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5.2.1 THE IMPORTANCE OF EXCRETION

The Importance of Excretion

- **Excretion** is the process by which **toxic waste products of metabolism** and substances in **excess of requirement** are **removed** from the body
- For example:
  - The **lungs** excrete the waste product **carbon dioxide** by gas exchange and the act of breathing out (exhalation)
  - The **kidneys** produce urine that contains the waste product **urea** in solution
- Excretion is a key process in **homeostasis** and is important in **maintaining metabolism**, as metabolic waste can have **serious negative consequences** on the body if allowed to **accumulate**

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Metabolic waste

- As mammals are active, warm-blooded animals, they have **high metabolic rates**, which means they also produce relatively **large amounts of metabolic waste**
- This metabolic waste includes:
  - **Carbon dioxide**
  - **Nitrogenous waste** (ammonia, urea and uric acid)
  - **Bile pigments** (produced during the breakdown of haemoglobin)
- Carbon dioxide is produced from the decarboxylation of respiratory substrates
- Ammonia is produced from the deamination of excess amino acids
- If these two waste products are not excreted properly, they can accumulate and **change the cytoplasm and body fluid pH**, which can cause **enzymes** to work **less efficiently**
- The effects that different metabolic wastes can have on the body if allowed to accumulate are summarised in the table below
  - Note that the liver is a key organ in producing all of these excretory substances (except for carbon dioxide)

Metabolic Wastes Table

Metabolic waste product	Source	Effect(s) on body if allowed to accumulate
Carbon dioxide	The decarboxylation of respiratory substrates during aerobic respiration in mitochondria	Cells damaged if blood pH falls below normal range (acidosis)
Ammonia	The deamination of excess amino acids in liver cells	Increases cytoplasm pH and interferes with metabolic processes (e.g. respiration) and receptors for neurotransmitters in the brain
Urea	The ornithine cycle in liver cells	Urea readily diffuses into cells. This decreases their water potential, causing them to absorb water by osmosis and expand until they burst
Uric acid	The breaking down of adenine and guanine (i.e. purines) in the liver	Uric acid may form crystals in joints, causing gout (a very painful form of arthritis)
Bile pigments	The breaking down of the haem groups of haemoglobin in liver cells	Bile pigments accumulate in the skin turning it yellow (jaundice)

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5.2.2 THE MAMMALIAN LIVER: STRUCTURE

The Mammalian Liver: Structure

External structure

- The liver carries out several important roles in the body, including the **breakdown of unwanted or toxic substances** and the **production of excretory waste**
- In order to carry out these roles successfully, the liver requires a **constant blood supply**
  - The liver is actually supplied with blood from **two different sources**
  - It receives **oxygenated** blood from the **heart** via the **hepatic artery**
  - It also receives **deoxygenated** blood from the **digestive system** via the **hepatic portal vein**. This allows the liver to **absorb** and **metabolise** many of the nutrients that are absorbed into the blood in the small intestine
- **Deoxygenated** blood then **leaves** the liver in the **hepatic vein** and flows back to the heart
- The liver is also connected directly to the **gall bladder**
  - **Bile salts** (that help to digest fats) and **bile pigments** (a waste product from the breakdown of haemoglobin) are **stored** in the gall bladder as part of the **bile**
  - The bile is then **released** into the **duodenum** via the **bile duct**

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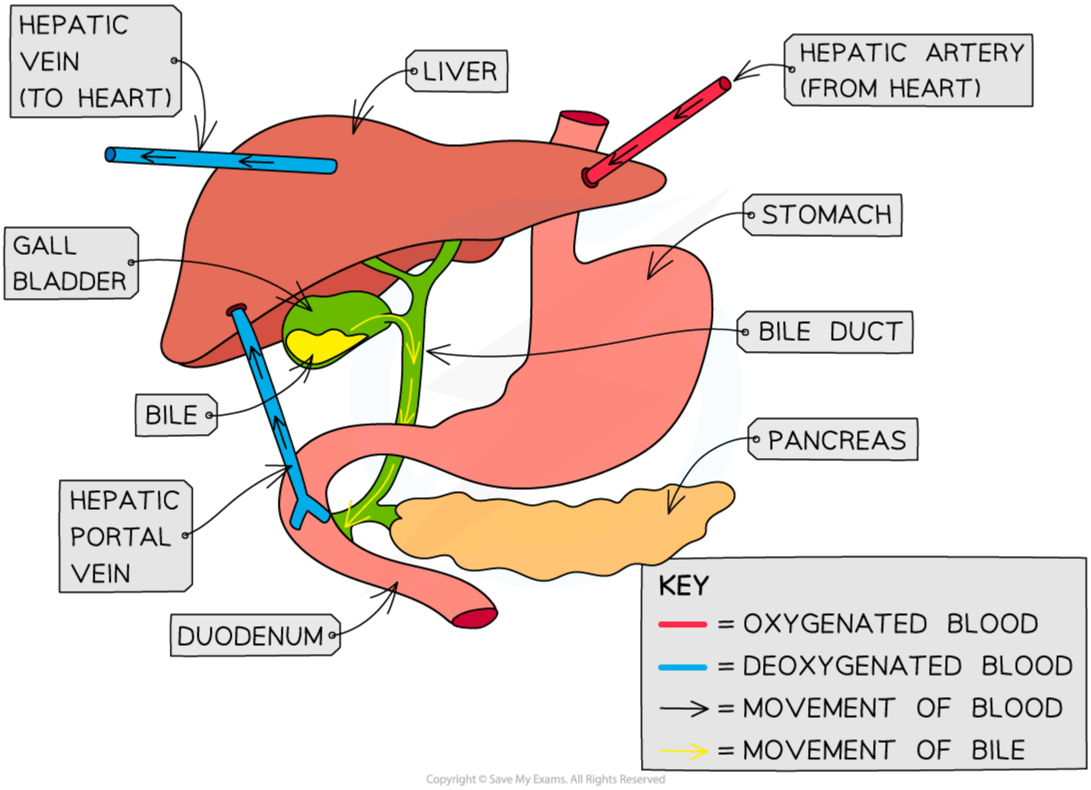

The external structure of the liver, its blood supply and its connection to the gall bladder and duodenum.

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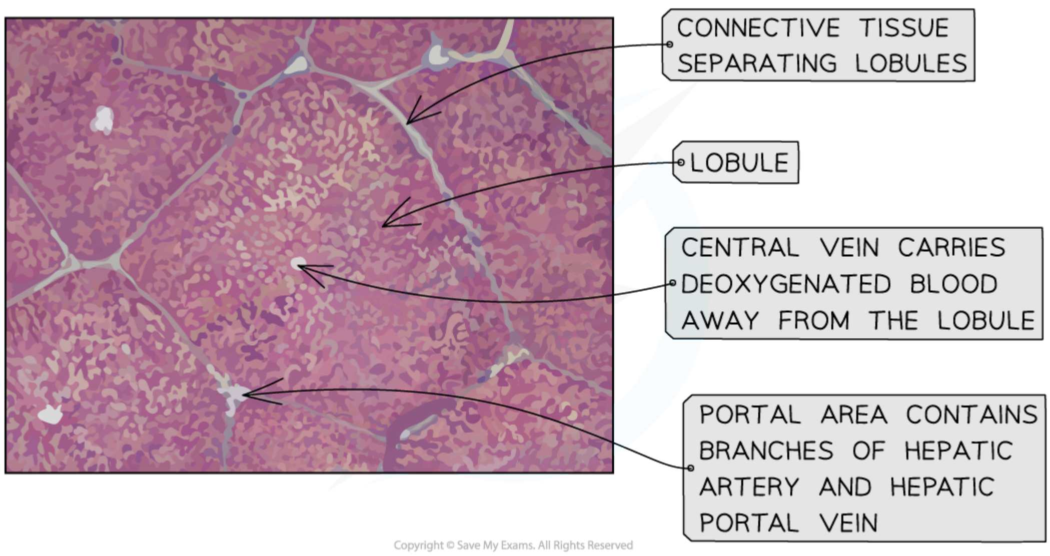
Internal structure

- The **internal** structure of the liver is **fairly simple**
- Unlike some organs, the liver is not made up of lots of different cell types that are all specialised for different functions
    - Instead, the liver is mainly made up of cells known as **hepatocytes** that carry out almost all the functions required
- The liver is divided into **many lobules**, which are separated from each other by **connective tissue** (a tissue that consists of cells that secrete an extracellular matrix)
- **Branches** of the **hepatic artery** and the **hepatic portal vein** supply each lobule with **blood**
- This blood is carried in **wide capillaries** known as **sinusoids**
    - The sinusoids are lined with an **incomplete layer** of **endothelial cells**
    - This allows blood to reach the **hepatocytes**, ensuring substances can be **exchanged** between the blood and these cells
    - Each hepatocyte has a **large surface area** in contact with the blood to **maximise** the exchange of substances
- Each lobule is also connected to a **branch** of the **hepatic vein** that **drains blood away** from the lobule
- The lobule is known as the **functional unit** of the liver, as all the functions of the liver occur **within each individual lobule**



Labelled photomicrograph of a liver lobule (x30).

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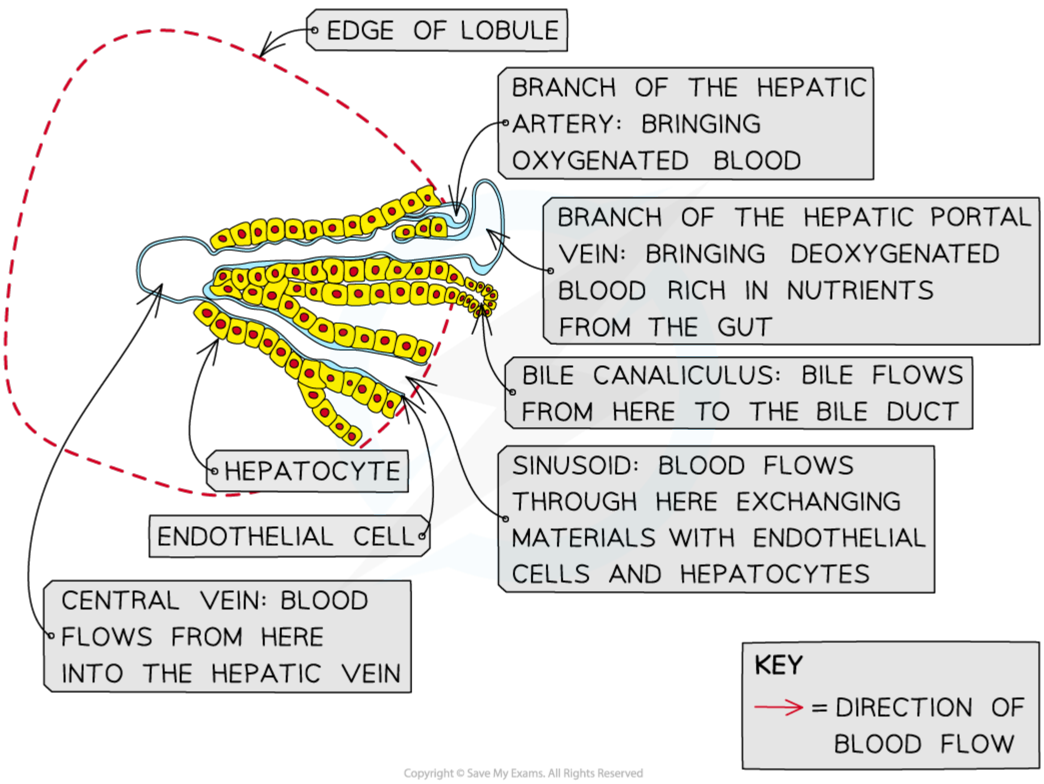

How the blood vessels, sinusoids and hepatocytes are arranged inside a liver lobule.

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5.2.3 THE MAMMALIAN LIVER: FUNCTION

The Mammalian Liver: Function

- The liver is mainly made up of cells known as **hepatocytes** that carry out almost all the functions required
- These functions include:
  - **The storage of glycogen**
  - **The formation of urea**
  - **Detoxification**

The storage of glycogen

- One of the main functions of the liver is to **store glucose as the polysaccharide glycogen**
  - The liver plays a vital role in the conversion of glucose into glycogen (a process known as **glycogenesis**)
  - The conversion between these molecules helps to **regulate blood glucose concentration**
- Glycogenesis is the synthesis of glycogen from glucose molecules
- **Insulin** triggers this process after it detects an increased blood glucose concentration
- The synthesis of glycogen **removes glucose molecules from the bloodstream** and decreases the blood glucose concentration to within a normal range
- Glycogen acts as a **compact** and **efficient carbohydrate storage molecule**

The formation of urea

- The **protein** in our diets is digested into **amino acids**
  - These amino acids are then absorbed into the blood and transported to the **liver**
- Instead of being excreted, excess amino acids (which are a good source of energy) are **deaminated** – the **amino** (**-NH_2**) **group** is **removed** so that the rest of the molecule can be used
- This process is known as **deamination**:
  - The amino group (-NH_2) of an amino acid is removed, together with an extra hydrogen atom
  - These combine to form **ammonia** (**NH_3**), which forms **ammonium ions** (**NH_4^+**) in the cytoplasm
  - The remaining **keto acid** (a type of organic acid) may enter the **Krebs cycle** (in the mitochondria) to be **respired**, be converted to **glucose**, or converted to **glycogen or fat for storage**

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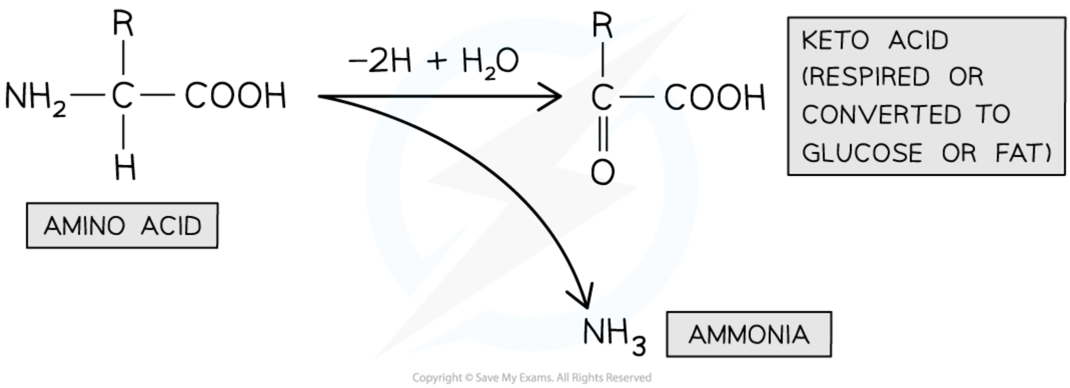

Deamination of an amino acid

- **Ammonia** is a **very soluble** and **highly toxic** compound that is produced during deamination
- It can be very damaging if allowed to build up in the blood
- This is avoided by **converting ammonia** to **urea**
  - Urea is **less soluble** and **less toxic** than ammonia
- Ammonia is **combined with carbon dioxide** to form urea
- This occurs via a series of reactions that occur in a cycle, known as the **ornithine cycle** (or **urea cycle**)
  - During this cycle, **one molecule of urea** is produced from **one molecule of carbon dioxide** and **two amino groups** (from two amino acids)
- The urea diffuses through the phospholipid bilayer of the membranes of the **hepatocytes** and is then transported to the **kidneys** dissolved in the blood plasma

Formation of urea

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Detoxification

- Detoxification is the term used to describe the **breakdown** (by the **liver)** of substances that are **not needed** or are **toxic**
- These substances include:
    - **Lactate**
    - **Alcohol**
    - **Hormones**
    - **Medicinal drugs**

Lactate metabolism

- Lactate is the end product of **anaerobic respiration** (produced by skeletal muscles during strenuous activity when there is insufficient oxygen in the blood – lactate diffuses out of the muscles and into the blood)
- Lactate is an **energy-rich compound** that can be **respired** by cardiac muscle and some other tissues. Excess lactate is absorbed by **hepatocytes** and **metabolised**
- In the liver, lactate is converted to **pyruvate**
    - Some of this pyruvate enters **mitochondria** and is **respired aerobically** to provide the energy required to convert the rest of the lactate to **glucose**
    - Some of this glucose is stored as **glycogen** and the remaining glucose enters the **blood** to maintain the **blood glucose concentration**

Alcohol metabolism

- Once consumed, alcohol (in the form of **ethanol**) is absorbed in the stomach and transported in the blood until it is absorbed by **hepatocytes**
- Similar to lactate, ethanol is a **source of energy** that is **respired** by **hepatocytes** (in preference to **fat**)
- As the metabolism of ethanol generates a large amount of ATP, hepatocytes do not metabolise as much fat as usual and instead **store** the fat, which causes the condition known as **fatty liver**
- This stored fat **reduces the ability of the hepatocytes to carry out their many functions** and can eventually lead to severe problems such as **cirrhosis,** which is the scarring (fibrosis) of the liver caused by excessive alcohol consumption

Hormone metabolism

- Hormones are also **metabolised**
- Protein hormones (e.g. insulin and glucagon) and peptide hormones (e.g. anti-diuretic hormone) are hydrolysed into amino acids, which can then be converted to urea

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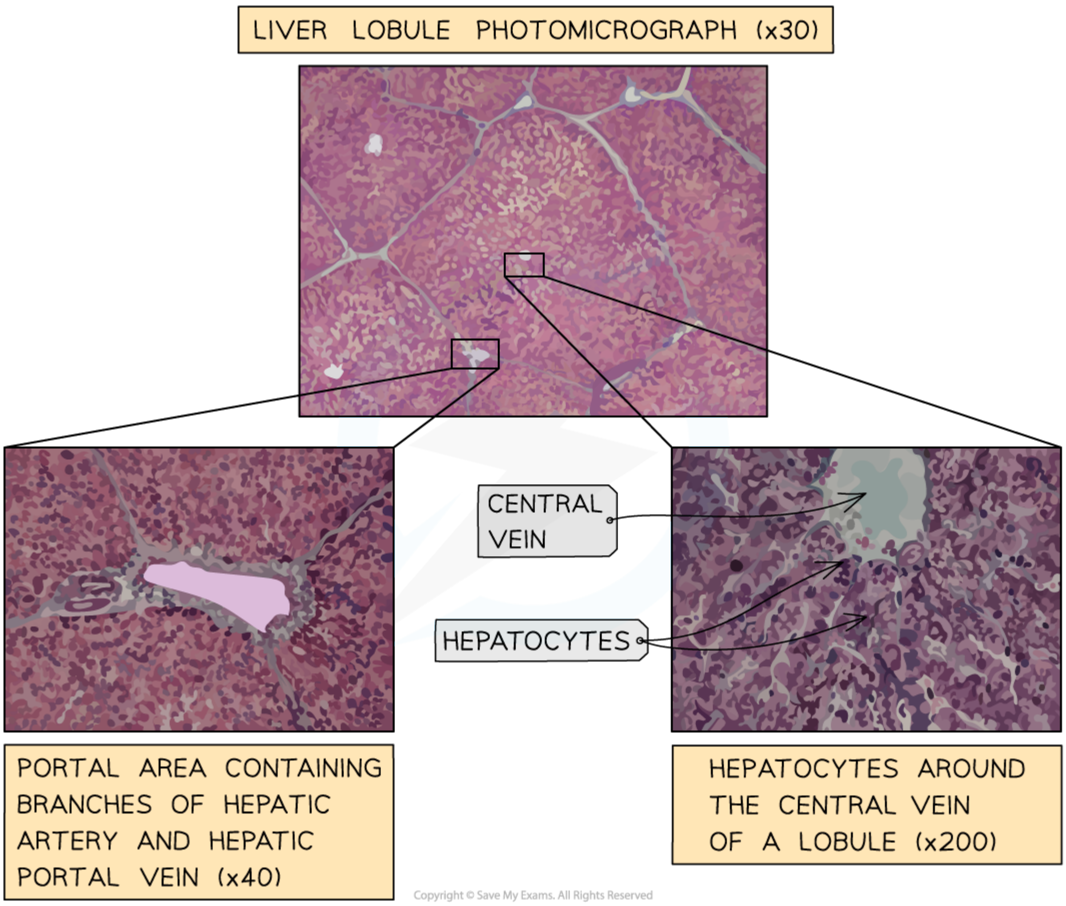
5.2.4 THE LIVER UNDER THE MICROSCOPE

The Liver Under the Microscope

- **Histology** (also known as **microscopic anatomy** or **microanatomy**) is the branch of biology that studies the microscopic anatomy of **biological tissues**
- The histology of the **liver** can be studied by **staining** sections of liver tissue and viewing them under a **microscope**
- These stained samples can then be examined for **drawing** and **labelling**
- Some example labelled diagrams of stained liver tissue are shown below



The liver under the microscope

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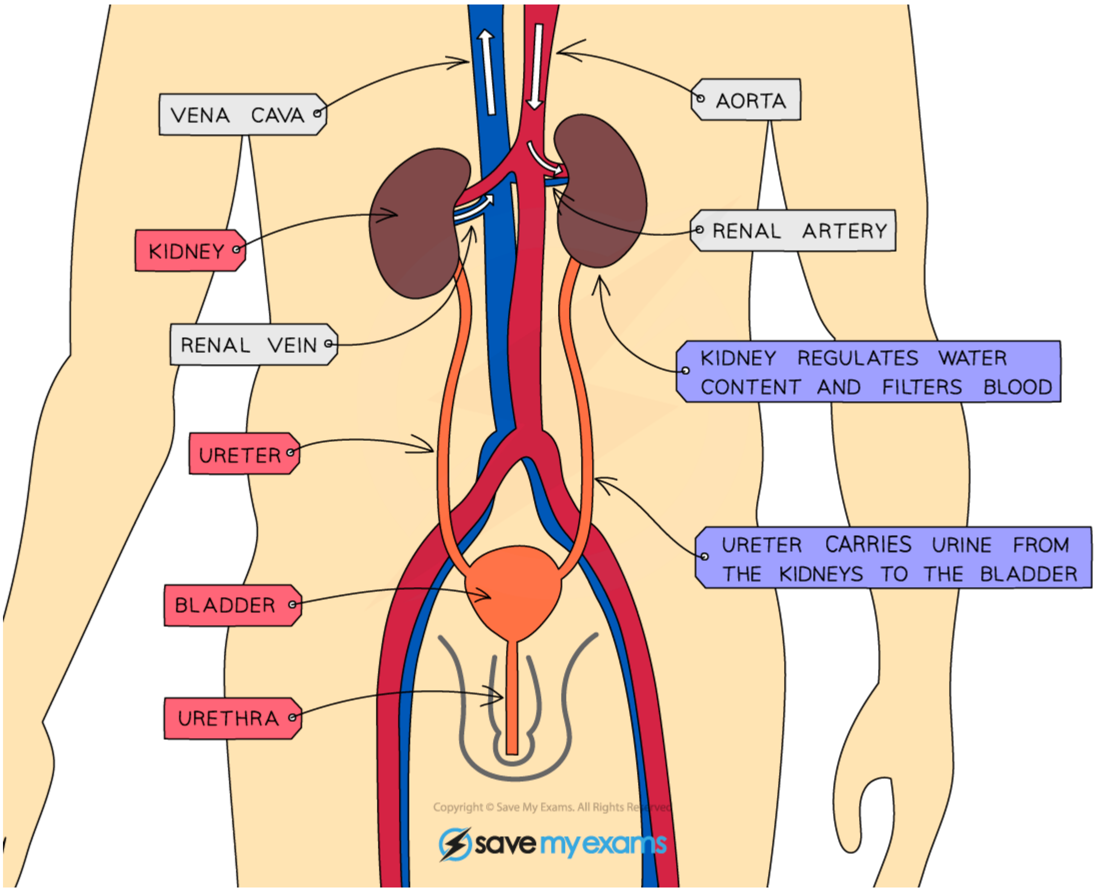
5.2.5 THE MAMMALIAN KIDNEY: STRUCTURE

The Mammalian Kidney: Structure

- Humans have **two** kidneys
- The kidneys are responsible for carrying out two very important functions:
  - As an **osmoregulatory organ** – **they regulate the water content of the blood** (vital for maintaining blood pressure)
  - As an **excretory organ** – **they excrete the toxic waste products of metabolism** (such as **urea**) and substances in excess of requirements (such as **salts**)



The position of the kidneys and their associated structures

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Kidney Function & Structure Table

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 a fairly tough outer layer known as the **fibrous capsule**
- Beneath the fibrous capsule, the kidney has **three main areas**:
    - The **cortex** (contains the glomerulus, as well as the Bowman's capsule, proximal convoluted tubule, and distal convoluted tubule of the nephrons)
    - The **medulla** (contains the loop of Henle and collecting duct of the nephrons)
    - The **renal pelvis** (where the ureter joins the kidney)

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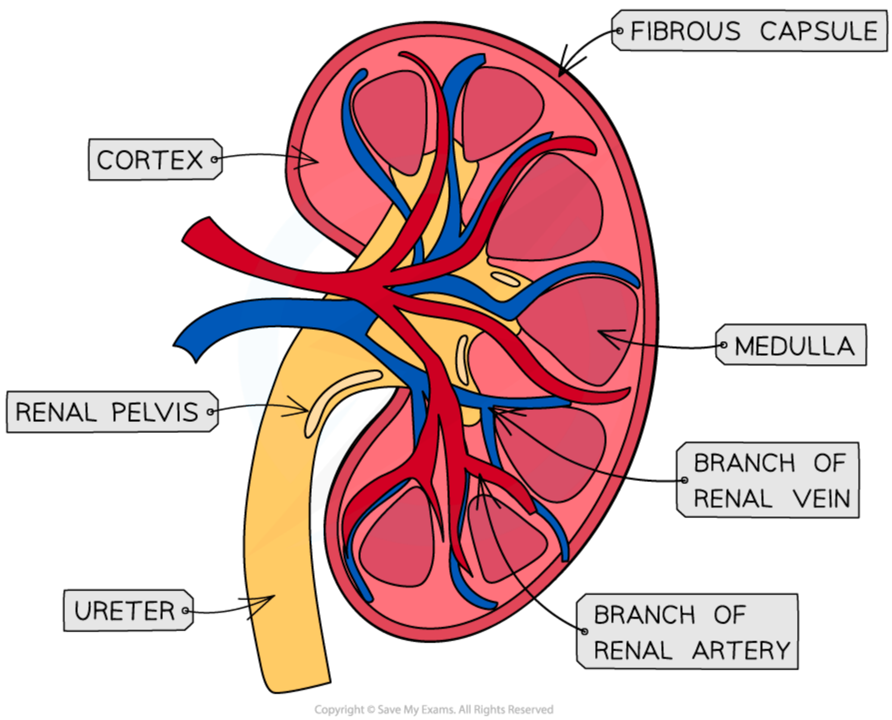

A cross-section of a kidney (as seen when cut in half vertically)

- Each kidney contains **thousands** of **tiny tubes**, known as **nephrons**
- The nephron is the **functional unit** of the kidney – the nephrons are responsible for the **formation of urine**

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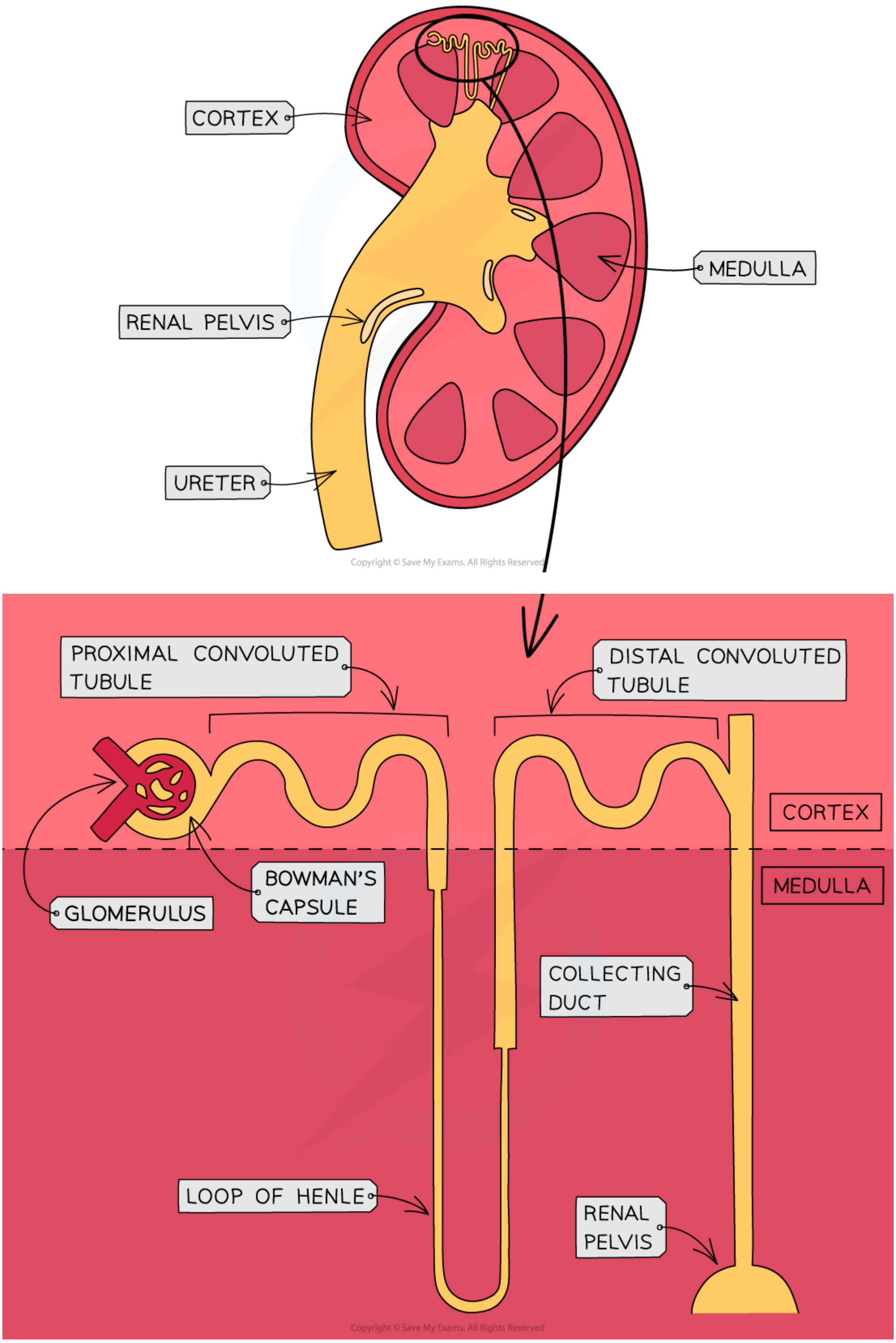

The location and structure of a nephron

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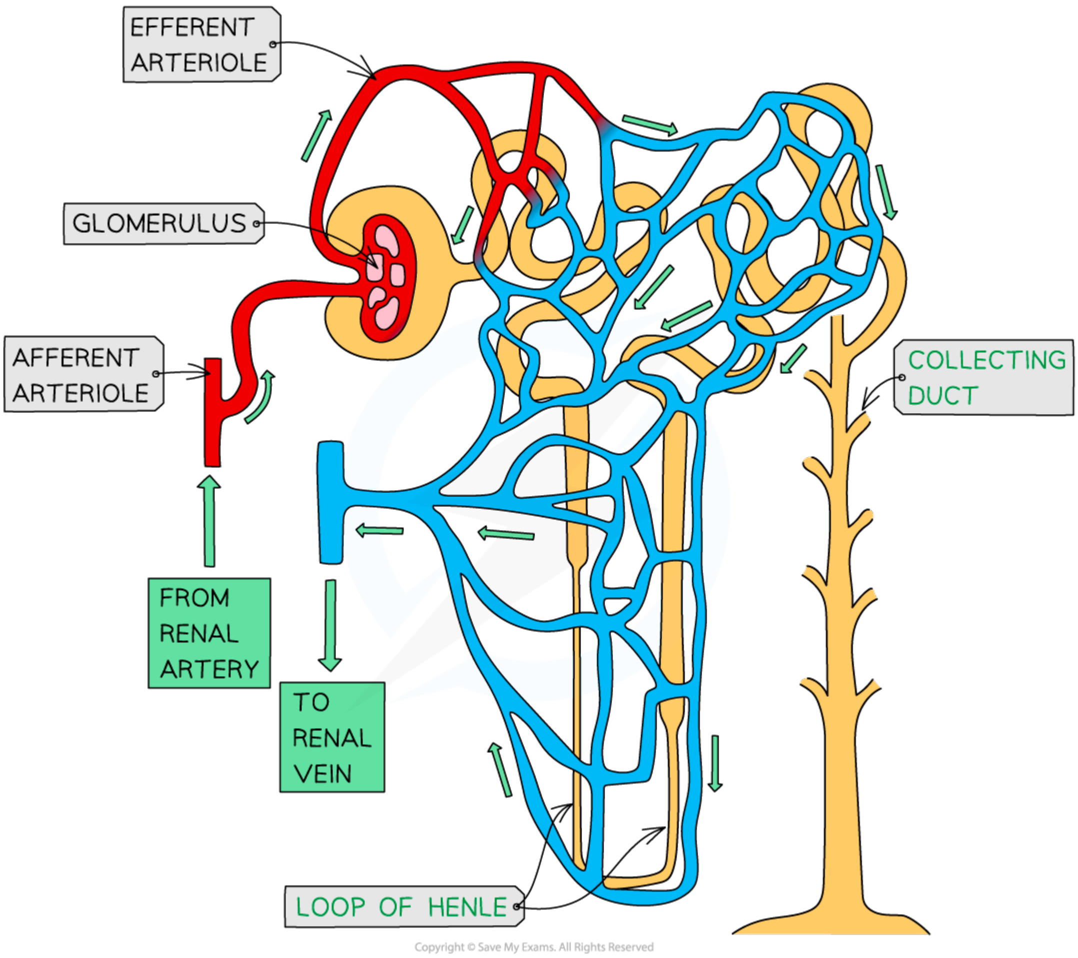
- There is also a network of **blood vessels** associated with each nephron:
  - **Within the Bowman's capsule** of each nephron is a structure known as the **glomerulus**
  - Each glomerulus is supplied with blood by an **afferent arteriole** (which carries blood from the **renal artery**)
  - The capillaries of the glomerulus rejoin to form an **efferent arteriole**
  - Blood then flows from the efferent arteriole into a network of capillaries that run closely alongside the rest of the nephron
  - Blood from these capillaries eventually flows into the **renal vein**



The blood supply associated with a nephron

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5.2.6 THE MAMMALIAN KIDNEY: FUNCTION

The Mammalian Kidney: Function

- The nephron is the **functional unit** of the kidney – the nephrons are responsible for the **formation of urine**
- The process of urine formation in the kidneys occurs in **two stages**:
    - **Ultrafiltration**
    - **Selective reabsorption**

The Two Stages of Urine Production in the Kidneys Table

Stage	Name of process	Where process occurs	Explanation of process
1	Ultrafiltration	Bowman's capsule	Small molecules (including **amino acids, water, glucose, urea and inorganic ions**) are filtered out of the blood capillaries of the glomerulus and **into the Bowman's capsule** to form filtrate known as glomerular filtrate.
2	Selective reabsorption	Proximal convoluted tubule	**Useful molecules** are taken back (**reabsorbed**) from the filtrate and returned to the blood as the filtrate flows along the nephron.

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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** – each capillary endothelial cell is perforated by thousands of tiny membrane-lined circular holes
  - The next layer is the **basement membrane** – this is made up of a network of collagen and glycoproteins
  - The second cell layer is the **epithelium of the Bowman's capsule** – these epithelial cells have many tiny finger-like projections with gaps in between them and are known as **podocytes**
- As blood passes through the glomerular capillaries, the holes in the capillary endothelial cells and **the gaps between the podocytes** allows substances dissolved in the blood plasma to pass into the Bowman's capsule
  - The fluid that filters through from the blood into the Bowman's capsule is known as the **glomerular filtrate**
  - The main substances that pass out of the capillaries and form the glomerular filtrate are: **amino acids, water, glucose, urea and inorganic ions** (mainly Na^+, K^+ and Cl^-)
- **Red and white blood cells** and **platelets** remain in the blood as they are **too large** to pass through the holes in the capillary endothelial cells
- The **basement membrane** acts as a **filter** as it **stops large protein molecules** from getting through

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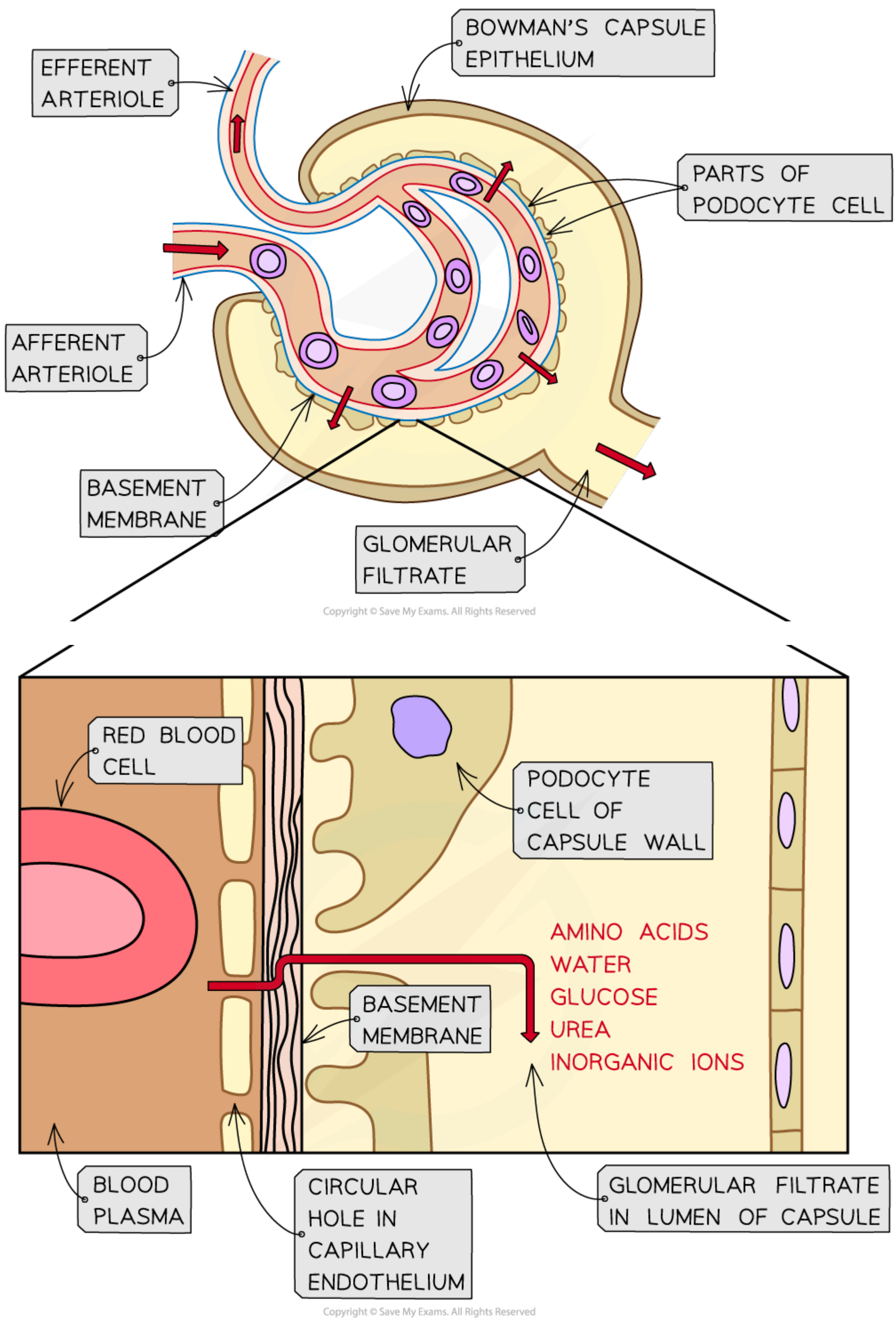

Ultrafiltration occurs when small molecules (such as amino acids, water, glucose, urea and inorganic ions) filter out of the blood and into the Bowman's capsule to form glomerular filtrate. These molecules must pass through three layers during this process: the capillary endothelium, the basement membrane and the Bowman's capsule epithelium

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The process of ultrafiltration

- Ultrafiltration occurs due to the **differences in water potential** between the **plasma** in the **glomerular capillaries** and the **filtrate** in the **Bowman's capsule**
  - Remember – water moves down a water potential gradient, from a region of higher water potential to a region of lower water potential. Water potential is increased by high pressure and decreased by the presence of solutes

Factors Affecting Water Potential in the Glomerulus & Bowman's Capsule Table

Factor affecting water potential	How factor affects water potential in the glomerulus and Bowman's capsule	Resulting movement of water
Pressure	○ As the afferent arteriole is wider than the efferent arteriole, the blood pressure is relatively high in the glomerular capillaries. ○ This raises the water potential of the blood plasma in the glomerular capillaries above the water potential of the filtrate in the Bowman's capsule.	Water moves down the water potential gradient, from the blood plasma in the glomerular capillaries into the Bowman's capsule.
Solute concentration	○ Whilst the basement membrane allows most solutes within the blood plasma to filter into the Bowman's capsule, plasma protein molecules are too big to get through and stay in the blood. ○ As a result, the solute concentration in the blood plasma in the glomerular capillaries is higher than that in the filtrate in the Bowman's capsule. ○ This makes the water potential of the blood plasma lower than that of the filtrate in the Bowman's capsule.	Water moves down the water potential gradient from the Bowman's capsule into the blood plasma in the glomerular capillaries.

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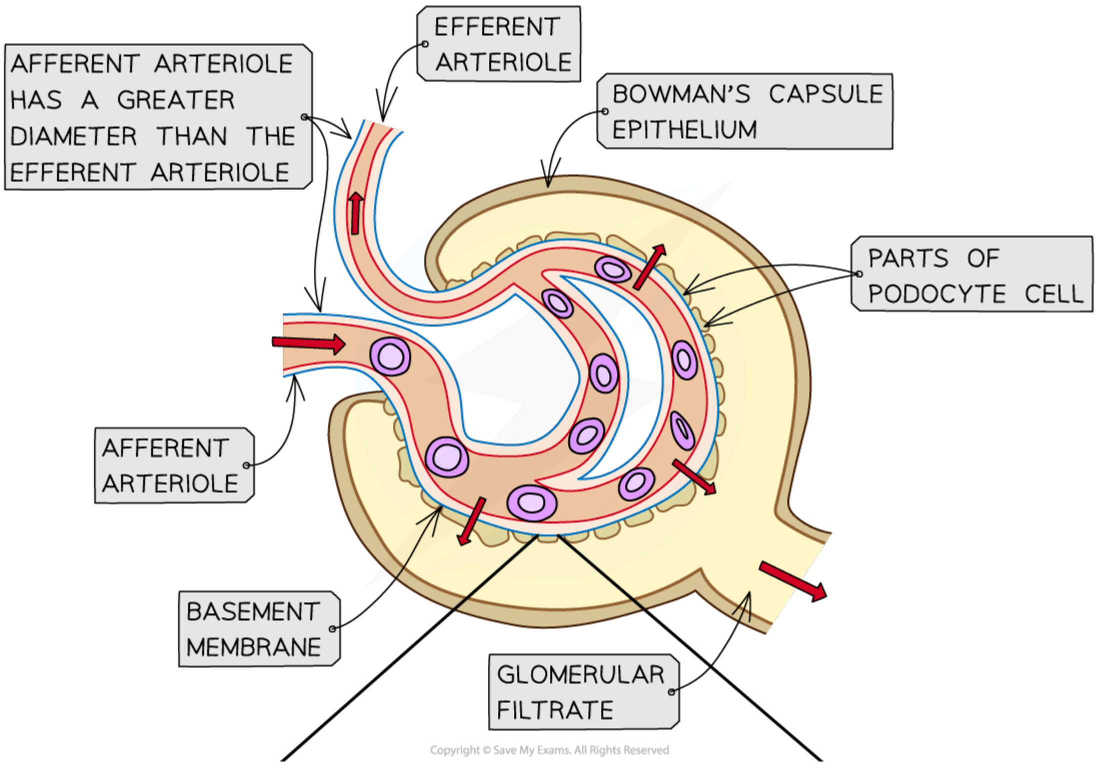
- Overall, the effect of the pressure gradient **outweighs** the effect of solute gradient
- Therefore, the water potential of the blood plasma in the glomerulus is **higher** than the water potential of the filtrate in the Bowman's capsule
- This means that as blood flows through the glomerulus, there is an **overall movement of water down the water potential gradient from the blood into the Bowman's capsule**



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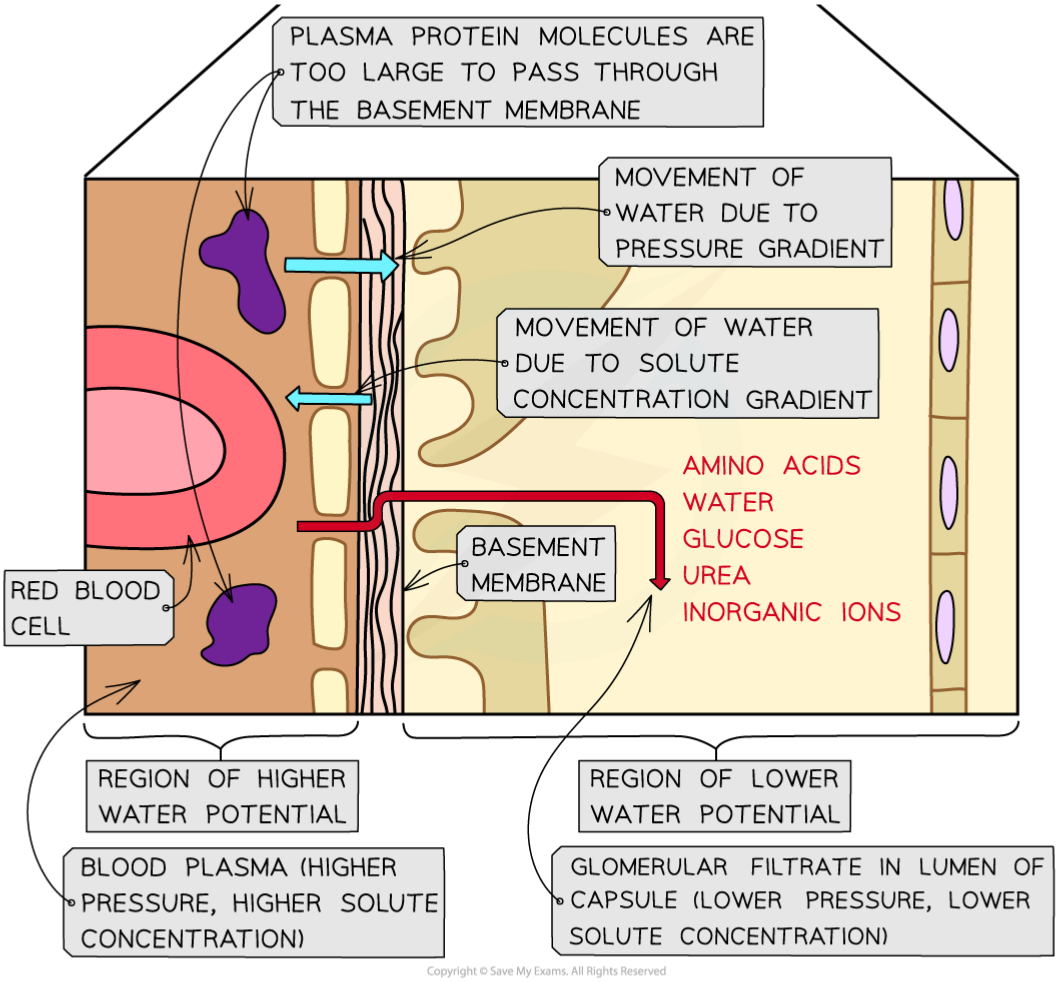

As blood flows through the glomerulus, there is an overall movement of water down the water potential gradient from the blood plasma (region of higher water potential) into the Bowman's capsule (region of lower water potential)

Selective reabsorption

- Many of the substances that end up in the **glomerular filtrate** actually need to be **kept** by the body
- These substances are **reabsorbed** into the blood as the filtrate passes along the nephron
- This process is knowns as **selective reabsorption** as only certain substances are reabsorbed
- Most of this reabsorption occurs in the **proximal convoluted tubule**
- 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:
  - Microvilli
  - Co-transporter proteins
  - A high number of mitochondria
  - Tightly packed cells

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Adaptations for Selective Reabsorption Table

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

- Blood capillaries are located very close to the outer surface of the proximal convoluted tubule
  - As the blood in these capillaries comes straight from the glomerulus, it has very little plasma and has lost much of its water, inorganic ions and other small solutes
- The basal membranes (of the proximal convoluted tubule epithelial cells) are the sections of the cell membrane that are closest to the blood capillaries
- **Sodium-potassium pumps** in these **basal membranes** move sodium ions out of the epithelial cells and into the blood, where they are carried away
- This **lowers the concentration of sodium ions inside the epithelial cells**, causing sodium ions in the filtrate to diffuse down their concentration gradient through the luminal membranes (of the epithelial cells)
- These sodium ions do not diffuse freely through the luminal membranes – they must pass through **co-transporter proteins** in the membrane
- There are several types of these co-transporter proteins – each type transports **a sodium ion and another solute** from the filtrate (eg. glucose or a particular amino acid)
- Once inside the epithelial cells these solutes diffuse down their concentration gradients, passing through transport proteins in the basal membranes (of the epithelial cells) into the blood

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Molecules reabsorbed from the proximal convoluted tubule during selective reabsorption

- **All glucose** in the glomerular filtrate is reabsorbed into the blood
  - This means no glucose should be present in the urine
- **Amino acids, vitamins and inorganic ions** are reabsorbed
- The movement of all these solutes from the proximal convoluted tubule into the capillaries **increases** the water potential of the **filtrate** and **decreases** the water potential of the **blood** in the capillaries
  - This creates a steep water potential gradient and **causes water to move into the blood by osmosis**
- A significant amount of **urea** is reabsorbed too
  - The concentration of urea in the filtrate is higher than in the capillaries, causing urea to diffuse from the filtrate back into the blood

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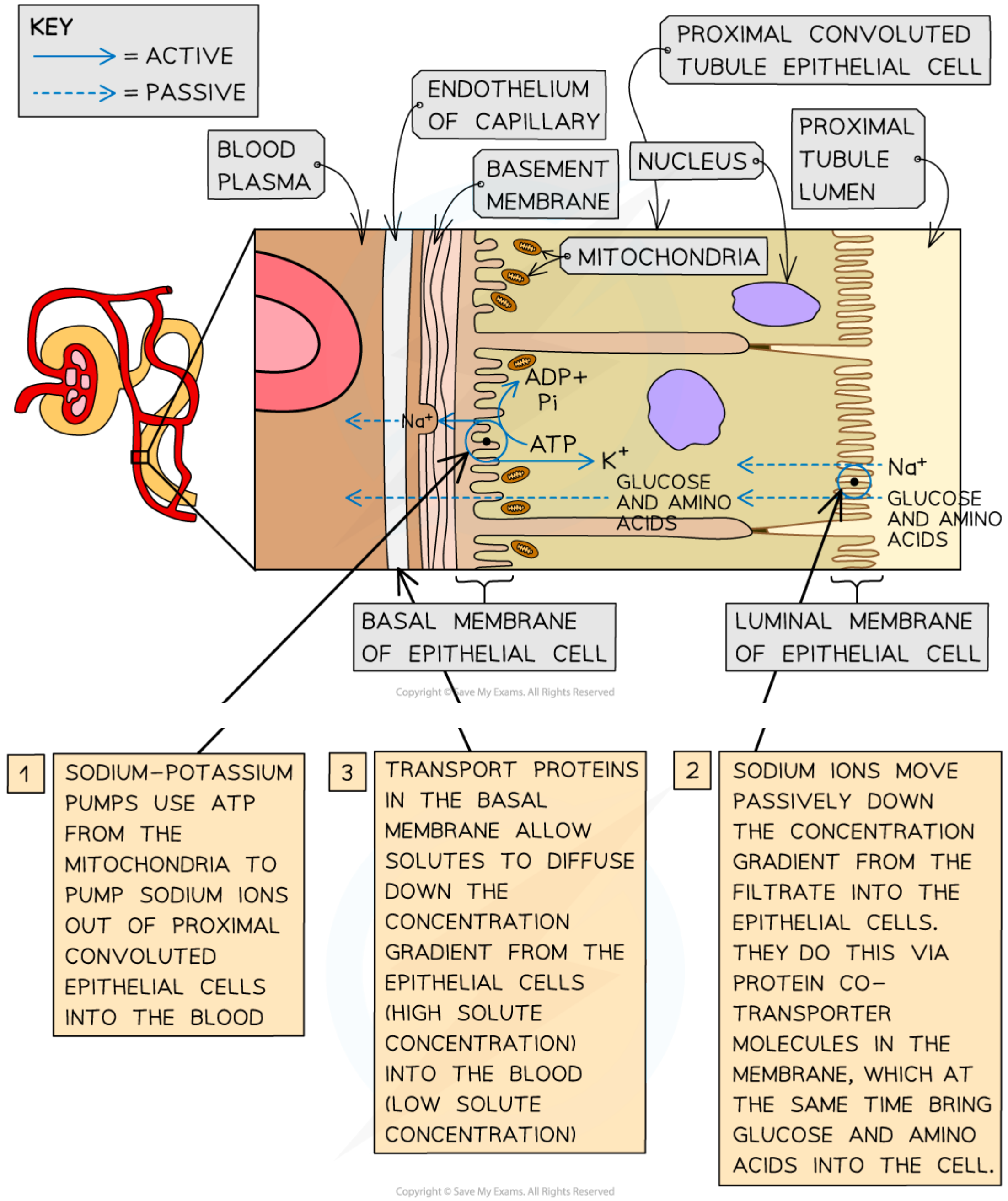

Selective reabsorption in the proximal convoluted tubule

- After the necessary reabsorption of amino acids, water, glucose and inorganic ions is complete, **the filtrate eventually leaves the nephron** and is now referred to as **urine**
- This urine then flows out of the kidneys, along the ureters and into the **bladder**, where it is temporarily stored

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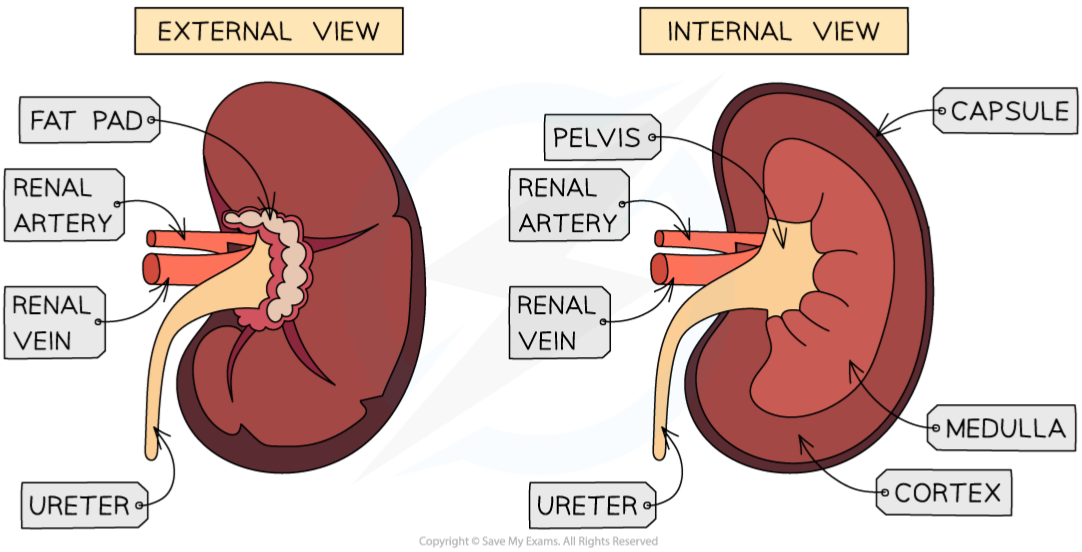
5.2.7 THE KIDNEY UNDER THE MICROSCOPE

The Kidney Under the Microscope

- **Dissections** are a vital part of scientific research
- They allow for the **external** and **internal structures** of organs to be **examined** so that theories can be made about how they **function**
- Some examples of labelled diagrams of the external and internal structures of the kidneys are shown below



The results of a kidney dissection showing the gross structure of the kidney, including the external structure and a vertical section showing the internal structure.

The histology of the kidney and nephrons

- **Histology** (also known as **microscopic anatomy** or **microanatomy**) is the branch of biology that studies the microscopic anatomy of **biological tissues**
- The histology of the **kidney** and specifically the histology of the **functional unit** of the kidney, the **nephron**, can be studied by **staining** sections of kidney tissue and viewing them under a **microscope**
- These stained samples can then be examined for **drawing** and **labelling** to identify the different structures within the nephron
    - **It is not possible to see complete nephrons in any section of stained kidney tissue because they are irregular structures that do not lie in any one plane within the kidney**
- Some examples of labelled diagrams of stained kidney tissue are shown below – these photomicrograph diagrams show the **parts of many adjacent nephrons**

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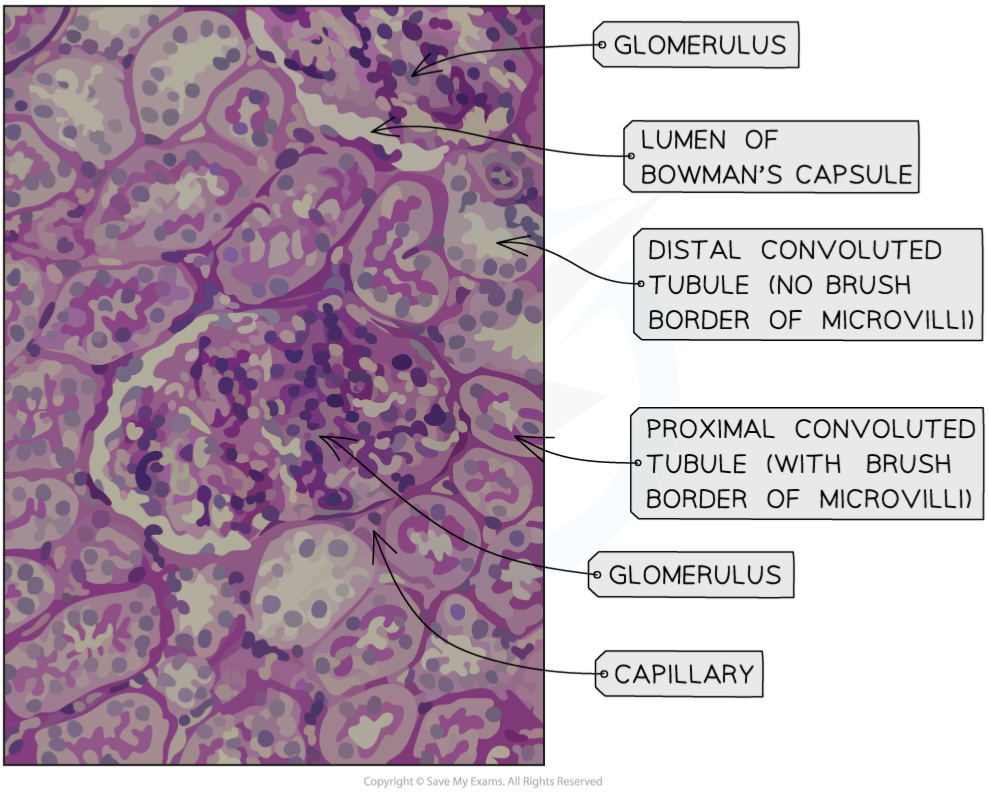

The histology of the nephron can be seen in stained sections of kidney tissue. Above: a photomicrograph (×200) of the cortex of the kidney (artistic impression).

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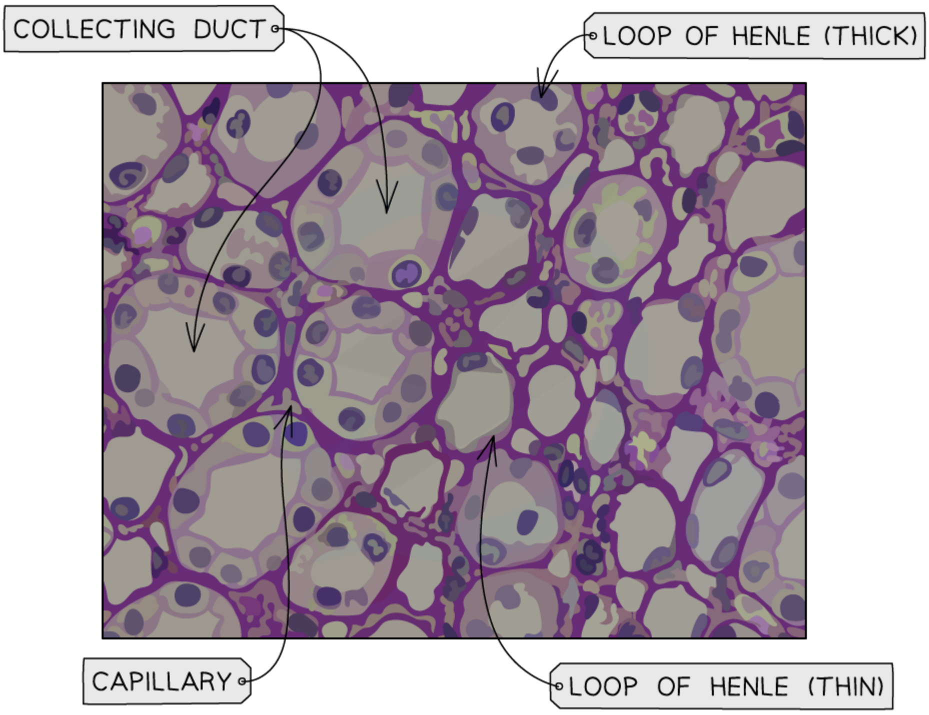

The histology of the nephron can be seen in stained sections of kidney tissue. Above: a photomicrograph (×600) of the medulla of the kidney (artistic impression).

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5.2.8 OSMOREGULATION

Osmoregulation

- The control of the **water potential** of body fluids is known as **osmoregulation**
- Osmoregulation is a key part of **homeostasis**
- Specialised **sensory neurones**, known as **osmoreceptors**, monitor the water potential of the blood (these osmoreceptors are found in an area of the brain known as the **hypothalamus**)
- If the osmoreceptors detect a **decrease** in the water potential of the **blood**, nerve impulses are sent along these sensory neurones to the **posterior pituitary gland** (another part of the brain just below the hypothalamus)
- These nerve impulses stimulate the posterior pituitary gland to release **antidiuretic hormone (ADH)**
- ADH molecules enter the blood and travel throughout the body
- ADH causes the **kidneys** to **reabsorb** more water
- This **reduces the loss of water in the urine**

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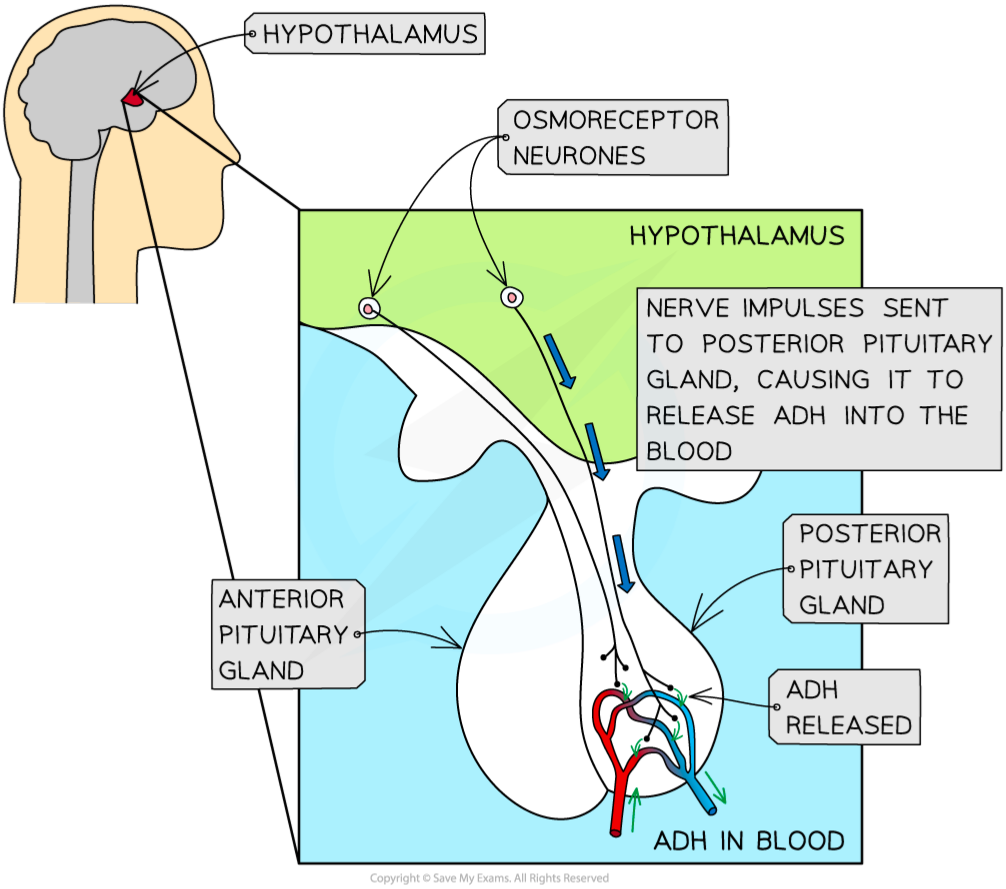

When osmoreceptors detect a decrease in blood water potential, nerve impulses stimulate the release of ADH at the posterior pituitary gland. This ADH then travels in the blood to the kidneys, causing them to increase water reabsorption.

5.2 Excretion

YOUR NOTES
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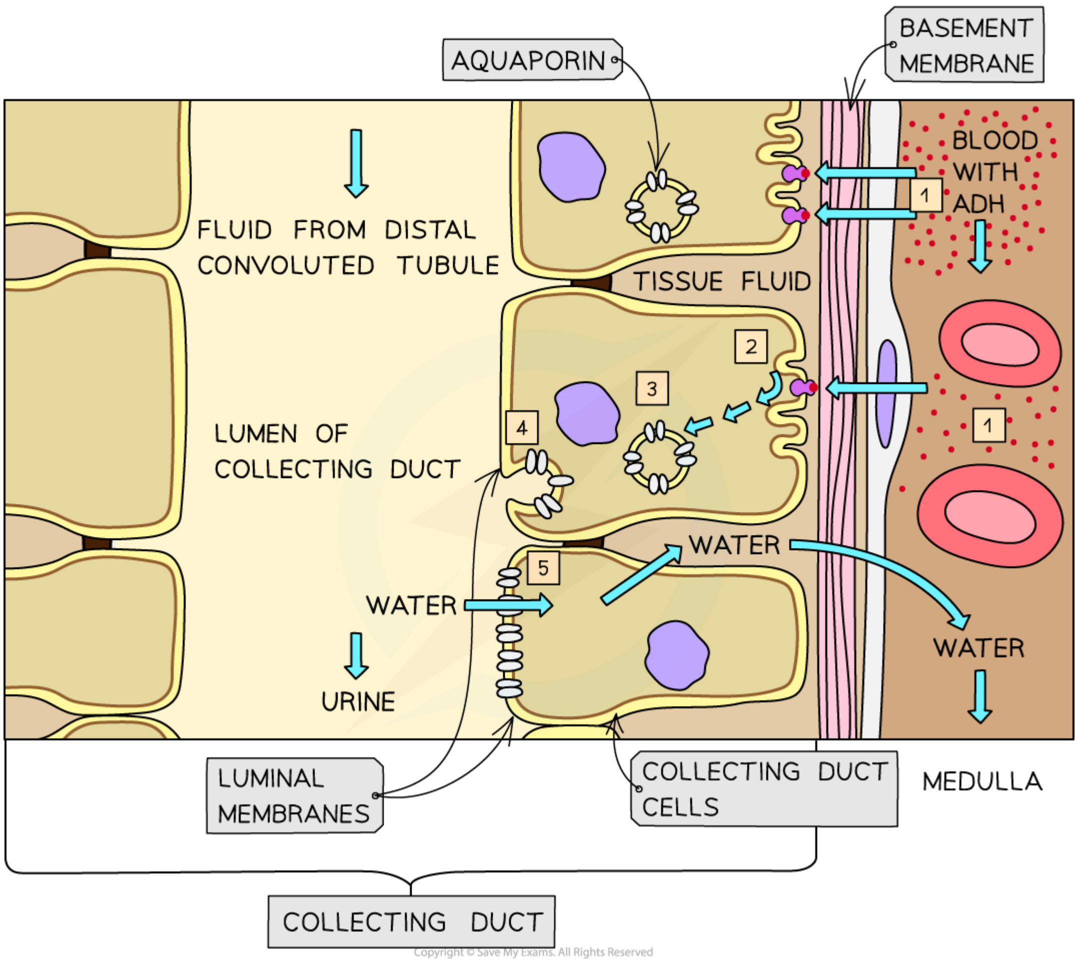
The effect of ADH on the kidneys

- Water is reabsorbed by **osmosis** from the **filtrate** in the **nephron**
- This reabsorption occurs as the filtrate passes through structures known as **collecting ducts**
- **ADH** causes the **luminal membranes** (ie. those facing the lumen of the nephron) of the collecting duct cells to become **more permeable** to water
- ADH does this by causing an **increase** in the number of **aquaporins** (water-permeable channels) in the luminal membranes of the collecting duct cells. This occurs in the following way:
    - Collecting duct cells contain **vesicles**, the membranes of which contain many **aquaporins**
    - ADH molecules bind to receptor proteins, activating a signalling cascade that leads to the **phosphorylation** of the aquaporin molecules
    - This activates the aquaporins, causing the **vesicles** (with aquaporin-containing membranes) to **fuse** with the **luminal membranes** of the collecting duct cells
    - This **increases the permeability** of the membrane to water
- As the filtrate in the nephron travels along the collecting duct, water molecules move from the collecting duct (**high water potential**), through the aquaporins, and into the **tissue fluid** and **blood plasma** in the **medulla** (**low water potential**)
- As the filtrate in the collecting duct loses water it becomes more **concentrated**
- As a result, a **small volume of concentrated urine** is produced. This flows from the kidneys, through the ureters and into the bladder

5.2 Excretion

YOUR NOTES ⬇



1. ADH BINDS TO RECEPTOR PROTEINS IN THE CELL SURFACE MEMBRANES OF THE COLLECTING DUCT CELLS
2. AQUAPORINS ARE PHOSPHORYLATED
3. VESICLES (WITH AQUAPORIN–CONTAINING MEMBRANES) MOVE TOWARDS LUMINAL MEMBRANES OF COLLECTING DUCT CELLS
4. VESICLES FUSE WITH LUMINAL MEMBRANES
5. WATER MOVES THROUGH AQUAPORINS DOWN THE WATER POTENTIAL GRADIENT INTO THE CONCENTRATED TISSUE FLUID AND BLOOD PLASMA IN THE MEDULLA OF THE KIDNEY

How ADH affects water reabsorption in the collecting duct of the nephron

5.2 Excretion

YOUR NOTES

Exam Tip

If the water potential of the blood is too high, the exact opposite happens:

- Osmoreceptors in the hypothalamus are not stimulated
- No nerve impulses are sent to the posterior pituitary gland
- No ADH released
- Aquaporins are moved out of the luminal membranes of the collecting duct cells
- Collecting duct cells are no longer permeable to water
- The filtrate flows along collecting duct but loses no water and is very dilute
- A large volume of dilute urine is produced
- This flows from the kidneys, through the ureters and into the bladder

5.2 Excretion

YOUR NOTES
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5.2.9 KIDNEY FAILURE

Kidney Failure

- Kidney failure can occur in **one or both** kidneys due to a variety of reasons, including (but not limited to):
  - Blood loss in an accident
  - High blood pressure
  - Diabetes
  - Overuse of certain drugs (e.g. aspirin)
  - Certain infections
- Kidney failure is dangerous and can be **fatal** within a relatively short time period
- In some cases, kidney failure happens **suddenly** and only lasts for a **short time** but in other cases, it can become a **long-term condition**
- If the kidneys fail:
  - **Urea, water, salts and various toxins** are **retained** and **not excreted**
  - Less blood is **filtered** by the glomerulus, causing the **glomerular filtration rate** (GFR) to **decrease**
  - This leads to a **build-up of toxins** in the blood
  - In addition, the **electrolyte balance** in the blood is **disrupted** (the concentrations of ions and charged compounds are not maintained)

The importance of the balance of electrolytes

- The disruption of the electrolyte balance in the blood as a result of kidney failure can have very **harmful consequences**
- **Excess potassium ions** in the blood can lead to abdominal cramps, tiredness, muscle weakness and even paralysis
- If potassium ion concentrations continue to increase, the **frequency of impulses from the sinoatrial node** in the heart may **decrease**, potentially leading to **arrhythmia** and **cardiac arrest**
- Depending on the body's needs, the kidneys either conserve or secrete **sodium**, which plays an important role in **neuromuscular function, fluid balance and acid/base balance**
- A build-up of sodium can cause disorientation, muscle spasms, higher blood pressure and general weakness

5.2 Excretion

YOUR NOTES
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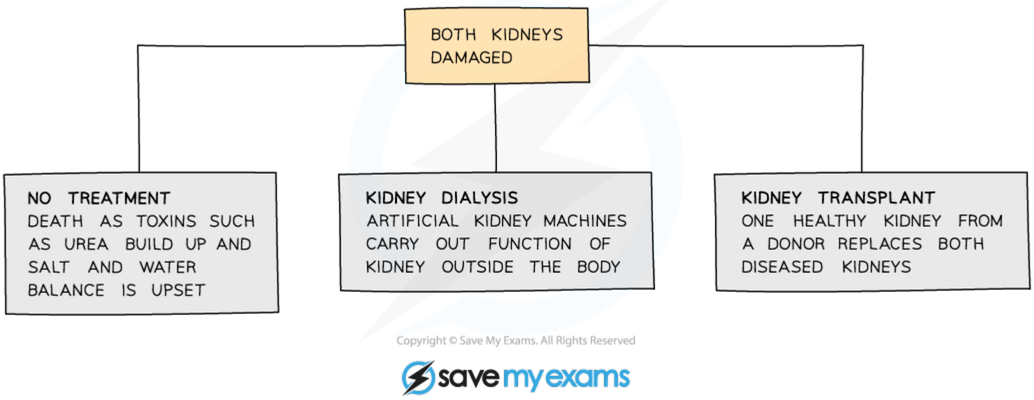
Potential treatments for kidney failure

- Humans can survive with **one** functioning kidney, but if both are damaged then there will quickly be a **build-up of toxic wastes** in the body which will be **fatal** if not removed
- There are **two forms** of treatment for kidney failure
  - **Renal dialysis** – toxins, metabolic waste products and excess substances are removed from the blood by diffusion via a dialysis membrane)
  - **Kidney transplant** – the non-functioning kidney (or kidneys) is replaced with a functioning kidney



Treatment options for total kidney failure

5.2 Excretion

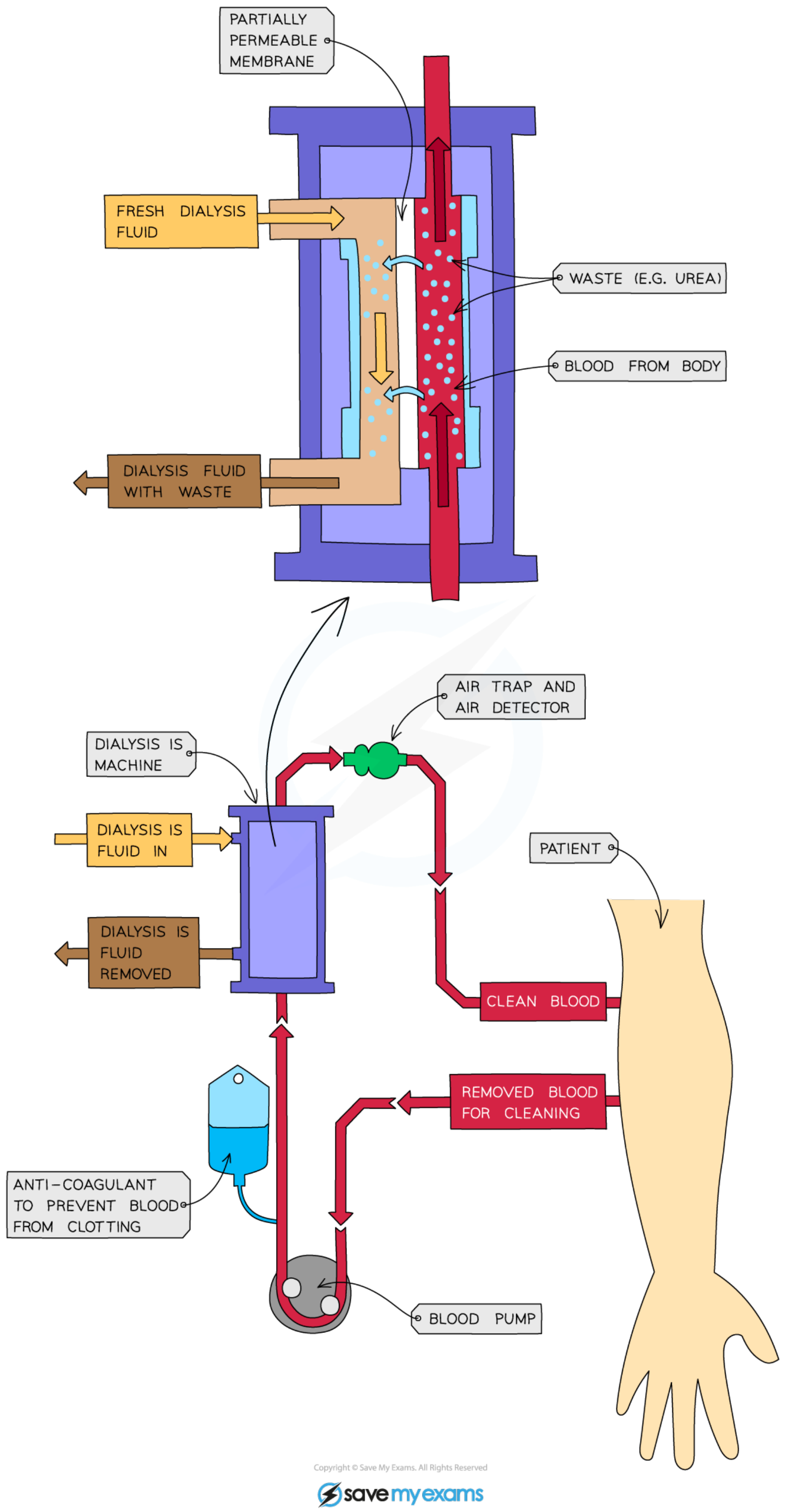
YOUR NOTES

Renal dialysis

- Dialysis is the term used to describe the separation of small and large molecules using a **partially permeable membrane**
- **Renal dialysis** is used as a treatment for kidney failure and comes in two forms:
  - **Haemodialysis**
  - **Peritoneal dialysis**
- For haemodialysis:
  - The patient requires **regular treatment** in a hospital or at home using a **machine** known as a **haemodialyser**, which acts as an artificial kidney
  - In this dialysis machine, partially permeable dialysis membranes **separate** the patient's **blood** from the **dialysis fluid** (known as the **dialysate**)
  - The blood is passed through **tubes** of **dialysis membrane**, which are surrounded by **dialysate**
  - The dialysate contains substances **needed** in the blood (e.g. **glucose** and **sodium ions**) in the **right concentrations** (i.e. concentrations similar to a normal level in blood)
  - As the dialysate contains a **glucose** concentration **equal** to a **normal blood sugar level**, this prevents the net movement of glucose across the membrane as **no concentration gradient** exists
  - As the dialysis fluid contains a **salt** concentration **similar to the ideal blood concentration**, movement of salts across the membrane only occurs where there is an **imbalance** (if the blood is too low in salts, they will diffuse into the blood; if the blood is too high in salts, they will diffuse out of the blood)
  - The fluid in the machine is **continually refreshed** so that **concentration gradients are maintained** between the dialysis fluids and the blood
  - Importantly, the dialysate contains **no urea**
  - This causes urea to diffuse down its concentration gradient **from the blood into the dialysate** and is eventually disposed of
  - The haemodialyser is designed so that the patient's blood and the dialysate flow in **opposite directions**, creating a concentration gradient along the length of the dialyser component of the machine
  - This means that each time blood circulates through the machine, some more of the urea it contains passes into the dialysate, until almost all of it is removed (after approximately 3 hours)
  - The drug **heparin** is added to the blood as it is an **anticoagulant** (blood thinner) that **prevents the formation of blood clots**

5.2 Excretion

YOUR NOTES



How haemodialysis works

5.2 Excretion

YOUR NOTES
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- For peritoneal dialysis:
  - Dialysate is introduced to the **abdominal cavity** through a **catheter** (a thin tube that enters a part of the body)
  - Urea, other metabolic waste products and excess substances diffuse **from the blood supply** across the abdominal lining (known as the peritoneum) **into the dialysate**
  - This dialysate is then removed and replaced with more
- Both forms of dialysis impose heavy **restrictions** on the lives of patients that rely on them, as they have to make **regular trips to the hospital** to receive the treatment, which takes at least 3 hours each time. In addition, patients have to **carefully control their diet** to minimise their urea production and their salt intake

Kidney transplant

- An alternative to these potentially restricting dialysis treatments is to have a kidney transplant
- Although **only one kidney is required** for a transplant (one functioning kidney can replace two non-functioning kidneys) a **donor** with a **compatible blood group** must be found
- Even with this, a kidney transplant patient must still take medication to stop their immune system from **rejecting** the donated kidney as this kidney will often be of a different **tissue type**
- **Kidney transplants** are a better long term solution to kidney failure than dialysis; however, there are several **disadvantages** to kidney transplants, including:
  - Donors won't have the same antigens on cell surfaces so there will be some **immune response** to the new kidney (risk of rejection is reduced – but not removed – by 'tissue typing' the donor and the recipient first)
  - This has to be suppressed by taking **immunosuppressant drugs** for the rest of their lives – these can have long term side effects and leave the patient vulnerable to infections
  - There are **not enough donors** to cope with the demand
- However, if a healthy, close matched kidney is available, then the **benefits** of a transplant over dialysis include:
  - The patient has **much more freedom** as they are not tied to having dialysis several times a week in one place
  - Their **diets** can be **much less restrictive** than they are when on dialysis
  - The use of dialysis machines is **very expensive** and so this cost is removed
  - A kidney transplant is a long-term solution whereas **dialysis will only work for a limited time**

5.2 Excretion

Exam Tip

When answering questions about dialysis, the best answers will refer to **differences in concentration gradients** between the dialysis fluid (the dialysate) and the blood, and use this to explain why substances move in certain directions.

5.2 Excretion

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5.2.10 EXCRETORY PRODUCTS & MEDICAL DIAGNOSIS

Excretory Products & Medical Diagnosis

Urine tests

- The **most common** urine test is to look for 'sugar' (**glucose**) in the urine:
  - All the glucose in the glomerular filtrate should be **reabsorbed** by the proximal convoluted tubule (PCT) and therefore there should be **no glucose present** in the urine
  - If a urine test shows that there **is** glucose present, this suggests that there is something wrong with the person's **homeostatic control of glucose** (in particular there may be something wrong with the **functioning of insulin**)
- Urine can also be tested for **ketones**:
  - Ketones, such as acetone (propanone) and acetoacetate, are produced by the metabolism of people who have **diabetes**
  - If a urine or blood test shows that there are ketones present, this suggests the person has diabetes mellitus
- Urine can also be tested for **proteins**:
  - If a urine test shows that there is protein present, this suggests that the person's **blood pressure may be too high**, or it may indicate a **kidney infection** or that there is something wrong with their **blood filtration mechanism**
- Positive tests for **nitrate ions** in the urine indicate the person has a **bacterial infection** in the **urinary tract**

Pregnancy tests

- Urine samples can also be used in **pregnancy testing**
- Pregnancy testing sticks contain **monoclonal antibody** molecules that are specific to a **hormone** produced **during pregnancy** (that therefore becomes present in the **mother's urine**)
  - This hormone is **human chorionic gonadotropin** (**hCG**), which is secreted by the early embryo after it has implanted in the uterus
  - The antibodies in the testing sticks all originate from a **single clone** of B lymphocyte cells that all produce the **same antibody specific to hCG**
  - This **minimises** the chances of **false test results**

5.2 Excretion

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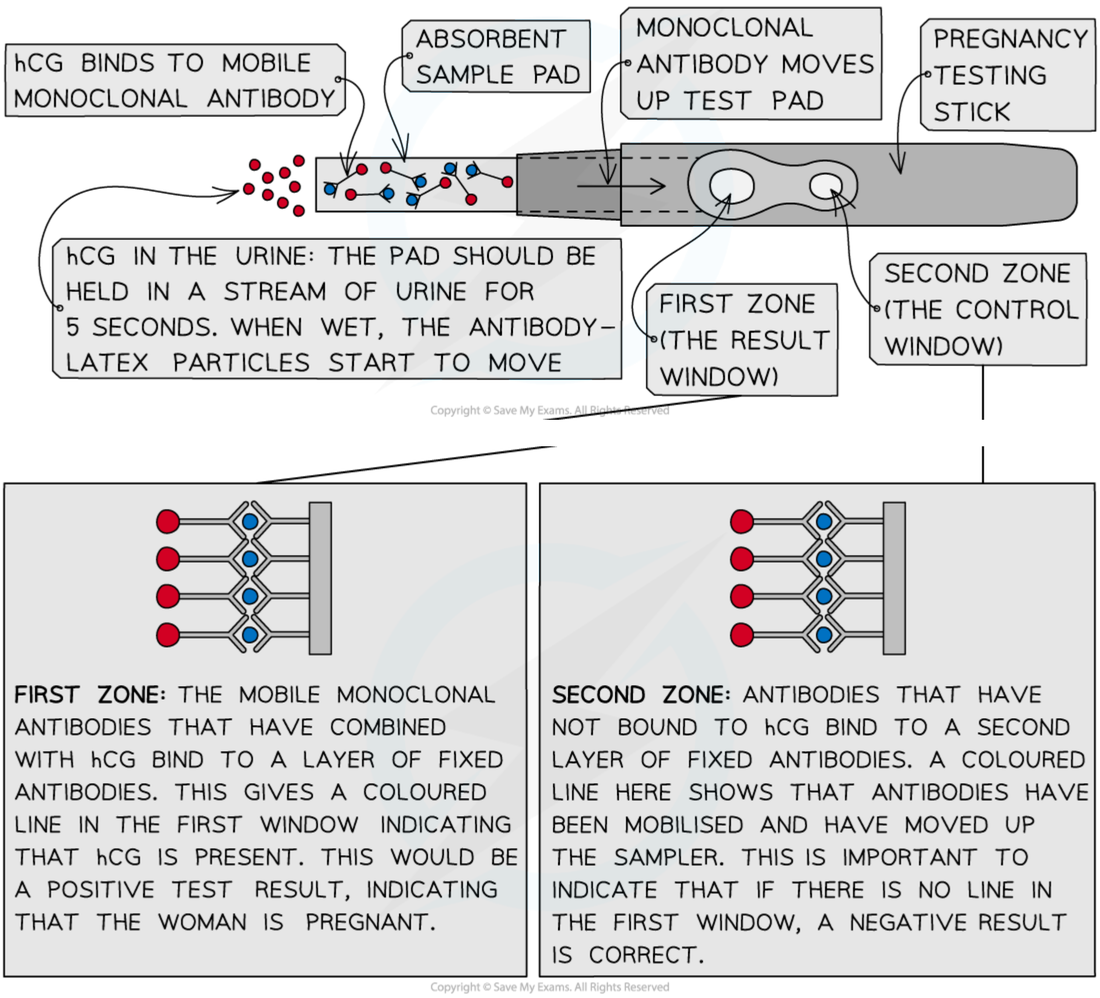

Monoclonal antibodies are used to detect the presence of the hormone hCG in the urine of pregnant women.

Testing for anabolic steroids

- Urine samples can also be used to test for **anabolic steroids**
- For example, athletes are regularly tested for anabolic steroids as these can be used to rapidly build muscle mass by stimulating protein synthesis
- Anabolic steroids are detected in urine via **gas chromatography** or **mass spectrometry**