Kidney Notes

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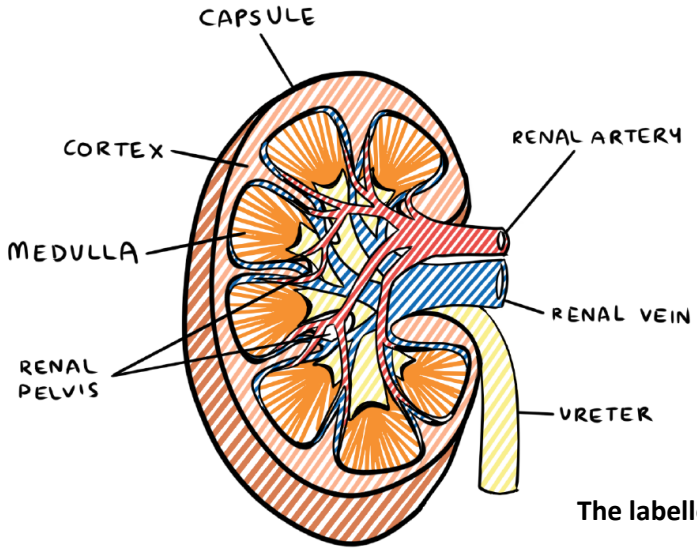
The kidneys are two vital, bean shaped organs, located in the back of the abdomen and have **two** key roles within the body:

1. They **regulate the water content** of the blood.
2. They filter the blood to **remove urea**, a toxic waste product of metabolism.



The labelled Kidney

What is Urine?

It is an excretion from the body that mainly consists of:

1. **Urea** – from the breakdown of amino acids.
2. **Excess salts.**
3. **Excess Water.**
4. **It is sterile** – meaning that there are typically no microorganisms present in it.

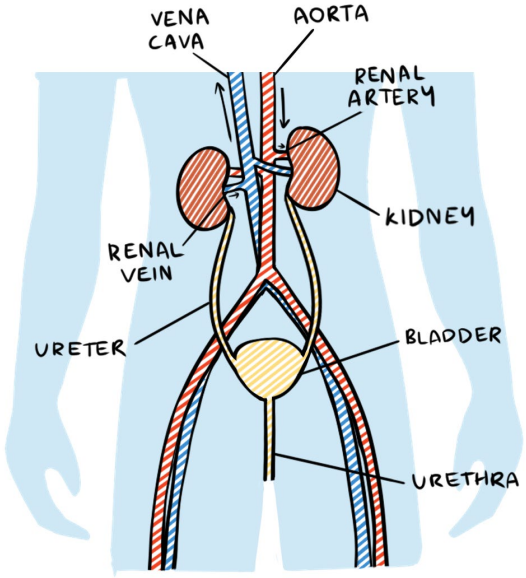
Waste Products of Metabolism

As stated previously the kidneys filter the blood to remove one of the waste products of metabolism. But what are the waste products and how are they removed?

1. **Carbon dioxide** is a product of aerobic respiration which is excreted through the lungs when we breathe out.
2. **Urea** is produced in the liver when excess amino acids are broken down. The kidneys filter it from the blood and make urine, which is stored in the bladder temporarily.

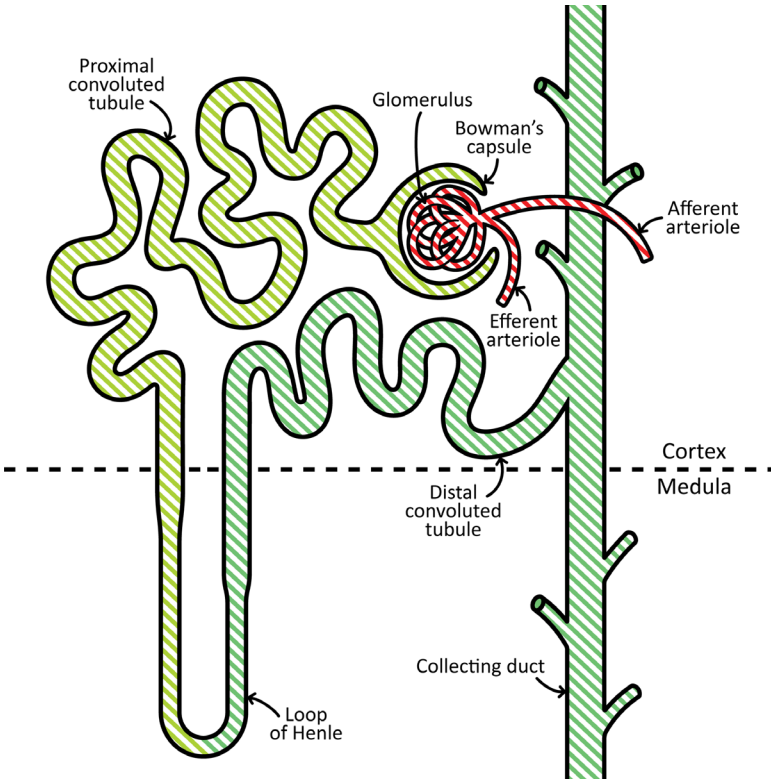
The Urinary System

Below is a diagram of the complete urinary system that comes up in the GCSEs. Please do practice labelling this as it's important to know how it's all interconnected 😊



Structure	Function
Kidney	removes urea from the blood in the process of **ultrafiltration**.
Renal artery	carries **oxygenated blood containing urea** to the kidney.
Renal vein	carries blood away from the kidney. This blood has **much less urea in it**.
Ureter	carries urine to the bladder.
Bladder	stores urine until it is released.
Urethra	allows urine to flow from the bladder out of the body.

The Kidney Nephron



What is a kidney nephron?

The nephron is where the blood is filtered to remove the toxic urea.

Also lots of useful materials, which were filtered out with the urea are reabsorbed here.

Nephrons are very small and each kidney has about 1 million of them.

For GCSE you must be able to describe how the process of **ultrafiltration** occurs within the glomerulus of the kidney nephron.

What is Ultrafiltration and how does ultrafiltration work?
Ultrafiltration: the filtration of the blood under high pressure and it occurs in the Bowman's capsule of the nephron.
How does ultrafiltration work? The pressure inside the glomerulus is very high, this forces most of the plasma out of the blood. The plasma carries the urea.
The step by step 😊
Step 1: The glomerulus is enclosed by the Bowman's capsule the first part of the nephron.
Step 2: The arteriole leading into the glomerulus is a lot wider than the arteriole leading out.
Result: there is higher blood pressure in the capillaries of the glomerulus. This pressure forces almost all plasma out of the blood by ultrafiltration.
What is not filtered out? during ultrafiltration, large molecules like proteins and whole cells like red blood cells are too big to pass through the filter, so they remain in the blood in the glomerulus." This is a common exam question.
The best analogy that we can give for how the kidney removes urea and then reabsorbs useful materials is it's like cleaning a fridge 😊.
When you clean a fridge you take everything out (the plasma) you clean it and throw away anything you don't want (ultrafiltration) and then put back the things you want (reabsorption). Hope that helps 😊

Reabsorption

The plasma that has just been removed from the blood contains large amounts of useful materials, we don't want to lose these so they must be reabsorbed. In fact, after the Bowman's capsule the rest of the nephron is all geared towards reabsorption!

The Proximal Convoluted Tubule (PCT) – its name means "the first bendy tube" 😊

What is it? The proximal convoluted tubule is the longest and widest part of the nephron. **How is it adapted for its role?** It is lined with epithelial cells containing microvilli to ensure a large surface area and numerous mitochondria to provide ATP for active transport.
What happens here? In this part of the nephron over 80% of the filtrate (including all of the glucose, most of the water, and some of the mineral ions) is reabsorbed into the tissue fluid and then to the blood. This ensures that all the "useful" materials that were filtered out of the blood (such as glucose and amino acids) are now returned to the blood. **How are Glucose, Amino Acids & Water reabsorbed?** All glucose and all amino acids are reabsorbed by **active transport** from the filtrate to the tissue fluid. They then diffuse from the tissue fluid into the blood capillaries. It's a two step process 😊 **Note**: the tissue fluid is the fluid that surrounds all cells. Cells are not surrounded by blood. Water is reabsorbed by osmosis.

Homeostasis

The Kidneys also play a key role in **osmoregulation** – the regulation of the water concentration of the blood. Before we go into osmoregulation I think it's vital to identify the hypothalamus and explain what it does.
The Hypothalamus is the region of the brain that regulates the temperature of the body as well as regulating the water concentration of the blood.

So what happens when there is too little water in the blood?
1. The hypothalamus detects the change.
2. The hypothalamus causes the pituitary gland to produce **more** antidiuretic hormone (ADH).
3. ADH travels to the kidneys via the blood stream. It then causes the collecting duct of the kidney nephron to become **more** permeable to water.
4. Therefore **more** water is reabsorbed back into the blood and **less** is lost as urine.
5. This brings the blood water concentration back to normal.

So what happens when there is too much water in the blood?
1. The hypothalamus detects the change.
2. The hypothalamus causes the pituitary gland to produce **less** antidiuretic hormone (ADH).
3. As there is now less ADH in the bloodstream, this then causes the collecting duct of the kidney nephron to become **less** permeable to water.
4. Therefore **less** water is reabsorbed back into the blood and **more** is lost as urine.
5. This brings the blood water concentration back to normal.

Exam note: You have probably noticed that there are only **four words** different between the two paragraphs 😊. This makes osmoregulation quite nice and easy to learn. If it were to come up as a 4, 5 or 6 mark question you would probably (depending on the question) need to describe what happens when there is too little **and** too much water. Make sure you read the question carefully, we can't say that enough.

Kidney disease

Glucose in the urine indicates a person has diabetes. The glucose levels in the blood of a person with diabetes are so high the kidney is unable to reabsorb it all. It can be identified using a Benedict's test.

Benedict's test
Add a few drops of Benedict's solution. The sample must be **heated**. If glucose is present a **brick red colour** will be seen. If absent then there is no colour change (solution remains blue).

Protein in the urine indicates damage in the kidney, as generally proteins in the blood are too large to pass through into the Bowman's capsule.

Biuret test
Biuret reagent is added to a sample of urine. If proteins are present then a purple or lilac colour will be seen. If absent then no colour change will be seen (solution remains blue).

Kidney failure

Damage to a kidney from accidents or disease can lead to a build-up of urea in the body. Humans can survive with one kidney, but for people who suffer from total kidney failure this would be fatal if not treated.
Treatment is available for kidney failure and can be by organ transplant or by using kidney dialysis.

Organ transplant: a patient receives a kidney from a donor.

Advantages of organ transplant:
1. Long periods of kidney **dialysis are not necessary**.
2. The person can now have an **unrestricted diet**.
3. The person can **live for longer** than a person undergoing dialysis.

Disadvantages of organ transplant:
1. The greatest risk is **organ rejection**.
2. **A major surgical operation is needed**.
3. Needing to take **drugs which suppress the immune system** for the rest of the patient's life. This could leave the patient more likely to contract other diseases and or have more complications.
4. **Risk of infection** from the operation.
5. It can also be **difficult to find a donor organ with a matching tissue type**.

Kidney Dialysis

Patients with kidney failure can be kept alive by using kidney dialysis until a transplant becomes available.

Advantages of kidney dialysis:

1. **It does not involve a major surgical operation**.
2. It can **keep a patient alive and healthy** while he or she is **waiting for a suitable donor to be found**.

Disadvantages of kidney dialysis:

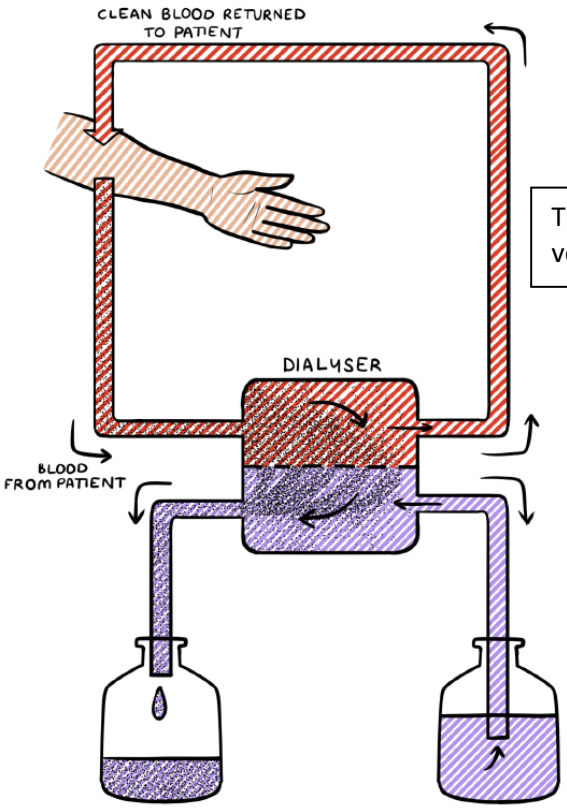
1. Patients need to **spend many hours every week attached to a dialysis machine**.
2. Patients **need to follow a carefully controlled diet**.
3. **Dialysis machines and dialysis fluid are both expensive**.

How Dialysis Works

Note: dialysis uses diffusion to remove urea and excess salts from the blood into the dialysis fluid.

Diffusion: the movement of a substance from an area of high concentration to an area of low concentration. Moving down its concentration gradient.

Unfiltered blood that is high in urea is taken from a blood vessel in the arm, mixed with blood thinners or an anti-coagulant to prevent clotting, and pumped into the dialysis machine.



This diagram shows a very simplified version of how kidney dialysis works.

1. The blood is removed from the patient and flows into the dialyser where it is kept separated from dialysis fluid by a **partially permeable membrane**.
2. The dialysis fluid contains the same concentration of glucose and a normal, healthy concentration of salts. This ensures that useful glucose does not diffuse out of the blood. It also means that **only excess salts** from the patient's blood will diffuse into the fluid, down their concentration gradient.
3. **The dialysis fluid contains no urea**, so the urea diffuses from the blood in to the dialysis fluid from the high concentration in the blood to the lower concentration in the dialysis fluid.
4. The blood and dialysis fluid move in opposite directions across the membrane (**a counter current system**) in order to maintain a steep concentration gradient along the whole tube.
5. The clean blood is returned to the patient and the waste dialysis fluid is disposed of.

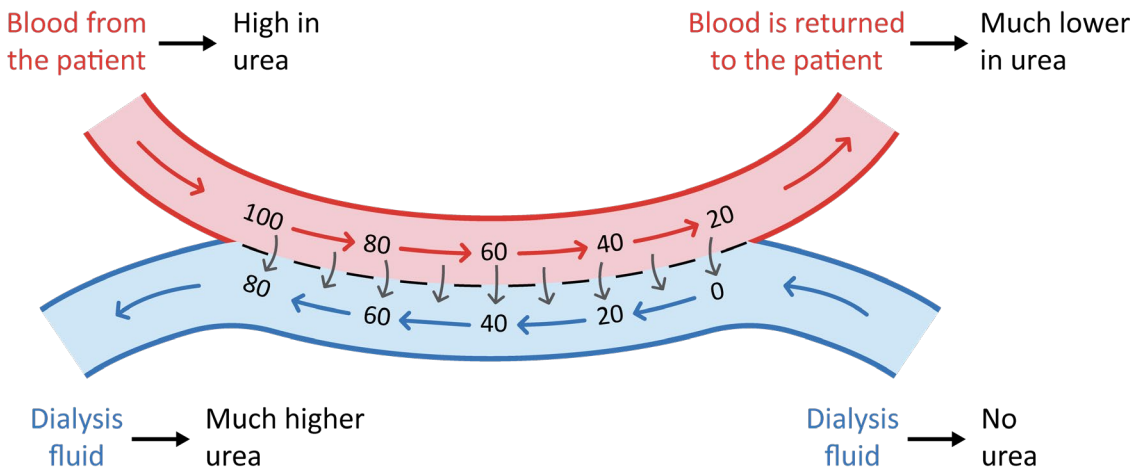
A Counter Current System

In the previous section we mentioned that dialysis works using a **counter current system**. But what is a counter system and what does it do? Before we go on, it should be stated that counter current systems are only **mentioned** at GCSE and not really explained. We have included them here just explain how they work but we **don't need it** for the exams.

A counter current system: a system when two fluids flow in opposite directions to each other across a partially permeable membrane.

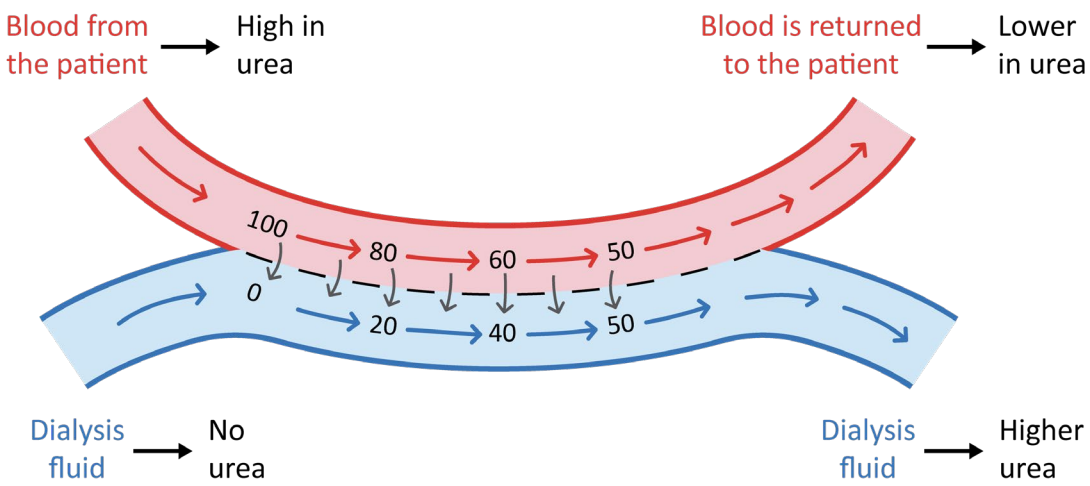
What does this system do? It maintains a steep concentration gradient along the entire length of the exchange surface, which maximises the rate of diffusion.

How does this work in a dialysis machine? As mentioned above the point of it is to maintain a concentration gradient across the whole exchange surface. The figure below shows the effect of the counter current system on the concentration of urea inside a dialysis machine.



We can see in the figure above, a concentration gradient has allowed diffusion of urea to take place over the entire surface of the partially permeable membrane.

What would happen if we didn't use a counter current system in dialysis? Well, diffusion of urea would still take place. **BUT!** The concentration gradient would not be maintained across the whole surface so diffusion of urea would effectively stop at some point on the partially permeable membrane.
The figure below shows the effect of both fluids moving parallel to each other in the same direction.



We can clearly see here that the concentration gradient is not maintained when the fluids are not using the counter current system. So we just wouldn't do this. We would use a counter current system which would maximise the efficiency of diffusion across the whole exchange surface. That's that 😊