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EB Education Revision Guide

How to work with Homeostasis: Part 3
Osmoregulation

...helping everybody achieve Even Better

What you need to know about Homeostasis: Part 3

- Osmoregulation

a) Why your body regulates water levels
b) How your body detects changes in water levels
c) How your body controls water levels
d) What happens if the kidneys do not work

Osmoregulation

Why?

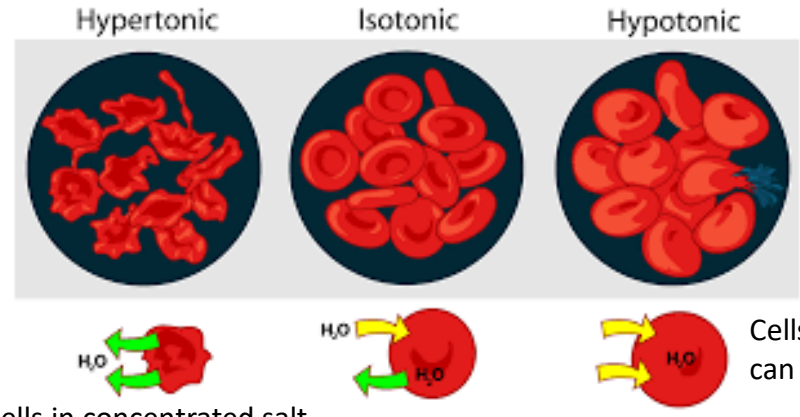
Controlling the water content in your blood is known as osmoregulation.

The water content of your blood needs to be controlled for your cells to function normally.

If the concentration of water in the blood is too high, then water can move into cells by OSMOSIS. They can burst if too much water moves into them (lysis).

If the concentration of water is too low then water will move out of cells and into the blood, causing cells to shrink (crenation).

The kidneys control the water content of the blood.



Cells in concentrated salt solution– can shrink and shrivel

Cells in distilled water – can swell and burst

TOP TIP

Plant cells do not burst when they contain too much water as the rigid cell wall prevents them bursting. They will swell and become turgid, helping to support the plant.

Hormonal Control

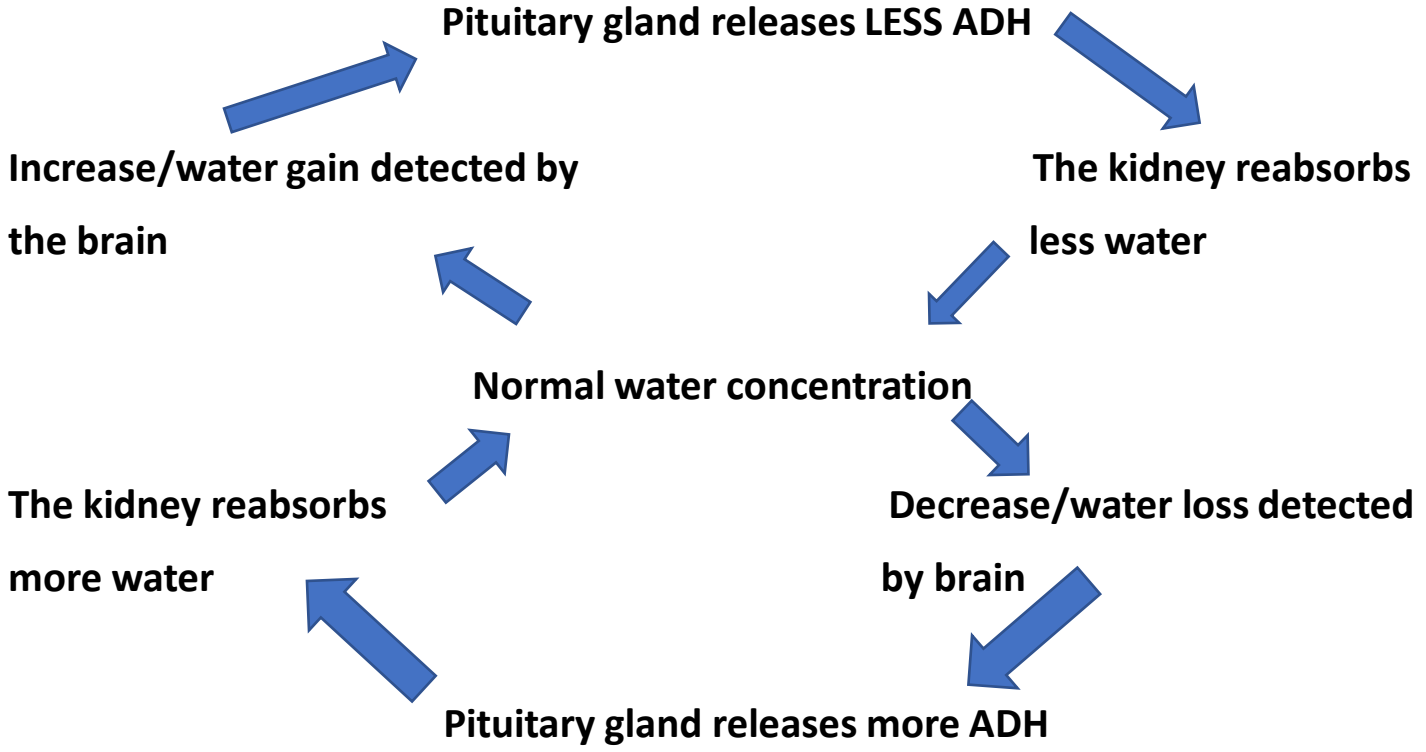
How does the body respond?

The brain monitors the water content of the blood. It instructs the PITUITARY GLAND to release ADH (Anti-diuretic hormone) into the blood. How much ADH is released depends on how much water needs to be reabsorbed into the blood.

ADH works by making the COLLECTING DUCTS in the NEPHRONS of the kidneys more permeable, so more water is reabsorbed into the blood. This prevents dehydration.

How the kidneys work will be covered in later slides.

It is a negative feedback system.



Hormonal Control

Beyond GCSE

The water potential of the blood is monitored by OSMORECEPTORS in the HYPOTHALAMUS.

Dehydrated:

When the water potential decreases, water moves out of the osmoreceptor cells by osmosis causing the cells to decrease in volume. This sends a signal to other cells in the hypothalamus, which send a signal to the POSTERIOR PITUITARY GLAND.

The posterior pituitary gland releases ADH (anti-diuretic hormone) into the blood.

ADH increases the permeability of the DISTAL CONVOLUTED TUBULE and the COLLECTING DUCT.

More water is reabsorbed into the MEDULLA and the blood by osmosis.

A small volume of concentrated urine is produced, meaning the body loses less water.

Hydrated:

If you have taken in a lot of water, the water potential of the blood will rise.

This is detected by osmoreceptor cells in the hypothalamus– and the posterior pituitary gland will release less ADH into the blood.

Less ADH means the distal convoluted tubule and the collecting duct become less permeable, so less water is reabsorbed.

A large volume of dilute urine is produced, meaning more water is lost from the body.

The Kidneys

What do they do?

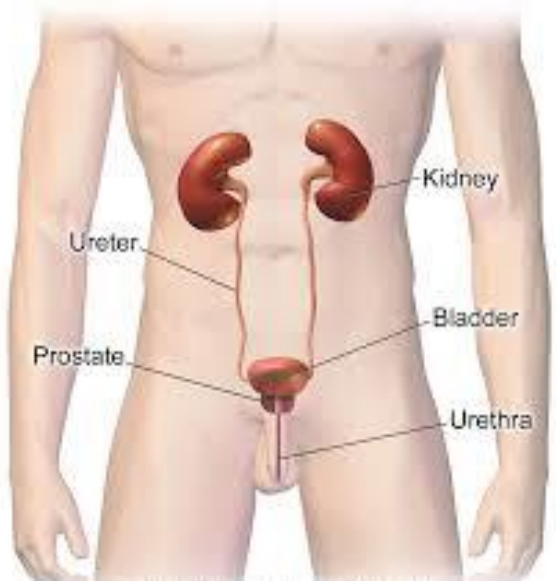
The kidneys have three main jobs:

1. They remove UREA from the blood. Urea is made in the liver, when excess amino acids are broken down
2. They maintain the ion levels in the blood
3. They maintain the water content of the blood

The kidneys work by filtering materials out of the blood under high pressure.

They then reabsorb useful materials – and the rest is excreted from the body in urine.

The kidneys



Osmoregulation

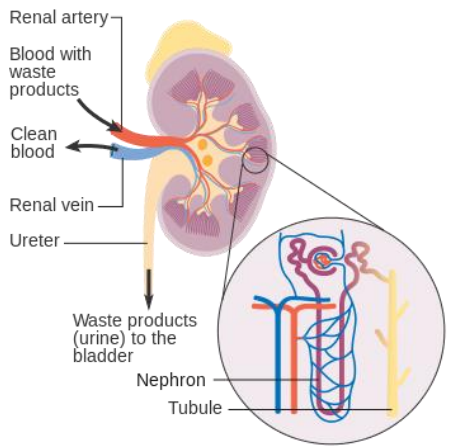
How do they work?

The kidneys are full of NEPHRONS. This is where filtration happens.

In each nephron:

1. Ultrafiltration

The liquid part of the blood, which contains water, urea, ions and glucose is forced out of the GLOMERULUS and into the BOWMAN'S CAPSULE at high pressure. Large molecules like blood cells and proteins are too big to pass through the membranes, and so they remain in the blood.



2. Reabsorption

The filtrate then flows along the nephron, where useful substances are reabsorbed.

ALL glucose is SELECTIVELY REABSORBED. It is moved back into the blood against the concentration gradient.

As many ions as needed are reabsorbed.

As much water as needed is reabsorbed, how much is controlled by the levels of ADH in the blood.

3. Excretion

The remainder (urea, excess water, excess ions) leave the nephron via the collecting duct. It all moves into the URETER, and is then stored in the BLADDER as urine.

Urine is removed from the body through the URETHRA.

Osmoregulation

ULTRAFILTRATION HAPPENS HERE

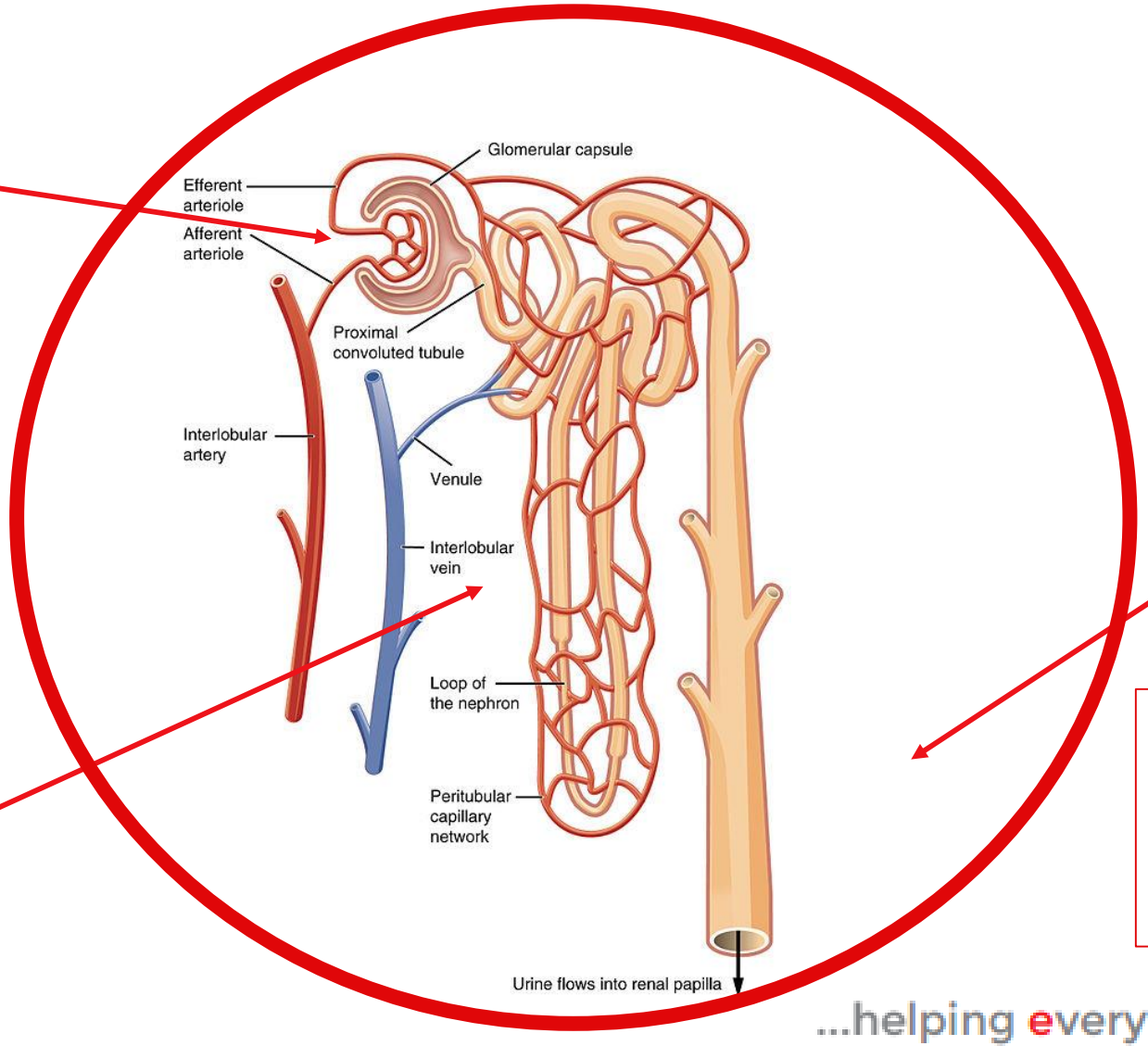
Remaining in blood:
Blood cells/proteins

Entering the nephron:
Water, glucose, urea ions

REABSORPTION HAPPENS HERE

Reabsorbed:
All glucose, some ions and some water

Remaining:
Urea, some ions, some water



EXCRETION

The remaining substances pass out of the collecting duct and pass via the ureter into the bladder, before being excreted in urine.

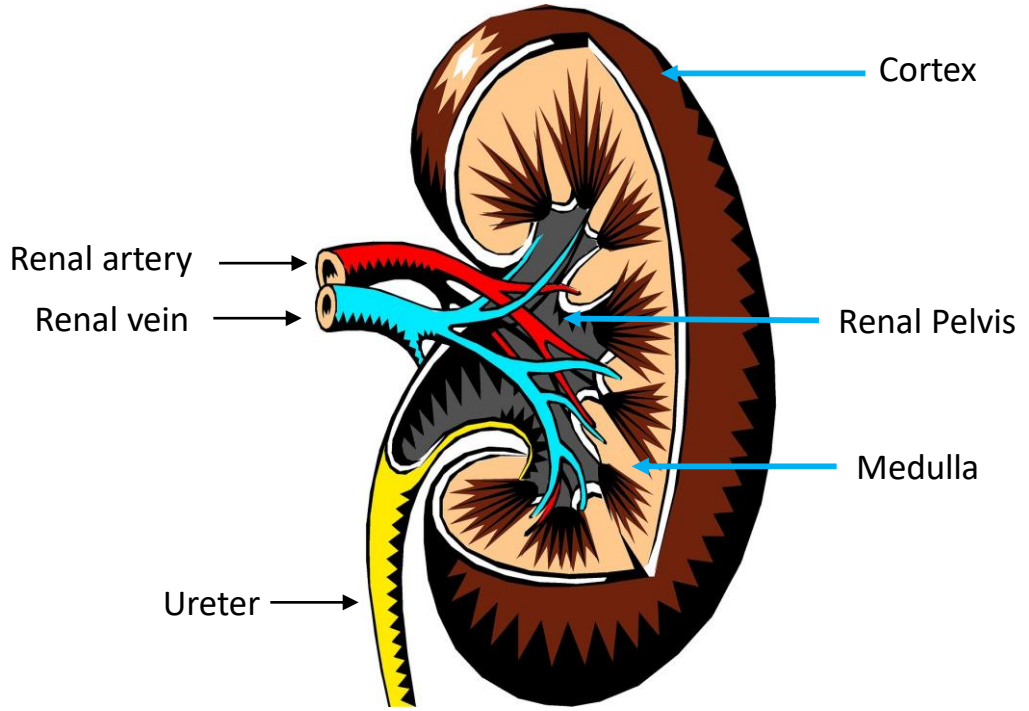
TOP TIP:
Animals living in drought conditions have longer loops of Henle. This means they can reabsorb more water.

Osmoregulation

Beyond GCSE

Kidneys are made up of about a million nephrons.
The **nephrons** spread across the cortex and medulla of the kidney.
Blood enters the organ via the renal artery and exits via the renal vein.

In between, it passes through tiny capillaries that surround the continuous tube constituting the nephron.



Osmoregulation

Beyond GCSE

Structure of nephrons

Each nephron is made of four functional parts.

- **Bowman's capsule**

Ultrafiltration unit
Filters blood
Separates large particles from small particles

- **Proximal tubule**

Involved in selective reabsorption
Re-absorbs valuable substances, such as glucose

- **Loop of Henle**

Creates low water potential in the medulla
Allows water to be reabsorbed

- **Distal tubule (leading to a collecting duct)**

Involved in osmoregulation
Varies the amount of water reabsorbed into the blood

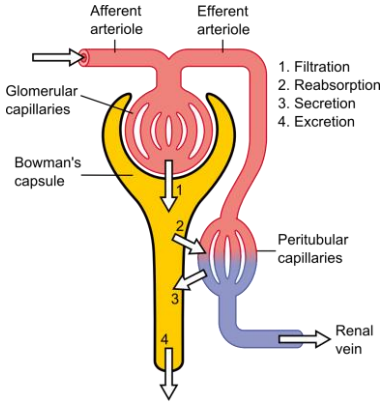
- **Collecting Duct**

Involved in osmoregulation

Blood Vessels

Glomerulus
The site of filtration. Tight, knot-like, high pressure bundle of capillaries
Afferent arteriole
Wider diameter than the efferent arteriole. Brings blood from the renal artery and passes through the glomerulus
Efferent arteriole
Narrower vessel that restricts blood flow and raises blood pressure.
Carries blood from the glomerulus to two capillary networks (one to proximal/distal convoluted tubules, and one to Loop of Henle)
Peri-tubular capillaries
Low pressure capillary bed which runs around the convoluted tubules and absorbs fluid from them
Vasa Recta
Un-branched capillaries which are similar in shape to the Loop of Henle
Descending limb carries blood deep into the medulla
Ascending limb brings blood back to the cortex

Osmoregulation Ultrafiltration



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Route through the nephrons

1) Blood enters afferent arterioles in the cortex of kidney from the renal artery

2)The arterioles split into the glomerulus, which sits inside the Bowman's capsule

3) Efferent arteriole takes filtered blood away from the glomerulus

4) Liquid and small molecules pass through 3 layers (capillary wall, basement membrane and epithelium of Bowman's capsule) into the Bowman's capsule and enter the nephron tubules. This is known as the glomerular filtrate. Specialised cells called podocytes wrap around capillaries of the glomerulus. They have finger like projections called processes that ensure gaps between cells and increase surface area.

5) The filtrate passes along the rest of the nephron

6)The filtrate then flows through the collecting duct and passes out of the kidney along the ureter

What is happening?

Ultrafiltration takes place in the glomerulus.

Efferent arterioles are smaller than afferent arterioles so the blood in the glomerulus is under high pressure

High pressure forces liquid and small molecules in the blood out of the capillary and into the Bowman's capsule.

Large molecules (proteins/blood cells) cannot pass through so remain in the blood

Useful substances are reabsorbed

Osmoregulation
Reabsorption

Beyond GCSE

Selective Reabsorption

The glomerular filtrate now flows along the proximal convoluted tubule (PCT), through the loop of Henle, and along the distal convoluted tubule (DCT).

Selective reabsorption takes place

Useful substances move into the capillary network that is wrapped around the nephrons.

The epithelium of the wall of the PCT has microvilli to provide a large surface area.

Useful solutes such as glucose are reabsorbed along the PCT by active transport, facilitated diffusion and co-transport.

The water potential of the blood is lower than the filtrate so water enters the blood by osmosis. Water is reabsorbed from the PCT, loop of Henle, DCT and collecting duct.

The filtrate that leaves the collecting duct is urine

This moves along the ureter to the bladder

TOP TIP:
Urine contains: WATER, UREA, DISSOLVED SALTS, EXCESS VITAMINS, HORMONES
Urine should not contain: PROTEINS, BLOOD CELLS, GLUCOSE

Osmoregulation

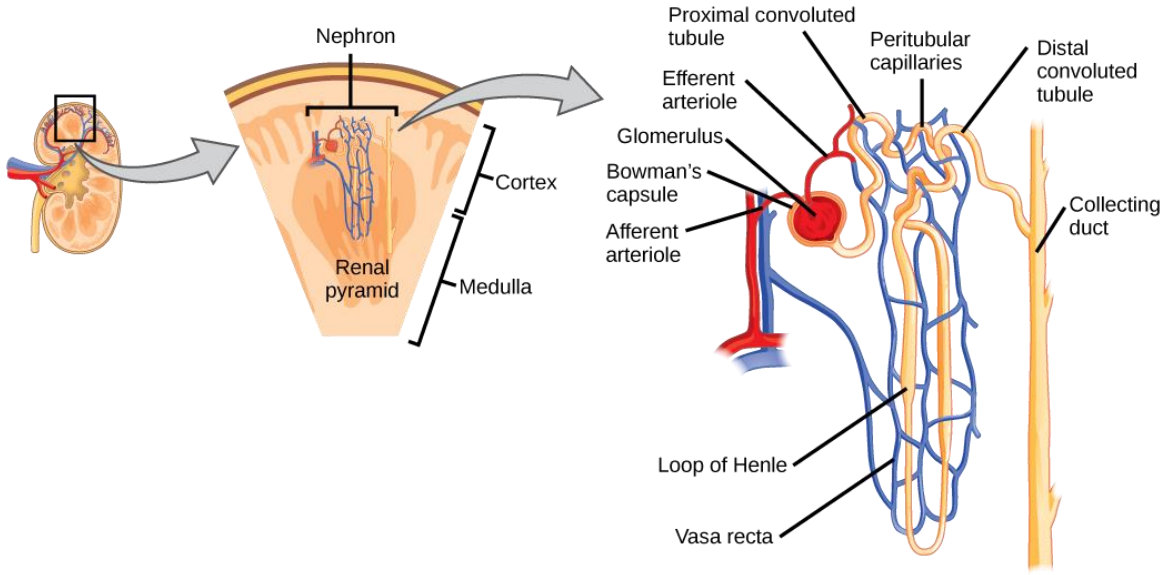
Beyond GCSE

Regulating Water Potential

This mostly takes place in the loop of Henle, DCT and collecting duct.

The volume of water reabsorbed by the DCT and collecting duct is controlled by ADH (see previous slides).

The loop of Henle is found in the medulla, and has a descending limb and an ascending limb. These control the movement of sodium ions, so that water can be reabsorbed into the blood by osmosis.



Osmoregulation

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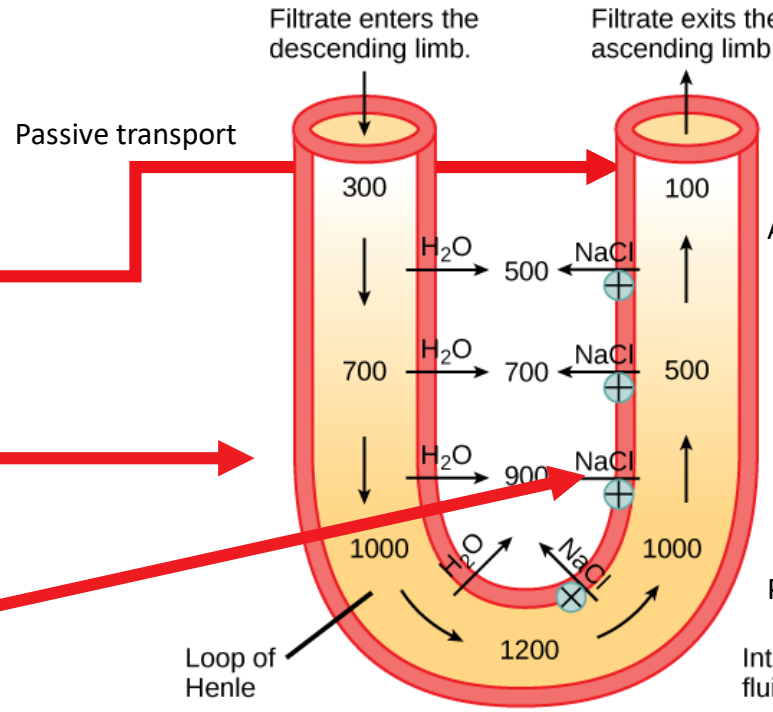
1) The ascending limb in IMPERMEABLE to water. Na^+ ions are pumped out of here into the medulla by diffusion (at the base) and active transport (higher up). Water stays inside the limb, thus creating a low water potential in the medulla due to the high concentration of ions.

2) As there is now a lower water potential in the medulla, water moves out of the descending limb which is PERMEABLE to water and into the medulla by osmosis. The filtrate becomes more concentrated (as ions cannot diffuse out in the descending limb). Water is reabsorbed into the blood.

3) Na+ ions diffuse out of the ascending limb near the bottom into the medulla. This lowers the water potential even more. Water remains in the ascending limb as it cannot move out.

4) In the distal convoluted tubule water will move out by osmosis and is reabsorbed into the blood.

5) In the collecting duct, water will also move out by osmosis. This is because the ion concentration in the medulla has been increased during previous stages, lowering the water potential.



Descending limb is highly permeable to water but impermeable to solutes

Ascending limb is nearly impermeable to water but highly permeable to Na^+ and Cl^-

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Kidney Failure

How can it be treated?

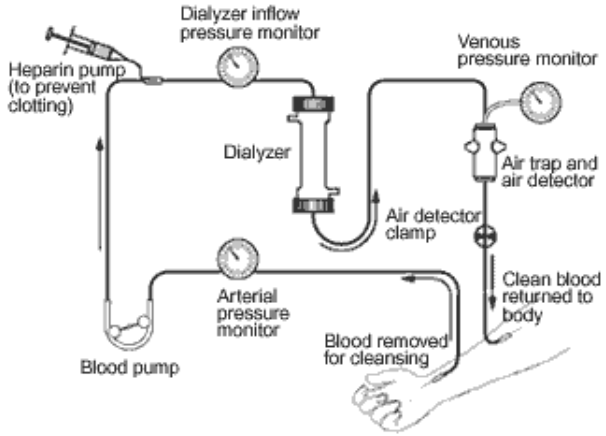
If a person has kidney failure, they are unable to filter their blood.

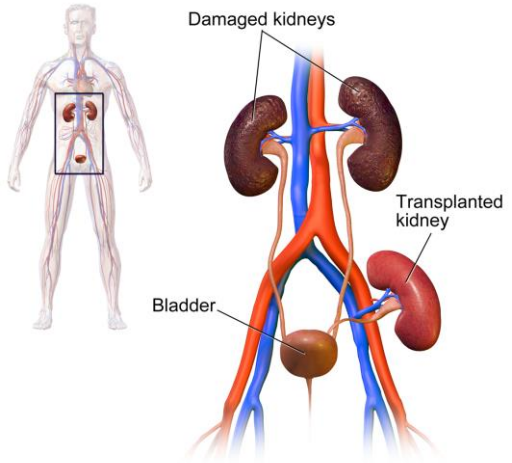
Kidney failure has serious consequences as it means that the water and ion balance cannot be regulated, and the levels of toxic urea build up in the body. This would ultimately be fatal if not treated

There are 2 possible treatments:

- Dialysis

- Kidney Transplant





Kidney Transplant

Kidney Failure

Dialysis

In this procedure, patients are connected to a dialysis machine which acts as an artificial kidney to remove most of the urea and restore/maintain the water and ion balance of the blood.

'Dirty' blood (high in urea) is taken from a blood vessel in the arm, mixed with blood thinners to prevent clotting, and pumped into the machine.

Inside the machine - separated by a partially permeable membrane the blood flows in the opposite direction to dialysis fluid, allowing exchange to occur between the two where a concentration gradient exists.

Dialysis fluid has the same concentration of salts and glucose as blood plasma and no urea. This means glucose is not removed from the blood, ions only move if there is an imbalance and urea will diffuse from the blood into the fluid.

Large molecules cannot move through the membrane.

Kidney dialysis requires highly specialised and expensive machinery. The patient must be connected to this machinery 2-3 times a week for periods (on average) of between 4-6 hours at a time.

Diet must be monitored carefully in between dialysis sessions, avoiding foods with high salt and high protein as excess amino acids are broken down into urea.

Kidney Failure

Kidney Transplants

This is the only cure for kidney failure.

The patient will receive a healthy kidney from either someone who has died, and are on the organ donor register, or from a living donor.

The donor kidney could be rejected by the patient's immune system, which may attack it with antibodies.

- The donor kidney must have a tissue type that closely matches the patient's
- The patient must take immunosuppressant drugs to stop the immune system attacking the transplanted kidney
- There may be a long waiting list to received a donor kidney

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Your turn:

1. Diabetes insipidus results in people being unable to produce sufficient ADH.

A medical study was undertaken, where the ADH levels in the blood of 10 people was measured.

The table below shows the results. Half of the patients have diabetes insipidus, and half do not.

People with diabetes insipidus	ADH level in blood/µg per dm^3
A	0.2
B	0.2
C	0.0
D	0.1
E	0.1
Mean ADH Level	

People without diabetes insipidus	ADH level in blood/µg per dm^3
F	5.3
G	2.6
H	4.7
I	3.5
J	2.4
Mean ADH Level	

a) Calculate the mean ADH levels for people with and without diabetes insipidus.

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b) Suggest a possible reason for the wide range of ADH levels in people who do not suffer from diabetes insipidus.

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c) Where is ADH released from?

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d) What symptoms could diabetes insipidus cause?

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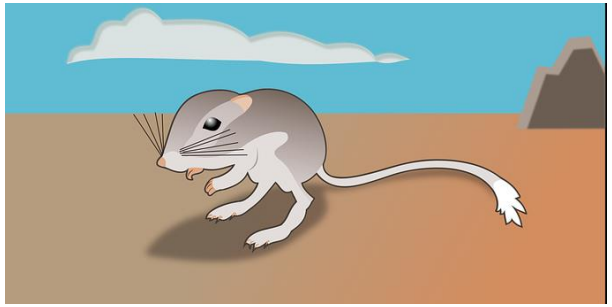
e) Explain how ADH regulates the water content of the blood. (6)

Your turn:

2. The cartoon below shows a kangaroo rat. These mammals survive in desert conditions. This means their bodies can cope with higher concentrations of sodium ions in their blood than humans can.



a) What is the name of the process that controls water levels in the body?

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b) The loop of Henle in the kangaroo rat is longer than it is in most mammals.
Explain why this is of benefit to the kangaroo rat.

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c) Blood entering the nephron of the rat is filtered to remove excess water and sodium ions.
Explain how this happens.

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Your turn:

d) The table below shows the average volume of ADH which is stored in the pituitary gland of 1000 kangaroo rats.
The higher the volume of ADH stored in the pituitary gland, the lower the volume in the blood.

Concentration of NaCl (salt) fed to rats (mol dm^{-3})	Volume of ADH stored in pituitary gland (dm^3)
0.00	48
0.30	37
0.60	9
0.80	7
1.00	7

Explain, in as much detail as you can, how ADH contributes towards controlling the levels of water and sodium ions in the blood. (6)

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Your turn:

3. The concentration of substances in the blood is controlled by the kidneys.

a) Explain why glucose is present in the blood, but is not excreted in urine in healthy people.

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The table below compares the concentration of different substances found in the urine of healthy and unhealthy individuals.

Substance	Concentration in g/dm^3	
	Healthy person	Person with kidney disease
Glucose	0	0
Amino acids	0	0
Protein	0	7
Mineral Ions	17	17
Urea	23	23

b) Suggest what could be causing the difference in the composition of urine in the healthy individual and the individual with kidney disease.

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c) Kidney disease can be treated using a dialysis machine or by a kidney transplant.
Use your knowledge and understanding to compare the advantages and disadvantages of these two treatments. (6)

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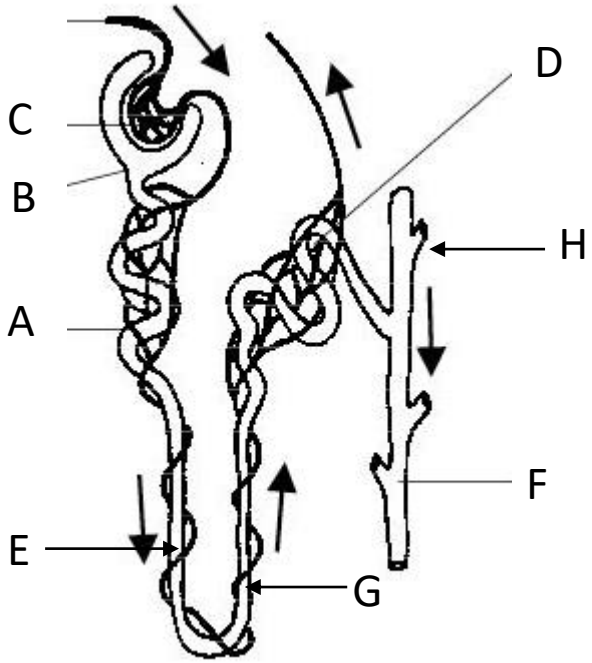
Your turn:

Beyond GCSE:



1. Identify from the diagram

The region/regions which are present in the cortex

……

The region/regions where glucose is selectively reabsorbed into the blood

……

The region/regions where podocytes are found

……

b) *Dipodomys deserti*, the kangaroo rat lives in the desert, and endures hot and dry conditions. Relative to its size, it only excretes very small volumes of urine.
The kangaroo rat has a longer loop of Henle than other mammals of a similar size that live in different conditions.
Explain how this adaptation helps the desert kangaroo rat survive.

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Your turn:

Beyond GCSE

2. Blood is filtered as it passes through the kidney, and the urine formed in the nephron leaves the kidney through the ureter.

The table below shows the concentration of some of the components of blood, glomerular filtrate and urine.

Component	Blood (g $100cm^{-3}$)	Glomerular filtrate (g $100cm^{-3}$)	Urine (g $100cm^{-3}$)
Urea	0.02	0.02	1.70
Glucose	0.11	0.11	0.00
Amino acids	0.04	0.04	0.00
Large proteins	7.00	0.00	0.00
Inorganic ions	0.85	0.85	Up to 3.50

The table below shows the presence or absence of erythrocytes in blood, glomerular filtrate and urine.

Component	Blood	Glomerular filtrate	Urine
Erthrocytes	present	absent	absent

Using both tables, explain the changes in fluid composition. Include appropriate technical terms in your answer.

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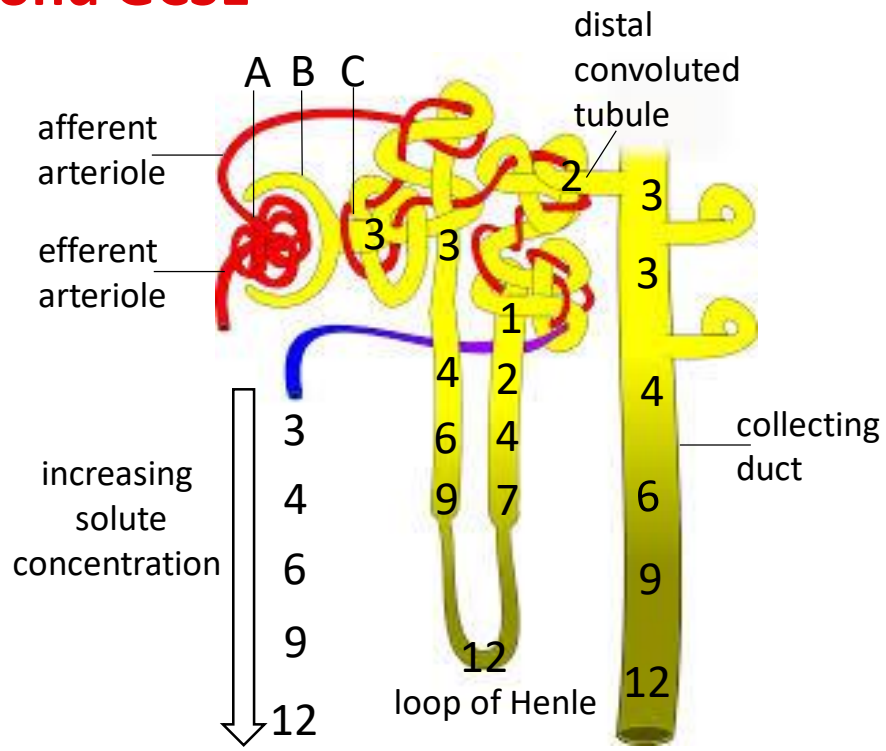
Your turn:

Beyond GCSE



3. The kidney is composed of many nephrons. Above is a diagram of a nephron. The numbers indicate the relative concentrations of solutes in the tubule and the tissue fluid which surrounds the tubule.

a) Name the parts of the nephron labelled A, B and C.

A.....

B.....

C.....

b) Complete the table below.

Statement	Part(s) of the nephron
Glucose is reabsorbed into the blood	
Walls are impermeable to water	
Contains podocytes	
Most of the water is reabsorbed into the blood	
ADH acts on the walls	

c) Explain the role of the loop of Henle in the production of urine. Use appropriate technical terms in your answer.

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Answers:

1. Diabetes insipidus results in people being unable to produce sufficient ADH.

A medical study was undertaken, where the ADH levels in the blood of 10 people was measured.

The table below shows the results. Half of the patients have diabetes insipidus, and half do not.

People with diabetes insipidus	ADH level in blood/µg per dm^3
A	0.2
B	0.2
C	0.0
D	0.1
E	0.1
Mean ADH Level	0.12

People without diabetes insipidus	ADH level in blood/µg per dm^3
F	5.3
G	2.6
H	4.7
I	3.5
J	2.4
Mean ADH Level	3.7

a) Calculate the mean ADH levels for people with and without diabetes insipidus.

People with: 0.2 +0.2 + 0.0 +0.1 +0.1 = 0.6/5 = 0.12

People without: 5.3 + 2.6 +4.7 + 3.5 + 2.4 = 18.5/5 = 3.7

b) Suggest a possible reason for the wide range of ADH levels in people who do not suffer from diabetes insipidus.

Variation in salt intake and hydration levels/drug taking/differences in body size/variation between people

c) Where is ADH released from?

Pituitary gland

d) What symptoms could diabetes insipidus cause?

Dehydration, thirst, increased urine volume, frequent urination, dilute urine

Answers

e) Explain how ADH regulates the water content of the blood. (6)

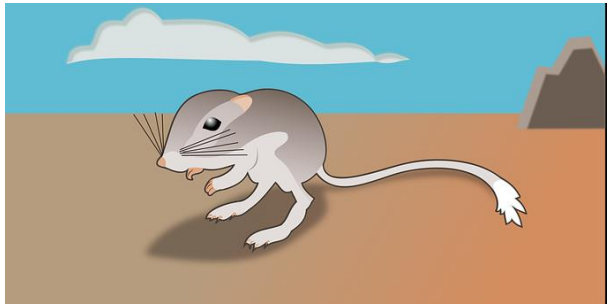
It is an example of negative feedback.

Hydration:
Increased water or decreased salt levels in the blood are detected by the hypothalamus.
The pituitary gland decreases the release of ADH
This in turn decreases the permeability of the collecting ducts/tubules/nephrons.
Consequently less water is reabsorbed.
This results in an increased volume of urine and the water content of the blood decreases

Dehydration:
Decreased water or increased salt levels in the blood are detected by the hypothalamus.
The pituitary gland increases the release of ADH.
This in turn increases the permeability of the collecting ducts/tubules/nephron.
Consequently more water is reabsorbed.
This results in a decreased volume of urine and the water content of the blood increases

Answers:

2. The cartoon below shows a kangaroo rat. These mammals survive in desert conditions. This means their bodies can cope with higher concentrations of sodium ions in their blood than humans can.



a) What is the name of the process that controls water levels in the body?

Osmoregulation

b) The loop of Henle in the kangaroo rat is longer than it is in most mammals.
Explain why this is of benefit to the kangaroo rat.

As the rat lives in the desert it needs to retain as much water as possible. A longer loop of Henle will allow more water to be reabsorbed, because water is reabsorbed from the loop of Henle.

c) Blood entering the nephron of the rat is filtered to remove excess water and sodium ions.
Explain how this happens.

Ultrafiltration happens in the glomerulus. The liquid part of the blood and small molecules pass into the Bowman's capsule. Water is reabsorbed in the convoluted tubules and loop of Henle. Urine production takes place in the collecting duct and excess water and sodium ions are removed.

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Answers:

d) The table below shows the average volume of ADH which is stored in the pituitary gland of 1000 kangaroo rats. The higher the volume of ADH stored in the pituitary gland, the lower the volume in the blood.

Concentration of NaCl (salt) fed to rats (mol dm^{-3})	Volume of ADH stored in pituitary gland (dm^3)
0.00	48
0.30	37
0.60	9
0.80	7
1.00	7

Explain, in as much detail as you can, how ADH contributes towards controlling the levels of water and sodium ions in the blood. (6)

Water content:
Increased ADH levels result in more water being reabsorbed into the blood. This will prevent dehydration.
Decreased ADH causes less water to be reabsorbed, and a greater volume of urine to be produced.
At 0.0mol dm^{-3} of sodium ions the volume of ADH stored in the pituitary gland is highest so the lowest amount of ADH is released, and less water is reabsorbed.

Sodium ions:
As sodium ion concentration increases the levels of ADH stored decrease.
At 0.30 mol dm^{-3} ADH stored reduced by 11, so a small amount of water is reabsorbed.
At 0.60 mol dm^{-3} ADH stored reduced by a further 28 so a greater amount of water is reabsorbed.
The volume of ADH stored remains stable at 7 causing the maximum amount of water to be reabsorbed, preventing dehydration when sodium levels are high.

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Answers:

3. The concentration of substances in the blood is controlled by the kidneys.

a) Explain why glucose is present in the blood but is not excreted in urine in healthy people.

Glucose is filtered out of the blood

All the filtered glucose is then taken back into the blood / reabsorbed by active transport.

The table below compares the concentration of different substances found in the urine of healthy and unhealthy individuals.

Substance	Concentration in g/dm^3	
	Healthy person	Person with kidney disease
Glucose	0	0
Amino acids	0	0
Protein	0	7
Mineral Ions	17	17
Urea	23	23

b) Suggest what could be causing the difference in the composition of urine in the healthy individual and the individual with kidney disease.

In a healthy person protein is not present because proteins are too large to pass through into the urine. The protein remains in the blood.

In a person with kidney disease the 'filter' allows protein through.

c) Kidney disease can be treated using a dialysis machine or by a kidney transplant.

Use your knowledge and understanding to compare the advantages and disadvantages of these two treatments. (6)

advantages of transplant over dialysis

- no build-up of toxins / keeps blood concentration constant
- prevents high blood pressure
- restricted diet or fluid intake is not needed or time wasted on dialysis
- blood clots or infection may result from dialysis
- with dialysis, blood may not clot properly due to anti-clotting drugs
- dialysis is more expensive

disadvantages of transplant over dialysis

- rejection / problem finding tissue match
- need to use immuno-suppressant drugs which could lead to other infections
- there are dangers during operations

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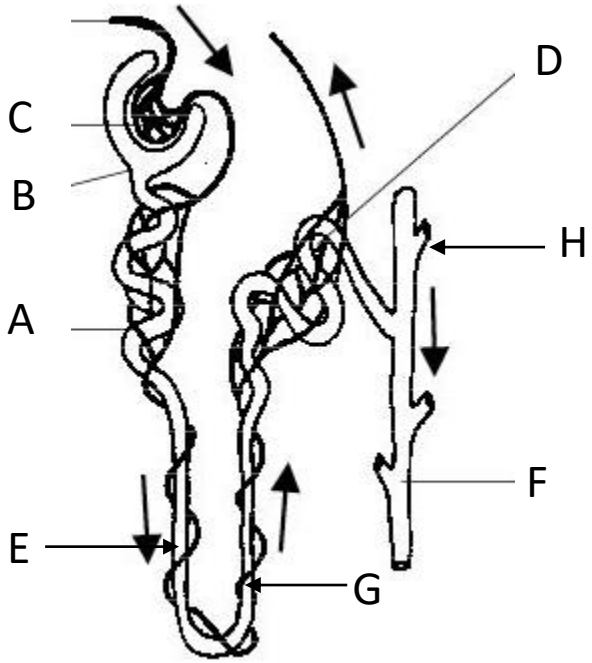
Answers:

Beyond GCSE:



1. a) Identify from the diagram:

The region/regions which are present in the cortex

A, B, C, D, H

The region/regions where glucose is selectively reabsorbed into the blood

A

The region/regions where podocytes are found

B or C

b) *Dipodomys deserti*, the kangaroo rat lives in the desert, and endures hot and dry conditions. Relative to its size, it only excretes very small volumes of urine.
The kangaroo rat has a longer loop of Henle than other mammals of a similar size that live in different conditions.
Explain how this adaptation helps the desert kangaroo rat survive.

More sodium and chloride ions are pumped out of ascending limb into medulla. This builds up a greater water potential gradient allowing reabsorption of more water.

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Answers:

Beyond GCSE

2. Blood is filtered as it passes through the kidney, and the urine formed in the nephron leaves the kidney through the ureter.

The table below shows the concentration of some of the components of blood, glomerular filtrate and urine.

Component	Blood (g $100cm^{-3}$)	Glomerular filtrate (g $100cm^{-3}$)	Urine (g $100cm^{-3}$)
Urea	0.02	0.02	1.70
Glucose	0.11	0.11	0.00
Amino acids	0.04	0.04	0.00
Large proteins	7.00	0.00	0.00
Inorganic ions	0.85	0.85	Up to 3.50

The table below shows the presence or absence of erythrocytes in blood, glomerular filtrate and urine.

Component	Blood	Glomerular filtrate	Urine
Erythrocytes	present	absent	absent

Using both tables, explain the changes in fluid composition.
Include appropriate technical terms in your answer.

Large molecules/proteins/blood cells cannot leave the blood. Small molecules can (glucose, amino acids, urea).
The endothelium/basement membrane prevents the large molecules reaching the Bowman's capsule so they remain in the blood.
All glucose is reabsorbed at the PCT
All amino acids reabsorbed at the PCT
Some ions are reabsorbed into the blood
Urea and ion concentration increases between filtrate and urine because urea and ions are moved into the tubule and water is removed.

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Answers:

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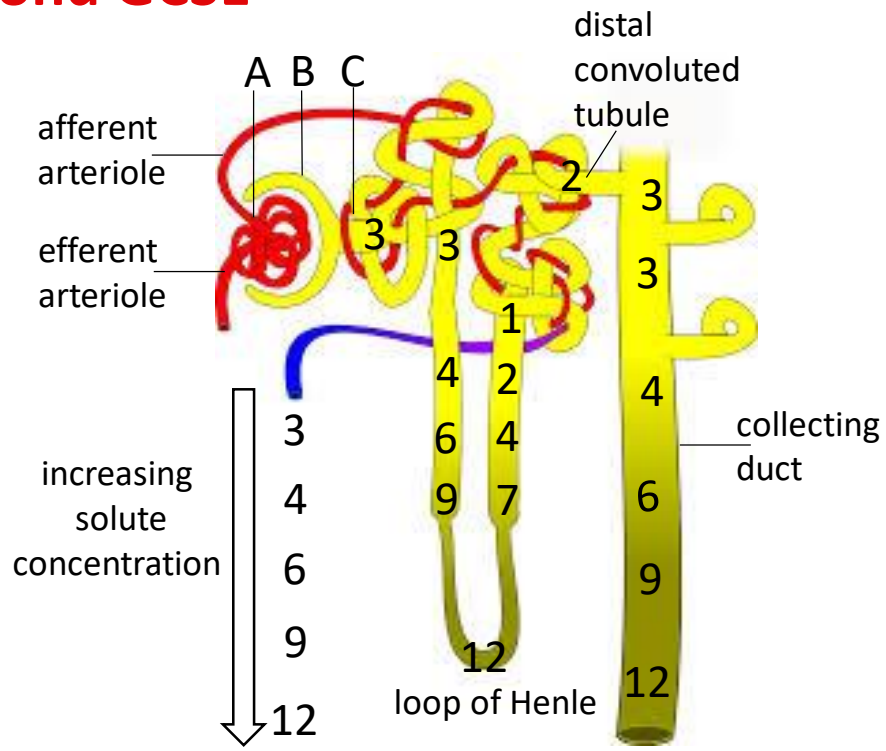

3. The kidney is composed of many nephrons. Above is a diagram of a nephron. The numbers indicate the relative concentrations of solutes in the tubule and the tissue fluid which surrounds the tubule.

a) Name the parts of the nephron labelled A, B and C.

A Glomerulus

B Bowman's capsule

C Proximal convoluted tubule

b) Complete the table below.

Statement	Part(s) of the nephron
Glucose is reabsorbed into the blood	Proximal convoluted tubule
Walls are impermeable to water	Ascending limb of Loop of Henle
Contains podocytes	Bowman's capsule
Most of the water is reabsorbed into the blood	Proximal convoluted tubule
ADH acts on the walls	Collecting duct/distal convoluted tubule

Answers:

Beyond GCSE

c) Explain the role of the loop of Henle in the production of urine.
Use appropriate technical terms in your answer.

The loop of Henle causes a decrease in water potential in the medulla.
In the ascending limb there is active transport of sodium and chloride ions into the medulla decreasing the water potential in the medulla.
The walls of the descending limb are permeable to water, so water travels out of the descending limb by osmosis.
The water potential of tissues surrounding the collecting duct is lower than the fluid inside it, so water is removed from the filtrate in the collecting duct.

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