F 6 Biology: Ch 23 - Osmoregulation & Excretion

Name:__________________________________( )

23.1 Introduction

Animals living under terrestrial conditions tend to lose water by evaporation. Those living in surroundings more concentrated than their tissue fluid lose water by *osmosis*. Animals in a dilute environment have to face the problem of water flooding into the body by osmosis. Both problems have led to structural and physiological adaptations in order to maintain the balance of water & solutes.

Excretion is the process by which waste products of the organism's metabolism are eliminated from the body.

Secretion is the production by the cells substances useful to the body.

Egestion is the removal of undigested food & other substances which have never been involved in metabolism.

23.2 Excretory Products

3 main waste products of nitrogenous metabolism: ammonia, urea and uric acid

23.2.1 Ammonia

Ammonia is derived from the breakdown of proteins and nucleic acids in the body. It is very toxic and is never allowed to accumulate within the body tissues or fluids. It is extremely soluble and diffuses readily across cell membranes. It is the main excretory product of *marine invertebrates* & *all fresh water animals*.

23.2.2 Urea

Urea is produced by the ornithine cycle with expenditure of some energy. It is much less toxic than ammonia, less water is needed for its elimination because the tissues can tolerate higher concentrations of it.

23.2.3 Uric Acid

The synthesis of uric acid spends more energy than urea, but it is advantageous to many animals. It is insoluble, non-toxic and requires very little water for its removal from the body -- a suitable product for animals in desert places.

23.3 Osmoregulation & Excretion in Animals (not required in syllabus)

23.3.1 Protozoa

- by contractile vacuole

23.3.2 Insects

- Malpighian tubules secreting uric acid

23.3.3 Freshwater Teleosts

- excrete ammonia and dilute urine

23.3.4 Marine Teleosts

- small kidney with trimethylamine as excretory product requiring very little water

23.3.5 Marine Elasmobranchs

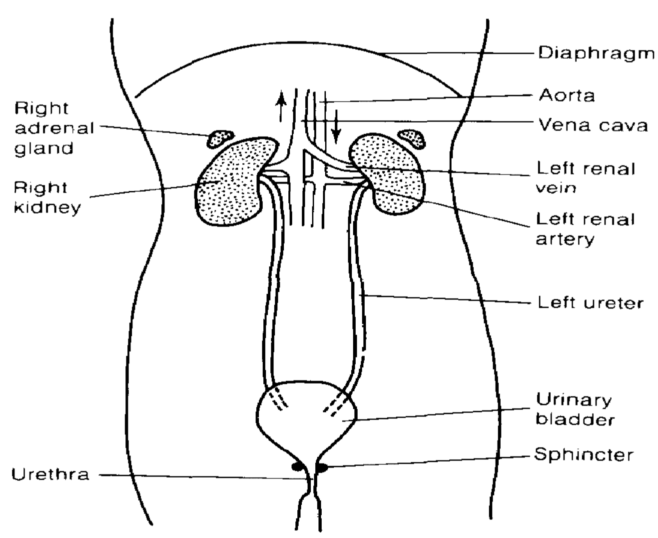
- have hypertonic blood by retaining urea & trimethylamine

23.3.6 Birds

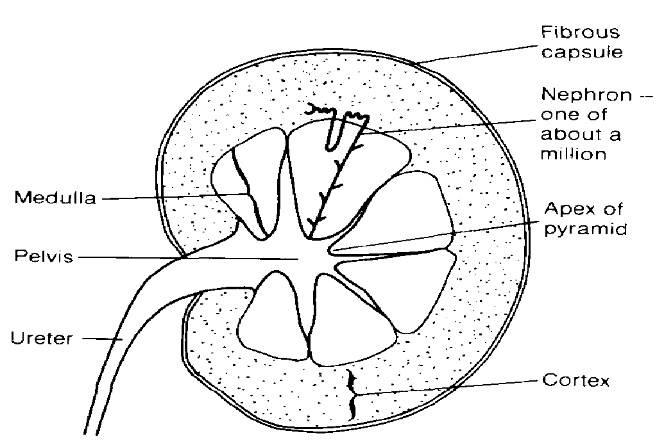
- excrete uric acid

23.3.7 Mammals

- excrete urea through kidneys



Position of the kidneys in man



Mammalian kidney to show position of a nephron (LS)

23.4 The Mammalian Kidney

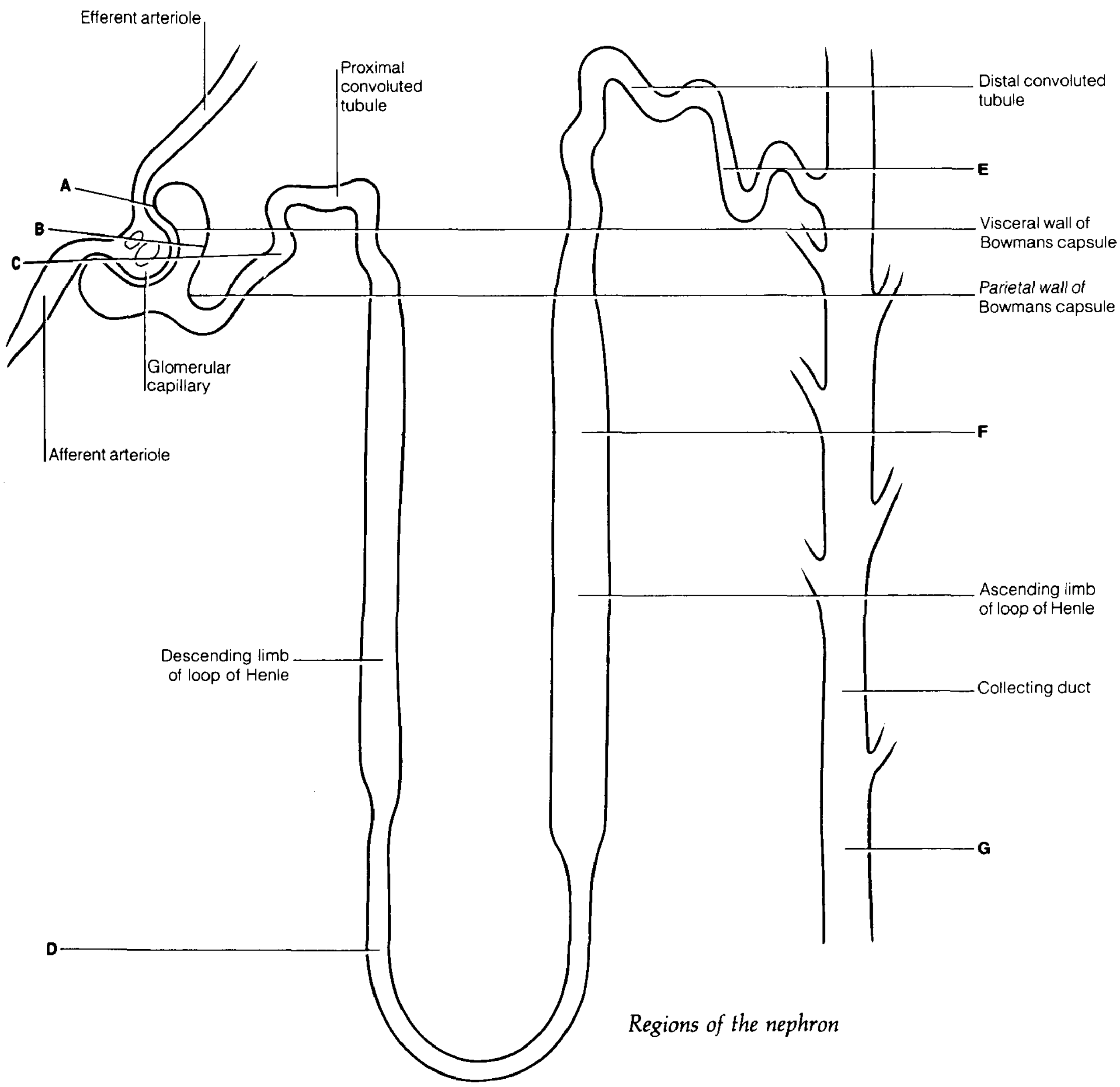
23.4.1 Structure of The Nephron

Each kidney is made of millions of tiny tubules called ***nephrons***, each of which consists of a ***Bowman's capsule*** and ***a uriniferous tubule*** joining to a ***collecting duct***.

F 6 Biology: Ch 23 - Osmoregulation & Excretion

Name:________________________________( )

A branch of the renal artery enters the Bowman's capsule as the ***glomerulus***, then splits up into capillaries which spread out and wrap around the tubule. Finally, these capillaries join up to the ***renal vein***.



Regions of the nephron

23.4.2 Gross Structure of The Kidney

renal artery: brings blood from heart (dorsal aorta) to kidney
renal vein: takes blood away from kidney to heart (inferior vena cava)
ureter: carries urine from kidney to bladder
bladder: stores urine temporarily
urethra: muscular tube from bladder for excreting urine;
sphincter muscle regulate the exit of urine from bladder
cortex: outer region
medulla: inner region
pelvis: central region which leads to ureter

23.4.3 Functions of The Nephron

- organ of nitrogen excretion;
- maintain composition of body fluid constant

1. Ultrafiltration

- Blood reaching the glomerulus is under high pressure because
  1. diameter of artery entering the glomerulus is greater than that leaving
  2. the heart has a high pumping force
- As a result, small molecules in blood are squeezed through the capillary walls into the capsular space of the Bowman's capsule

F 6 Biology: Ch 23 - Osmoregulation & Excretion

Name:________________________________( )

- Cells of Bowman's capsule:
  inner *podocytes* and
  outer *squamous epithelium*
- The ***glomerular filtrate*** contains water, amino acids, glucose, minerals and urea; blood cells & proteins are <u>too large to pass through</u>
- Ultrafiltration is a passive process and selection of substances passing from the blood into the glomerular filtrate is made entirely according to the relative molecular mass

2. Reabsorption

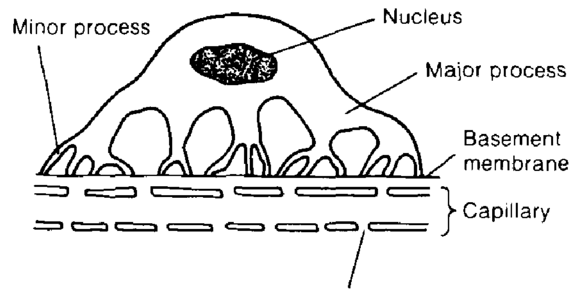
- As fluid travels along tubule, all the glucose & amino acids, most water & some salts are ***reabsorbed*** back into the capillaries around the tubule
- ***Urea*** is ***not reabsorbed*** at all; fluid goes down the <u>collecting duct</u> as ***urine***
- Reabsorption of glucose, amino acids & some salts begins in the first convolution & is finished at the loop of Henle;
  Reabsorption occurs by ***active transport***;
  Most ***water*** is reabsorbed in the collecting duct by ***osmosis***

<u>Features of the proximal convoluted tubule</u>:

1. Brush border
2. Basal membrane folded near blood capillary with numerous mitochondria
3. Tubular filtrate is isotonic with blood in its surrounding capillaries:

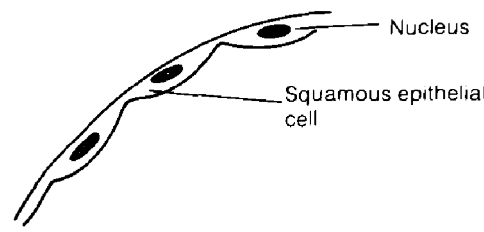
Over 80% of the glomerular filtrate is reabsorbed here, including all the food substances and most of the sodium chloride and water. The constant removal of these substances from the cells of the convoluted tubule causes others to enter from the lumen of the tubule by diffusion. NaCl is actively taken into the tubule with water enters them by osmosis. About 50% of the urea in the tubular filtrate returns to the blood by diffusion. Small proteins which have been forced out of the blood in the Bowman's capsule are taken up at the base of the microvilli by <u>pinocytosis</u>.

A



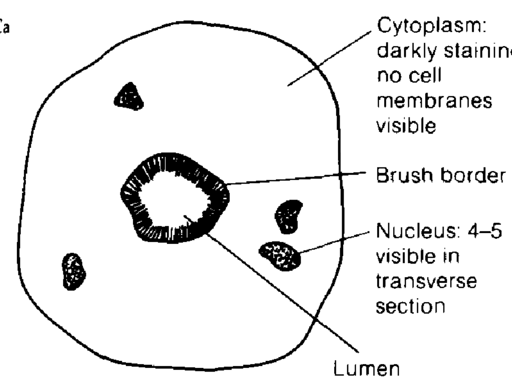
A Podocyte from visceral wall of Bowman's capsule

B



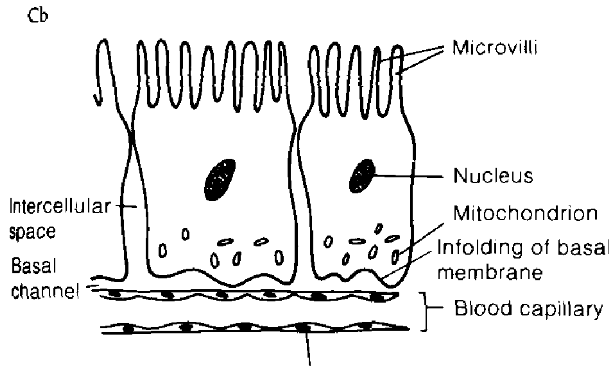
B Parietal wall of Bowman's capsule

Ca



Diameter 50–60 μm

Cb



C (a) TS proximal convoluted tubule
(b) Detail of two cells from proximal convoluted tubule

Detailed diagrams of the areas marked in Fig.

<u>*Loop of Henle*</u> - for water conservation by producing hypertonic urine.

The loop of Henle causes a build-up of NaCl in the medulla and this results in the movement of water out of the collecting ducts by <u>osmosis</u>. NaCl becomes concentrated in the medulla by a method called <u>***countercurrent multiplier***</u>:

1. The descending limb of the loop of Henle is narrow & its walls are permeable to water. The walls of the wider, ascending limb are thick and <u>impermeable</u> to water.
2. Na & Cl ions are actively removed along the ascending limb, making the interstitial fluid & the blood in the <u>vasa recta</u> very concentrated, especially towards the apex of the loop.

F 6 Biology: Ch 23 - Osmoregulation & Excretion

Name:________________________________( )

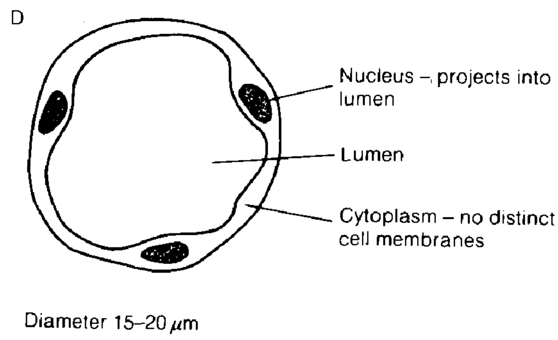
3. Flow of blood in the vasa recta is slow and so the high salt concentration causes water to be drawn out of the descending limb by osmosis into the vasa recta.
4. The difference in the osmotic potential between the ascending and descending limbs at any one level is small but over the whole length of the loop these have a <u>cumulative effect</u> → very low osmotic potential at the apex of the loop.
5. The longer the loop, the greater the difference in osmotic potential.
6. Countercurrent mechanism also operates between the two limbs of the vasa recta whose walls are freely permeable to water, ions and urea:

   As the descending capillary enters the medulla it encounters an increasingly concentrated interstitial fluid. This causes water to leave the plasma by osmosis and NaCl & urea to enter it. As the ascending limb leaves the medulla the surroundings become gradually less concentrated, water re-enters & NaCl and urea leave the plasma. All these movements are passive, requiring no energy.

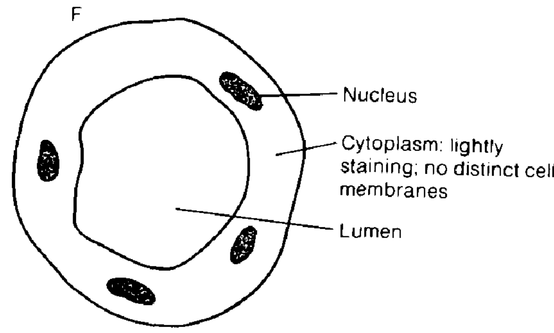
** The concentration of the filtrate leaving the loop of Henle is __________ than that entering it.

<u>Distal convoluted tubule</u>:

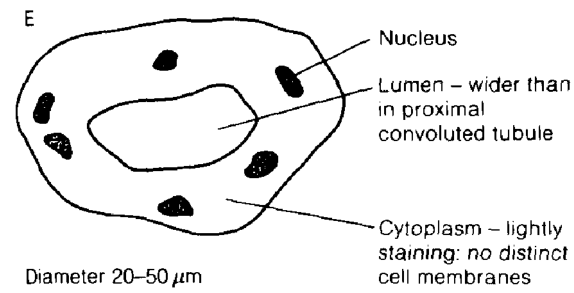
The cells in this region are very similar to those of the proximal convoluted tubule, having a brush border and numerous mitochondria. The permeability of their membranes is affected by hormones with precise control of salt and water balance of the blood. The distal convoluted tubule also controls the pH of the blood, maintaining it at 7.4 by excreting hydrogen ions and retaining HCO_3^- ions if pH falls, and the reverse if it rises. As a result the pH of the urine may vary between 4.5 and 8.5.



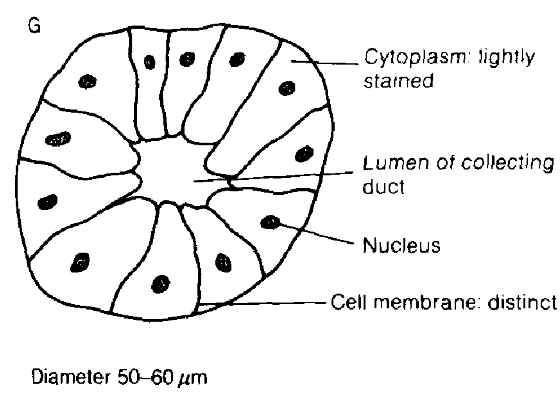
D Loop of Henle – thin segment (TS)



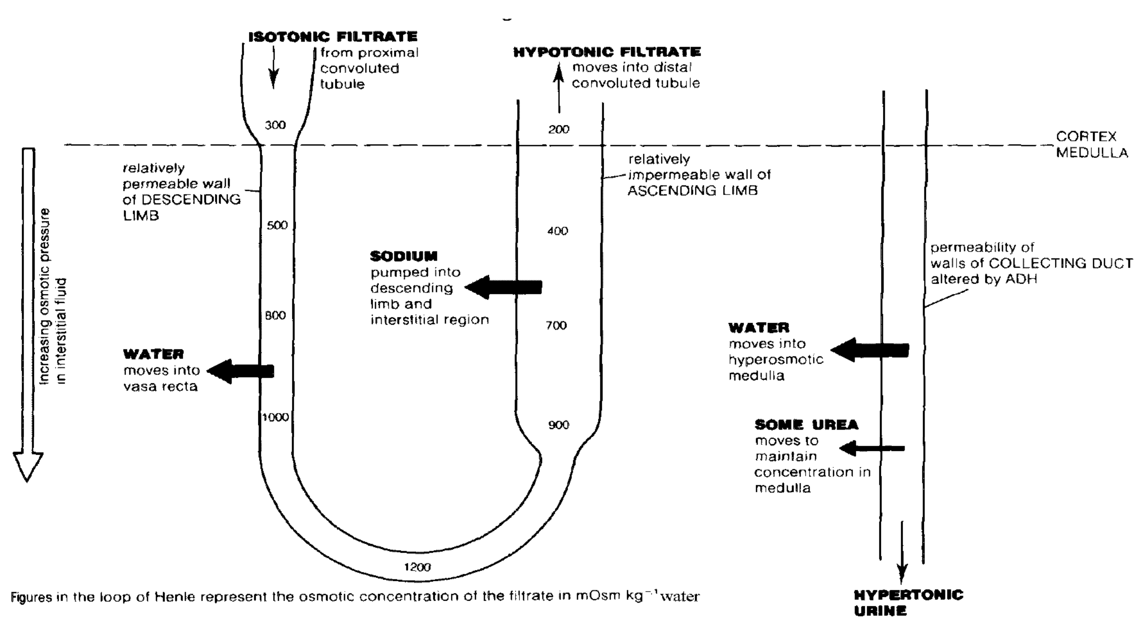
F Loop of Henle – thick segment (TS)



E Distal convoluted tubule (TS)



G Collecting duct (TS)



Counter-current multiplier of the loop of Henle

F 6 Biology: Ch 23 - Osmoregulation & Excretion

Name:________________________________( )

Collecting duct:

Hormones control the permeability of the walls of the collecting duct. If the walls are water-permeable, water leaves the ducts to pass into the hyperosmotic surroundings and concentrated urine is produced. If the ducts are impermeable to water the final urine will be less concentrated.

23.5 Hormonal Control of Osmoregulation & Excretion - Antidiuretic Hormone and Aldosterone

23.5.1 Antidiuretic Hormone (ADH)

ADH affects the ______________________ of the distal convoluted tubule and collecting duct.

A decrease in blood osmotic potential can be caused by:

1.

2.

3.

osmotic potential ↓

→ osmoreceptors (in hypothalamus)

→ posterior pituitary gland

→ ADH ↑

→ permeability of distal convoluted tubule to water & collecting duct ↑

→ hypertonic urine is produced

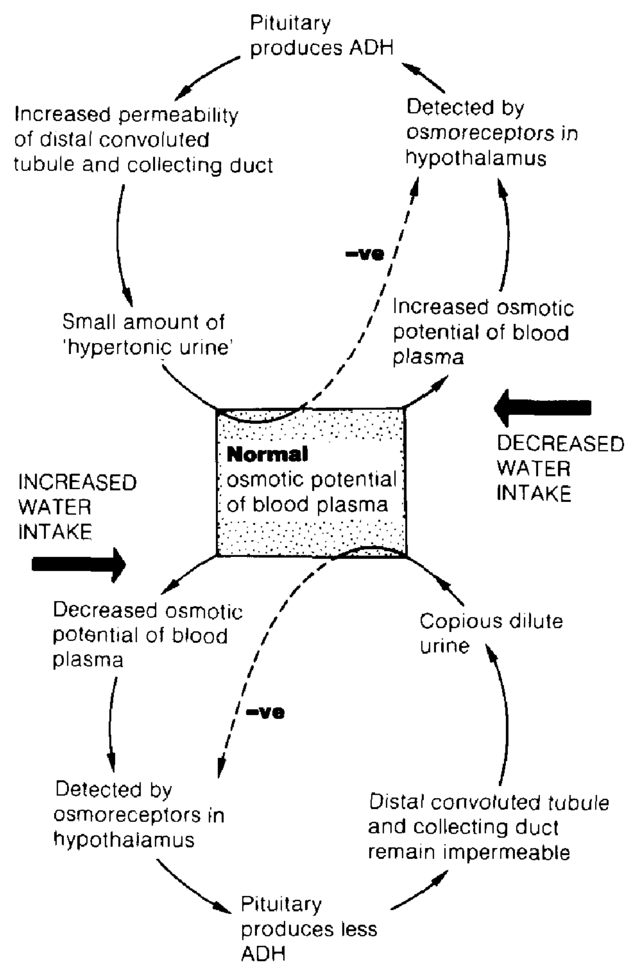
ADH also increases the permeability of collecting duct to urea which passes into the medulla, decreasing the osmotic potential and causing more water to be lost from the descending loop of Henle.

If osmotic potential increases due to :

1.

2.

3.



Regulation of ADH production

then ADH production is inhibited and the walls of the distal convoluted tubule and collecting duct remaining impermeable to water and urea → hypotonic urine

diabetes insipidus: a condition in which a person is unable to produce sufficient level of ADH, resulting in producing large volumes of very dilute urine.

23.5.2 Aldosterone

A hormone responsible for maintaining a more or less constant sodium level in the plasma and it has a secondary effect on water reabsorption.

Na^+ ↓ → blood volume → juxtaglomerular complex (in nephron) → renin

→ angiotensin (in liver) → adrenal cortex

→ aldosterone secretion → Na^+ actively reabsorbed from glomerular filtrate into capillaries

→ Na^+ ↓ with water → blood volume ↑

F 6 Biology: Ch 23 - Osmoregulation & Excretion

Name:__________________________________( )

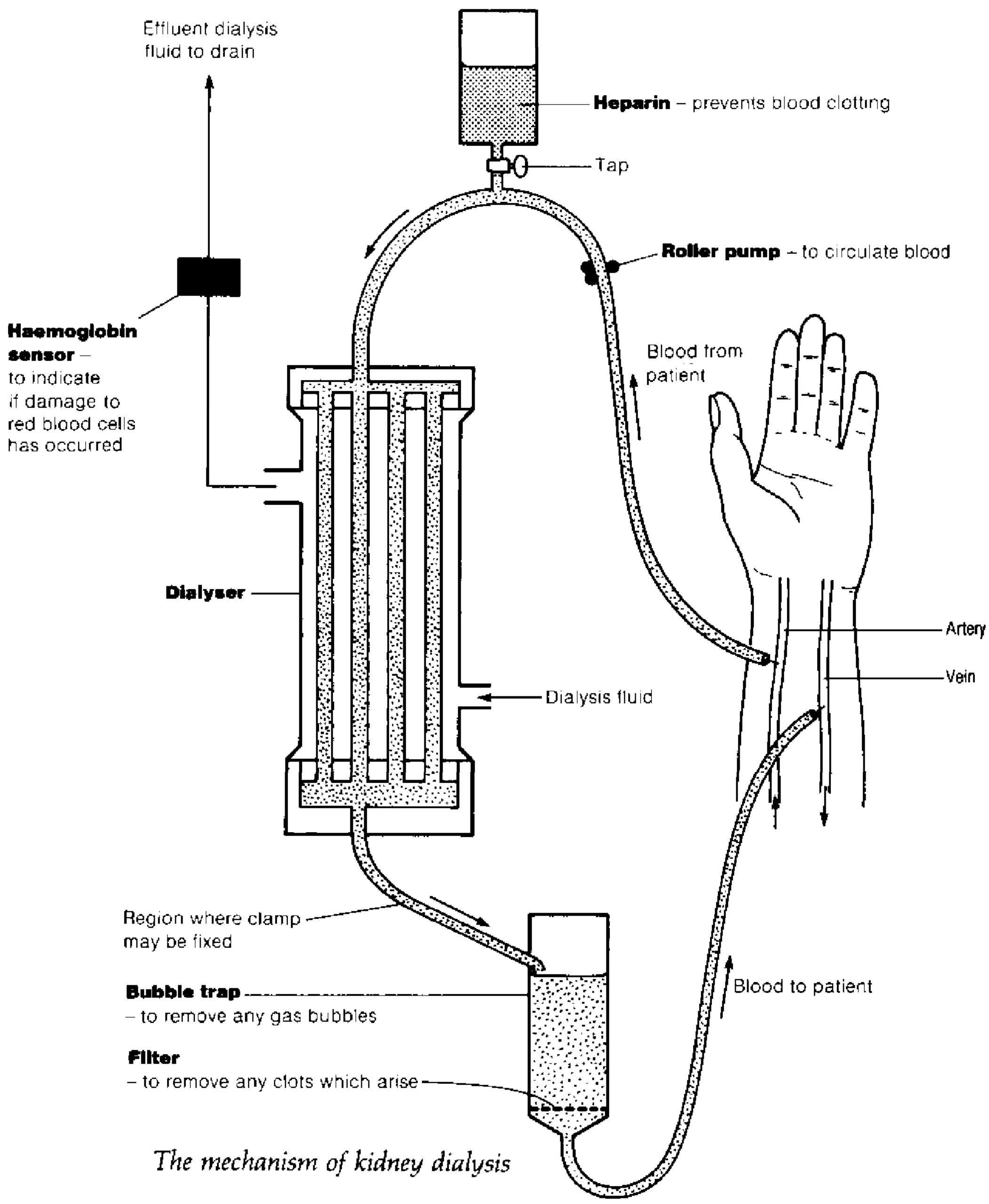
23.6 Kidney Failure - Dialysis & Transplant

- The kidney machine makes use of the principle of ***dialysis***;
  Cellophane acts as a selectively permeable membrane
- Counter-current flow ensures the most efficient exchange of material across the membrane
- Dialysis fluid contains glucose & minerals at the ***same*** concentration as normal plasma so that blood will not lose any glucose or salts at all
- When blood leaves the machine, nearly all urea is removed
- Bath fluid flows in an opposite direction to blood to increase efficiency of removing urea

Drawbacks: spend considerable time (10 hours of dialysis for a few days only), observe a rigid diet, risk of anaemia, infection or bone disease

Kidney Transplant

If a suitable donor is available the diseased kidneys of the patient can be removed or left in place and the healthy donor kidneys are ***transplanted***.



The mechanism of kidney dialysis

Excretion in Plants

Plants do not have nitrogenous waste products in the same way as animals. They synthesize their own organic compounds according to their own needs. CO_2 & H_2O
released by respiration are used for photosynthesis and so these do not need to be excreted during daylight. Organic wastes are stored in non-living parts of the plant, e.g. heartwood, where they do not affect the living tissue. Excess minerals, e.g. Ca, may combine with oxalic acid or pectic acid to form crystals and safely stored in plant cells. Other excess ions may accumulate in leaves, petals, fruits and seeds. They will be lost from the plant when the leaves and petals fall or when fruits and seeds are dispersed.