

EXCRETION AND HOMEOSTASIS

Common terms

1. **Excretion** is the removal of waste products produced as a result of metabolic processes in an organism. E.g. urea and carbon dioxide.
2. **Osmoregulation:** is the process by which osmotic pressure of blood and tissue fluid is kept constant.
3. **Secretion:** is the active or passive flow of substances from living cells. Such substances as enzymes, hormones, mucus etc.
4. **Homeostasis:** This is the maintenance of a relatively constant internal environment of the body.

The internal environment of the body is composed of blood and tissue fluid which surround cells.

Factors of the internal environment that are kept constant

- Body temperature
- pH
- Water content
- Glucose concentration
- Salt content
- Levels of carbon dioxide etc

Note

Egestion, *the removal of undigested food materials* should not be confused with excretion because most of the contents of the faeces, apart from the bile pigments, have not taken part in reactions in the cells of the body.

SIGNIFICANCE OF EXCRETION

- Eliminates waste products formed during body metabolism
- Removal of waste products which would be toxic to body cells
- It allows for the removal of unwanted materials taken into the body along with useful nutrients
- It involves the removal of materials synthesized in excess of the current body demands

- Continuous removal of waste products allows for maintenance of a constant internal environment of the body.

Excretory products arise in a number of ways and these include, from:-

- Unwanted substances absorbed with food
- Absorption of excess nutrients
- Osmoregulatory processes
- Breakdown of protoplasmic constituents
- From body metabolism

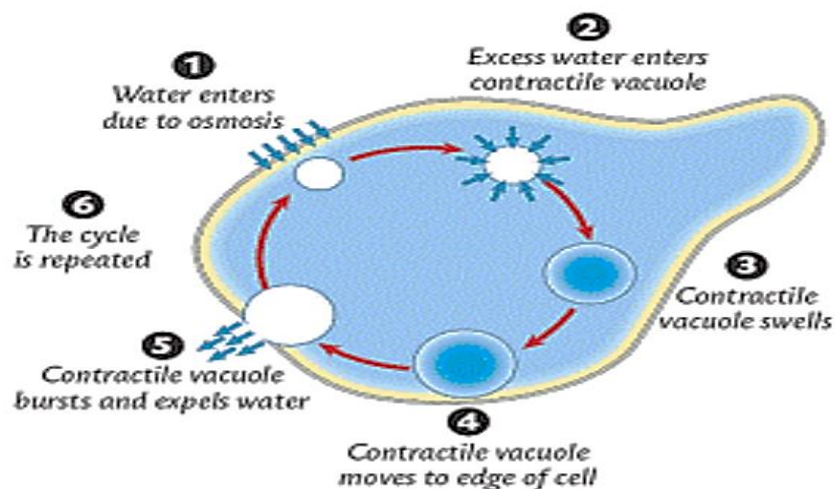
Excretion in lower organisms e.g. protozoa

Protozoans such as amoeba and paramecium **carbon dioxide, excess water** and **ammonia** are the main waste materials. These waste materials are excreted out by the process of diffusion through general body surface.

Contractile vacuoles present in protozoans also play some role in the removal of excess water. In the process below:-

Excess water present in the cytoplasm of amoeba enters the contractile vacuole by osmosis. As the contractile vacuole enlarges due to entry of water, it moves close to the plasma membrane, fuses with it and bursts to release its contents into the surrounding.

Illustration



EXCRETION IN PLANTS

Plants lack specialized excretory organs and have few excretion related problems because of the following reasons:

- Plants are producers and synthesise all their organic nutrients in sufficient amounts, rarely do excesses occur
- They usually reuse most of the waste products in other metabolic processes. Carbon dioxide is used up in photosynthesis
- Most of their waste molecules are simple molecules such as oxygen, carbon dioxide and water which can easily diffuse through stomata
- Plants store some of their wastes in organs such as fruits, bark, petals and leaves which are periodically shed off thus eliminating the waste products. These include iron, tannins, nicotinic acid etc.
- Some of the waste products can be stored in dead tissues of the plant such as the cortex without any harmful effects
- Plants produce waste products at a slower rate since due to lower metabolic rates. At a slow rate, waste products can't affect plant metabolism.

Plants deal with their waste products through the following ways

- **Diffusion** of gaseous wastes like oxygen and carbon dioxide through stomata and lenticels
- **Transpiration**; plants can lose excess water as vapour through the stomata into the atmosphere
- **Recycling**, most of the plant waste products are used as raw materials in other processes. E.g. CO₂ in photosynthesis
- **Deposition**; Some toxic wastes like alkaloids, nicotine, quinine and cocaine are deposited in dead tissues and peripheral structures like leaves and fruits which are later lost from the plant.

Useful plant waste products to man

<i>Waste products</i>	<i>Source</i>	<i>Importance</i>
Gums	Barks of plants e.g. Acacia.	Necessary in food processing industries such as making of chewing gum
Resins	Conifers	For manufacture of paint
Latex	rubber tree	for making rubber used to make tyres and other rubber products
Nicotine	Found in leaves of tobacco plant,	for making insecticides
Cocaine	Leaves of cocoa plant	➤ Pain relieving drug ➤ Local anaesthesia
Tannin	Wood or bark of trees e.g. Acacia, wattle	➤ For treatment of leather
Quinine	Bark of cinchona tree	➤ Making drugs for treating malaria
Oxygen	Released through stomata	➤ For aerobic respiration

Other plant waste products include *carbon dioxide* given off during respiration and *excess water* given off during transpiration.

EXCRETION AND OSMOREGULATION IN ANIMALS

EXCRETORY PRODUCTS

Excretory products are categorized as nitrogenous waste products and non-nitrogenous waste products. The table below summarises the **source and fate of the major waste products** among organisms

1. Non-nitrogenous wastes: These waste products do not contain nitrogen.

The table of non-nitrogenous wastes from different animals

<i>Excretory</i>	<i>How formed</i>	<i>How & where excreted</i>
Carbon dioxide	During respiration of most living things	Diffusion through stomata in plants, diffusion from respiratory surface in animals.
Water	In Aerobic respiration	By osmosis or evaporation at the cell surface
Mineral Ions	Metabolism of mineral nutrients	Excreted in urine and sweat
Bile pigments	In breakdown of haemoglobin	In bile stored in the gall bladder and egested in faeces out of body.

2. NITROGENOUS WASTES: These are waste products that contain nitrogen.

They are formed as products of metabolism of **protein (amino acids)**.

These include

- Ammonia
- Urea
- Trimethylamine oxide
- Uric acid

A table summarising the chief nitrogenous waste products of different animals and their habitats

Animal	Habitat	Chief nitrogenous waste	Excretory organ
Fresh water invertebrates	Fresh water	Ammonia	Surface membrane
Insects and other arthropods	Land (terrestrial)	Uric acid	Malpighian tubules
Cartilaginous fish	Marine water (sea/ocean)	Urea	Kidney
Fresh water fish (bony)	Fresh waters	Ammonia	Kidney
Marine water fish (bony)	Marine waters	Trimethylamine oxide	Kidney
Larval amphibians	Fresh water	Ammonia	Gills
Adult amphibians	Terrestrial/fresh water	Urea	Kidney
Reptiles and birds	Terrestrial	Uric acid	Kidney
Mammals like humans	Terrestrial	Urea	Kidney

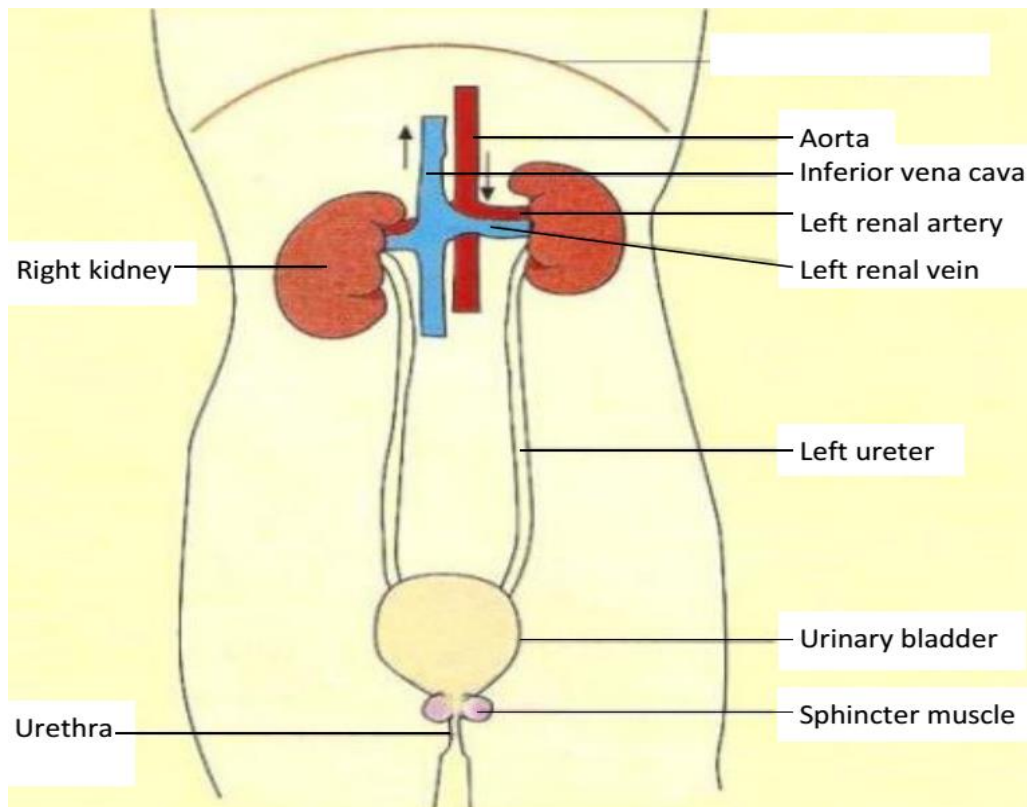
EXCRETION AND OSMOREGULATION IN MAMMALS

A table showing the main excretory organs and the excretory products in man

Organs	Products	Excretory substance
Kidney	Urine	Urea, excess salts & H ₂ O
Lungs	Exhaled breath	CO ₂ and H ₂ O
Skin	Sweat	Excess salts, water and urea
Liver	Bile pigments	Bile pigments

THE KIDNEY AND THE EXCRETORY SYSTEM

Structure of urinary system

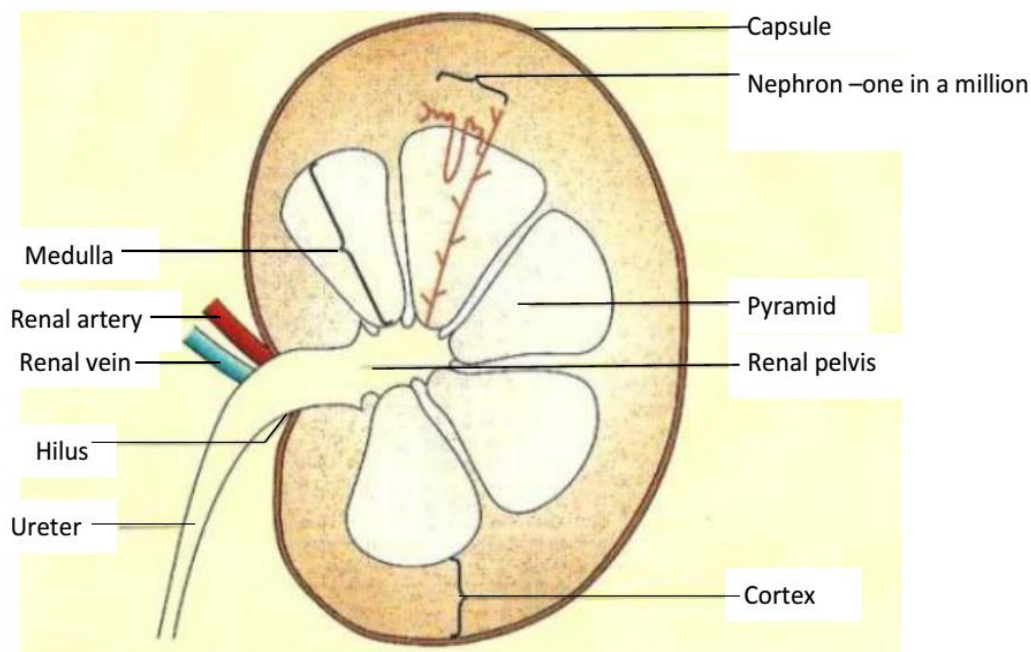


Parts and functions of the urinary system

- 1) **Aorta:** It carries oxygenated blood with all food nutrients to the kidney.
- 2) **Renal artery:** This arises from dorsal aorta. It brings blood containing excretory products to the kidney.
- 3) **Renal vein:** It carries filtered blood from the kidney to the posterior vena cava.
- 4) **Ureter:** These are two narrow tubes arising from hilum of each kidney. They connect the kidneys to the urinary bladder. They transport urine to the urinary bladder.
- 5) **Urinary bladder:** It is a thick walled elastic sac-like structure which temporarily stores urine.
- 6) **Sphincter muscle:** These muscles are elastic thus can contract and relax to control urine flow.
- 7) **Urethra:** It is a passage for urine to the outside of the body.

THE KIDNEY

Structure of the kidney



The kidneys are solid bean-shaped structures and they occur in pairs in mammals. They are reddish-brown in colour enclosed in a transparent membrane and attached to the back of the abdominal cavity.

The kidney tissue consists of many capillaries and renal tubules connected together by connective tissue. The kidney has three major parts.

1. The **cortex** which is a dark outer part. It consists of the Bowman's capsule which is responsible for ultra-filtration of blood passing across it.
2. The **medulla**, which is a lighter inner, part. It is made up of many cone-shaped portions called pyramids.
3. The **pelvis** is the area where the ureter leaves the kidney.

The kidney performs three major functions in the body.

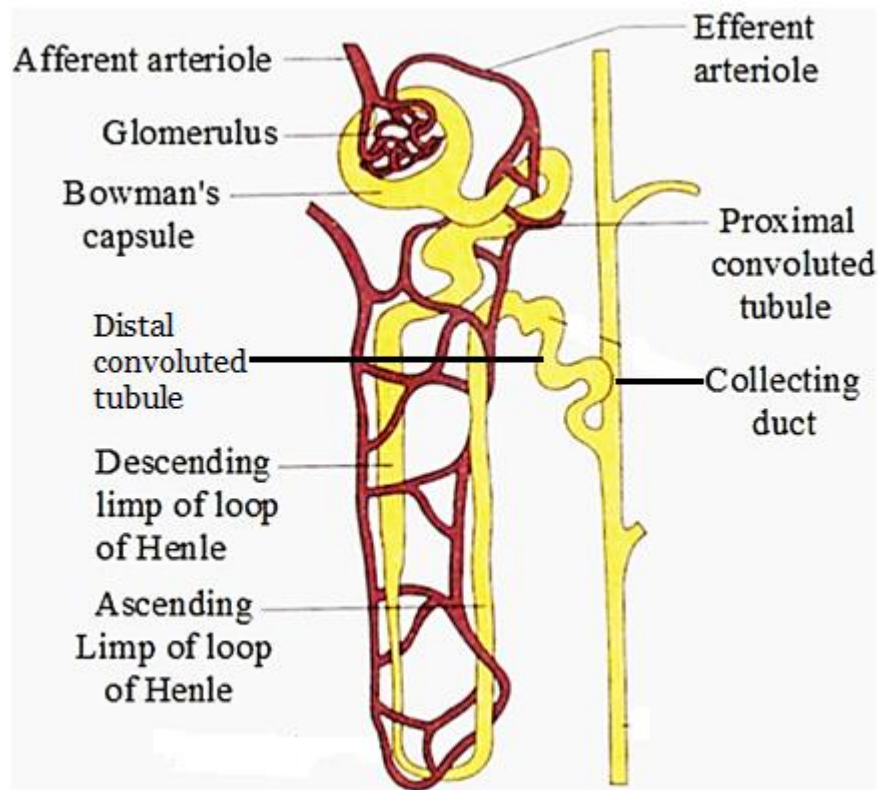
1. It carries out excretion.
2. It carries out the function of osmoregulation.
3. It ensures maintenance of suitable blood pH

The kidney is made up of several microscopic structures (functional units) called nephrons where the actual excretion and osmoregulation takes place.

THE NEPHRONE

This is the functional unit in the kidney. It carries out the function of excretion and osmoregulation in the kidney.

Structure of the nephron



Parts of nephron

1. **Bowman's capsule:** is a cup-shaped structure, It contains a dense-network of highly coiled capillaries that form a knot called **glomerulus**. The glomerulus is formed from the wider arteriole of renal artery called afferent arteriole. It is located in the cortex.

Functions: contains glomerular capillaries involved in **ultra-filtration**.

Filters small molecules in blood such as urea, glucose, amino acids, and mineral ions through its basement membrane.

Adaptations of the Bowman's capsule to collect the filtrate

- Large cup-shaped structure to provide more space for collecting more filtrate.
- Is cup shaped to provide surface area to enclose glomerular capillaries which carry out ultra-filtration

- Porous basement membrane to allow filtration of materials.
2. **Glomeruli;** these are numerous capillaries found in the Bowman's capsule formed due to branching of the afferent arteriole

Adaptations of the glomerulus to ultra-filtration

- Afferent arteriole wider than the efferent arteriole creating a high blood pressure that forces small molecules out of the glomerulus.
 - Many blood capillaries to provide a large surface area for ultra-filtration.
 - Porous membrane to can allow small sized molecules to pass through.
3. **Proximal convoluted tubule:** is a highly coiled structure leading from the Bowman's capsule.

Function: It is a site where re-absorption of useful materials such as glucose and some small amino acids and water from glomerular filtrate back to blood takes place.

Adaptations of proximal convoluted tubule to its function

- Long providing a large surface area over which absorption of materials can occur
 - Tubule one cell thick to reduce the diffusion distance for faster diffusion of materials
 - Cells in the walls have microvilli to increase the surface area over which absorption can occur
 - Surrounded by numerous blood capillaries for rapid transportation of absorbed materials
 - Cells in the walls contain large quantities of mitochondria to produce a large quantity of ATP for rapid active transport of materials.
4. **Loop of Henle:** is a U shaped tubule, made up of a descending (going down) limb and an ascending (going up) limb.

Function:

- Re-absorption of water.
- Re-absorption of mineral ions.

Adaptation of loop of Henle to its function

- Long to increase surface area for reabsorption of water and mineral ions.
- Blood capillaries running along its length to transport away water and salts to maintain a concentration gradient.

5. **Distal convoluted tubule:** this is the second coiled tube found after the ascending limb of loop of Henle.

Function: For re-absorption of ions like chloride ions, sodium ions together with water.

Adaptation of distal convoluted tubule to its function

- Coiled to slow down movement of renal fluid so as to increase the reabsorption of mineral ions.
- Has cells sensitive to antidiuretic hormone to allow water reabsorption

6. **Collecting duct:** a tubule to which numerous distal tubules attach to deliver renal fluid.

Functions

- Carries urine from the distal tubule to the pelvis of kidney.
- Allows reabsorption of water thus conserving it.

URINE FORMATION

The process of urine formation takes place in the nephron. It occurs in two phases.

1. **Ultra-filtration:** which is filtration of small molecules through tiny pores at high pressures.

2. **Selective re-absorption:** is the process of taking back into blood of some of the essential substances still required by the body from the glomerular filtrate. It is called re-absorption because initial absorption took place in the ileum.

Ultra filtration

- ✓ Much blood comes from the **afferent arteriole** into the glomerulus at high pressure due to pumping action of the heart.
- ✓ More pressure is generated in the blood capillaries of the glomerulus since the afferent arteriole which brings in blood has a wider lumen compared to the efferent arteriole which takes blood out of the glomeruli.
- ✓ The pressure forces small molecules such as *glucose, urea, water, salts and vitamins* to filter out of the walls of blood capillaries to form the glomerular filtrate.
- ✓ *Proteins and blood cells do not filter out* because they have larger molecules, which cannot pass through the tiny pores in the walls of the glomerulus.
- ✓ The filtrate formed moves from the Bowman's capsule through the capsular space and **pores** in **basement membrane** to **proximal convoluted tubule** where selective reabsorption starts to occur.

The pressure required for ultra-filtration is derive from; pressure due to pumping action of heart, pressure developed due to difference in size of afferent arteriole and efferent arteriole, hydrostatic pressure of blood.

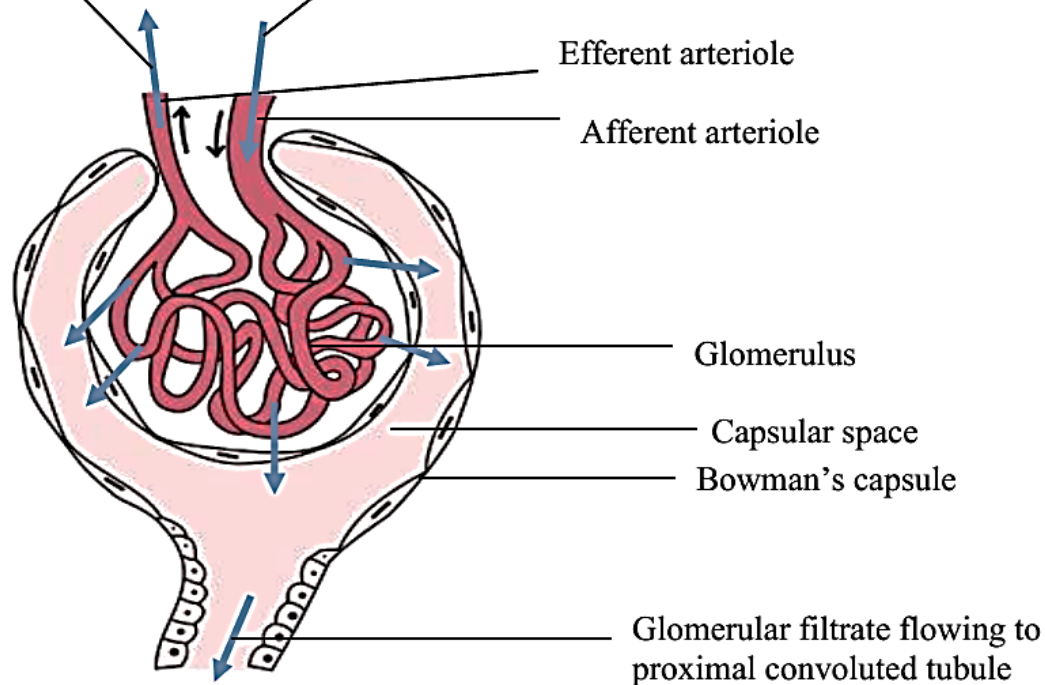
NOTE: Ultrafiltration is a passive, mechanical process that occurs due to pressure.

- Selection of substances passing through from the blood into the filtrate within the nephron is achieved purely on the basis of size.

Diagrammatic illustration of ultrafiltration

Blood leaving the glomerulus contains proteins and blood cells because they have bigger molecules, which cannot pass through the walls of the glomerulus.

Blood entering through the afferent vessel contains proteins, red blood cells, white blood cells, urea, water, salts, amino acids and vitamins.



Selective reabsorption

In the proximal convoluted tubule:

- ✓ Most of the food materials are re-absorbed into the blood capillaries via the proximal convoluted tubule first by **diffusion** like sodium ions, chloride ions and then by **active transport** e.g. all the glucose, amino acids, vitamins, and some mineral ions, some water is re absorbed by **osmosis**.

In the loop of Henle:

- ✓ *As the filtrate flows down the descending limb, water is re absorbed back into the capillaries by **osmosis** leading to increased concentration of the filtrate down the descending limb. Highest concentration of the filtrate is at tip of the loop.*

- ✓ As the filtrate ascends, first in the thin section, sodium ions and chloride ions are reabsorbed by **diffusion** and in the thick section of the ascending limb of loop of Henle, salts like Na^+ and K^+ are reabsorbed by **active transport**. This leads to a decrease in concentration of the glomerular filtrate in the ascending limb.

In the distal convoluted tubule:

- ✓ Selective re-absorption of salts by diffusion occurs.
- ✓ Substances such as Urea are actively transported (secreted) from blood into the filtrate.
- ✓ Water is reabsorbed **only** due to stimulation by Anti diuretic hormone (ADH)

In the collecting duct:

- ✓ Water is lost to the highly concentrated medulla tissues by osmosis from which later the remaining filtrate is **urine** which goes via the ureter and temporarily stored in the urinary bladder.
- ✓ Water is reabsorbed **only** due to stimulation by Anti diuretic hormone (ADH)

Summary of the steps involved in formation of urine in the kidneys

Region of nephron	Function
Bowman's capsule	Ultra filtration of the blood in glomerulus; high hydrostatic pressure produces an ultra-filtrate free of plasma proteins and red blood cells
Proximal convoluted tubules	<ul style="list-style-type: none"> • Reabsorption of useful substances such as Na^+, K^+, Cl^-, HCO_3^-, amino acids and glucose by a mixture of diffusion and active transport • Reabsorption of water by osmosis • Reabsorption of urea by diffusion
Loop of Henle	Reabsorption of water from the collecting duct

Distal convoluted tubule	<ul style="list-style-type: none"> • Reabsorption of Na⁺ • Reabsorption of water under the control of ADH • Secretion of H⁺, NH₄⁺ and reabsorption of HCO₃⁻ to control blood pH • Secretion of some drugs
Collecting duct	Reabsorption of water under control of ADH

Comparison of composition of substances in blood and urine

substance	%age conc in the following fluids		urine	Appr.increase in conc of urine
	Plasma	glomerular filtrate.		
Plasma protein	7.5	0	0	-
Glucose	0.1	0.1	0	-
Sodium ion	0.32	0.32	0.35	X 1
Chloride ion	0.37	0.37	0.60	X 2
Urea	0.03	0.03	2.0	X 60
Water	91.9	91.9	95.0	X 1

Explanation of observations

- ✓ There are proteins in blood plasma but none in glomerular filtrate and urine because proteins are not filtered out of the blood vessels into the glomerulus due to the large size of their molecules.
- ✓ Urea is more in urine than in both blood plasma and glomerular filtrate, this increase is because of two reasons;
 - Extensive re-absorption of water from the glomerular filtrate back into blood causing an increase in amount of urea per unit volume of urine
 - Secretion of excess urea in blood into the distal convoluted tubules
- ✓ Glucose is present in glomerular filtrate and completely absent in urine. This is because glucose molecules are small in size and pass through the glomerular

pores into the filtrate. However, all the glucose molecules are reabsorbed back in the proximal convoluted tubules hence absent in urine

- ✓ Salts like chlorides and sodium ions are more in urine than in blood. This is because they are in excess in blood and few are reabsorbed back into the blood. Because of this they tend to concentrate in urine.
- ✓ Water is more in urine than in blood because it is used to dissolve urea.

NOTE: the relative amounts of water in urine and in blood varies depending on the amount of water in the body, amount of solutes in the body, temperature and body activity.

OSMOREGULATION

This is the process by which osmotic pressure of body fluids is kept constant.

Significance of osmoregulation

The osmotic pressure of blood must be regulated within narrow limits in order to prevent the body cells from either losing or gaining too much water.

If too much water is gained the cells would burst and if the body has less water, the body fluids will become more concentrated and cells will crenate, this would result in the damage of body tissues thus greatly affecting the functioning of the body.

The osmotic pressure of the body fluids depends on the balance between the concentration of water and salts in them. Decreasing the amount of water in blood or increasing the amount of dissolved salts results into increase in the osmotic pressure of blood and vice versa

Sources and losses of water and salts from the body.

The body gains water from:-	The body lose water through:-
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<ul style="list-style-type: none"> ✓ Food eaten, ✓ Drinking water ✓ Body metabolic processes like respiration ✓ Absorption from surrounding for fresh water organisms 	<ul style="list-style-type: none"> ✓ Passing it out with faeces and urine, Sweating ✓ As vapour in exhaled air ✓ Osmosis into surrounding water for marine organisms
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Salts are gained from	Salts are lost through
<ul style="list-style-type: none"> ✓ Food ✓ drinks 	<ul style="list-style-type: none"> ✓ sweat ✓ urine ✓ diffusion into surrounding water

NOTE:

The overall effect of osmoregulation is to strike a balance between water and mineral salt loss and gain

Role of the kidney in osmoregulation

The osmotic pressure of blood is under the control of the **hypothalamus** which stimulates the **pituitary gland** to release a hormone called **Anti-diuretic hormone (ADH)** also known as **Vasopressin**

Regulation of the osmotic pressure of the blood when it high

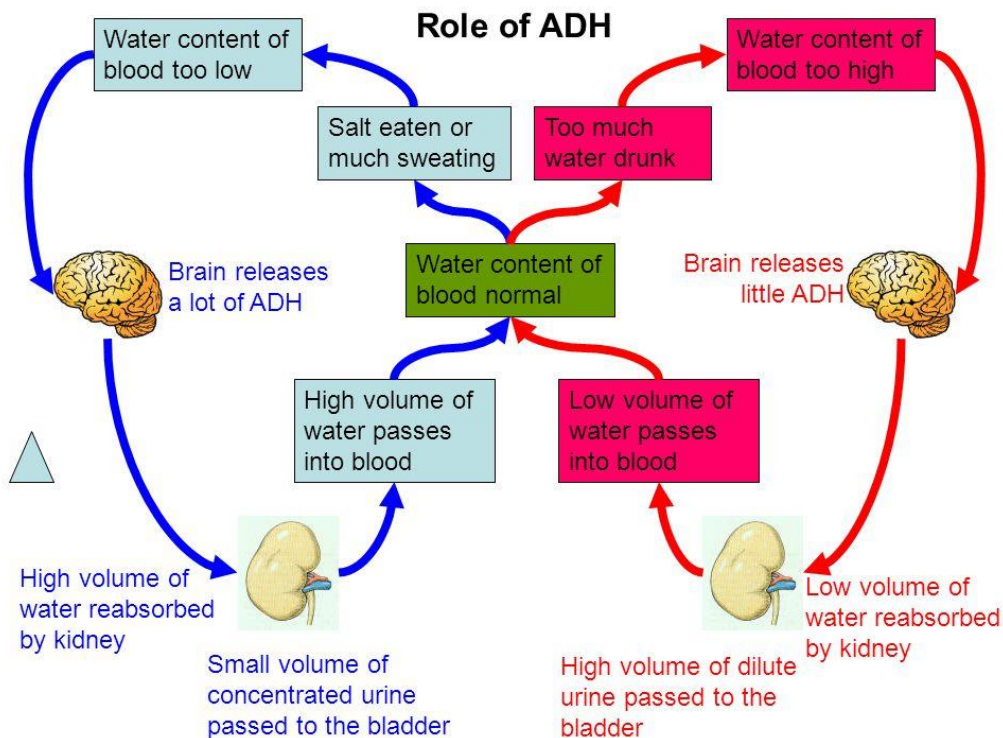
- ✓ A decrease in the amount of water in blood due to taking of salty meals, this leads to increase in osmotic pressure of blood.
- ✓ Increased osmotic pressure is detected by the osmoreceptors in the hypothalamus, this stimulates the posterior pituitary gland to release more Anti-Diuretic hormone (ADH) into blood.
- ✓ ADH reaches the kidney tubules and increases their permeability to water hence more water is reabsorbed back to blood.

- ✓ Little water is lost in urine and more retained in the blood increasing the volume of water in blood back to normal.
- ✓ In addition the individual feels thirsty and drinks more water until the water levels increase to normal.

Regulation of the osmotic pressure of the blood when it low

- ✓ In case of excess water in blood e.g. when an individual takes a lot of water, the osmotic pressure is lower than normal.
- ✓ Release of ADH is inhibited/ less ADH is secreted from pituitary gland.
- ✓ Kidney tubules become less permeable to water and urea,
- ✓ Little water is reabsorbed and much is lost in urine.
- ✓ Little water is taken through drinking until the water level reduces back to normal.

Summary



Note:

- ❖ On a cold day one the metabolic rate increases so as to generate more heat in the body to maintain the body temperature constant. This result into generation of much water yet little is lost in sweat. This explains why one needs to urinate several times in a short period of time.
- ❖ In the same way; because of the high metabolic rate, one tends to feel hungry faster on a cold day as food is quickly broken down to generate heat
- ❖ A person whose pituitary gland is faulty can't produce adequate amount of ADH produces large volumes of dilute urine (Diuresis) and urinates frequently. This disorder is known as **diabetes inspidus** and may lead to dehydration
- ❖ Alcohol tends to inhibit release of adrenaline leading to increase in volume and frequency of urine formation.

Role of the liver in formation and elimination of urea

End products of protein digestion i.e. amino acids are absorbed into blood capillaries in the villi in the ileum, blood capillaries join up to form hepatic portal vein, which transports the amino acids through the blood stream to the liver.

In the liver excess amino acids cannot be store in the body. Excess amino acids are split by enzymes during the process of deamination by liver cells producing ammonia and an acid, the acid is converted into carbohydrates or fat and stored, ammonia combines with carbon dioxide to form urea and water, urea dissolves in the blood plasma, and is transported to the kidneys where it is eliminated in the urine, a small amount also excreted in sweat.

Role of the mammalian liver in glucose regulation

Significance of blood sugar regulation

- Prevents the cells running short of glucose in case its level drops, since glucose (blood sugar) is the main source of energy decrease in its concentration below normal would result in less energy being produced, slowing down metabolic reactions in the body that need energy.
- Too much glucose would increase the osmotic pressure of blood, causing the cells to take in more water by osmosis causing their bursting, slowing down metabolic reactions.

Control of blood glucose levels

The normal blood glucose level is **90mg/100cm³ of blood**, though it may increase greatly after a meal of carbohydrates or decrease during starvation. Blood glucose concentration is controlled by the pancreas. The pancreas has glucose receptor cells which monitor the concentration of glucose in the blood, and it also has **endocrine cells** (called *the islets of Langerhans*), which secrete two hormones. The alpha cells (α cells) secrete a hormone called **glucagon**, while the beta cells (β cells) secrete a hormone called **insulin**. These two hormones are antagonistic, and have opposite effects on blood glucose.

Mechanism of blood sugar regulation

After a meal of carbohydrates, glucose is absorbed from the gut into the **hepatic portal vein**, increasing the blood glucose concentration. This is detected by the pancreas, which secretes insulin from its beta cells which moves through the blood stream to the liver where it promotes.

- Conversion of glucose to glycogen for storage in the liver
- Conversion of glucose to fats for storage in fat adipose tissues
- Increase in breakdown of glucose by respiration to provide energy.

This reduces to glucose level back to normal (set point) level, the pancreas stops secreting insulin.

If the glucose level falls too far for example during starvation or fasting, the pancreas detects this, the **alpha cells** of the pancreas release **glucagon hormone** into blood. This is moves through the blood stream to the liver where it promotes:

- Breakdown of glycogen to glucose
- Breakdown of fats to glucose
- Reduction glucose breakdown by respiration.

This allows the glucose levels to increase back to normal, the pancreas stops producing glucagon.

Failure to produce insulin causes the presence of much glucose in urine a condition known as ***diabetes mellitus***.

NOTE:

- ❖ An individual whose pancreas cannot secrete **sufficient amounts of insulin** suffers an abnormality called **diabetes mellitus**. The blood glucose level increases such that some glucose may not be reabsorbed from the proximal convoluted tubules thus **appearing in urine**. The condition is treated by **injecting a patient with insulin**.
- ❖ The treatment cannot be administered orally being that it's a protein that would be broken down by enzymes into amino acids.
- ❖ Diabetic individuals are advised to eat frequently to replace the glucose lost in urine

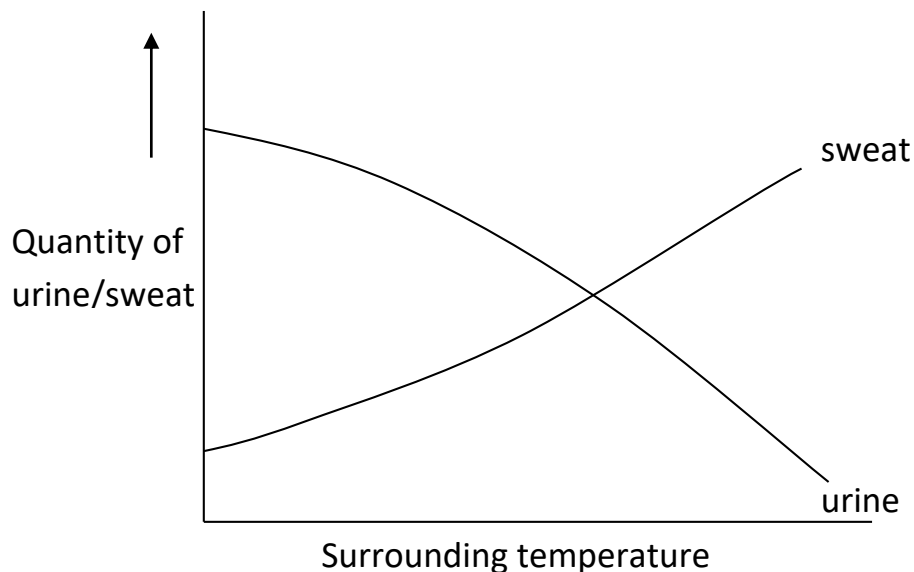
Functions of the liver

- Regulation of blood glucose levels. The liver converts excess glucose to glycogen which can be broken down to glucose thus maintaining a constant amount of glucose in blood

- Formation and distribution of fats. The liver converts excess glucose to fats for storage in fat tissues in the body
- Production of red blood cells in infants whose bones are not fully developed. NB: In adults, the role of red blood cell production is taken up by bone marrows and liver takes on an opposite role of breaking down old red blood cells.
- Formation of bile; bile contains pigments from breakdown of haemoglobin in the liver and bile salts. It is stored in the gall bladder and added to food in the duodenum during digestion
- Storage of iron, iron from haemoglobin breakdown is stored in the liver for later use
- Storage of vitamins; fat-soluble vitamins A, D, E and K are commonly stored in the liver. This explains why a liver is a good source of vitamins
- Deamination; excess amino acids are deaminated in the liver, forming ammonia which is converted to urea and eliminated in urine. The remaining portion of the amino acid is converted to a carbohydrate which can be respired.
- Detoxification; the liver converts any toxic substances into harmless substances which can be excreted in urine. E.g. nicotine, drugs, alcohol
- Manufacture of plasma proteins like fibrinogen which is needed for blood clotting.
- Storage of blood; the liver has a vast network of blood vessels which can store a large volume of blood.
- Heat production; given the wide range of metabolic reactions occurring in the liver, significant amount of heat is produced thus maintaining a constant body temperature.

TRIAL QUESTIONS

The graph below shows the variation in the amount of sweat and urine with temperature in humans.



- (a) How does the increase in temperature affect
- (i) urine production? (ii) sweat production? (2 marks)
- (b) Explain your answer in (a)(i) above
- (i) Explanation for (a) (i) (ii) Explanation for (a) (ii) (4mks)
- (c) State three conditions under which humans pass out concentrated urine. (1 ½ mks)
- (d) A part from sweating, state three other body responses by mammals to overheating. (1 ½ mks)

ROLE OF LUNGS IN EXCRETION AND HOMEOSTASIS

Getting rid of excessive heat

When cold air from the atmosphere enters the respiratory system it is warmed as it absorbs heat from the blood in blood vessels by conduction, the warm air is then exhaled, resulting in a significant source of heat loss.

Removal of water

In coming dry air from the environment dissolves in the mucus, this is warmed until it forms water vapour. Also, water vapour formed during metabolism diffuses into the alveolar sac and is expelled during exhalation.

Removal of carbon dioxide

Carbon dioxide produced during metabolism diffuses along its concentration gradient from the blood to the alveolar air at the lungs, this is expelled out of the body during exhalation.

SAMPLE QUESTIONS

1. (a) Describe the process of urine formation in man
(b) Describe the difference between glomerular filtration rates between an animal living in fresh water and one living in a desert though they may be of the same size
(c) State with a reason the major nitrogenous waste excreted by each of the animals above
2. (a) State the conditions under which a human being can produce
 - (i) Concentrated urine
 - (ii) Dilute urine
 - (iii) Urine containing glucose

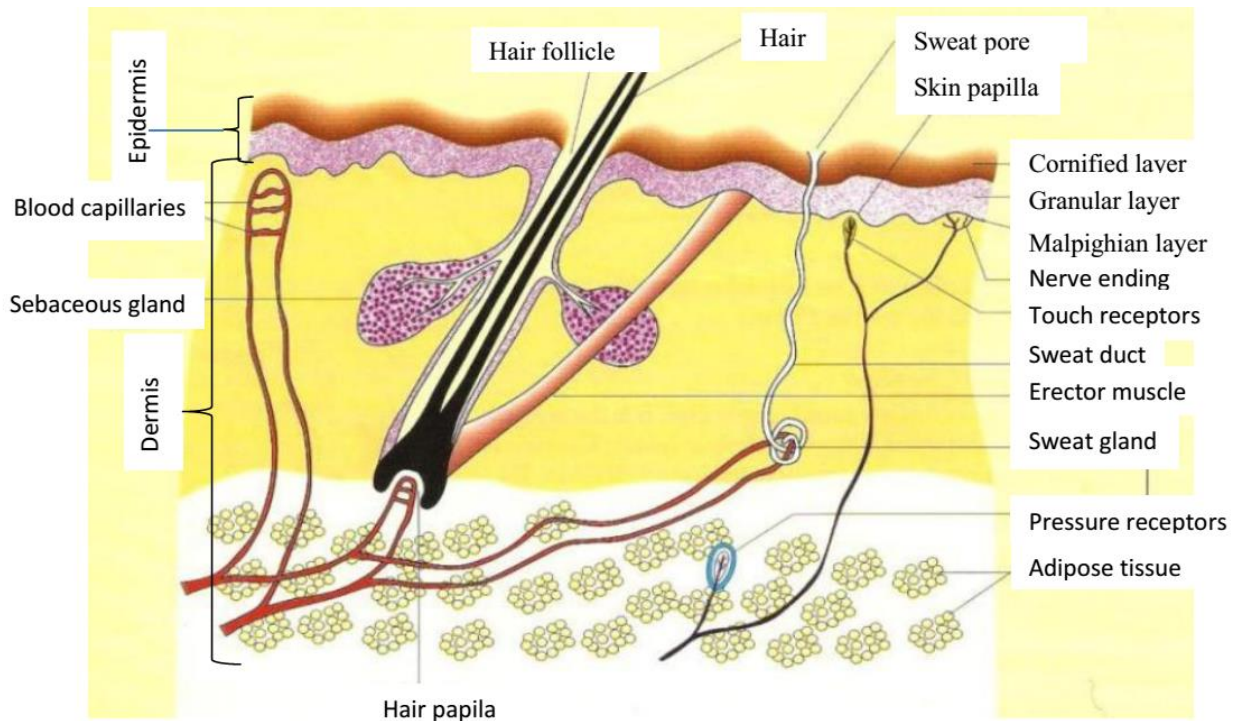
(b) Briefly describe the experiment you would carry out to test for presence of glucose in urine of a patient

3. How the structures of the mammalian nephron are related to the functions they perform / adaptations of the mammalian nephron to its functions.

THE SKIN

This is the most extensively distributed tissue found all over the body of mammals. It is a continuous protective layer over the body.

Structure of the skin



The skin consists of two main layers.

1. The epidermis (outer layer)
2. The dermis (inner layer)

THE EPIDERMIS:

This is made up of three sub layers.

- a) The Malpighian layer.
- b) The granular layer.
- c) The cornified layer.

1) The Malpighian layer

This is the inner most sub layer in the epidermis. It consists of dividing cells which give rise to cells of the granular layer. It secretes a pigment called melanin, which gives the skin its colour and protects the skin from ultraviolet rays. Albinos do not produce melanin in their skins.

2) The granular layer

This contains living cells arising from the malpighian layer. It is the biggest layer of the epidermis. It gives rise to cells of the cornified layer.

3) The cornified layer.

This is the outermost layer of the skin. It is made up of dead cells, which are keratinized. Cells of this layer continuously wear away and are replaced by cells from the granular layer. Its function is to protect the inner parts of the body from mechanical injury and entry of bacteria and other germs. It also offers water proofing to the skin.

THE DERMIS:

This is the inner layer of the skin. It is below the malpighian layer. It is thicker than the epidermis. It contains the sweat glands, nerve fibres, fat cells and blood capillaries.

Other parts of the skin

1) Hairs.

The hairs extend from the dermis through the epidermis. They arise from hair follicles in the dermis. They protect the body and trap a layer of air on the skin, which insulates the body against heat loss.

2) Sebaceous gland

This secretes an oily substance called sebum. This oil softens the cornified layer and prevents it from cracking. The oil also provides water proofing to the skin.

3) Nerve endings.

These perceive external stimuli and transport impulses to the central nervous system.

4) Sweat glands.

These are coiled tubular glands located in the dermis. They excrete sweat, which is released out of the skin through the sweat duct.

Functions of the skin

- i) To protect the tissue below it from mechanical damage, bacterial and viral infections.
- ii) It also prevents excess loss of water from the body.
- iii) It is a sense organ and it is sensitive to pain, touch and heat.
- iv) It keeps the body temperature of endothermic organisms constant.
- v) It synthesizes vitamin D in presence of sunlight.
- vi) It is an excretory organ. It excretes sweat, which contains urea, water and excess salts.

TEMPERATURE REGULATION IN MAMMALS

Temperature regulation is the process of maintaining a fairly constant body temperature despite changes in the environmental temperature.

This is important because it ensures an ideal temperature for body metabolic reactions which are controlled by enzymes to take place faster.

NB: To maintain body temperature constant, there must be a balance between heat loss and gain. Mammals gain heat through the following ways:

- Radiation directly from the sun and warm objects in the environment
- Convection from warm air or water molecules in contact with the body
- Conduction from hot objects in direct contact with the body
- Metabolic reactions in the body (for endotherms)

Ways by which organisms lose heat include;

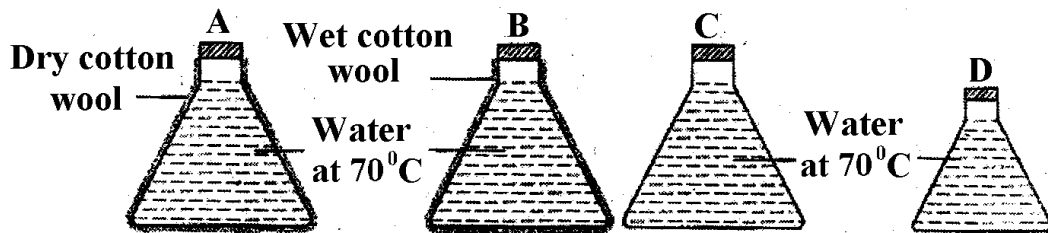
- Evaporation of water .e.g. during sweating
- Conduction to cold objects in contact with the body.
- Convection to cold air or water molecules in contact with the body
- Radiation of heat to cold objects in the environment

The rate of heat loss and gain depends on;

- Surface area to volume ratio i.e.
Small organisms having a large surface area to volume ratio tend to lose more heat than the large ones with small surface area to volume ratio.
- Temperature of surrounding environment: Organisms tend to lose more heat in cold environment and gain more in hot environment.
- Rate of respiration: The higher the rate of respiration, the more heat energy gained by the body.
- Humidity of the environment: Heat loss increases in humid conditions because high humidity makes the environment colder.

Trial question

Figure 5 shows four flasks A, B, C, D each filled with hot water at 70°C and left to cool. Flask A is insulated with dry cotton wool, flask B with wet cotton wool, flask C is not insulated and flask D is smaller in size and not insulated. The flasks represent mammalian bodies.



The table below shows the temperature in each flask in figure 5, recorded at 10 minute intervals for 30 minutes.

Flask	(Temperature (°C) at 10 minute intervals)			
	0(min)	10(min)	20(min)	30(min)
A	70	66	62	60
B	70	50	38	30
C	70	60	53	48
D	70	53	40	38

Study the information and answer the questions that follow:

- (a) For each flask draw a graph to show the changes in temperature with time in the space on next page. Use the same X and Y axes for all the graphs. (06 marks)
- (b) Calculate the average rate of cooling in each flask. (04 marks)
- (c) Explain the rate of cooling in
- (i) flask A (02mks) (ii) flask B(03mks)
- (iii) flask C (02mks) (iv) flask D(02mks)
- (d) From the information, state two factors that affect the rate of cooling from a body. (01 mark)

MEANS OF TEMPERATURE REGULATION

Mammals are grouped into two according to their ability or inability to maintain a constant body temperature; i.e. Homoiothermic and poikilothermic animals

POIKILOTHERMIC ANIMALS (Ectothermic animals)

These are animals whose body temperature changes with change in environmental temperature (Greek; **Poikilos** means **various**). Such Animals are called **ectothermic** because their bodies mainly obtain heat from the environment. Their body temperature therefore is always lower than environmental temperature hence the term cold blooded animals

Examples include:-

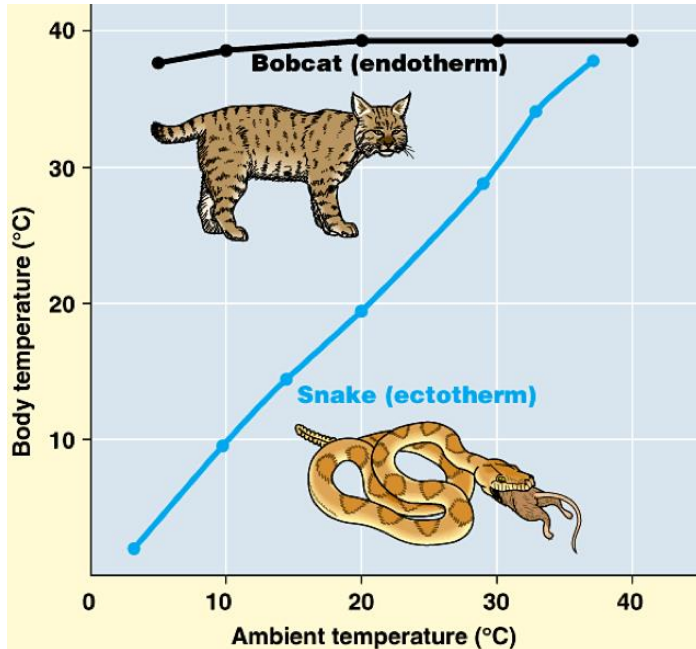
- all invertebrates,
- fish,
- amphibians
- reptiles

Homoiothermic animals (Endothermic animals)

These are animals that maintain a constant body temperature despite changes in environmental temperatures. (Greek; **Homoios** means **constant**). Such animal are also called endothermic because heat is mainly generated by metabolic reactions occurring within the body.

Examples include: - birds and mammals only.

The graph below shows the relationship between body temperature & environmental temperature of an ectotherm and an endotherm



Observations

- The body temperature of endotherms remains almost constant despite the increase in surrounding temperature.
- The body temperature of ectotherms varies with environmental temperature.

Control of body temperature in endotherms

When temperature is high, organisms respond in a way that lowers down the temperature and when the temperature is low, organisms respond in a way that raises their body temperature. These responses are categorized into two types.

1. Physiological responses. These are involuntary actions and they occur in body organs in response to temperature changes.

2. Behavioral responses. These are voluntary responses from the organism. The organism consciously decides what to do when external and internal temperatures change.

Response to cold weather in endothermic animals

Physiological means.

- ✓ The erector pill muscles of the hair contract to make the hairs stand upright to the skin. The hairs trap a layer of air, which insulates the skin.
- ✓ The rate of sweating reduces in order to reduce on the amount of heat lost through it.
- ✓ The metabolic activity of the liver increases to produce energy in form of heat.
- ✓ Blood vessels near the skin constrict in the process called vasoconstriction to reduce on the blood reaching the skin. This reduces heat loss through radiation.
- ✓ Small animals like the mouse undergo hibernation where they dig holes and live deep in them to reduce heat loss
- ✓ Shivering. This is the rhythmic contractions of the skeletal muscles. It results into production of heat energy.
- ✓ Some have a thick fat layer to act as an insulator.
- ✓ Some are very big and thus have a small surface area to volume ratio. This reduces the rate of heat loss.
- ✓ Some have few sweat glands to reduce of the heat lost during sweating

Behavioral means.

Endotherms may raise their body temperature behaviourally through;

- ✓ Sitting near hot bodied to raise their body temperature by conduction or radiation.
- ✓ Humans take hot drinks.
- ✓ They do physical exercises to raise the metabolic activity of the body.
- ✓ They can take a hot bath

- ✓ Hibernation. This is a state of long rest by burrowing into crevices and holes during extreme coldness.
- ✓ They put on thick clothes, which insulate their bodies.
- ✓ Sun bathing

Response to hot weather in endothermic animals

In hot environment, animals control the body temperature by increasing heat loss and lowering heat production through the following ways:

Physiological means.

- ✓ The erector pilli muscle of the skin relaxes making the hairs to fall on the skin. This allows heat loss by radiation.
- ✓ The metabolic rate of the body reduces to reduce on the amount of heat produced.
- ✓ Sweating increases. In this process excessive heat is lost as latent heat of vaporization to evaporate the sweat from the body hence losing heat.
- ✓ Vasodilatation. Vessels dilate and allow more blood to reach the skin surface in order to lose heat to the surroundings by radiation.
- ✓ Animals living in hot environments have a thin fat layer to reduce on the insulation.
- ✓ Having little hairs on the body to allow easy loss of heat.
- ✓ Having less fat to reduce on the insulation effect of fats.
- ✓ Having a large surface area to volume ratio. To allow a faster rate of heat loss.
- ✓ Some have a lot of sweat glands to increase heat loss through sweat.
- ✓ Having many blood vessels near the skin for easy loss of heat by radiation.

Behavioural means.

- ✓ Some rest on cold bodies like rocks to lose heat by conduction.
- ✓ Humans sit near fans.

- ✓ Some take cold drinks.
- ✓ They put on light clothes
- ✓ Panting. This involves hanging out of the tongue for example in dogs. This results into evaporation from the mouth, which eventually cools the animal.
- ✓ Swimming.
- ✓ Resting under shade.
- ✓ Bathing cold water.
- ✓ Aestivation. This is a state of long rest by burrowing in crevices and holes during extreme hotness.
- ✓ Putting on lighter clothes in man.

TEMPERATURE CONTROL IN ECTOTHERMIC ANIMALS

Their body temperature is controlled by only behavioral means.

During hot conditions, they lose heat by.

- ✓ They rest on cold rocks to lose heat by conduction.
- ✓ They rest on cold stones and in shades to lose heat.
- ✓ They burrow in cracks and lose heat by radiation.
- ✓ Aestivation. This is a state of long rest by burrowing underground or under rocks during high temperatures.
- ✓ Thermal gaping. This is the opening of the mouth to lose water by evaporation. This results into cooling. Thermal gaping occurs in crocodiles and a few other reptiles.

During cold conditions, they gain heat by;

- ✓ Resting on hot rocks to gain heat by conduction.
- ✓ They rest under the sun to gain heat by radiation.
- ✓ They rest near hot bodies to gain heat by radiation.
- ✓ They burrow in hot sand to gain heat by conduction.

- ✓ Basking in the sun to gain heat.
- ✓ Hibernation. This is a state of long rest by burrowing into crevices and holes during extreme coldness.

Advantages of endothermy

- They are able to live in a wide range of environment irrespective of the prevailing temperature; because they are able to regulate their body temperature.
- They remain active at all times of the day as they regulate their body temperature
- Body processes occur efficiently because the body temperature is maintained near to optimum temperatures for body enzymes.
- Endotherms show faster responses to changes in the environment which increases chances of survival.

Disadvantages of endothermy

- Much food must be consumed to maintain a high rate of metabolism to generate heat.
- Much heat is lost from the body as the body temperature is higher than that of the environment.

Advantages of ectothermy

- Ectotherms consume less food as heat is mainly obtained from the environment.
- They produce fewer wastes due to low metabolism.

Disadvantages of ectothermy

- Slow responses to stimuli due to low metabolic when the temperature is low
- They can occupy a limited range of habitats where temperatures are favourable
- They are not active at some times of the day when temperatures are too high or low

TRIAL QUESTION

Table 1 shows the body surface area and volume of two land mammals A and B. Table 2 shows the rate of metabolism in arbitrary units, of the two animals at varying environmental temperatures.

Table 1

Mammal;	Surface area (m²)	Volume (m³)
A	1.2	0.92
B	0.6	0.18

Table 2

Environmental Temperature (°C)	Metabolic rate (arbitrary units)	
	Mammal A	Mammal B
16	10.5	12.9
18	8.9	10.9
20	7.5	9.2
22	6.4	7.8
24	5.6	6.7
26	5.0	5.8

- (a) From Table 1
- (i) work out the surface area: volume ratio of each mammal (2mks)
 - (ii) State the structural difference between mammal A and B. (02mks)
- (b) Using the space provided, plot on the same graph the metabolic rate me two animals against environmental temperature. (07mks)
- (c) From your graph, determine the metabolic rate of each environmental temperature of 25°C.

- (d) (i) How does environmental temperature affect the metabolic rate of the mammals? (02 marks)
- (ii) Explain why variation of temperature affects the metabolic rate of the mammals as stated in (c) (i), (02 marks)
- e) From the information provided explain why at any environmental temperature, the metabolic rate of mammal B is higher than that of mammal A. (03mks)