HOMEOSTASIS, OSMOREGULATION AND EXCRETION

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Syllabus extract

Specific objectives The learner should be able to :	**Content**
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• Explain the feedback mechanism related to the endocrine and nervous systems. • Identify the main internal and external causes of changes in the internal environment. • Describe the formation, composition and movement of tissue fluid and its relationship to the blood and lymph.	• Feedback mechanism related to the endocrine and nervous systems in homeostatic activities. • Causes of changes in the internal environment. • Formation, composition and movement of tissue fluid and its relationship to the blood and lymph.
Principles of homeostasis practical • Relate organism's ways of life to their environmental condition.	• Adaptation of organisms to different environmental conditions.
Regulation of glucose • Describe the role of hormones in sugar regulation. • Explain the negative feedback mechanism in the process of blood glucose control. • Discuss the cause and effects of blood sugar imbalance in the body. • Relate the microstructure of the liver and pancreas to their functions. • Discuss the functions of the liver and the pancreas in regulation of glucose in the body.	• Action of insulin, glucagon and adrenalin in blood sugar control. • The negative feedback mechanism in the process of blood glucose control. • Causes and effects of blood sugar imbalances in the body. • Microstructure of the liver and pancreas and their functions. • Role of the liver and the pancreas in glucose regulation.
Regulation of glucose practical • Test urine sample for sugar • Relate structure of liver and pancreas to their function.	• Identification of sugar in urine • Histology of liver and pancreas: micro structure and their function.
Regulation of carbondioxide • Describe the regulation of respiratory gases. • Discuss the role of feedback mechanism in response to oxygen deprivation. • Explain the effects of fluctuations of respiratory gases on the rate of breathing. • Explain the role of respiratory centre in the brain in controlling respiration and bold circulation. • Describe the different physiological changes that take place during exercise and at high altitude.	• Control of respiratory gases. • Role of feedback mechanism in response to oxygen deprivation. • Effects of fluctuation in oxygen and carbondioxide gases on the rate of breathing. • Role of medullary centres in controlling respiration and blood circulation. • Physiological changes that take place during exercise and at high altitude
Regulation of carbondioxide practical • Determine the rate of breathing at different levels of activity.	• Effect of different levels of activity on the rate breathing.
Temperature regulation • Explain the importance of temperature regulation • Discuss the morphological, physiological and behaviour adaptation. To temperature change in the environment. • Describe the responses to cold and hot conditions by endothermic and ectothermic animals. • Explain the role of the brain and thermoreceptors in temperature regulation. • Describe the different processes in which plants minimize overheating.	• Importance of temperature regulation. • Morphological, physiological and behaviorism, adaptations to temperature changes in the environment. • Response to cold and hot conditions by endothermic and ectothermic animals. • The role of the Brain hypothalamus and thermoreceptors in heat regulation. • Temperature control in plants.
Regulation of temperature practical	• Effects of temperature conditions on animal behavior.

• Collect and interpret data related to effects of temperature regulation.	
Excretion • Describe the structure and role of excretory organs in mammals. • Describe the structure and functions of the nephron • Describe the formation of urea and urine. • Describe excretion process in other organisms • Explain excretion in plants.	• Structure and functions of excretory organs in mammals: kidney, liver, skin and lungs. • Structure and function of the nephron. • Formation of urea and urine. • Excretion in other organisms: Protoctista, insects, fish, amphibians and birds. • Excretion in plants.
• Identify and draw sections of parts of kidney • Dissect, display, draw and label the urinary system.	• Histology of the kidney: cortex, medulla, different regions of the nephron. • Urinary system of a toad, rat/ rabbit
Osmoregulation • Describe the role of the brain, endocrine glands and nephrons in osmoregulation. • Explain the negative feedback mechanism involving Anti- Diuretic Hormone (ADH). • Discuss principles of osmoregulation in organisms living in marine, fresh water and terrestrial habitats. • Explain animals' adaptations to varying water availability in their habitats. • Explain osmoregulation in plants and how plants are adapted to varying wager availability in their habitats.	• Role of the hypothalamus, pituitary gland, adrenal gland and nephrons in varying osmotic pressure of blood. • Role of negative feedback mechanism involving anti-diuretic hormone (ADH). • Principles of osmoregulation in marine, fresh water and terrestrial organism. • Adaptations of animals to varying water availability in habitats. • Osmoregulation in plants (xerophytes, hydrophytes, mesophytes, halophytes)

HOMEOSTASIS

Homeostasis (homo, same; stasis, state) is the relative constancy of the body's internal environment regardless of the conditions in the external environment.

Examples of components of the internal environment that are homeostatically controlled include;

a. Concentration of blood glucose at 90mg/100cm^3
b. Average core body temperature at 37^{o}C or 98.6^{o}F
c. Blood pressure at the brachial artery averages near 120/80
d. Blood levels of ions such as Na^+, Cl^-, Ca^{2+}e.t.c.
e. Concentration of carbon dioxide

Cybernetics is the study of control systems i.e. *self-regulating*/self-adjusting systems which operate by means of feedback mechanisms. **A feedback mechanism** is one in which an input stimulus causes an output response that 'feeds back' to the initial input.

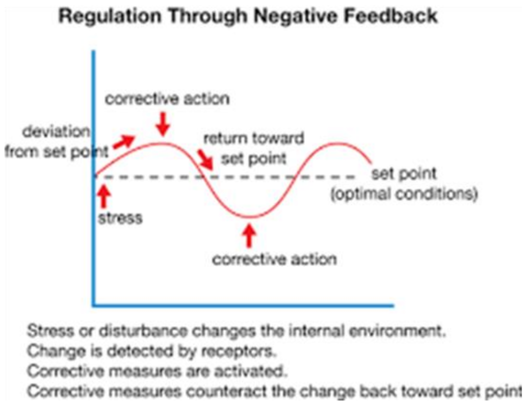
The internal state of an animal's body is a dynamic equilibrium i.e. many physical and chemical changes do occur that the net result is that, the changes are maintained constant by feedback systems so as to enable cells function efficiently.

Feedback may be positive or negative

a. Negative feedback

A mechanism in which the effect of deviation from the normal condition triggers a response that eliminates its deviation in order to reduce further corrective action of the control system once the set point value has been reached.

In negative feedback mechanism, a stimulus causes a sensory receptor to signal the **regulatory centre** in the brain. The regulatory centre then signals an effector to respond and the response cancels/reverses the stimulus to restore the condition to the norm.



b. Positive feedback

A mechanism in which the effect of deviation from the normal condition intensifies the original response such that the change tends to proceed in the same direction as the initial stimulus.

Examples of positive feedback include;

i. A 10^{o}C decrease in temperature doubles metabolic activity, releasing more heat that raises the activity even more
ii. During child birth, stretching of the uterus by the foetus stimulates contraction and the contractions stimulate further stretching. The cycle continues until the foetus is expelled.
iii. During blood clotting, to stop bleeding in order to keep blood volume constant. One clotting factor activates another in a **cascade** that leads quickly to the formation of a clot. A **cascade effect** is the way in which a small amount of, say a hormone, can cause a target organ to produce a large amount of the product.

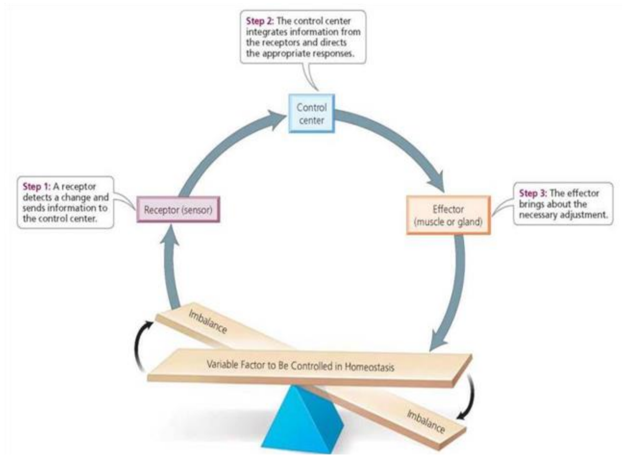
ESSENTIAL COMPONENTS OF A CONTROL SYSTEM

Each control system must have the following essential components;

a. Receptors/detectors

These are parts of the body hat constantly monitor and detect changes from the reference point/norm in the internal environment and then signal the deviations.

Temperature receptors in the skin provide information on variation in temperature of external environment.



b. Control centre

This is usually the brain that coordinates the information received from the various receptors and sends out instructions which will correct this deviation.

Variations in temperature of external environment are conveyed to the **hypothalamus** of the brain.

c. Effector/responding organs

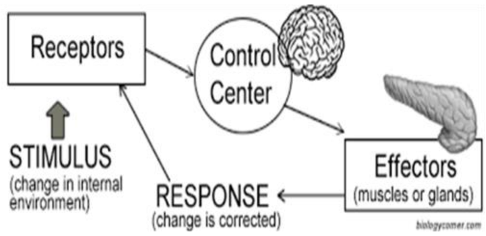
These are parts of the body that bring about the necessary changes needed to return the system to the reference point/norm. The hypothalamus initiates corrective responses in effectors like blood vessels and skin to restore the temperature back to the normal. The average temperature is 37ºC.

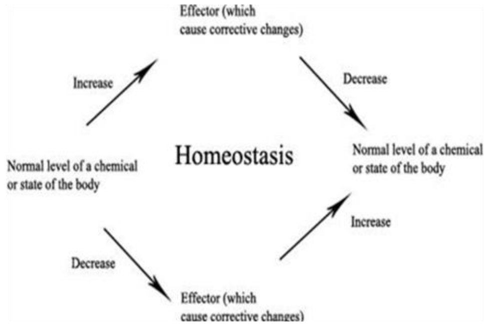
d. Reference point/norm

This is the set level at which the system operates

e. Feedback loop

Hormones and/or nerve impulses that inform the receptor of any change in the system as a result of the action of the effectors.





(Fig 19.1 & 19.2 R. Soper page 648)

TISSUE FLUID

This is the fluid that is derived from blood plasma by filtration through capillaries. It is found around tissue cells and contains molecules that enter from or exit to the capillaries. The body's internal environment consists of tissue fluid and blood that bathes cells. It may be called the **interstitial** or **intercellular fluid.**

FORMATION OF TISSUE FLUID

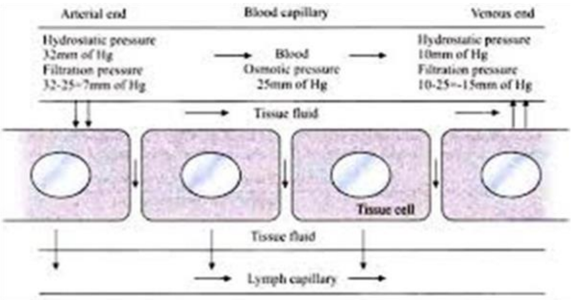
Tissue fluid is formed by **ultrafiltration** i.e. hydrostatic pressure of blood forces small molecules to exit blood capillaries via fine pores on the basement membrane but large molecules are held back.

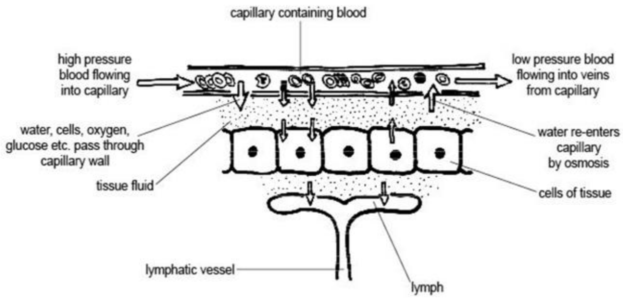
Fluid movement in and out of capillaries depends on the balance between the **blood pressure** (hydrostatic pressure) and **osmotic pressure** (solute potential). Osmotic pressure is created by the presence of salts and plasma proteins in blood while blood pressure is created by the pumping action of the heart and the resistance to blood flow caused by the small size of the lumen of capillaries.

At the arterial end of the capillary bed, blood pressure is higher than osmotic pressure of blood. This results into the forced exit of small molecules like glucose, water, amino acids, ions, oxygen, and small plasma protein molecules via fine pores on the basement membrane of arterioles BUT large plasma protein molecules and red blood cells are retained.

Midway along the capillary bed where the blood pressure is lower, the two forces of blood pressure and osmotic pressure essentially cancel each other and the substances diffuse according to their concentration gradients i.e. glucose, oxygen and other solutes diffuse out of the capillary while carbondioxide and other wastes diffuse into the capillary. No net movement of water occurs.

At the venule end of the capillary bed, blood pressure is lower than osmotic pressure of blood, resulting into entry of water, carbondioxide, wastes and solutes into the capillaries. However, the total amount of fluid exiting capillaries at the arterial end exceeds that entering at the venule end. This is because the osmotic pressure causing the entry of fluids at the venule end is lower than the blood pressure causing exit of fluid at the arterial end, resulting into failure of some fluid flowing in capillaries, forming what is called **tissue fluid**.





(Roberts and Reiss, page 268)	**Note**. Tissue fluid is drained by the lymphatic system, where it becomes lymph which eventually passes into the veins at the same rate as it is formed, failure of which results in a condition known as **oedema**.

HOMEOSTASIS IN UNICELLULAR ORGANISMS AND CELLS OF MULTICELLULAR ORGANISMS

At cellular level, the internal environment of a cell is its cytoplasm while the cell's immediate surrounding constitutes its external environment.

Tissue fluid in most animals and sap in plants, constitute the external environment of cells of multi cellular animals and plants respectively, but form the internal environment of these organisms.

The constituents of a cell cytoplasm are modulated by the partial permeability of its cell membranes and the level of activity of its enzymes.

The cell surface membrane selectively allows entry and exit of molecules at a strictly controlled rate by diffusion gradient, osmotic gradients and active transport.

The nature and amounts of materials synthesised is controlled by the rates of protein synthesis and they catalyse most anabolic and catabolic reactions within cells.

Therefore, relative constancy of the cell's internal environment depends on supply of metabolites, utilisation of cellular material or out put through activity of the modulators.

HOMEOSTATIC ROLE OF THE LIVER AND THE PANCREAS

A. Structure

The liver is the largest internal organ of the body, weighing about 1.5kg in humans, which is about 3.4% of the total body mass. The liver's external shape is of little importance, but the internal structures reveals precious details

The liver is composed of structural and functional units called **lobules**, which are cylindrical in shape, numbering over 1000 with each being approximately 1mm in diameter. Liver cells (**hepatocytes**) closely pack in each lobule in various rows radiating outwards from the centre. Hepatocytes which are in contact with blood vessels bear microvilli. Hepatocytes are characterised by similarity in structure and function, prominent nuclei, Golgi complex, glycogen granules, peroxisomes, numerous mitochondria, fat granules and lysosomes. Peroxisomes contain catalase and other oxidative enzymes responsible for detoxification.
Located between lobules are triads consisting of a branch of the **hepatic artery** which bring oxygenated blood to the liver, a branch of the **hepatic portal vein** which brings nutrients from the gut and the bile duct that drains bile from the liver. A **central vein** (branch of the hepatic vein) runs longitudinally mid-way each lobule and is linked by **sinusoids** to the interlobular vessels (hepatic artery and hepatic portal vein). Sinusoids radiate from the centre to the periphery of the lobule and their endothelial lining is perforated. Sinusoids alternate with the **bile canaliculi**; small canals that carry bile. Attached to the walls of sinusoids are macrophagus cells called **Kupffer cells**

(Roberts and Reiss, page 277 fig 16.11 & Soper page 667 fig. 19.21)

Function of Kupffer cells

- Kupffer cells ingest worn out red blood cells, bacteria and foreign particles from the blood flowing through the liver. Kupffer cells show amoeboid movements which engulf, ingest and destroy pathogens. The Kupffer cells are permanently located in the liver and thus they engulf protozoan parasites.
- Kupffer cells form cytoplasmic extensions to form pseudopodia which surround and engulf microorganisms. Microorganisms are completely surrounded by pseudopodia to form phagocytotic vesicles which pinch off the cell membrane into the cytoplasm
- The phagosome fuse with the lysosome to form phagolysosome. Inside the phagolysosome are microbes which are broken down by hydrolytic enzymes.

B. How structure is related to function

i. Kupffer cells ingest worn-out red blood cells, bacteria and foreign particles from the blood flowing through the liver
ii. Closeness of hepatocytes with sinusoids and canaliculi enables them to receive nutrients and expel waste products
iii. The excellent blood supply provides nutrients to the cells and enables waste to be carried away
iv. Hepatocytes bear numerous mitochondria for ATP production required in providing energy that facilitate some of the metabolic reactions
v. The liver is large, providing a large surface area for metabolic reactions to occur
vi. Hepatocytes bear numerous peroxisomes containing catalase and other oxidative enzymes responsible for detoxification of poisonous substances in the liver
vii. Its tissue is elastic, enabling expansion to store a large volume of blood
viii. Hepatocytes are similar in structure (undifferentiated) enabling them to perform various metabolic functions

C. Functions of the liver

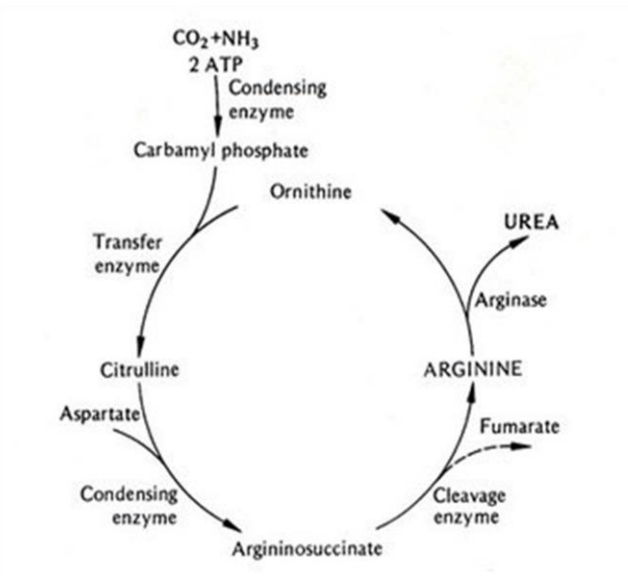
Some of the functions of the liver, out of the estimated 500 that it performs, are **digestive**, **regulatory** and **excretory**.

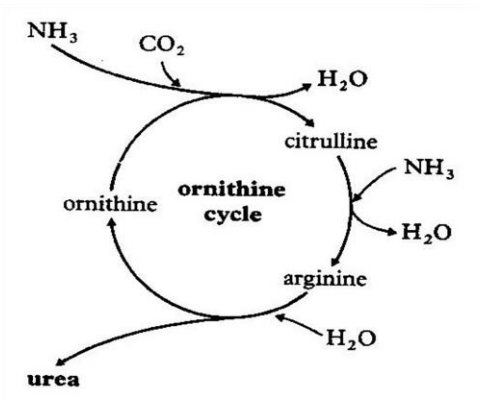
I. It maintains a steady blood glucose concentration by conversion of glucose into glycogen (if above the norm) and vice versa (if below the norm), under the influence of hormones. The liver's carbohydrate metabolism involves the following;
    i. Glycogenesis, promoted by insulin
    ii. Glycogenolysis, promoted by glucagon
    iii. Lactic acid metabolism, initiated by the enzyme lactate dehydrogenase
    iv. Gluconeogenesis, promoted by cortisone and adrenaline hormone

(Fig 19.4 R.Soper page 650 & Fig 13.6 Chilton page 107)

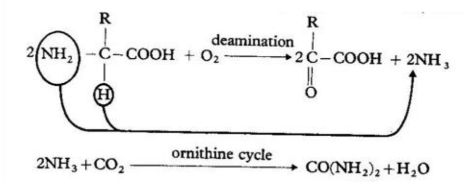
II. The liver regulates amino acids and proteins (protein metabolism) in the body

Excess amino acids are not stored in the body, any surplus is gotten rid of by the liver through **deamination**. Deamination involves removal of the amino group (-NH_2) from the amino acid to form ammonia, which in mammals is converted through a series of reactions (**ornithine cycle**) to urea, $CO(NH_2)_2$, which is shed from the liver cells into the blood stream and transported to the kidney for excretion. The amino acid residue is fed into the carbohydrate metabolism pathway and oxidised to release energy.





The liver also carries out **transamination** i.e. it transfers amino groups from amino acids to other organic compounds to form amino acids that are deficient in the diet.



III. The liver regulates lipids (lipid metabolism) in the body
   i. Excess carbohydrate is converted to fat
   ii. Stored fat are de-saturated prior to oxidation
   iii. It synthesizes and degrades phospholipids and cholesterol
   iv. It synthesizes lipid transporting globulins

Excess cholesterol in blood is excreted into bile by the liver to avoid accumulation, which can result in arteriosclerosis (narrowing of the lumen of arteries) which can cause thrombosis (blood clotting in blood vessels). If cholesterol is greatly in excess in bile it forms gall stones, which can block the bile duct.

IV. The liver forms red blood cells in the foetus and breaks down worn out red blood cells in adults. The liver's Kupffer cells break down worn out red blood cells to form the bile pigment, bilirubin, which is excreted in bile. The haemoglobin is broken down into globin, a protein and haem, from which iron is removed and stored

V. The liver detoxifies poisonous substances i.e. naturally occurring compounds absorbed by the body which can be toxic if allowed to accumulate are rendered harmless by the liver cells (hepatocytes) e.g. ethanol is oxidised to ethanal. Products of detoxification are usually excreted, but sometimes they are stored

VI. It synthesizes plasma proteins from amino acids. They include albumin (a transport molecule), globulin (a transport molecule of hormones), prothrombin and fibrinogen (clotting factors)

VII. The liver produces bile, which is a mixture of salts and cholesterol. Bile emulsifies fats during digestion in the duodenum

VIII. The liver stores fat soluble vitamins A, D, E, K and water soluble vitamins B_{12} and C.

IX. The liver stores minerals like iron, potassium, copper, zinc and trace elements

X. The liver stores up to 1500cm^3 of blood in its vast network of blood vessels, hence acting as a blood reservoir during emergency cases

XI. The liver destroys all hormones after exerting their effects in the body

REGULATION OF BLOOD GLUCOSE

The concentration of glucose is 90-100mg of glucose per 100cm^3 approximately 0.1% or 0.1g per 100cm^3 of blood. Glucose in blood provides the cells of a mammal's body with an energy source. If the concentration of blood glucose falls, cell respiration will be slowed and cells will die. Cells in the brain are particularly susceptible and a lack of glucose causes coma. On the other hand, too high a blood glucose concentration makes the water potential of blood to lose water by osmosis. The glucose level may lower to 70mg per 100cm^3 of blood, this is known as **hypoglycaemia** or rise to 150-200mg of blood and this is known as **hyperglycaemia**.

HOW THE LIVER AND PANCREAS INTERACT TO MAINTAIN GLUCOSE LEVELS CONSTANT

Hyperglycaemia stimulates the **beta cells of the islets of Langerhans** in the pancreas to secrete the hormone **insulin** into blood (occurs when the rate of glucose intake from the gut exceeds the rate of oxidation or conversion to glycogen). Insulin binds to body cells with insulin receptors and leads to processes which reduce glucose concentration, for example;

i. Increased cellular respiration in muscle and liver cells to form carbondioxide and water
ii. Increased **glycogenesis** (formation of glycogen from glucose) in muscle and liver cells
iii. Increased conversion of glucose to fat and protein in adipose tissue
iv. Increased uptake of glucose in muscle cells

Hypoglycaemia inhibits insulin secretion but stimulates **alpha cells of the islets of Langerhans** in the pancreas to secrete the hormone **glucagon** into blood. Glucagon binds to liver cells since they are the only ones with glucagon receptors, causing them to increase blood glucose level through;

i. Increased **glycogenolysis** (hydrolysis of glycogen to glucose)
ii. Increased formation of glucose from amino acids and glycerol. The formation of glucose from non-carbohydrate sources is called **gluconeogenesis**. This leads to wasting away of tissues, which occurs in extreme starvation, causing the blood sugar in the hepatic artery to be higher than that in the hepatic vein.

Note:

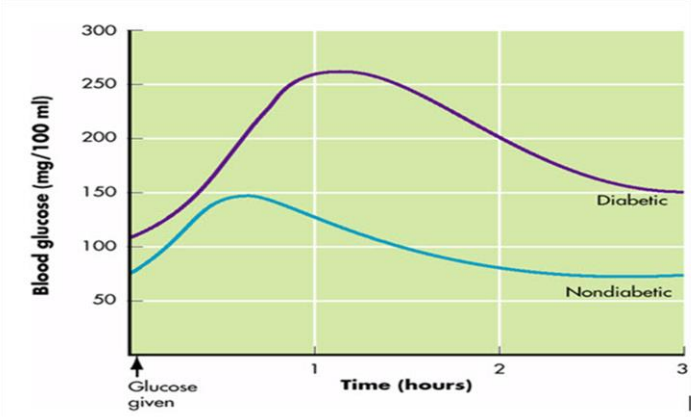
1. When blood glucose levels return to normal levels, the circulating insulin and glucagon hormones are metabolized and then removed at the kidneys, and so rapidly disappear from the blood.
2. Insulin and glucagon are not the only hormones that control the blood glucose concentration. For example;

i. **Adrenaline** (from adrenal medulla) causes hydrolysis of glycogen during acute stress or excitement and the usage of glucose and thus increases and reduces its concentration in blood respectively.
ii. **Cortisol** (from the adrenal cortex) causes formation of glucose from amino acids and glycerol when glycogen exhausts, hence increasing glucose concentration in blood.
iii. **Growth hormone** (from the anterior pituitary) increases the glucose concentration in blood through fat breakdown.
iv. **Thyroxine** (from the thyroid gland) stimulates the metabolic rate e.g. increased glucose breakdown.

3. In some people there may be insufficient secretion of insulin or the cells may be insensitive to insulin, resulting into a condition known as **diabetes mellitus**. Insulin dependent diabetes is caused by insufficient secretion of insulin (due to under activity of the islets of Langerhans) while insulin independent diabetes results from insensitivity of cells to insulin. Symptoms of diabetes include;
   - Hyperglycemia, glucose exceeds the maximum which can be reabsorbed from the renal filtrate in the kidneys leading to glycosuria
   - Glycosuria (glucose excreted in urine)
   - Frequent copious urine (due to the presence of glucose in urine that disturbs the water potential gradient which normally results in water reabsorption from the nephrons)
   - Visual disturbances
   - Itching of genitals
   - Fatigue
   - Rapid weight loss (breakdown of glucose is uninhibited hence the stores of glycogen in the liver and muscle are used up. Body fats and proteins are then used as respiratory substrates causing a rapid loss of body mass)
   - Drowsiness
   - Skin disorders e.g. boils
   - General weakness

Liver disorders

a. **Hepatitis**, which is an inflammation, caused by hepatitis viruses A, B, C, D and E.
b. **Jaundice**, which is characterised by a yellowish tint to the white of the eyes and a lightly pigmented skin
c. **Cirrhosis**, the liver becomes fatty, then fibrous and it is common in alcoholics
d. **Liver cancer** which is caused by exposure to chemicals like cigarette smoke, radiations e.g. X-rays, or genetic pathways.



(Fig 19.22 R. Soper page 668)

Regulators and conformers

Conformers and regulators are two broad groups of organisms by classification based on how they behave according to the changes in the environment they live.

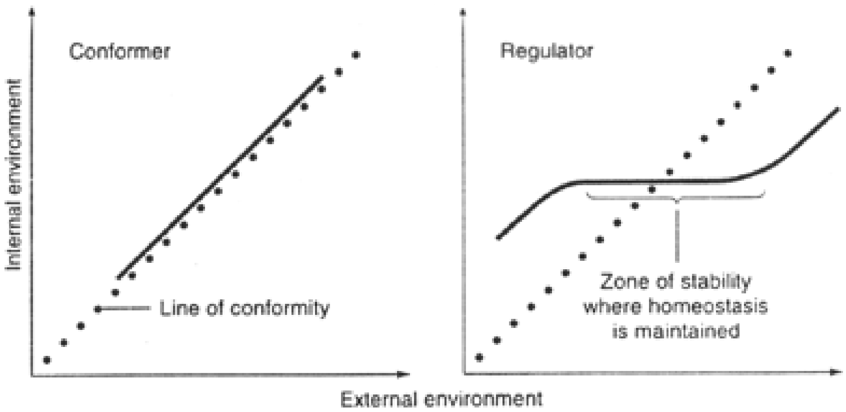
A **conformer** is dependent upon the changes in the external environment, whereas a **regulator** can control their internal environment regardless of external environmental change to a large extent

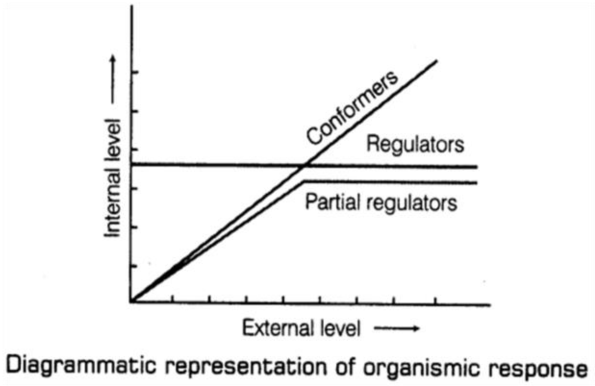
Conformers

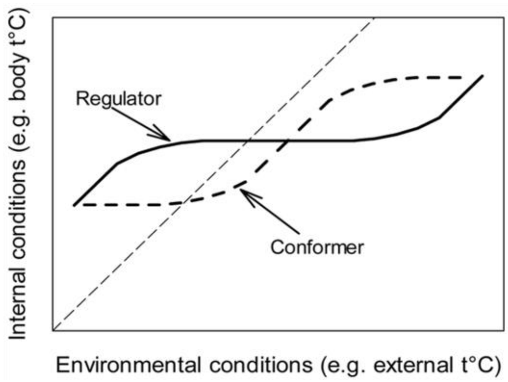
1. They have little homeostasis
2. They are ectothermic - their body temperature changes according to their environment
3. Osmotic concentration of body fluids varies according to that of external medium.
4. They consume lesser amount of energy.
5. They have a narrow range of distribution.
6. They are less active creatures.

Regulators

1. They have homeostasis - internal regulatory mechanisms to control their internal environments.
2. They are endothermic - they generate heat internally to regulate their internal body temperature.
3. Their body fluids have a fixed osmotic concentration.
4. They consume large amount of energy.
5. They have a wide range of distribution.







THERMAL REGULATION (TEMPERATURE CONTROL)

When reference is made to body temperature in animal studies it usually refers to the **core temperature**. This is the temperature of the tissue below a level of 2.5cm beneath the surface of the skin. This temperature is most easily measured taking the temperature of the rectum (rectal temperature). Temperatures near the surface of the body can vary tremendously depending upon position and external temperature. The temperature of animals must be regulated because;

I. Most body enzymes act effectively within a narrow temperature range of 35-38^oC. Temperatures above 45^0C denature enzymes and other proteins. Temperatures below the narrow range inactivate enzymes. Inactivation and denaturation of enzymes are both fatal.

II. Excessively high or low temperatures disorganise the structure and functioning of cell surface membranes, and consequently affects entry and exit of substances resulting into death of the organism.

<u>Terms associated with thermoregulation</u>

a. **Endotherm**, an organism capable of maintaining a stable body temperature independent of the environmental temperature by generating heat metabolically when environmental temperature is low e.g. mammals and birds
b. **Endothermy**, the ability of animals to maintain a constant internal body temperature
Advantages
- Animals are able to exploit various environments regardless of the existing temperatures
- Enzyme controlled reactions proceed without much interruption most of the time
- Since high metabolic reactions are maintained all the time (atleast five times than that of an homeotherm of equal size and body temperature), plenty of energy is availed to support body processes

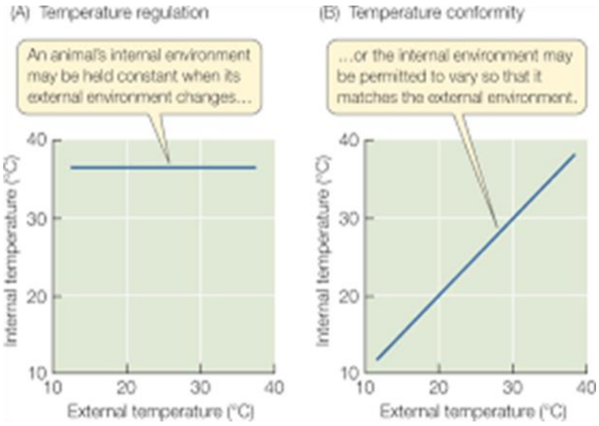
Disadvantages
- There's high food intake during low environmental temperatures to support the metabolic reactions that liberate heat
- Enzyme controlled reactions are slowed during low temperatures because enzymes become inactive
- Enzyme controlled reactions are slowed during low temperatures to avoid overheating of the body, and efficient insulation when the external temperature is too low.

c. **Homeotherm,** an organism capable of maintaining a stable body temperature independent of the environmental temperature e.g. mammals and birds
d. **Ectotherm**, an organism whose body temperature is regulated by behaviour or by the surrounding e.g. reptiles, fish, amphibians, insects e.t.c (all other animals except mammals and birds)
Advantage
- There is low food intake since regulation of temperature is by behavioural means and from the environment

Disadvantages
- Animals have limited environments to exploit depending on the existing external temperature
- Their activities are limited during instances of extreme temperature

e. **Poikilotherm,** an animal with a body temperature that fluctuates with that of the external environment e.g. retiles, fish, amphibians, insects e.t.c. (all other animals except mammals and birds)

(Fig 19.6 R. Soper page 653)



HEAT GAIN AND LOSS IN ORGANISMS

Heat gain, heat is gained as a by-product of metabolism from exothermic reactions

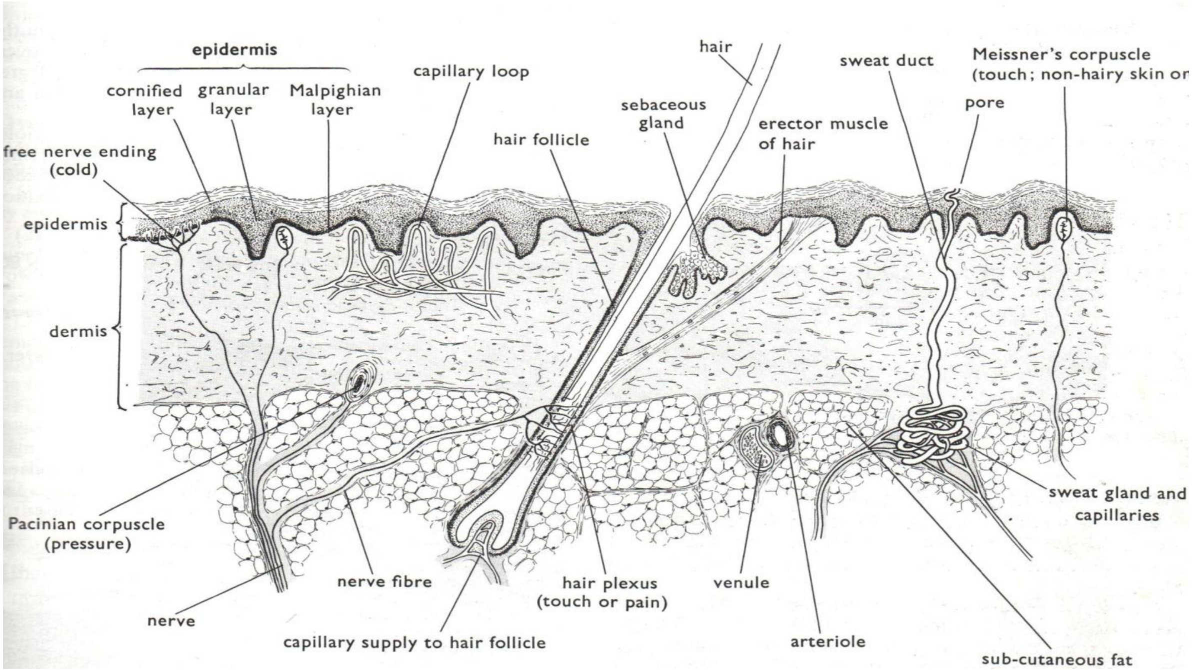
Heat loss, heat is lost by evaporation of water from the body during sweating and from body surfaces like the mouth and respiratory surfaces of land dwelling animals.

Heat may be gained or lost to the environment by **radiation**. This is the transfer of energy in the form of electromagnetic waves.

Heat may be gained or lost to the environment by **convection**. This is the transfer of heat by currents of air or water

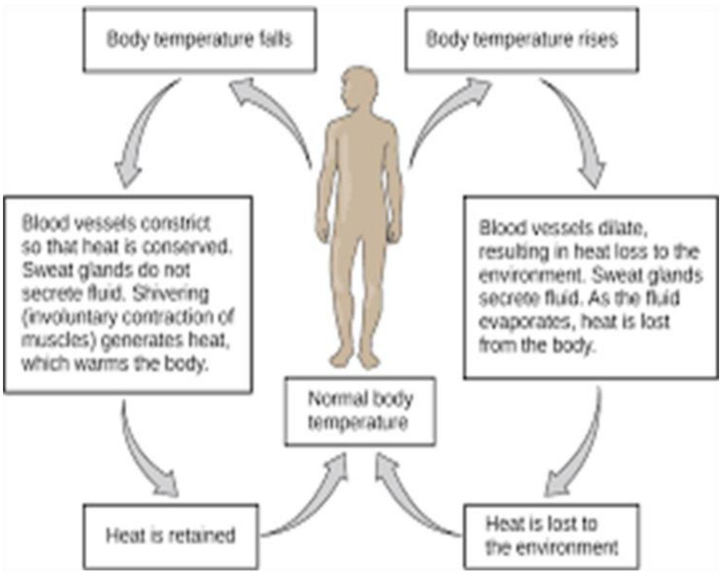
Heat may be gained or lost to the environment by **conduction**. This is the transfer of heat by the collisions of molecules. Conduction is particularly important between organisms and the ground or water, since air is a poor conductor of heat

THE HUMAN SKIN



Functions of the skin

i. It is the major organ involved in temperature regulation in the body
ii. It provides protection against mechanical damage, ultra violet radiation from the sun, microorganism invasion and water loss by underlying tissues
iii. It is a sense organ, containing sensory nerve endings for detecting temperature, touch, pressure and pain
iv. It is an excretory organ of urea, salt and excess water
v. It manufactures vitamin D when exposed to sunlight. The dermis contains lipids called steroids which are converted into vitamin D by ultraviolet light.



Heat is produced unevenly in the body. Skeletal muscle releases a lot of heat during exercise. Another important source of heat is the liver. Blood flowing through circulatory system has kinetic energy which is converted to heat energy when the blood meets resistance mainly in the arterioles. As blood flows through the skeletal muscles and liver it absorbs heat and distributes it to parts of the body where little heat is produced. When blood flows near the body surface heat is lost through the skin.

Response of endotherms to variation in the external temperature

Response to hot conditions

a. Physical and physiological means

- Metabolic rate reduces to minimise on the heat generated in the body
- Erector pili muscles relax to lower hairs/fur, so that no insulating layer of air is trapped near the skin surface enabling much heat to be lost.

- Panting occurs in dogs, birds and cats to increase evaporation of heat from the lungs, pharynx and other moist surfaces to cool the body
- Sweat production by sweat glands increases to enable evaporation of water from the skin surface. (there are two types of sweat glands, **eccrine** and **apocrine**. Eccrine glands are the most common being found in most regions of the body. Apocrine glands are found in the armpits, around the nipples, the pubic region, hands, feet and anus. These release an odourless fluid which may later produce a strong odour due to bacterial activity in the fluid)
- Vasodilation occurs i.e. superficial capillaries dilate to increase blood flow so that much heat can be lost by conduction and radiation. This cooling is more marked in the limbs than in the rest of the body.

b. Behavioural means (in man)

- Taking cold drinks
- Putting on light clothing
- Moving to shady places
- Switching on a fun
- Taking a bath
- Being active mainly at night (nocturnability)

(Fig 2 Kent page 154)

Response to cold conditions

a. Physical and physiological means

- Shivering, which is due to the involuntary contractions of the skeletal muscles, occurs so as to generate heat metabolically
- Metabolic rate increases to generate extra heat in the body, in the short term by the secretion of adrenaline and thyroxine. This occurs particularly in muscles and liver cells. Special brown fat may also be metabolized.
- Erector pili muscles contract to cause hairs/fur to ‘stand on end’ to trap an insulating layer of air near the skin to reduce heat loss by convection
- Sweat production by sweat glands reduces/stops to reduce evaporation of heat from the skin surface. (sweating occurs due to rise of core temperature)
- Vasoconstriction occurs i.e. superficial capillaries narrow to reduce blood flow so that heat loss by conduction and radiation can be minimised
- Cuddling occurs among

b. Behavioural means (in man)

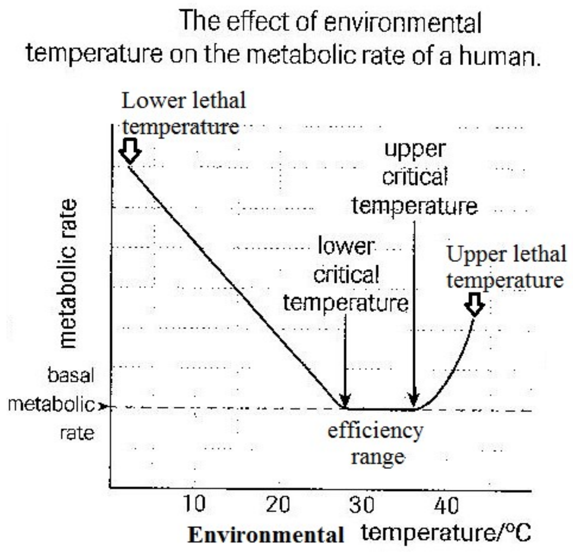
- Taking hot drinks
- Putting on thick clothes
- Turning on heat in houses
- Moving near a heat source e.g. fire

(Fig 15.6 Roberts page 236)

EFFECT OF CHANGING THE ENVIRONMENTAL TEMPERATURE

Two separate groups of **naked people**, one is exposed to gradually cooling air while another is exposed to gradually increasing air temperature. Their metabolic rates, physical changes and internal core body temperature are observed. Naked people are used to avoid physical interference of clothes or covering such that observations made are based on physiological responses only.

(Fig 15.6 Roberts page 238)



Low critical temperature, this is a low environmental temperature at which physical mechanisms like vasoconstrictions and erection of hair fail to maintain body temperature constant, triggering a rise to generate heat to maintain body temperature constant

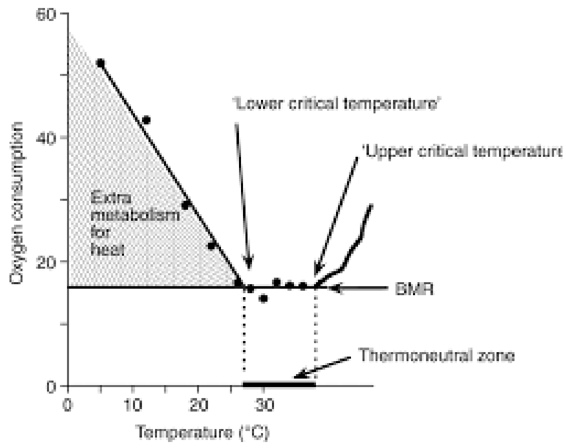
Lower lethal temperature, this is extremely low temperature at which increased metabolic rate fails to generate enough heat to maintain body temperature constant, resulting into death of the organism

Hypothermia, is a condition that results when heat loss greatly exceeds heat gain from metabolism due to prolonged exposure to cold, resulting into great reduction in core body temperature of the organism

High critical temperature, this is a high environmental temperature at which physical mechanisms like sweating and vasodilation fail to maintain temperature constant, triggering a rise in metabolic rate and body temperature as environmental temperature rises

Upper lethal temperature, this is an extremely high environmental temperature at which increased metabolic rate generates excessive heat which denatures enzymes and other structures, resulting into death of the organism.

Efficiency range (range of temperature neutrality), this is the external temperature range at which the body's physical mechanisms are capable of maintaining temperature constant. In man this is 27-31°C.The efficiency range varies according to the environmental temperature in which the animal inhabits. This is because animals have the ability to acclimatize. If the environmental temperature is high, acclimatization is by raising the upper critical temperature and if low, acclimatization is by lowering the lower critical temperature.



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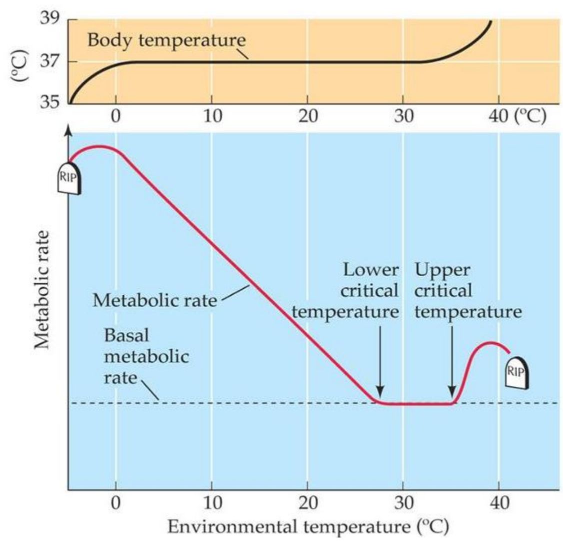


(Fig 18.7 Roberts and Reiss page 311 and Fig 15.7 Roberts page 439)

Observations from the graph

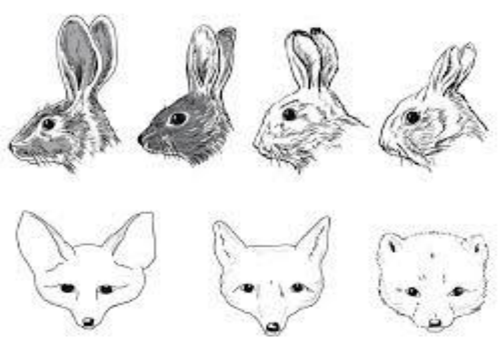
a. the low critical temperature for animals living in cold places is much lower than for those which live in warm places
b. the lower lethal temperature is much lower for cold-dwellers than for warm dwellers
c. below the lower critical temperature, the metabolic rate of warm-dwellers rises more sharply than in cold-dwellers
d. the metabolic rate starts to rise at a much critical temperature for cold-dwellers than that for warm-dwellers

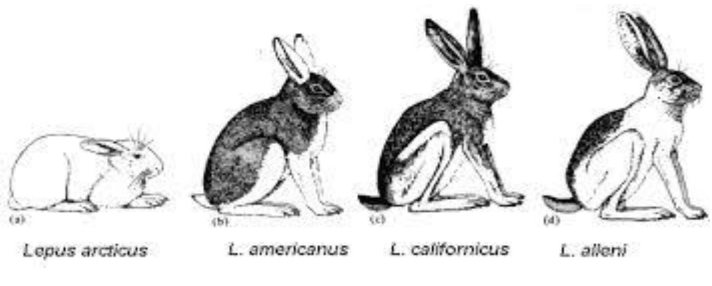
ADAPTATIONS TO EXTREME CLIMATES

Adaptations of life to low temperature

a. structural adaptations

- possession of thick fur for trapping a layer of air that is warmed and remains insulating the body against heat loss e.g. polar bears
- possession of a thick layer of subcutaneous fat for insulating against heat loss e.g. polar bears
- development of a large body size as compared to their counterparts in warmer climates to reduce the surface area to volume ratio in order to reduce heat loss e.g. whales and polar bears i.e. **Bergman's rule**
- extremities such as ear lobes are of reduced size than those of related species in warmer climates to reduce surface area for heat loss i.e. ***Allen's rule***





b. other adaptations

- Development of a counter current heat exchange system in limbs to enable heat conservation by minimizing its loss to the environment e.g. in ducks legs and dolphin flippers
  The counter current heat exchange system is a heat conservation mechanism in limbs where there's effective heat transfer at all levels to the periphery of the limbs, by conduction from the incoming warmer arterial blood to the outgoing colder venous blood
- Small sized animals hibernate e.g. bats, hamsters, hedgehogs and rodents like mice. **Hibernation** is a seasonal response by animals to cold temperatures during which they become dormant, body temperature and metabolic rate fall to the minimum required for maintaining the vital activities of the body. The animals are said to be in a 'deep sleep' to reduce energy needs to survive the winter when food is scarce. ***Brown fat*** is conserved and used up rapidly at the end of hibernation to quickly raise the metabolic heat. Brown fat owes its colour to the numerous

mitochondria it contains. The mitochondria generate heat and not ATP. Animals moving out of hibernation break it down and it generates heat more quickly than ordinary fat since it has good blood and nerve supply

- Some animals migrate to warmer places e.g. birds like swallows
  (Fig 15.8 Roberts page 239 OR Fig 19.18 R. Soper page 664)

Adaptations of life to high temperature

a. Structural adaptations

- Bodies are thinly insulated with fat to increase heat loss
- Development of smaller body size than their counterparts in colder climates to increase surface area to volume ratio in order to increase heat loss
- Extremities, such as ear lobes are large, thin with a rich blood supply to enable heat loss more easily e.g. the elephant's ears
- Having tissues that are tolerant to large temperature fluctuations between day and night e.g. the camel

b. Other adaptations

- Some animals **aestivate**. Aestivation is a seasonal response by animals to drought or excessive heat during which they become dormant, and the metabolic rate decreases followed by a decrease in body temperature to a minimum, required for maintaining the vital activities of the body. The ***African lungfish*** burrows into mud until the dry season ends, earthworms and garden snails also aestivate.

(Fig 18.10 Roberts and Reiss page 312 & Fig 21.6 Chilton page 167)

Case study 1: adaptation to extreme heat, the camel

1. It faces the sun, therefore exposing a small surface area to the sun's radiation
2. Its body is insulated by fat on top, which minimizes heat gain by radiation
3. The underpart of its body, which has much less insulation, radiates heat out to the ground cooled by the animals' shadow
4. Flattened nostrils which retard water loss
5. It excretes very concentrated urine
6. They can tolerate the loss of more than 25 percent of their body weight in water
7. They can go without drinking for as long as an entire week in the summer and three weeks in winter

8. It can tolerate a fluctuation in internal body temperature of 5 to 6°C i.e. it stores heat during day by letting ist temperature rise up and then release it during the night and begins the following below its normal temperature i.e. storing up coolness
9. The hump acts as an insulator and impedes heat flow into the body core

ROLE OF THE BRAIN IN TEMPERATURE CONTROL

The ***thermoregulatory centre of the brain, the hypothalamus,*** is responsible for temperature regulation in the body. Variation in body temperature is directly monitored by heat receptors in the hypothalamus and indirectly by receptors in the skin. Receptors in the skin monitor variation in external temperature. There are two types of thermoreceptors, hot and cold, which generate nerve impulses when suitably stimulated. Some pass to the hypothalamus and others to the sensory areas of the cortex, where the sensations associated with temperature are experienced according to the intensity of stimulation, the duration and the numbers of receptors stimulated.

If the temperature of blood flowing through the hypothalamus decreases, the ***heat regain centre*** is stimulated to send impulses to the liver and muscles to raise the metabolic rate so as to generate heat, and to the skin to cause vasoconstriction, reduction in sweat production, contraction of the erector pili muscles and shivering. The overall result is increased body temperature back to normal.

If the temperature of blood flowing through the hypothalamus rises, the ***heat loss centre*** is stimulated to send impulses to the skin to cause vasodilation to enable more heat loss at the skin surface, increase sweat production to enable more evaporation, relaxation of erector pili muscles to lower the hairs to avoid air insulation and to inhibit shivering so as to minimise heat production by metabolic reactions. All these enable lowering of temperature to normal.

Variation in external temperature stimulates receptors in the skin to send impulses to the brain and the animal's behaviour is modified accordingly e.g. if the skin heats up, the animal may move to a shade, while cooling of the skin surface may give rise to increased metabolic activity.

(Fig 15.3 & 15.5 Roberts page 236 & 237)

Table on pg 661 soper

TEMPERATURE CONTROL IN ECTOTHERMS

This is mainly achieved through modification of behaviour of the organism, which may include;

- Basking in the sun, at varying angles to the sun's rays so as to gain heat e.g. lizards and crocodiles
- Hiding in burrows, holes or crevices in rocks away from sunlight reduces temperature e.g. lizards
- Panting and exposing the moist tissues of the mouth, by licking the body surface or by swallowing in water, an animal can increase evaporation and so heat loss from the body
- Thermal gaping, opening the mouth to enable evaporation of moisture from the buccal cavity to cool blood e.g. alligators
- Thermal dancing when it is hot i.e. lifting of opposite pairs of feet alternately so that they can cool in air e.g. shovel-snout lizards
- Salivation over the neck and legs in tortoises to increase loss of heat as a result of water evaporating from such surfaces

The amount of heat absorbed depends upon;

- The colour of the organism
- Its surface area
- Its position relative to the sun's rays

TEMPERATURE CONTROL IN PLANTS

Plants lose and gain heat by the same physical processes as animals i.e. radiation, convection, conduction and evaporation

Plant tissues can tolerate wide fluctuations in temperature and are adapted to live in a variety of habitats, but still they must regulate the temperature to avoid overheating which would denature enzymes, and freezing of tissues which would slow down the metabolic processes.

Plants prevent overheating by;

- Transpiration, as water evaporate into the atmosphere it cools down the body of the plant
- Wilting, parenchyma cells lose turgidity to reduce the surface area of leaves and stems exposed to the sun, hence avoiding much heat gain
- Possession of a shiny cuticle on leaves to reflect heat (sun's radiation) and avoid overheating
- Possession of small needle-like leaves in some plants also reduces excessive heat gain from the sun's rays

Plants prevent freezing by;

- Producing spores or seeds which are very temperature resistant
- Losing the easily damaged leaves when external temperature is low e.g. during winter in temperate plants
- Orienting leaves to take maximum advantage of light at any one time so that they do not shade each other

EXCRETION AND OSMOREGULATION

Excretion is the expulsion of waste products of metabolism from the body. Examples of waste products of metabolism include; carbon dioxide, urea, uric acid, ammonia, bile, excess water, excess mineral salts, oxygen (plants) e.t.c.

Osmoregulation is the control of water and salt balance so that the concentration of dissolved substances in the body fluids remains constant. It includes concentration of various ions e.g. Na^+, K^+, Cl^- and water content.

Homeostasis is the maintenance of a constant internal environment within in a narrow range regardless of the conditions in the external environment.

Secretion is the production of substances useful to the body by cells. For example release of hormones and digestive juices.

Egestion is the removal from the body of undigested food and other substances, which have never been involved in the metabolic activities of cells. For example, elimination of faeces from the gut (defeacation) and undigested food from the food vacuole of amoeba.

Significance of excretion and osmoregulation

1. Enables removal of unwanted by-products of metabolic pathways to prevent unbalancing of the chemical equilibrium of reactions
2. Removes toxic wastes, that if accumulated would affect the metabolic activities of organisms e.g. may act as enzyme inhibitors
3. It regulates ionic concentration of the body fluids to facilitate efficiency of cell activities e.g. nervous coordination protein synthesis, hormone production, muscle contraction, enzyme activity e.t.c.
4. It regulates the water content of body fluids
5. Enables regulation of ions that have a major influence on the pH of body fluids e.g. H^+, and HCO_3^-.
6. It removes unwanted substances that are taken in along with food.
7. Enables removal of excess nutrients which if allowed to accumulate would interfere will cell activities e.g proteins and fats
8. Removal of toxic substances liberated by pathogenic micro-organisms e.g. poisons

EXCRETION AND OSMOREGULATION IN PLANTS

EXCRETION

Plants do not have complex/elaborate excretory systems as those in animals because of the following reasons;

- Toxic wastes do not accumulate because they are utilised by the plants e.g. carbon dioxide and water are raw materials for photosynthesis while oxygen participates in respiration
- The rate and amount of catabolism is much slower and much less than that of animals of similar weight and as a result, the waste products accumulate more slowly
- Plant synthesise all their organic requirements according to demand, leaving no excess proteins hence very little excretion of nitrogenous waste substances occurs.
- Organic acids which would be harmful to plants often combine with excess cations and precipitate as insoluble crystals which can be safely stored in plant cells e.g. excess calcium ions combine with oxalic and peptic acids to form the non-toxic calcium oxalate and calcium pectate.
- Extra gaseous wastes are removed from plant bodies by simple diffusion through the stomata and lenticels
- Most of the organic waste substances formed are non-harmful and can be stored in the plant tissues which are removed periodically e.g. leaves and barks
- Some plants wastes such as resins in organs that later fall off e.g. leaves
- Excess water and dissolved gases are removed by **exudation** e.g. gums, resins, latex and rubber
- In some plants, excess water with dissolved salts oozes out through **hydathodes**, a process called guttation

Excretory products of plants include;

a. *Carbon dioxide, water and oxygen* from respiration and photosynthesis respectively
b. *Anthocyanins* stored in petals, leaves, fruits and barks.
c. *Tannins* deposited in dead tree tissues like barks and wood
d. Calcium oxalate, calcium carbonates and latex (rubber)
e. *Alkaloids* like quinine, cannabis, cocaine, caffeine, morphine e.t.c.
f.

OSMOREGULATION

Plants are categorised into four major groups depending on the amount of water in their environment;

a. Hydrophytes are plants that live completely or partially submerged in fresh water. They have enough water and therefore there's no problem of obtaining it e.g. water lilies, water hyacinth, water lettuce e.t.c. They need to get rid of excess water, absorb maximum sunlight, remain buoyant and absorb respiratory gases. Their characteristics include;

i. Submerged plants

- The lamina is thin to allow water and dissolved oxygen to enter the leaves by osmosis through the epidermis
- They have numerous chloroplasts to trap as much light as possible for photosynthesis
- They are broad to increase on the surface area for trapping sunlight and diffusion of respiratory gases

ii. Partially submerged plants

- The leaves have thick waxy cuticle on the upper layer to minimise water loss
- Stomata are located only on the upper surface to permit exchange of gases with the atmosphere

iii. Floating plants

- Some species bear numerous hairs on the upper surface to trap air and so make the plant buoyant e.g. the water fern
- Water hyacinth has air filled tissues in the swollen base of the leaf petioles which makes the plant float
- The air filled tissues of the hyacinth also store oxygen
- Their roots are freely suspended in water from which they derive their mineral nutrients
- Their leaves have a large surface area (broad) to trap as much light as possible for photosynthesis

b. **Mesophytes** are plants inhabiting normal well-watered soils. They have the following characteristics;

- The leaf surface of some plants is hairy thus trapping air which forms a humid insulating layer that lowers the rate of transpiration
- They have more stomata on the lower surface than on the upper surface to reduce on water loss through the stomata
- Some plants have a milky latex which, being viscous, reduce transpiration
- A thick waxy transparent cuticle on the upper surface which minimises water loss through the upper epidermis yet still permits light penetration into the leaf

c. **Halophytes** are plants inhabiting areas of high salinity e.g. estuaries and salt marshes. They have a problem of absorbing water from their highly saline surrounding and getting rid of excess salts. Their characteristics include;

- They have special salt-secreting glands located on the upper epidermis. These extract and remove excess salts absorbed into the tissues from the saline water
- They produce aerial stilt or prop roots which grow down into the soft mud and give the plant firm anchorage and support
- They have special aerial roots called pneumatophores which project upwards from the soil so as to take up oxygen through the numerous lenticels on their surface
- They are viviparous i.e. the seeds germinate while the fruit is still on the parent plant
- The seedlings are long and pointed to enable them penetrate the mud when they drop off from the parent plant

d. **Xerophytes** are plants inhabiting dry areas e.g. deserts. Their characteristics include the following;

i. Modified leaves

- Some have very small leaves to reduce the surface area for transpiration
- Some shed their small leaves in the dry season
- The leaves of some are reduced to small spines
- The leaves may be small, rolled-up and needle-like
- There's a waxy cuticle on the surface of the leaves to reduce on the transpiration rate

ii. Distribution of stomata

- They generally have few stomata, and these are mainly located on the lower leaf surface
- The stomata in cacti are located in grooves or sunken pits
- In cacti, stomata open at night

iii. Water storage in plant tissues. Some plants store water in leaves e.g. Bryophyllum and stems e.g. banana
iv. They have deep and extensive rooting systems
v. Some plants are very short-lived i.e. they grow, blossom and produce seeds in a short wet season
vi. Milky latex. Some plants have a white latex in their stems which reduces on their rate of transpiration and also makes them distasteful to herbivores.

Adaptation of xerophytes for surviving unfavourable water balance i.e. more loss than uptake from the soil

Structural adaptations

i. Possession of extremely deep roots to obtain water from deep below the water table e.g. acacia
ii. Shallow root systems for absorbing moisture even slight showering e.g. cactus
iii. Possession of fleshy succulent stems and leaves that store water in large parenchyma cells e.g. brophyllum and cactus
iv. Hairy epidermis for trapping humid air and reduce on the transpiration rate
v. Possession of stomata which are sunken in hairy leaf surfaces to trap air and reduce on the transpiration rate
vi. Rolling/folding of leaves to reduce on transpiration e.g. marram grass (*Ammophila*)
vii. Possession of a thick cuticle which is impermeable to water e.g. prickly pear (*Opuntia*)
viii. Reduction of surface area over which transpiration has to occur by having small leaves

Physiological adaptations

i. Reversal of the normal stomatal rhythms in some plants i.e. opening stomata at night and closing during day time so as to reduce on water evaporation
ii. Increased levels of abscisic acid, which induces stomatal closure so as to reduce water loss
iii. Possession of tissues tolerant to dessication i.e. low solute potential of cytoplasm and production of resistant enzymes
iv. Leaf fall in deciduous trees so as to cut down transpiration
v. Survival of drought as seeds or spores that are highly dehydrated and protected within a hard case

EXCRETION AND OSMOREGULATION IN ANIMALS

Different animals use different organs to carry out excretory and osmoregulatory processes. The organs of some animals are shown in the table below;

Animals	Excretory and osmoregulatory structures
Unicellular organisms	Cell surface membrane
Platyhelminthes	Flame cells
Crustaceans	Antennal glands
Annelids	Nephridia
Arachnids	Book lungs
Insects	Malpighian tubules
Fish	Gills and kidneys
Amphibians	Lungs, kidneys, liver, gills and skin
Birds and reptiles	Lungs, kidneys and liver
Mammals	Lungs, kidneys, liver and skin

Animals excrete more than one product and the predominance of one over the others is determined by three factors;

a. The production of enzymes necessary to convert ammonia to either urea or uric acid
b. The availability of water in the habitat for the removal of the nitrogenous excretory material
c. The animal's ability to control water loss or uptake by the body

The nitrogenous excretory products of animals include;

i. **Ammonia** which is highly soluble and readily diffusible, excreted by fresh water bony fish, protozoans, porifera and cnidarians which live in abundance of water. Such animals are said to be **ammoniotellic**.
ii. **Urea** is less toxic than ammonia and very soluble hence easily diluted before elimination, so it is excreted by some terrestrial animals like mammals and marine ones whose body fluids are hypotonic to seawater. Animals that excrete urea as the main nitrogenous product are said to be **ureotelic**.
iii. **Uric acid** is almost nontoxic and highly insoluble, requiring very little water for its elimination so it is excreted by animals living in very arid conditions e.g. birds, insects and reptiles, which live in areas of water shortage. These animals are said to be **uricotelic**
iv. **Trimethylamine oxide** is soluble but nontoxic, requiring relatively less water for its elimination, so it is excreted by marine bony fishes suffering from water shortage
v. **Guanine** is less soluble than uric acid and requires no water for its elimination hence it is excreted by terrestrial spiders that live in scarcity of water.

Summary of the relationship between excretory produce and habitats of some animal groups

Animal	Habitat	Excretory product	Nature of product
Mammals	Terrestrial	Urea	Nitrogenous wastes
Birds and terrestrial insects	Terrestrial	Uric acid	
Protozoa and fresh water bony fish	Aquatic	Ammonia	
Spiders	Terrestrial	Guanine	
Marine bony fish	Aquatic	Trimethylamine oxide	
Mammals	Terrestrial	Bile salts	Non-nitrogenous wastes
Mammals, birds and reptiles	Terrestrial	Excess water and mineral salts	
Mammals, birds and protozoa	Terrestrial	Carbon dioxide	

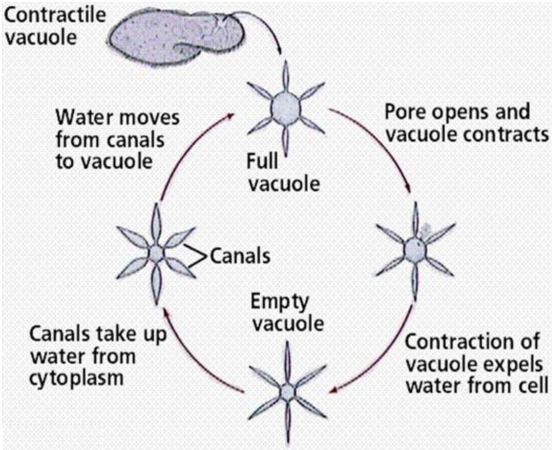
EXCRETION AND OSMOREGULATION IN FRESHWATER PROTOZOANS

(Fig 14.10 Roberts page 221 & Fig 20.2 R. Soper page 676 OR Fig 18.7 Clegg page 378)

Protozoans include amoeba and paramecium and they use the contractile vacuoles to carry out osmoregulation. Since the cell contents are hypertonic to the surrounding, and the cell membrane is partially permeable, there is constant influx of water into the cytoplasm by osmosis.

Small vesicles in the cytoplasm fill up with fluid from the cytoplasm and pump salts back into the cytoplasm by active transport, using energy provided by ATP from the numerous mitochondria surrounding the vesicles.

The vesicles, now containing water, fuse with the contractile vacuole which gradually expands. The impermeability of the vacuolar membrane to water prevents osmotic outflow of water. On reaching a certain size, the contractile vacuole fuses with the cell surface membrane, contracts suddenly and releases its water.



NOTE;

1. Protozoa living in sea water are isotonic with their environment whereas freshwater protozoan are hypertonic to their surroundings.
2. The frequency of contractile vacuole discharge decreases with increase in salinity of surrounding water. In fresh water, the frequency is high to expel water as fast as possible to avoid bursting of the cell.
3. Excretion of carbon dioxide and ammonia in protozoa is by simple diffusion across the cell surface membrane

EXCRETION AND OSMOREGULATION IN TERRESTRIAL INSECTS

Excretion

The excretory system of an insect consists of **malpighian tubules** that extend throughout the body cavity. The ends of the malpighian tubules are closed but the epithelial cells absorb nitrogenous wastes like **sodium and potassium urate** from blood. Muscles in the tubule wall produce peristaltic movements that stir up the blood. Water and carbon dioxide react with potassium urate in the tubule cells to form **potassium hydrogen carbonate** and **uric acid**.

Potassium hydrogen carbonate is absorbed back into blood while uric acid is deposited in the tubule lumen. As uric acid moves from the distal to the proximal end of the malpighian tubule, water is vigorously taken back into blood in the haemocoel, causing a fall in the pH of the contents of the lumen of the tubule. This fall in pH causes the uric acid to form crystals, in which state it is passed into the hindgut and mixed with the faeces. Almost no water has been lost with the acid and more water is reabsorbed from the mixture of uric acid and faeces by the **rectal glands** in the walls of the rectum.

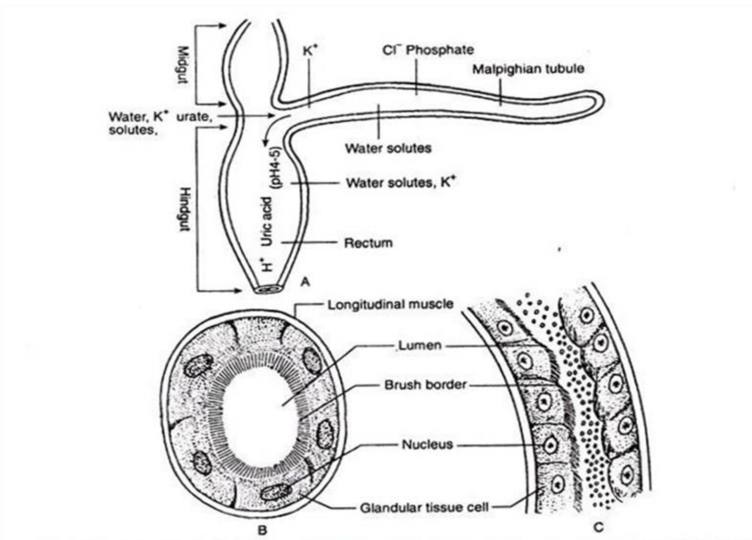


Fig. 18.58: Malpighian tubule of *Periplaneta*. A. Location of Malpighian tubule. B. Transverse section of Malpighian tubule. C. Longitudinal section of Malpighian tubule.

(Fig 14.14 A & B Roberts Page 226 OR Fig 18.8 Clegg page 378

Osmoregulation in selected organisms

A. Shore crab (carcinus)
Antennal glands at the base of the antennae excrete excess water and nitrogenous wastes. Antennal glands are incapable of holding back salts (they may eliminate salts and water alike)
B. Mitten crab (Eriocheir)
What happens in the shore crab also happens in the Mitten crab except that here the inward secretion of salts is sufficient enough to enable the animal to flourish in fresh water.
C. Cray fish
Here antennal glands are capable of eliminating excess water but reabsorbs salts, resulting into production of urine hypotonic to blood an **internal osmotic pressure** (**OPi**) higher than **external osmotic pressure** (**OPe**).
Reabsorption of salts occurs as urine flows along the coiled tubule.

Drawing of antennal glands of Cray fish and shore crab.

The graph below shows changes in the internal osmotic pressure (OPi) of blood with external osmotic pressure in the surrounding medium (OPe) in three different genera of crabs

(Fig 14.9 Roberts page 220)

Explanations of the variations in osmotic pressure of blood

- OPi of carcinus slightly decreases with slight lowering of OPe (little dilution of sea water) but osmoregulation breaks down and OPi drops drastically when external medium (OPe) becomes too dilute. Carcinus in fresh water experiences osmotic extraction of water from the body leading to dehydration of body tissue, hence cannot exploit fresh water fully.
- OPi of Eriocheir slightly decreases throughout (in both sea and fresh water) because the animal is able to osmoregulate in all concentrations of external medium. Eriocheir can tolerate much greater dilution and survive in both fresh water and sea water
- A change in OPe results in a similar change in OPi of blood, which is an indicator that Maia crab cannot osmoregulate

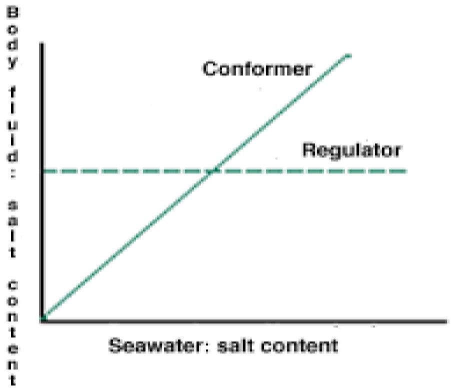
EXCRETION AND OSMOREGULATION IN FISH

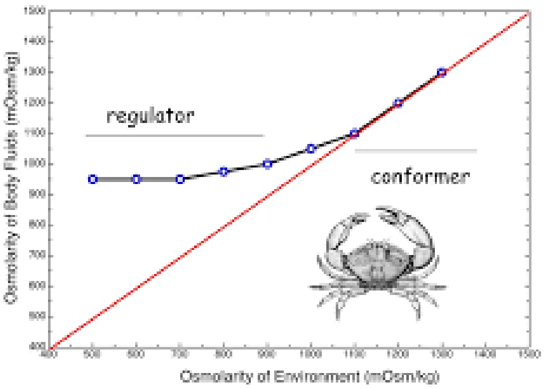
Osmosis and Osmolarity

All animals-regardless of phylogeny, habitat, or type of waste produced-face the same need for osmoregulation. Over time, water uptake and loss must balance. If water uptake is excessive, animal cells swell and burst; if water loss is substantial, they shrivel and die. Water enters and leaves cells by osmosis. Recall that osmosis is a special case of diffusion, is the movement of water across a selectively permeable membrane. It occurs whenever two solutions separated by the membrane differ in osmotic pressure or **osmolarity** (total solute concentration expressed as molarity, or moles of solute per liter of solution). If two solutions separated by a selectively permeable membrane have the same osmolarity, they are said to be **isoosmotic**. Under these conditions, water molecules continually cross the membrane but they do so at equal rates in both directions. In other words, there is no net movement of water by osmosis between isoosmotic solutions. When two solutions differ in osmolarity, the one with the greater concentration of solutes is said to be **hyperosmotic**, and the more dilute solution is said to be **hypoosmotic**. Water therefore moves by osmosis from a hypoosmotic solution to a hyperosmotic one.

Osmotic Challenges

An animal can maintain water balance in two ways. One is to be an **osmoconformer** which is isoosmotic with its surroundings i.e. its body fluids are in osmotic balance with its balance. The second is to be an **osmoregulator**, which controls its internal osmolarity independent of that of its environment.



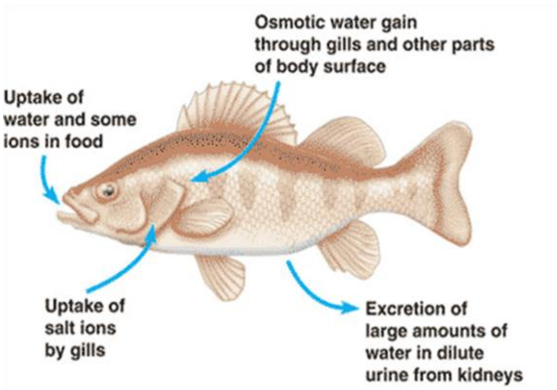


All osmoconformers are marine animals. Because an osmoconformer's internal osmolarity is the same as that of its environment, there is no tendency to gain or lose water. Many osmoconformers live in water that has a stable composition and hence have a constant internal osmolarity. Osmoregulation enables animals to live in environments that are uninhabitable for osmoconformers, such as freshwater and terrestrial habitats. It also allows many marine animals to maintain an internal osmolarity different from that of seawater. To survive in a hypoosmotic environment, an osmoregulator must discharge excess water. In a hyperosmotic environment, an osmoregulator must instead take in water to offset osmotic loss. Most animals, whether osmoconformers or osmoregulators, cannot tolerate substantial changes in external osmolarity and are said to be **stenohaline** (from the Greek stenos, narrow, and halos, salt). In contrast, **euryhaline** animals (from the Greek eurys. broad), which include certain osmoconformers and osmoregulators, can survive large fluctuations in external osmolarity. Many barnacles and mussels covered and uncovered by ocean tides are euryhaline osmoconformers; familiar examples of euryhaline osmoregulators are the various species of salmon

A. Fresh water teleosts (bony fish) e.g. tilapia, trout, stickle e.t.c. (OPi > OPe)

The water potential of the tissues is more negative than that of freshwater bodies but less negative than that of sea water. The surface of their gills and the gut are permeable to water.

The excretory and osmoregulatory organs are **gills and kidneys**. The internal body fluids are **hypertonic** to the surrounding water and therefore there is **osmotic influx of water** across the gills, lining of mouth and pharynx. There is also **efflux** of solutes (ions and ammonia) into water by diffusion hence the kidneys are not important in the excretion of nitrogenous wastes. The problem of intake of water and loss of ions is solved by;



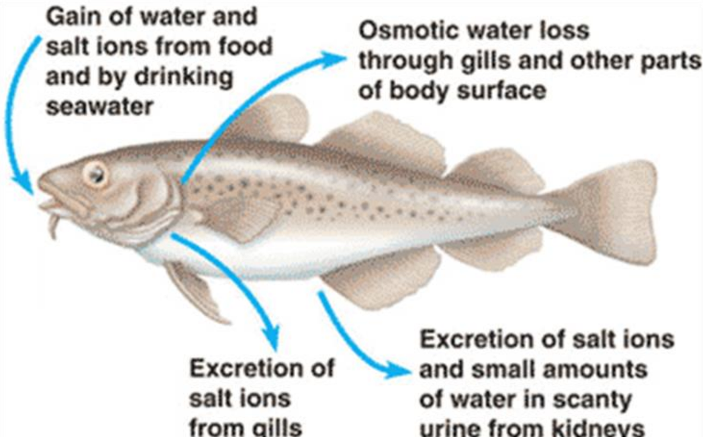
- Producing large volumes of dilute (hypotonic) urine
- Reabsorbing ions across the nephron tubules, from the glomerular filtrate back into blood. The high glomerular filtration rate is enabled by **numerous large glomeruli** in the kidneys.
- Active uptake of salts from water by **chloride secretory cells** in the gills

B. Marine teleosts e.g. Cod, Mackerel (OPi < OPe)

The excretory and osmoregulatory organs are **gills and kidneys**. The internal body fluids being hypotonic to the surrounding water, there is osmotic extraction of water from the body leading to dehydration of the tissues, a situation described as physiological drought. This is overcome by

- Drinking large volumes of sea water
- Having a kidney with a low filtration rate enabled by the few small sized glomeruli
- Excreting trimethylamine oxide, which is soluble but non-toxic and requires little water for elimination

The divalent ions (Ca^{2+}, Mg^{2+}, SO_4^{2-}) in sea water that a marine fish drinks are eliminated through the anus while the monovalent ions (K^+, Na^+, Cl^-) are absorbed into blood and are actively transported out of blood across the gills, reverse to the direction in fresh water fish. The divalent ions that enter blood are secreted into the nephron tubules and excreted in urine. The waste products are selectively extracted from blood by the tubule cells and ultrafiltration does not occur



A. Marine elasmobranchs (cartilaginous fish) e.g. dog fish, sharks, rays e.t.c.

Their tissue is slightly hypertonic to the seawater causing a slight influx of water, which is readily expelled by the kidneys. Hypertonic tissue fluid results from retention of urea which is facilitated by;

- Impermeability of gills to urea
- Urea reabsorption from the nephron tubules, maintaining its concentration at over 100 times higher than that in animals
- Tolerance of tissues and enzymes to high urea concentration

B. Migratory fish e.g. salmon and eels

Their ability to move from one extreme osmotic environment (fresh water) to another (sea water) is achieved by;

- Changes in kidney filtration rates
- Reversal of the direction in which the chloride secretory cells transfer cells i.e. in fresh water, they take in salt and they may move the salts out in sea water.

OSMOREGULATION IN TERRESTRIAL ANIMALS

Terrestrial animals lose water through evaporation from the permeable surface exposed to the atmosphere. They exhibit different physiological, morphological and behavioural adaptations so as to minimise water loss.

Behavioural adaptations

i. Change of habitat depending on the weather conditions
ii. Some animals **aestivate** e.g. the African lung fish
Aestivation is the seasonal response by animals to drought or excessive heat, during which they become dormant, body temperature rate decrease to the minimum required for maintaining the vital activities of the body. It is an adaptation for temperature regulation as well as water conservation. During aestivation, the African lung fish burrows and encases in a cocoon of hard mud lined with mucus

Morphological/structural adaptations

Possession of water proof integuments which include the keratinous scales of reptile, cornfield epithelium of mammals and the waxy cuticle of insects.

Physiological adaptations

i. Reduction in glomerular filtration rate e.g. the desert frog (*Chiroleptes*) has few glomeruli than its relatives living in moist temperate regions
ii. Production of non-toxic nitrogenous wastes e.g. insoluble uric acid (reptiles, birds and insects) and the relatively less toxic urea (mammals and amphibians) that require little water for removal
iii. Extensive water reabsorption from glomerular filtrate (mammals and birds) and rectum (insects) e.g. the kangaroo rat has an extra-long loop of Henle enabling it to produce hypertonic urine

iv. Use of metabolic water from fat through respiration. This explains why desert animals like the kangaroo rat tend to metabolise fat which yield more water on oxidation than carbohydrates
v. Possession of tissues tolerant to dehydration e.g. a camel can survive for a long time without drinking water
vi. Ability to sweat abnormally high temperatures e.g. a camel begins sweating at 41°C
vii. Ability to reduce the need for nitrogenous excretion e.g. a camel secretes urea into the lumen of the alimentary canal where bacteria convert it to protein which is then utilised as food

Case study 2: adaptation to lack of water, the Kangaroo rat

The kangaroo rat, a desert inhabitant, may spend its entire life without drinking water. It lives on seeds and other dry plant materials.

1. It has no sweat glands, therefore no water lost as sweat
2. Being nocturnal, it searches for food only when the external temperature is relatively cool.
3. Its feaces have a very low water content
4. Its urine is highly concentrated
5. Some cooling of the expired air takes place in its long nose, with condensation of water

OSMOREGULATION IN AMPHIBIANS AND REPTILES

The kidneys of amphibians are identical to those of fresh water fish since the amphibians were the first terrestrial animals. Reptiles on the other hand, have different kidney structures because they live in diverse habitats;

a. Those that are living mainly in fresh water e.g. some crocodiles, possess kidneys like those of fresh water fishes and amphibians
b. Marine reptiles e.g. some crocodiles, turtles, sea snakes and some lizards e.g. the Iguana possess kidneys identical to those of their fresh water relatives. However, since these kidneys reabsorb salt, marine reptiles cannot excrete a great deal of salt in their urine. Instead they eliminate excess salt by means of salt secreting glands located near the nose or the eye, hence ‘the turtle shedding tears’
c. Terrestrial reptiles reabsorb much of the salt and water in the nephron tubules of the kidneys, enabling the reptiles to conserve blood volume in the dry environment

EXCRETION AND OSMOREGULATION IN MAMMALS AND BIRDS

Mammals and birds are the only vertebrates able to produce urine that has a higher osmotic concentration than their body fluids. This enables them to excrete waste products in a small volume of water so that more water can be retained in the body. For example, human kidneys produce urine 4.2 times as concentrated as their blood plasma, the camel, gerbil and pocket mouse can excrete urine 8, 14 and 22 times as concentrated as their blood plasma respectively. Birds however have relatively few or no nephrons with long loops, so they cannot produce urine that is concentrated as that of mammals. Marine birds e.g. Penguins, Gulls and Cormorants drink salt water and then excrete the excess salt from **salt secreting nasal glands** near the eyes, giving an impression that these birds have runny noses.

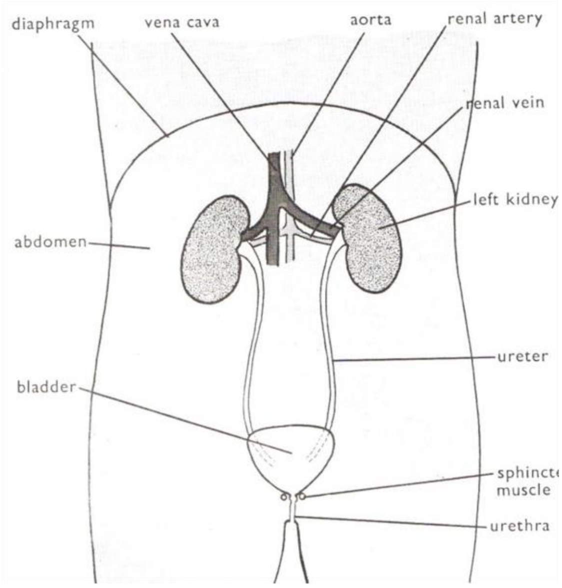
Note

1. The production of hypertonic urine is accomplished by a portion of the nephron called the loop of Henle found only in the kidneys of mammals and birds
2. The ability to produce concentrated (hypertonic) urine enables the organism to conserve water and is a useful adaptation to terrestrial life

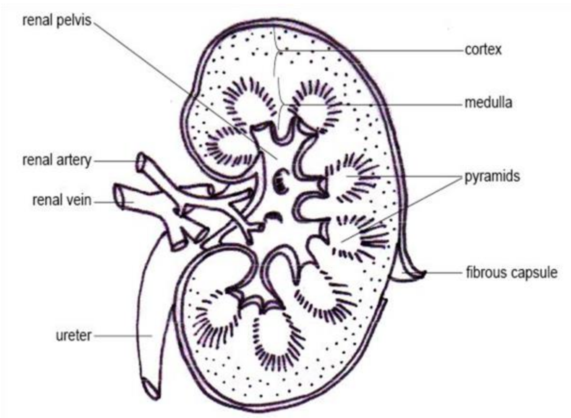
EXCRETORY SYSTEM IN MAN

The main organs in the excretory system are kidneys. The two kidneys are bean-shaped and situated at the back of the abdominal cavity just above the waist. They are supplied by blood from the renal artery which is a branch of the aorta. The ureter drains urine from the kidneys to the urinary bladder where it is stored temporarily. Urethra connects the kidneys to the bladder. The urinary bladder has the sphincter muscles which hold the urine in the bladder and only open under the control of the brain in adults to let urine out but in infants, it opens whenever the bladder is full. Urine passes through the urethra, by peristalsis, to the outside of the body.

Diagram showing the general structure of the excretory system



Vertical section through a human kidney showing the internal structure



Internally each kidney consists of three regions

- The outer cortex which is large
- The medulla
- The pelvis

A medulla projects into the pelvis by a tissue called the pyramid

Each kidney is made up of thousands of tiny tubules called nephrons. The nephron is the functional unit of the kidney and excretion takes place in the nephron of the kidney. In mammals, these nephrons are particularly numerous, with long tubules for water reabsorption, and together they form a very compact kidney known as **metanephric kidney**. This form is also found in reptiles and birds since it is the most adapted for the production of concentrated urine so necessary for terrestrial animals.

Each nephron begins in the cortex, loops down into the medulla and back into the cortex and then it goes back again into the medulla. In the pelvis, they empty their contents into the ureter. There are two types of nephrons depending on the length and nature of their loops of Henle. **Cortical nephrons** have 'short-reach' loops which project to the boundary between the outer and inner zones of the medulla. **Juxtamedullary** nephrons have 'long-reach' loops which extend deeper into the medulla, usually to the tips (papillae) of the pyramids. In human kidneys, about 85% of nephrons are cortical.

NOTE: the nephron of the kidney carries out the two important functions of the kidney i.e. the kidney has two functions excretion and osmoregulation.

EXCRETORY AND HOMEOSTATIC FUNCTIONS OF THE KIDNEYS

1. Excretion of metabolic waste products such as urea, excess water, uric acid, ammonia, creatine e.t.c.
2. Regulation of water and solute content of blood
3. Maintenance of pH of body fluids at 7.4 (acid-base balance by removing or neutralizing excess acidic or basic ions)
4. Regulation of blood levels of ions as Na^+, K^+, Cl^-, Ca^{2+} e.t.c.
5. Secretion of hormone, erythropoietin, which stimulates red blood cell production for transporting oxygen
6. Retention of important nutrients such as glucose and amino acids through reabsorption from the glomerular filtrate into blood

STRUCTURE OF THE MAMMALIAN KIDNEY

(Fig 14.1 Roberts page 211)

EXCRETORY FUNCTION OF THE KIDNEY

The kidney accomplishes its excretory function by a number of processes which occur at different regions of the nephron;

i. **Ultrafiltration (pressure filtration)** at the glomerulus of the Bowman's capsule
ii. **Selective reabsorption** in the tubules
iii. **Tubular secretion** at the proximal and distal convoluted tubules
iv. **Counter current multiplier** effect in the loop of Henle
v. **Water reabsorption** in the distal convoluted tubule and collecting duct

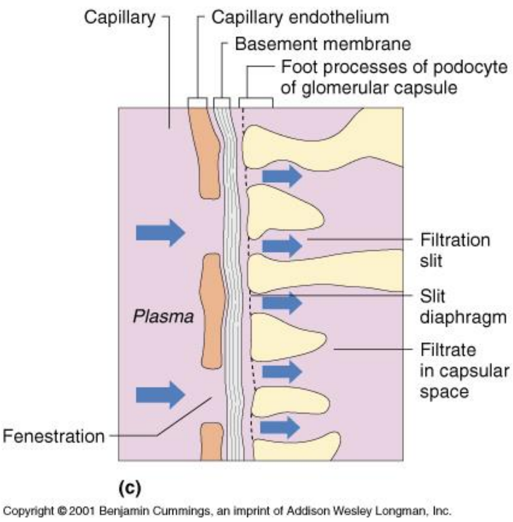
ULTRAFILTRATION

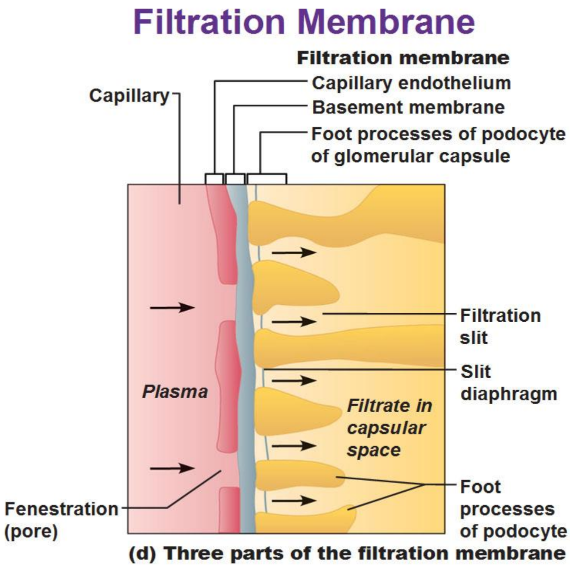
This is the first stage of urine formation at the glomerular capillary wall of the kidney nephrons during which hydrostatic pressure forces small molecules in blood of the glomerular capillaries to pass across the basement membrane into the capsular space BUT large molecules are held back. The capillaries of glomerulus are more permeable than capillaries elsewhere in the body.

The substances that are forced by pressure to pass passively across the basement membrane filter include small molecules like water, glucose, amino acids, vitamins, urea, uric acid, ions, creatine and some hormones while large the large molecules retained in blood include red blood cells, platelets, white blood cells and large sized plasma proteins.

Although filtration occurs through three layers of the glomerular capillary, the endothelium is a coarse screen retaining only blood cells. The negatively charged basement membrane retains negatively charged large sized protein molecules while the selective filtration occurs at the diaphragm of the slit pores formed by the foot-like projections of supporting cells **podocytes.** These have extensions called **foot processes** which support the basement membrane and capillary. Between the foot processes are **slit pores** which facilitate the process of filtration.

(Fig 17.5 Roberts and Reiss page 383)





SELECTIVE REABSORPTION AT THE TUBULES

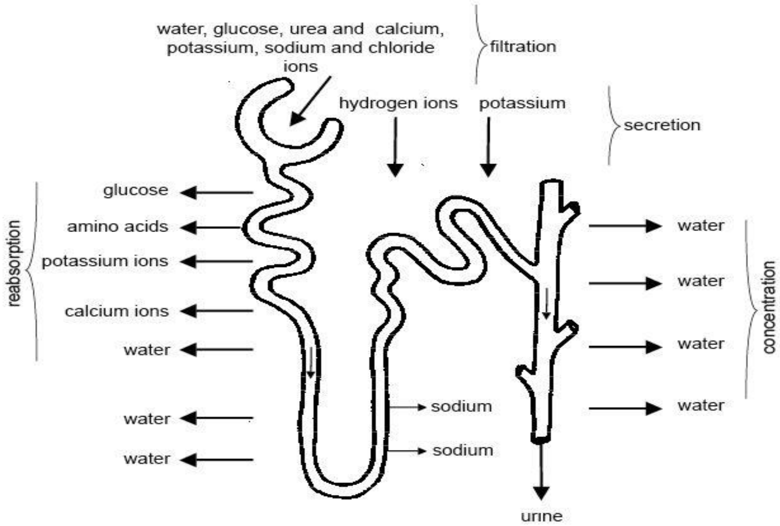
Because particle size and rather than their importance determines the substance to pass through the basement membrane during ultrafiltration, useful substances such as glucose enter the capsular space to form the glomerular filtrate and they have to be absorbed later. Selective reabsorption of individual substances is at a rate just sufficient to maintain normal concentrations in the blood. Any excess stays in the nephron.

Since the transfer of materials from the filtrate into the blood is against a concentration gradient, selective reabsorption is active. The energy for **active uptake** is provided by respiration in the nephron's cells which contain many mitochondria. The efficiency of reabsorption is helped by the presence of numerous **microvilli** which greatly enlarge the surface area through which the materials pass.

As the glomerular filtrate (renal fluid) flows along the tubule of the nephron, all the glucose, 85% of water, Na^+, Cl^-, amino acids, vitamins, hormones, 50% of urea are absorbed from the proximal convoluted tubule into the surrounding blood capillaries.

Glucose, amino acids, Na^+, $H_2PO_4^-$, and HCO_3^-, diffuse into the proximal convoluted tubule and then actively transported into the blood capillaries. The active uptake of Na^+ is followed by the passive uptake of Cl^- which raises the osmotic pressure in the cells, enabling entry of water into the capillaries by osmosis.

50% of urea is reabsorbed by diffusion but the small sized proteins in the renal filtrate are removed by pinocytosis. As a result of this activity, the tubular filtrate is isotonic with the blood in the surrounding capillaries.



(Fig 17.7 Roberts and Reiss page 284)

TUBULAR SECRETION AT THE PROXIMAL CONVOLUTED TUBULE

Finally active secretion of unwanted substances like creatine, some urea, ammonia (active transport), uric acid, H^+ (active transport), and K^+ occurs from blood capillaries into the proximal convoluted tubule.

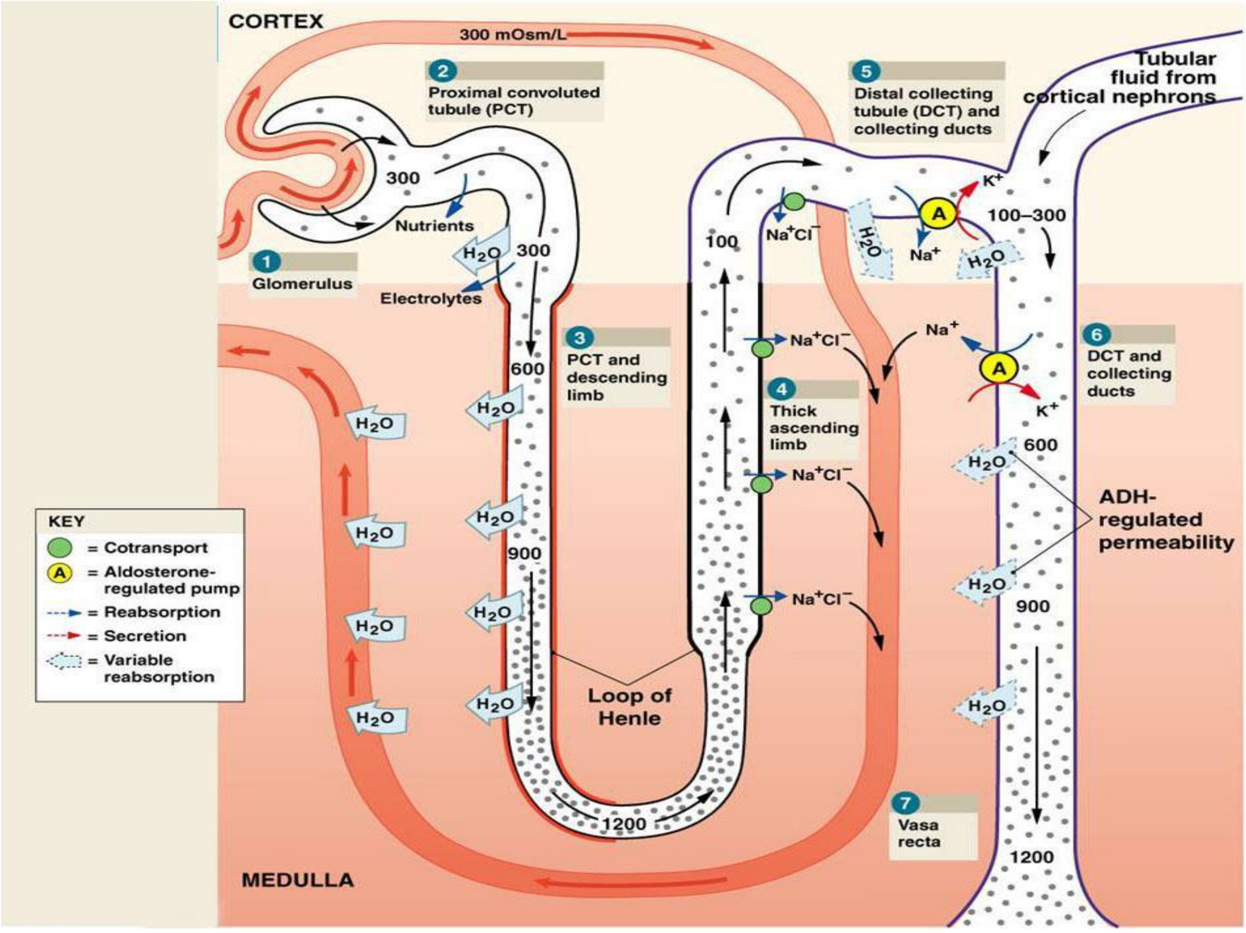
COUNTER CURRENT MULTIPLIER EFFECT IN THE LOOP OF HENLE

This is a mechanism which occurs in the loop of Henle, resulting into creation of a very high concentration gradient between the tissue fluid and blood in the medulla, and the urine in the collecting duct.

The wider ascending limb of the loop of Henle is relatively impermeable to water while the descending limb is freely permeable to water BUT impermeable to salts. Na^+ and Cl^- are actively pumped out of the upper part of the narrow ascending limb but diffuse from the lower part, raising the solute concentration in the interstitial region between the two limbs which leads to lowering of the ion concentration in the ascending limb. Water is osmotically drawn from the descending limb and collecting duct and carried away by blood in the vesa recta, resulting into a slightly higher concentration in the descending limb than the adjacent ascending limb and hypertonic urine is formed.

The difference in the osmotic concentration between the ascending and descending limbs at any one level is small but over the whole length of the loop these have a cumulative effect. This is due to the active transfer of salt which takes place at all levels of the loop of Henle. At any given level the effect of this is to raise the concentration in the descending limb very slightly above that in the ascending limb, the so called **unit effect**. The concentration effect is multiplied such that the fluid in and around the loop of Henle becomes saltier with the saltiest region being the hair pin bend. The glomerular filtrate becomes less salty as it goes up to the ascending limb. The longer the loop, the greater the difference in concentration

(Fig 20.4 Kent page 149 and Roberts and Reiss page 285)



The movement of water from the descending limb into the **peritubular fluid** would result in a water potential of zero. However, the gradient is maintained by another **counter-current** mechanism in the medullary blood. The **vasa recta** vessels bring blood into the medulla from the afferent arterioles of the juxtamedullary nephrons. Blood flows relatively slowly in the vasa recta which carry about 10% of the total kidney blood flow. Like the loops of Henle, the vasa recta turn and then pass back into the cortex. Blood entering the vasa recta from the cortex has the same solute concentration as the peritubular fluid in the cortex. The walls of the vesa recta are very permeable to water and solutes of small relative molecular mass. As blood flows deeper into the medulla it becomes surrounded by tissue fluid with an increasing concentration of solute. Hence a lower water potential. The resulting water potential gradient causes water to leave blood by osmosis. Solutes also enter the blood from the peritubular fluid. The blood becomes more concentrated. This exchange continues as the blood approaches the hair pin of the vesa recta. The solute concentration of the blood is always slightly different from that of the peritubular fluid because of the time taken to reach equilibrium and the fact that the blood continuously flows.

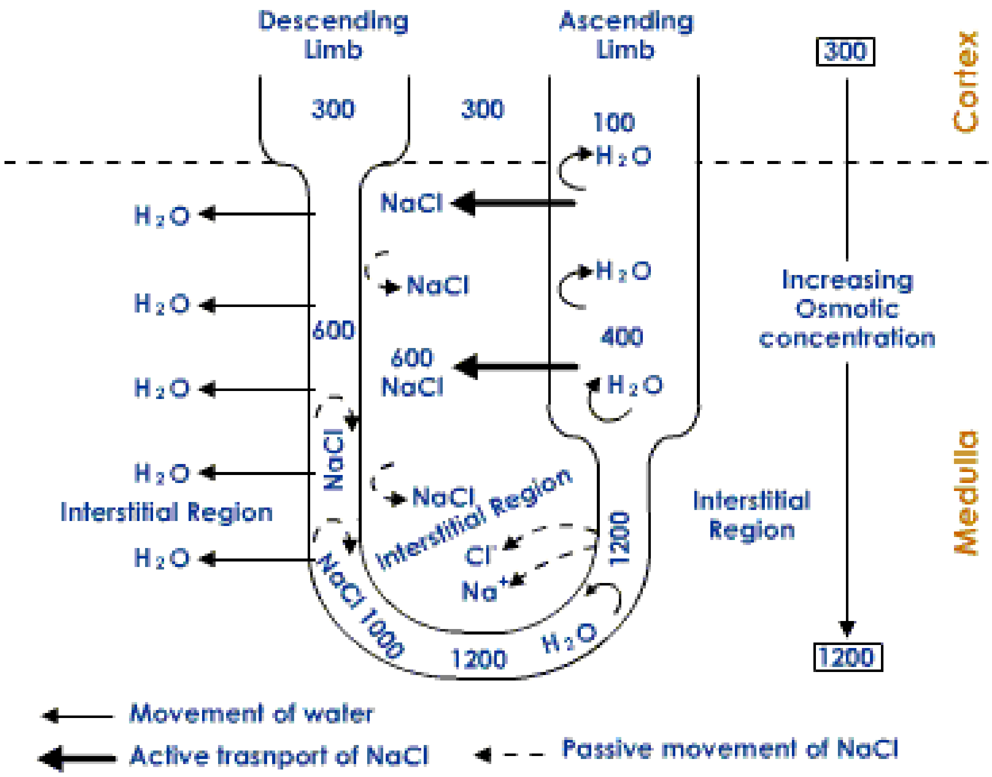
The blood turns the hairpin and begins to flow back towards the cortex. As blood ascends the medulla it absorbs water by osmosis from the peritubular fluid, solutes leave the vesa recta by diffusion. This passive counter-current exchange preserves the water potential gradient in the medulla. There is a slightly greater absorption of water by the ascending vesa recta than is lost to the peritubular fluid from the descending vesa recta. This is because the plasma proteins in the vesa recta attract water. These proteins cannot leave the blood. They counteract the osmotic loss from the descending limb of the vasa recta but add to the osmotic gain in the ascending vesa recta.

Note: the **vesa recta** acts as a **counter-current exchanger** which enables the osmotic concentration of plasma *leaving* the kidney to remain at a steady state irrespective of the osmotic concentration of plasma *entering* the kidney.

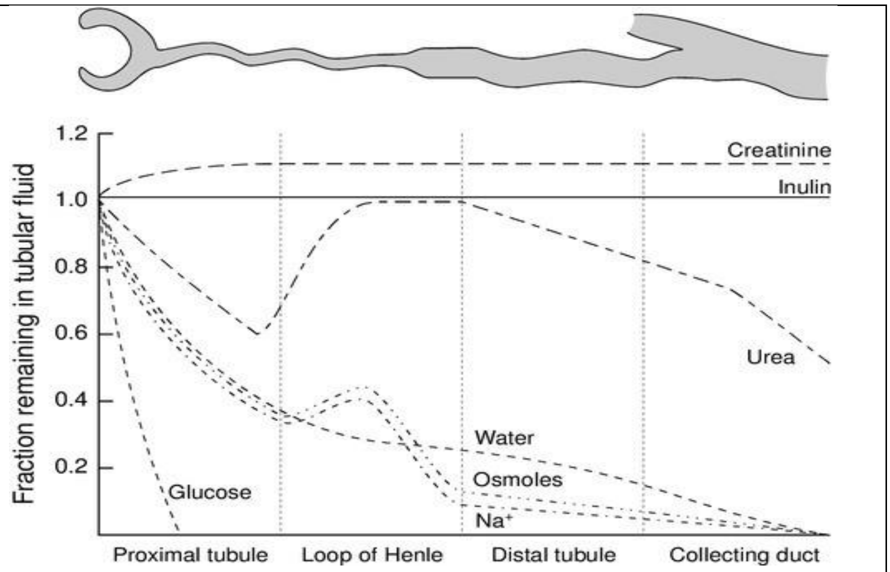
WATER REABSORPTION

This occurs in the distal convoluted tubule and collecting duct. It is under the influence of hormones which regulate water content and solute content of blood.

As fluid flows down the collecting duct, water is drawn out of it osmotically into the interstitial fluid, resulting in hypertonic urine production.



As well as helping to maintain a high concentration around the apex of the loop of Henle, the countercurrent multiplier mechanism allows the osmotic concentration of the plasma leaving the kidney to remain more or less constant regardless of the osmotic concentration of blood entering it. As the descending capillary enters the medulla it encounters an increasingly concentrated interstitial fluid. This causes water to leave the plasma by osmosis and sodium chloride and urea enter it. As the ascending limb leaves the medulla the surroundings become gradually less concentrated, water re-enters and sodium chloride and urea leave the plasma, passively. (it must be remembered that the build-up of sodium chloride in the region surrounding the apex of the loop will enable the filtrate to be further concentrated by reabsorption of water from it in the collecting duct)

Changes in the **renal-plasma ratio** of glucose, urea and chloride in the kidney of a frog. A renal plasma ratio of 1.0 means that the concentrations are the same in the renal fluid and plasma. If the ratio is greater than 1.0 the concentration is greater in the renal fluid than in the plasma. If it is less than 1.0, the concentration is lower in the renal fluid than in the plasma. Urea rises mainly because of the large amount of water reabsorbed. ***This data shows whether a substance is reabsorbed or not***.	

(Fig 14.5 Roberts page 215)

Region of nephron	Activity
Bowman's capsule	Ultrafiltration of blood in the glomerulus under hydrostatic pressure produces an ultra-filtrate free of plasma proteins and cellular elements of the blood
First convoluted tubule	Reabsorption of water by osmosis
	Reabsorption of solutes such as Na^+, K^+, Cl^-, HCO_3^-, amino acids and glucose by a mixture of active and passive processes
Loop of Henle	Active secretion of chloride ions from ultra-filtrate in ascending limb
Second convoluted tubule	Reabsorption of Na^+
	Facultative reabsorption of water under control of ADH
	Secretion of H^+, NH_4^+, urea, creatinine and some drugs
Collecting duct	Facultative reabsorption of water under control of ADH

ADAPTATIONS OF THE MAMMALIAN NEPHRON TO ITS FUNCTIONS

a. The tubules

- the proximal convoluted tubule cells;
  - Bear numerous microvilli at the free end to increase the surface area for reabsorption of substances like glucose, amino acids, vitamins, sodium chloride and water.
  - Contain numerous mitochondria to form ATP that provide energy required in active transport of glucose, amino acids, Na^+, $H_2PO_4^-$ and HCO_3^- into the blood capillaries.
  - The cell surface membrane is indented to form a large area of intercellular spaces bathed with fluid
  - Contain numerous pinocytic vesicles, which enable digestion of small protein molecules from the renal filtrate
- The loop of Henle is U-shaped with parallel, opposite flows of tubular fluid in its limbs to provide a multiplier effect that creates a concentration gradient which enables increased water reabsorption
- The capillaries of vesa recta from the loops are in close proximity with tubules to increase the reabsorption of useful substances from the filtrate
- The distal convoluted tubule is long and coiled to increase the surface area for reabsorption of water and mineral salts
- The distal and proximal convoluted tubules are coiled to slow down the movement of renal filtrate to allow more time for efficient reabsorption of substances like water and mineral salts

b. Parts other than the tubule

- Afferent arterial entering the Bowman's capsule has a wider lumen than that of the efferent arterial leaving it, resulting into high hydrostatic pressure that causes ultra-filtration to occur
- The Bowman's capsule is funnel-shaped to direct the renal filtrate into the proximal convoluted tubule
- The structural arrangement of the three layers of the glomerular capillary enables the diaphragms of slit pores formed by foot-like projections of podocytes to offer selective filtration while blood cells and the negatively charged large plasma protein are retained by endothelium and basement membrane respectively

Why does urine production almost stop after serious bleeding?

The amount of urine produced is proportional to the amount of blood flowing through the kidneys. The total blood volume in the body reduces if serious bleeding occurs, resulting into diversion of blood from other tissues (including the kidneys) to brain to maintain life. Therefore the volume of blood flowing through the kidneys reduces greatly to the extent that less ultra-filtration occurs leading to formation of less urine.

HOMEOSTATIC FUNCTIONS OF THE KIDNEY

The kidneys carries out it homeostatic functions with other organs of the body under the influence of several hormones. The homeostatic functions of the kidney include;

i. **Maintenance of pH of body fluids** at 7.4 (acid base balance) to avoid denaturing of enzymes and other proteins, which would result into death
ii. **Regulation of blood levels of ions** such as Na^+, K^+, Cl^-, Ca^{2+} e.t.c.
iii. **Regulation of water and solute content of blood** (osmotic regulation)

MAINTENANCE OF pH OF BODY FLUIDS

The body produces more acids than bases, causing the blood pH to become low (acidic) from the normal pH of 7.4 due to the increase in the concentration of hydrogen ions (H^+) that are produced by metabolic processes. In the cells of the distal convoluted tubule, the carbon dioxide from aerobic respiration, catalyzed by carbonic anhydrase enzyme, reacts with water to form carbonic acid, which dissociates into hydrogen carbonate ions. The hydrogen ions are pumped into lumen where they are buffered by hydrogen phosphate (HPO_4^{2-}) as it takes up sodium ions to form sodium hydrogen phosphate (NaH_2PO_4) which is excreted in urine while retaining the hydrogen carbonate ions.

Equation 1

Equation 2

Exceptional lowering of pH causes the cells lining the distal convoluted tubule to deaminate glutamine, amino acid, to form ammonia. The ammonia then combines with hydrogen ions to form ammonium ions which are excreted. Blood pH then rises (becomes less acidic) due to the absorption of the hydrogen carbonate ions that are produced by the dissociation of carbonic acid. In order to control pH, the hydrogen carbonate ions are excreted while the hydrogen ions are retained.

Note;

- Within the plasma, hydrogen carbonate, proteins and hydrogen phosphate act as pH buffers by temporarily taking up any excess hydrogen ions and at the same time keeping the pH constant
- The body maintains a constant pH by;
  i. Expulsion of carbon dioxide by lungs, which would accumulate and react with water to form carbonic acid
  ii. The buffering mechanisms involving plasma proteins in blood
  iii. The kidneys expelling hydrogen ions and retaining hydrogen carbonate ions
- The acid-balance (pH) is maintained by the **lungs**, **blood** and **the kidneys**.

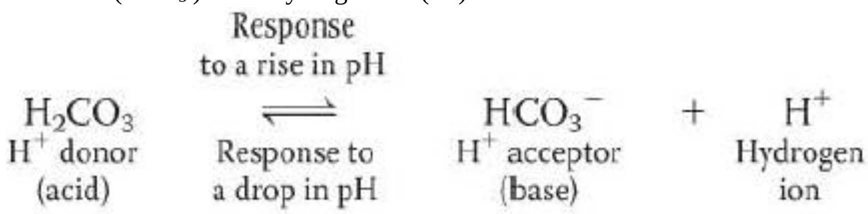
BUFFER SYSYTEMS

The internal pH of most living cells is close to 7. Even a slight change in pH can be harmful, because the chemical processes of the cell are very sensitive to the concentrations of hydrogen and hydroxide ions. The pH of human blood is very close to 7.4, which is slightly basic. A person cannot survive for more than a few minutes if the blood pH drops to 7 or rises to 7.8, and a chemical system exists in the blood that maintains a stable pH.

If you add 0.01 mol of a strong acid to a litre of pure water, the pH drops from 7.0 to 2.0. If the same amount of acid is added to a litre of blood, however, the pH decrease is only from 7.4 to 7.3. Why does the addition of acid have so much less of an effect on the pH of blood than it does on the pH of water? The presence of substances called **buffers** allows for a relatively constant pH in biological fluids despite the addition of acids or bases. Buffers are substances that minimise changes in the concentrations of H^+ and OH^- in a solution. They do so by accepting hydrogen ions from the solution when they are in excess and donating hydrogen ions to the solution when they have been depleted. Most buffer solutions contain a weak acid and its corresponding base, which combine reversibly with hydrogen ions. There are several buffers that contribute to pH stability in human blood and many other biological solutions. They include;

a. The carbonic acid-bicarbonate buffer system

Carbonic acid (H_2CO_3) is formed when carbon dioxide (CO_2) reacts with water in blood plasma, it then dissociates to yield a bicarbonate ion (HCO_3^-) and a hydrogen ion (H^+):



The chemical equilibrium between carbonic acid and bicarbonate acts as a pH regulator, the reaction shifting left or right as other processes in the solution add or remove hydrogen ions.

- If the H^+ concentration in blood begins to fall (that is, if pH rises), the reaction proceeds to the right and more carbonic acid dissociates, replenishing hydrogen ions.
- When H^+ concentration in blood begins to rise (when pH drops), the reaction proceeds to the left, with HCO_3^- (the base) removing the hydrogen ions from the solution and forming H_2CO_3

Thus, the carbonic acid-bicarbonate buffering system consists of an acid and a base in equilibrium with each other. Most other buffers are also acid-base pairs.

b. Phosphate buffer system

This is a solution of HPO_4^{2-} and $H_2PO_4^-$

The dihydrogen phosphate ($H_2PO_4^-$) dissociates into hydrogen phosphate (HPO_4^{2-}) and hydrogen ions (H^+). Addition of small quantities of acid will cause the excess incoming hydrogen ions to react with hydrogen phosphate ions forming dihydrogen phosphate.

Equation

When an excess of the base is added, the excess incoming hydroxyl ions will react with hydrogen ions forming water and leading to further dissociation of dihydrogen ions to replenish the hydrogen ions and form hydrogen phosphate ions

Equation

c. Protein buffer system

This is due to the hydroxyl group and amino group attached to the amino acids that make up proteins. When excess hydroxide ions are added to the solution containing amino acids, the carboxyl group of the amino acid donates a proton which reacts with hydroxyl ions forming water thus lowering the pH. When excess hydrogen ions are added, they react with the amino group forming ammonium ions thus raising the pH to normal.

REGULATION OF BLOOD LEVELS OF IONS

The kidney closely regulates the concentration of ions such as Na^+, K^+, H^+, Ca^{2+}, Cl^- and HCO_3^-. These ions are important for their specific roles in various chemical processes, such as maintenance of protein structure, membrane permeability, propagation of the nerve impulse and muscle contraction. Some are important in the regulation of the pH of blood, which is also regulated, in part, by the kidneys. The concentration of particular types of ions in blood and tissue fluid is regulated in three ways. Hormones control the;

i. Uptake of ions from the gut into the blood stream
ii. Removal of ions from the body by kidneys and elimination in the urine
iii. Release of ions into the blood stream from organs which contain them in high concentration

Regulation of calcium ions (Ca^{2+})

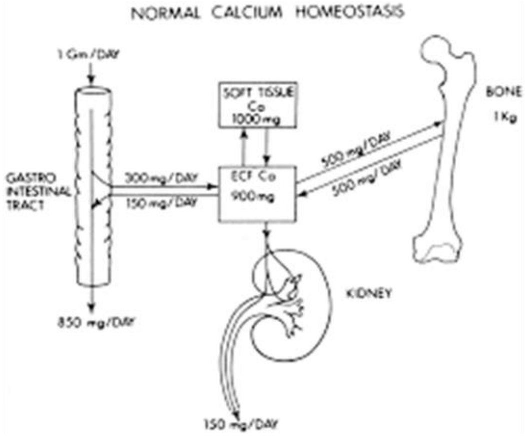
Low blood calcium level stimulate the *parathyroid gland* to secrete *parathormone* (*parathyroid hormone*) which increases the calcium level and decreases the phosphate level by promoting;

- Bone break down by osteoclasts
- Calcium retention by the kidneys
- Excretion of hydrogen phosphate in the urine
- Activation of vitamin D, which in turn stimulates the absorption of calcium from the gut

High blood levels of calcium stimulate the *thyroid gland* to secrete *calcitonin* hormone, which increases bone build u by osteoblasts so as to reduce calcium levels.

Note:

i. Calcium plays an important role in nerve conduction, muscle contraction and blood clotting
ii. Deficiency of the parathyroid hormone results in tetany i.e. shaking of the body due to continuous muscle contraction caused by increase excitability of the nerves which fire spontaneously and without rest



A decrease in blood sodium leads to decreased blood volume and reduced blood pressure because less water is drawn into blood by osmosis.

The *juxtaglomerular complex*, situated between the distal convoluted tubule and the afferent arteriole, is stimulated to release the enzyme **renin** (not the digestive rennin). Renin catalyses the conversion of *angiotensinogen*, a plasma protein into a hormone *angiotensin,* which stimulates the adrenal cortex to secrete aldosterone hormone. Aldosterone has the following effects;

- Stimulates the active uptake of sodium ions from the glomerular filtrate into the plasma of capillaries surrounding the nephron. This induces osmotic uptake of water into blood thus increasing blood volume and sodium level back to the norm, accompanied by loss of potassium ions
- Stimulates sodium absorption in the gut and decreases loss of sodium in sweat so as to raise sodium levels to cause an osmotic in flow of water thus increasing the blood volume and pressure
- Stimulates the brain to increase the sensation of thirst

Increased sodium levels in blood cause increase blood volume and pressure less production of urine.

Note:

Low levels of sodium in blood are detected by the hypothalamus, which stimulates the anterior pituitary gland to secrete the *andrenocorticotrophic hormone (ACTH),* which also controls the activity of the adrenal cortex i.e. secretion of *aldosterone hormone*.

OSMOTIC REGULATION

Increased concentration of solutes in blood (little water relative to salts) is detected by osmoreceptors in the hypothalamus which stimulate the posterior pituitary gland to secrete *antidiuretic hormone (ADH)/ vasopressin* and at the same time triggers the sensation of thirst, resulting into the drinking of water. ADH increases the permeability of the distal convoluted tubule and the collecting duct to water, allowing the osmotic flow of water from the glomerular filtrate into the cortex and medulla hence reducing the osmotic pressure of blood but increasing that of urine. ADH also increases the permeability of the collecting duct to urea, enabling its diffusion into the medulla tissue fluid where it increases the osmotic pressure, leading to the extraction of water from the descending limb.

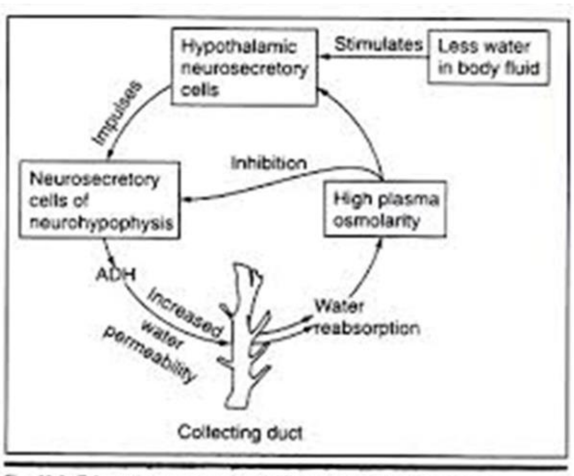


Fig. 11.1: Schematic representation shows retention of water by ADH

Low solute concentration in blood (too much relative to salts) inhibits ADH release, tubule walls and collecting ducts become impermeable to water, less water is reabsorbed from the glomerular filtrate into blood and a large volume of dilute urine is passed out hence raising the osmotic pressure of blood.

Note:

- **Diuresis** is the production of copious dilute urine and antidiuresis is the opposite
- Insufficient production of ADH leads to a condition known as ***diabetes inspidus*** characterised by frequent copious urination
- Increase in blood osmotic pressure results from ingestion of little water, much sweating, ingestion of large amounts of salt while a decrease in blood osmotic pressure may be due to little sweating, ingestion of large volumes of water and little salt intake.

SAMPLE QUESTIONS

1. (a)Outline the ways in which water lost and gained by terrestrial animals (04 marks)
   (b) Outline the ways in which these water losses are controlled in terrestrial animals by;
   i. Structural, (03 marks)
   ii. Physiological, (07 marks)
   iii. Behavioural adaptations. (04 marks)
   (c) To what extent do terrestrial plants have similar adaptations to animals for the prevention of excessive water loss? (02 marks)
2. (a) Describe the role of the mammalian kidney is the following processes;
   i. Osmoregulation
   ii. Excretion (14 marks)
   (b) Explain the significance of the following as excretory products
   i. Ethanol in yeast
   ii. Ammonia in freshwater teleosts (06 marks)
3. Two species of amoeba were transferred from their natural habitats to different dilutions of sea water, and each individual was given time to adjust to its new environment. The table below shows data about the rate of vacuolar contractions with varying solute concentrations.

Sea water concentration in % (normal sea water = 100%)	**Number of vacuolar contractions per hour**	
	Species A	***Species B***
5	82	20
10	74	63
15	65	64
20	58	56
30	34	31
40	14	13
50	0	6
60	0	0

(a) Plot the results of the experiment as a graph

(b) Describe the functioning of the contractile vacuole.

(c) Explain by reference to the data, the difference in vacuolar contraction in the two species of Amoeba when placed in the higher concentrations of seawater.

(d) What information may be deduced about the natural habitats of the two species from the rates of vacuolar contractions?

4. (a) Explain the absence of elaborate nervous systems in animals such as protozoans

(a) How are the organisms in the multicellular state at a disadvantage?

5. (a) Amino acid metabolism in animals leads to the formation of nitrogenous waste products. Explain briefly why nitrogenous waste does not occur in plants (02 marks)
   (b) Analysis of the glomerular filtrate and the urine of a mammal yielded the following mean daily values;

	Glomerular filtrate	Urine

Urea Water	60g 180dm^3	35g 1.5dm^3

(i) 150dm^3 of water is reabsorbed by the proximal tubules. Calculate the percentage of water from the filtrate that is reabsorbed elsewhere.

(ii) Name two other regions of the tubules where this further reabsorption of water takes place (03 marks)

(c) In mammalian kidneys, the relative length of the loops of Henle shows considerable variation from one species to another. Suggest, with reasons, the type of habitat in which you would expect to find species with extremely long loops of Henle. (03 marks)

(d) Nitrogenous waste in animals may occur as ammonia, urea or uric acid. Ammonia is very soluble and highly toxic, urea is soluble and mildly toxic; uric acid is insoluble and non-toxic. The table below shows the percentage of these three compounds in the urine of four different animals.

	Ammonia	Urea	Uric acid
Freshwater fish	56	6	0
Seawater fish	7	81	0
Lizard	0	0	91
Bird	3	4	72

(i) Offer an explanation for the difference in the main excretory compound in freshwater and seawater fish (05)

(ii) Both lizards and birds are terrestrial egg-laying animals. How do these characteristics relate to the nature of their main excretory products? (02 marks)

6. (a) Discuss the role of the vesa recta (08 marks)
(b) Describe the role of ADH in osmoregulation. (12 marks)

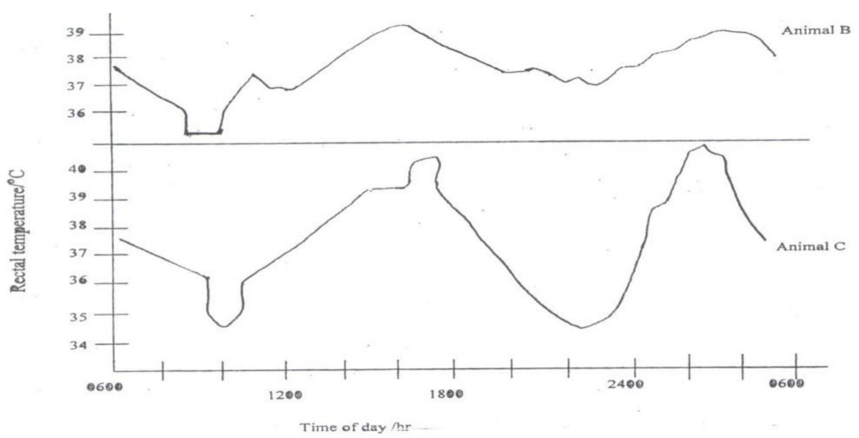
7. (a) Explain why plants are normally more vulnerable to having too little water than too much (08 marks)
(b) Explain how terrestrial insects minimise water loss. (12 marks)

8. Two mammals were subjected to different environmental temperatures and each time the temperatures were varied, their metabolic rates were determined. The results were tabulated as shown below

Environmental temperature/^{0}C		-20	-15	-10	-5	0	5	10	15	20	25	30	35	40	45	50
Relative metabolic rate	Mammal A	4.0	3.5	3.1	2.6	2.2	1.8	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.1	1.2
	Mammal B						5.0	4.0	3.0	2.0	1.1	1.1	1.1	1.1	1.2	1.3

(a) Plot suitable graphs to show the relative relationships
(b) Describe each of the graphs you have plotted
(c) Explain the observed patterns of relationship
(d) Why did the experiment fail to determine the relative metabolic rate of mammal B for temperatures above 50^{0}C and below 5^{0}C?
(e) Assuming that these mammals show very close evolutionary relation relationships; distinguish between their relative sizes and show how they are related to their survival in different environmental conditions

9. The graph below shows the fluctuations in the rectal temperature of two desert animals (camels). Animal B was allowed unlimited access to drinking water, animal C was not provided with water.



i. Explain why rectal temperature was measured rather than skin temperature (01 mark)

ii. Explain the variation in rectal temperature of animal B (03 marks)
iii. Suggest why there is a smaller daily temperature fluctuation in animal B that in animal C (02 rks)

10. (a) Discuss the role of the aortic and carotid bodies in regulating respiratory rate in mammals (06 mas)
(b) Describe the changes that occur in the body of an athlete just before, during and after a race (14 ks)

11. a) Define the following terms; (03 marks)
    i. Excretion
    ii. Osmoregulation
    iii. Homeostasis
    (b) Name and describe the roles of the components of a homeostatic control system (7marks)
    (c) Describe the hormonal regulation of blood sugar (10 marks)

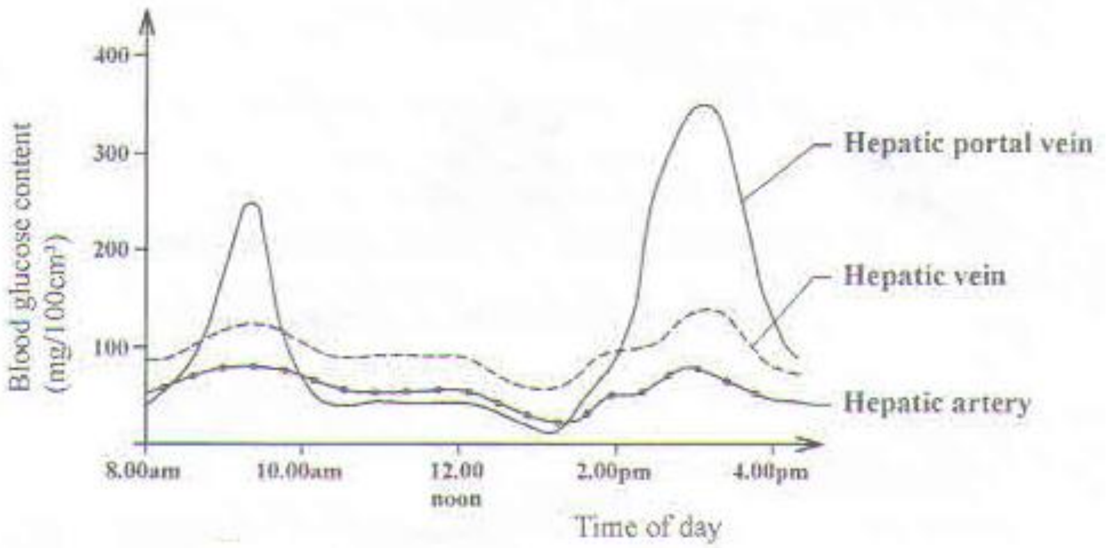
12. (a) Outline the process of osmoregulation is a grass hopper (04 marks)
(a) Explain why different organisms excrete different nitrogenous wastes in form of ammonia, urea and uric acid.

13. (a) What is meant by the term counter current system? (02 marks)
(b) Explain the different forms of countercurrent systems in vertebrates (18 marks)

14. (a) Describe how secretions from the pancreas and adrenal glands affect metabolism of absorbed carbohydrates (12)
(b) Under what circumstances may blood sugar;
    i. Appear in excreted urine (04 marks)
    ii. Level be higher in hepatic artery than in hepatic vein (04 marks)

15. (a) With examples, describe the adaptations of animals to water conservation
(b) Explain how dry crystals of uric acid are formed in insects
(c) Explain how euryhaline fish carry out osmoregulation

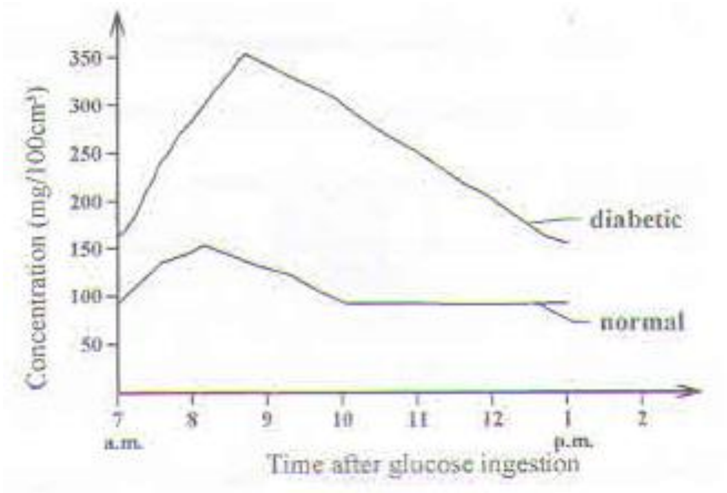
16. (a) The figure below shows the average blood glucose levels in three major vessels of the liver of an individual, who had meals at 7:00am and 1:00pm. Use the information to answer the questions that follow.



i. Compare the levels of glucose in:
- Hepatic artery and hepatic vein (04 marks)
- Hepatic artery and hepatic portal vein (04 marks)

ii. Explain the differences in the levels of glucose in the:
- Hepatic artery and hepatic vein (09 marks)
- Hepatic artery and hepatic portal vein (09 marks)

(b) The figure below shows blood glucose levels in a normal and diabetic individual, after both individuals were given a sugar solution at 7:00am. Study the information and answer the questions that follow.



i. Compare the levels of blood glucose between the two individuals (05 marks)
ii. Give an explanation for the observed pattern of the levels of glucose in the two individuals (05 marks)

(c) What is the significance of the physiological process illustrated in the two figures above (04 marks)

17. Heat loss (-) and gains (+) were monitored and recorded, of a naked human being at varying environmental temperatures. The heat losses and gains by the internal body environment (body core), heat losses and gains by the skin surface as a result of radiation and convention and also heat losses as a result of evaporation, with varying environmental temperature, are shown in the table below. Study the figure and answer the questions that follow.

Environmental temperature (°C)	Heat loss (-) and heat gain (+) in arbitrary units		
	Skin surface		Body core
	By radiation and convection	By evaporation	
20.0	-160	-20.0	-120
22.5	-135	-22.5	-85
25.0	-110	-25.0	-50
27.5	-85	-27.5	-20
30.0	-55	-30.0	0
32.5	-25	-60.0	+5
35.0	+5	-100.0	+5
37.5	+40	-140.0	+5
40.0	+80	-180.0	0

a) Represent the data above graphically
b) Describe the relationship between the heat loss and gain by the skin surface as a result of radiation and convection and heat loss as a result of evaporation from the skin (04 marks)
c) How does the relationship in (a) affect the losses and gains of heat by the body core? (03 marks)
d) Explain the trend of heat losses and gains by the
    i. Skin surface as a result of radiation and convection (10 marks)
    ii. Skin surface as a result of evaporation (08 marks)
    iii. Body core (12 marks)

What is the significance of maintaining body temperature in animals? (03 marks

18. (a) Explain how the following are adapted for their functions
    i. Kidney
    ii. Liver
    iii. Respiratory system in mammals

(b) Describe the control of the following in humans
    i. pH
    ii. salt balance
    iii. osmotic pressure of blood and urine

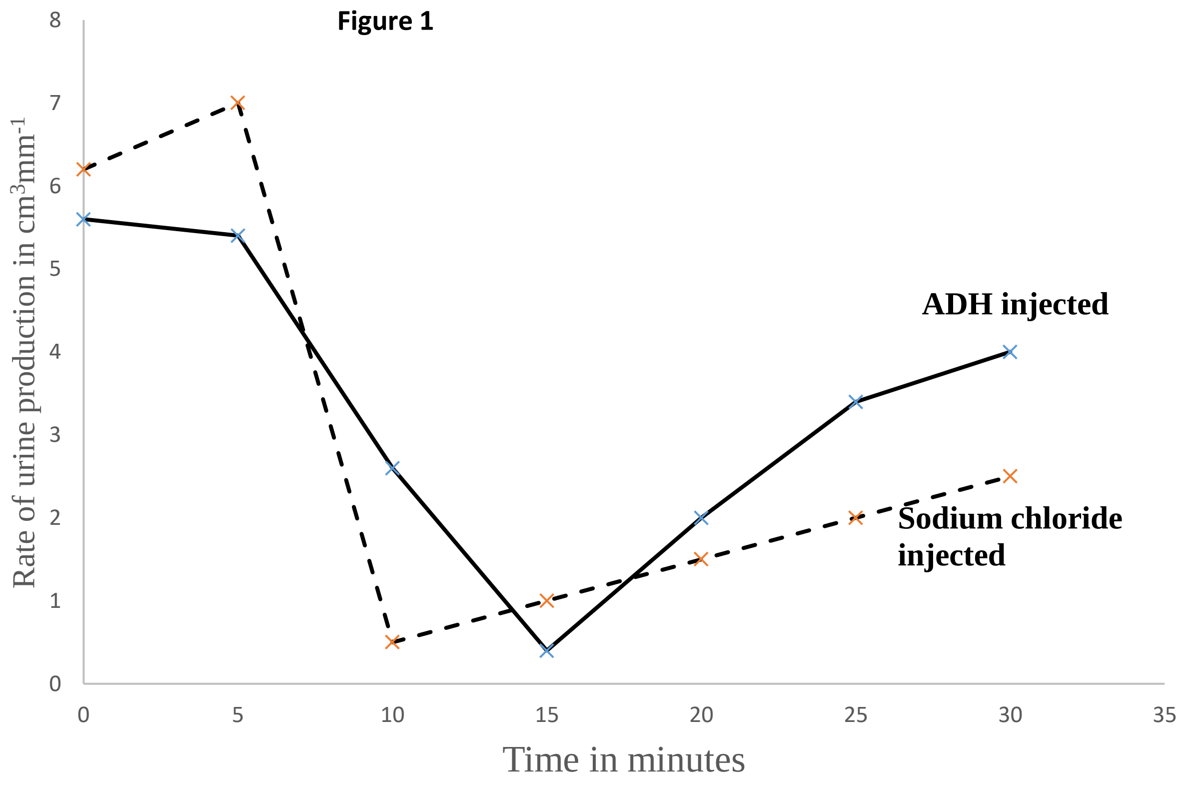
19. (a) Describe how the following organisms carry out osmoregulation (10 marks)
    i. Fresh water teleosts
    ii. Marine elasmobraches
    (b) How are terrestrial animals adapted to prevent desiccation (10 marks)

20. a) What is the importance of osmotic control in animals?
    (b) Explain the methods of regulating salt and water contents of the body in mammals.
    (c) Describe the means by which blood circulation is maintained and controlled in a mammal.

21. (a) What is meant by **positive feedback**? (02 marks)
    (b) Explain negative feedback with reference to blood sugar control (07 marks)
    (c) Explain the maintenance of the normal level of water in blood sugar control at a steady state (11 ma

22. (a) Describe how the loop of Henle operates as a counter-current multiplier (08 marks)
    (b) Explain how different terrestrial animals have solved their osmotic challenges (12 marks)

23. In an experiment, the rate of urine production and maximum urine concentration produced by mammals were determined.
    In experiment 1, investigations were carried out into separate effects of sodium chloride and Anti-Diuretic Hormone (ADH) on urine production of a child over a period of 30 minutes.
    On one occasion, an intravenous injection containing 10cm^3 of 0.5% sodium chloride solution was injected five minute after measurements had begun.
    On another occasion, an intravenous injection containing 1cm^3 of ADH was injected five minute after measurements had begun.
    The results are shown in figure 1 below



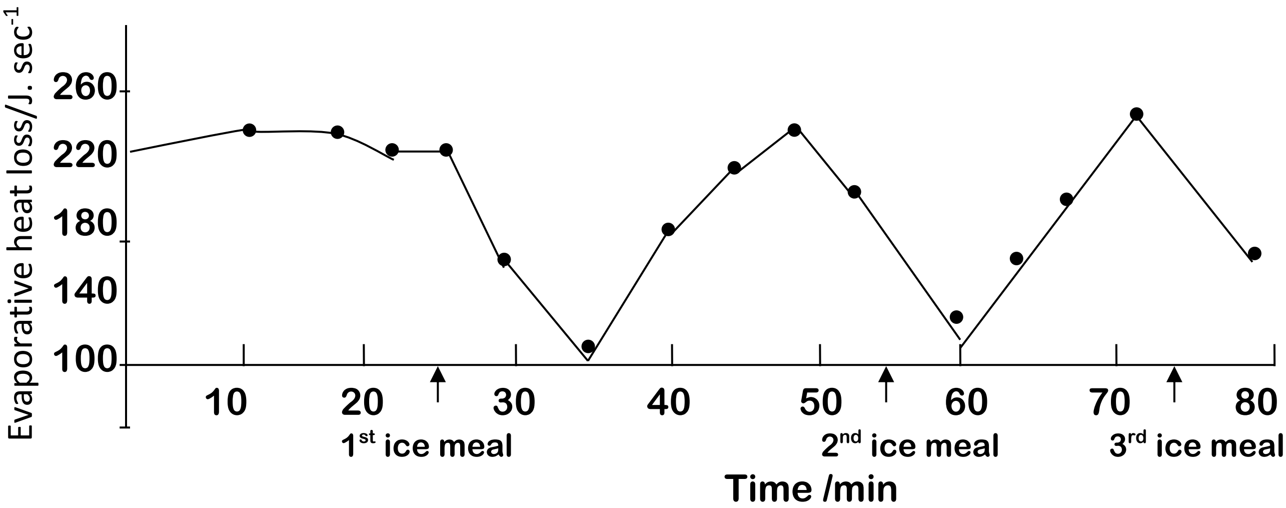
In experiment 2, the thickness of the medulla in relation to the rest of the kidney and the maximum urine from six different mammals were determined. The results are shown in the table below.

Mammal	Relative thickness of medulla	Maximum urine concentration in arbitrary units
Beaver	1.0	52
Pig	1.3	110
Human	2.6	140
Squirrel	5.2	300

Kangaroo rat	7.8	550
Animal X	9.8	940

a) Describe the variations in the rate of urine production before and after;
   (i) Sodium chloride was injected. (03 marks)
   (ii) ADH was injected. (04 mark
b) Compare the rate of urine production when sodium chloride and ADH were injected. (10 marks)
c) Explain the effects of ADH on urine production. (10 marks)
d) Explain the differences shown by the relationship between rate of urine production when sodium chloride was injected and when ADH was injected (02 marks)
e) From the table
   (i) Explain the relationship between urine concentration and relative thickness of medulla. (08 marks)
   (ii) With a reason, suggest the natural habitats of the beaver and animal **X**. (04 marks)

24. A special calorimeter was developed into which a volunteer human being could be placed, so that measurements of the temperature of the skin surface and hypothalamus were made. The calorimeter temperature was maintained at 45^0C, and both the skin surface and hypothalamus temperature rose initially but stabilized within 15 minutes. After fourty minutes into the calorimeter the person was given a quantity of iced water to drink which was repeated thirty minutes later.
The graph below shows the body energy loss due to sweating taken at 5 minute interval.

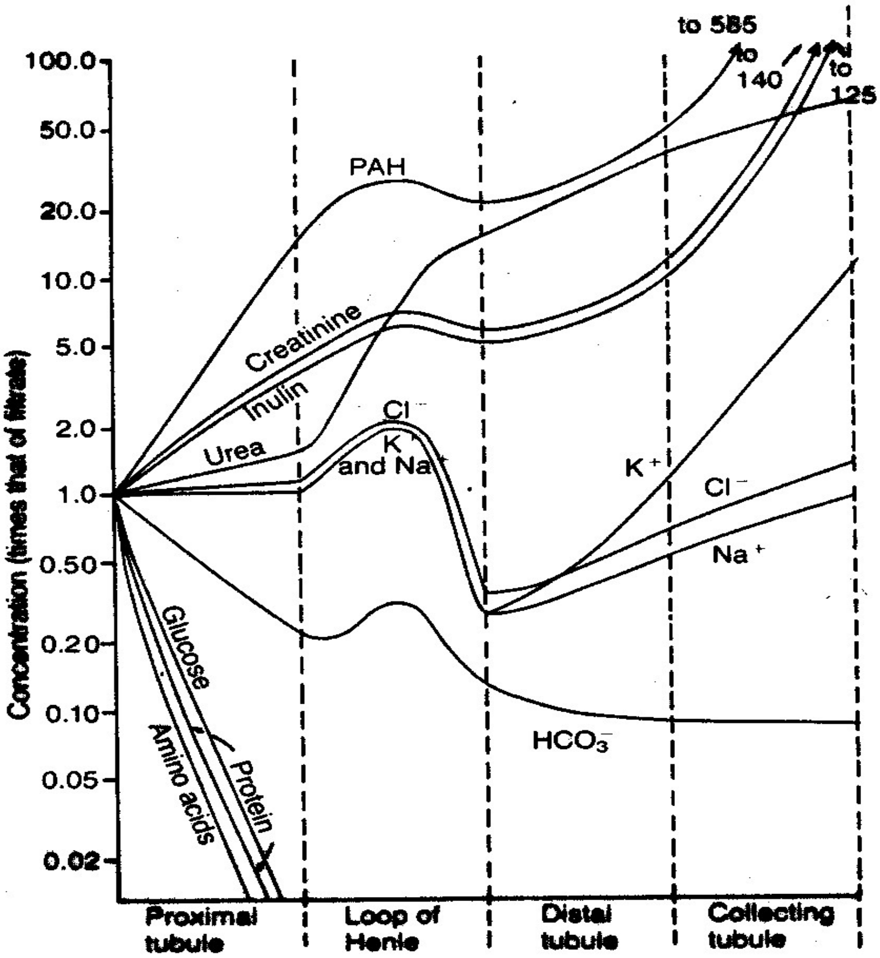


The table shows the temperature of the skin surface and that of the hypothalamus taken at the same time with heat loss after the initial cold drink.

Time after entering calorimeter (min)	Temperature (°C)	
	Skin	Hypothalamus
40	36.5	37.5
45	37.1	37.2
50	37.5	36.9
55	37.3	37.2
60	37.1	37.4
65	37.0	37.5
70	36.9	37.4
75	37.3	37.1
80	37.2	37.2
85	37.1	37.4

a) Represent the above information on the graph paper. (7marks)
b) Explain the relationship between;
(i) Skin temperature and energy loss by evaporation. (8marks)
(ii) Temperature of hypothalamus and energy loss by evaporation. (8marks)
c) Why;
(i) A special calorimeter was used. (1mark)
(ii) Iced water was not given at the start of the experiment. (4marks)
(iii) The skin temperature rises shortly after ingestion of iced water. (4marks)
d) State and explain what would happen in each if;
(i) The inside of the calorimeter was kept at a constant temperature of 10^0C. (5marks)
(ii) A lizard was used instead of a human being. (3marks)

25. The figure below shows variation in concentration of **cations** (K^+, Na^+), **inorganic anions** (HCO_3^-, Cl^-), **organic anion** (*p*-aminohippurate - PAH), **inulin**, (a fructose Polymer), **excretory wastes** (Urea and Creatinine – a product of muscle metabolism derived from creatine phosphate), and **metabolites** (glucose, amino acids and protein of low molecular weight) along the different regions of the nephron. Inulin is not synthesized, destroyed, or stored in the kidneys



(a) Explain the trend in the concentration of the following along the different regions of the nephron

(i) Ions
(ii) Metabolites
(iii) Excretory wastes

(b) ***Account for the***:

(i) Absence of cells, immunoglobulins, and large molecular weight proteins in glomerular filtrate.

(ii) Clinical importance of selective filtration of cells, immunoglobulins, and large molecular weight proteins.

(c) ***Explain why the***:

(i) Rate of plasma ultrafiltration in the kidney glomeruli far exceed that in all other capillary beds.

(ii) Proximal tubular fluid is essentially isosmotic to plasma.

(d) What is the significance of producing concentrated urine osmotically to a named land dweller

26. (a) Explain how the following buffer systems operate to bring about an acid base balance in the body
    i. Phosphate buffer system *(04 marks)*
    ii. Protein buffer system *(04 marks)*

    (b) Describe the renal control of pH *(12 marks)*

27. (a) Describe the source and fate of major excretory products in living organisms (10 Marks)
    (b) Explain how fresh water bony fishes overcome their osmoregulatory challenges (10 Marks)

28. (a) What is osmoregulation? (02 marks)
    (b) What is the importance of osmotic control in animals? (03 marks)
    (c) Describe the method by which salt and water content of the body is regulated in mammals (15 ma

29. (a) An Arabian camel, storing mainly fat in its hump, weighs 400kg and lives in deserts where the temperature by day is often 40^0C. The fat in the camel's hump weighs 40kg and is a source of metabolic water. The table shows the day temperature, oxygen content and water content of desert air and air expired from the camel's lungs.

	Temperature (^{0}C)	Oxygen content (cm^3dm^{-3})	Water content (mg^3dm^{-3})
Desert air	40	200	5
Expired air	37	160	44

During aerobic respiration 1g of fat requires $2dm^3$ oxygen and yields 1.07g of water

i. How do these figures show that the fat in the camel's hump cannot be its only source of water
ii. A 70Kg human contains 14Kg of fat. Compare the proportion of and distribution of fat in the camel and the human. Suggest why the differences are advantageous to each mammal.

(b) Mammals can produce urine more concentrated than blood plasma.

i. By means of annotations (notes) on a diagram, explain how the filtrate is concentrated as it passes along the nephron to the pelvis of the kidney
ii. The concentration of urine produced by the camel can be twice that of a human. Suggest how the structure of the camel kidney may differ from that of the human kidney and how this can account for the camel's greater urine concentration.

(d) Mammals which in deserts have very long loops of Henle while aquatic mammals, like beavers, have short loops of Henle. Explain the advantages of these adaptations

30. (a) What are the benefits and the costs of maintaining a constant, high body temperature in mammals?
    (b) Describe the responses of a mammal to cold temperatures, in both the short term and the long term
    (c) Why is prolonged exposure to cold frequently fatal?

31. (a) Distinguish between **negative** and **positive** feedback loops. 2 *marks*
    (b) Explain how feedback mechanisms regulate each of the following:

    (i) The menstrual cycle in a non-pregnant human female 10 *marks*
    (ii) Blood glucose levels in humans. 8 *marks*

32. (a) Explain the mechanism by which each of the following organs conserve and maintain water balance.
    (i) Mammalian kidney (07 marks)
    (ii) Insect Malpighian tubule (05 marks)

    (b) (i) Define the term counter current exchange system (02 marks)
    (ii) State the significance of any three counter current exchange systems to different groups of animals?

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