

HOMEOSTASIS

Homeostasis is the maintenance of the relative constancy of the body's internal environment regardless of the conditions in the external environment.

In other words, it is the process by which internal environment of the body is maintained fairly constant.

Internal environment refers to the immediate surrounding of body cells. This is mainly the body fluids which include blood, lymph and tissue fluid.

Tissue fluid is the immediate fluid surrounding body cells but not blood.

Parameters are the **factors/conditions** of internal environment which must kept fairly constant and these include the following;

- (i) Average core body temperature at 37°C/98.6°F.
- (ii) Concentration of blood glucose at 90mg/100cm³.
- (iii) Blood pH at 7.4.
- (iv) Blood pressure in branchial artery 120/80.
- (v) Blood levels of ions; sodium ions, potassium ions, chloride ions and calcium ions.
- (vi) Concentration of respiratory gases, carbon dioxide and oxygen.
- (vii) Osmotic pressure [quantity of water relative to salts/solutes].
- (viii) Heart rate and so on

NB: These conditions/parameters are not maintained absolutely constant but in a **steady state/dynamic equilibrium**-that is, within a narrow range.

SIGNIFICANCE OF HOMEOSTASIS

Homeostasis prevents **cell death** and ensures that **body physiology proceeds efficiently**; as it maintains a narrow range of conditions within which body enzymes, membrane proteins and other vital proteins work efficiently; since they are sensitive to changes in key parameters such as pH and temperature among others, which cause their **denaturation, inactivation or inhibition**; thereby impeding body physiology. Similarly, it maintains osmotic potential of cells thereby **preventing cells from shrinking or expansion/bursting** on loss or entry of excess water by osmosis, and ensures that body cells and thus organisms **release energy needed for various metabolic activities at a constant rate** by regulating blood glucose level.

Therefore, homeostasis maintains the stability of body's internal environment (cellular environment) which provides the organism with a degree of independence of the external environment. This enables the organism to inhabit a wide range of habitats including **extreme and hostile** environments and exploit a variety of resources available in such habitats.

Functions of homeostatic control in cells

For maintenance of a constant temperature for efficient enzyme action.

For maintenance of a constant pH for efficient enzyme action.

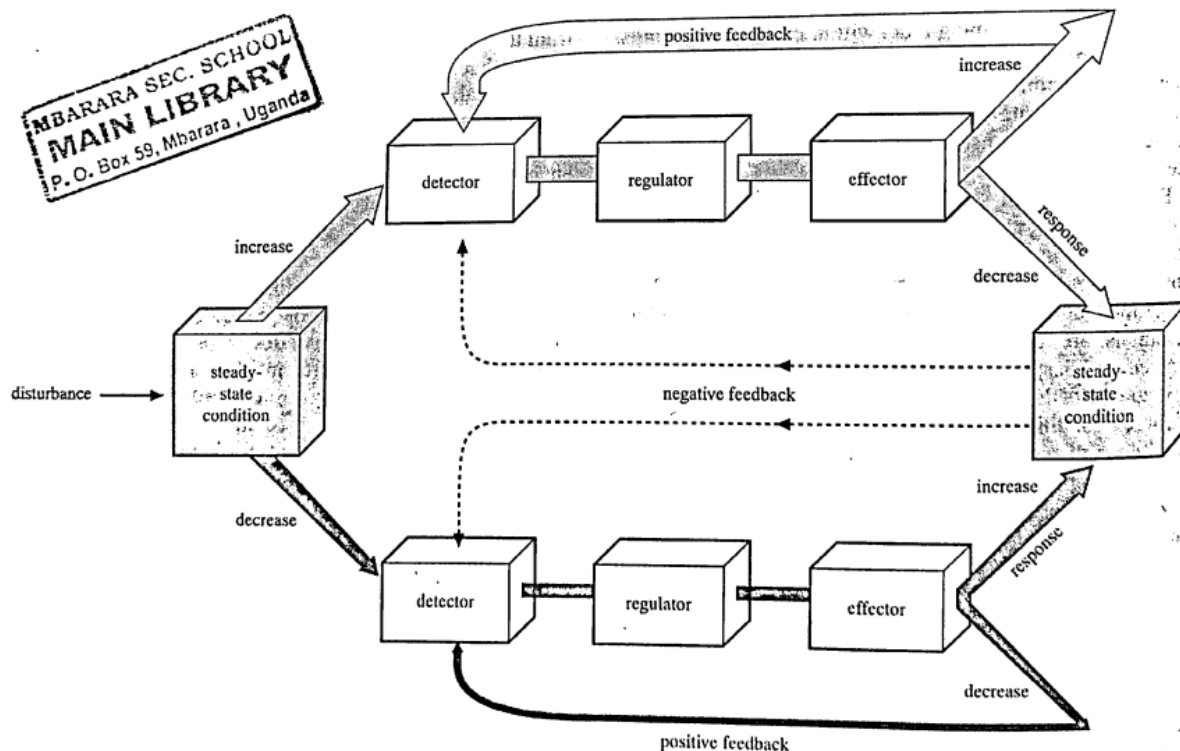
For maintenance of a constant water potential to prevent bursting of cells.

For maintenance of a constant solute potential to prevent bursting of cells.

ESSENTIAL COMPONENTS OF A HOMEOSTATIC CONTROL SYSTEM

1. **Reference point/norm/set point/steady state condition;** Is set level (normal value) at which the system operates/optimum level of variable being controlled. E.g. See examples of parameters given above.
2. **Detectors/receptors;** are parts of the body that constantly monitor and detect changes from reference point/norm in the internal environment and then signal the deviations to the control centre; e.g. thermoreceptors in the skin.
3. **Regulator/comparator/control centre;** usually brain; coordinates the information from various receptors and sends out instructions which will correct the deviations.
4. **Effectors/responding organs;** are parts of the body that bring about the necessary changes needed to return the system to the norm. e.g. muscles and glands.
5. **Feedback loop;** refers to the hormones/nerve impulses that inform the receptors of any change in the system as a result of the action of the effectors.

Illustration



OPERATION OF THE HOMEOSTATIC SYSTEM

A homeostatic system **operates as self-regulating system** which operates by means of feedback mechanism.

Feedback mechanism is a system which detects a change in the level of a parameter and sends back information to the production centre for the body to respond.

In other words, it is a mechanism in which an input stimulus causes an output response that feeds back to the initial input. It can be **positive** or **negative feedback mechanism**.

Negative feedback mechanism; Is a control system 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.

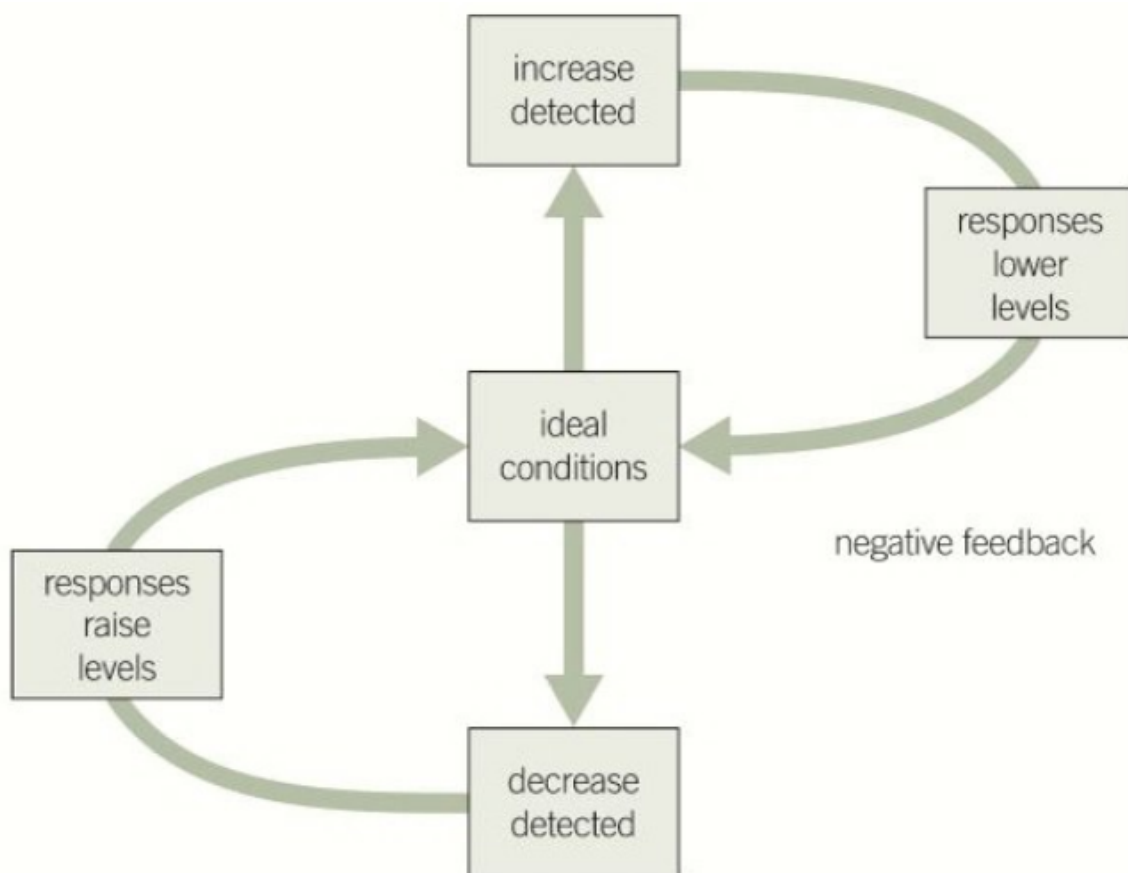
In other words, it is where any deviation in homeostatically controlled parameter from the norm induces corrective measures to restore the deviation back to norm.

HINT: Most of the parameters in biological system are controlled by this mechanism whereby an increase counteracted by decrease and vice versa to return to the set point. E.g. Increase in body temperature causes body to lose more heat. Hence negative feedback mechanism is common in biological systems.

Why common in biological systems?

It increases the stability of the internal environment of the body thereby enabling the organism to be independence of fluctuations in the external environment and thus, extreme and hostile environments are inhabited due to maintenance of the stability of internal environment by negative feedback.

Illustrative scheme



Positive feedback mechanism; Is a control system in which the effect of deviation from the normal condition/norm intensifies the original response such that change tends to proceed in the same direction as the initial stimulus.

In other words, it is where any deviation in homeostatically controlled parameter is amplified in order to be normalized. It is due to breakdown/failure of the corrective mechanism.

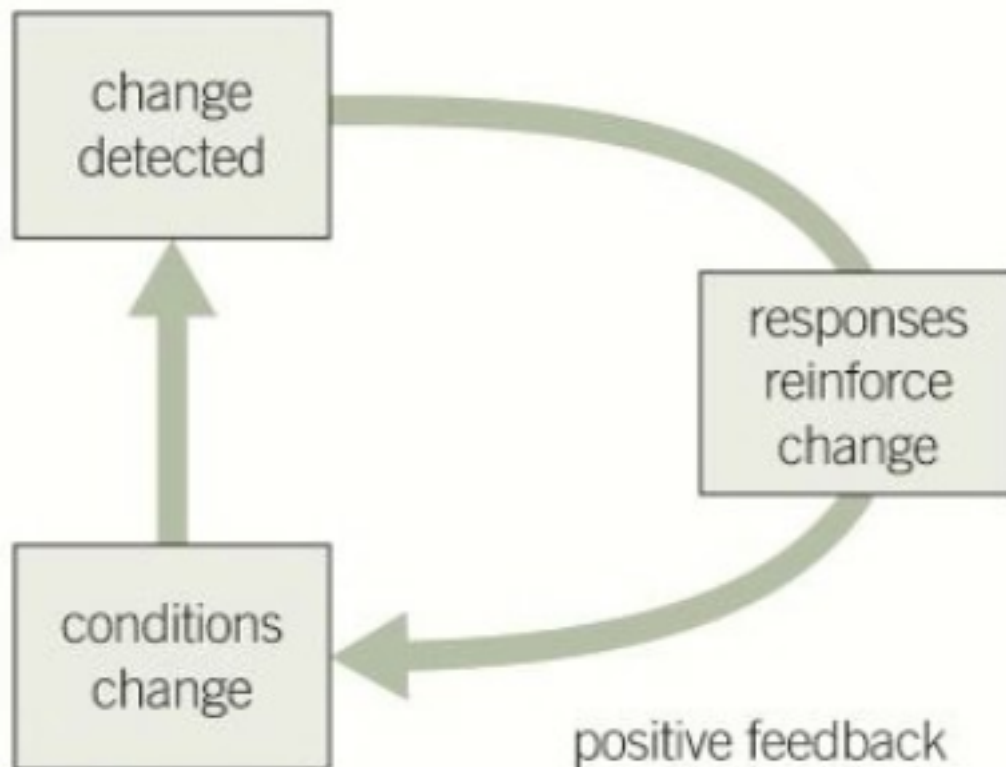
E.g.

- ✓ 10°C increase in temperature doubles metabolic activity, leading to more heat production; which rises the metabolic activity even more.

- ✓ In blood clotting to stop bleeding and keep blood volume constant; 1 clotting factor activate the other leading to cascade that results into quick clot-that's, accumulation of platelets during blood clotting-that is, blood clotting cascade.
- ✓ In child birth; oxytocin release; leads to contraction of uterus/uterine muscles which stimulates further oxytocin release till the foetus is expelled-that's, Secretion of oxytocin during labour/delivery/parturition.
- ✓ In propagation of nerve impulse; depolarization of the membrane of neurone leads to increased sodium ions permeability; thus, sodium ions pass into the axon; leading to further depolarization; thus, more sodium ions enter into the axon/axoplasm that results into development of the action potential-that's, ionic movement during nerve impulse propagation.
- ✓ Control of sleeping by hypothalamus.
- ✓ Secretion of sexual fluids like semen during ejaculation.

NOTE: Positive feedback mechanism is **rare** in biological systems because it increases the instability of the system.

Illustrative scheme



HINT:

- (i) **Cascade** is where a small amount of say, hormone causes the target organ to produce a large amount of the product.
- (ii) The **efficiency of a control system** is measured in terms of how little a parameter is displaced from the norm and how fast the norm is restored to the set point.

THE PROCESS OF OPERATION OF A HOMEOSTATIC SYSTEM

For any homeostatic process to work, the system must be with a receptor, a control centre (control mechanism) and an effector.

The receptor detects changes in a parameter (deviations) and sends information (sensory impulses) to the control centre/regulator which analyzes the information from the receptor and responds by sending appropriate instructions (motor impulses) to the appropriate effector(s). The effectors respond and execute the instructions from the control centre by taking corrective measures/actions through changing the properties of the parameter so as to correct/restore the set point. Upon returning to the set point, the effectors inform the receptor(s) about the correction via feedback loop (impulses/hormones); so that the receptor(s) stop(s) detecting and reporting the deviations to the control centre/regulator.

MAINTAINING A STABLE INTERNAL ENVIRONMENT

How unicellular organisms and cells of multicellular organisms control their internal environment?

At cellular level, the internal environment is cytoplasm. Tissue fluid is the external environment of animal cells; sap for plant cells but are internal environment of the organism.

Entry and exit of cell is due to diffusion gradient, osmotic gradient and active transport. The nature of and amount of materials, is controlled by the rate of protein synthesis; that form enzymes (and hormones) that catalyze (and regulate) the most catabolic and anabolic reactions of cells. Thereby ensuring a stable composition of the internal environment.

EFFECT OF VARYING INTERNAL ENVIRONMENT ON BODY/BODY PHYSIOLOGY

If the key parameters of the internal environment such as core temperature, pH, osmotic pressure, glucose levels and oxygen levels are not kept within their required narrow range/limits; this results into fatal consequences like enzyme denaturation, destruction of cells and permanent tissue and organ damage, which can culminate into death once vital organs like the brain, kidneys, lungs and heart are fatally damaged. Such fatal consequences can arise from undesired conditions like hyperthermia, hypothermia, hyperglycemia, hypoglycemia, acidosis, alkalosis, cell bursting/lysis and so on which are associated with instability of the biological system due to lack of homeostatic control. Therefore, the internal environment of the body such as composition of blood and interstitial fluid must be maintained fairly constant to ensure that body enzymes and other vital proteins like hormones and membrane proteins which are sensitive to changes in factors of internal environment especially temperature and pH work efficiently for body physiological processes to proceed normally.

THERMOREGULATION/TEMPERATURE REGULATION

NECESSITY FOR THERMOREGULATION

The body enzymes efficiently work within 35-38°C; excess above 45°C denatures them and are inactivated if it decreases below the range; both of which are fatal. [to provide/maintain the narrow range within which body enzymes work efficiently since are denature if excess and inactivated if too low].

Too high or too low temperature disorganizes the structure and functioning of cell surface membranes; by affecting the entry and exist of substances leading to death of the organisms.

IMPORTANT TERMS

1. **Endothermy**; is ability of animals to maintain a constant body temperature. Like mammals and birds.
2. **Endotherm/homeotherm/homiotherm/warm blooded animal**; an organism capable of maintaining a stable body temperature independent of environment temperature; by generating heat metabolically when the environmental temperature is low.

Hint: Stop on environmental temperature for **homiotherm**; continue for **endotherm**.

MEANS OF HEAT GAIN AND LOSS

Heat gain; as byproduct of metabolism from exothermic reactions.

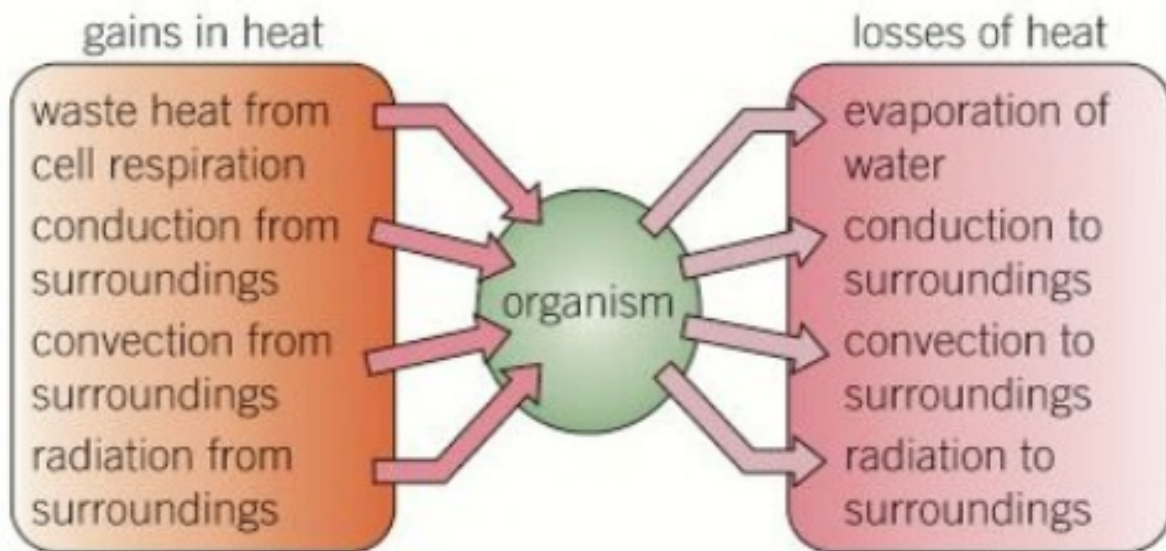
Heat loss;

- Through evaporation of water during sweating.
- From body surface, mouth during respiration.

Gained/lost by; hot to cold thermal gradient (determinant).

1. **Radiation**; transfer of energy in form of electromagnetic wave; is the main one.
2. **Conduction**; transfer of heat by collisions of molecules; between the organism and ground/water because air does not conduct heat well.
The organism must have (there must be) a physical contact between the objects
3. **Convection**; transfer of heat by current in air and water.
4. **Evaporation**; heat lose during conversion of water to water vapour; only heat loss not again; unlike the others; over the skin, buccal cavity, lungs during sweating and panting/thermogapping.

ILLUSTRATIVE SUMMARY



ADVANTAGES AND DISADVANTAGES OF ENDOTHERMY

Advantages

- (i) Animals exploit various environment, regardless of temperatures.
- (ii) Enzymes- controlled reactions proceed without much interruption.
- (iii) Because of high metabolic reactions/rate; a lot of energy is produced which supports body processes.

Disadvantages

- (i) High food intake during low environmental temperature to liberate heat.
- (ii) Enzyme-controlled reactions can be slowed during low temperature which inactive enzymes.
- (iii) Requires efficient cooling mechanism during hot temperature to avoid overheating; and efficient insulation when external temperature is low.

TEMPERATURE CONTROL IN ENDOTHERMS

Response/reaction of an endotherm to temperature variation of external environment

RESPONSE TO HOT CONDITIONS	RESPONSE TO COLD CONDITIONS
Physical & physiological means	Physical & physiological means
<ul style="list-style-type: none"> • Vasodilation; superficial capillaries dilate; increase blood flow near skin surface; heat lost by conduction and radiation; blood can also be taken to reservoirs like spleen. • Sweat production by sweat glands increase; leading to evaporation of heat from the skin surface; affected by environmental temperature & humidity, wind=fan. • Panting in birds, dogs; increase heat loss; via evaporation from lungs, pharynx and other moist surfaces. • Erector pili muscle relax, lower hairs/fur; thus no insulating layer of air trapped near the skin leading to heat loss. • Metabolic rate reduces to minimize heat generation by the body. 	<ul style="list-style-type: none"> • Vasoconstriction; (i.e.) superficial capillaries narrow/constrict; decrease blood flow near skin surface; to reduce heat lost by conduction and radiation. • Sweat production by sweat glands reduces/stops; reducing/stopping evaporation of heat from the skin surface; thus more heat is conserved. • Shivering; involuntary contractions of skeletal muscles; thus heat is generated due to vibration [as the organism vibrates]. • Erector pili muscle contract, raise hairs/fur; thus insulating layer of air(moisture) is trapped near the skin that reduces heat loss. It leads to development of 'goose flesh'/goose pimples. • Metabolic rate increases especially of muscles(skeletal) and liver cells; special brown fat metabolized to increase heat generation by the body. Brown fat is rich in blood supply.
Behavioural means(in man)	Behavioural means
<ul style="list-style-type: none"> • Taking cold drinks. • Putting on light clothes • Moving/migrating to shady places. • Taking a bath(cold). • Being active mainly at night(nocturnality/nocturnability) 	<ul style="list-style-type: none"> • Taking hot drinks. • Putting on thick/heavy clothes • Moving/migrating to near fire/heat source. • Turning on heat in the house.

TEMPERATURE REGULATION IN ENDOTHERMS

This involves environment, hypothalamus, skin and blood temperature.

Increase in body temperature beyond the normal is called **hyperthermia**; thus, avoid this term when describing the process.

Hyperthermia can cause heat stroke; dry skin; mental confusion and loss of muscular coordination.

Hypothermia is a condition when body temperature has decreased a lot.

Peripheral thermoreceptors detect the change in environmental temperature and send the sensory nerve impulses to the hypothalamus before even the core body temperature changes.

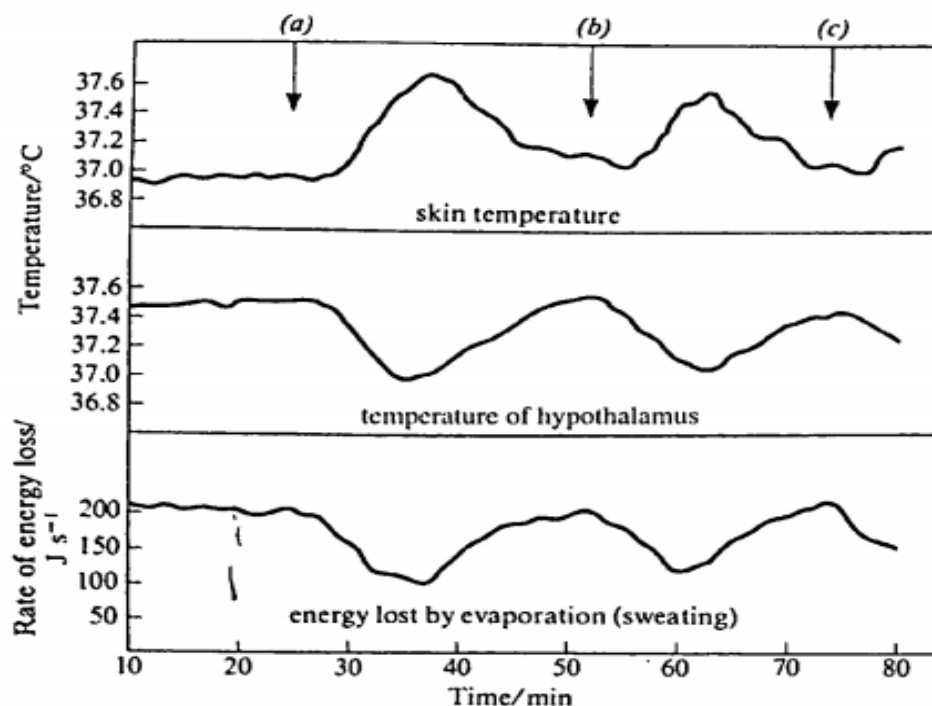
The **central thermoreceptors** within **thermoregulatory centre** in the hypothalamus detect temperature of blood passing through it.

Description of the process

Increase in skin temperature, blood temperature of blood passing through the thermoregulatory centre in hypothalamus and cerebral cortex; stimulates hot thermoreceptors to fire sensory impulses to the hypothalamus heat loss centre (located in anterior hypothalamus); which responds by sending motor impulses to sweat glands, skin arterioles causing increased sweating and vasodilation respectively; muscles and liver leading to decrease in metabolic rate; which results into decrease in blood temperature.

Decrease in skin temperature and blood temperature of blood passing through the thermoregulatory centre in hypothalamus and cerebral cortex; stimulates the cold thermoreceptors to trigger sensory nerve impulses to the hypothalamus heat gain centre (located in posterior hypothalamus); which responds by sending motor impulses to the skin, skeletal muscles and hair erector pili muscles; causing vasoconstriction, shivering and contraction of erector pili muscles to raise hair; and also stimulating (ACTH & TSH) the release of adrenaline and thyroxine hormone from adrenal glands and thyroid gland which increase metabolic rate; thereby increasing heat generation which increases blood temperature.

GRAPHICAL ANALYSIS



NB: Iced water/ice was swallowed at point (a), (b) and (c).

Effect of swallowing ice

When ice is ingested, the body core temperature decreases and the skin temperature increases. This is because in the gut, the cold ice absorbs heat from blood; this reduces the temperature of blood moving to the hypothalamus and the body core; this sets in mechanisms to raise the core body temperature like decrease in the rate of sweating to conserve heat within the body; the reduction in the rate of heat loss from the skin surface causes an increase in the skin temperature.

Explanation(specifics)

Ice is swallowed after sometime after the start; to allow the subject to equilibrate with the surrounding.

Skin temperature

It increases rapidly following decrease in hypothalamic temperature due to fall in evaporation since iced water lowers the temperature of (blood flowing through) the hypothalamus; thus, thermoregulatory centre (heat gain centre is activated); resulting in fall of evaporation, no losing latent heat of vaporization from the skin; thus increase in skin temperature.

Temperature of hypothalamus/hypothalamic temperature

Increases because blood passing through the hypothalamus is at core body temperature detected by the thermoreceptor in the hypothalamus of brain; thus decrease in skin temperature.

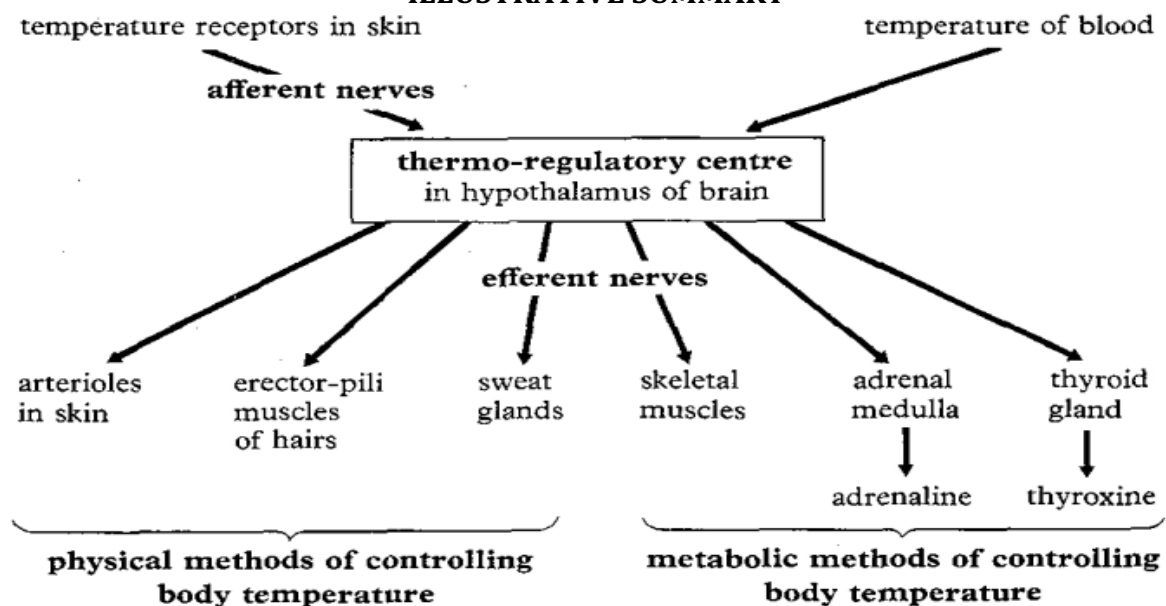
Energy lost by evaporation(sweating)

Its change is directly related to temperature of hypothalamus; therefore, is controlled by hypothalamus.

NB:

- (i) The set point is 36.7°C (BS)/37°C(Kent), but it can fluctuate up to 37°C and down to 35.8°C; the person dies at 43°C and 26°C.
- (ii) During fever, the temperature set point, is set to a higher level as if new set point; since the core body temperature (original set point) is now lower; so the body shivers, feels cold till the core temperature reaches new normal; it is caused by toxins and pyrogens. i.e. **Pyrogens** released like during bacterial infection **rise the set point** to about 40°C.

ILLUSTRATIVE SUMMARY



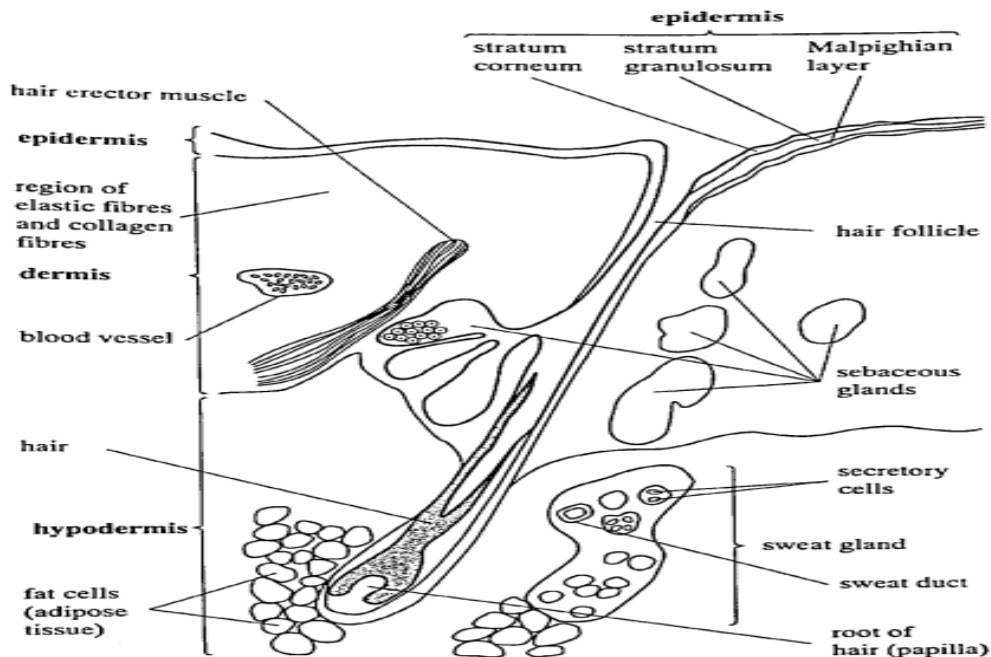
THE ROLE OF BRAIN/HYPOTHALAMUS IN THERMOREGULATION

The brain has **hypothalamus** as **thermoregulatory centre** containing **heat loss centre** (cold centre) in the anterior hypothalamus and **heat gain centre** (hot centre) in the posterior hypothalamus, with **central thermoreceptors** sensitive to changes in temperature of blood flowing through it; enabling it to switch on or off heat generation processes or loss processes/measures thereby serving as a thermostat. For instance, increase in temperature of blood passing through the hypothalamus stimulates the **central thermoreceptors** in it which activate the **heat loss centre** to send impulses to the appropriate effectors such as the **liver, skin** and **muscles** which respond by setting in motion processes/measures that **encourage heat loss** and **lower heat generation**; as discussed under the responses of endotherms to hot conditions above. Likewise, decrease in **skin surface temperature** stimulates **peripheral thermoreceptors** of skin to fire sensory impulses to **heat gain centre** which is activated and responds by sending motor impulses to appropriate effectors like **skin, liver** and **muscles** which respond by initiating **heat generation/production** and **conservation processes**; as discussed under the responses of endotherms to cold conditions above.

THE HUMAN SKIN

This is the largest organ of the body.

Structure



Functions of the parts

- Erector pili muscle contracts; hair stand leading o thermoregulation and also appear big to frighten off attackers.
- Malpighian layer; has special cells; melanocytes; that produce melanin; pigment for skin colour; protect cells from UV light.
- Sweat gland; is a coiled tubular that secretes sweat, cool the body; (i) eccrine sweat glands-found in most body parts; (ii) apocrine sweat glands; found in armpits, nipples, pubic region, hands, feet and anus.
- Subcutaneous tissue; reduces heat loss.

- Sensory nerve; carry nerve impulses;
- Dermis; region of elastic fibres and collagen fibres.
- Epidermis; with stratified epithelium; composed of stratnum basale (basement membrane), stratnum spirosum, stratnum granulosum (granular layer, Kent), Stratnum corneum(cornified layer, Kent). The 3 form Malpighian layer/cograspinog
- Stratnum corneum; can form keratin, making it tough and water proof in areas of friction.
- Stratnum spirosum; divides by mitosis to replace cells that wear out.
- Sebaceous gland; produce sebum; oil substance that forms water proof layer; is free of bacteria skin
- Meissner's corpuscle; detect touch, cold, pain and heat.

Functions of skin

- Temperature regulation
- Provide protection against mechanical damage, UV light from the sun, microorganism, water loss from underlying tissues.
- Sense organ; nerves detect temperature, touch, pressure, pain.
- Excretory organ for urea, salt and excess water.
- Manufactures vitamin D when exposed to sunlight; has lipids called sterols which are converted by UV light to vitamin D.

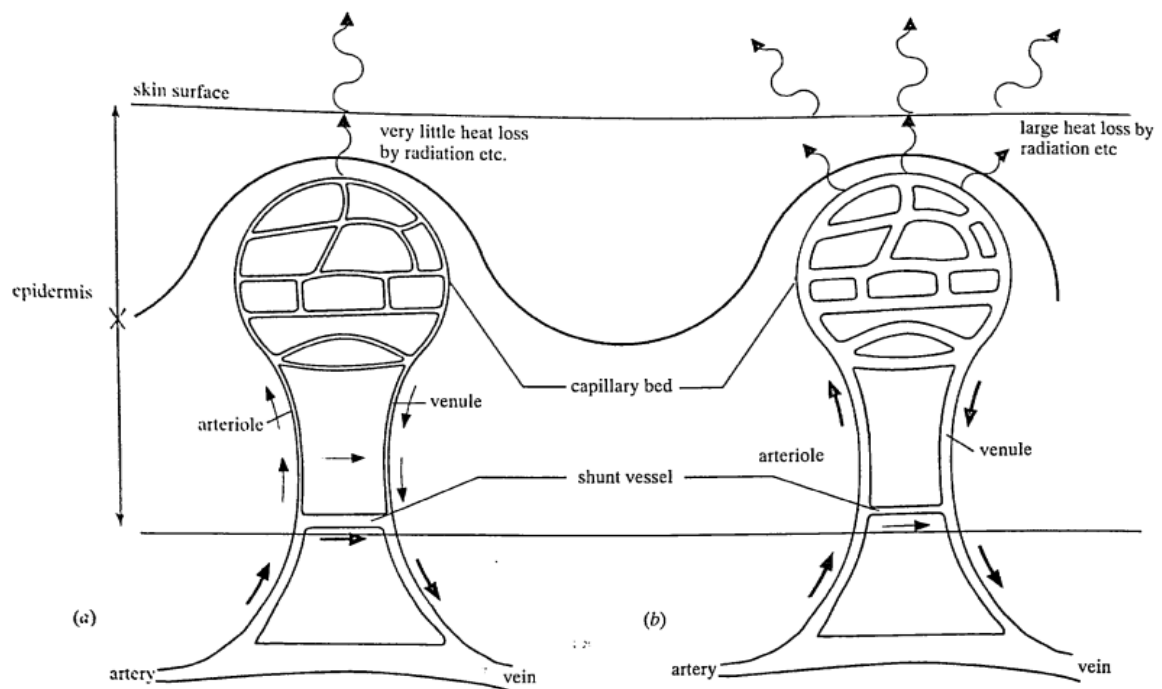
Vasodilation and vasoconstriction

On vasoconstriction; arteriole and superficial capillaries constrict, decrease blood flow through the capillaries; to keep cell alive, only little blood flows; most bypasses through shunt vessel which dilate; decrease heat loss-very little heat loss by conduction and convection.

If it's too long, it results into **frostbite**.

On vasodilation; arteriole and superficial capillaries dilate, increase blood flow through the capillaries; little blood bypasses through shunt vessel which constrict; increase heat loss-i.e. more heat loss by conduction and convection.

Illustration



THE ROLE OF SKIN IN THERMOREGULATION

The skin contains peripheral thermoreceptors that detect fluctuations in the peripheral temperature/skin surface temperature due to changes in ambient temperature and send sensory nerve impulses to thermoregulatory centre which responds by firing motor impulses to appropriate effectors like skin, muscles and glands that initiate heat production and conservation processes/responses or encourage heat loss and lower heat generation processes depending on body temperature. For example;

- ✓ Vasodilation that brings blood to surface to increase heat loss by evaporation.
- ✓ Contraction of erector-pili muscles, raising skin hair which trap warm air on skin surface beneath erect hair, insulating the body thus, heat loss increased.
- ✓ Relaxation of erector-pili muscles, skin hair lies flat on skin, no air moisture trapped thus heat loss increased.
- ✓ Sudorific/sweat glands produce sweat which evaporates with heat thus heat loss increased; dry skin due to inhibition of sweating decreased heat loss.

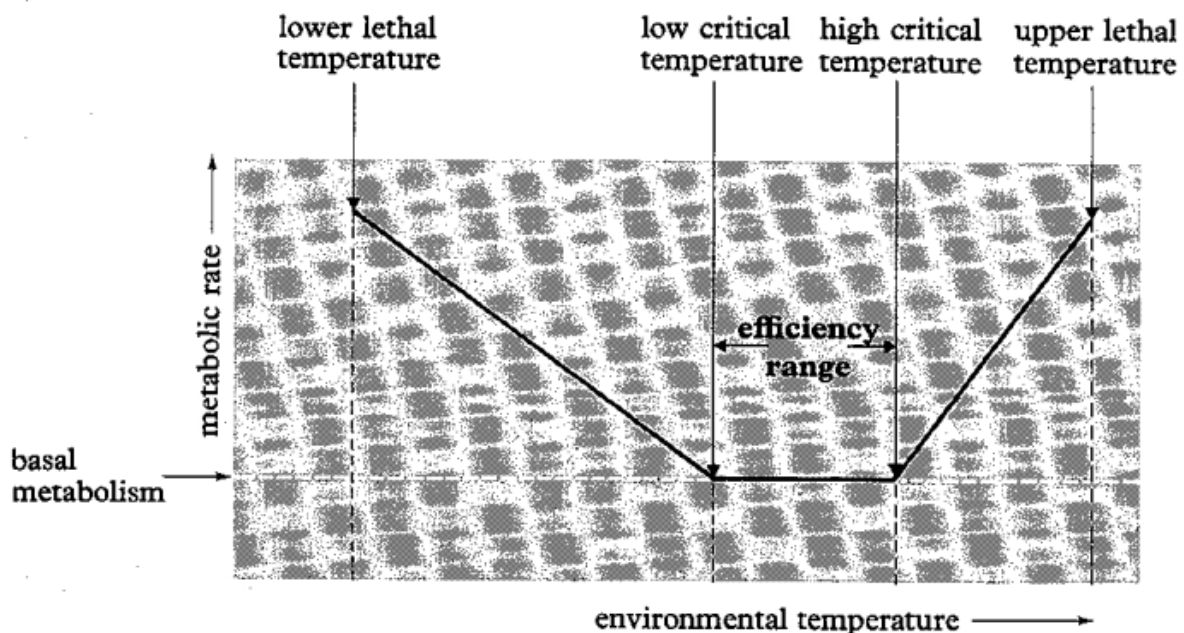
The same response of thermoregulatory centre stimulates the thermoregulatory centre to initiate voluntary activities like taking muscular exercise in severe cold or moving into a shade in case of extreme hotness.

Similarly, skin has adipose tissue in hypodermis/subcutaneous fat layer with brown fats which generate heat by respiration/thermogenesis due to numerous mitochondria they possess; and white fats which insulate the body against heat loss.

EFFECT OF ENVIRONMENTAL TEMPERATURE ON BODY TEMPERATURE

Experiment was carried out using (on) naked people; to avoid physical interference of clothes/covering; therefore, observations are now based on purely physiological response of the body.

Illustrative graph



INTERPRETATION

Efficiency range/range of thermoneutrality; is the range of environmental/external temperature at which the body's physical mechanisms are capable of maintaining body temperature constant.

In man, it's 27°C-31°C, but it varies according to the natural habitat because animals have the ability to acclimatize by rising upper critical temperature or lowering lower critical temperature. E.g. The low critical temperature for animal in cold places is much lower than those in warm place; i.e. desert Kangaroo (Dipodomys) is 30°C but for arctic fox is -40°C.

Likewise, the lower lethal temperature much lower for cold dwellers than in warm dwellers.

Below low critical temperature, the metabolic rate of warm dwellers rises more sharply/rapidly than that cold dwellers.

Illustrative graph

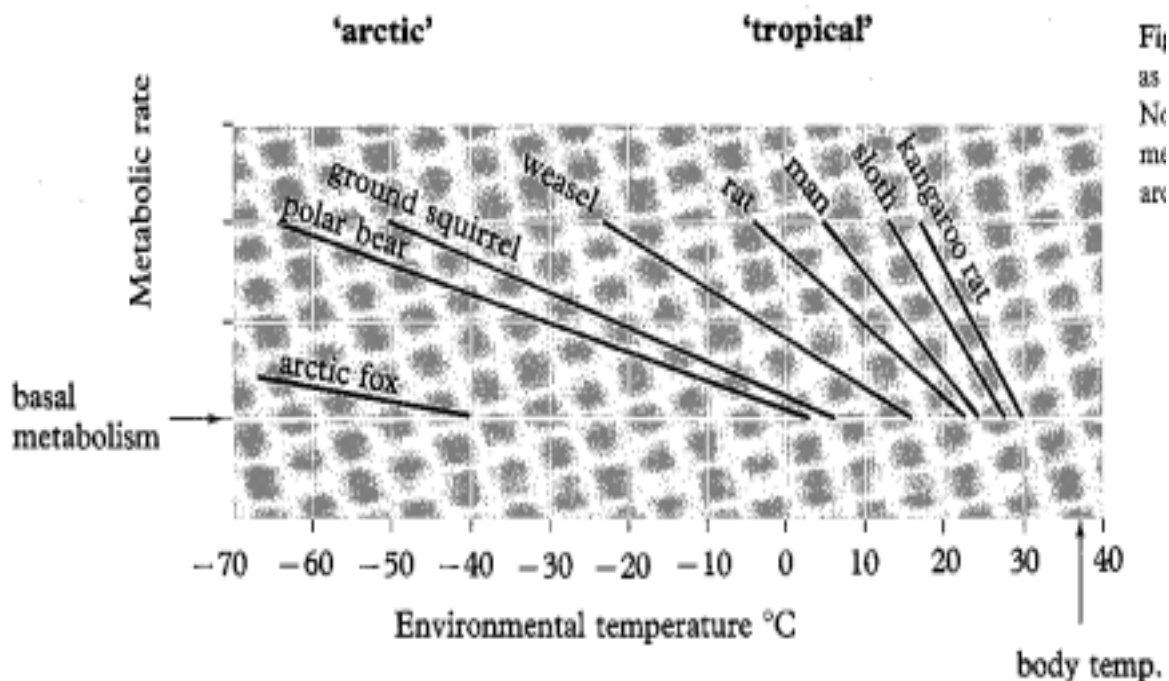


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High critical temperature; is the high environment temperature at which physical mechanisms like sweating, vasodilation etc fail to maintain body temperature constant; triggering a rise in metabolic rate and body temperature as the environmental temperature increases.

Upper lethal temperature; is the extremely high environmental temperature at which increases metabolic rate generates excess heat which denatures enzymes and other structures (structural proteins) leading to death of the organism.

Low critical temperature; is the low environmental temperature at which physical mechanisms like vasoconstriction etc fail to maintain body temperature; triggering rise in metabolic rate to generate heat to maintain body temperature constant.

Lower lethal temperature; is the extremely low environmental temperature at which increased metabolic rate fails to generate enough heat to maintain body temperature constant leading to 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(ness) leading to great reduction in core body temperature of the organism.

ADAPTATIONS OF ANIMALS TO EXTREME CLIMATE

ADAPTATIONS TO LOW TEMPERATURE

(a) Structural adaptations

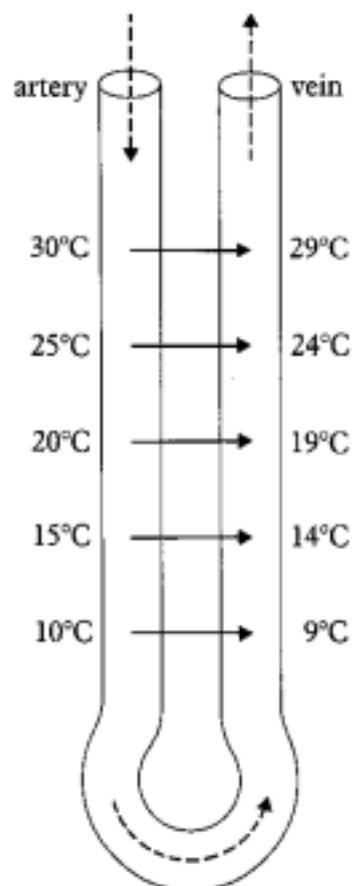
- Have thick fur/hair to trap a layer of air which warm and insulate the body against heat loss like polar bears.
- Have thick layer of subcutaneous fat for insulate the body against heat loss; e.g. polar bears and seals.
- Development of a larger body size than their counterparts in warmer climates to reduce the surface area to volume ratio; thus, reduce heat loss; e.g. whales, polar bears; termed as **Bergman's rule**(Body).
- Extremities like ear lobes had reduced size than related species in warmer climates; which reduce surface area for heat loss; termed as **Allen's rule**.

(b) Other adaptations

- Develop **counter current heat exchange system** in limbs; thus heat conserved; by minimizing heat loss to the environment; e.g. duck's legs, dolphin's flippers, testes of mammals(BS).

In this system, heat is transferred from incoming arterial warmer blood to colder venous blood.

Illustration



- Small sized animals hibernate; e.g. bats, dormice (sleeping mice), hamsters, hedgehog and rodents(mice).
- Hibernation; is a seasonal response by animals to cold temperature; where they become dormant, body temperature and metabolic rate fall to the minimum required for maintaining vital activities of the body. The conserved brown fat is

used rapidly at the end of hibernation to raise metabolic heat. Brown fat; owes colour to numerous mitochondria; mitochondria generate heat other than ATP.

- Animals migrate to warmer places like birds like swallows, golden plovers.

ADAPTATIONS TO HIGH TEMPERATURE; The above are reversed

(a) Structural adaptations

- Development of small body size than their counterparts in colder climates; which increase surface area to volume ratio; to increase heat loss.
- Extremities like ear lobes are larger, thin which rich blood supply for easy heat loss; e.g. elephant earlobes.
- Have tissues tolerant to large temperature fluctuation between day and night e.g. camel.
- Bodies thinly insulated with fat to increase loss.
- Nocturnal, are active at night when temperatures are low to prevent overheating. e.g. Kangaroo rat.

(b) Other adaptations

- Some aestivate;
Aestivation is a seasonal response by animals to drought/excess heat; where they become dormant and body temperature and metabolic rate fall to the minimum required for maintaining vital activities of the body; like African lung fish burrows into mud till dry season end, earthworms and garden snails.
- Migration; move to the shade to minimize heat absorption from the environment.

MAINTENANCE OF WATER CONTENT IN THE BODY

REGULATION OF WATER AND SOLUTE CONTENT OF BLOOD (OSMOTIC REGULATION)

Decrease in (blood)water level below the normal/too little water/ due to reduced water uptake; increases the osmotic pressure of blood_beyond the norm; which stimulates the osmoreceptors in the hypothalamus; to increase ADH/Vasopressin [messenger] output from posterior lobe of pituitary; which circulates via blood stream to kidney tubules, stimulating aquaporin channels in walls of distal convoluted tubule and collecting duct to open; increasing their permeability to water; thus, more water reabsorbed back into blood stream; increasing the water level to norm; leading to production of reduced volume of concentrated urine. Also, the hypothalamic thirst centre is activated leading to the feeling of thirst; thus drinking water.

Increase in water level beyond the norm/too much water in blood due increase water uptake; lowers/decreases the osmotic pressure of blood; thus, less/no stimulation of the osmoreceptors in hypothalamus; leading to decreased/no (which decreases) ADH/vasopressin output(messenger) from posterior lobe of pituitary gland; which circulates in blood to the kidney tubules, hence aquaporin channels in the walls of distal convoluted tubule & collecting duct to close; decreasing their permeability to water; less/no water is reabsorbed; leading to production of copious dilute urine; Also, urea diffusion to medulla is reduced which would increase osmotic uptake of water; Also, hypothalamic thirst centre is deactivated, no feeling of thirst ; no drinking of water; ingest large amounts of salts.

NB:

- (i) **Diuresis;** is the production of copious (large amount) dilute urine.
- (ii) **Antidiuresis;** is the production of small amount of concentrated urine.
- (iii) Insufficient production of ADH leads to **diabetes insipidus;** which is the frequent production of copious urine.

HINT: Homeostasis, excretion and osmoregulation are inseparable.

EXCRETION AND OSMOREGULATION

These are inseparable from homeostasis because they effect **homeostatic control.**

Excretion; Is the expulsion from the body of waste products of metabolism.

Like: carbon dioxide, urea, uric acid, ammonia, excess water, excess mineral salts, bile pigments, oxygen in plants etc.

Homeostasis; Is the maintenance by the body of internal environment within narrow range of conditions regardless of the conditions in the external environment.

Like conditions of; concentration of blood glucose, core body temperature, blood pH (acid-base balance), concentration of oxygen and carbon dioxide.

Osmoregulation; Is the control of water and salt balance so that the concentration of dissolved substances in body fluids remains constant.

It involves controlling osmotic conditions especially the concentration of ions like sodium ions, potassium ions, chloride ions and water content.

Secretion; Is the production of substances useful to body by the cells. Like release of hormones, digestive juices/enzymes etc.

Egestion; Is the removal from the body of undigested food and other substances which have never been involved in metabolic activity of cells. Like elimination of faeces from the gut(defecation), undigested food from food vacuole of amoeba.

Importance of osmoregulation/osmotic control

- Regulates the concentration of body fluids leading/to ensure efficiency of cell activities like nervous coordination, protein synthesis, hormonal production, muscle contraction, enzyme activity, respiratory pigment production etc.
- Regulates water content of body fluids.
- Regulates ions with effect on pH like hydrogen ions and bicarbonate ions.
- Removes excess nutrients taken in which if accumulate interfere with cell activities.
- Gives an organism increased environmental independence.

OSMOREGULATION IN PLANTS

1. **Xerophytes:** These are plants which colonise arid and semi-arid areas (hot and dry areas)-that's, inhabit dry areas/desert/semi-desert/sand dunes. Their **osmoregulatory problem** is water loss by evapotranspiration.

Structural adaptations	Physiological adaptations
<ul style="list-style-type: none">• Have extremely deep roots to absorb water from below water table e.g. acacia, oleander.• Have shallow root system to absorb water on surface after light/slight showering, like cactus.• Have fleshy, succulent stems and leaves to store water in	<ul style="list-style-type: none">• Reversal of stomatal rhythm; open at night, close during the day to reduce water loss by transpiration like CAM plants.• Have increase ABA levels to induce stomatal closure so as to minimize water loss by transpiration.

<p>large parenchyma cells like Bryophyllum, cactus.</p> <ul style="list-style-type: none"> • Have reduced number of stomata (on upper epidermis) to reduce water loss by transpiration. • Have sunken stomata that trap air that reduces water loss by transpiration. • Have hairy leaf surface that reflect solar radiation and trap air to reduce water loss by transpiration. • Have rolled/curled/folded leaves to reduce surface area over which water loss occurs by transpiration like marram grass(<i>Ammophila</i>). • Have thick cuticle that is impermeable to water to minimize water loss by transpiration like prickly pear(<i>Opuntia</i>). • Some have leaves reduced to spikes to reduce the surface area over which water loss occurs by transpiration. • Some have shiny leaf surface to reflect radiation to reduce overheating. 	<ul style="list-style-type: none"> • Possess tissues that are tolerant to desiccation due to low solute potential and production of resistant enzymes. • Leaf fall in deciduous plants to cut transpiration. • Survival of drought as seeds or spores; <p>NB: Winter freeze water leading to physiological drought.</p>
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SUMMARY OF ADAPTATIONS FOR SURVIVAL

- Some have curled leaves to reduce the surface area over which water loss occurs by transpiration.
- Some possess small(needle-shaped) leaves which offer a small surface area for water loss thus water loss minimized.
- Some shed off their leaves periodically to minimize water loss by transpiration
- Some have few stomata to minimize water loss by transpiration
- Some have stomata sunken in grooves and pits to create a film of still air near them, thereby reducing water loss by transpiration.
- Some have leaves with a thick, impermeable, waxy and shiny cuticle to minimize water loss by transpiration
- Some have leaves reduced to thorns to minimize water loss by transpiration.
- Reversal of stomatal rhythm; open their stomata at night and close them during day to minimize water loss by transpiration.
- Some have succulent tissues to store enough water like cactus.
- Some have long and deeply penetrating roots to penetrate deep in soil and absorb enough water.

- Some have a network of superficial fibrous roots to absorb enough water from the surface even after a brief rainfall.
- Some have hairy leaves to trap a film of still air thereby minimizing water loss by transpiration.
- Some have hairy stem to trap a film of still air, thereby minimizing water loss by transpiration
- Some have perennating organs to survive adverse environmental conditions.

2. **Mesophytes**; these inhabit normal well aerated soils e.g. angiosperms such as yams.

Have problems with temperature, ionic concentration(nutrients), water, light and wind that vary. They lose water by evaporation during hot and dry conditions.

Adaptations

- Wilt in excess water loss to conserve water.
- Have a thick cuticle to minimize water loss by transpiration.
- Some like deciduous trees shed off their leaves to minimize water loss by transpiration-that's, shed of leaves in summer and winter to conserve water.
- Some have protected stomata by hair to minimize water loss by transpiration.
- Have leaves of varying shapes and sizes, depending on the amount of water in soil and also due to their water demands.
- Some have succulent tissues for water storage.
- Are ecologically distributed, depending on their water demands, and availability.
- Have more stomata pores at the lower epidermis than at the upper epidermis to minimize water loss by transpiration.
- Some have perennating organs to survive adverse environmental conditions.
- Have few stomata on upper leaf surface to minimize water loss.

3. **Halophytes**; these are aquatic plants that live in marine water/colonise soil of high salinity like salt marsh and estuaries-that's, inhabit areas of high salinity like estuaries, salt marshes; the salinity can be caused by tide that reduce water. E.g. cad grass and glasswort.

Their **osmoregulatory problem** is osmotic loss of water due to hypotonic body fluids to external medium.

Adaptations

- Have roots with a very high solute concentration more than that of external medium in order to absorb enough water osmotically from medium of high salinity –that is, they have roots with higher solute concentration than other plants to take up water by osmosis.
- Have succulent tissues for water storage –that's, they store water in succulent tissues.
- Are highly tolerant to **physiological drought** which is the condition when the plant roots unable to absorb water from surrounding soil solution due to a low water potential of soil, mainly due to a high salt concentration-that's, have tissues tolerant to water stress.
- Some have perennating organs to survive adverse environmental conditions.
- Some can shed off their leaves to minimize excessive water loss.

- Some have salt glands at the margins of their leaves, to excrete the excess salts- that is, they excrete excess salts, actively deposit them in special epidermal bladder cells; then fall off or burst e.g. Australian saltbush (*Atriplex spongiosa*)
 - Have most xeromorphic features to reduce water loss.
 - Have reduced stomata on both sides to minimize water loss.
 - Some have buoyant leaves for easy floating on water to reduce water stress.
4. **Hydrophytes**; completely/partially submerged in fresh water like water lilies, water hyacinth, water lettuce and elodea. [Are aquatic plants that live in freshwater.
- Their **osmoregulatory problem/challenge** is osmotic intake water due to hypertonic body fluids to external medium.]
- Adaptations**
- Carry out **mechanical osmoregulation**; since their body fluids are hypertonic to that of the external medium, they tend to take in water by osmosis, which leads to turgidity of their cells until full turgor is reached whereby no more water can enter into the cell.
 - Have **broad leaves** which offer a large surface over which a large volume of water in excess is lost from their tissues.
 - Have **numerous stomata** at the upper epidermis than the lower epidermis, to get rid of excess water by evaporation.
 - Have a **thick waxy cuticle** to prevent excess water from entering into their body tissues.
 - Have **poorly developed vascular bundles** to become less dense and float easily; to minimize the rate of water up take/water absorption.
 - Have **spongy tissue with numerous large intercellular airspaces** for buoyancy and storage of enough oxygen.
 - Most of them have **perennating organs** like rhizomes to survive in unfavorable environmental conditions.
 - **Have hydathodes** to exude water for increased water loss.
 - Have broad **spongy** leaves for easy floating.
 - Have aerenchyma with large intercellular air spaces to store air for easy floating.
 - Have **tissues tolerant** to ethanol from anaerobic respiration.

TECHNIQUES EMPLOYED BY MAN TO MANAGE PLANTS UNDER DIFFERENT ENVIRONMENTS/HABITATS

Man has employed both traditional and modern agricultural practices or techniques to effectively manage plants in different environmental conditions for high crop yields and thus, ensuring food security as discussed below;

(a) In arid and semi-arid areas

In these dry environments, plants are mainly challenged with water stress and heat stress. Therefore, the techniques employed by the farmers are geared towards curbing these challenges as discussed herein;

- (i) Irrigation**; this is aimed at preventing water stress and heat stress. It usually **precise watering of roots** directly to minimize evapotranspiration and water wastage. This practice is associated with

use of rain water for irrigation, which is collected on large scale and stored using run off stores or dams.

- (ii) **Planting drought-resistant crop varieties** that can withstand drought conditions and water stress since such crops require little water for proper growth. Such crop varieties are developed through **genetic engineering** or **selective breeding**.
- (iii) Carrying out soil health practices like **mulching** to retain soil moisture and **conservation tillage** to reduce soil structure destruction thus, preventing soil erosion.
- (iv) **Agroforestry**; integration of trees as **windbreaks** to shield crops from drying winds and improve on microclimates; trees also involve in water recycling hence, rainfall formation and climate modification.
- (v) Growing crops in controlled settings like **greenhouses** and **hydroponics**. These settings allow manipulation of the key limiting factors of photosynthesis. E.g. greenhouses also allowing provision of optimum light intensity for maximum photosynthesis by using artificial light provided by electric bulbs; increasing carbon dioxide concentration of optimum level by burning clean fuels like paraffin and increasing temperature to optimum level required for efficient activity of photosynthetic enzymes by using paraffin heaters. Hydroponics allow growth of plants in nutrient-rich water without soil to ensure maximum supply of nutrients to plants especially in areas with infertile soils and limited land for agriculture like in urban centres.

(b) **Tropical areas**

Tropics are associated with high rainfall, heat and humidity which increase leaching/soil erosion, pests and diseases. Therefore, the following measures are employed to manage plants.

- (i) Use of **drainage systems** to drain excess water and **raised beds** to prevent waterlogging.
- (ii) **Planting cover crops** like pumpkins to suppress growth of weeds and prevent soil erosion thus, retention of soil nutrients.
- (iii) Planting **disease-resistant crop varieties** obtained by genetic engineering or selective breeding to minimizing the effects of diseases.
- (iv) Adopting **integrated pest management technique**; involving careful use of biological and cultural methods to control pest populations by minimizing chemical (pesticides) use. For example, use of beneficial insects as control agents to keep pest population in check, crop rotation to break pest cycles and improves soil fertility if legumes which add nitrates to the soil are included, and where applying pesticides where necessary.
- (v) Use of **organic manure** like compost or farm yard manure to maintain/improve soil fertility.
- (vi) Adjusting **planting dates based on predictive climate models** to avoid peak rainy seasons or heat waves.
- (vii) **Agroforestry**; incorporating trees that complete crops to minimize soil erosion since tree roots bind soil particles together.

(c) **Temperate areas**

- (i) **Crop rotation** and **diversification** to break pest cycles, prevent soil exhaustion and erosion as well as maintaining soil fertility.
- (ii) Planting **cover crops** to prevent soil erosion thus, maintain soil fertility.

- (iii) Use of row covers/mulches to protect soil against frost and regulate soil temperature/maintain soil warmth. Mulching also provides cold periods for **vernalization** of crops like bulbs and fruit trees to break dormancy.
- (iv) Growing crops in **greenhouses or high tunnels** to provide warmer temperatures for plant growth.
- (v) Planting **cold-resistant crop varieties** to ensure successful survival of crops.
- (vi) Use of **windbreaks** like trees and **snow fences** to reduce wind-chill and desiccation.
- (vii) Use of **soil warming cables/black plastic mulches** to accelerate spring thawing/ keep the soil warm for proper plant growth/early planting.

(d) **General methods**

- Crop rotation and diversification; as explained above.
- Weed control methods; mechanical removal by hoeing or hand-picking; chemical method; using specific herbicides; biological method, using natural enemies as control agent to control weeds and minimize environmental pollution.
- Light manipulation; use of reflective surfaces to increase light intensity; use of shade cloths to reduce light intensity.
- Mixed farming; involving growing of crops and rearing of animals on the same farm. Livestock give organic manure for plant growth; crops give feeds to farm animals, which promotes productivity while reducing environmental pollution.
- Considering climate forecasting in decision making to match rainy seasons with planting or sowing.
- Growing crops in controlled settings like **greenhouses, hydroponics** and **vertical farms** These settings allow manipulation of the key limiting factors of photosynthesis. E.g. The **greenhouses** also allowing provision of optimum light intensity for maximum photosynthesis by using artificial light provided by electric bulbs; increasing carbon dioxide concentration to optimum level by burning clean fuels like paraffin and increasing temperature to optimum level required for efficient activity of photosynthetic enzymes by using paraffin heaters. **Hydroponics** allow growth of plants in nutrient-rich water without soil/ infertile soil to ensure maximum supply of nutrients to plants especially in areas with infertile soils and limited land for agriculture like in urban centres. Vertical farming stacks layers of crops to maximize space in areas with limited space for agriculture like in urban centres. This is often integrated with automatic nutrient delivery and monitoring systems for increased efficiency. These farms are vital in soil/space-limited settings like urban areas.

EXCRETORY PRODUCTS IN PLANTS

- Carbon dioxide, water, and oxygen from respiration and photosynthesis.
- Anthocyanins in petals, leaves, fruits and barks.
- Tannins deposited in dead tree tissues like wood, barks.
- Calcium oxalates, calcium carbonate and latex(rubber).
- Alkaloids like quinine, cannabis, cocaine, caffeine and morphine(narcotic/analgesic) etc.

The excretory products of plants which are beneficial to man are produced as **secondary metabolites** and they possess various applications in our daily life as discussed herein;

BENEFITS OF PLANT EXCRETORY PRODUCTS TO MAN

EXCRETORY PRODUCT	BENEFIT/APPLICATION IN DAILY LIFE
Latex	<ul style="list-style-type: none"> • Used in rubber production e.g. natural rubber and rigid materials like tyres, shoe soles & electrical insulators and so on being inert and resilient with high dielectric strength etc. • For manufacturing latex paints, adhesives and chewing gum, elastic bands, glues, tapes and seals. • For making surgical gloves, catheters, condoms and bandages etc due its elasticity (medical applications).
Anthocyanins	<ul style="list-style-type: none"> • Used as natural food colours e.g. red, purple and blue hues in beverages and candies. • Antioxidant supplements e.g. anti-cancer and anti-inflammatory agents. • For pigmentation and UV-light protection in cosmetics industry. • Used as plant stress response and pH indicators.
Saponins	<ul style="list-style-type: none"> • Used as foaming agents in soaps, detergents and shampoos. Thus, skin cleansers as facial and body cleansing agents. • Used as hair care agents like cleansers and moisturizers in cosmetic industry. • Used as anti-ageing agents to prevent wrinkles and oxidative damage thus, reducing the rate of ageing. • Medicine; used as anti-inflammatory agents (IBD) and cholesterol-lowering agent to lower blood cholesterol levels thus vital for cardiovascular health/manage CVDs; used as anticancer agents to manage cancers since they induce apoptosis, inhibit cell proliferation and suppress angiogenesis; are also used as antimicrobial and antiviral agents. • Used in immunotherapies as adjuvants or vaccines since they are <u>immune cells stimulants</u>. • Used as biopesticides e.g. natural insecticides, fungicides, herbicides to control pest population in agriculture. • Used as food additives like foaming agents in beverages e.g. root beer and in foods. • Used as natural preservatives in beverages and packed foods.

	<ul style="list-style-type: none"> • Used as natural emulsifiers to stabilize emulsions in beverages and desserts. • Used in fire extinguishers. • For fishing as fish poisons.
Oils	<ul style="list-style-type: none"> • Used as lubricants in machines within industries. • Used as biofuels to provide energy like soybean and palm oil. • For culinary purposes like cooking oils such as olive and sunflower oil. • Essential oils are used as fragrances, moisturizers, hair and skin care agents in cosmetics. • Antiseptic agents; used to inhibit growth and spreading of microbes like bacteria, fungi and viruses on living tissues or external surfaces thereby preventing infections as the disrupt microbial cell membrane and metabolic processes. E.g. Tea tree oil due to its broad spectrum antiseptic action against <i>C. albicans</i>, <i>S.aureus</i> etc. • Antibacterial drugs; used to kill/inhibit growth of specific bacteria by disrupting cell walls, inhibiting essential enzymes; disrupting biofilm functioning, thereby treating bacterial infections. E.g. Clove oil used to manage foodborne pathogens like <i>E.coli</i> and <i>S.typhi</i> etc. • Antioxidants; used to protect cells from oxidative damage/oxidative stress by neutralizing oxygen free radicals/ reactive oxygen species. Thus, used to manage cancers by preventing chronic inflammation (anti-inflammatory agents) and contribute to anti-ageing. Like rosemary oil added in cosmetics to protect skin from UV-induced damage; lemon oil used as food preservative to prevent rancidity/aerial oxidation. • Analgesics; used as pain relievers/killers by inhibiting secretion of neurotransmitter substances and reducing inflammation. E.g. Peppermint oil relieves headache and lavender oil relieves menstrual pain/cramps etc. • Choleretics; increase bile synthesis from cholesterol and flow thus, used to treat digestive disorders like indigestion and gall bladder issues like gall stone formation due to

	<p>crystallization of excess cholesterol in the liver. E.g. Peppermint oil and lemon balm oil.</p> <ul style="list-style-type: none"> • Anesthetic agents; used to induce temporary and local loss of sensitivity and pain (for sedation) in dentistry and minor surgeries; for painless surgeries. E.g. clove oil and lavender oil. • Biopesticides; to kill or repel pests such as fungi, aphids and mosquitoes. E.g. neem oil used in mosquito repellent sprays etc. • Fragrants; used provide natural scents in perfumes, candles and air fresheners to evoke emotions or mask odour; mood enhancers and calm inducers since they are immune system and nerve stimulants. E.g. Bergamot oil, sandalwood oil • Aromatherapy; provide natural scents and bioactive compounds the therapeutic effects through olfaction that reduce stress, anxiety, pain and promote sleep (calmness/mood enhancers) by reducing cortisol secretion. Thereby promoting emotional and physiological wellbeing. E.g. Eucalyptus oil and rose oil etc.
Quinine	<ul style="list-style-type: none"> • Used as antiparasitic drug to treat infections caused by parasites like <i>Plasmodia</i> and <i>Babesia</i> thus, antimalarial drug that treats malaria and antiprotozoal drug that treats other protozoal infections like babesiosis among others. • Used as flavouring agent in tonic water due to its bitter flavour and in beverages • Used as antipyretic agent to manage/treat fever. • Used as analgesic agent to relive pain as painkiller. Thus, used to manage muscle cramps as muscle cramp reliever in some medical treatments.

ADAPTATIONS OF ANIMALS TO DIFFERENT WATER AVAILABILITY IN THEIR ENVIRONMENTS

This is achieved by **homeostatic control of body water** in a process known as **osmoregulation**. It involves structural, physiological and behavioural mechanisms of maintaining a constant balance between solutes and water content in the body as discussed herein.

OSMOREGULATION IN ANIMALS

NB: Osmoregulation in animals is discussed in order of their evolution- that is, from fresh water to sea water and then to land.

As regards animals, animals are divided into 2 groups namely;

1. **Osmotic conformers/osmoconformers;** are animals whose osmotic concentration of body fluids fluctuates according to that of the environment; e.g. freshwater lower animals. Such as;
 - ✓ **Euryhaline osmotic conformers** (tissue tolerant species); are species that tolerate wide external and therefore internal osmotic fluctuation like in brackish water.
 - ✓ **Sternohaline osmotic conformers**(steno=small); are species that tolerate only limited external and internal osmotic fluctuation. They inhabit limited environment; like hagfish is strictly marine.
2. **Osmotic regulators/osmoregulators;** are animals that maintain/regulate their internal body osmolarity within narrow limits despite environmental changes (remain hyperosmotic); e.g. most marine vertebrates and fresh water higher animals. Such as;
 - ✓ Euryhaline osmotic regulators; are species that maintain within narrow limits the internal body osmolarity over a wide range of environmental changes. Like migratory fish e.g. eel, moves from fresh to sea water; salmon, moves from sea to fresh for spawning.
 - ✓ Stenohaline osmoregulators; are species that regulate the internal body osmolarity over a narrow range of environmental changes.

OSMOREGULATION IN SEA WATER

- Animals first evolved in sea; most marine invertebrates are osmoconformers; life started in sea evolution.

SHORE CRAB (*carcinus maenas*)

This is capable of some degree of osmoregulation; osmoregulation breaks if external medium is too dilute. So it can't migrate far up the river; it even breaks on transition to highly concentrated external medium.

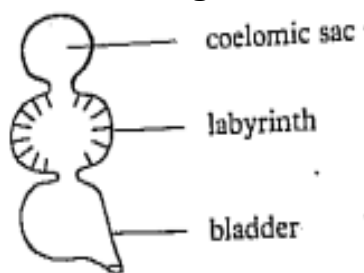
In too dilute medium like fresh water, osmotic influx of water leads to increased urine production because it would increase internal volume and hydrostatic pressure to lethal levels. Thus, internal osmotic pressure (O_{Pi}) increases rapidly initially, then increases slowly and later increases rapidly.

It inhabits estuarine/brackish water.

It uses antennal glands for excretion and osmoregulation; each has 2 antennal glands. Water, salts and glucose are absorbed into coelomic sac; flow to spongy like cavity called **labyrinth**; where ammonia is absorbed and glucose reabsorbed. The remaining contents flow bladder which opens into a small pore at the base of the antenna on the head, where isotonic urine is eliminated.

The gills absorb salts from the surrounding medium into the blood against the concentration gradient to maintain O_{Pi} higher than external osmotic pressure(O_{pe}).

Antennal gland



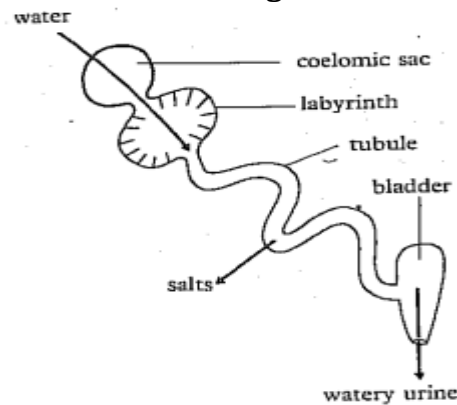
CRAY FISH (maia/spider crab)

This can't osmoregulate at all. So, a change in OPE leads to the same change in OPi of blood.

It lives in freshwater, seawater and brackish water.

Water, salts and glucose are absorbed into coelomic sac; flow to spongy-like cavity called **labyrinth**; where ammonia is absorbed and glucose reabsorbed. The remaining contents flow to coiled tubule, where salts are reabsorbed for only cray fish. Thus, excrete water and nitrogenous compounds leading hypotonic urine.

Antennal gland



MITTEN CRAB(Eriocheir)

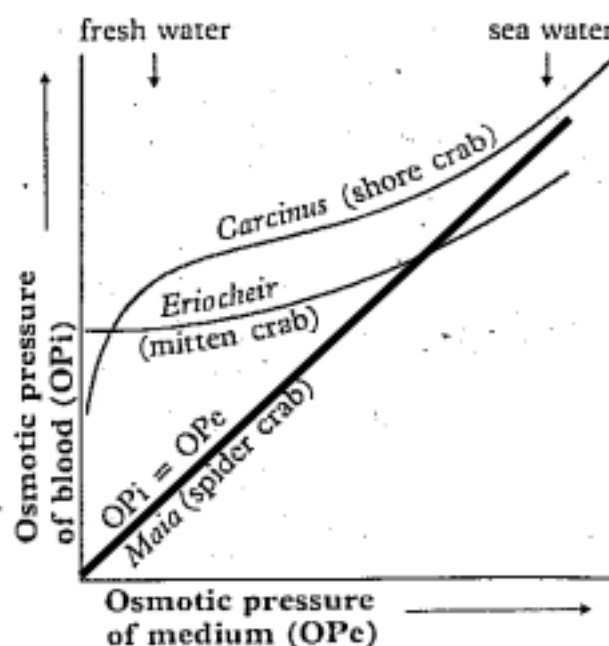
This has osmoregulatory abilities even with too much dilution except in highly concentrated external medium. Thus, the OPi remains relatively constant at first, then increases gradually.

The explanation for this is the same as shore crab except inward secretion is sufficiently enough to enable the animals to flourish in freshwater.

It inhabits freshwater and brackish water.

NB: Shore crab and mitten crab are incapable of holding back salts; therefore, they eliminate salts and water leading to formation of isotonic urine.

Summarizing graph



NB: Animals can avoid dilution by behavioural means; like eustuarine snail burrows into mud; escaping periodic dilution.

FRESHWATER TELEOSTS/BONY FISH e.g. Tilapia, stickleback, trout

Their body fluids are hypertonic to freshwater, so, they have higher internal osmotic pressure (OP_i) than external osmotic pressure(OP_e). Therefore; they use gills and kidneys for excretion and osmoregulation, and uptake metabolites and ions from food in the gut.

Osmoregulatory problems

1. Osmotic influx of water across gills, buccal cavity/mouth lining and pharynx.
2. Efflux of solutes (ions and ammonia) into water by diffusion.

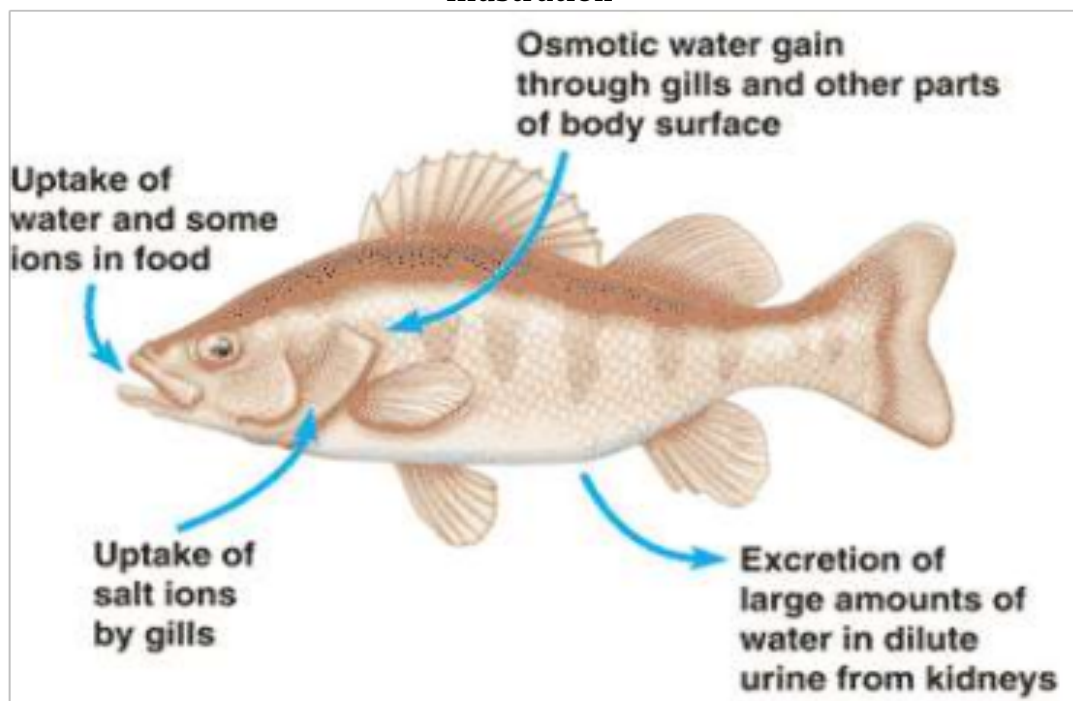
Solutions/adaptations

1. Don't drink water; produce large volume of dilute(hypotonic) urine.
2. Active uptake of solutes from water by chloride secretory cells in gills.
3. Reabsorb ions across kidney tubules from glomerular filtrate back to blood.
4. Have numerous large glomeruli thus, high glomerular filtrate so as to lose a lot of water in the urine.
5. Produce large volume of dilute urine with some ammonia and some ions; since it excretes ammonia that requires a lot of water for elimination.

Summary for freshwater teleosts

- Excrete highly toxic ammonia that require more water for elimination; since highly soluble in water.
- Excrete large volume of dilute urine; due to possession of numerous & large glomeruli; thus, high glomerular filtration rate; coupled by numerous nephrones.
- Extensive salt reabsorption along kidney tubules into blood by diffusion and active transport.
- Inward active pumping salts from external medium into the body; by chloride secretory cells in gills;
- Short loops of Henle thus, less water reabsorption into the body;

Illustration



MARINE TELEOSTS e.g. cod, Mackerel, whiting

Their body fluids are hypotonic to seawater; so, they have lower O_{Pi} than O_{Pe}. Therefore, they use gills and kidneys for excretion and osmoregulation; and uptake metabolites and salts from food and sea water in the gut.

Osmoregulatory problems

1. Osmotic loss/extraction of water across gills, buccal cavity/mouth lining and pharynx leading to dehydration of tissues; thus, physiological drought.
2. Influx of salts into the body through gills by diffusion.

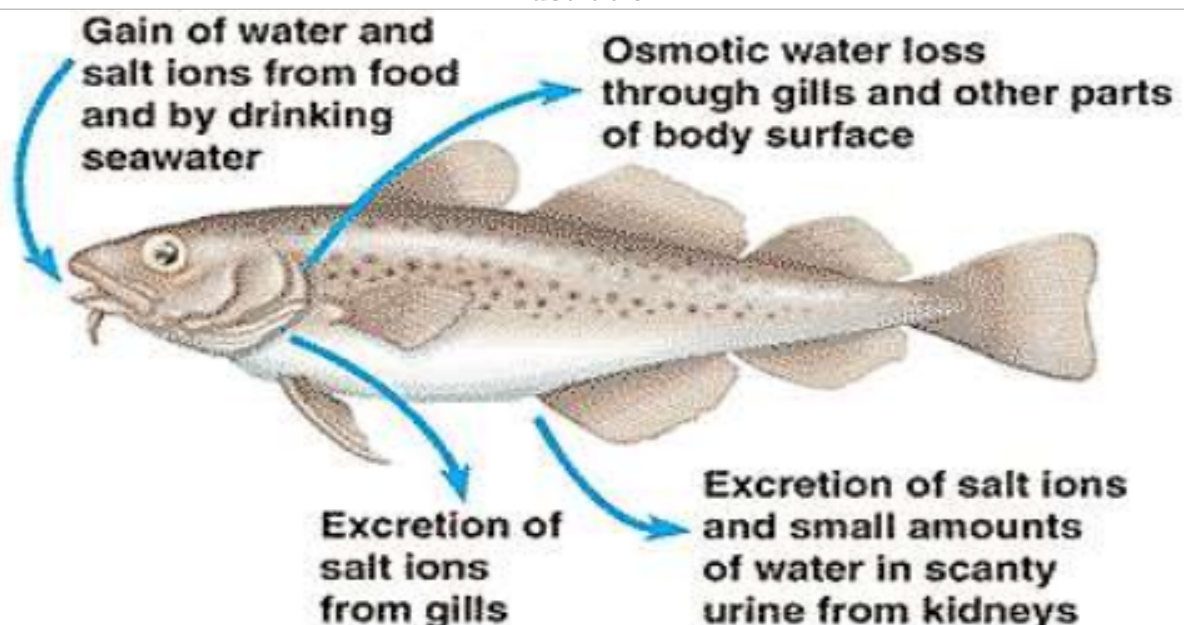
Solutions/adaptations

1. Swallow/drink large amounts of water to compensate for water loss.
2. Monovalent ions like potassium, sodium and chloride ions in drunk/swallowed water are absorbed into blood and then actively transported/pumped out through gills by chloride secretory cells.
3. Divalent ions like calcium, magnesium and sulphate ions drunk in water are eliminated through anus.
4. Have few small sized glomeruli thus, low glomerular filtration to minimize water loss through urination.
5. Produce small quantity of urine which is isotonic to body fluids; since it excretes trimethylamine oxide that is soluble in water but non-toxic thus, requires a little water for elimination. Hence, less water is lost in urine.

Summary for marine teleosts

- Excrete less toxic TMO which requires little water for elimination thus, more water is conserved in the body.
- Excrete small volume of urine due to possession of few and small glomeruli (some lack glomeruli); thus, low glomerular filtration rate; coupled by a few nephrons thus, less water is lost via urination.
- Swallow/drink a lot of salt water to compensate for water loss.
- Outward active pumping/secretion of excess salts by chloride secretory cells in gills.
- Have long loops of Henle; more water reabsorption into the body.

Illustration



MARINE ELASMOBRANCHS (CARTILAGINOUS FISH); e.g. dog fish, sharks and rays. These possess O_{Pi} greater than O_{Pe} . So, their tissue fluid is slightly hypertonic to sea water.

They experience slight influx of water; which is solved by eliminating it by kidneys. Have hypertonic tissue fluid because of urea retention since their gills are impermeable to urea. Urea is reabsorbed from nephron tubules.

Their tissues and enzymes are tolerant to high urea concentration. And the toxic urea is detoxified by trimethylamine oxide(TMO/TMAO).

MIGRATORY FISHES; e.g. salmon and eels.

Salmon live in fresh water; after 3 years, they migrate to sea water for spawning.

Eels live in sea water; but after 3 years, they migrate to fresh water for spawning.

They keep moving from one extreme environment (sea) to other (fresh water) due to;

- ✓ Changes in kidney filtration rate.
- ✓ Reversal of direction in which chloride secretory cells transfer salts; i.e. take in in fresh water and move out in sea water.

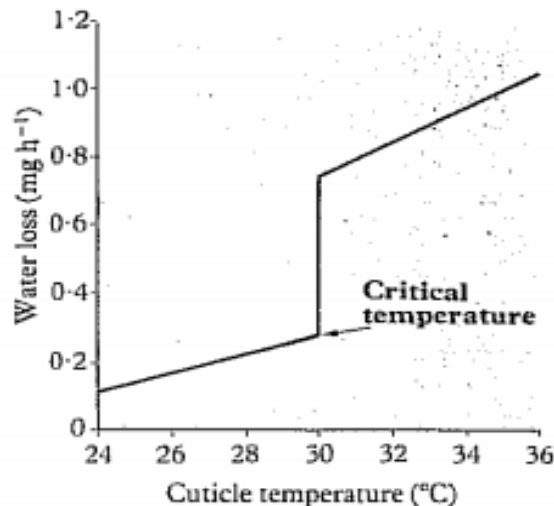
Their migration from freshwater back to sea is due to evolution. After spawning, adult returns to original habitat.

TERRESTRIAL INSECTS

Their osmoregulation (adaptations for water conservation)

- They have **impermeable cuticular covering with the wax(a waxy cuticle)** that minimizes water loss. The skin is thin and can allow water loss but covered with irregularly arranged wax to prevent water loss. The wax covers an organized layer of lipids.

A graph showing the variation of water loss with cuticle temperature of a cockroach/insect.



Explanation

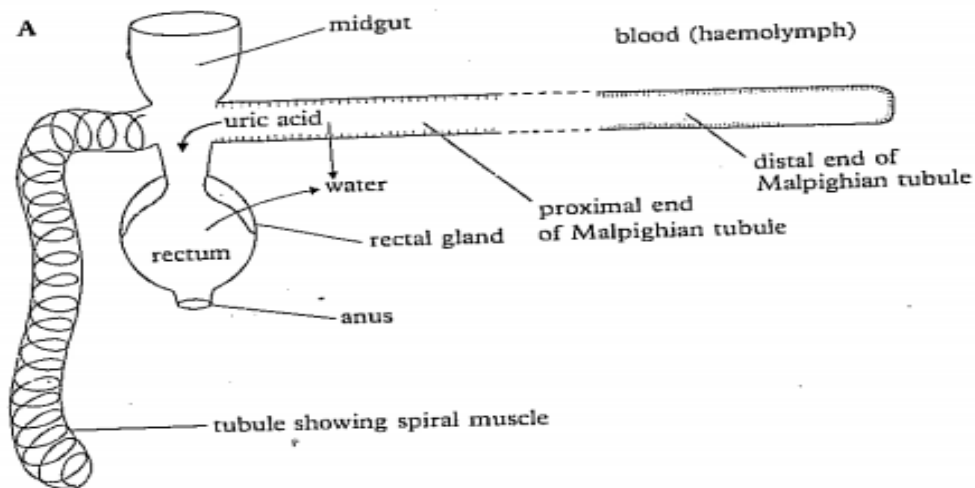
From 24°C to 30°C the rate of water loss increases gradually; upto critical temperature/transitional temperature; because temperature is still low. At critical temperature(FA)/transitional temperature(BS)/30°C, the rate of water loss increases very rapidly; because the ordered orientation of lipid/wax layer breaks down; and the cuticle becomes more permeable to water. Rubbing of the cuticle with sharp materials like sand also breaks down the wax layer.

From 30°C to 36°C the rate of water loss increases gradually; less water is still present.

NB: Critical temperature/transitional temperature is the environmental/cuticular temperature which if exceeded, evaporation rate increases rapidly.

- Production of **non-toxic waste and almost insoluble uric acid** that requires less amount of water for elimination; thus, more water is conserved.
- Laying **cleidoic eggs** thus, water loss is prevented during embryo development by relatively impermeable shell.
- Possession of **valve-like structures and hair** in the spiracles to reduce water loss.
- Have **rectal glands** that reabsorb water from uric acid thus, water conservation.

Structural illustration



Summary for insects

- Possession of water proofed exoskeleton with impermeable a waxy cuticle which minimizes water loss by evaporation.
- Possession of valve-like structures in spiracles; which minimize water loss during exhalation.
- Possession of hairs in spiracles, minimizes water loss during exhalation.

OSMOREGULATION IN TERRESTRIAL VERTEBRATES

Water is gained by;

- Drinking water directly.
- Taking water along with food.
- Obtaining metabolic water from metabolism as by product (respiration).

Water is lost by;

- Urinating it in urine.
- Defecating it in faeces.
- Sweating
- Evaporation from lungs.
- External secretions like tears.

Physiological adaptations against water loss

- Reduction in glomerular filtration rate; by having few and small glomeruli like desert frog, *chiroleptes*, [**Kangaroo rat**] than their relatives living in moist temperatures.

- Production of non-toxic nitrogenous wastes, insoluble uric acid by birds, and most reptiles like snakes, lizards etc, relatively less toxic urea by mammals which require less water for elimination.
- Extensive water reabsorption from glomerular filtrate by mammals, birds and rectum by birds; kangaroo rat have extra-long loop of Henle; increasing surface area for water reabsorption leading to production of hypertonic urine.
- Use of metabolic water from oxidation of fats; like camel and kangaroo rat (*Dipodops*) mostly metabolise fats.
- Possession of tissues tolerant to dehydration like camel can survive a week without drinking water but gulps 80 litres in 10 minutes for quick rehydration.
- Ability to reduce sweat at abnormally higher temperature; like camel at 41°C yet the normal body temperature is 34°C
- Ability to reduce the need for nitrogenous excretion like camel secrete urea into the lumen of the alimentary canal; where bacteria convert it into proteins which are utilized as food.
- Some don't sweat like dogs to conserve water.
- Some have fewer nephrons to reduce on glomerular filtration rate.

Structural/morphological adaptations against water loss

- Possession of water proof integuments like keratinous scales of reptiles, cornified epithelium/thick keratinized skin, fur of mammals and waxy cuticle of insects, scales and feathers of birds.;

Behavioral adaptations

- Change habitat depending on weather conditions.
- Some aestivate like African lungfish burrows down, encase itself in a cocoon of hard mud, lined with mucus to survive prolonged periods of hot conditions/drought.
- Nocturnality/nocturnal e.g. Kangaroo rat.

Aestivation is the seasonal response by animals to drought/excessive heat; during which they become dormant, body temperature and metabolic rate fall to minimum; required for vital activities of the body only.

AMPHIBIANS

- Have kidneys that are identical to those of freshwater fish.
- Body fluids are hypertonic to freshwater thus, suffer from osmotic influx of water; which is readily lost by kidneys expelling large volume of urine; salt loss by diffusion is replaced by actively being pumped across the skin.
- During aestivation, amphibians instead of usual ammonia form urea which is less toxic, that can be retained till water is available for elimination.
- Don't drink water; water is gained by osmosis via the skin and in food.

Summary for amphibians

- ✓ Osmotic influx of water, this water lost readily by kidneys expelling of large volume of urine.
- ✓ Salt loss by diffusion, replaced actively across the skin to minimize osmotic influx of water by lowering internal osmotic pressure(O_{Pe}).
- ✓ During aestivation, form least toxic urea instead of ammonia; that is retained till water is available for excretion.
- ✓ Never drink water; thus, gain water osmotically via skin/ from food consumed.

- ✓ Reduced glomerular filtration rate e.g. desert frog, *Chiroleptes*; few glomeruli than those in moist temperate regions.
- ✓ Produce non-toxic nitrogenous wastes e.g. insoluble uric acid (like reptiles, birds, insects) and less toxic urea; require less water for excretion (amphibians).

REPTILES

- It's the same as that for marine and sea birds like cormorants, penguins and gulls.
- In freshwater, crocodiles have kidneys as those of fresh water fish; marine reptiles like some crocodiles, turtles, sea snakes, some lizards such Iguana;
- Have kidneys that reabsorb salts; excrete excess salt by salt secreting glands near nose/eyes hence turtles shedding tears.

HINT: Nasal glands give an impression that a bird is having a running nose.

- Reabsorb water along kidney tubules but can't produce urine that is more concentrated than blood.
- Lay cleidoic eggs with waterproof embryonic membrane and supporting shell.
- Absorption of water by cloaca, after rectum from faeces and nitrogenous wastes,
- Produce uric acid, minimize water loss through urination.
- Have water proof scales and keratinized skin to minimize water loss through evaporation
- Have kidneys with reduced glomeruli thus, reduced glomerular filtration rate and hence, water loss through urination.
- Water absorption from faeces and nitrogenous wastes by cloaca.
- Excrete less toxic insoluble uric acid thus require little water for elimination.
- Excrete less toxic insoluble uric acid thus require little water for elimination.

OSMOREGULATION IN MAMMALS AND BIRDS

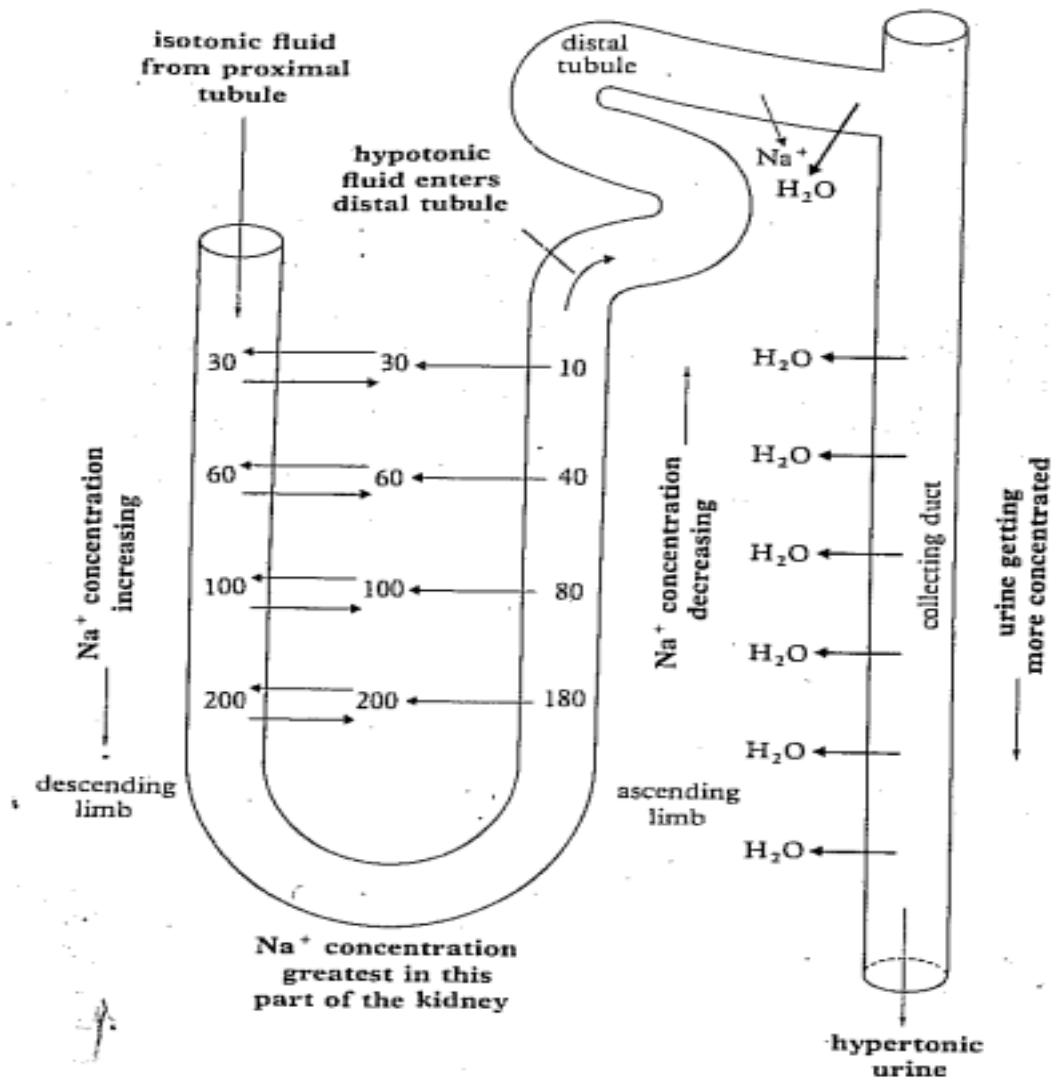
NOTE: Mammals and birds are the only vertebrates with kidneys having very long loops of Henle, enabling them to produce hypertonic urine to their body fluids. Thus, conserve more water as they excrete waste products in small volume of water but mainly mammals.

The influence of ADH and counter-current multiplier effect are vital concepts in regulating content in mammalian body.

The mechanism of counter-current multiplier effect

The counter current multiplier effect takes place in the loops of Henle in kidney nephrons. The ascending limb of the loop of Henle; is impermeable; to water and the descending limb is permeable to water; sodium ions and chloride ions are actively pumped; out of the ascending limb; into the interstitial region; raising the solute potential; of that region of the medulla. Water; is passively; lost by osmosis; from the descending limb/loop; and collecting duct; into the interstitial region lowering the solute potential; and is absorbed into the surrounding blood capillaries; vasa recta, making the renal fluid in the descending limb hypertonic; while the renal fluid in the ascending limb more dilute.

Illustration



Birds

- Have impermeable skin covered by feathers to prevent water loss by evaporation.
- They also lack sweat glands to prevent excessive water loss.
- They excrete carbon dioxide using the lungs
- They excrete the nontoxic and insoluble uric acid to minimize water loss from the body.
- They have few and small glomeruli to reduce the rate of glomerular filtration hence minimizing water loss in urine.
- They have a relatively long loop of Henle to accumulate a high salt concentration in tissue fluid of medulla for maximum osmotic water reabsorption into the blood stream.
- They undergo cloacal water reabsorption
- The marine birds have nasal or salt glands which actively pump excess salts out of the body.

NOTE: Birds lose a lot of water during expiration.

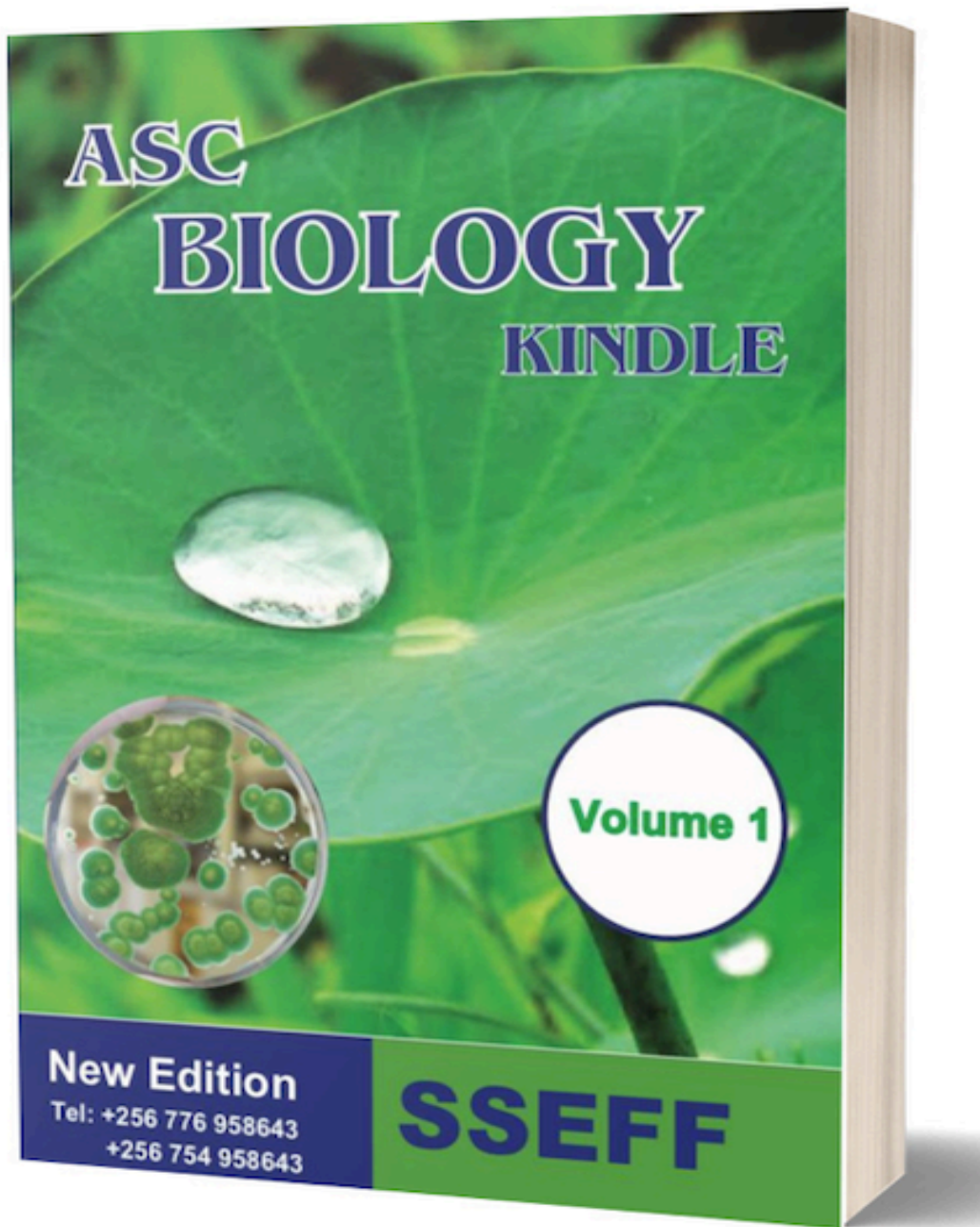
ADAPTATIONS OF VERTEBRATES IN DRY ENVIRONMENTS TO WATER STRESS

1. Have longer loops of Henle to increase surface area for reabsorption of much water from the glomerular filtrate.
2. Have fewer nephrons in their kidneys so that less water is filtered and more conserved/Low filtration rate to minimize water loss.
3. Have body cells which are tolerant to dehydration so, they can take long periods without drinking water.
4. Oxidation of fats to provide metabolic water for use as in camel/use metabolic water from oxidation of food reserves/fats to minimize water loss like in kangaroo rat.
5. Rectal absorption of water from fecal matter to conserve water as in a camel and kangaroo rat.
6. Have high urea concentration in their blood which aids reabsorption of water from kidney tubules.
7. Some have slit-like and closeable nostrils guarded by dense hairs to prevent water loss by evaporation in breath.
8. Their bodies are covered with a water proof integument to prevent evaporation through the skin.
9. Exhale air at a reduced temperature below body temperature to reduce evaporation of water from lungs. E.g. kangaroo rat.
10. Produce non-toxic wastes that require little water for excretion that more water is conserved like uric acids in birds, etc.
11. Produce concentrated urine due to water reabsorption from kidney tubules thus more water is conserved as less is lost in urine.
12. Reduced sweating/tolerance to conserve water like humans.
13. Undergo a state of dormancy/aestivation to minimize water loss as in lungfish.
14. Some have a dried mucus lining the nostrils to absorb moisture from exhaled air.
15. Exhibit counter current multiplier mechanism for increased water reabsorption from the kidney tubules.

TAKE-HOME FOR TERRESTRIAL DWELLERS

Water conservation; due to temperature fluctuations in terrestrial environment by ;

- ✓ Less glomerular filtrate to reduce on the amount of water lost through urine;
- ✓ Development of long loops of Henle; to increase surface area for water reabsorption; thus minimizing water loss through urines;
- ✓ Some pass out/excrete less toxic nitrogenous wastes; that require less water for their elimination; to conserve their water like uric acid; by birds; insects;
- ✓ Developed water proof structures/integuments; like scales; fur; thick skin layer that minimize water loss like in reptiles; birds; mammals; insects (waxy cuticle) etc;
- ✓ Increased tendency to use metabolic water; from oxidation of fats.



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