

IONIC & OSMOTIC REGULATION

The life originated in sea, so most of the animals have body salt concentration similar to seawater. In due course the life diversified to different environments to avoid competition. The organisms got adapted to i) live in fresh water, ii) to highly saline water, iii) Estuaries, iv) Terrestrial living whereas some animals showed migratory behaviour - migrating from sea to river & back.

Due to this type of diversified living they started facing problems of ionic & osmotic regulation i.e. regulation of salt & water contents respectively. According to composition of environment in which the animals are living can be grouped into 4 categories

- (i) organisms living in isosmotic environment [living in sea]
- (ii) organisms living in hyposmotic environment [living in freshwater]
- (iii) organisms living in hyperosmotic environment [living in high salinity water]
- (iv) organisms living on land – Terrestrial living.

Ionic & osmotic problems of iso-osmotic living

All the marine organisms are said to live in isosmotic environment because the composition of marine water &

that of cell cytoplasm are such that the osmotic pressure is equal On either sides of cell membrane. Hence it is felt that the organisms will not face

water & ionic regulation problems. However it is not true. The animals have characteristic salt composition in their tissues, which is different than the seawater, & hence they have to struggle to maintain it to constant.

So also in the body of animals metabolic activities are going on due to which metabolites accumulate in cell leading to change in osmotic pressure. Due to which water enters in. when the excess water is given out by the cells some salts are lost along with it & the cells have to make up the loss. Thus even in isoosmotic environment the organisms have to carry on ionic & osmotic regulation. However the organisms try to minimize these problems by developing different type of mechanisms.

i) Modification of body surface

The organism try to make up their body surface impermeable to water. So that the problem of water entering into the body is minimized. Arthropoda have calcified exoskeleton, Fishes have scale, & even in annelids i.e. in Nereids etc. exoskeleton is hardened. If hard exoskeleton is absent the animals secrete mucus around the body so that osmotic regulation problem is minimized.



Inspite of this water can enter into the bodies of these organisms through flexible joints or thin walled joints or respiratory surfaces. This water has to be regulated & when it is excreted some required salts may be lost. To avoid this the organisms have developed specialised tissue Nephridia. In unicellular organisms contractile vacuole

along with that the marine water is ingested. When marine water is ingested it has high Na & other salts so the animals get excess dose of salt than required & to tackle them different organisms have specialized tissues to eliminate excessive salts ions.

- i) In lower invertebrates normally general body surface acts as ionic regulation surface i.e. it can absorb or eliminate the salts as per required.
- ii) In fish we find the cells of gills act as salt regulatory surface. Whereas in case elasmobranchs salt gland is present associated with rectum. It opens into cloaca.

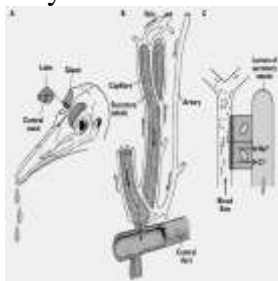


In case of turtle specialised salts glands are present which open in orbit of eye & that is why often it is said that the **“turtle cry salty tears.”**

In Iguana specialised salt glands are present. They open in nostrils & hence it is said that the **“Iguana sneeze out excessive salt.”**

In sea snakes salt glands open in mouth.

In case of marine birds salt glands open in nasal passage. Thus we say that with different specialised tissue the organisms can manage the ionic and osmotic contents of the body.



With ontogeny i.e. with development from young to adult the tissues handling cause change.

Ex. In Herring fish experiment was done & it was found that the egg in fresh water swell, in high saline water shrink & are resistant to ionic & osmotic pressure. But when the larva comes out, general body surface regulates water & salt. In embryo gastula the ectoderm regulates water & salt. In adult, gills & kidney start regulating water & salt.

Apart from this they are helped by hormones & among hormones prolactin & Adrenal play vital role. Prolactin affects Gills, Kidney & skin.

Adrenal hormones in marine fishes affects the gills & guts. It helps in absorption through gut & elimination through gills.

Organisms living in hypo-osmotic environment

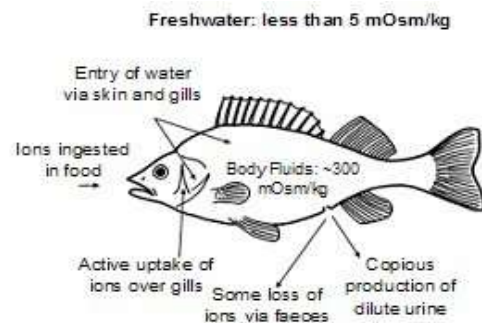
- They include fresh water organisms,
- All Estuarine organisms
- They also include migratory organisms.

The problems faced by the organism -

- 1) Water enters the body & the cells & the body will swell. (Water gain)
- 2) Salts are leached out from the body (Salt loss)

Proof

Polychaet *Nereis diversicolour* was studied, the polychaete was kept in dilute marine water or fresh water.



Conclusion – Calcium ions proved important in water regulation.

Again an experiment was done on *Nereis* & the polychaete was kept in sucrose solution isoosmotic to seawater. It was found that they lost weight due to loss of salt. This proves that in hypoosmotic condition the organism face two problems

- i) salt loss from body
- ii) water gain by the body

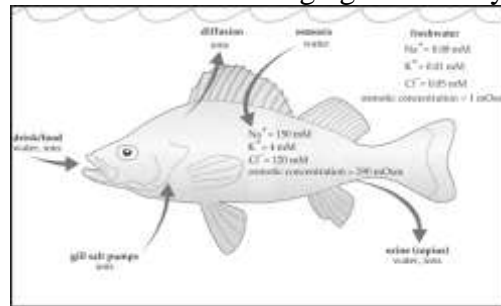
To overcome this the organism make there body surface impermeable to water / ions by calcification / chitinization etc. or secretion of mucus on body.

Inspite of this the water gain is through flexible 'thin walled' joint, & respiration surface & when there is gain of water then the osmotic regulation should be done. When water is eliminated salts are lost.

To prevent salt loss the kidneys are modified. For example *Eriocheir* (Crab) is Euryhaline. It can live in Marine as well as fresh water. When in fresh water it produces urine isosmotic to body fluids to keep the salt loss minimum. Even then there is loss of salt. To overcome this it shows absorption of salt through epithelial cells of the gills.



Prawns (Euryhaline) when in fresh water absorb salts through general body surface.



Fish : try to minimise salt by producing dilute urine. But still whatever salt is lost, is regulated by absorption through cells of gills.

In Eel *Anguilla*

When in fresh water Gills absorb salts but in marine water gills excrete salts.



In Amphibia. Hypotonic urine is produced but at the same time they absorb salts through general body surface. The adjustment of osmotic & ionic regulation is brought about by the hormones & most of the hormones are diuretic. These hormones produce dilute urine or hypotonic urine.

In case of Earthworm the diuretic hormone is secreted by brain cells. In Pulmonate snails – green cells of pleural ganglion secrete diuretic hormone. In case of higher animals pituitary secretes the diuretic hormone. This hormone has favourable effect on gills, salt gland & general body surface.

Fish *Fundulus* when kept in dilute sea water or in fresh water can survive. But if the pituitary is removed it can not survive in fresh water. But in such fish, if the pituitary extract is injected it survives. Thus the prolactin secreted by pituitary plays an important role in ionic & osmotic regulation.



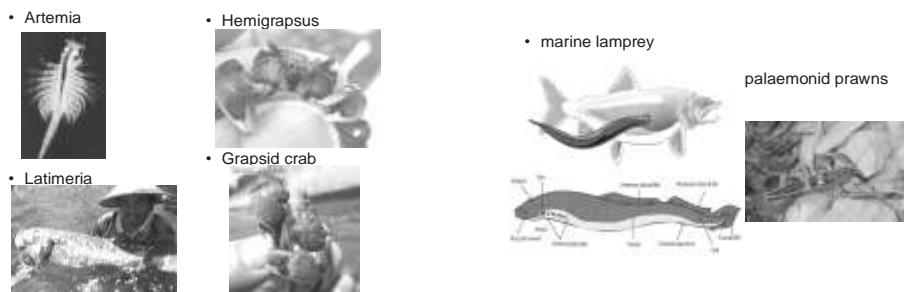
Stickle back lives in fresh water during summer & in marine water during winter & when it is in fresh water in prolactin secretion rises.

Adrenal cortex hormones are also important for fresh water living or marine water living. In marine water it causes excretion of salts through gills / excretory surfaces. In fresh water living there is absorption of salt as and when required.

Hyperosmotic living

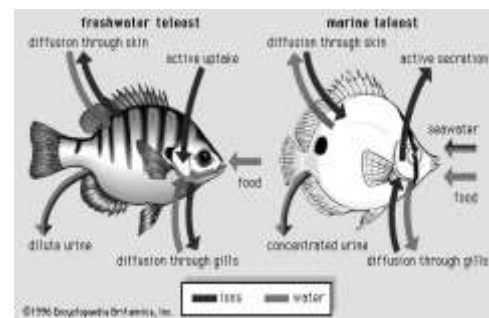
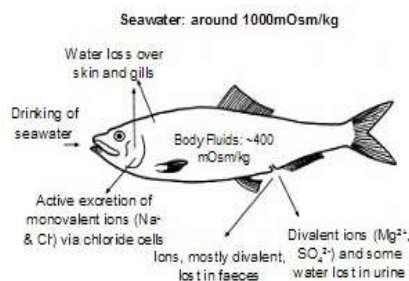
Ionic & osmotic problems of hyperosmotic living

Organisms in hyperosmotic environment are few like marine lamprey, teleost fishes, grapsid crabs (*Polygrapsus* & *Hemigrapsus*), palaemonid prawns, coelacanth fish (*Latimeria*). Their body fluid is dilute than sea water & therefore there are living is hyperosmotic. Some organisms live in evaporating water of salt pans. for example *Artemia* (Brine shrimp) breeds in crystalline water. *Aedes* mosquito larvae (breeding in seawater)

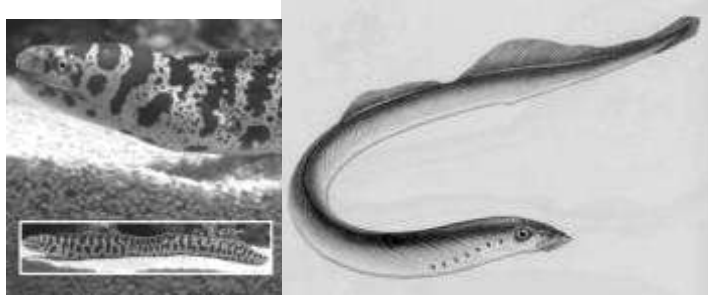


Problems arising

- 1) water loss from body
- 2) salt gain



Water loss is so severe that they have to drink water very often. Eel when in fresh water don't drink water but when in marine water it drinks salty water to overcome water loss which leads to the addition of salts in the body resulting in excess of salt in the body.



In eels excessive salts are eliminated by acidophilic cells of gills.

In case of cyclostomata & fishes when salt water is ingested it creates another problem. Water absorption in the intestine becomes difficult due to salty contents of the lumen. To overcome this problem salts are actively absorbed in anterior oesophagus and then water is absorbed in the intestine. The excessive absorbed are excreted through gills. Apart from this specialized salts excreting glands help in elimination of salts.

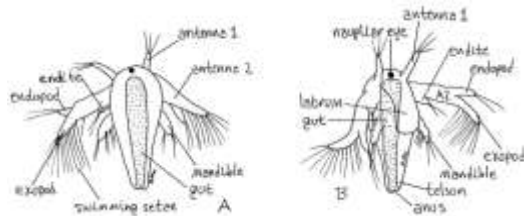
It has been shown that in Eel when in fresh water oesophagus is permeable to water & salt. In marine water oesophagus impermeable to water & absorb only salt so that marine water gets diluted & water absorption is possible in rectum.

The organisms in hyperosmotic environment try to reduce water loss by reducing the quantity of urine produced. For this purpose they show modification in their kidney where the less amount of urine is produced. For example in some animals the no. of glomeruli is less or in some glomeruli are present but there neck is constricted so that there is no ultrafiltration.

While in some fishes like Toad fish (Opsanus) glomeruli are altogether absent. It is always found the kidneys are well modified. Kidneys eliminate monovalent ions while gills eliminate SO_4^- or Mg^{++} .



courtesy U.S. Geological Survey



In Artemia salina is a Euryhaine animal, it can live in glass distilled water or crystallizing marine water. In crystallizing marine water it drinks salty water & excess NaCl is excreted through gills or branchial glands. In these glands it is seen that the Cl is given out actively & Na is given out passively. Salt excretion is very rapid. In larval Artemia branchial gland is absent. In them neck gland & cephalothorax does the excretory function.

Aedes larvae – In marine water they drink excess salt water & eliminate salts by producing salty excreta. For this purpose their posterior part of rectum secretes unwanted salts in excreta. (When in fresh water anterior rectum absorbs salts.) These larvae also have anal papillae which help in ionic & water regulation.



The organisms in hyperosmotic living have one more mechanism to minimize ionic and osmotic problems. They accumulate metabolites so as to maintain the body fluid concentration similar to concentration of water in which they live.

In some organism trimethylamine oxide – TMAO & NPS – ninhydrin positive substance like Taurin & glycoxilic acid stored in tissue so as to make tissue isoosmotic & prevent salt loss.

Specially molluscs show accumulation of NPS. It is also shown by green toad (*Bufo viridis*) which also accumulates urea & salts in its body.



The cartilaginous fishes like shark accumulate urea in their bodies to make their body fluid isosmotic to the environment.

Add on hormones and pumps

Ionic Pumps and hormones

During ionic regulation organism need active transport of ions either inward or outward. For which there are various pumps available such Na, K, Cl, Mg, Ca. Na pump is most studied. Whenever Na^+ accumulates inside tissue & K^+ outside tissue it stimulates Na^+ pump. It activates enzyme of ATPase & energy is used for elimination of Na^+ . Oxygen consumption is also increases. In absence of Mg^{++} Na-pump can not work. Normally in this pump Na^+ is exchanged with K^+ or H^+ or NH_4^+ . Cl^- is exchanged with HCO_3^- .

Like Na-pump, Cl-pump is studied in frog .

K-pump is studied in *Cercaria*. It is also studied the Ca^{++} is important in ionic & osmotic regulation for permeability of membrane.

Hormones play important role in regulation of different pumps

Prolactin affects the cells of Gills , Skin, Kidney and prevents salt loss in fresh water.

Thyroid hormone decrease actively in hypoosmotic regulation & rises actively in hyperosmotic regulation.

Adrenal hormone

Aldosterone increases Na absorption & water retention. Renin is important for regulation of Ca^{++} in blood.

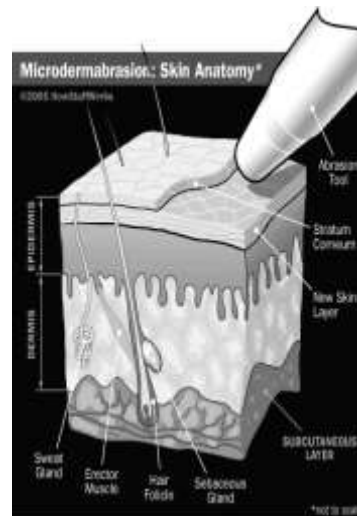
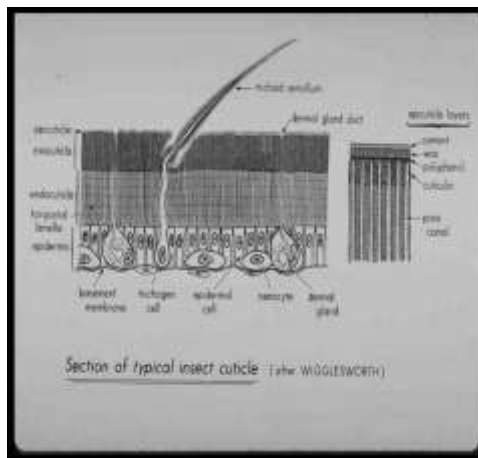
Thus there are different hormones & pumps at tissue level to regulation ions & water.

Problems of terrestrial living

- Water loss is main problem.
- Along with water loss salt (ionic) loss is also seen.
 - Water loss is from i) Integumentary water loss
 - ii) Respiratory surface water loss
 - iii) Urinary water loss

Prevention of integumentary water loss

- Animals make their integument impermeable to water
 - ◆ Arthropods use chitin & calcium
 - ◆ Insects have chitinous integument + Waxy layer on body due to this evaporation is prevented to a great extent.
 - ◆ In vertebrates there is a layer stratum corneum which is keratinized epithelium to prevent water loss. (In Amphibian the stratum corneum is absent. So they depend much on water.



Prevention of Respiratory surface water loss

- Insects have cyclical respiration. In cockroaches the spiracles remain closed for a long time & remain open for a short time. During open phase large amount of CO_2 is given out.
- In birds, mammals & reptiles the nasal mucosa is moist due to which vapour is condensed & water going out is minimized.
- In some desert animals like Kangaroo rats the nasal passage is longer and moist to prevent water loss.



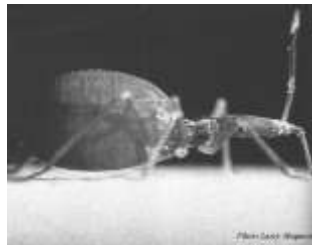
Thus the animals try to prevent respiratory surface water loss.

Prevention of Urinary water loss

- For this mainly kidneys have to be modified
- Kidneys in amphibians, mammals & reptiles have less no. of glomeruli. This causes low filtration & less urine formation.
- Mammals have loop of Henle in which ions & water is reabsorbed. It facilitates more absorption of water whenever needed.
- In amphibians & turtles water from urine is absorbed in urinary bladder.
- Birds, crocodiles, lizards urine is given out in cloaca. It is passed in the rectum where water is reabsorbed.

For further prevention all these organisms are equipped with hormones hormones like antidiuretic hormone (ADH) and diuretic hormones (DH).

- They are secreted in earthworm by brain cells.
- In snails secreted by green cells of pleural ganglion or yellow cells.
- In insects secreted by Thoracic ganglion.
- In Rhodnius bug, when fully fed, crop is full of blood. Due to this pressure is developed on thoracic ganglion, it secretes diuretic hormones & excess of water is removed.



- Desert mammals need more hormone for regulation & pituitary is larger in size,

Apart from this the animals are equipped with some additional phenomena. - like absorption of water from surrounding e.g.

- Insects have vesicles associated with rectum which absorbs water vapour or moisture from air. These vesicles are pencil like.
- Amphibians absorb water from surrounding through their skin.
- Some animals have ability to efficiently use metabolic water
- Especially in desert mammal the metabolic water generated
- Ex. Kangaroo rat don't consume water at all. Fat rich food products are consumed more to regulate metabolic rate.

Ionic Regulation

Normally ions are lost through urine. The terrestrial animals try to minimize ion loss through different ways. The ions are also restored through the salts in the food.

For this the animals show different behaviors.

Ex. Herbivores animals consume grass which is raw and does not contain much salts. Therefore animals like deer show salt licking phenomenon to regulate ions. The salt levels in the body affect preferences of the animals. e.g. Rats that are given salt free diet prefer to drink salty water rather than normal water.

Hormonal regulation of salts :

Different hormones in different organisms play important role in regulation of salts.

- ◆ In Pulmonate snails green cells of pleural ganglion & Yellow cells of parietal ganglion secrete hormones for ionic balance.
- ◆ In corpora cardiaca in insects secretes chloride Transport stimulating hormone (TSH) that stimulates cyclic AMP production in rectal cells & activates the chloride pump for regulation. This hormone also has effect on cells of Malpighian tubules.

Hormones of higher organism

- ◆ In vertebrates pituitary & adrenal gland hormones are important in ionic regulation.
- ◆ These hormones in birds affect salt glands & cause ionic regulation
- ◆ In mammals they affect the kidney, intestine, skin mammary glands & amniotic membrane.

Adreno cortico steroid (Aldosteron) secreted by adrenal cortex is responsible for ionic regulation

If adrenal cortex is removed it causes loss of Na, Cl & water & retention of potassium. Thus aldosteron governs absorption of Na, Cl & water & excretion of 'K'. It not only affects kidney but also sweat glands, salivary glands & intestine. It is present in amphibian, reptiles, birds & mammals.

Apart from this adrenaline, thyroid hormones & also insulin have effect on ionic or electrolyte regulation.

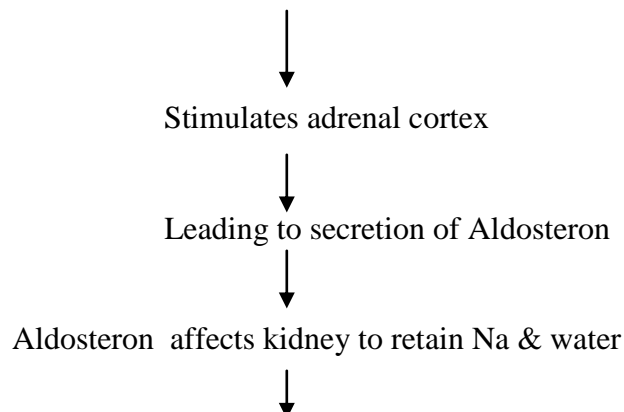
- **Renin – Angiotensin system** is highly evolved in mammalian kidney & it regulates Na, Cl & blood pressure etc.

In mammals kidney there is Juxta glomerular apparatus (JG apparatus) which is made up of two components

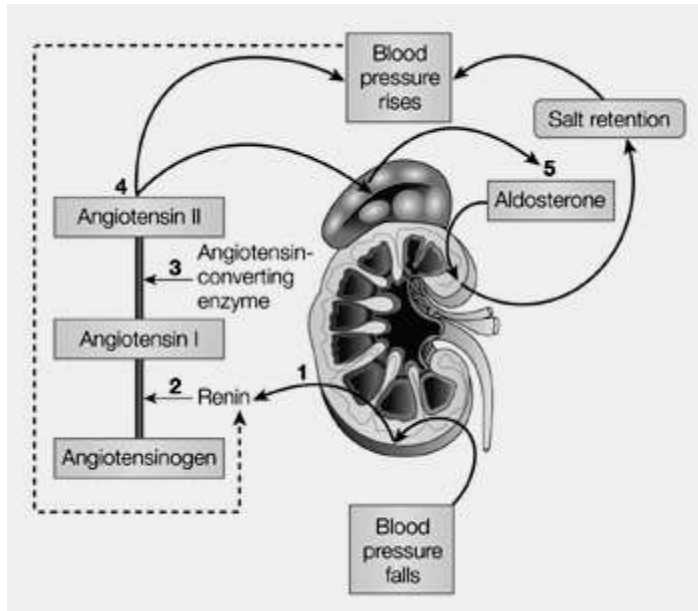
- Juxta glomerular cells present in afferent glomerular artery.
- Macula Densa cells in distal convoluted tubules. These together form JG apparatus.

This apparatus is sensitive to low B.P., low Na & Cl in blood, low extra cellular fluid or non-epinephrine/ nor-adrenaline & whenever influenced by these it is stimulated & produces an enzyme Renin. This enzyme acts on Angiotensinogen in plasma and converts it to Angiotensin I which is converted to Angiotensin II . It causes vasoconstriction to rise B.P

Angiotensin II also secretes nor-epinephrine



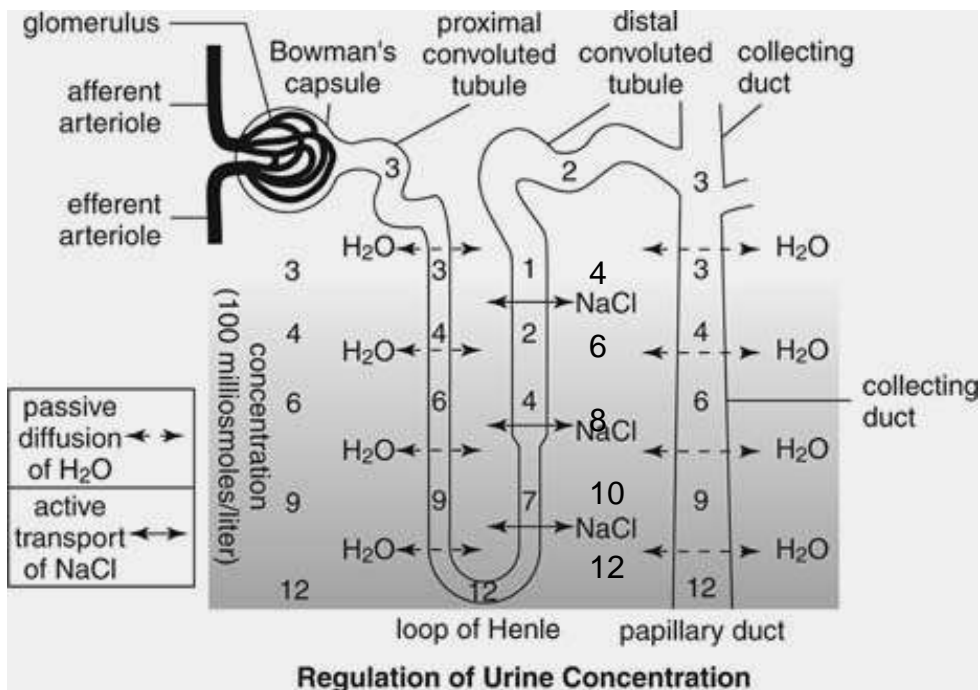
The net result is rise in B.P., rise in Na & water. This change leads to feed back inhibition of the JG apparatus to stop the reaction chain.



Counter current multiplier system

We know very well that in mammals there is hair pin loop i.e. loop of Henley which is used re absorption of urine & water. 180 l urine is formed by ultra filtration in a day but actually only 1.5 l urine is finally excreted. This is due to re absorption in the loop of Henley

In loop of Henley there is counter current multiplier system due to which Na, Ca, K & Mg and water are reabsorbed.



As shown in the diagram in the descending limb water goes out passively and Na enters in causing built up of salt concentration. The ascending limb is impermeable to water & pump out Na to build a concentration gradient of salt on both sides(In

interstitial fluid). Due to this gradient when urine comes down in collecting tubule it meets with a salt gradient of higher concentration. Walls of collecting duct are permeable to water. So water gets reabsorbed thus minimizing water loss.

In this system urine follows in counter current manner i.e. downward → upward → downward & higher concentration gradient is formed or multiple concentration gradient is formed. Hence the system is known as counter current multiplier system.

Temperature Regulation

Relation between temperature and biological activities

Temperature fluctuation is less in aquatic ecosystem and more in terrestrial ecosystem

Ocean → -2 to + 30°C

Land → -70 to + 85°C

Life exists between 0 to 40°C

Few bacteria & algae can live at 70°C [e. g. in hot water springs]

Some blue green alga *Synechococcus* can survive in temp. 75°C.

Eggs of a fresh water crustacean *Triops* can survive temp. 80°C to 103°C

Temp. affect chemical Reaction Rate (reaction rate is higher at higher temp.)

Therefore it affects Metabolic Rate. This is indicated by increase in oxygen consumption.

Therefore Growth.

Very high temperature can cause heat death, which due to—

1. Denaturation of proteins, thermal coagulation.
2. Thermal inactivation of enzymes.
3. Inadequate oxygen supply.
4. Damage to membrane structure.

Very low temperature can cause cold death. This depends on the tolerance of the organisms.

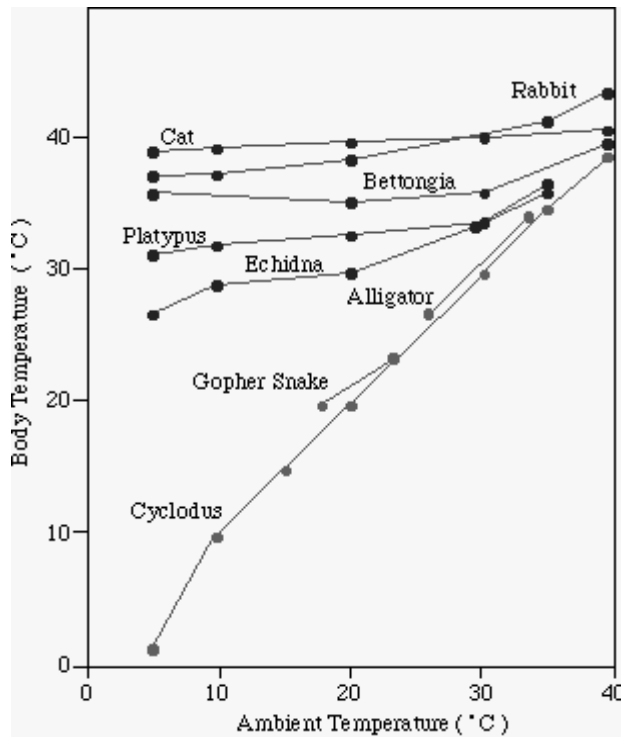
1. Guppies die at 10°C. (normally live at 23°C)
2. Some can survive freezing temperatures. Arctic fish *Trematomus* can swim at temp. - 1.3°C. They have anti freeze substance in their blood/ body fluid.

Poikilotherms (Cold blooded animals)Poikilos means changeable. – have T_b almost similar to the environment. However due to metabolic processes T_b is slightly higher than T_a Ex. In Fish muscle temp. is 0.44oC higher than T_a . (T_a = Ambient temp. T_b = body temp.)

Homootherms – Maintain constant T_b . The constancy required especially for Nervous system. Due to the constancy of T_b they can occupy the environments of widely fluctuating temperatures.

Heterotherms – Regulate when they are active not when resting Ex. Armadillo, sloth, Marsupials etc.

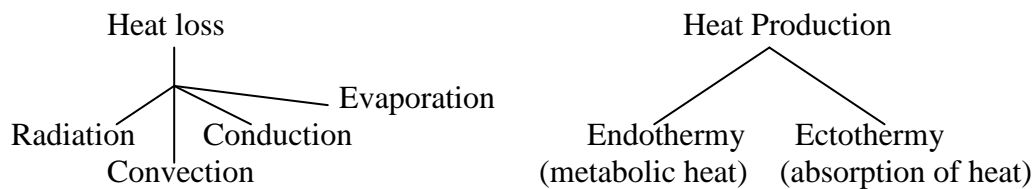
The temperature regulating ability is better in higher mammals and birds as compared to the lower mammals and reptiles. (Phylogenetic trend) This is illustrated by the following figure.



It shows better regulation in cat, rabbit as compared to Platypus, Echidna which are better than snake and alligator

The regulation ability also shows Ontogenetic trend i.e. young Regulate less, adult regulate better. New born are usually Poikilothermic, need more care. Exception to this Caribou calf (type of deer.)

Temperature Regulation – is a Balance between heat loss and heat gain.



For good Regulation Animals need

1. Sensitive Thermostat
2. Ability to use metabolic heat
3. Insulation to avoid Heat loss

Homeotherms have all these & they also can change metabolic rate according to need. Poikilotherms – have poor insulation. They can not change basal metabolic rate. Hence they are poor regulators of temperature.

Following figure shows how the homeotherms manage in changing ambient temperatures.

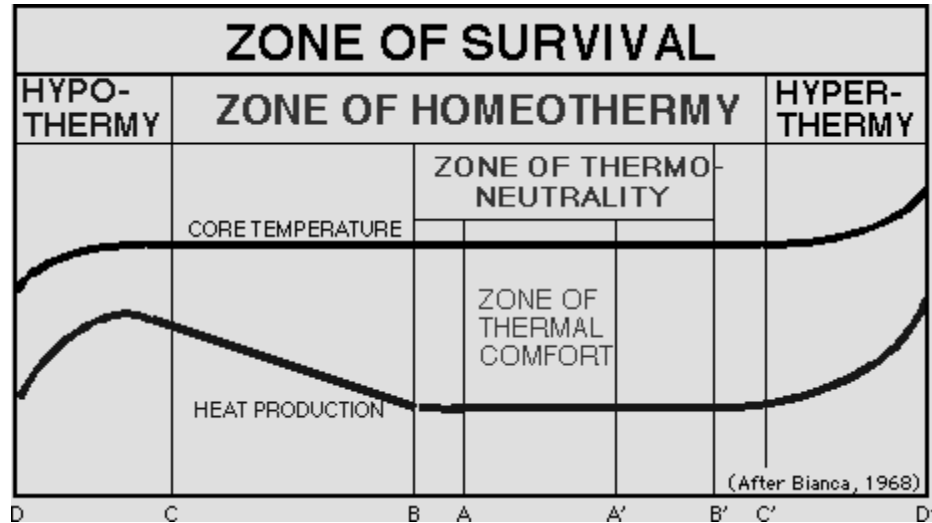


Figure - Zone of Survival (after Bianca 1968).

Within the "Zone of Homeothermy" (C to C'), a mammal can maintain a constant, or steady state, core temperature. Within the "**Zone of Thermal Comfort**" (A to A'), there is little sensation of heat or cold, and a steady state core temperature can be maintained without any efforts. **B to B'** is **Thermoneutral zone when Basal Metabolic Rate (BMR) is the lowest**.

At the **lower critical temperature (B)**, heat produced by increased metabolic activity maintains homeothermy. However, at **C (Incipient lethal temp. low)**, heat production cannot balance heat loss, the core temperature begins to fall, and the animal becomes **hypothermic**. With more cooling, heat production peaks, and then declines, further lowering the core temperature. At the lethal body temperature (**Cold death -D**), an animal dies from the cold. For most species, the lower lethal temperature is 59-68°F (15-20°C), or about 36°F (20°C) **below the normal core temperature**.

With air temperature rising above the "Zone of Thermal Comfort" (A), the animal makes efforts for cooling. At the **upper critical temperature (B')**, increased sweating and (or) panting may be associated with lowered metabolic heat production. At **C' (Incipient lethal temp. high)**, further intensification of sweating and (or) panting cannot maintain homeothermy, and the animal becomes **hyperthermic**. The rise in core temperature increases the metabolic rate **via the van't Hoff effect, triggering positive feedback, which further increases the core temperature**. Thermal death of an adult occurs at (**Heat death**) **D**. For mammals, the van't Hoff effect is the two-to three-fold rise in heat production caused by an 18°F (10°C) rise in tissue temperature. For most mammals, the upper lethal body temperature is 108-113°F (42-45°C), or about 5.4 to 10.8°F (3 to 6°C) above the normal core temperature.

Critical Temperature & Thermo neutral zone vary from Animal to animal. Critical temperature in naked man is 25 to 27°C. In Arctic fox it is -30 to -40°C

Dogs, cat, rabbits, sheep can lower BMR (about 20%) in hot conditions. Homeotherms can change thickness of insulation.

BMR is the lowest in homeotherms for maintaining constancy of T_b observed in thermoneutral zone. In this zone the animal is most comfortable. The boundaries of thermoneutral zone form critical temperature low & high from where the animal has to struggle for maintaining constant T_b . Critical temperature & thermoneutral zone vary from animal to animal.

Temp. regulation in homeotherms i.e. Birds & Mammals.

Elephant 36°C , Man 37°C , Rat, Horse, Cow – 38°C , Cat, Pigs, Dogs, Sheep – 39°C

Rabbit, Chicken – 41°C , Sparrow 43°C

In general

Monotherms }

} $30 - 36^{\circ}\text{C}$

Marsupials }

Higher mammals have $36-38^{\circ}\text{C}$ Birds 39 to 42°C

Heat production in homeotherms :

1] Exergonic oxidative reaction

Food is oxidised to produce energy. These reactions are carried through out the life. Heat production is **non-shivering type heat energy or thermogenesis.**

Ingestion of food – Causes rise BMR & also lead to increase in temperature. This is known as specific dynamic action of food. Spicy food causes more rise in temperature.

2] Muscular contraction

High muscular activity & exercises increases body temperature (t_b) from 37°C upto 40°C .

Shivering thermogenesis – When exposed to cold, rapid muscle contraction is shown by the animals. It produces $16000 \text{ Kcal/m}^2/24\text{hrs}$

Ex. Man in 4°C bath show 18 fold rise in heat production by shivering.

3] Endocrine factors (are fast in action)

Non-epinephrine & epinephrine rise metabolic rate, therefore temperature increases.

Thyroxins - (are slow in action)

Hyperthyroidism – rises metabolic rate

rises temperature by 0.5°C

Hypothyroidism – rises temperature by 0.5°C

decreases temperature

Brown Fat – B.A.T. – (Brown adipose tissue) a special tissue in mammals.

Special thermogenic tissue found in new born mammals including man. Present in all new born mammals in cold region. It helps them to fight cold. Also present in hibernating mammals & helps them in Arousal.

It produces heat by oxidizing fat and the heat production is so rapid, like a furnace.

Location – found in neck & Thorasic region.

It warms the heart & brain first.

Then heat spreads through circulation.

Difference between normal white fat and brown fat.

White Fat	B.A.T.
→ Cells round & small	→ Cells large, polygonal
→ Few fat droplets	→ Numerous fat droplets
→ Few vacuoles	→ Many vacuoles
→ Few mitochondria	→ Numerous small mitochondria
	→ It also has high protein & phospholipids
	→ It also has cholesterol, enzyme, myoglobins, flavin compounds, cytochrome and they give reddish brown colour.

How BAT gets stimulated and releases energy?

Stimulus through sympathetic Adrenelgic nerves



Secrete N Epinephrine



Binds numerous receptors on BAT cells.

1,50,000/cell ! Therefore cells are very sensitive.



ATP $\xrightarrow{\text{ATPase}}$ AMP (acts as 2nd messenger)

Mobilizes lipase



Free fatty acids (FFA)



Oxidized in mitochondria & this leads to rise in O₂ consumption

Heat loss – It has to be regulated because at low temperature heat production has to be increased. Metabolic rate rises, food requirement rises. But food availability less due to winter.

Therefore heat conservation has to be done. In different environment, heat loss is by different ways :-

Aquatic life – conduction more
Terristerial life – Evaporation – 40 %
Radiation - 55 %

At low temperature, heat loss is by conduction & radiation whereas at high temperature, heat gain is by conduction & radiation.

Evaporative heat loss is always there i.e. 0.6 Kcal/gm evaporation of water.

There are different mechanism to regulate heat loss.

Mammals in hot environment increase sweating to raise evaporative heat loss. They also show panting to raise evaporative heat loss. Some mammals become nocturnal to avoid evaporative heat loss.

Birds don't have sweat gland. They tolerate hyperthermia (T_b 2⁰C more warmer than mammals). They also show evaporation from respiratory surface & also from thoracic & abdominal air sacs.

An experiment was done on Birds. The air sacs were inactivated which caused 50 – 60 % reduction in evaporation leading to hyperthermia.

In hot air, pigeons show rise in tidal volume (i.e. volume of air / breath) which causes more evaporation & cooling.

For this purpose, air sacs are useful for pigeons.

Temp	Resp. Rate / min	Tidal Vol. / min.	Total air flow / min.
42 ⁰ C	46	4	184 ml/min.
44 ⁰ C	51	12	612 ml/min.

Birds show panting & Gullar fluttter. (Rapid movement of floor of mouth & throat). By this they achieve cooling by evaporation.

Storks & Egrets dip legs in water. In storks they often urinate on legs (1 urination / min).

In cold environment insulation is useful to prevent heat loss.

Birds have feathers & mammals have hair.

Mammals adjust their coat thickness. the coat is thicker in winter & thinner in summer. They even change their colour. Mammals in temperate region have thicker fur.

Small animals can't have thick fur. Therefore shelter in burrows e.g. Mice.

Some mammals have naked skin like pigs, whales and walrus. But they have a thick fat layer below skin which has low melting point , so it remains in fluid condition in low temperature also. The Eskimos use this fat & apply it to their shoes to keep it soft. This fat acts as insulator & also as source of energy.

The animals living in cold environment have skin which is resistant to cold & the sensitivity of skin is lower due to fat deposition. But still the nerves are sufficiently sensitive.

Eg. Pigs remain comfortable at 8⁰C but man becomes uncomfortable at 31⁰C . In seal when skin is at 0⁰C, 5 cm below the body is warm.

In Whales fat layer is present called as Blubber for body heat regulation.

Arctic fox has thick fur & is comfortable at -40°C . This insulation which protects the animal during cold becomes a problem when the animal is active and warmed up because it prevents heat loss.

During metabolic activity, metabolism is fast so more heat is produced which has to be given out.

For this purpose animals have thinly insulated extremities.

In Arctic fox, legs are thinly insulated so while sleeping it curls up to cover the legs.

When active, heat is given out through the legs.

In Gulls, Arctic dogs & Reindeers have extremities thinly insulated.

- But they can tolerate cold
- Remain sensitive
- Remain flexible (low M.P. fat)

Rete Mirabile

Arterial blood gives heat to cool venous blood which is going in body therefore heat is conserved. During activity fast circulation through rete mirabile therefore useful in going out heat.

In JackRabbit, external ears are big which help in giving out heat in summer. But in cold environment circulation is reduced in the ears.

In cold environment, X-Ray of ears looks black

In hot environment, X-Ray of ears looks bright

Thermostat (Regulator)

In mammals – Hypothalamus

In Birds – Spinal cord

Anterior hypothalamus protect against heat. Post hypothalamus protect against cold.

Stimulii from different parts of the body are received.



Messages to body through effector nerves. Message is also sent to Autonomous nervous system which controls sweat gland, cutaneous blood flow, pilo erection.

Even if Autonomous Nervous System is damaged, blood vessels respond to lower blood temperature. In cold, the Blood vessels contract & in hot, the Blood vessels expand.

When there is prolonged change in T_a



It Stimulates endocrine system.

(Thyroid) – long term effect.

(adrenal) – short term effect.



In cold, secretion rises

In hot, secretion decreases

Affect Metabolic rate to regulate temperature. Animals extreme cold show adaptation of body i.e. C.N.S. tolerate & functions at low T_a . Nerve Axons, heart also tolerant & functional at low T_a .

Temperature Regulation in Poikilotherms :

Poikilotherms cannot alter metabolic rate.

Low $T_a \rightarrow$ low metabolic rate

High $T_a \rightarrow$ high metabolic rate

Even then they try to maintain T_b constant by various phenomena

i) Gradient selection behaviour

Animals show movement towards a particular temperature, suitable for their survival.

Eg. 1) Free living Nematodes – When exposed to thermal gradient, shift to middle part.

Parasitic nematodes select warmer temperature even if they suffer damage.

2) Housefly larvae – select warm (feeding) temperature 15°C to 33°C .

But pupating larvae selects cold temperature because warm temperature will be harmful to pupa.

This type of gradient selection can be altered by acclimation.

ii) Metabolic Warming –

This is also a behavioural adaptation in poikilotherms.

Eg. Butterflies show warming up movement of wings.

Female Python coils around eggs & keeps her body warm by muscle contraction.

Cold waterfishes like Tuna & Sharks swim fast to maintain high T_b (14°C higher than T_a) They die if prevented from swimming. Hence they are kept in circular tank.

Due to fast swimming gaseous exchange also is possible.

iii) Heat gain from environment or heat loss to environment –

Desert locust remain inactive in morning when temp. (T_a) below 17°C & start moving at T_a 17°C to 20°C . Make body perpendicular to sunlight so that body is exposed to more sunlight and heat is gained to make the body warm.

During noon $\rightarrow T_a = 40^{\circ}\text{C}$

Therefore the locusts rest in bush and keep body parallel to sun rays so that minimum surface is exposed and heat gain is minimum.

In the Evening – Again keep body perpendicular to sun rays to gain heat by absorption.

Butterflies – bask in sunlight to gain heat by ectothermy.

Lizards – Bask in sunlight for absorption of heat. To avoid heat loss to cool substratum, keep body on dry grass.

Body colour of poikilotherms also helps in losing or gaining heat.

Snout Beetle – Living in hot environment has light colour. Absorb only 26% heat.

Carrion Beetle – living in cold environment. Body is therefore dark & absorb 95% heat.

Nocturnal moths – have furry insulation to prevent heat loss. They show shivering thermogenesis of thoracic muscles.

Iguana in cold environment – has Dark colour absorb 74% heat & Reflect 6%.

Phrynosoma (horned toad) – is light colour in hot environment & dark in cold environment & absorb 65% of heat.

Earless lizard – lives in Desert & in night burries in the sand.

Takes head out in the morning. Blood filled sinuses in the head region get heated in sunlight. When warm blood spreads in the body, the lizard emerges out.

Snakes in Arctic region have longer body so that they can absorb more amount of heat by increasing surface area.

Lizard chuck walla shows panting for evaporative cooling.

Use of evaporative heat loss by Bee, for cooling—In summer bees bring water to the hive and do fanning to increase evaporative heat loss to achieve cooling
In winter bees show clustering to prevent heat loss and keep the hive warm & they keep on changing their places.

Reptiles in cold reduce cutaneous flow & in hot the cutaneous flow increases.

In insects they have waxy layer on cuticle.

$T_a > 30^{\circ}\text{C}$ layer melts evaporation rises therefore cooling is achieved.

T_a less than 30°C the wax layer prevents evaporation.

Snakes in northern region show viviparity for survival. (e.g. Vipers)

In Poikilotherms the Thermostat is C.N.S,

Peripheral Receptors send stimuli to C.N.S. & according to the signals sent the CNS modifies the insect behaviour so that heat is gained or lost. Thus through regulation of heat loss and heat gain, the poikilotherms also try to regulate the body temperature.

Acclimation & Acclimatization

When an animal is subjected to changed condition in laboratory, animal shows compensatory changes to new environment. These changes are known as acclimation. In other words acclimation is adjustment to laboratory conditions.

In case of temperature regulation acclimation is of 2 types i) Cold Acclimation ii) Hot or warm Acclimation

Acclimatization – Compensatory adjustment of organism to change in the environment, in nature or natural condition is known as acclimatization. Adjustment to seasonal changes in temperature come under acclimatization.

Normally when an animal is exposed to a T_a lower than normal then initially the body temperature T_b drops, thereafter the animal compensates and tries to bring the T_b to normal. When exposed to hot T_a the T_b initially increases and then the animal tries to bring it to normal through compensation.

As shown in the figure when an animal from Normal temp. t_a is subjected to cold t_a , then there is initial drop in body temp. as shown by position 4. If the animal is exposed to hot environment there is initial rise in body temp. shown by pattern 4. If the body temp (t_b) from 4 settles to 2 then the compensation is known as “perfect compensation” & acclimation as “Perfect Acclimation”. If the temp. settles between 2 & 4 i.e. 3 then compensation is not full proof so known as ‘partial compensation’ & hence known as “partial Acclimation”

If the body temp (t_b) settles to pattern 1 i.e. in cold T_a the body becomes warmer than normal & in hot T_a it becomes cooler than normal then the compensation is known as “over shoot” or “excess compensation”. And if the body temp. as shown from pattern 4 changes to 5 i.e. in cold it further drops & in hot environment it further rises then the compensation is not there or it indicates “no compensation.”

The animals, depending upon their genetic ability show different type of compensation. However it is difficult to generalize about compensation because there are too many variations in acclimatory compensation.

Many animals show compensatory changes in particular range of temp.

So also the acclimation depends on physiological state of animal such as hormonal state, health, injuries etc.

Not only the animals show different type of acclimatory compensation. It is found that in an animal different tissue show different type of acclimatory compensations. This is of course is related to the importance of tissue in the body.

As shown in diagram below a fish trout when acclimated to 16 to 8⁰C temp. following Precht's pattern was seen in which brain showed perfect acclimation, liver showed over shoot compensation, whole body showed partial compensation & gills showed no compensation.

It is generally observed that the animals which show torpidity & hibernation or are poor in compensatory acclimation. Whereas the animals that remain active in extreme environment are better in compensatory acclimation.

The animals which live in tropics & polar environment enjoy stable environment & hence are poor in compensatory acclimation as compared to those living in temperate environment which have more temperature fluctuations.

Changes that occur during Acclimation & Acclimatization

There are various changes that take place in Acclimation & Acclimatization that include physiological changes like glycolysis, electron transport cycle & Krebs's cycle.

In cold acclimation protein & enzyme secretion is more as compared to hot acclimation. All the changes during acclimation are not understood except the following -

Normally changes occur in --

- i) Protein & phospholipid synthesis & turnover.
- ii) Synthesis of isozymes suitable for new environment.
- iii) Modification of membrane lipids.

Normally membrane lipids become unsaturated fats so that they remain fluid in cold condition.

Likewise animals show behavioural responses (refer to Gradient selection in poikilotherms)

Cold Acclimation

When birds or mammals are kept at low temp. in laboratory, initially their body temperature falls down but then they show rise in metabolic rate, rise in O₂ consumption. This change is proportional to change in temp. As oxidation is faster, the food intake rises. The enzymes in liver, muscles and mitochondria rise. Glucose, pentose, fatty acid pathways are mobilised. They become faster. Adrenal & thyroid secretion rises. Most important is that the peripheral circulation rises to keep skin warm & in them normally insulation by fur coat does not change.

Cold Acclimatization

This is a slow process & is seasonal. The change is prolonged & gradual & hence the compensatory changes are different. In nature when change occurs the animal show changes in thickness of fur coat. They reduce the peripheral circulation & both these prevent heat loss. This is because in environment with approach of winter there is scarcity of food. It is found that the thickness of fur rises in large animals. In them fat is mobilised & unsaturated fat gets deposited in joints & extremity so that the flexibility is maintained. Their CNS, tissue, nerves gradually gain resistance to stand

the cold. Sparrow gain resistance at rate 6° drop / month. For sensitivity of tissues is increased . There is higher sensitivity of the tissues to neurotransmitter or the transmitter subs. Along with these the animal show behavioural changes in them.

Ex. Dog, rats, bees show aggregation phenomenon in cold season.

Acclimation & Acclimatization for heat & hot environment show similar changes & hence considered together. When skin heat receptors feel heat they lead to reflex responses which include

- 1) Dilatation of cutaneous blood vessels to rise blood flow in the skin so that heat is given away.
- 2) Sweating rises.
- 3) If Sweat glands are absent (birds) then evaporation from respiratory surface rises.

All these processes cause evaporation of water & hence cooling. In man in cool air 1 litre water/day is evaporated from body surface. Rise by 1°C rises water evaporation at a rate 20 ml/hr.

Donkeys & camels live in desert environment where t_a is high. In them to save water sweating start late or at higher temp. It starts between $31-35^{\circ}\text{C}$ temp. The organism have to tolerate hyperthermia.

The stimulus for sweating is different in different animals. In some exposure to sun causes sweating. In female sheep sweating is stimulated when mammary glands are heated, in male sheep sweating is stimulated when scrotal sac skin is heated. In general sweating causes evaporative heat loss. However birds don't have sweat gland & hence they show evaporation from respiratory surface.

Ex. : Gullar flutter – Pigeon, Storks

Panting – hawk, pigeon etc.

Fluffing of feathers – Ostrich, Pigeon, sparrows.

Dusting of feathers or dust bath – sparrow, ostrich. This is how they try to achieve cooling.

Desert birds soar high in the air & enjoy cool air currents.

A bird 'Bobby' spreads the wings & keeps legs under shadow so that cooling is achieved.

Stork urinates on the leg or shows panting & this stops when it enters water.

In mammals respiratory surface evaporation is raised. In cows pulmonary evaporation rises 3 fold when temp. rises to 68°F to 111°F .

Dogs & cats show panting.

In goats horns play important role in cooling. If horns are covered by woollen cap the goat dies because of rised brain temp.

In human beings, also when a person is heat acclimated certain physiological modifications are seen.

- a) capacity of sweating is doubled.
- b) sweating starts earlier.
- c) sweat contains less salt.
- d) efficiency of cardio vascular system rises.

Hibernation, Aestivation & Torpidity

Hibernation :

It is a seasonal dormancy shown by the animal which may be shallow or deep for a short period or a longer period. It is shown in winter season hence winter sleep or winter dormancy.

In hibernation there is extreme drop in temp. of body due to which physiological processes become extremely slow & hence energy is conserved. For this purpose the animals need lot of preparation.

In hibernating animal the thermo regulator is set to a low temp. (normally 2⁰C). Heat conservation mechanism is turned off & animal enters into a deep sleep. Hibernation is shown by certain animals like monotremes, insectivorous, rodents, bats i.e. mainly mammals. It occurs in form of annual cycle & is governed by hormones because if serum of a hibernating ground squirrel is injected in an active ground squirrel it shows hibernation.

Preparation of hibernation :

Various physiological changes occur during hibernation. In favourable season usually the animals show fat accumulation. The carbohydrates are converted to fat & stored. Hamster store food material in their nest & they show deposition of low m.p. fat.

Hedgehog show rise in insulin & rise in thyroxine. In them if thyroxine is injected hibernation is retarded.

Pituitary & adrenal glands play important role in hibernation.

Pituitary causes hibernation in hamster whereas adrenalectomy leads to failure of hibernation. Thus endocrine factors play important role in hibernation but their mechanism is complex.

In hamster if adrenal gland is removed hibernation is prevented but in a hibernating hamster adrenal activity is low. So also if nor-adrenaline is injected then also no thermogenic response is seen.

The t_b of hibernating animals drops slowly normally at a rate 2-4 ⁰C/hr & drop is associated with peripheral vasodilatation & reduced muscle tone.

During hibernation

T_b falls down



Heat rate reduces significantly

In ground squirrel it is 200-400 / min whereas in hibernating ground squirrel it is 7-10 beats / min. Beats become irregular. Heart remains functional at low temp. & it is not sensitive to vagus inhibition.

Respiratory rate of animal drops. There is a drop in cardiac output. In ground squirrel it reduce to 1/65 as compared to normal.

In some species the blood is collected in spleen which rises in size so also erythrocyte count & haemoglobin level rises & clotting time is prolonged.

Nervous system remains active even at 9⁰C the brain shows response to peripheral stimuli.

Magnesium content of serum becomes high in hibernating hedgehog & Marmoset bat.

Hypothalamus plays an important role in hibernation. Posterior hypothalamus is important for hibernation & anterior is important for arousal. In a hibernating ground

squirrel if posterior hypothalamus is damaged, it fails to hibernate & if anterior hypothalamus is damaged it fails to arouse.

Hibernating animals has a unique ability to prevent drop in the temp. which can be serious. If the body temp. becomes very low the animal shows arousal, they feed & again hibernate. In some animals for this purpose there is cyclical arousing. Ground squirrel wakes up after every 11 days where as hamsters also wake up every few days, feed & hibernate.

During hibernation the overall metabolic rate is 20-1000 times slower. In spite of this there is a weight loss in the animal which can be from 10-30%.

The hibernating animals show resistance to adverse condition (other than temp.)

Ex. When hibernating ground squirrel is exposed to ionising radiations there are no ill effects seen during hibernation. However when they arouse the ill effects are apparent.

Arousal or Waking up :

Waking up is very fast in the animal. A bat is kept for 144 days in refrigerator become active when taken out. In ground squirrel the temp. rises from $4^{\circ}\text{C} - 35^{\circ}\text{C}$ in 4 hrs. In Birch mouse the temp. rises from $1^{\circ}\text{C} / \text{min}$. In this arousal process the animals are helped by specialised tissue known as brown adipose tissue. It produces heat like a furnace in very high amount. Usually the stimulus for arousal is changed season & warming of ta. All the are stimulator or super cooling also acts as stimulator for arousal.

When the stimuli is reached a series of process takes place. Due to stimuli peripheral blood vessel contract called as vasoconstriction. So blood flow towards thoracic muscle causing warming. So also autonomous stimuli are send to BAT (Brown adipose tissue) & it is activated by nor-epinephrine. Due to which BAT is activated & starts oxidation of triglycerides or unsaturated fats. In arousal autonomous nervous system is activated, then BAT is activated, Heat is produced, heart rate become faster than respiratory rate rises leading to arousal.

Thus mammals living in living environment. Their winter is long & severe so this unique phenomenon of hibernation by which the animals bring down their metabolic & rate & conserve their energy during adverse condition.

Torpidity (Torpor)

Daily sleep (Torpor) is seen in bats, Birds & mammals. This phenomenon is daily dormancy. In this the T_b rapidly drops down to reduce metabolic rate due to which the animal conserves energy.

Torpidity many a times is related to environmental condition & food availability. In some animals when food is scarce they can raise torpidity from few hrs to few days. Whereas some animals can show continuation of torpidity into hibernation & aestivation.

Bat (especially microchiropteron) – show Diurnal torpidity which is during day time, is seen in summer to avoid ill effects of intense heat.

Myotis (bat) shows Torpidity in hot summer days, where the T_b drops to 5°C so that metabolic rate is reduced. This bat when is cooled below 5°C don't wake up & dies because of super cooling. However the same bat during winter hibernates if a hibernating bat is supercooled it wakes up & become active or it regulates the temp. to maintain it to 5°C . Thus torporing bat cannot resist supercooling whereas hibernating bat can resist supercooling.

2) Humming bird – smallest 1.7 g

largest 19 g

They have very high energy requirement as they are very active and the metabolism is high. At around 27°C temp., in the blue throated humming bird the heart beat is 7 to 21 beats /sec. The O₂ consumption of the bird is 1.18 ml/g/hr. The energy requirement of the bird is so high that if the body temp. remain normal at night time (when the bird is not feeding) , the bird will die due to energy shortage. To overcome this the animals shows torpidity. Due to drop in temp. Heart rate became less & the O₂ requirement becomes 1/10th of normal.

If this torporing bird is cooled to 8°C then many a times the bird dies due to super cooling , it cannot wake up.

3) Desert Rodents show torpor mainly to overcome the food scarcity. In pigmy mouse the T_b is dropped to 23°C during day time for a period of 12 hrs & they become active at night. In Kangaroo Rats we find that the duration of torpidity is adjusted according to food. It can be from few hours to few days.

Thus torpidity is a diurnal phenomenon in which the animal allows to drop in T_b to conserve energy.

Aestivation (Summer sleep or summer dormancy)

Some animals have ability to remain dormant during unfavourable summer months when there is water scarcity or intense heat.

Aestivation is shown by desert animals And variety of them like snails, ground squirrel etc. some show aestivation & hibernation. e.g. Snails show hibernation / aestivation according to availability of water. Ground squirrel aestivate in summer and hibernate in winter. Normally in insects, during summer the adults die but the eggs & pupae survive by remaining dormant. In case of snails, sawbugs, shrimps adults remain dormant in unfavourable condition.

Desert Amphibians. show aestivation / dormancy

Ex. Spade foot toad – has spur like projection on hind leg for digging. In drought period it starts digging & burrows in the soil. It encloses itself in gelatinously material, mud ,sand & remain their for 8-9 months. It wake up with 1st showers of rain & life cycle is completed in 3 months.

In the same manner ticks & mites show dormant condition. They remain dormant during winter & summer & remain active only during spring.

e.g. Dermacentre (Rocky mountain wood tick)

Mammals like kangaroo rat, pocket mouse aestivate when there is scarcity of food whereas in white footed mouse aestivation occurs when there is shortage of water.

Some birds like swift aestivation is due to scarcity of food.

A very unique phenomenon is shown by lung fishes like Protopterus, Lepidosiren, Neoceratodus which show aestivation. They remain alive in earthen cocoon for many years & for this purpose they store urea in their tissues to absorb water. The metabolic rate falls to 1/100 due to which they can aestivate for a long period.

Thus torpidity, aestivation hibernation are the phenomena in which the animals allows the T_b to drop down & thus conserves energy. By conserving energy they can overcome adverse conditions. The phenomena are similar to each other & the purpose is conservation of energy only. The only difference in them is length of dormancy & the season of dormancy.