

THERMOREGULATION AND OSMOREGULATION

STUDENTS' LEARNING OUTCOMES

After studying this chapter, the students will be able to:

- Describe three elements i.e., receptors, control center and effectors which operate homeostatic mechanisms.
- Relate the homeostatic mechanisms with the negative and positive feedback systems.
- Define thermoregulation and explain its needs.
- Classify animals on the basis of the source of body heat i.e., ectotherms and endotherms.
- Classify the animals on the basis of the ability to thermoregulate i.e., poikilotherms and homeotherms.
- Describe the regulatory strategies in man for thermoregulation.
- Differentiate between osmoconformers and osmoregulators.
- Define osmoregulation.
- Explain the problems faced by osmoregulators.
- Explain the different methods of osmoregulation found in freshwater, marine water and terrestrial animals.

In this chapter, we will study homeostasis. We will explore the mechanisms of thermoregulation and osmoregulation and examine the importance of maintaining homeostasis for the health and survival of human beings.

13.1 - HOMEOSTASIS

Homeostasis is a vital process by which living organisms maintain a stable internal environment, despite changes in their external environment. Homeostasis consists of a wide range of mechanisms that work together to regulate the body's internal environment. Important processes of homeostasis are thermoregulation, osmoregulation, and excretion.

13.1.1 - Basic Mechanism of Homeostasis

Homeostasis is maintained through the collaboration of three essential elements i.e., receptors, control centre, and effectors.

1- Receptors

Receptors or sensors are specialized structures (organs, tissues, cells or subcellular components) that detect changes in the internal or external environment. They also transmit the information of changes to the control centre. For example,

receptors cells present in the skin can detect changes in temperature. Similarly, receptors cells in the blood vessels can detect changes in blood pressure and pass information of the control centre.

2- Control Centre

The control centres receive information from the receptors, process this information, and send appropriate message to the effectors. These messages ensure that the internal environment remains within a narrow range of set points. These set points are optimal for the body's function. The brain, spinal cord and endocrine glands act as control centres in homeostasis.

3- Effectors

Effectors are the parts of the body which respond when they receive message from the control centres. Muscles and glands act as effectors. Muscles respond by contracting while glands release their secretion. In this way, the responses of effectors restore the internal environment to its set points. For example, when the body temperature drops below the set point, effectors in the skin and muscles cause shivering and vasoconstriction. This response increases heat production and raises the body temperature to the set point.

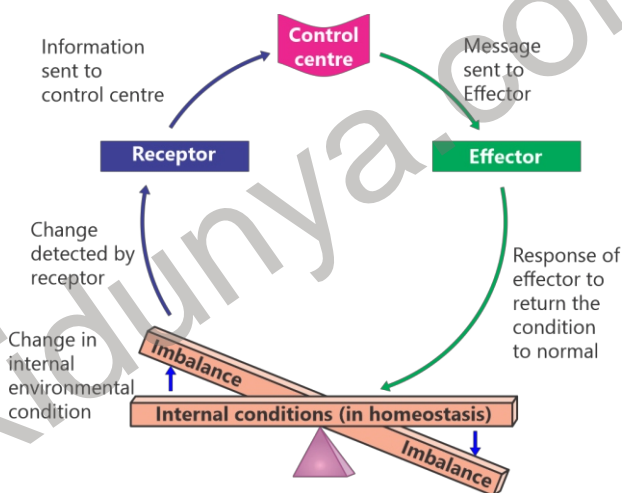


Figure 13.1: Elements of homeostasis

13.1.2- Feedback Mechanisms

Feedback mechanisms are the foundations of homeostasis. These are the regulatory processes in which the output or product of a system is used to control the behavior of the system itself. There are two types of feedback mechanisms.

Negative Feedback

A negative feedback system is a mechanism in which the output or product of a system reduces the activity of the system. It is the most common form of regulation. Common examples of negative feedback include the regulation of body temperature, blood glucose levels, and hormone secretion.

For example, if body temperature exceeds the set point of 37°C, the thermoreceptors in the hypothalamus of brain detect this change. They send signals to the control centre (thermoregulator in hypothalamus). The control centre sends messages to effectors (e.g., sweat glands). The effectors respond by producing sweat which lowers the temperature. The output of this process (lowering of temperature to the set point) influences the thermoreceptors negatively. As a result, the thermoreceptors stop sending message to the control centre.

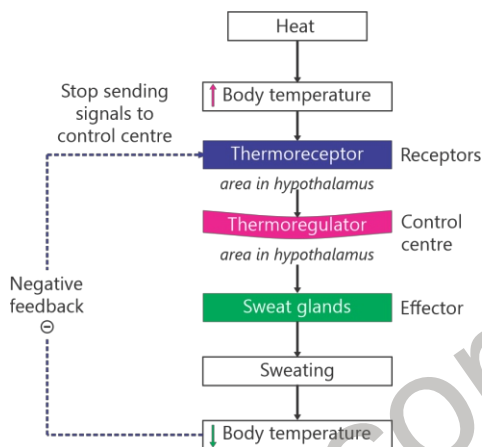


Figure 13.2: Negative feedback system to control body temperature

Positive Feedback

A positive feedback system is a regulatory mechanism in which the output or product feed increases the activity of the system. In this way, the positive feedback enhances the original stimulus. In homeostasis, positive feedback is less common than negative feedback. It often happens in the processes that require rapid and significant changes e.g., blood clotting, labour and childbirth.

For example, during childbirth, contractions of the uterus send nerve impulses to the control centre (part of hypothalamus). The control centre sends signals to pituitary gland to release oxytocin hormone. Oxytocin then stimulates further contractions of the uterus, which in turn sends more nerve impulses to hypothalamus, leading to the release of more oxytocin. This positive feedback loop continues until the baby is born.

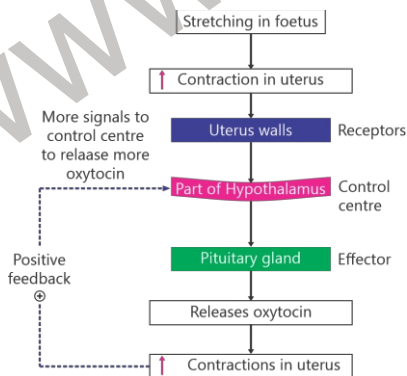


Figure 13.3: Positive feedback system to in childbirth

Unregulated Positive Feedback

Sometimes, the un-regulated positive feedback systems can result in health problems. For example; in severe inflammation or infection, the immune cells release proteins called cytokines. These proteins further stimulate the immune response. If this positive-feedback is not properly regulated, it can lead to excessive inflammation and tissue damage.

13.2- OSMOREGULATION

The maintenance of the balance of water and solutes in the body fluids is called osmoregulation. It ensures that the body fluids do not become too dilute or too concentrated. It is essential for many physiological processes, including maintaining proper blood pressure, enabling the proper function of organs, and regulating metabolism.

Recalling

- Osmosis is the diffusion of water across a membrane, and it always occurs from a more dilute (hypotonic) solution to a less dilute (hypertonic) solution.
- The osmotic pressure of a solution is a measure of its tendency to take in water by osmosis.

13.2.1- Osmoregulators and Osmoconformers

On the basis of the ability of osmoregulation, the animals are divided into two groups i.e., osmoconformers and osmoregulators.

Osmoconformers

Osmoconformers are the animals which allow the osmotic concentrations of their body fluids to match their environment. They cannot maintain the concentration of water and solutes in their bodies. So, these concentrations change with the changes in surrounding medium and they remain isotonic to their environment. Such animals are usually found in environments with relatively stable solute concentrations, such as marine water. Examples of osmoconformers include all marine invertebrates, some freshwater invertebrates and some marine vertebrates like hag fishes, sharks and rays.

Osmoregulators

The animals that can regulate the concentrations of water and solute in body fluids are osmoregulators. They can maintain constant internal concentrations despite the changing concentration in the environment. They use various mechanisms for osmoregulation e.g., active transport of salts, accumulation of salts, and water conservation etc. Most vertebrates in aquatic and terrestrial environments are osmoregulators.

13.2.2- Problems and Methods of Osmoregulation

Osmoregulation in Freshwater

Generally, the freshwater animals are hypertonic to their environment. It means that they have higher solute concentration in body fluids than the surrounding water. Water continuously enters their bodies through osmosis, particularly across permeable surfaces like gills. Essential salts and ions (like Na^+ and Cl^-) diffuse out of the body into the surrounding water.

In osmoregulation, they prevent water from entering their bodies and eliminate the excess water that does enter. For this purpose, they produce large volumes of diluted urine. To compensate the loss of salts, they actively transport salts back into their bodies. Unlike their marine water animals, freshwater animals rarely drink water.

Osmoregulation in Marine Water

Most marine animals are hypotonic to their environment. This means that external environment has a much higher solute (salt) concentration than their internal tissues. Water constantly leaves their bodies via osmosis through the gills and skin. Salts continuously diffuse from the environment into their bodies. In addition, they have excess of salts in the body due to drinking of sea water.

To compensate for the water loss, marine animals drink seawater continuously. They also conserve water by producing very small amounts of highly concentrated urine. To remove the excess salts, specialized chloride cells in the gills use energy (ATP) to actively pump salts out of the blood and back into the environment. They also remove excess salts through their kidneys. Some marine fishes also have special salt excreting glands in rectum called rectal glands. These glands remove salts from blood into the digestive tract which are then eliminated along with faeces.

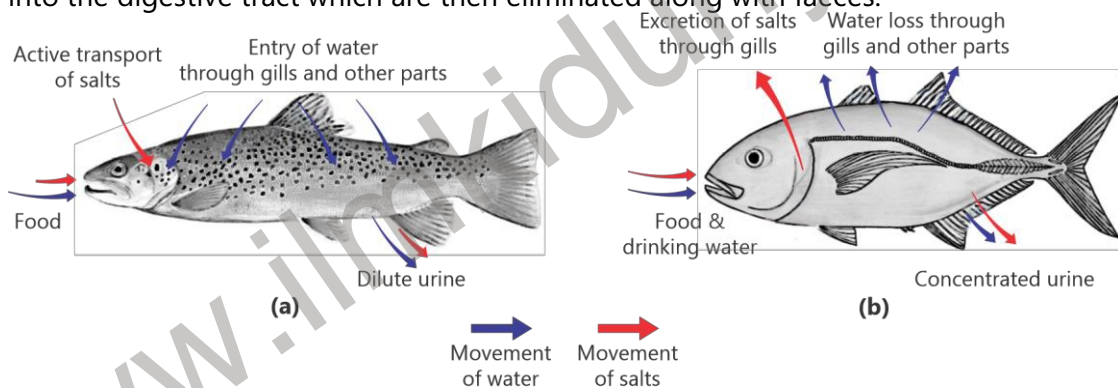


Figure 13.4: Osmoregulation in (a)- freshwater and (b)- marine water

Osmoregulation in Terrestrial Habitats

Terrestrial animals lose water to the environment through evaporation from respiratory surfaces, through the skin, and via the excretion of waste. They have to ensure that water intake (from drinking and food) and metabolic water production is equal to the water lost to the environment. These animals have anatomical, physiological, and behavioral adaptations to maintain osmotic balance.

They have relatively impermeable outer layers to prevent evaporative water loss. For example, insects possess a waxy exoskeleton made of chitin. Reptiles have waterproof scales made of keratin. Mammals and birds have dead, keratinized skin cells and also have oil secreting glands in skin.

Their kidneys play a vital role to retain water inside the body. Moreover, they convert the primary waste product of protein metabolism i.e., ammonia into urea or uric acid which require less amount of water for excretion.

Many desert animals stay underground during the heat of the day to avoid evaporation. They emerge only at night when the air is cooler and more humid. These animals feed upon seeds of desert plants in which large amount of carbohydrate are stored. Some animals, like the Kangaroo Rat, survive entirely on metabolic water (produced as a by-product of cellular respiration).

Anhydrobiosis:

Certain invertebrates, like tardigrades (water bears), enter a dormant state when they lose almost all their body water. They come to active life years later when water returns.

13.2.3- Nature of Excretory Products in relation to Habitat

In many animals, osmoregulation is coupled with the removal of metabolic wastes from the body. The nitrogenous wastes (e.g., ammonia, urea, uric acid) are the main metabolic wastes. These wastes are excreted as water solutes. The animals of different types of habitats excrete different forms of nitrogenous wastes. For example;

1- Ammonia – NH₃

It is produced when amino group (-NH₂) is removed from amino acids and nucleic acids and is combined with H⁺ to form ammonia (NH₃) in the liver. Ammonia is highly toxic and so it is excreted rapidly. One gram of ammonia requires 500 mL of water to dissolve it to nontoxic level. Such plenty of water can only be afforded by freshwater animals e.g., most fishes, protozoans, sponges, coelenterates. The marine animals excrete ammonia directly into the water. Animals which excrete ammonia as their major nitrogenous wastes are called **ammonotelic**.

2- Urea - CO(NH₂)₂

As the terrestrial animals face the challenge of conserving water, they cannot afford to excrete ammonia with a plenty of water. They convert ammonia to urea in their liver and then excrete urea through kidneys. Urea is less toxic than ammonia. One gram of urea requires 50 mL water to dilute it to the nontoxic level. The animals which excrete urea as their major nitrogenous waste product are called **ureotelic**.

Humans also excrete a small amount of uric acid in urine. Uric acid is a by-product of the breakdown of purines (found in many foods, particularly meat and some types of vegetables).

Uric acid is produced in the liver. In healthy individuals, most of the uric acid produced is excreted in the urine, but when there is an excess of uric acid in the blood, it can lead to the formation of uric acid crystals in joints and tissues, causing painful conditions such as gout.

3- Uric acid - $C_5H_4N_4O_3$

Some animals, such as insects, desert animals, birds and most reptiles face an extreme water conservation challenge due to the arid nature of their environment. They cannot afford to even excrete urea. They convert ammonia to uric acid by using lot of energy. Uric acid is even less toxic than urea. It is less soluble in water and makes precipitates. One gram of uric acid requires just 1 mL of water for its excretion. The animals which excrete uric acid are called **uricotelics**.

13.3- THERMOREGULATION

Thermoregulation is the homeostatic process by which organisms maintain their internal body temperature within a tolerable range, regardless of the temperature of the external environment.

Thermoregulation is very important for animals. We know that enzymes have an optimal temperature at which they function most efficiently. If temperature falls below the optimal, enzyme-substrate collisions decrease, and metabolic rates drop. If temperatures rises well above the optimal, enzymes begin to denature and lose their function permanently. Similarly, the lipid bilayer of cell membranes is temperature-sensitive. At high temperatures, cell membranes can lose their selective permeability. Low temperatures can make membranes rigid and brittle.

13.3.1- Types of Animals on the basis of Heat Source

Ectotherms

Ectotherms are animals that gain most of their body heat from external sources. Their internal temperature generally fluctuates with the temperature of their surroundings. Most invertebrates are ectotherms. Among the vertebrates, fishes, amphibians, and reptiles are ectotherms. In ectotherms, the metabolism rate is very low. They cannot produce enough heat to raise and maintain their body temperature. So, they rely on the heat from the environment. Ectotherms use behavioral thermoregulation. If they are too cold, they bask in the sun (radiation) or sit on a warm rock (conduction). If they are too hot, they seek shade or burrow into the cool earth. In very cold climates, they become dormant during the coldest months.

Endotherms

Endotherms generate the majority of their body heat through internal metabolism. They maintain a relatively constant body temperature, often higher than the environment. Birds and mammals are endotherms. When it gets cold, they may shiver (muscle contractions) or burn brown adipose tissue for heat. Most endotherms have insulation to retain heat such as hair, feathers, or fat.

13.3.2- Types of Animals on the basis ability of Thermoregulation

Poikilotherms

Poikilotherms are the animals that are unable to maintain their body temperature within narrow limits. Their body temperature varies considerably, usually matching the temperature of environment. All invertebrates are poikilotherms. The vertebrates: fishes, amphibian and reptiles are also poikilotherms.

Poikilotherms do not need to consume massive amounts of food to "fuel" a constant temperature. It allows them to survive in nutrient-poor environments where a homeotherm would starve.

Homeotherms

These animals maintain relatively constant internal body temperatures, regardless of environmental fluctuations. They use "thermostats" (hypothalamus in the brain) to trigger cooling or heating responses. Examples include mammals and birds. For instance, humans maintain their internal temperature at roughly 37°C whether they are in very cold or very hot environments.

13.3.3- Thermoregulation in Humans

Humans are endothermic homeotherms. They regulate body temperature through negative feedback mechanism. For example; the thermoreceptors present in skin detect an increase or decrease in body temperature. They send signals to the control centre i.e., hypothalamus which also contains thermoreceptors. Hypothalamus sends signals to muscles and glands which produce corrective responses e.g.,

Responses to Overheating (Hyperthermia)

When body temperature rises above 37°C (hyperthermia), vasodilation occurs. It is the expansion of blood capillaries which lie just beneath the epidermis of the skin. So, there is more flow of blood in these capillaries to remove more heat from blood. Responses also include sweating. Evaporation of sweat carries heat from the body and produces cooling effect. The thyroid gland may decrease the secretion of thyroxine, which lowers the basal metabolic rate. So, the internal heat production is reduced.

The thermoreceptors also stimulate the higher centres of brain. So, we 'feel' warmth or coldness. It allows us to take more actions like taking a bath or turning the fans or heaters on.

Responses to Cooling (Hypothermia)

When body temperature falls below 37°C (hypothermia), the responses may include vasoconstriction, shivering and increase in metabolic rate. Vasoconstriction reduces blood flow to the skin and so there is less loss of heat from blood. Shivering (spasmodic contraction of skeletal muscles) produces heat which helps to raise the

body temperature. Tiny muscles at the base of hair follicles contract (goosebumps). Air is trapped in the erected hair and act as insulator for the heat. Increased metabolic rate also produces heat to raise the body temperature.

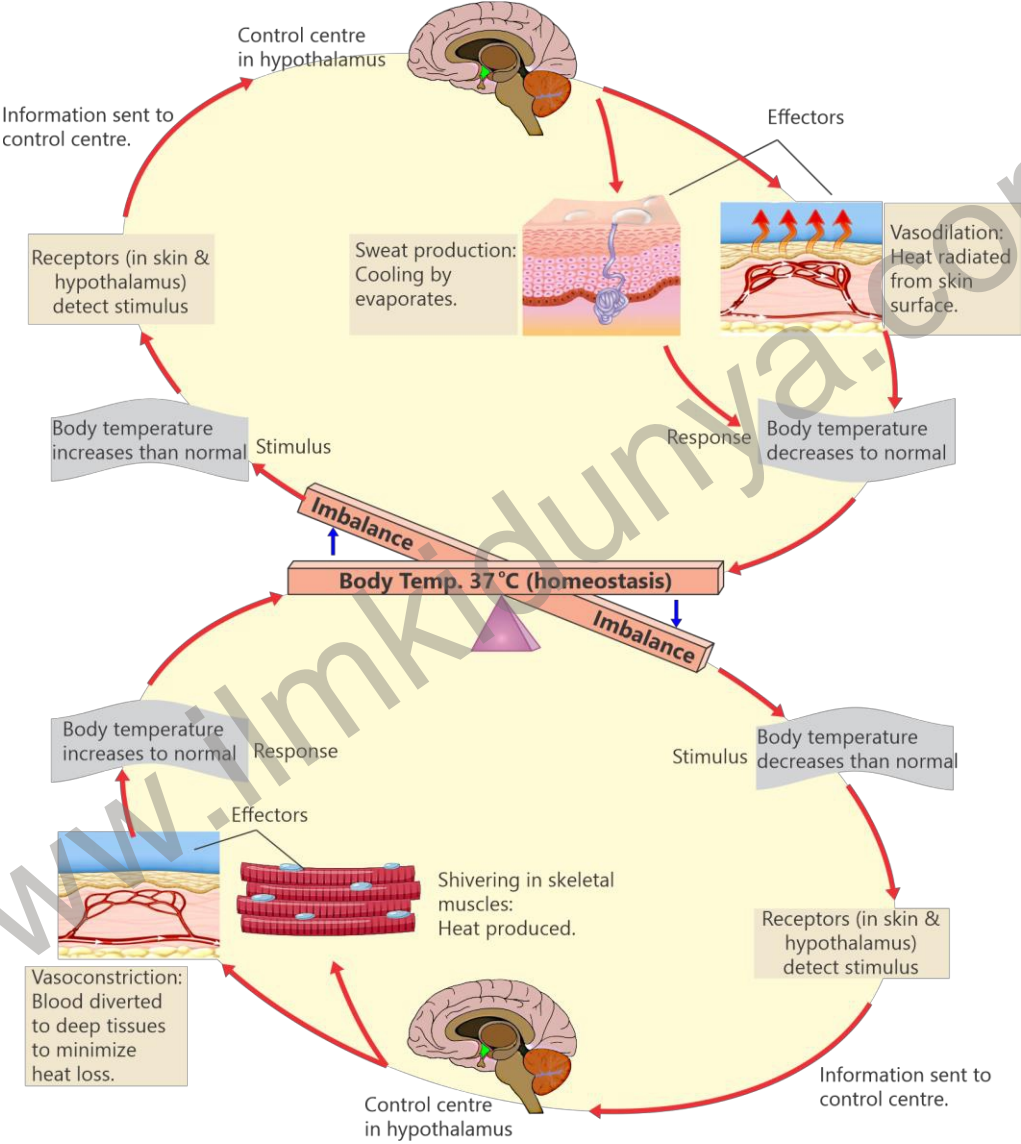


Figure 13.5: Thermoregulation in humans

EXERCISE**SECTION 1: MULTIPLE CHOICE QUESTIONS**

- Which term covers the rest of the three?
 - Osmoregulation
 - Excretion
 - Thermoregulation
 - Homeostasis
- Marine fishes compensate for water loss by:
 - Producing dilute urine
 - Drinking seawater
 - Absorbing salt
 - Reducing thirst
- How do freshwater fish primarily gain water?
 - Drinking
 - Active transport
 - Osmosis
 - Diffusion
- What is the primary heat source for endotherms?
 - Sunlight
 - Internal metabolism
 - Warm rocks
 - Convection
- What is the control center for human thermoregulation?
 - Pituitary gland
 - Hypothalamus
 - Adrenal gland
 - Medulla oblongata
- Which waste product requires the most water for excretion?
 - Ammonia
 - Urea
 - Uric acid
 - Creatinine
- Which nitrogenous waste is the least toxic and water-insoluble?
 - Urea
 - Ammonia
 - Uric acid
 - Nitrate
- In which part of the body, the conversion of ammonia to urea takes place?
 - Liver
 - Muscles
 - Brain
 - Small intestine

SECTION 2: SHORT QUESTIONS

- Define osmoregulators and osmoconformers.
- Define thermoregulation and explain its needs.
- What are the two types of animals on the basis of the ability to thermoregulate?
- Differentiate between:
 - Osmoregulators and osmoconformers
 - Ectotherms and endotherms
 - Vasodilatation and vasoconstriction

- Homeotherms and poikilotherms
- Ammoniotelic and ureotelic
- Ureotelic and uricotelic

SECTION 3: LONG QUESTIONS

1. Describe three elements which operate homeostatic mechanisms.
2. Relate the homeostatic mechanisms with the negative and positive feedback systems.
3. Explain the different methods of osmoregulation found in freshwater, marine water and terrestrial habitats.
4. Explain the nature of nitrogenous wastes in relation to habitat.
5. Classify animals on the basis of the source of body's heat.
6. Classify the animals on the bases of the ability to thermoregulate.
7. Describe the regulatory strategies in man for thermoregulation.

INQUISITIVE QUESTIONS

1. Why positive feedback mechanisms in humans are sometimes associated with severe health problems?
2. List some of the behavioural responses of the animals to maintain homeostasis.
3. Draw a flow chart to show negative feedback of homeostatic mechanisms by taking an example of hormone.