



THERMOREGULATION HOMEOSTASIS

Students' learning outcomes

After studying this chapter, students will be able to:

1. [B-12-R-74] Define thermoregulation and explain its needs.
2. [B-12-R-75] Classify animals on the basis of the source of body heat i.e., ectotherms and endotherms.
3. [B-12-R-76] Classify the animals on the basis of the ability to thermoregulate i.e., poikilotherms and homeotherms.
4. [B-12-R-77] Describe the regulatory strategies in man for thermoregulation.
5. [B-12-R-78] Describe three elements i.e., receptors, control center and effectors which operate homeostatic mechanisms.
6. [B-12-R-79] Relate the homeostatic mechanisms with the negative and positive feedback systems.
7. [B-12-R-80] Differentiate between osmoconformers and osmoregulators.
8. [B-12-R-81] Define osmoregulation.
9. [B-12-R-82] Explain the problems faced by osmoregulators.
10. [B-12-R-83] Explain the different methods of osmoregulation found in freshwater, marine water and terrestrial.

Humans, like most mammals can maintain a constant body temperature, despite changes in the surroundings. The core temperature of the human body remains reasonably constant at 37°C . It can fluctuate by a degree or so, more during fever, but it is generally very stable.

8.1 THERMOREGULATION

Heat is produced inside the body as a byproduct of metabolic reactions. Heat production occurs more generally in the organs of the body. Since heat is a byproduct of metabolism, the amount of heat produced depends on metabolic rate.

8.1.1 Thermoregulation and its needs

Thermoregulation is defined as the maintenance of internal temperature within a range that allows cells to function efficiently. The body works to maintain a stable internal temperature. Temperature colder or warmer than the enzymes optimum range, changes the shape of the active site and chemical reactions to stop. The main purpose of thermoregulation is to keep the enzyme systems of the body working properly.

8.1.2 Classification of Animals on the Basis of Temperature

Animals can be classified on the basis of the ability to thermoregulate and the source of body heat.

a. Classification of the animals on the basis of the ability to thermoregulate.

Animals can be classified based upon ability to maintain constant body temperature as poikilotherms and homeotherms.

Poikilotherms are all non-vertebrates, fishes, amphibians and reptiles. These are unable to maintain their body temperature within the narrow limits using physiological mechanisms.

Homeotherms are birds and mammals which are able to maintain a fairly constant body temperature by using physiological mechanisms.

b. Classification of animals on the basis of the source of body heat

Animals are also classified on the basis of source of body's heat as ectotherms and endotherms.

Ectotherms animals produce metabolic heat at low level that is also exchanged quickly with environment. They rely more on heat derived from the environment to raise their body temperature. Examples are most invertebrates, fishes, amphibians and reptiles.

Endotherms animals produce their own body heat through heat production as byproduct during metabolism in muscles or by the action of hormones that increase metabolic rate. The examples of endotherms are birds and mammals.

8.1.3 Thermoregulatory Strategies in Man

Thermoregulatory center in human body is located in the **hypothalamus** which acts as a thermostat. It can detect the temperature of the blood that passes through it and if the temperature increases or decreases even slightly, the hypothalamus initiates corrective responses such as sweating or shivering. When we encounter a particularly warm or cold environment, temperature receptors in the skin inform the hypothalamus. They also stimulate the higher, voluntary centers of the brain. This means that we 'feel' changing our clothing or turning the heating up or down. Often, this behavioral response corrects the situation without the need for any physiological response.

I. Physiological Responses to Heat

There are two main physiological responses when hypothalamus detects an increase in blood temperature: a. Vasodilation, b. Sweating

a. Vasodilation

One way to increase heat loss is to supply the capillaries in the skin with a **greater volume of blood**, which then loses heat to the environment via radiation. **Arterioles** have muscles in their walls that can relax or contract to allow more or less blood to flow through them. During vasodilation these **muscles relax**, causing the arterioles near the skin to **dilate** and allowing more blood to flow through capillaries.

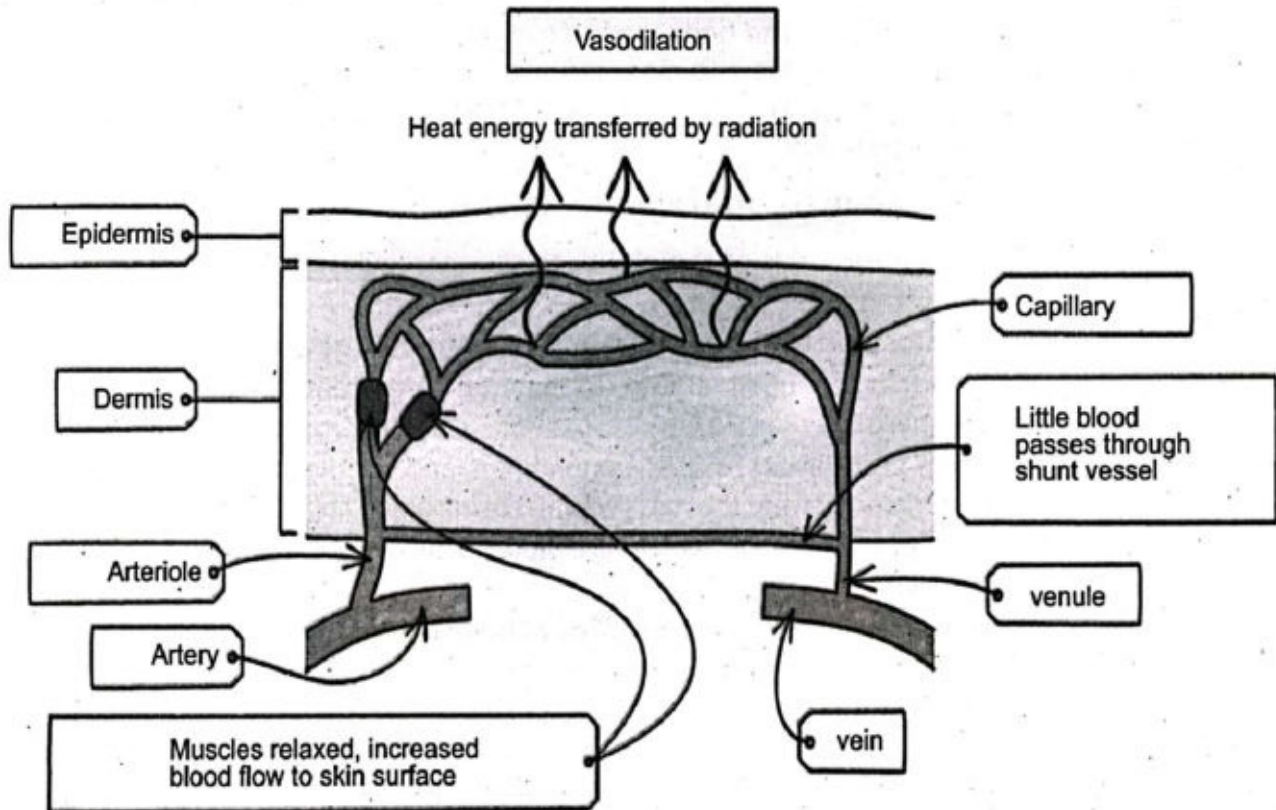


Fig. 8.1: Mechanisms of vasodilation

b. Sweating

Sweat is a salty solution made by sweat glands. Evaporation of sweat from the skin's surface leads to cooling. As the sweat evaporates, it absorbs heat from the body, thereby cooling the skin and helping to regulate internal body temperature. The efficiency of sweating depends on humidity. In dry air, humans can tolerate temperature of 65°C for several hours. In humid air, however, when the sweat cannot evaporate, temperatures of only 56°C cause overheating.

II. Physiological Responses to Cold

There are four main physiological responses when hypothalamus detects a drop in blood temperature: a. Shivering, b. Vasoconstriction, c. Piloerection, d. Increased metabolic rate

a. Shivering

We shiver when muscles contract and relax rapidly. Shivering muscles give out four or five times as much heat as resting muscles.

b. Vasoconstriction

One way to decrease heat loss is to supply the capillaries in the skin with a smaller volume of blood, minimizing the loss of heat to the environment via radiation. During vasoconstriction the muscles in the arteriole walls contract, causing the arterioles near the skin to constrict and allowing less blood to flow through capillaries the blood is diverted through shunt vessels, which are further down in the skin and therefore do not lose heat to the environment. Vasoconstriction reduces heat loss from the blood as it flows through the skin

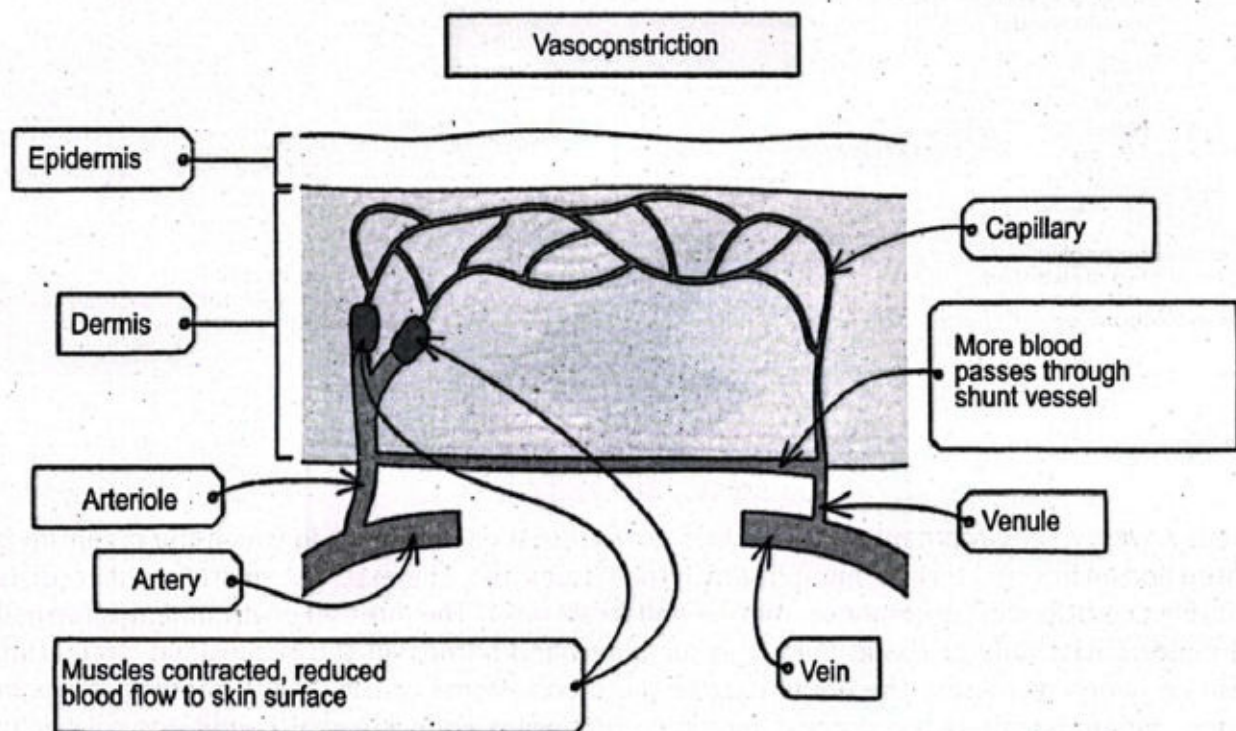


Fig. 8.2: Mechanisms of vasoconstriction

c. Piloerection

It means literally 'erection of hairs' and involves a reflex. In most mammals, piloerection makes the fur 'thicker', so that it traps more air to provide extra insulation. In humans, the **erector pili** muscles in the skin pull the tiny hairs upright, and succeed in creating goose bumps.

d. Increased metabolic rate

The body secretes the hormone adrenaline in response to cold. This raises metabolic rate and therefore increases heat production.

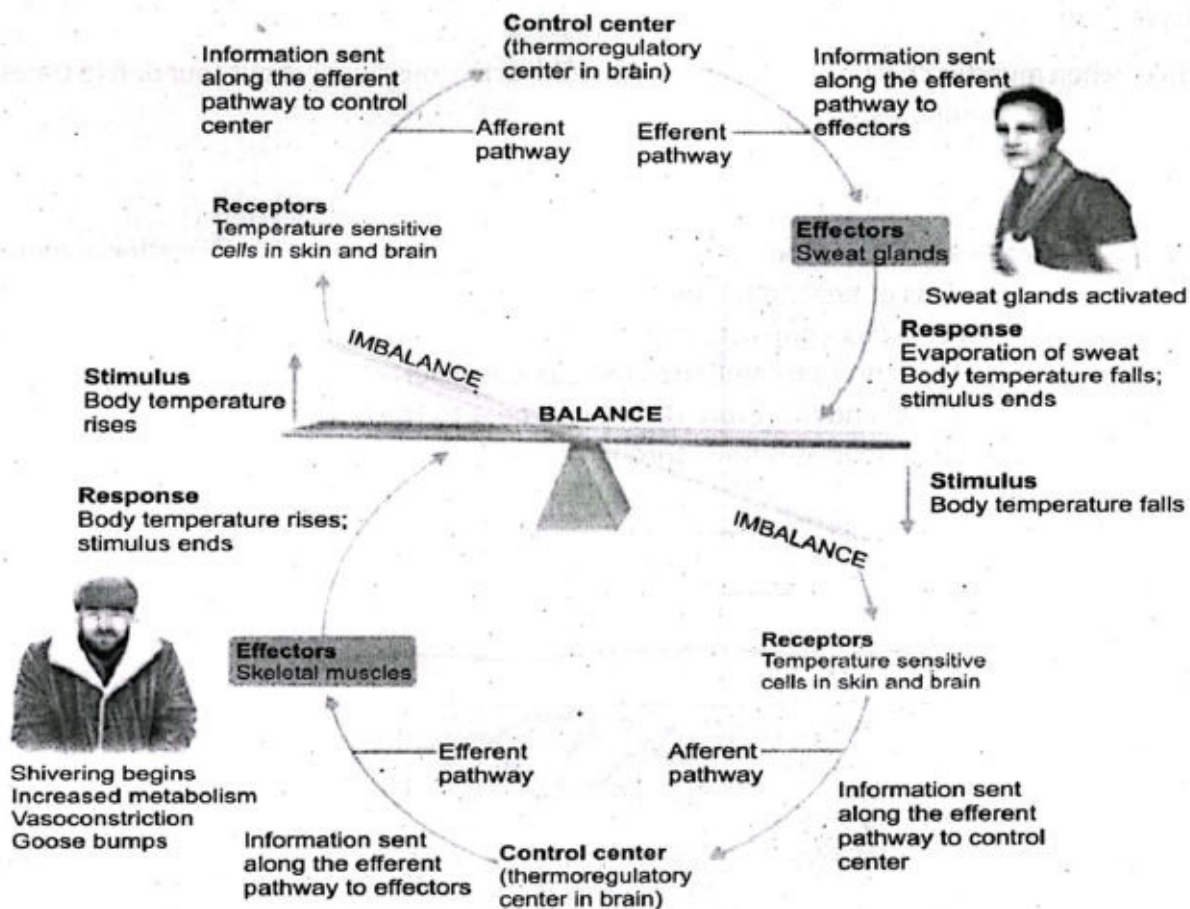


Fig. 8.3: Thermoregulation in human

8.2 HOMEOSTASIS

Animals have two environments in their lives, an external environment in which the organism is situated and an internal environment in which the tissues live. The external environment consists of varying conditions of atmosphere, marine and freshwater. The internal environment is formed by the interstitial fluid or tissue fluid that surrounds and bathes all the tissues and circulating fluids like lymph or plasma the liquid part of the blood. Homeostasis means 'keeping things in balance'. Homeostasis is the process by which organisms keep internal conditions relatively constant despite changes in external environment.

The human organ systems are working constantly to maintain a controlled, stable environment. The digestive system takes in and digests food, providing nutrient molecules that enter the blood and replace the nutrients that are constantly being used by the body cells. The respiratory system adds oxygen to the blood and removes carbon dioxide. The amount of oxygen taken in and carbon dioxide given off can be increased to meet the body needs. The liver and kidneys contribute greatly to homeostasis. For example, immediately after glucose enters the blood, it can be removed by the liver and stored as glycogen. Later glycogen is broken down to replace the glucose used by the blood cells. In this way, the glucose composition of the blood remains the same. The hormone insulin, secreted by the pancreas, regulates glycogen storage. The kidneys are also under hormonal influence as they excrete wastes and salts, substances that can affect the pH level of the blood.

8.2.1 Components of homeostatic mechanisms

Adjustment of physiological systems within the body is called homeostatic regulation. It involves three parts or mechanisms: (1) the receptor, (2) the control center, and (3) the effector.

Receptor

The receptor receives information that something in the environment is changing. It responds to changes in the environment, either external or internal. Receptors include thermoreceptors and mechanoreceptors etc.

Control Center

The control center or integration center receives and processes information from the receptor. The control centers include the the renin-angiotensin system (RA).

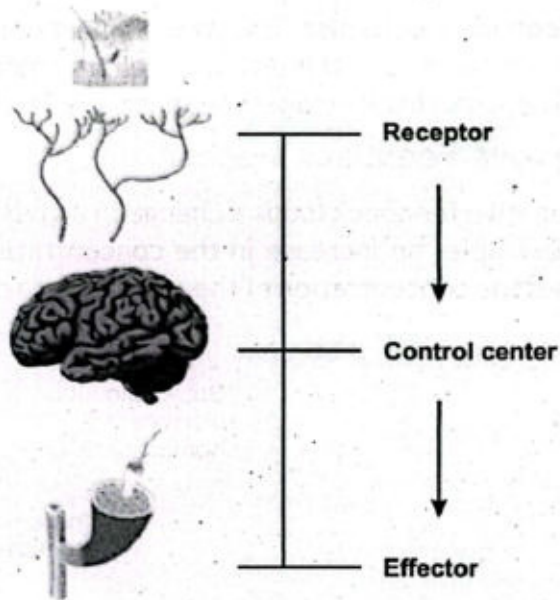
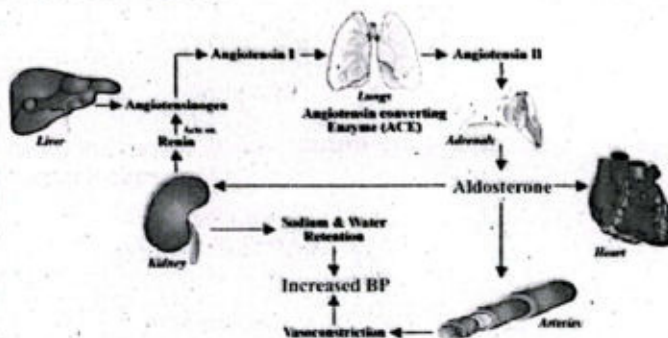


Fig. 8.4: Components of homeostatic mechanisms

For your information

The renin-angiotensin system (RAS), also known as the renin-angiotensin-aldosterone system (RAAS), is a critical hormonal system that regulates blood pressure and fluid balance. It is the system of hormones, proteins, enzymes and reactions. It regulates your blood pressure by increasing sodium (salt) reabsorption, water reabsorption (retention) and vascular tone (the degree to which your blood vessels constrict, or narrow). The RAAS consists of three major substances, including Renin (an enzyme), Angiotensin II (a hormone), and Aldosterone (a hormone).



Effector

The effector responds to the commands of the control center by either opposing or enhancing the stimulus. This ongoing process continually works to restore and maintain homeostasis. For example, during body temperature regulation, temperature receptors in the skin communicate information to the brain (the control center) which signals the effectors: blood vessels and sweat glands in the skin. As the internal and external environments of the body are constantly changing, adjustments must be made continuously to stay at or near a specific value: the set point.

8.2.2 Control of homeostatic mechanism

Homeostasis is maintained by negative feedback loops within the organism. In contrast, positive feedback loops push the organism further out of homeostasis, but may be necessary for life to occur. Homeostasis is controlled by the nervous and endocrine systems in mammals.

Feedback

A **feedback mechanism** is a physiological regulation system in a living body that works to return the body to its normal internal state, or commonly known as homeostasis. In a living system, the feedback mechanism takes the shape of a loop, which aids in maintaining homeostasis.

Negative Feedback Mechanism

In negative feedback loops a change in a given direction causes change in the opposite direction. For example, an increase in the concentration of a substance causes feedback that ultimately causes the concentration of the substance to decrease.

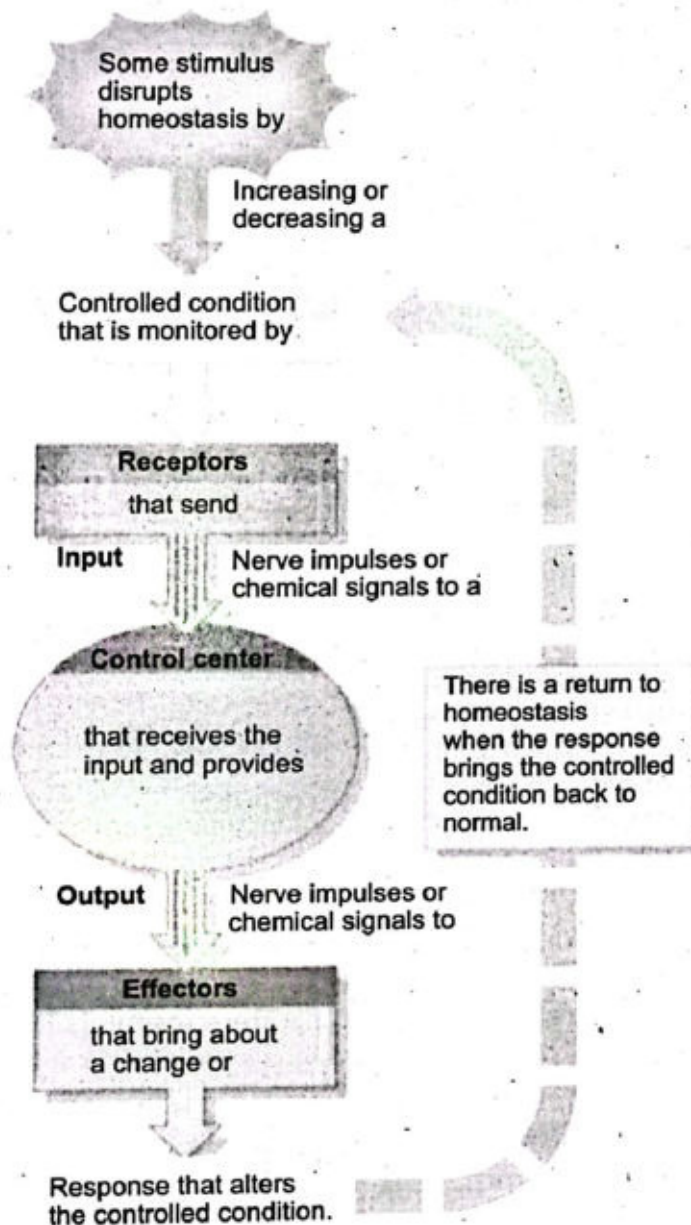


Fig. 8.5: Negative feedback flowsheet

Any homeostatic process that changes the direction of the stimulus is a negative feedback loop. It may either increase or decrease the stimulus, but the stimulus is not allowed to continue as it did before the receptor sensed it. In other words, if a level is too high, the body does something to bring it down; conversely, if a level is too low, the body does something to raise it; hence, the term: negative feedback.

An example of negative feedback is the maintenance of blood glucose levels. When an animal has eaten, blood glucose levels rise, which is sensed by the nervous system. Specialized cells in the pancreas (part of the endocrine system) sense the increase, releasing the hormone insulin. Insulin causes blood glucose levels to decrease, as would be expected in a negative feedback system. However, if an animal has not eaten and blood glucose levels decrease, this is sensed in a different group of cells in the pancreas: the hormone glucagon is released, causing glucose levels to increase. This is still a negative feedback loop, but not in the direction expected by the use of the term "negative."

Another example of an increase as a result of a feedback loop is the control of blood calcium. If calcium levels decrease, specialized cells in the parathyroid gland sense this and release parathyroid hormone (PTH), causing an increased absorption of calcium through the intestines and kidneys. The effects of PTH are to raise blood levels of calcium. Negative feedback loops are the predominant mechanism used in homeostasis.

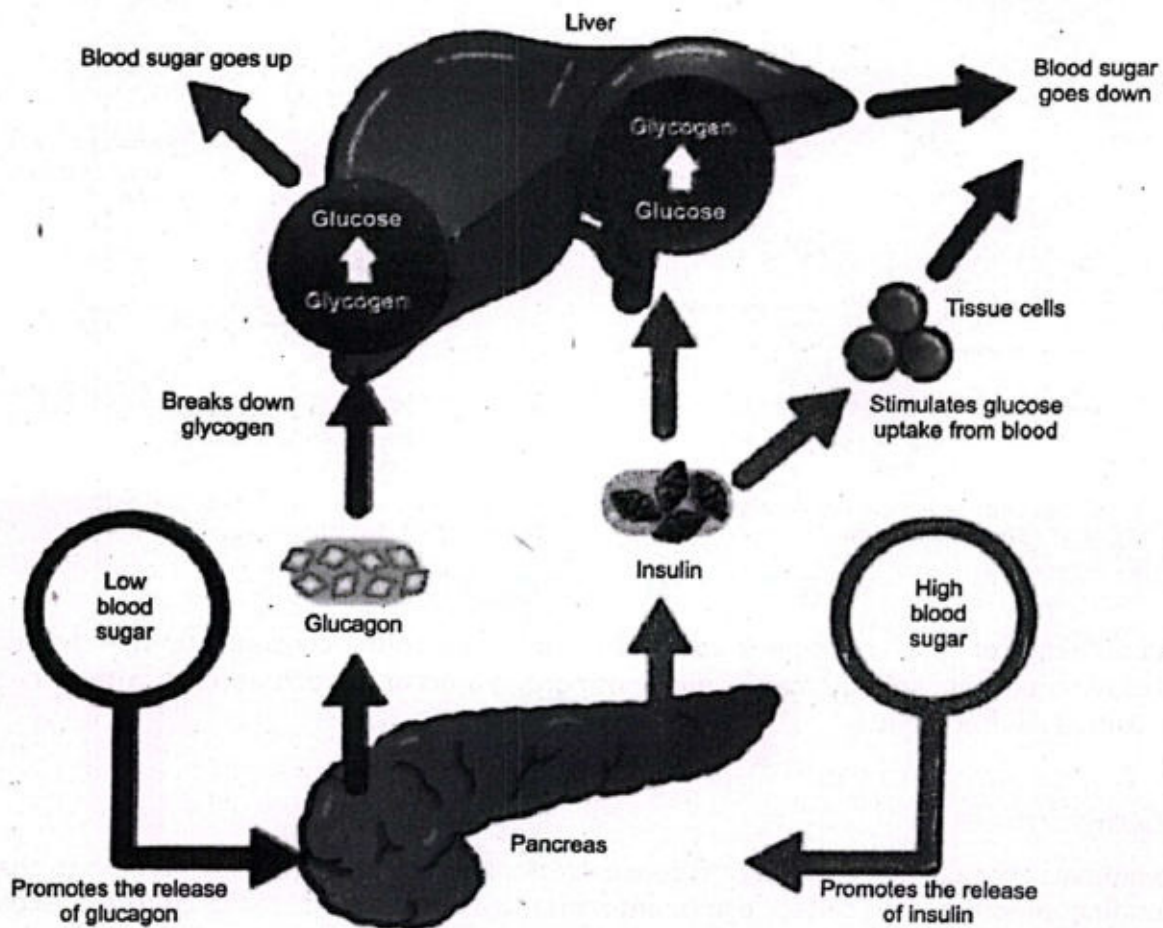


Fig. 8.6: Blood sugar levels are controlled by a negative feedback flowsheet

Positive Feedback Mechanism

In positive feedback loops, a change in a given direction causes additional change in the same direction. An increase in the concentration of a substance causes feedback that produces continued increases in concentration.

When a wound creates bleeding, the body responds by clotting the blood and preventing blood loss through a positive feedback loop. The wounded blood vessel wall releases substances that start the clotting process. Platelets in the blood begin to adhere to the wounded area and produce substances that attract more platelets. As the platelets continue to accumulate, more chemicals are released, and more platelets are drawn to the clot location. The clotting process is accelerated by the positive feedback until the clot is large enough to halt the bleeding.

Another example of positive feedback is uterine contractions during childbirth. The hormone oxytocin, made by the endocrine system, stimulates the contraction of the uterus. This produces pain sensed by the nervous system. Instead of lowering the oxytocin and causing the pain to subside, more oxytocin is produced until the contractions are powerful enough to produce childbirth.

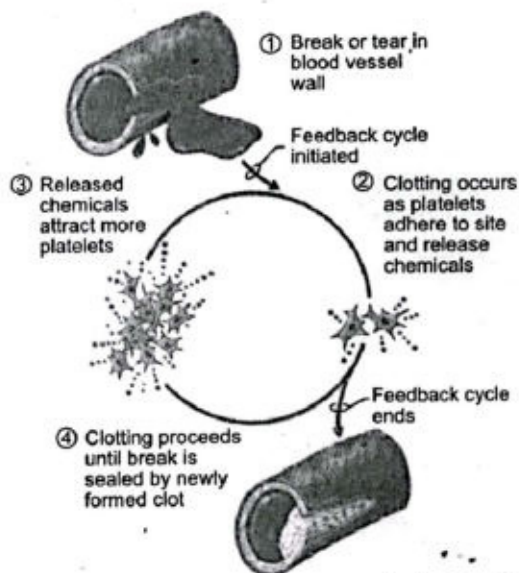


Fig. 8.7: Blood Clotting Mechanism during Positive feedback system.

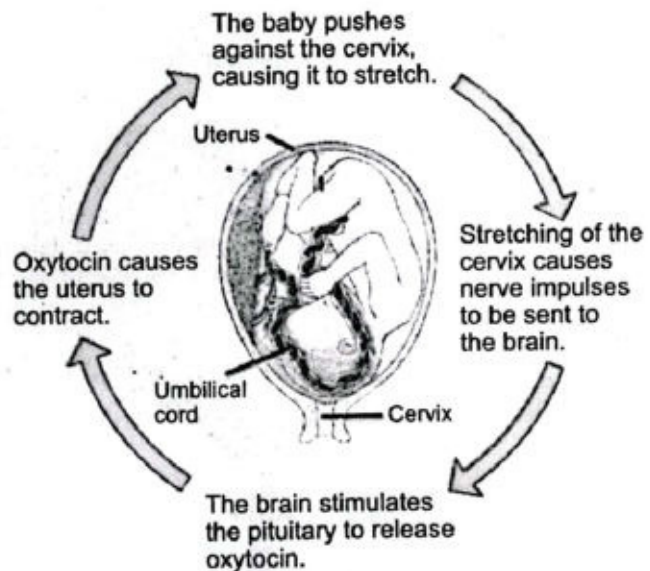


Fig. 8.8: Positive feedback loop: The birth of a human infant is the result of positive feedback

8.3 OSMOREGULATION

The maintenance of constant osmotic conditions (water and solute concentration) in the body is called osmoregulation. Animals may be either osmoregulators or osmoconformers with respect to their external environment.

8.3.1 Osmoconformers and Osmoregulators

Osmoconformers

Those animals that change the osmotic concentrations of the body fluids according to that of surrounding medium are called **osmoconformers**. These are isotonic to their external environment. These include all marine invertebrates, some freshwater invertebrates and some marine vertebrates like *Myxine* (hag fishes) and elasmobranchs (sharks and rays).

Osmoregulators

Those animals that can maintain internal osmotic concentrations different from the surrounding medium are called **osmoregulators**. Such animals are hypotonic or hypertonic to their environment. Almost all of the freshwater animals and most of the marine vertebrates are osmoregulators.

The unusual higher osmotic concentration than other vertebrates of marine habitat is

maintained by high levels of urea and trimethylamine oxide (TMAO) in the blood. These organic substances are called **osmolytes** because they increase the osmotic (solute) concentration.

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In most vertebrates, the level of urea to this high concentration would damage the proteins because it is chaotropic (denaturing) agent that disrupts non-covalent and ionic bonds between amino acids residues, but the presence of TMAO helps to stabilize these protein molecules against the adverse effects of urea.

8.3.2 Problems faced by Osmoregulators

Since, freshwater animals live in hypotonic environment, therefore, water constantly enters the body and they also face deficiency of salts, so they have to lose excess water and maintain higher salt concentration than their environment.

On the other hand, most of the **marine teleosts** (bony fishes) are hypotonic to sea water. So these fishes have problem to lose water to the environment, especially across the gill epithelium. They also have problem of excess of salts in the body due to drinking of sea water.

Terrestrial animals are also hypotonic to the outer environment. Evaporation of water that leads to the dehydration is the major problem faced by these animals.

8.3.3 Osmoregulatory Adaptations in Animals

Freshwater animals

Almost all of the freshwater animals are osmoregulators. These animals are generally hypertonic to their outer environment. These animals deal with these problems by producing large volume of diluted urine. Their kidney reabsorbs the salts that are required. Salts are also obtained from the

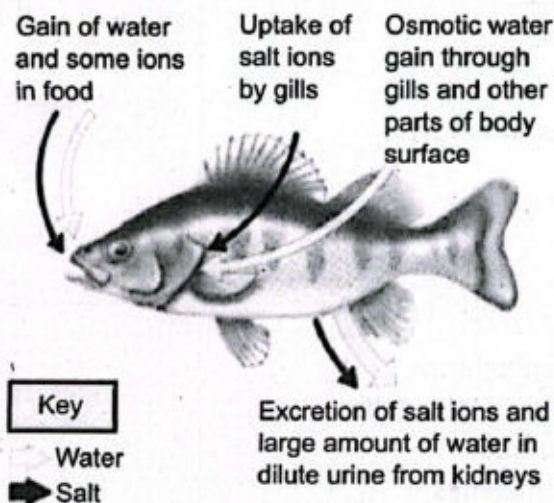


Fig. 8.9: Osmoregulation in freshwater animals

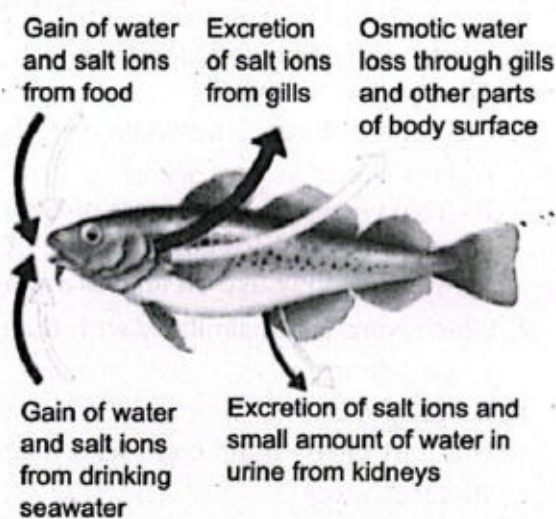


Fig. 8.10: Osmoregulation in marine animals

food they eat. These animals also actively transport salts from the external dilute medium with the help of special salt cells called **ionocytes**. Ionocytes are found in the amphibian skin and gills of fishes.

Marine animals

Teleosts (*bony fishes*) are osmoregulators in marine environment which are hypotonic to their environment. So these fishes have tendency to lose water to the environment, especially across the gill epithelium. In order to replace the water loss, these fishes usually drink large amount of water unlike freshwater fishes.

They also have problem of excess of salts in the body due to drinking of sea water. Among the excess salts, Na^+ , Cl^- and some amount of K^+ are removed across the gill epithelium while divalent ions like Mg^{++} , Ca^{++} are excreted by the kidney. Some fishes also have special salt secreting glands in the wall of rectum called **rectal glands** that remove salts into the digestive tract which are then eliminated from the body during egestion.

Terrestrial animals

The successful groups of land animals are arthropods among the invertebrates and reptile, birds and mammals among the vertebrates. The presence of chitinous exoskeleton in arthropods and dead keratinized skin in vertebrates are adaptation to reduce water loss by their bodies.

Desert mammals are very much resistant in this regard. They can tolerate against strong degree of dehydration by special metabolic and behavioural adaptation. This characteristic is called **anhydrobiosis**. Actually, these animals feed upon seeds of desert plants in which large amount of carbohydrate are stored. During the breakdown of these compounds; water is produced as by-product that is utilized by these animals. Best example of such animals is kangaroo rat. They avoid day time heat and emerge at night. Ninety percent of the water that they use is metabolic water derived from cellular oxidation.

EXERCISE

Section I: Multiple Choice Questions

Select the correct answer:

- The main difference between endotherms and ectotherms is
 - how they conserve water
 - from where they get most of their body heat
 - whether they are cold or warm blooded
 - whether they live on land or water
- Which word is not similarly with the others?

A. ectoderms	B. endoderms
C. homeothermic	D. warm-blooded
- This part of the brain controls temperature regulation.

A. cerebellum	B. thalamus
C. hypothalamus	D. hippocampus

4. If body temperature decreases, which one of the following is incorrect?
 - A. vasoconstriction
 - B. hair raised
 - C. increase metabolic rate
 - D. sweating
5. The body's ability to maintain a constant body temperature is called what:
 - A. thermoregulation
 - B. modification
 - C. adaptation
 - D. lucky
6. The liver's functions are required for
 - A. thermoregulation
 - B. osmoregulation
 - C. homeostasis
 - D. all of these
7. The mechanism of regulation, generally between organism and its environment, of solutes and the gain and the loss of water is called
 - A. homeostasis
 - B. hemostasis
 - C. osmoregulation
 - D. thermoregulation
8. In a hot summer after noon, if your body's homeostatic machinery keep your internal temperature quite lower than that of external than this is an example of
 - A. positive feed back
 - B. negative feed back
 - C. feed back
 - D. osmoregulation
9. The characteristic which enable animals to tolerate dehydration is called
 - A. osmoconformation
 - B. osmoregulation
 - C. anhydrobiosis
 - D. anhydrosis
10. Homeostasis
 - A. must always be restored using negative feedback mechanisms
 - B. provides for the tight regulation of all physiological variables
 - C. is the sum of all chemical reactions in the body
 - D. is a combination of positive and negative feedback mechanisms
11. A negative feedback mechanism comprise
 - A. detectors, comparators, a fixed set point and effectors
 - B. detectors, amplifiers, comparators, a set point and effectors
 - C. detectors, attenuators, comparators, a set point and effectors
 - D. detectors, comparators, a variable set point and effectors
12. Positive feedback
 - A. does not exist in physiological systems
 - B. is seen in the initiation of an action potential when sodium entry causes depolarization which in turn leads to potassium exit
 - C. is unstable and requires some mechanism to break the feedback loop
 - D. is switched off by negative feedback mechanisms
13. Which of the following is an example of a positive feedback mechanism?
 - A. the control of blood sugar by insulin
 - B. blood clotting
 - C. the control of blood pressure
 - D. the regulation of body temperature

14. Which of the following components of a homeostatic regulatory mechanism is responsible for detecting a stimulus?
 - A. an effector
 - B. a control center
 - C. a receptor
 - D. an afferent pathway
15. Which of the following phrases most correctly defines homeostasis? Homeostasis involves the maintenance of internal conditions within _____.
 - A. specific set-points.
 - B. specific normal ranges.
 - C. ranges higher than external conditions.
 - D. ranges equal to external conditions.
16. Homeostasis is best conceived as a state of:
 - A. negative feedback
 - B. dynamic consistency
 - C. positive feedback
 - D. hormone regulation
17. Insulin is a hormone that acts to:
 - A. stimulate metabolism in the body
 - B. increase blood sugar levels
 - C. decrease blood sugar levels
 - D. stimulate the formation of blood clots
18. A setpoint is usually:
 - A. the top of a normal range
 - B. the bottom of a normal range
 - C. in the middle of a normal range
 - D. the point at which changes can no longer occur

Section II: Short Answer Questions

1. Define or describe very briefly the following.

a. osmoregulation	b. osmoregulators	c. osmoconformers
d. vasodilation	e. vasoconstrictors	f. thermoregulation
g. poikilotherms	h. homeotherms	i. ectotherms
j. endotherms	k. homeostasis	
2. What are the problems faced by osmoregulators?
3. Describe the osmoregulatory adaptations in :

a. Freshwater animals	b. Marine animals	c. Terrestrial animals
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4. What are the needs of thermoregulation?
5. What is a feedback mechanism?
6. Identify and define the four interacting components that maintain homeostasis in feedback loops.
7. Give two examples of physiological processes that are controlled by positive feedback loops.

Section III: Extensive Answer Questions

1. Classify animals on the basis of temperature.
2. What are the thermoregulatory strategies in man?
3. How various human organs system to maintain controlled stable environment.
4. Explain components of homeostatic mechanism.
5. Describe with example the negative feedback mechanism with relation to homeostasis.
6. Describe with example the positive feedback mechanism with relation to homeostasis.
7. Compare and contrast negative and positive feedback loops.
8. Explain how negative feedback controls body temperature.