18

HOMEOSTASIS : THE STEADY STATE

In the previous lesson you studied about the nervous system. There, you noted how the body functions in a coordinated manner to bring about any required effect or change. You also learnt about the hormones and how they work in a way so that the body knows when to start, when to speed up, when to slow down and when to stop an event that ocurs inside the body. In this lesson, you will study about the phenomenon called **homeostasis** which means 'keeping steady state'. Homeostasis operates for a variety of needs inside our body and one such need is the regulation of body temperature called **thermoregulation**. This lesson mainly covers various aspects of thermoregulation.

OBJECTIVES

After studying this lesson, you will be able to :

- *define the term homeostasis and explain its needs in the body;*
- *explain the term thermoregulation and justify its need in the body;*
- *differentiate between endotherms and ectotherms;*
- *list the body parts involved in thermoregulation and explain how they contribute towards heat production and heat loss;*
- *name the principal heat regulating centre in our body and describe how it acts;*
- *explain the term 'feed back' and differentiate between positive and negative feedback mechanisms.*

18.1 CONCEPT OF HOMEOSTASIS

Homeostasis (*homeo* : same/steady, *stasis* : state) is a phenomenon in which the body regulates its functions to keep the internal conditions as stable as possible.

Homeostasis is necessary because the body cells need to have suitable conditions around them for proper functioning. These conditions include, the presence of proper concentration of chemicals, proper temperature, and a suitable pH (degree of salinity or acidity), etc. inside its cells. But these conditions inside our body as well as inside other organisms keep fluctuating within a narrow range. Tolerance to any change from this range differs in different organisms. Organisms adopt a variety of measures to cope with such changes.

To understand the concept of homeostasis (keeping steady state) consider the following five examples in the humans:

Example 1. Drinking water and keeping a 'steady water balance'.

In all kinds of weather, your blood and other body fluids must maintain a particular percentage of water. If the volume of water in the body tends to rise, the excess is passed out in urine and, if it tends to fall short, more water is withheld inside the blood to the extent required. Thus, the body maintains a steady state (= homeostasis) of water content.

- In hot summers you feel thirsty at regular intervals. You drink lots of water or even cold drinks, yet you do not urinate much. The urine passed out is more concentrated. This is because during hot weather you lose more water through perspiration but your body needs to maintain its requisite amount of water and so the water is withheld within, by passing out only little and concentrated urine.
- In cold winters you donot feel much thirsty. You do not drink large quantities of water. But, may be, you take more of hot drinks only to keep warm. During such days you urinate more frequently and the urine passed out is more dilute.

Example 2. Eating sugar and keeping steady sugar level in blood

Suppose you have been consuming too much sugar in food, beverages and sweets. Presuming you are otherwise normal, your body will handle the excess sugar (more than the normal percentage in the blood) by storing it in the form of **glycogen** in the liver.

At some other time, when you are fasting or doing much physical work, your blood sugar is used up rapidly. At that time, the liver converts the stored glycogen back into its usable form, that is glucose, to fill the gap and restore the normal blood sugar level.

Example 3. Maintaining normal steady state of blood alkalinity

Sometimes you eat too much salt (sodium chloride) in your food. But your blood normally maintains only the particular level of alkalinity (pH 7.34-7.43) which is only slightly alkaline. Any extra salt consumed is passed out through urine as it cannot be stored in the body.

If at some other time you have been eating too little salt, or you are losing much of it through sweating, your kidneys will hold back the required quantity through sodium-potassium balance.

Example 4. Managing the number of red blood cells

A normal human adult possesses about 5 million red blood corpuscles (RBCs) per cubic millimetre of blood.

Whenever a plain-dweller visits a hill station at high altitude without any break-journey in between, he is likely to feel exhausted for a couple of days. Later, the person becomes normal. At high altitudes the atmospheric pressure is lower and the amount of oxygen carried by this normal number of RBCs is insufficient. Within a day or two, the body adds more RBCs into the blood to pick up the normal required quantity of oxygen.

When the same person returns to the plains at a lower altitude the higher RBC level that was acquired at the hills now begins to take up oxygen in excess, which is harmful. The body readjusts the red blood cells which get reduced in number to become stable at the original level.

Example 5. Warming and cooling of the body (maintaining steady body temperature)

During hot summers you wear light clothes. You perspire a lot, you sit under a fan or under a tree and feel comfortable. Your body is trying to cool against the higher temperature outside.

Then, there is the reverse side, that is, cold winter. Inspite of wearing thick warm clothes you still feel cold. In mid-daytime, you go out in the open sunshine to warm yourself. At night, you cover yourself with a thick blanket. You are doing all this to maintain warmth inside steadily your body.

In both the above situations, you are trying to regulate your internal body temperature. This is called thermoregulation. You will learn more about thermoregulation in subsequent sections of this lesson.

INTEXT QUESTIONS 18.1

1. Define homeostasis.

   ....

2. List any three chemicals whose concentration in our body has to be maintained at partcular levels.

   (i) ....

   (ii) ....

   (iii) ....

3. To obtain enough oxygen for respiration at high altitudes, what does the body do?

   ....

18.2 THERMOREGULATION — WHY IS IT NECESSARY?

18.2.1 Limits of heat tolerance

The living organisms can normally survive only within a certain range of temperature of about 0-45° C. However, organisms tend to make adjustments, if they happen to be at places of higher or lower temperature.

A. Above 45°C, the organisms may suffer in many ways:

- the enzymes are destroyed,
- proteins get denatured,
- plasma membrane breaks down, and
- cells suffer lack of oxygen.

B. Below 0°C. At temperatures below freezing point, the cells may burst by the formation of needle-like ice crystals inside and between the cells and the organisms cannot survive.

The above stated effects due to temperature changes are because enzymes function normally within a certain range of temperature.

18.2.2 Efficiency of enzymes at different temperatures

Enzymes carry out almost all the chemical reactions occuring inside our body. They have several characteristics and the most important one is their relation with respect to temperature.

- **At 0°C**. The enzymes are inactive.
- The rate of enzyme-catalyzed reactions doubles with every 10 degrees rise in temperature between 4-40°C.
- **On warming.** Whenever the temperature rises, the enzymes start working faster. If the temperature becomes too high (more than 40°C) the enzymes begin to work too rapidly and produce unwanted intermediate chemicals and not the required ones. At still higher temperatures the enzymes get denatured (destroyed).
- The enzymes act best at a narrow temperature range, usually between 35-40°C (optimum temperature meaning the most suitable temperature)
- **On cooling.** At temperatures lower than the optimum temperature the enzymes become less and less efficient. At freezing temperatures the enzymes may turn totally inactive.

INTEXT QUESTIONS 18.2

1. How do the following temperatures affect the enzymes?

   (i) 45°C and above ....

   (ii) 0°C and below ....

2. (i) At what temperature range do enzymes act best?

....

(ii) What technical term do you use for this temperature?

....

18.3 CLASSIFICATION OF ANIMALS BASED ON THEIR TEMPERATURE TOLERANCE

Based on the capability and the manner of regulating body heat, all animals found on earth are grouped into two main categories: endotherms and ectotherms

18.3.1 Endotherms and Ectotherms

A. ENDOTHERMS (*endo* : inside, *therm* : heat) : Examples: All birds and mammals. Endotherms are organisms, which maintain a steady body temperature irrespective of the temperature of the surroundings. Two other terms often used synonymously for endotherms are

- **Homoiotherms** (homoio: same; therm: heat) refers to keeping the same or constant (warm) body temperature, and
- **Warm-blooded** (oldest term and seldom used now) means animals which are felt warm whenever touched. If you hold a pigeon in your hand or feel a rabbit by touch even when it is intensely cold outside, you will find them warm.

B. ECTOTHERMS (ecto: outside, therm: heat) : Those animals whose body temperature rises and falls with the rise and fall of surrounding temperature are termed Ectotherms. All animals other than birds and mammals are ectotherms. Examples: Fish, frogs, lizards, insects, earthworms, etc. Two other terms often used synonymously with ectotherms are

- ***Poikilotherms*** (*poikilo* : changing/varying, therm: heat) referring to acquiring the body temperature from that of the surroundings.
- ***Cold-blooded*** (oldest term and seldom used now) means animals which are cold when touched. If you hold a frog in your hand or feel the touch of a cockroach, they are always colder than your body.

18.3.2 Characteristics of Endotherms

1. With an **internal heat-regulating mechanism,** the endotherms (birds and mammals) are able to maintain their body temperature within a narrow range of 2°C (37-39°C.) irrespective of the outside temperature whether intensely cold or severely hot. Birds are usually slightly warmer than the mammals.
2. An **efficient insulation mechanism** helps maintain body temperature
   - Birds have feathers to trap air for preventing heat loss. When cold, the feathers are raised (fluffing) to trap more air to increase insulation.

- Mammals have two sources of insulation: (i) hairs and (ii) subcutaneous or under-skin fat. The hairs trap the air. When it is too cold the hairs are raised (goose flesh) to increase insulation. The under-skin fat prevents conduction of heat outwards. This fat layer is thicker in the colder region inhabitants for better prevention of heat loss and thinner in those living in warmer regions to allow greater heat loss.

18.3.3 How some endotherms cope with unfavorable temperatures

- **Polar bears, penguins** and several other animals live in the ice-covered polar regions. They maintain their body temperature by generating heat and preventing heat loss through thick fur and a thick layer of under-skin fat.

- **Camels, desert rats** and several other tolerate the intense heat of the tropical deserts mainly by promoting heat loss.

> Camel is a desert dweller of hot climate. It needs to possess more of heat loss mechanisms and cut down the heat- retaining ones. Most of its skin has no fat layer. But, look at the hump, it stores a huge bulk of fat only as reserve food.

- **Squirrels, goats, pigeons** etc. live in moderate climate and they too have to adjust their body temperature according to the changing conditions of the outside. They adjust both in winter and summer to maintain normal body heat.

  Humans too are endotherms. When required we supplement our natural heat-regulating mechanisms by artificial methods like clothing, using the fan, bathing, room heating, room- cooling, etc.

18.3.4 Some ectotherms and how they cope unfavorable temperature conditions

Consider the following examples:

- **Frogs** hibernate under the ground in cold winters and aestivate during hot summers to avoid heat and escape from cold. Hibernation or wintersleep is characterised by the animal slowing down its activites and resting underground. During hibernation the 'basal metabolic rate' remains low.
- **Fishes** live in water. Water seldom undergoes extreme temperature changes like the ones on land. Still, fishes either make minor adjustments in their body parts to minimize the heat loss or heat gain or, if they are unable to do so, they migrate to less harsh regions.
- **Lizards** and **crocodiles** bask in the open sun to warm themselves during cold weather. When hot, they move to shades. When feeling hot, the crocodiles even open their mouths wide to allow evaporation of water for cooling purposes, something like the panting of dogs.
- **Honey bees**, during cold winter nights, huddle together inside the hive to conserve body heat collectively. During hot summers they even operate a kind of 'desert cooler' by sprinkling some water on the honeycombs and fanning with their wings for cooling the honey combs.

INTEXT QUESTIONS 18.3

1. Classify the following animals as endotherm or ectotherm:

   Camel, Bat, Earthworm, Cockroach, Fish, Wall lizard, Polar bear, sparrow

   Endotherms ....

   Ectotherms ....

2. Explain the following terms and give one or more synonymous terms for each:

   (i) Poikilotherms ....

   (ii) Homoiotherms ....

3. Mention one way each by which each of the following fight severe cold:

   (i) Crocodile ....

   (ii) Honey bee ....

   (iii) Common frog ....

   (iv) Wall lizard ....

18.4 MECHANISM OF HOMEOSTASIS OF BODY TEMPERATURE (THERMOREGULATION) IN HUMANS

18.4.1 Normal core body temperature

The starting point in any homeostasis is the identification of its set or the normal point. The set point of human body temperature is taken as 37°C, which is also called the normal or core body temperature. The core body temperature refers to the temperature of the combined portion of the trunk, head and upper part of arms and legs. Our body temperature otherwise is not uniform throughout.

- The surface skin temperature is usually lowest but it varies considerably due to a variety of external and internal conditions.
- The armpit usually records 1 degree less than the temperature inside the mouth.
- The anal temperature is 1 degree higher than the core body temperature. In very young children, the clinical thermometer is placed inside the anus and the temperature recorded is reduced by one degree to assess if the child is having any fever.
- For all practical purposes, the oral (mouth) temperature is taken as normal body temperature, which is usually 37°C (±0.5).

Whenever the core body temperature departs from the normal, the body takes corrective measures. For example :

- If the temperature falls, there is increased heat production in the body along with prevention of heat loss.
- If body temperature rises there is cooling to give out excess heat.

You will read about such steps in more details in the next sub-section.

18.4.2 Mechanisms of Thermoregulation

The principal heat-regulating centre is located in the **hypothalamus**, a part of the forebrain. This part acts like a thermostat.

- When the body has to face cooling below the normal temperature, it '*switches on*' or speeds up the heat-producing processes and simultaneously '*shuts off*' the heat-losing ones.
- When the body faces overheating during summer or after intense physical exercise, it accelerates the cooling process and '*switches off*' the heat- producing ones.

A. Keeping warm in cold weather

Thermoregulation in cold weather is achieved in two ways : preventing loss of body heat and generating more body heat.

1. **Preventing loss of body heat** - This is achieved in two ways:

   (a) ***Vasoconstriction***. Vasoconstriction means narrowing of blood vessels (Fig.18.1a). As a result of vasoconstriction in the skin,

   - the blood supply to the skin is reduced and there is less loss of heat by convection, conduction and radiation.
   - With the reduced blood supply to the sweat glands in the skin, there is less or no secretion of the sweat and thus there is no evaporation of water and no loss of heat

   Have you ever observed that in very cold weather you look pale or bluish? This is due to reduced blood supply to the skin caused by vasoconstriction.

   (b) ***By posture***. At times when we feel cold,

   - We hold our arms cross-folded tightly over the chest while standing or sitting.
   - While sleeping in bed we often hold our arms and legs closely folded near the body in a curved posture.

   Such postures reduce the exposed body surface for heat radiation.

2. **Generating more body heat :** The metabolic rate is increased and more heat is produced in the body cells. The muscular activity is also increased which is sometimes in the form of shivering.

B. Keeping cool in hot weather (Fig. 18.1b)

When the outside temperature is high or when a person is engaged in strenuous physical work there is overproduction of heat within the body. The extra heat is given out in two principal ways.

1. **Increased heat radiation from the body**. This is brought about by increasing the blood supply to the skin through vasodilation (widening of the blood vessels). The increased blood flow into the skin allows more heat to reach the body surface and radiate out heat. (Fig. 18.1b).
2. **Increased sweating.** Increased blood supply to the skin through vasodilation makes more water available to the sweat glands. They pour out more sweat and the evaporation of sweat cools the body. We often speed up evaporation of sweat by using fans. The fans by themselves do not cool the air, it is the movement of air that increases evaporation of the sweat to produce more cooling.

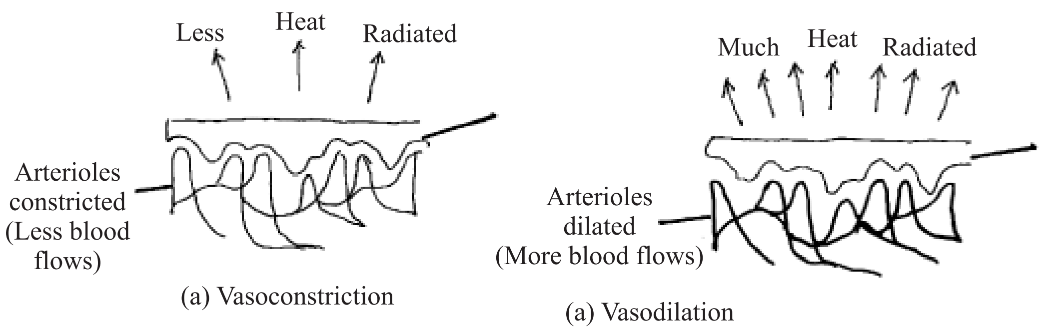

Fig 18.1 Blood vessels in the skin during temperature regulation.
(a) Vasoconstriction for cutting down heat loss
(b) Vasodilation to increase heat loss

18.4.3 Components of Homeostasis

Homeostasis of any kind involves four components:

1. **Set point or the norm** - This is the normal level of any factor in the body. The set point may have a small or large range. For example, the normal set point of human body temperature is approximately 37^{o} C (with 0.5^{o} C plus or minus).
2. **Sensor -** This consists of the sensory part that perceives the change in the set point. The sensor in thermoregulation comprises the heat receptors in (i) the skin and (ii) hypothalamus, the part of the brain which perceives the temperature of the flowing blood.
3. **Integrating centre -** The integrating centre is the part, which receives the information about the change in the set point of the particular state, interprets it and then sends the command for correction. In thermoregulation the integrating centre is hypothalamus plus some adjoining parts of the brain.
4. **Effectors -** The effectors are the agencies, which act to restore the set point. For example, (i) ***Sweat glands***, which pour out the sweat to produce cold by evaporation, (ii) ***Skin blood vessels***, which widen (vasodilate) to bring more blood to the body surface for radiating out heat and (iii) ***Skeletal muscles***, which vigorously contract (shivering) to produce heat

The flow chart given here (Fig.18.2) explains the different steps in thermoregulation in humans.

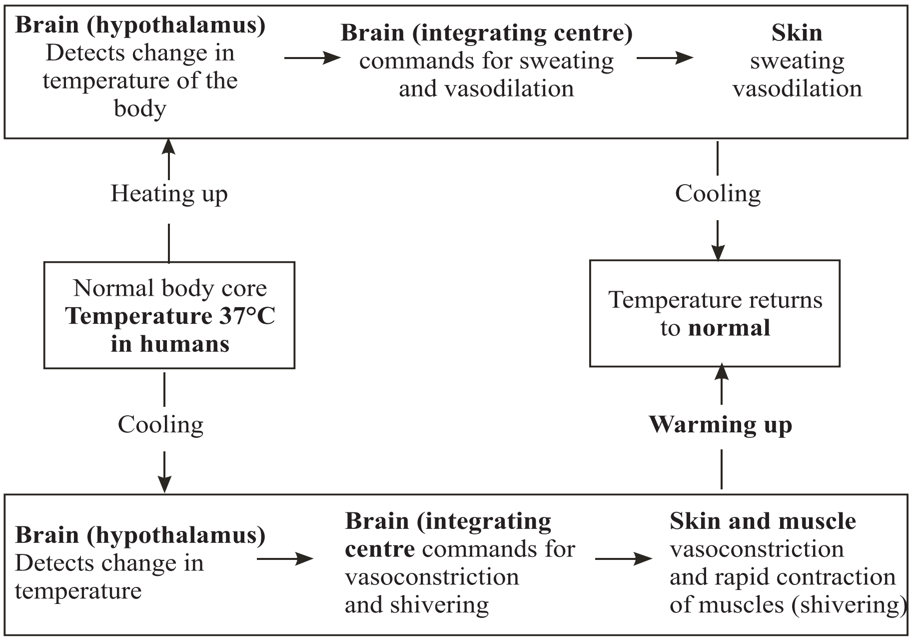

Fig 18.2 Mechanism of temperature control in humans

18.4.4 Types of Regulatory Systems– Physiological and Behavioral

The regulatory steps for thermoregulation in humans as described above can be considered under two headings – **physiological** and **behavioral.**

Physiological regulation : Changes in blood circulation like vasodilation or vasoconstriction, sweating or not sweating, increase or decrease in cell metabolism, shivering, etc. All these adjustments are not under the control of will.

Behavioral regulation. It includes the conscious and subconscious acts. For example:

When it is hot we often

- Fan ourselves (to promote evaporation of sweat)
- Move to any shaded or cooler place,
- Stretch out the limbs while resting in the bed.

When it is cold we

- move to warmer places (open sunshine or in front of heat radiators)
- prevent entry of cold winds (close the windows)
- wrap ourselves inside blanket (to cut down heat radiation)
- fold both arms or both arms and legs tightly close to the body (to reduce radiation of heat from the body).

INTEXT QUESTIONS 18.4

1. Rearrange the following in their correct sequence in homeostasis:

   Effector, Set point, Integrating centre, Sensor.

   ....

2. State in one word or sentence :

   (i) The normal body core temperature of humans.

   ....

   (ii) The function of feathers in bird and the hairs of rabbit.

   ....

   (iii) Effect of shivering.

   ....

18.5 FEEDBACK MECHANISMS–NEGATIVE AND POSITIVE

The feedback in the living systems are of two types: negative to reverse a condition and positive to continue in the direction of the change.

In thermoregulation the kind of feedback mechanism operating is of the negative type. Any **deviation from the set point has to be reversed** to bring it back to the normal condition. Therefore, a command has to be given to the organs concerned to function in a manner so that the deviation is corrected and brought back to the normal state.

Positive feedback is very rare in the living systems. One such example is that of coagulation of blood. This process includes several steps in succession. The first feedback does not revive the set point, so it is not a negative feedback, instead it produces the next and the third and so on until the last one completes the process by plugging the cut in the blood vessel. All the feedback mechanisms in blood coagulation are of the positive type.

INTEXT QUESTIONS 18.5

1. Name the two kinds of feed back mechanisms.

   ....

2. Which kind of feed back mechanism normally operates in homeostasis?

   ....

WHAT YOU HAVE LEARNT

- The term homeostasis means steady state. The homeostatic processes keep the conditions in the body within narrow limits.
- Homeostasis occurs for several conditions in the body such as water content, sugar level, body temperature, etc.
- Most homeostatic regulations work through negative feed back which means reversing the change to the norm. Very seldom there is positive feedback which produces changes in the same direction as the first one.
- Enzymes are highly sensitive to temperature changes. They work best at about 37°C called optimum temperature.
- The animals are categorized into two groups: Endotherms with internal heat-regulating mechanisms such as birds and mammals, and ectotherms whose body temperature rises or falls with that of the surroundings, such as frogs, fishes, insects, etc.
- The endotherms have a variety of heat regulating systems such as sweating and vasodilation to lose heat during hot weather, increasing body metabolism or shivering to generate heat and presence of heat insulating structures like feathers, hairs and subcutaneous fat when it is cold.
- The ectotherms avoid excessive cold or excessive heat by hiding underground – hibernation(winter sleep) and aestivation (summer sleep)
- All homeostatic mechanisms consist of a norm or set point, a sensor, an integrating centre and the effectors.
- In thermoregulation in humans, the sense receptors in skin and hypothalamus serve as sensor, hypothalamus and some adjoining parts of the brain as integrating centre, and the skin, blood vessels contained in the skin and skeletal muscles etc serve as effectors.

TERMINAL EXERCISES

1. List the three conditions necessary for the body cells to function properly.
2. When do we pass out more concentrated urine–during hot summers or cold winters ?
3. How does our body deal with any extra sugar absorbed into the blood after meals?
4. What is our normal RBC count per cubic millimetre? Will it go up or go down if a plain dweller shifts to a mountain or hill?

5. In which temperature range do the enzymes in our body act best?
6. Name the two terms often used synonymously for ectotherms.
7. Name any two animals, which tolerate the intense heat of the deserts by promoting heat loss.
8. Which kind of feedback mechanism–the positive or the negative, normally operates in bringing about water-salt balance in our body.
9. How is the enzymatic activity affected upon cooling?
10. How do honeybees fight cold during intense winter?
11. Differentiate between the two terms homeotherms and poikilotherms.
12. Give any two examples of preventing loss of body heat by postural behaviour in humans.
13. List the components of homeostasis in their proper sequence.
14. Differentiate between positive and negative feedback mechanism.
15. Explain the role of the following in thermoregulation in humans:
    (i) Sweat glands
    (ii) Skeletal muscles
    (iii) Blood vessels in the skin
16. What is meant by feed back mechanism? What are its two types? Which one of these is applicable to thermoregulation and why?
17. Why is thermoregulation required in our body?
18. Differentiate between endotherms and ectotherms. Which ones of these do you think can survive better if there is a suden change in environmental temperature?
19. Differentiate between physiological and behavioral responses for thermoregulation in humans.
20. Explain the role of hypothalamus during heat regulation in humans.
21. Explain the relationship between sensor and integrating centre during any one kind of homeostasis.

ANSWERS TO INTEXT QUESTIONS

18.1 1. Homeostasis is the regulation of a steady internal condition.
2. (i) sugar, (ii) salt, (iii) water
3. The body adds more RBCs to the blood

18.2 1. (i) Denatured (ii) inactive
2. (i) 35-40°C, (ii) Optimum temperature

18.3 1. Endotherms : Camel, Bat, Polar bear, sparrow

Ectotherms : Earthworm, Cockroach, Fish, Wall lizard

2. Poikilotherms : Animals whose body temperature changes along with that of the surroundings

Warm blooded : Animals whose body temperature remains steady and does not change with that of the surroundings

3. **Crocodile :** Basks in the sun on the land

Honey bees : Crowd together for collective warmth

Common frog : Hibernates

Wall lizard : Hides at safe places

18.4 1. Set point, Sensor, Integrating centre, Effectors

2. (i) 37°C (ii) trap air to prevent heat loss

(iii) warms up in cold weather

18.5 1. Negative and positive

2. Negative.