UNIT 7 TEMPERATURE RELATIONS IN ANIMALS

Structure

7.1 INTRODUCTION

In the previous unit you have studied about physiology of movement in the animals. In this unit you will learn how the animal's life is related to the temperature of the environment. Basically there are two types of animals, (1) the animals whose body temperature changes with that of the environment, and (2) the animals who maintain their body temperature constant, independent of the environment. In this unit you will learn the effect of temperature on animals, their tolerance to the heat and cold, their behavioural and physiological adaptations to escape the rigors of extreme temperatures and also about regulatory mechanisms that operate in maintaining the body temperature.

Objectives

After reading this unit you should be able to :

- differentiate poikilothermy and homeothermy
- explain the effect of temperature on animals and explain how animals tolerate the extreme temperatures
- explain the behavioural and physiological adaptations of animals to escape the rigors of extreme temperatures
- elucidate the thermoregulatory mechanisms that influence the behaviour and physiology of the animals.

7.2 THERMAL RELATIONS

You are aware that almost all physiological processes are regulated by the action of specific enzymes, and that the rate of an enzyme mediated reaction is related to temperatures.

Therefore, the temperature of an animal's body generally has profound effects on function. The cells, tissues and organs of all animals function within a narrow range of temperatures. However, outside the favourable temperature range, many animals can survive in an inactive or **torpid** state. In fact, some can survive freezing at extremely low temperatures. For instance, in polar regions numerous fish and invertebrates live in water at – 1.8°C. At the other extreme, in hot springs, a few animals can live at about 70°C, and a few thermophilic bacteria thrive above the boiling point of water. Body temperature of most animals, particularly that of all aquatic invertebrates remains the same as that of their surroundings. Thus, the body temperature of these animals changes with the changing ambient temperature. Birds and mammals in contrast, usually maintain their body temperature nearly constant and independent of the environment. All the animals whose body temperature fluctuates with that of the environment have traditionally been called **poikilothermic** (poikilo = changing). To this category belong all the so-called **cold blooded** animals. The birds and mammals which maintain nearly constant body temperatures are classified as **homeothermic** or the so-called **warm blooded** animals. Nevertheless, it should be noted that there is no easy way to classify satisfactorily the various responses to the thermal environment. The above terminology is not very accurate. For instance, the blood of cold blooded animal is not alwlays cold; or a tropical fish or a desert lizard or an insect sitting in the sun may have a higher body temperature than a mammal. Furthermore, a few birds and mammals exhibit **torpor** or **hibernation** during which period their temperature decreases to near the freezing point of water. These examples should serve to explain the inaccuracy of the terminology used. However, the basic difference between the so-called poikilothermic and homeothermic animals is that the homeothermic are able to maintain their body temperature by metabolic heat production whereas, the poikilothermic are unable to do so. Consequently, in recent years, the terms **ectothermic** and **endothermic** are used to denote the animals that depend on external heat sources (mainly solar radiation) and others which are able to maintain a high body temperature by endogenous heat production (endothermic) respectively. These definitions also have their limitations since several invertebrates and vertebrates can at times maintain a substantial difference between their own temperature and that of the surroundings. In the following section you will learn such varied relations and their physiological and ecological implications.

SAQ 1

Match the following terms given in column A with their definitions in column B.

1) Poikilotherms	[ ]	a) Animals that depend on external [illegible]
2) Homeotherms	[ ]	b) Animals which are able to maintain a high body temperature by endogenous heat production
3) Ectotherms	[ ]	c) Animals which maintain their body temperature nearly constant independent of the environment
4) Endotherms	[ ]	d) Animals whose body temperature fluctuates with that of the environment.

7.3 EFFECTS OF TEMPERATURE

The effects of temperature on individual organisms have profound physiological and ecological significance. The metabolic rate in both homeotherms and poikilotherms is often influenced by the **ambient** temperature. Within limits, a temperature increase accelerates most processes. In general, a rise of 10°C in temperature is known to increase the rate of a reaction to about two to three-fold. The increase in a rate caused by a 10°C increase in temperature is called the Q_{10}. If the rate doubles, Q_{10} is 2; if the rate triples, Q_{10} is 3; and so on. Thus, the energetic demands placed on the environment by an organism increase or decrease with thermal circumstances. Temperature is also significant in that the animal must be able to survive various thermal changes imposed on it throughout the year. The distribution and habitat of species may thus be influenced by thermal effects. When temperature exceeds viable limits at certain times or places it causes a physiological or ecological stress condition. Mammals and birds exposed to heat in deserts, for example, may face critical problems of dehydration if required to expend large amounts of water on **evaporative cooling** to keep their body temperatures from rising beyond the tolerance limits. Fish in summer may have high metabolic rates because their body temperatures are elevated in the warm waters. However, at the same time, they may be forced with relatively low oxygen availability because warm water tends to hold less dissolved oxygen than cold water. The interaction of these factors may prove critical.

Animals differ in the range of temperatures they can tolerate. Some have a very narrow tolerance range, while others exhibit wider range. Furthermore, temperature tolerance may change with time, and a certain degree of adaptation is possible so that continued exposure to a temperature close to the limit of tolerance often extends the limit. Some organisms are more sensitive to extreme temperatures during certain periods of their lives, particularly during the early stages of development.

7.3.1 Tolerance to High Temperature

No animal is known to live and carry out its complete life cycle at a temperature over 50°C. However, an animal in a resting stage may be extremely tolerant to high temperatures. For example, a fly larva (*Polypedilum*) from Nigeria and Ugandá is known to tolerate dehydration, and in the dehydrated state it can survive a temperature of 102°C for one minute and afterward grow and metamorphose successfully. Likewise, the eggs of a fresh water crustacean (*Triops* from Sudan) survive through winter and early summer in dry mud, where they may be exposed to temperature of up to 80°C. In the laboratory they are known to withstand even higher temperature, close to boiling temperature of water. Apparently, upper temperature limit for life cannot be accurately defined.

When a group of animals of a given species are exposed to a temperature close to the limit of their tolerance, some may die and others survive. The **lethal temperature** is commonly defined as that temperature at which 50% of animals die and 50% survive. It is written as T_{50}. Obviously, the lethal temperature value changes with the species, the stage of the life cycle, the previous adaptation of the animal to a given environment and so on. The factors responsible for death due to heat are believed to be the following:

i) Degeneration of proteins which occurs above 45 – 50°C known as **thermal coagulation**

ii) Thermal inactivation of enzymes at the rates that exceed rates of formation

iii) Inadequate oxygen supply

iv) Different temperature effects (Q_{10}) on interdependent metabolic reactions

v) Temperature effects on membrane structure

Now let us learn more about these factors.

Denaturisation of proteins due to temperatures above 45 – 50°C is quite common. However, in some animals such as the Antarctic fish of the genus *Trematomus* are very sensitive to heat so that above 6°C the proteins (inclusive of enzymes) denature. It is difficult to explain how such a low temperature (+6°C) can cause denaturation of proteins or inactivation of enzymes in the fish. The third possibility that thermal death occurs due to inadequate oxygen supply is also difficult to explain in certain situations. For example, supplying of insects with pure oxygen instead of air does not enable them to survive at higher temperatures. Likewise, the trout, a cold-water fish, dies in warm water even if the oxygen content of the water is increased several fold by aeration with pure oxygen. The fourth possibility envisages that different temperature sensitivities of the several hundred metabolic enzymes that participate in the intermediary metabolism may lead to a derangement of normal biochemical balance of the organism and eventual death. However, in most cases, heat death is not necessarily always due to enzyme inactivation. In fact other possibilities mentioned above may be contributory. The last possibility, changes in membrane structure and function (fluidity and permeability), is very important and covers a broad range of subjects. Temperature has profound effects on higher orders of protein structure, protein-lipid interactions, lipid-lipid interactions, and so on. Such disturbance in the integrity of membrane function appears to be the primary factor in heat damage to organisms.

7.3.2 Tolerance to Cold and Freezing Temperatures

In the earlier section you have been studying about tolerance of animals to high temperature. Now in this subsection we will study about tolerance to cold and freezing temperatures.

The effects of low temperature are equally perplexing as those of high temperature. Some organisms can tolerate extensive freezing but most animals cannot. Animals that live in temperature and cold regions are often exposed to long periods of winter temperatures that are far below the freezing point of water. Survival of ectothermic animals at such subzero temperature depends upon the physiological and biochemical characteristics that can be described as **cold hardiness**. An animal can develop cold hardiness either by developing capacity for **freeze tolerance** or by avoiding ice formation even if exposed to temperatures as low as –40°C to –50°C. The latter are regarded as **freeze intolerant**. The intertidal marine invertebrates of colder zones are freeze tolerant in the sense that they survive extensive ice formation within their bodies. Many other animals also survive in spite of extensive ice formation. For example, midge *Chironomous* larva from Alaska can be frozen and thawed repeatedly without injury. Several species of insects are known to contain high concentration of **glycerol** in their body fluids. It is well-known that glycerol protects red blood cells and mammalian spermatozoa from injury caused by freezing. Therefore, glycerol is widely used for this purpose and samples of human or bull sperm can be kept frozen and viable for several years using glycerol. Without such treatment, freezing is lethal to sperms. Only a few vertebrates tolerate extensive ice formation. Birds and mammals, however, are not known to tolerate freezing.

Super cooling is a phenomenon where body water is allowed to cool far below 0°C without formation of ice. Glycerol is effective in lowering both the freezing point and also the super cooling point. In addition, glycerol improves the tolerance to freezing in animals that tolerate ice formation. In some animals antifreeze compounds are found. For example in the Antarctic fish *Trematomous borchgrevinki* the blood contains a glycoprotein that acts as an antifreeze substance.

7.3.3 Acclimation and Acclimatisation

The tolerance limit of a given species is not fixed. Exposure to a near lethal temperature often leads to a certain degree of adaptation so that a previously lethal temperature is tolerated. Frequently, the range of thermal tolerance is different for the same species in summer and in winter. A winter animal exhibits tolerance for temperature so low that it is lethal to a summer animal; conversely, the winter animal is less tolerant to high temperature than a summer animal. Such changes in the temperature tolerance with climatic changes are called **acclimatisation**. Similar effects can be simulated in laboratory experiments by keeping animals for some time at given temperatures. To distinguish the adaptation or adjustment that takes place in laboratory experiments from natural acclimatisation, the response to experimental conditions is often described by the term **acclimation**. Indeed, animals may show long-term physiological adjustments in response to diverse environmental agents, including (in addition to temperature) humidity, salinity, oxygen supply, photoperiod and food supply, to name a few. Furthermore, acclimation or acclimatisation can potentially be exhibited in virtually any physiological property and sometimes in behavioural and morphological properties as well.

SAQ 2

Fill in the blank spaces and compare your answers with that given in Section [illegible]

a) A rise in 10°C in temperature is known to increase the rate of a reaction [illegible] to three-fold. The increase in a rate caused by 10°C increase in temperature is called the ....

b) Some organisms are more sensitive to extreme temperature [illegible] during ..

c) No animal is known to live and carry out its complete life [illegible] temperature over..............

d) Freeze tolerant species of insects are known to contain high concentration [illegible] in their body fluids, which protects their tissues from injury caused by fre[illegible]

e) Changes in the temperature tolerance with climatic changes are called ......

7.4 TEMPERATURE REGULATION IN POIKILOTHERMS

After studying the effects of temperature on animals, you will now learn about regulation of temperature in the poikilotherms.

The term poikilotherm refers to the lack of regulated constancy of the body temperature and it describes the actual physiological status of these organisms. As stated earlier, in recent years these animals have increasingly been termed **ectotherms**, with reference to the fact that their body temperatures are determined primarily by external thermal conditions. The term ectotherm emphasises the mechanism by which body temperature is determined, whereas poikilotherm emphasises variation of the body temperature with environmental conditions.

Although poikilotherms lack physiological mechanisms of controlling their body temperature, they are not necessarily devoid of means of control. They often exert exquisite control behaviourally, by selecting their thermal environment. Animals at all levels of phylogeny have developed mechanisms to meet the normal temperature variations of their surroundings and to withstand the extremes for periods of varying length. Basically, three types of compensatory mechanisms have been recognised:

i) Acclimation or acclimatisation

ii) Body temperature adjustment or regulation

iii) Genetic or evolutionary adaptation

The basic biochemical and cellular events occurring during acclimation and acclimatisation appear to be similar. These processes involve appropriate changes in the activity of various enzymes involved in the metabolism, changes in the lipid composition of the membranes, production of antifreeze substances, super cooling and freeze tolerance. Now we will study how poikilotherms regulate their body temperature.

7.4.1 Hibernation and Aestivation

Poikilotherms pass the winter in a resting state, known as **hibernation**. When they enter a resting state in response to heat or drought, the condition is called **aestivation**. In general poikilotherms derive two types of benefit from the resting states that may enter during times of environmental stress. First, by virtue of their special physiological state, the animals may enjoy an enhanced physiological ability to cope with the extreme conditions. (Example, increased freezing resistance etc.) Second, they are often permitted to remain continuously in favourable microhabitats. Their metabolism is depressed to such an extent that the store of nutrients (example, body fat) can augment. The variety of mechanisms exploited by poikilotherms in escaping some of the rigors of extreme temperatures may be divided into behavioural and physiological adaptations.

7.4.2 Behavioural Adjustments

When faced with a sudden temperature change, most animals make behavioural responses that enable them to avoid extreme or lethal conditions. Among the invertebrates and aquatic vertebrates this is the only kind of thermal adjustment. The terrestrial environment is more prone than aquatic to show sharp temperature changes. Insects and reptiles which are the most successful among the terrestrial poikilotherms exhibit many complex thermal

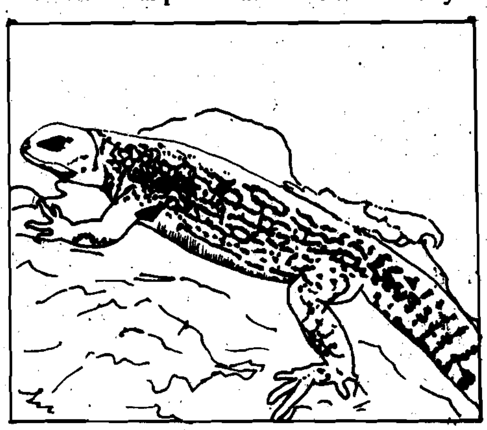

Fig. 7.1 : A Lizard basking on a rock.

responses. Capacities for rapid and appropriate responses to temperature changes are based on well developed sensory system. For example, the infrared sense organs located in the facial pit of the rattle snake can detect even very small temperature differences (0.001 to 0.005°C) which helps them in detecting warm blooded or cool (moist) prey as well as in orienting the animals to warm or cool environments.

Many insects and reptiles bask in the sun to warm their bodies and avoid extreme heat by seeking the shade or burrowing (Fig. 7.1).

7.4.3 Physiological Adjustments

Three examples of physiological thermoregulation in poikilotherms can be noted. These include:

i) Prompt cardiovascular response to a sharp change in environmental temperature

ii) Cutaneous vasodilation in the heat

iii) Vasoconstriction in cold as frequently noted in lizards and crocodiles.

A measure of temperature control is attained by minimising the flow of blood to the surface during the cold and increasing the flow during the heat. Thus the situation in reptiles, known as **dermovascular responses**, marks an evolutionary step between the vascular respiratory skin of amphibians and the dry but moisture permeable and sweating skin of mammals. Many animals cool their bodies through evaporation of moisture.

Poikilotherms that live in temperate zone experience drastic seasonal changes in the temperature. In these, the adaptations occur slowly and prepare the animals for winter cold or summer heat. Such preparations (example, formation of antifreezes etc.) involve the **neuroendocrine system** and **photoreceptors**. The latter, in fact, serves as a reliable clue to the adjustment of physiology in anticipation of seasonal changes.

Thirdly, some fishes and insects avoid thermal extremes by maintaining a relatively constant body temperature. This capacity of endothermy represents a third level of compensation, involving both morphological and physiological adaptations. In short, it represents the genetic and phylogenetic level of physiological thermoregulation. Several fishes and sharks are known to possess **heat exchangers** especially in the heavy trunk musculature with extensive network of blood vessels. Such heat exchangers are also found in association with the brain, retina and viscera.

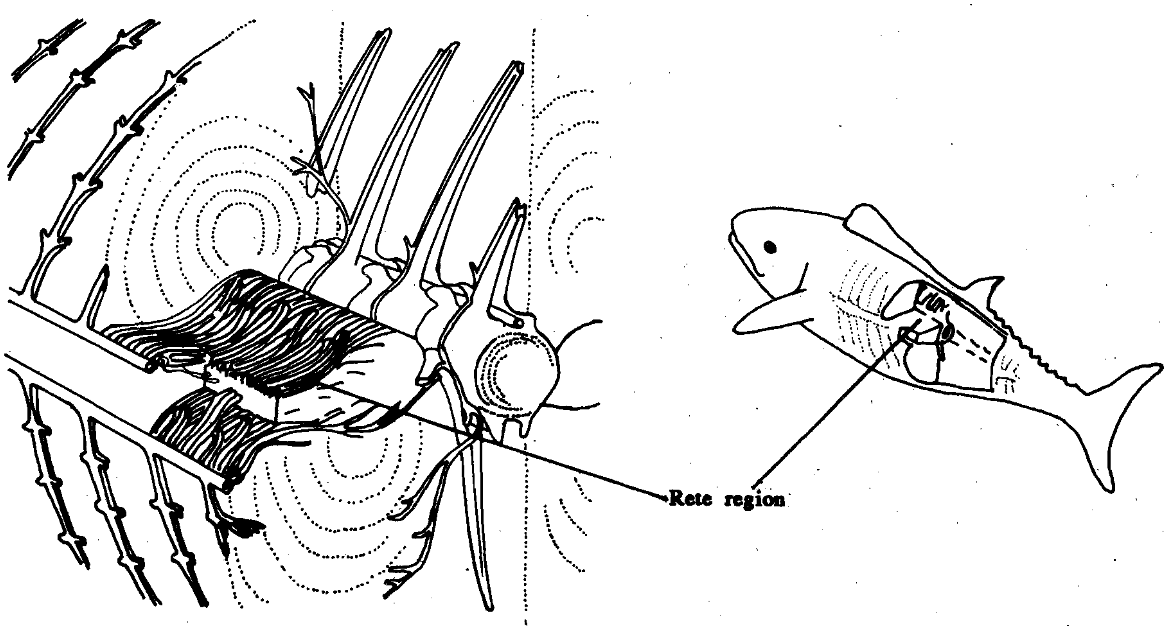

Fig. 7.2 : Rete mirabila in bluefin tuna fish.

Although heat exchangers vary in structure, the physiological principle involved is the same in all of them. They are, in fact, elaborate **retia mirabilia** composed of numerous, relatively long arterioles and venules. These small vessels are intermingled and lie in close contact parallel to one another with arterial and venous blood flowing in opposite directions (counter current). Cold arterial blood from the gills flows through the rete, where it is warmed by the venous blood heated in the actively metabolising muscles or visceral organs. Heat exchange is facilitated by the large number and arrangement of the retial vessels and by the slow passage of blood through them (Fig. 7.2).

Some insects are also able to maintain a warm body while foraging in cool environment. The bumble bee forages for nectar at temperatures as low as 5°C with a thoracic temperature at about 30°C which is essential for flight muscle activity. Bumble bees warm before flying by shivering. The queen bees generate heat and thus raise the temperatures in their hives. Several such examples can be found among the insects.

SAQ [illegible]

Fill in the blank spaces and compare your answers with those given in Section 7.8.

a) The infrared sense organs of the rattle snake located in the facial pit can detect [illegible] .... to .... °C.

b) .... response in reptiles mark an evolutionary step between the [illegible] skin of amphibians and the dry but moisture permeable and [illegible].

7.5 TEMPERATURE REGULATION IN HOMEOTHERMS

Homeothermy is regulation of body temperature by physiological means. The stabilisation of body temperature permits a steady high level of activity, both metabolic and locomotory. The advantages are obvious in behavioural, social and cultural evolution, demanding continuous association of individuals. Maintenance of a constant body temperature involves a perfect balance between heat production and heat loss. It demands a sensitive thermostat in the brain, a capacity not only to use heat formed as a byproduct of metabolism but also to increase the output of metabolic energy in accordance with demands. In addition, it requires several anatomical modifications such as appropriate insulation and special heat exchangers. In extreme conditions, the metabolic price of a regulated body temperature may become too high so that some species temporarily suspend temperature control (torpidity and hibernation) or migrate to more favourable climates. In man, there is behavioural evasion of extremes with the development of clothing, air conditioning and other technological devices.

7.5.1 Heat Production

In the homeotherms heat production must be elevated if the ambient temperature falls below the critical temperature. Although all metabolic processes result indirectly in the production of heat, birds and mammals have evolved processes that have the specific function of generating heat for thermoregulation. These thermogenic processes are basically meant to convert chemical energy to heat. They are :

i) **Shivering:** The mechanism of thermogenesis with which we are more familiar is shivering and all adult birds and mammals seem to use these mechanisms. Shivering is a high frequency, relatively uncoordinated contraction of skeletal muscles. All muscular contraction liberates heat, and obviously the conversion of chemical energy into thermal energy becomes the primary function of the contraction.

ii) **Nonshivering Thermogenesis:** The nonshivering thermogenesis is a widespread phenomenon in mammals. It refers to the processes that produce heat by means other than shivering. It is not certain whether birds produce heat by nonshivering. One of the well-known sites of nonshivering thermogenesis in mammals is **the brown adipose tissue,** also called **brown fat.** The brown adipose tissue contains great numbers of mitochondria and is richly vascularised. Release of norepinephrine into the tissue by the sympathetic nervous system results in a great increase in oxidation of lipid and release of heat. Brown fat, like nonshivering thermogenesis, is specially prominent in new born individuals, hibernators and cold acclimated adult mammals. The brown fat tends to occur in discrete masses, located in the neck, interscapular region, axillae and abdomen. Among hibernators brown fat is believed to help in rewarming the body during emergence from hibernation. New born mammals use brown fat in routine thermogenesis (Fig 7.3). The principal mechanism of heat production by brown fat is by uncoupling the oxidative phosphorylation that occurs in the mitochondria. Thus, oxidation of food-stuffs results in the production of heat.

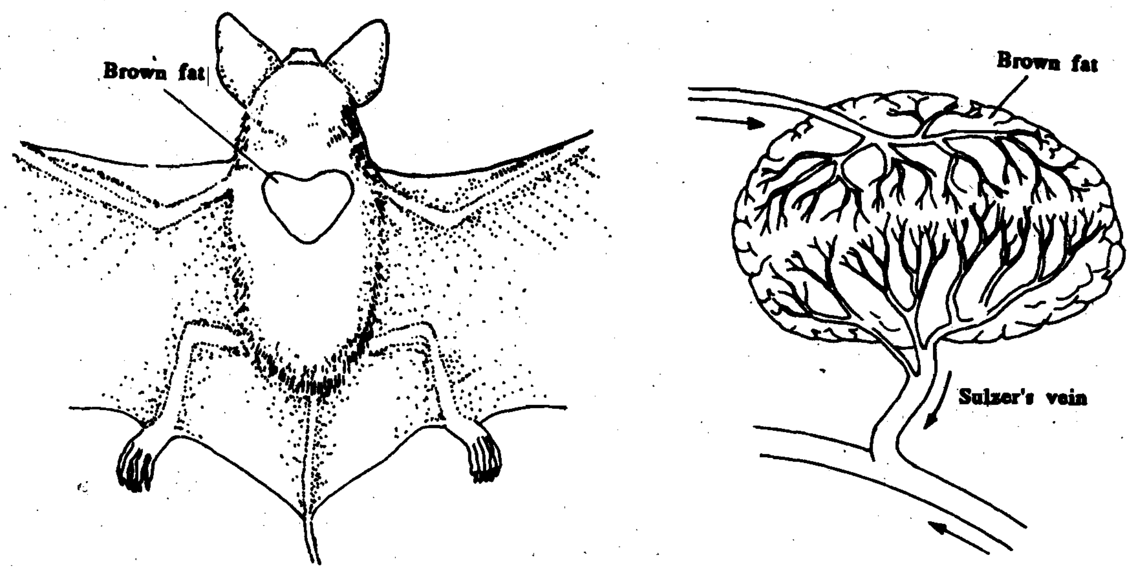

Fig. 7.3 : Brown fat deposition in the bat.

iii) Exercise: During physical activity heat production by exercise can to some extent substitute for heat generated by shivering. However, exercise also tends to facilitate heat loss by degrading body insulation. Therefore, relative significance of exercise in thermoregulation of birds and mammals is not very clear. After studying the ways in which homeotherms gain heat, we will now study how they lose the excess heat.

7.5.2 Heat Loss

Temperature regulation is extremely uneconomical if it depends only on variations in metabolism. Therefore, mechanisms for losing excess heat have been developed by both birds and mammals. In an aquatic environment, the entire heat transfer between the animal and the media is through **conduction.** However, in terrestrial habitat, only small amounts of heat are exchanged this way. Most of the homeotherms are terrestrial. In man, heat loss due to radiation accounts for about 55% and heat loss due to evaporation is about 40%. The amount of heat loss depends on the ambient temperature and the humidity. Loss of heat by radiation and conduction is usually effective in a cool environment. Whereas, at high temperature, the animals will actually receive heat by these routes. Evaporation however, is always a negative factor and it requires considerable energy expenditure. For instance, to vaporise one gram of water from the moist surfaces of the skin or respiratory epithelia, 0.6 kcal is required. This technique of cooling has been exploited in quite different ways by birds and mammals.

Birds have a dry and insulated skin with no integumentary organs to increase cooling by vaporisation. However, evaporative cooling occurs in birds through buccal and respiratory surfaces. The four major mechanisms of actively enhancing evaporative cooling that are known to be employed by birds and mammals are :

i) **sweating**

ii) **panting**

iii) **gular fluttering**

iv) **saliva spreading**

During **sweating** fluid is secreted by way of the sweat gland ducts through the epidermis onto the skin surface. Vigorous sweating occurs in many mammals including humans during hot environmental conditions. Sweating does not occur in birds. **Panting** is an increase in the breathing in response to heat stress and occurs widely in birds as well as mammals. Panting requires less muscular effort and thus is of advantage in losing heat. By comparison to sweating, panting holds at least two advantages. First, no loss of salts occurs. Second, the breathing activities of panting assure that the air saturated with water vapour is driven forcibly away from the evaporative surfaces. But during sweating the removal of water laden air is dependent on several other forces such as external winds. However, panting requires more energy than sweating. Many birds augment evaporative cooling by rapidly vibrating their gular area (the floor of their mouth) while holding their mouth open. These **gular flutterings** promote evaporation by increasing the flow of air over the bird's moist and highly vascular oral membranes. The fourth technique, **saliva spreading** is employed by many rodents and marsupials when exposed to heat stress. They spread saliva on their limbs, tails, chest or other body parts for further evaporative cooling. After studying about the ways by which the homeotherms gain heat or lose heat to keep their body temperature constant, we will study about the anatomical features that help the homeotherms in maintaining their body temperature constant.

7.5.3 Insulation by Fur and Feathers

There is a strong correlation between the extent of integumentary insulation and the rigors of natural environment. In general, Arctic or Antarctic species are better insulated than tropical species, with well marked seasonal variations in the thickness of fur (example, Polar bear) or feathers (example, penguins). Likewise, the aquatic mammals living in these areas such as seals and whales have thick layers of subcutaneous **blubber** (fatty layer) as a means of major insulation. However, it should be noted that the extent of fat deposition (blubber) is not the same in all parts of the body.

7.5.4 Heat Exchangers

Seals and whales have **flippers** and **flukes** that lack blubber and are poorly insulated. These appendages are well supplied with blood vessels and receive rich blood supply. Therefore, these thin structures with their large surface areas can lose substantial amounts of heat and aid in heat dissipation. However, excessive loss of heat is prevented due to the counter-current heat exchangers in which the blood flows in opposite direction. In the whale flipper, each artery is completely surrounded by veins, and as warm arterial blood flows into the flipper it is cooled by the cold venous blood that surrounds it on all sides. The arterial blood therefore, reaches the periphery precooled and hence loses little heat to the water. The heat has been transferred to the venous blood, which thus, is prewarmed before it reenters the body (Fig. 7.4).

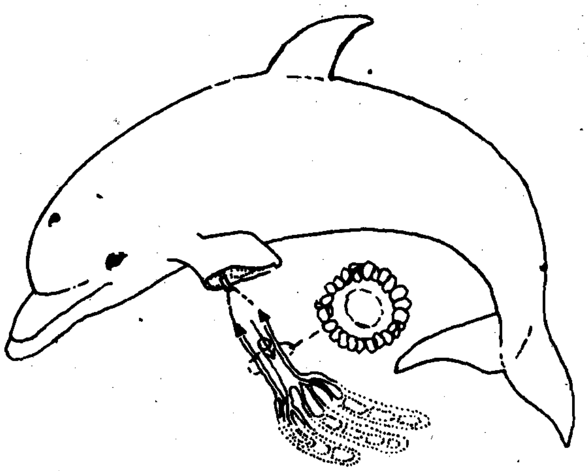

Fig. 7.4 : Countercurrent system for conserving heat in the flippers.

It is interesting to note that such countercurrent heat exchangers are found in a number of other animals. For example, sea cows, which live in tropical and subtropical water, have heat exchangers in their appendages. Even in human limbs some heat exchange takes place between the main arteries and the adjacent larger veins located deep within the tissue. In birds, heat exchange in the legs is very important especially in those that stand or swim in cold water. After studying about the anatomical features that help in maintaining the body temperature, we will now study the regulatory mechanisms that operate to maintain the body temperature.

7.5.5 Regulatory Mechanisms

The immediate response to acute temperature change is mediated through the central nervous system. The physiological thermostat has been located in the hypothalamus of the mammal and the spinal cord of the bird. These are the centres of reflex action and are activated by the temperature receptors of the skin or mucous membranes or directly through the changes in the temperature of the hypothalamus (or the blood circulating through it). The physiological thermostat through the efferent nerve fibres stimulate the muscles for panting and shivering and through the autonomic system it regulates the cutaneous blood vessels, the sweat glands and so on. In some of the amniotes, the pineal and parapineal organs influence thermoregulatory behaviour and physiology. Cardiovascular and cutaneous responses are acute reactions to temperature change. If the exposure is more prolonged, the endocrine system enters the picture and the metabolism is altered particularly by way of the thyroid and adrenal glands.

Hibernation, Aestivation and Daily Torpor

Although birds and mammals frequently function in the homeothermic mode and maintain relatively high stable temperatures, many mammals and some birds have the ability to relax their homeothermic responses and allow their body temperatures to fall, close to the level of low ambient temperatures. This phenomenon is called **controlled hypothermia.**

Hibernation, aestivation and daily torpor are states in which the animal relaxes its homeothermic processes almost completely within a certain range of ambient temperatures and, like a poikilotherm, allows its body temperature to equal ambient temperature. When body temperature is fixed to approximate ambient temperature for periods of several days or longer during winter, the phenomenon is termed **hibernation.** When this occurs during summer, it is called **aestivation.** If body temperature is freed to approximate ambient temperature for only part of each day, generally on many consecutive days, the phenomenon is called **daily torpor**, regardless of season. These three forms of controlled hypothermia are thus different manifestations of a single fundamental physiological process. During episodes of hypothermia, the heart rate and breathing rate decline along with metabolism. The animal may retain some ability to move and respond behaviourally to its environment at body temperatures well below normal, but there is increasing lethargy as body temperature falls, and at low temperatures the lethargy becomes extreme.

The chief benefit of these hypothermic states is a reduction in the animals' energy demand. This is evidently due to the fact that the animal no longer elevates its rate of metabolism to keep itself warm. Secondly, resultant body temperature itself lowers metabolism ("Q_{10} effect" about which you have studied in Section 7.3). Entry into hypothermic state also reduces an animal's water expenditures. In fact, for individuals suffering water shortage, the savings of water may be of greater significance than those of energy. Respiratory water losses are reduced during hypothermia for two reasons :

i) oxygen requirement as well as the rate of ventilation of lungs is reduced, and

ii) body temperature is lowered, and the exhaled air is cooler than during homeothermy and thus carries less water vapour with it.

Transcutaneous (through skin) water losses are also reduced because the drop in body temperature lowers the vapour pressures of the body fluids. Birds and mammals that are capable of hibernation, aestivation, or daily torpor are often termed **heterotherms**. A heterotherm is an animal that sometimes regulates its body temperature physiologically and some times does not. The heterotherm can enjoy, in a sense, the best of both the homeothermic and poikilothermic worlds. While thermoregulating at high body temperatures, the animal is able to move about with the independence of external thermal conditions and enjoy a prime advantage of homeothermy. When in hypothermia, on the other hand, it enjoys the comparatively low requirements for energy and water characteristic of poikilothermy. Insects that thermoregulate physiologically during flight are also heterotherms and enjoy similar benefits.

During hibernation, aestivation and daily torpor, the body temperature is brought about by a change in the operation of the animal's thermoregulatory control centres. The most striking is the ability of these animals to arouse from the hypothermic conditions. The hypothermic individuals are able to warm themselves back to a high body temperature using their own metabolic heat production. Arousal is accomplished by intense shivering and, in the case of mammals by nonshivering thermogenesis.

Hibernation is known in many mammals, including hamsters, many ground squirrels, dormice, woodchucks, some bats, some monotremes and some marsupials. Such mammals store large quantities of body fat during the months preceding entry to hibernation for use during the winter sleep. Hibernators arouse periodically and at such times they may excrete urine and faeces and consume food they have stored in their burrow or den. Aestivation has received much less attention than hibernation partly because it is not easy to detect. It has been reported mostly in species of desert ground squirrels.

Daily torpor is found in great many mammals and birds in both warm and cold situations. It occurs in numerous species of bats and rodents and in certain humming birds, swallows, swifts and so on. A characteristic of daily torpor is that the animal is hypothermic for part of each day but maintains an elevated body temperature during the rest of the day. Feeding and other activities are carried out during the later periods. When bats are undergoing daily torpor, they become hypothermic during day light hours and emerge to forage at night; humming birds become torpid at night and feed in day light. The mechanisms that regulate hibernation or daily torpor are complex and vary between the different species. It is believed that the hibernation may be under the control of **biological clock** in certain animals. Daily torpor may be employed as a response to immediate hardship such as storage of food. Effects of day length on hibernation or daily torpor are possibly mediated in at least some species by the **pineal gland** and its hormone **melatonin.**

In ending this unit it is perhaps necessary to offer a counter argument to the common belief that homeothermy is superior to poikilothermy. After all, nature being indifferent, the only criterion of success is perpetuation of the species, involving several subsidiary means for survival and reproduction at the individual level. When such a criteria is applied, poikilothermy can be as successful a mode of life as homeothermy. In fact, many poikilothermic taxa have persisted for hundreds of millions of years. Therefore, poikilothermy and homeothermy may be simply regarded as two extremes in a continuum of thermal relations that have been exploited in the evolution of animals in different habitats. Consequently, the so called advantages and disadvantages of various thermal relations, that we often visualise are in reality only highly relative judgements.

7.6 SUMMARY

You have studied in this unit that :

- Temperature of an animal's body has profound effects on the function of the animal.
- Poikilotherms are those animals whose body temperature changes with the changing ambient temperature and homeotherms are the animals who usually maintain their body temperature nearly constant and independent of the environment.
- Animals differ in the range of temperature they can tolerate. Some have a very narrow tolerance range, while others exhibit wider range.
- The factors responsible for death due to heat are : degeneration of proteins, thermal inactivation of enzymes, inadequate oxygen supply, different temperature effects on interdependent metabolic reactions and due to temperature effects on membrane structure.
- Poikilotherms, which lack physiological mechanisms of controlling their body temperature, often exert control behaviourally by hibernation and aestivation. Some of them also exhibit physiological thermoregulation.
- Homeotherms regulate body temperature by physiological means. They produce heat by shivering, by oxidative phosphorylation in the brown fat, and by doing exercise. They lose heat by radiation, evaporation, conduction, sweating, panting, gular fluttering and saliva spreading.
- Homeotherms have fur, feathers, flippers, flukes which help in maintaining the body temperature. They also exhibit hibernation, aestivation and daily torpor.
- The physiological thermostat located at the hypothalamus, pineal, parapinal organ, thyroid and adrenal glands influence thermoregulatory behaviour and physiology of the homeotherms.

7.7 TERMINAL QUESTIONS

1) Give two examples of the animals which survive outside the favourable temperature range.

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2) What are the factors responsible for death due to heat ?

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3) Explain at least two ways by which homeotherms produce heat and lose heat in order to regulate their body temperature.

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4) Explain briefly in the space given below the four major mechanisms of actively enhancing evaporative cooling employed by birds and mammals.

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5) What is meant by the phenomenon of controlled hypothermia ?

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7.8 ANSWERS

Self-assessment Questions

1) 1 —— d, 2 —— c, 3 —— a, 4 —— b.

2) (a) Q_{10} (b) early stages of development (c) 50°C (d) glycerol (e) acclimatisation

3) (a) 0.001 to 0.005°C (b) dermovascular

4) (a) Shivering (b) neck, interscapular region, new born, hibernators
(c) 50%, 40% (d) 0.6 (e) heat exchangers (f) hypothalamus, spinal cord
(g) daily torpor (h) biological clock

Terminal Questions

1) Please refer Subsection 7.3.1

2) Please refer Subsection 7.3.1

3) Please refer Section 7.5

4) Please refer Subsection 7.5.2