7

Thermoregulation

Introduction

Each and every activity of living organism is the result of biochemical processes that take place in their body. All such processes are so much temperature sensitive that even a slight change in temperature alters the rate of these reactions. Therefore, arises a need of maintenance of a specific body temperature for the life of an animal to be carried on in a perfect order. The way in which the organisms maintain their body temperature within a certain limited range is termed as *thermoregulation*.

All the animals are known to inhabit either aquatic or terrestrial or aerial habitat. Temperature within the water bodies does not vary much because of the high specific heat of water and thus the effects of change of temperature on organisms as such are not much. But the animals of terrestrial habitat are directly exposed to the radiant heat and also because of low specific heat of air, the temperature changes, with the diurnal and seasonal variations, are much prominent. Thus the temperature changes which terrestrial animals face, effect them to a much greater degree than to aquatic animals. Same is the case with aerial animals. They too have to face quite large temperature variations. Here their high rate of metabolism makes

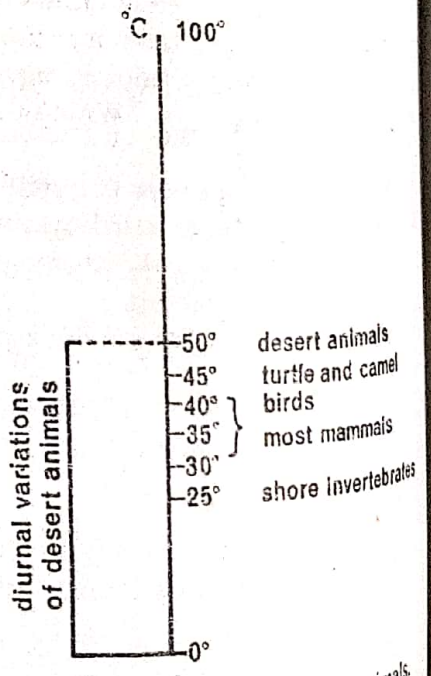

Fig. 7.1. Temperature tolerance in animals.

them able to tolerate higher temperatures. Temperatures which different animals can tolerate are shown in Fig. 7.1.

Thus the temperature adjustments are controlled by the physiological adjustments. Animals with a low rate of metabolism can not adjust themselves to extremes of temperature, but those with a high rate of metabolism are capable of manipulating the rate of metabolism so as to accord with the thermal changes taking place in the environment.

Types of Animals

Considering various aspects of temperature regulation, animals are classified in three different ways :

(1) Depending upon the body temperature the animals are grouped as warm blooded and cold blooded. But these terms are now replaced by more authentic terms i.e. *homoeotherms* and *poikilotherms.* Animals which inspite of fluctuations or great variations in the atmospheric temperatures maintain a relatively constant body temperature are categorized under homoeotherms. Whereas the animals whose body temperature varies with changes in environmental temperature come under the category of poikilotherms. The former i.e. the homoeotherms include birds and mammals; and aquatic animals, invertebrates, amphibians are included in the group poikilotherms.

(2) Because of their own oxidative metabolism some animals are capable of producing sufficient heat to maintain a constant body temperature. These animals are termed the *endothermic* animals. While others have low production and high conduction of heat with the result they have to depend upon the atmospheric heat for maintaining their body temperature. Such animals are put together under the term *ectothermic* animals to include vast number of animals e.g. the invertebrates fishes, amphibians, reptiles etc. Examples of endothermic animals are birds and mammals.

(3) There is a term *heterotherms* or the *facultative endoderms* to describe those animals which show variable characteristics of being able to generate heat and maintain their body temperature themselves at times when they are active and being unable to do so when they are at rest. So during the time of low metabolism they have to depend upon the atmospheric heat to regulate their body temperature like ectotherms and when active they behave like endotherms. Such animals, present just on the critical line, like monotremes, some marsupials, armadillos etc., are thus termed as facultative endotherms or heterotherms.

Temperature related changes in metabolism

As stated earlier too, the physiological processes are highly temperature sensitive and are confined to very acute temperature measurements. The

overall range of temperatures within which all the life processes fall is also very narrow. Environmental temperature whether rising or falling manipulates, the rate of metabolic processes accordingly. This fact has been studied by various authors Van't Hoff describes this generalisation in the following way—for every ten degrees rise in temperature the rate of biochemical reactions becomes almost double. This is known as Q_{10} law and is expressed as :

$$Q_{10} = \frac{(k_i + 10)}{k_i}$$

where k_i is the velocity constant at temperature t, and $k_i + 10$ is the velocity constant at temperature (t + 10).

In the case of chemical reactions the values of Q_{10} are found to be quite constant. However, in case of enzymatic reactions this law is not applicable linearly. At low temperature the enzymes become inactivated and at higher temperatures they get destroyed. It is very much logical that under such circumstances they will not follow any such law. Therefore, in the case of enzymatic reactions the Q_{10} law is followed but in a very limited range or temperatures.

With change in environmental temperature the rates of metabolic processes change consequently changing the body temperature. This is the case of poikilothermic animals. But we find that in homoeothermic animals the change in external temperature has no or very little effect on body temperature which remains almost constant and this is possible only because of certain temperature regulating mechanisms present in their tissues. Otherwise their tissues too behave in the fashion like those of poikilotherms show.

Also we see that the poikilotherms having low body temperatures are lower grade animals as compared to birds and mammals having higher body temperature. Thus, it can be said that higher body temperature favours more complex form of life.

Effect of low temperature

Response of animals to cold is varied. A few of them migrate to avoid the cold conditions while the others who face such low temperatures either mold themselves accordingly or are sure to be effected adversely. The low temperature effects the animals not only by slowing down the rate of metabolism but also by causing the ice to be formed in extracellular fluid. As a result the water comes out of the cells by osmosis and concentration of salts within the cells change. This produces lethal effects and the animals are prone to die if the same effect continues. This lethal temperature for different animals varies according to the dosage of exposure to low temperature and to the temperature in which the animal was living before its exposure to low temperature. On the other hand low temperatures may

arise by fast cooling. In this case the lowering of temperature is too fast to permit any ice crystals to be formed and the condition is thus less injurious.

To fight the conditions of low temperature, phenomenon of antifreezing i.e. an antifreezing substance is present in the body fluids. This increases the osmotic content but lowers the freezing point and thus protects the animal from being frozen. This is found inpoikilothermic animals. In homoeotherms all this is done by the temperature regulating mechanisms but it is found that as a result of severe cold, these mechanisms, if break down to operate, result in the death of the animal.

There are a number of theories explaining the cause of death because of cold but there is no general agreement and none of them is universally accepted.

Effect of high temperature

The cold temperatures are found to be lethal in their ultimacy. Similarly the high temperatures are found to effect the life of animals and the effects of high temperatures are much more severe than those of low temperature. Again the dependence of animal for temperature is based on the exposure time and temperature of environment that the animal was inhabiting befo the high temperature condition. As also clear from this aquatic animals face less variations in temperature because of high specific heat of H_2O and thus their lethal temperatures are lower as compared to those of land animals. Various ways in which the high temperatures are found to effect the animals may be one or more or all of the following.

After a certain limit, if the temperature rises the body activities cease down and the animals finally die. Protoplasm constituting the animals contains proteins and the enzymes (which are also proteins), coagulate and get denatured at high temperatures. Thus they effect the body activities in general and finally result in death. Also the excess of heat leads to an increased viscosity of cellular fluid. With the result vacuolation also takes place. Vacuolation leads to release of Ca^{++} ions within the cells and the Ca^{++} ions so released have a disruptive influence on the cell by affecting the permeability of plasma membrane. All these factors combinedly or alone affect the organisms adversely. Effect of high temperature is opposite to that of low temperatures if the increase in rise and fall respectively are rapid in that the slow heating permits the animal to acclamatise itself to the changing temperature whereas the fast healing suddenly attacks and destroys the activities of many enzymes or almost all of proteins causing immediate death.

Mechanism of heat regulation in poikilotherms

Their body temperature changes according to that of the environment and they don't have any control on it. This is because they lack the temperature regulating mechanisms. Still to a very small degree a regulation of

temperature is seen in these animals and this is by their behavioural and metabolic activities.

Many reptiles (snakes and lizards) are often found to bask in sun. This practice may increase their body temperature by even 20°C. This is because of absorption of solar radiation and conduction by the substrate. By fluttering of wings also some insects manage to raise the temperature of their flight muscles to the extent to make the flight possible. This method of generating metabolic heat is also very efficient as in bees and can raise the temperature by 10–12°C. Generally in fish and other aquatic poikilotherms there is no appreciable difference between their temperature and that of the surrounding water. The heat produced as a result of muscular activity during swimming is exchanged and equilibrium in temperature with that of the surrounding water is maintained. However, there are a few examples such as Tuna–a large and fast swimming fish in which the body temperature is higher than that of the water around it. This may be because of that the heat produced due to muscular activity is regulated by the counter current mechanism to some extent and this reduces the dissipation of heat. Besides these, there are certain special methods also which are in practice to overcome the handicaps of being poikilotherms. Such as larvae of butterfly, *Vanessa* group together in cold weather. This group as a whole is able to maintain a temperature of 1·5 to 2·0°C higher than that of the surrounding air. Workers of Polites (a social wasp) fan with their wings to produce a cooling effect. In extreme hot weather they put water on their combs which because of evaporation produces a cooling effect.

In this way it is seen that inspite of lack of heat regulatory mechanisms poikilotherms do have adopted different ways to adapt themselves to the hot or cold conditions.

Thermoregulation in homoeotherms

Homoeotherms, in contrast to the poikilotherms definitely maintain a constant body temperature (which may, however, vary to a very small extent within a certain limited range). Although reptiles are influenced by temperature as far as their body temperature is concerned, they are the first animals to show some kind of thermoregulatory device though at a very primary level. Birds and mammals are the groups that possess highly developed thermoregulatory centres, situated in the hypothalamus and are quite efficient. Homoeotherms work like a thermostat and their body temperature is regulated in the following manner : Whether heat produced or lost, it is adjusted against the environmental temperature by physical processes and the production is regulated by altering the metabolic rates or chemical regulation according to the body requirements.

In cold the heat is lost from the body by convection and radiation. This loss is reduced by lowering the temperature of body surface so as to lower

down the heat gradient between the animal and its atmosphere. As a result the heat given to the surroundings gets lowered and is conserved in the body of the animal itself. Also the loss of heat occurs by the process of conduction. This is quite much in homoeotherms because of their higher metabolic rate. This may be reduced by the presence of an insulating layer between the body surface and the tissue proper. Blood circulation in skin and the presence of layer of fat below the skin which works as an insulating layer in combination with the fur or feathers in the homoeotherms are the mechanisms to combat the loss of heat by both of these probabilities.

In the form of free nerve endings there are a number of temperature receptors in mammalian skin. In cold conditions the cold receptors get excited, increase the discharge of impulses into central nervous system. From there comes the reflex which causes the withdrawl of blood. As a consequence the temperature of inside of the body rises which in turn stimulates the receptors in the brain and finally the local skin reflexes are given. This ultimately leads to the erection of fur or hair. These enclose air within them forming an insulating layer. Also the central reflexes come into play and these cause some changes in the posture of the body as curling up of the body, shivering etc.

Likewise heating produces the reverse effects. More of blood is allowed to move to the skin to cause redness of the skin when more blood circulated through skin it causes more of heat loss. The rate of blood circulation also goes up and the fur and feathers are lowered down so that the insulating layer gets reduced.

The loss of water from the body in the form of sweating is also a method of controlling temperature. More and more water is given out as the temperature rises. For this there are present the sweat glands in the skin of mammals. However, birds, marsupials etc. lack these glands and therefore have to use some other methods for evaporation of water. The extent to which these means of prevention of body heat are present in various animals varies to a large degree. Animals inhabiting the polar regions or Arctic regions have to live in a permanently cold environment and accordingly possess a very thick coat of fur. For example the polar bear. Just opposite to it is the case of desert animals. They have to live almost permanently in hot climate. As a consequence their dermal fat is aggregated to a limited place in the body so that the heat loss may take place through rest of the surface easily. Here example of most common desert animal i.e. camel may be cited in which the dermal fat is found to be concentrated in the hump region. Likewise in aquatic homoeotherms e.g. seal, whales etc. body is so thickly insulated that the inside temperature is quite different from the body surface temperature, which is only slightly different from the temperature of surrounding water. The extremeties of body are not found to be insulated in this way and to compensate this there is found a thick network of arteries

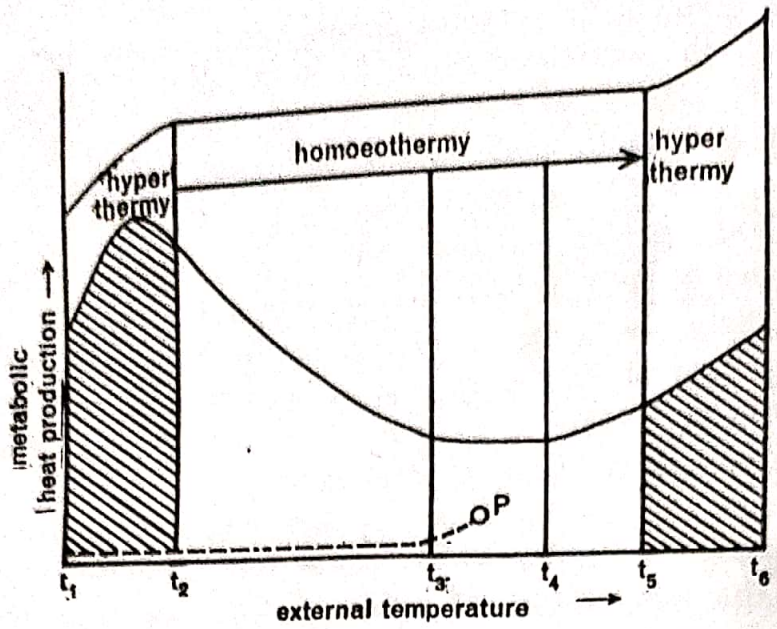

Fig. 7.2. Relationship of metabolic heat production in relation to environmental temperature.

and veins so that the heat gets transferred to venous blood from arterial one and does not get lost.

Homoeothermic animals are further assisted by a few chemical mechanisms in addition to these physical methods in regulating their body temperature. Increased activity of thyroid gland and of adrenal cortex (which finally cause) increased metabolic activity in a few tissues as muscles, liver etc. leading to the increased heat production are a few of them. Pattern of changed heat production as a result of metabolic activity effected by changed environmental temperature is given in Fig. 7.2.

Control of homoeothermy

Control of homoeothermy by the central nervous system is mainly carried out by hypothalamus in the brain. There is one centre for heat and three centres for cold stimulation. As soon as stimulus for heat is received the immediate response given to the skin is dilation of vessels and sweating. Similarly the cold centres respond by constriction of blood vessels, muscular contraction, shivering, retardation and finally cessation of sweating i.e. all the means of retaining heat in the body.

Pituitary gland controls the process by its hormonal secretions and nervous effects are brought about in addition by the motor neurons of spinal cord in case of shivering and autonomic nervous system in sweating and blood vessel constriction.

Heterotherms

Some low grade mammals like *Echidna, Opossum, Ornithorhyncus*, etc. are not very much efficient in maintaining a constant body temperature, and large fluctuation of temperature is observed in them. They may have a temperature that is a bit lower than that of the environment. To some extent their body temperature changes with that of the environment. Similarly a few

birds and smaller mammals (endotherms) show diurnal variations in their body temperature and this correlated with their changed metabolic activity during day and night. Because of the irregular insulation of body the temperature of different parts of body surface are found to differ from each other and also from the inside body temperature. Also the other physical means of temperature regulation work unevenly, leading to variable body temperature. More or less the chemical processes are responsible for maintaining the body temperature of these animals, though in a wide range.

Hibernation

In cold climatic conditions the food is scarce and also the food requirement to conduct normal metabolism becomes very high. Both these lead to many deaths because of starvation.

To prevent deaths from such situation many animals pass their winter in lethargic states. It is a pattern of adaptive hypothermia found in small animals like rodents, insectivores, bats etc. Because of low body temperatures the heat losses get minimised and thus only a small amount of food is required by the animal. Consequently the metabolic rate reduces down. Most of the body activities come to a very low level however, vital activities such as heart beat, respiration etc. continue. During hibernation the animals lives entirely on reserve foods and because they perform very less activities they are said to be in a sleeping state.

Generally the hibernating animals undergo this stage till winter lasts but there are a few in which the phenomenon is known to take place at other times also. For example in Bats we see diurnal changes and they sleep at day time, with a little search for food at night. Thus they behave as hibernators every day and the long winter sleep found in them may be considered as an extension of this daily hibernation.

The arousal from hibernation is a slow and complex process. Slowly and slowly the animal comes to its original metabolic rate and body temperature. The cause of this is thought to be shivering and nonshivering thermogenesis.

Hibernation, in homoeotherms, thus is a mode of temperature regulation against the cold conditions and the animals behave like poikilotherms to some extent. It is found that if the environmental temperature goes below zero the animal regains its own body temperature rather than lowering so much and starts all its metabolic reactions. Thus it is a well regulated process by virtue of which hibernators tide over the most adverse climate and thus is biologically important as it preserves the species.

Aestivation

Hibernation is a phenomenon adopted during hypothermic conditions and aestivation just opposite to it, used to tackle hyperthermic conditions. Many small animals as *Amoeba,* molluscs, even fish are found to enter a state of protection by cocoons. This follows a state of high ambient temperature.

Along with this the decreased water quantity around them, induces conditions of hyperthermia. These protective coverings assist to avoid the conditions of tissue dehydration, enzyme loss, turn off-of metabolic mechnisms, etc.

Acclimatization

Acclimatization is a phenomenon correlating the climatic and metabolic changes. Earlier this term was used to include the metabolic changes associated with the change in temperature and humidity of climate but now it includes all the metabolic changes because of changed O_2 content of water, salinity, food etc. With the climatic changes the overall behaviour of animals also changes and therefore to study any animal its climatic conditions are must to be studied.

Salinity, humidity and other climatic factors at every place and no animal has a constant environment. Thus to difine the process the ecological factors of a particular place are to be taken as constant.

Discontinuous distribution of animals all over the world and the migratory changes show that animals oppose the changed climatic conditions and which donot move, either die or have to change themselves accordingly.

Homeostasis

Animlas have evolved in such a way that there is more control and less variability in internal environment with respect to changed temperature, concentration of different nutrients, pH, O_2 content, degree of hydration and other factors and this control is termed *homeostasis.*

Important Questions

1. What are the effects of extremes of temperature on animals ?
2. Discuss the mechanism of heat regulation in poikilotherms.
3. Write short notes on : (i) Hibernation, (ii) Aestivation, (iii) Heterotherms, (iv) Poikilotherms, (v) Acclimatisation.
4. Describe the mechanisms of thermoregulation in a homeotherm animal.
5. Describe why the lower vertebrates undergo winter sleep. Mention the changes brought about by the animal during hibernation.