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A-Level Biology

Temperature regulation

The body temperature must be kept constant because enzymes work best at specific optimum temperature. For instance, human body temperature is about 36.9^0C which is the optimum temperature for its enzymes. At high temperature above 40^0C enzymes are denatured or too low temperatures lead to slowing of metabolic activities and impairing the activities of important organs such as the brain.

Types of temperature regulation.

Animals can be grouped into two groups basing on the mechanism of this body temperature regulations heat. Heat is lost if the body is hotter than the environment and vice vasa.

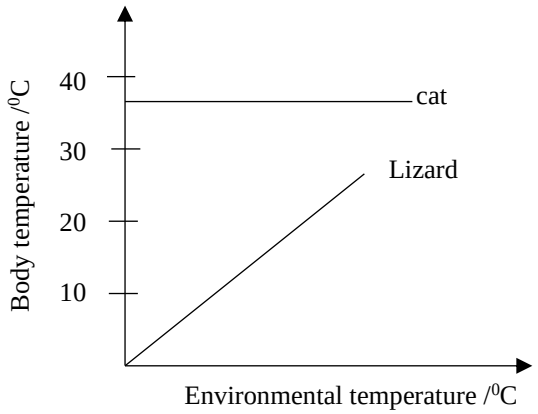
1. **Homoeothermic** or **"warm blooded"** or endothermic animals maintain body temperature by physiological means. i.e. they generate heat when their body temperature falls and increase the heat loss when their body temperature rises, e.g. mammals e.g. cat and birds.

2. **Poikilothermic** or **"cold blooded" or ectothermic** animals have varying body temperature varying with the environment temperature; optimal temperature is maintained by behaviour means, i.e. moving to cold places when it is hot or moving to hot places when it is cold. Examples of ectotherms are lizard, snake, frog.

Note: - The blood of ectotherms is not actually cold

- ectotherms regulate their body temperatures by behavioural means

The figure below shows the relationship between body temperature and environmental temperature for a cat (endothermal) and a lizard (ectotherm).



Advantages of being endothermic animals

1. Survives in a wide range of environmental temperatures
2. Metabolic reactions in the body are always carried out effectively no matter variations in surrounding temperature.
3. The response of the organism to stimuli are always quick
4. High metabolic activities

Disadvantages of endotherms

1. High food consumption to obtain energy
2. High demand for insulation in cold condition

Advantage of ectotherms

1. Low food consumption since it is not used to maintain body temperature.
2. Bodies are less affected by wide environmental temperature variation

Disadvantage of ectotherm

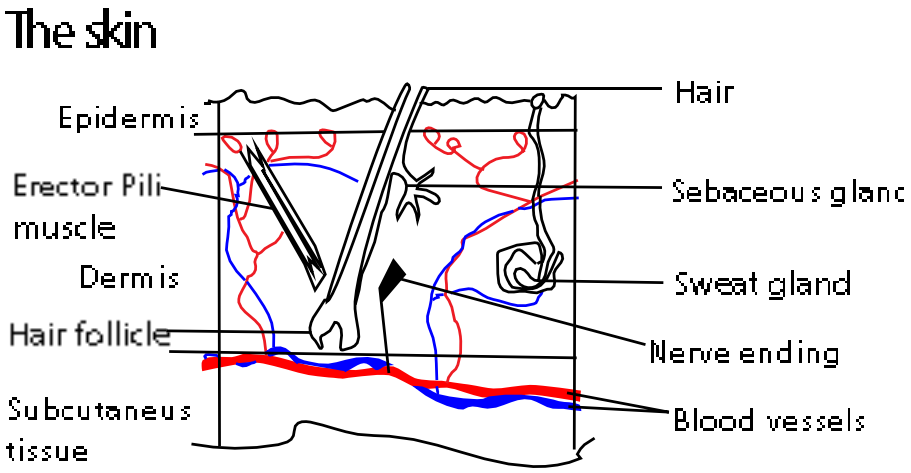
1. Low Basal metabolic rates
2. Slow response to stimuli
3. Limited ecological niches since they cannot survive in extreme temperature changes.

How heat energy is lost or gained.

Organisms loss or gain heat from the environment by four physical processes.

- **Conduction** in the transfer of heat energy from hotter to the cooler of two objects in contact with each other.
- **Radiation** is the heat transfer from a hot body to a cool one that are not in contact. It is a major source of heat loss.
- **Evaporation** is change of a liquid to a vapour, it is accompanied by cooling. This is the cause of cooling accompanied by sweating.

- **Convection:** is the movement of air resulting from local pockets of warm air being replaced by cooler air, and vice vasa. There air movement speeds up loss of heat by radiation and evaporation.
  In addition animals may loss heat through
- Urinating warm urine
- Vomiting
- Spitting
- Defaecating



The skin is divided into two main layers, the **epidermis** at the surface, and the **dermis** beneath. Below the dermis is another layer, not strictly part of the skin, called the **hypodermis.**

The epidermis is made up of **stratified epithelium.** The bottom-most layer of cells, the **Malpighian layer,** contains variable amounts of black pigments **melanin** which protects the body from the harmful effects of ultraviolet rays from the sun.

The cells of the Malpighian layer divide repeatedly in a plane horizontal to the surface of the body. As new cells are formed, the older ones get pushed outwards towards the surface, flattening as they do so. After a time, the cytoplasm become converted into scales of **Keratin,** giving rise to **Keratinised layer** at the surface of the epidermis. The keratinised layer protects the skin from damage and makes it water proof.

Oil is secreted on to the surface of the epidermis by sebaceous glands makes the hair supple and enhances the skin's water proofing properties.

The roots of the hair are embedded in the dermis or hypodermis. Running from the side of each hair follicle to the base of the epidermis is **erector pili muscle.** When this muscle contracts, the hair is pulled into a more vertical position. In this position hair trap a layer of air around the skin thereby insulating the skin from heat loss.

The dermis contains **sweat glands** which secrete a salty solution, **sweat.** The sweat passes down the **sweat ducts** to the surface of the epidermis, and its subsequent evaporation cools the skin and blood flowing through it.

The hypodermis contains variable amount of fat (subcutaneous fat) which insulate and prevent heat loss from the body.

Response of endotherms e.g. man to cold conditions

1. **The hair is raised** and brought into a more-or- less vertical position by contraction of erector pili muscle. Air gets trapped in the spaces between the hairs and being a poor conductor of heat, it serves as an insulator round the animals. In humans the body hair is much reduced, its placed being taken by clothes. Even so the erector pili muscles contract just the same, resulting in "goose pimple". In birds the feathers serve the same function as the hair of mammals, being raised in cold weather.

2. **Vasoconstriction: i.e.** the arterioles leading to the superficial capillaries constrict**.** As a result, the blood flow to the surface of the skin is reduced, thereby cutting down the heat energy from the blood to the surrounding.

3. The metabolic rate increases, the generation of heat inside the body to compensate for heat loss.

4. Decrease in sweating reduce heat loss through evaporation.

5. Shivering: at very low temperature skeletal muscles are stimulated to contract and relax automatically leading to production of heat.

Behavioural mechanism

1. Engaging in exercises (making a lot of noise in some organism)
2. Taking hot drink or bath
3. Wearing heavy clothes
4. Burrowing
5. Hibernation

Response of endotherms to hot conditions.

1. **The hairs are lowered:** by relaxation of erector pili muscles, so they lie flat against the surface of the skin, less air is trapped between the hairs, insulation is therefore reduced, and heat energy can be lost more readily by conduction, radiation and convection.

2. The arterioles leading to the superficial capillaries dilate. As a result, the blood flow to the surface is increased and more heat energy can be lost to the surrounding.

3. **Sweating or panting occur,** and evaporation of water from the moist skin or tongue cools the blood as it flows through the superficial capillaries. As a means of cooling the human body sweating is extremely important. In dogs and cats sweating is substituted with panting.

4. The metabolic rate decreases, reducing heat energy generated in the body.

Adaptations of endotherms to cold environment.

- The animals develop large volume to surface ratio. i.e. the extremities such as ear tend to be small and the animals tend to be larger.
- Animals in cold environment have thicker subcutaneous fat.
- Animal in cold environment tend to have heavy fur or hairs.
- Animals in cold environment develop high metabolic rates.
- Reduced extremities to reduce the surface area for heat loss.
- Animals in cold environment develop arteries and veins in close proximity, such that as blood flows down the arteries, heat energy passes from it to the much cooler blood which is returning in the opposite direction in the veins. The **counter current heat exchange system** is seen in flippers of dolphins and the legs of ducks, both of which are highly happen to be in cold water. It achieves two things. First it means that the arterial blood has already been cooled by the time it reaches the end of the limb, so that relatively little heat energy is lost to the surrounding. Secondly it warms the venous blood before it gets back to the main part of the body.

Adaptations of endotherms to Hot environment.

a. Have thin subcutaneous fat layer to promote heat loss
b. Are small compared to their counterpart in cold region to provide bigger surface area to volume ratio
c. Have large extremities to increase the surface area for heat loss.
d. They have many sweat glands to produce sweat whose evaporation cools the body
e. Have less fur

Behavioural control of body temperature

Many ectoderms respond to high environmental temperature by

- Moving to cool places
- Thermal gaping
- Aestivation
- Migration to cooler places

Ectoderms respond to cool environment temperatures by

- Moving to warm place
- Basking
- Sleeping in piles to reduce heat loss
- Burrowing

Adaptations of animals to live in cold environment

- Hibernating is a behavioural response by many temperature and artic animals to very cold temperature. The animal responds to very cold temperature by going into a deep sleep. The metabolic rate falls to the minimum required to keep life ticking over. The body temperature also falls, and is maintained at a much lower level than normal. Hibernation saves these animal of expending large heat energy in winter whilst the food is scarce surviving extremes of temperatures.

- **By super cooling:** Super cooling is the lowering of the temperature of a fluid to below its freezing point without the formation of ice. Ice crystals can damage tissues and super cooling provides a way of avoiding this. Experiments have shown that certain reptiles can be super cooled to as low as -8^0C without freezing. Plants and fishes also go in for super cooling.

- By freezing tolerance. Some organisms, notably plants and insects can tolerate the formation of ice in their tissues. Certain insects' larvae can recover after as much as 90% of the body has been frozen. In these organism's ice crystals form between, rather than inside the cells; later when the ice melts. In some species of fish ice damage is lessened by the presence of glycol in the tissues. glycerol is used in human blood banks and sperm banks to prevent injury to the cells when they are frozen for storage.

- **By using an antifreeze:** some fish employ anti-freeze such as glycerol and glyco-protein to lowers the freezing point so that the body fluids do not freeze in winter.

What about high temperatures?

The main adaptation here is tolerance. This enables certain types of algae to flourish in hot springs at temperatures of 55 to 60^0C. However, it is prokaryotes that show the greatest tolerance. There are many reports of bacteria growing in boiling hot springs to North America and New Zealand, but the jackpot must go to certain bacteria which have been discovered in the hot water rising from sulphate encrusted vents in the deep ocean floor. Some of these bacteria were living at temperatures of 350^0C. It is claimed that in the laboratory they reproduced enthusiastically in sea water at 250^0C, doubling in number every 40 minutes. Heat tolerant bacteria possess membranes which are more heat stable than those of other prokaryotes, and their enzymes work optimally at temperatures well above those that would denature the enzymes of other organism. e.g. **Thermophilus,** a bacteria which lives in hot springs, possesses enzymes that work best at 80^0C.

The brain and temperature regulation

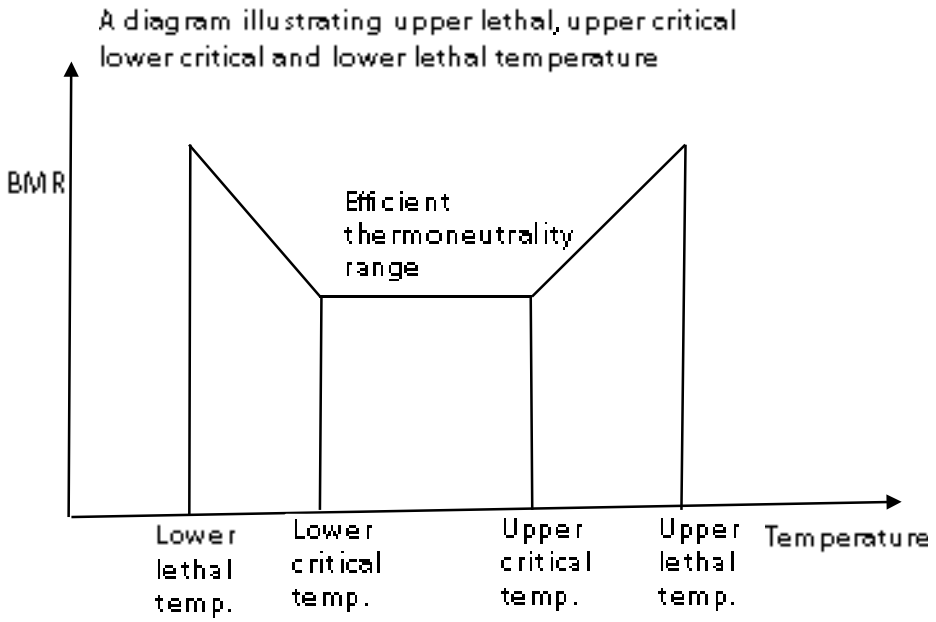
Thermoregulation centre in the brain is found in hypothalamus. Hypothalamus is sensitive to the temperature of blood flowing through it and responds by sending nerve impulses to the appropriate effector. If the temperature of blood is higher than normal, the thermos regulatory centre detects this and sets into motion the various processes that cool the body and the vice versa.

The upper and lower critical temperature of the body.

(a) The lower critical temperature.

The lower critical temperature is the environment temperature below which physical mechanism such as insulation cannot maintain body temperature. The lower critical temperatures are lower for arctic mammals (e.g. Eskimo dog, white fox) than for tropical mammals such as man
The lower critical temperature for arctic mammal is about -40^0C while that of man is 27^0C.
When the animal is cooled below the lower critical temperature, the basal metabolic rate increases to maintain the body temperature until the temperature reaches the lower lethal temperature below which the organism dies for failure to maintain body temperature.

Artic mammals have lower critical and lethal temperature due big layer of subcutaneous fats and thick fur for insulation; they have small extremities and their arteries and veins from extremities are close to each other to reduce heat loss.



(b) The Upper critical temperature.

The upper critical temperature (29^0C for man) is the environment temperature above which physical mechanism such as sweating, lowering hair cannot maintain body temperature. The upper critical temperatures are lower for arctic mammals (e.g. Eskimo dog, white fox) than for tropical mammals such as man

When the environmental temperature rises above the upper critical temperature, the basal metabolic rate increases due to increase in body temperature and enzymatic controlled reaction up to the upper lethal temperature above which enzymes are denatured and the organism dies.

Desert animal have higher critical and lethal temperatures than artic animals because the have low fat deposits and less hair to insulate the body

Temperature control in plants

- Transpiration lowers escalating temperature.
- Shiny cuticles reflect heat radiated by the sun.
- Having small leaves reduce surface area for heat absorption.

Exercise

1. Which one of the following conditions is correct about ectoderms?
   A. Have cold blood which is warmed by the surrounding
   B. Regulate body temperature mainly by metabolic reactions
   C. Much of the heat in their bodies is gained from the surroundings.
   D. Lack means to regulate body temperature.
2. A mammal eats more food than a reptile of equivalent body weight because the mammal
   A. Lives longer
   B. Controls its body temperature
   C. Egests more food
   D. Does not s absorb heat from its surrounding
3. Which one of the following occurs in a mammal when its thermoregulation centre detects a lower temperature of blood than normal?
   A. Shivering
   B. Decreased metabolic rate
   C. Flattening of body hair
   D. Increased sweating
4. The main difference between endotherms and ectoderms is that ectotherms
   A. Gain their body heat from internal sources
   B. Gain less heat than endotherms
   C. Gain the body heat from external sources
   D. Are lower animals while endotherms are higher animals.
5. Desert mammals' lower lethal temperature is higher than that of a mammal living in cold regions because a desert mammal has
   A. Small extremities
   B. Poor insulation mechanism
   C. Thick fur
   D. Small surface area: volume ratio
6. Which one of the following is the reason for hibernation of a humming bird every night?
   A. Its metabolic rate is so high
   B. It is too cold
   C. It feeds on nectar from flowers which close at night
   D. Its relatively large surface area would lose too much heat
7. Which one of the following may happen when a mammal is subjected to severe cold?
   A. The superficial blood vessels are dilated
   B. The hair is lowered
   C. Sweating or panting occur
   D. The rate of metabolism increase

8. Heat loss is most efficiently reduced in body extremities of endotherms having

A. Veins and arteries parallel and close to each other
B. Thick fur
C. Thick subcutaneous layer
D. few sweat glands

9. Which of the following is a chemical mechanism of coping with cold environment in mammalian body?
A. Vasoconstriction
B. Shivering
C. Raising of body hair
D. Insulation by the subcutaneous fat
10. Which one of the following structures are characteristics of hydrophytes?
A. Small leaves with thick cuticle
B. Broad and thick leaves with thin cuticle
C. Broad and thin leaves with large air spaces
D. Broad thin leaves with hairy surface
11. Which of the following adaptation would not assist animals living in arid environment?
A. Possession of thick fur
B. Ability to reduce filtrate volume
C. Us of metabolic water
D. Possession of special reabsorption mechanism
12. Temperate mammals such as polar bear have lower lethal temperatures than tropical ones. This is because of
A. Better insulation mechanisms in the tropical mammals
B. Body colour
C. Larger size in temperate mammals
D. Better insulation mechanism in temperate mammals
13. A mammal eats more food than a reptile of equivalent body weight because the mammal

A. lives longer.

B. controls its body temperature.

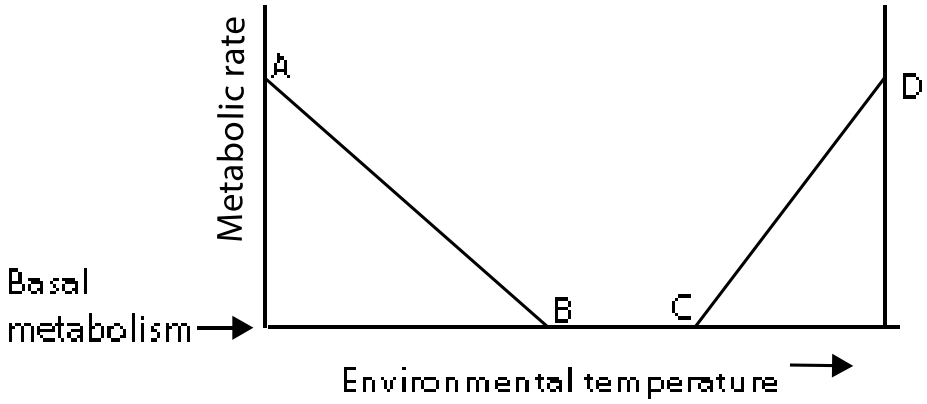
C. egests more food.

D. does not absorb heat from its surroundings.

14. Which of the following environmental factors has a direct effect on all organisms
A. Light
B. Humidity
C. Temperature
D. Rainfall

Paper 1 section B

15. Figure below shows the variation of metabolic rate with environmental temperature in a mammal



(a) What do points B and C represent?

(i) B …… (1mark)

(ii) C …… (1mark)

(b) Explain why the metabolic rate

(i) Is constant between points B and C (1mark)

……

……

(ii) Increases from point B to A (2matks)

……

……

(iii) Increases from C to D (3marks)

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……

(c) Explain how point B would differ between an animal living in cold regions and that living in warm region. (02marks)

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16. (a) (i) Outline the general features a physiological homeostatic system must have (3marks)

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(ii) What are the qualities of an efficient homeostatic system? (2marks)

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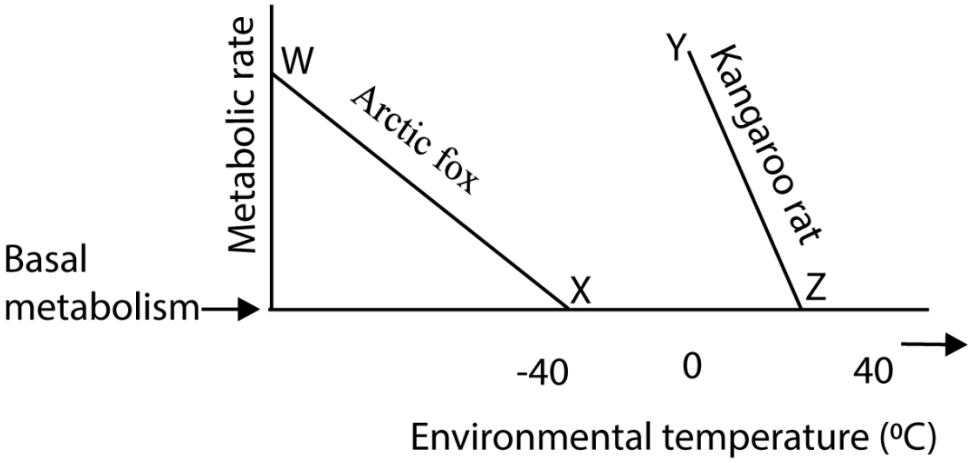
……

(b) Figure below shows the metabolic rates of the arctic fox (curve WX) and the Kangaroo rat (curve YZ) in relation to environmental temperature.



(i) What do points X and Z stand for? (1mark)

……
……

(ii) Give two differences in metabolic rates of the Kangaroo rat and the arctic fox in relation to environmental temperature. (2marks)

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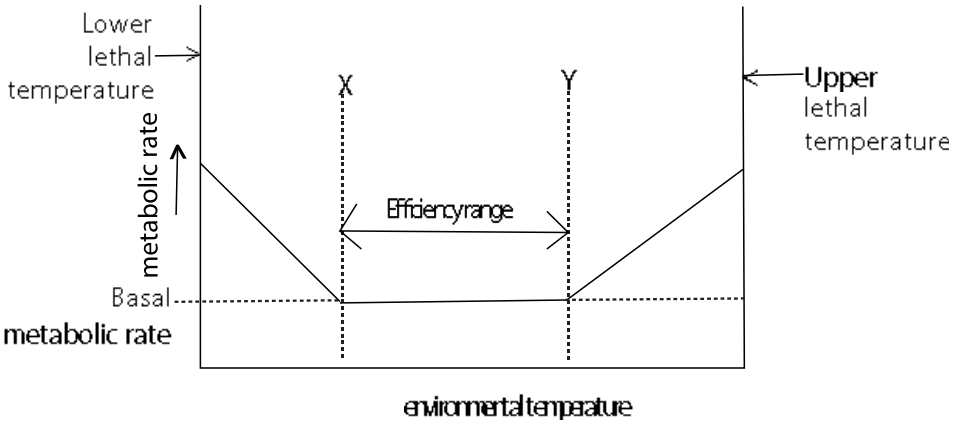
……
……

(iii) What do the differences you have stated (b)(ii) imply? (2marks)

……
……

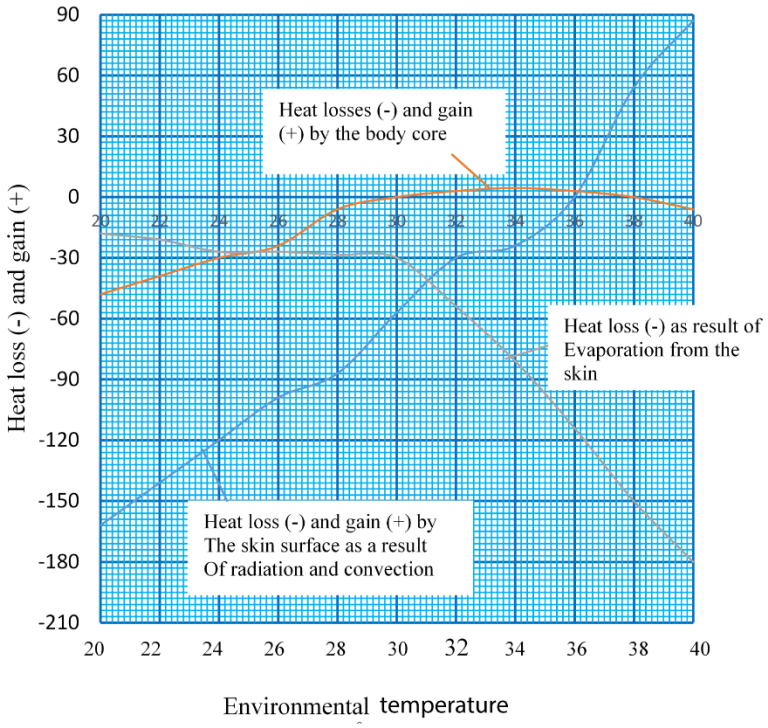
17. The figure shows the variation of metabolic rate with environmental temperature in a mammal



(a) What do temperature X and Y represent? (01marks each)
   (i) X ……
   (ii) Y …….
(b) What does the efficiency range mean? (02marks)
(c) Explain the variation of metabolic rate with environmental temperature outside the efficient range. (05marks)
(d) The efficiency range is not fixed but differs from animal to animal. Giving a reason, state how point X would differ between animals living in cold environment and that living in a hot environment. (02marks)

Assay questions

18. Heat loss (-) and heat again (+) were monitored and recorded, of a naked human being at varying environmental temperatures. The heat losses and gain by the internal body environment body core), heat losses and gain by the skin surfaces as a result of radiation and convection and also heat losses as a result of evaporation, with varying environmental temperature, are shown in figure below:
Study the figure and answer the questions that follow



(a) Describe the relationship between the heat loss and again by the skin surface as a result of radiation and convection and heat loss as a result as a result of evaporation from the skin. (4marks)
(b) How does the relationship in (a) affect the losses and gain of heat from the body core (3marks)?
(c) Explain the trend I heat losses and gain by the
    (i) Skin surface as a result of radiation and convection (10marks)
    (ii) Skin surface as a result of evaporation (08marks)
    (iii) Body core (12marks)
(d) What is the importance of maintaining body temperature in animals (3marks)

19 (a) Explain body size contribute to the survival of mammals in cold habitats (3marks)
(b) Describe how a camel is able to overcome heat stress in its habitat?

Answer to objective type questions

1.	D	4.	C	7.	D	10.	C	13..	B
2.	B	5.	B	8.	A	11.	A	14.	C
3	A	6.	D	9.	B	12	D		

Structured questions

15. (a)(i) B – lower critical temperature
C – higher critical temperature
(b)(i) Between B and C metabolic rate is constant because behavioural and physical means are enough to maintain body temperature.
(ii) B-A metabolic rate increases to generate heat for maintenance of body temperature
(iii) C to D metabolic rate increases because increase in temperature increases the rate of enzyme action
(c) Temperature B is lower for animals living in cold environment because they have higher insulation, (i.e. large subcutaneous fat and thick fur).

16. (a)(i) A physiological homeostatic system must have
- Receptor capable of detecting changes in environment
- A control mechanism/ regulator that initiates a corrective mechanism.
- Effector that carry out the corrective measure.

(b)(i) X – Lower critical temperature of the arctic fox.
Z- lower critical temperature of Kangaroo rat.
(ii) – metabolic rate of arctic fox starts to raise at a lower critical temperature than that of Kangaroo rat
- Below the critical temperatures, the metabolic rate of arctic fox raise less steeply compared to that of Kangaroo rat.

(iii) the arctic fox can survive better in cold environment than Kangaroo rat because it has a better insulation.

17. (a)(i) X – lower critical temperature
Y- upper critical temperature
(b) in efficient range the body is able to control its constant temperature by behavioural and physical means.
(c) Below the lower critical temperature metabolic rate increase to generate heat to maintain the body temperature

Above the higher critical temperature metabolic rate increases due to increase the enzymatic activity.
(d) X is lower for animals living in cold environment because they have higher insulation i.e. thick fur and big deposit of subcutaneous fats.

18. (a) At 20^0C, heat loss by radiation and convection is much higher (162 units) than that due to evaporation from the skin (18units)

Between 20-27^0, heat loss by evaporation from the skin increases gradually while loss through radiation and convection decreases rapidly.

Between 27-28.8 ^{0}C, loss through evaporation is constant while loss through radiation and convection continues to reduce.
Between 28.8 -31^{0}C, evaporation loss begins to increase more rapidly to equal to the due to radiation and convection by 31^0 C.

From 31 -40^{0}C, loss through evaporation increases very rapidly while that through radiation and convection decreases more gradually to zero at 35.0^{0}C and then the body starts gaining heat through radiation and convection rapidly up to 40^{0}C.

(b) At 20^{0}C, the body core is losing heat at a rate of 51units.
Heat loss decreases gradually from 20^{0}C until it reaches zero at 30^{0}C
From 30 -33^{0}C, the body core gains heat gradually and then at a constant rate between 34^{0}C and 37.4^{0}C.

Between 37.4 -40^{0}C, the body loses heat gradually.
(c)(i) At 20 ^{0}C, the body is at a much higher temperature than surrounding and so the temperature gradient is high, favouring loss of heat from the body surface mainly by radiation convection.

As environment temperature increases, the temperature gradient reduces so that heat loss through radiation and convection reduces while that through evaporation increases gradually .
Between 32 -35.4^{0}C, the temperature gradient is so small that heat loss through radiation and convection reduces more gradually until it reaches zero at 35.4^{0}C.

Between 35.4 -40^{0}C, now the temperature gradient reverses so that environment temperature becomes higher than body temperature. As a result, the body starts to gain heat by radiation and convection from the environment.

(ii) At 20^0C, external temperature is very low compared to the normal human body temperature. As a result, the skin surface blood vessels constrict to reduces blood flow to the skin and also the rate of sweating is greatly reduced by the thermoregulatory Centre. As such, loss of heat by evaporation from the skin surface is low.

At the same time, the erector muscles and skin surface hairs are standing on end. This traps a layer of air close the surface, which on top of being insulator, also traps vapour close to the skin

As a result, the rate of evaporation from the skin surface is very low.

As temperature increases, between 20 -27^0C, the vapour trapped in the hairs evaporates and also the rate of blood flow to the skin improves, sweat production increases and therefore heat loss by evaporation increases gradually.

(iii) Heat loss from body core occurs by a combination of radiation, convection, evaporation and conduction however, the body has regulatory mechanisms that resist subtle changes in core body temperature.

At 20^0C, body is losing heat by a combination of evaporation, radiation and convection.

However, much of the heat is lost through radiation and convection.

- To resist subtle drop in core body temperature, metabolic rate of the body core increase and the individual starts to shiver. These activates generate heat within the body core to make up for the losses from the body surface.
- As a response to low core body temperature, the hypothalamus triggers a reduction in sweat production, reduction in blood flow to the skin surface and contraction of the erector pili muscles so that the surface hairs stand on end.

All these events reduce heat loss from the body core from the body core until is it zero at 30^0C

As environment temperature comes close to the core body temperature remains constant for the range 34.8 – 37.4^0C

Above 37.4^0C, events are reversed in order to prevent subtle increases in core body temperature.

- The erector muscles relax so that the surface hairs lie flat on the skin surface, trapping no air between them.
- Blood flow to the skin surface is increased and
- Sweating increases so that heat loss from the body surface by evaporation increases greatly.
- Metabolic heat production and shivering stop.

The end result is that the body core starts to lose heat to the environment from 38-40^{o}C in order to give off the excess heat and maintain a constant body temperature

(d) Temperature must be maintained at a value optimum for the action of enzymes upon which the organized functioning of cells depends. At higher temperature Enzymes being protein in nature are denatured while at low temperature they are inactive.

19. (a) Mammals in cold habitats usually have a large body size as a result of extra fat deposits under the skin.

- The big size reduces the surface area to volume ratio and therefore reduces the rate of heat loss from their bodies across the surfaces.
- The fat deposits under the skin insulates and prevents heat loss to the environment.

(b) Strategies of the camel to overcome heat stress include:

- Possession of tissues which are tolerant to wide ranges of temperature.
- The camel stores heat in its tissues during day when temperature are very high and then loses it during the night by radiation, conduction and convection and not evaporation, when temperatures are low
- During the day, the camel behaves like an ectothermic animals, allowing its temperature to get close to those of the environment. This reduces the temperature difference between the hot air of the desert and its body so that the rate of heat gain from the surrounding is reduced.
- The fur that the camels skin acts as an efficient insulating barrier by reducing heat gain and loss by convection and conduction.