THE REGULATION OF THE INTERNAL ENVIRONMENT

01. Overview of homeostasis

The term "homeostasis" was proposed by Walter Bradford Cannon, an American physiologist during the 1920s, from the Greek "homoios" (equal, similar to), and "stasis" (state, position): "The coordinated physiological processes that maintain balance in the organism are so complex and so particular to creatures that they will involve the brain, the heart, the lungs, the kidneys and the spleen, all working cooperatively that I suggested a definition for these states, it is homeostasis".

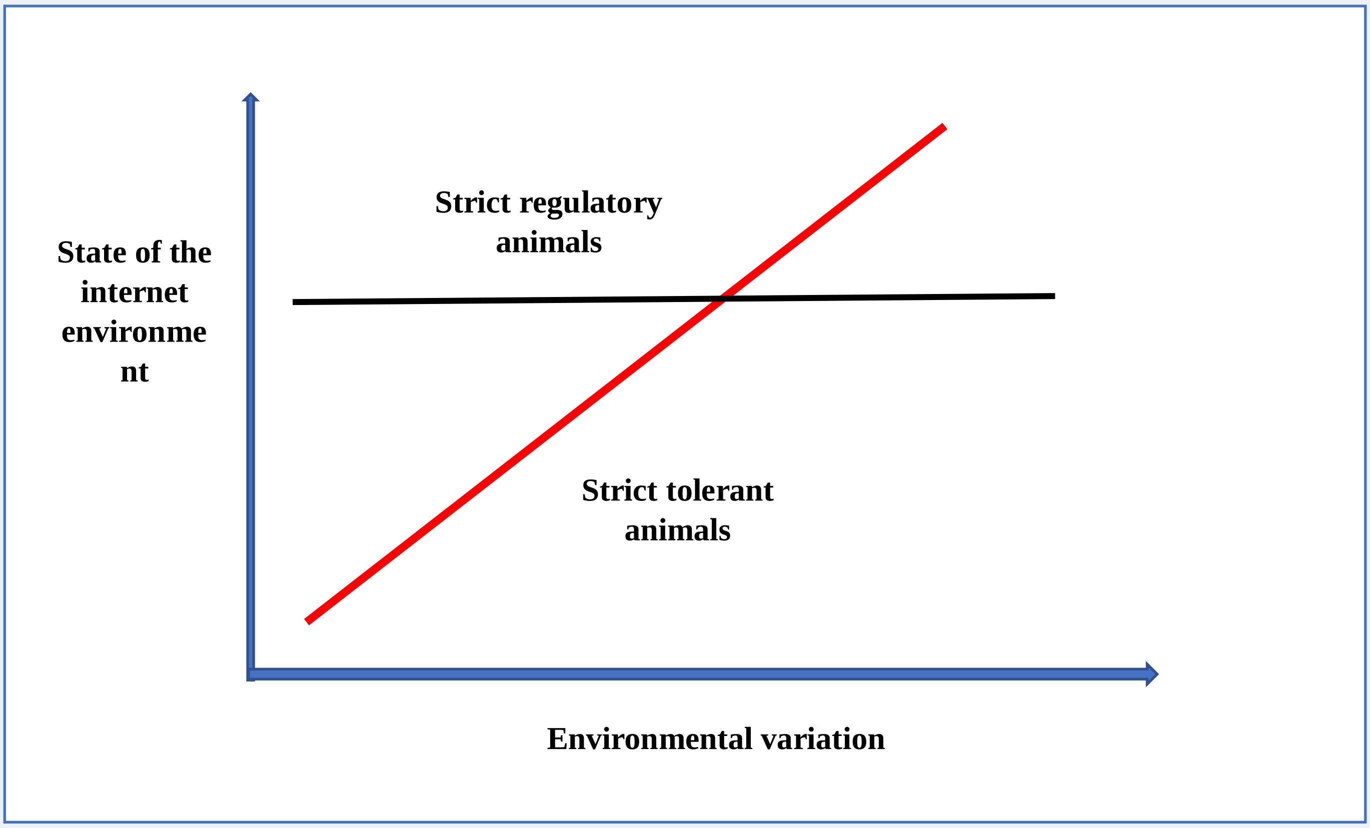
The word does not imply that something is at rest or motionless. Homeostasis: constant state! It means a condition - a condition that can vary, but is relatively constant" → "Regulation of the physiological constants of the inner environment"

1.1.Regulation and tolerance :

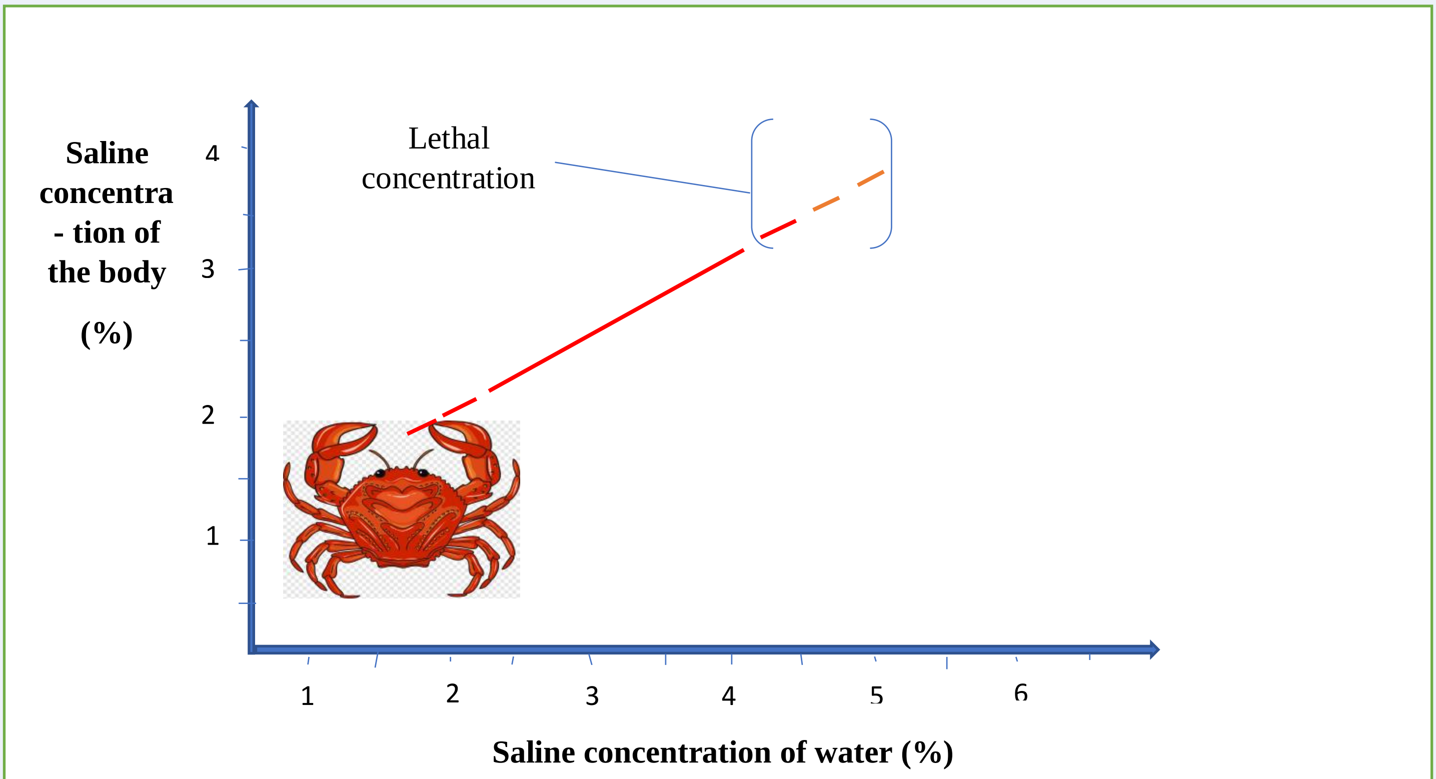
Regulation and tolerance are the two opposite reactions of animals to fluctuations in the environment.

An animal is qualified as a regulator with regard to a particular environmental variable if it uses homeostatic mechanisms to mitigate the change in its internal environment when its external environment fluctuates. For example, endotherms such as Mammals and Birds are thermoregulators: they maintain their body temperature around a reference value, regardless of changes in the temperature of the surrounding environment. Another example, Salmon spend part of their lives in salt water, and the other part, in fresh water. This change in their "osmotic environment" leads them to use osmoregulatory mechanisms to maintain normal concentrations of solutes in their blood and in their interstitial fluid.

Compared to these regulators, many other animals, especially those that live in relatively stable environments, are qualified as tolerant, because they support variations in their internal environment related to certain changes in the external environment (pic. 1a). Many marine invertebrates, such as the Spiders of the genus Libinia, live in environments where the salinity is relatively stable and they do not possess structures capable of osmoregulation. If they are placed in water whose salinity is variable, their only possible reactions consist in absorbing or rejecting water to adapt to the external environment, even if this internal response can cause their death in extreme situations (picf. 1b).



A). "When faced with a specific environmental variable, some animals regulate their internal environment, maintaining a near-constant state regardless of external fluctuations. Others exhibit tolerance, allowing their internal environment to vary with changes in the external environment. Most animals, however, demonstrate a combination of both strategies



Pic 01. comparison of the state of the internal environment of regulatory animals and tolerant animals

B). Sea spiders of the genus Libinia are osmoconformers. They are largely unable to regulate their internal salt concentration, which fluctuates in accordance with limited variations in the salinity of their natural environment. When subjected to laboratory conditions with salinities below 2.3% or above 4%, these crustaceans experience severe osmotic imbalances, leading to fatal water gain or loss. Despite their tolerance to certain salinity variations, these organisms lack the physiological mechanisms necessary to actively excrete or absorb

Strict tolerant or strict regulatory animals represent two limiting categories of a continuum. Most animals fall between these two extremes. For example, salmon perform osmoregulation while being tolerant of fluctuations in external temperature.

"Depending on the situation, most Animals use a combined form of these two strategies".

3.2. Homeostasis balances the gains as well as the losses of energy and matter in animals :

Like all organisms, animals are open systems that exchange energy and matter with the environment: food must provide them with essential nutrients and chemical energy; oxygen is essential for cellular respiration; CO_2 and other metabolic waste must be eliminated; heat and water must be exchanged; and so on. These incoming and outgoing flows of energy and substances are often fast and variable, but it is necessary that the animals maintain internal conditions relatively constant. This is how losses and gains must balance each other, otherwise possibly fatal imbalances may occur. In normal times, the amount of energy and matter that enters an animal does not exceed that which leaves, unless the animal is in a period of growth or reproduction.

Since homeostasis requires a precise balance of matter and energy, it can be considered as a set of allocations with gains and losses (thermal, energy, water allocations, etc.). Most of the allocations of energy and matter are interrelated: changes in the flow of one element are reflected in the exchanges of other elements. For example, when terrestrial animals exchange gases with the environment by breathing, they also lose water through a vaporization that takes place on the moistened surface of their lungs. These losses must be compensated by the absorption of an equivalent amount of water (in food or liquids). In addition, vaporization causes the body to lose heat, and this loss must be compensated for by the production of an equivalent amount of heat from another source.

3.3. The regulation of body temperature :

Thermoregulation is the mechanism by which animals maintain their internal temperature within an interval compatible with life. This ability is essential for survival because most biochemical and physiological processes are extremely sensitive to variations in body temperature. The speed of most enzymatic reactions decreases by a factor of two or three for each temperature decrease of 10 °C. The rise in temperature causes a slight acceleration in the speed of the enzymatic reactions until it becomes critical and the proteins begin to denature. For example, as the temperature rises, hemoglobin binds less efficiently to oxygen. The temperature also influences the properties of the membranes.

Each animal species has its own optimal temperature interval. Thermoregulation makes it possible to maintain body temperature in this interval, which allows its cells to function efficiently even if the external temperature fluctuates.

3.3.1. Endothermy and ectothermy :

The internal metabolism and the external environment are the heat sources of thermoregulation. Birds and Mammals are mainly endotherms, which means that metabolic activities constitute their main source of heat. Some reptiles, some Fish and many insect species are also endotherms. Most invertebrates, Fish, amphibians, lizards, snakes and turtles are ectotherms. They get almost all of their heat from their environment.

When we say of an animal that it is endothermic or ectothermic, we mean that it is mainly one or the other. It should be borne in mind that endothermy and ectothermy are not mutually exclusive modes of thermoregulation. For example, a bird is, first of all, an endotherm, but it can warm up in the sun in cold weather, like a lizard, which is an ectotherme.

The endotherms manage to maintain a very stable internal temperature even when the temperature of the environment fluctuates. This is why few ectotherms are active during the few months when freezing cold reigns over a large part of the Earth's surface.

3.3.2. Variations in body temperature :

The body temperature of animals can vary or be constant. An animal whose temperature which varies according to that of the environment is a poikilotherm (from the Greek poikilos, which means "variable"). Conversely, a homeotherm is an animal that maintains a relatively stable internal temperature. For example, largemouth bass is a poikilotherm, while river otter is a homeotherm.

The description of the ectotherms and of the endotherms may suggest that all the ectotherms are poikilotherms and that all the endotherms are homeotherms. In fact, there is no direct link between the heat source and the stability of body temperature. For example, many marine fish and invertebrates inhabit waters whose temperatures are so stable that their body temperature varies even less than that of humans and other mammals.

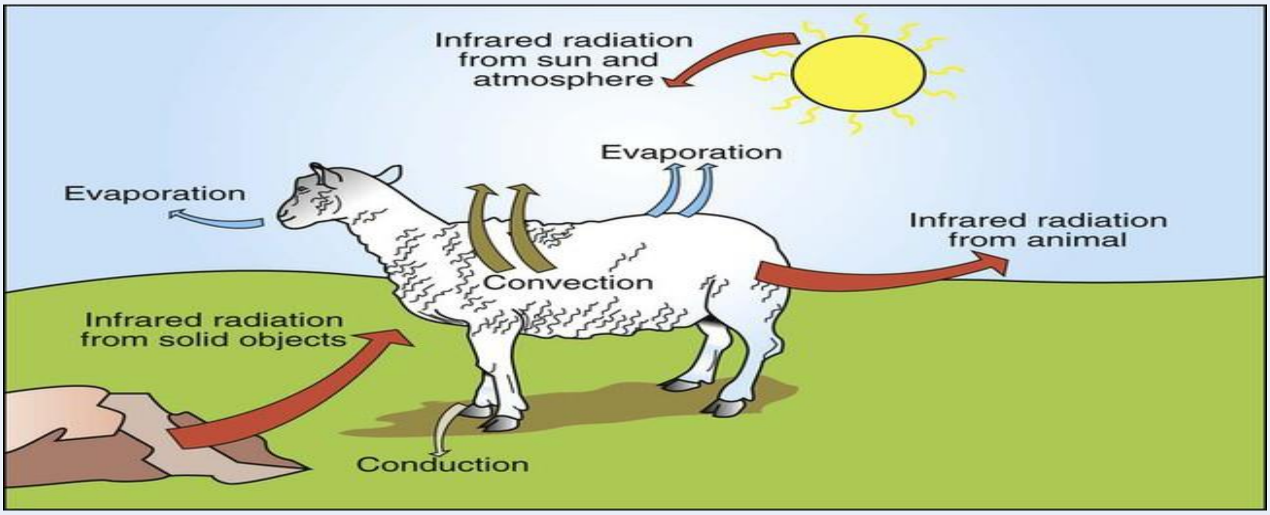
Conversely, some endotherms experience large variations in their internal temperature. For example, bats and hummingbirds can periodically enter a lethargic state marked by a decrease in their body temperature.

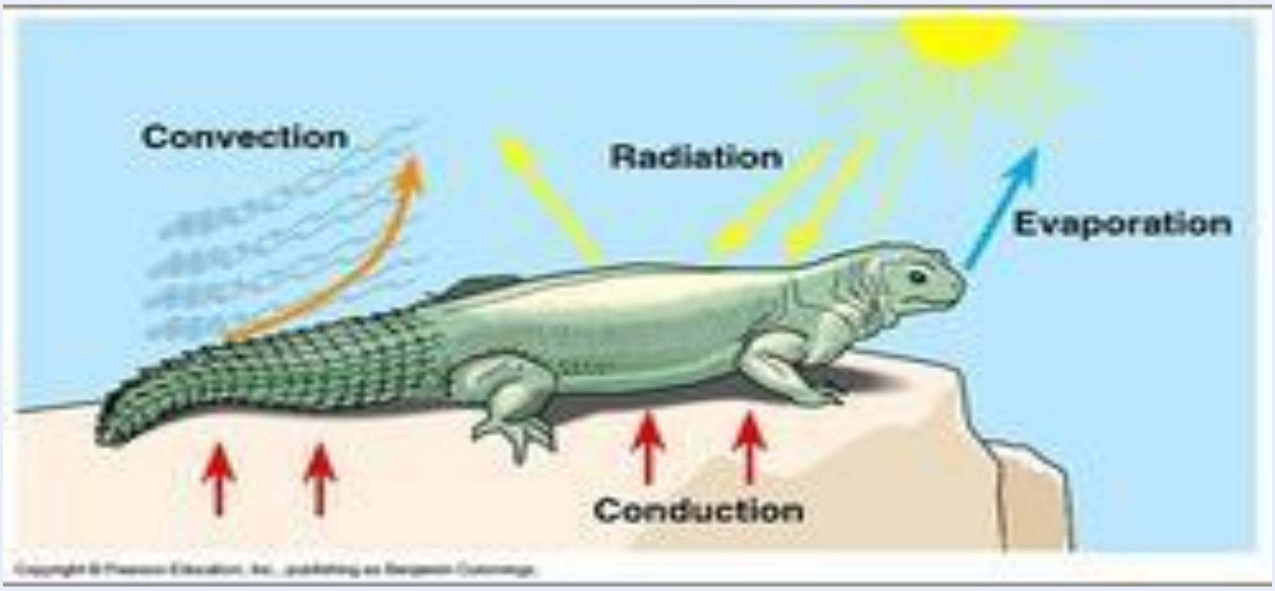
The idea that ectotherms are "cold-blooded" animals and that endotherms are "warm-blooded" animals constitutes another common misconception. The body temperature of ectotherms is not necessarily low. In fact, when they heat up in the sun, the internal temperature of many ectothermic lizards is higher than that of Mammals. Therefore, most scientists prefer not to use the terms cold-blooded and warm-blooded, which can mislead.

3.3.3. The balance between heat loss and gain :

Thermoregulation is the ability of an animal to modulate heat exchange with its environment. Like all objects, ectothermic and endothermic organisms exchange heat through four physical processes: conduction, convection, radiation and vaporization. Fig. 2 characterizes each of these mechanisms by which heat circulates in the organism and diffuses into the environment. It should be noted that heat always spreads from an object where the temperature is high to an object where it is lower.

Thermoregulation consists in maintaining an amount of heat equivalent to the amount of waste heat. Animals achieve this through mechanisms that reduce heat exchange as a whole or that favor the passage of heat in a particular direction. In mammals, several thermoregulation mechanisms are associated with the integumentary system, that is to say with the outer layer of the organism, consisting of the skin, hair and nails (claws or hooves in some species).





Picture 2 : Heat exchanges between an organism and her environment

1.Convection : contributes to heat exchange when air or water circulates on the surface of an animal.

2.Radiation : all objects whose temperature is above absolute zero emit "electromagnetic energy. here the lizard absorbs certain solar radiations, the energy it accumulates in this way is greater than that which its body loses by thermal radiation in the environment.

3.Animals can warm themselves through conduction by basking on rocks hotter than their bodies. This is a common behavior in reptiles.

- Reptiles often regulate their body temperature by conducting heat from warmer objects, such as rocks.

4. An animal loses a certain amount of heat due to the evaporative cooling of its body's moist surfaces exposed to the environment."

- « An animal loses some heat through the evaporation of moisture from its body surface.

➢ **The insulation**

Insulation constitutes a great thermoregulatory adaptation in Mammals and birds. It consists in reducing the heat flux between the body and the environment, and in lower the energy cost of maintaining the temperature. The hairs, feathers and fat layers formed by the adipose tissue contribute to the insulation.

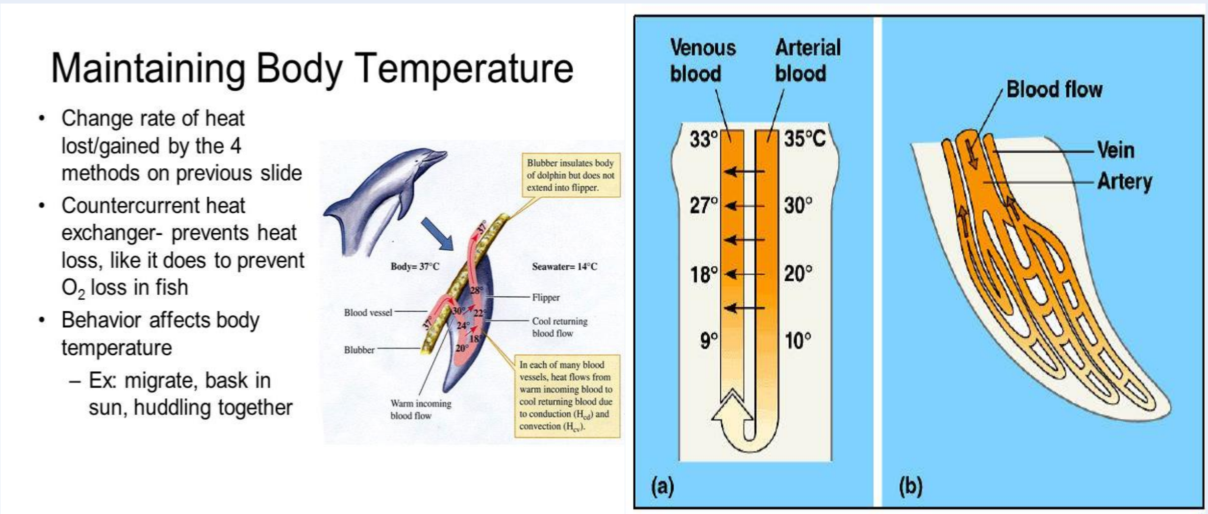
Many animals that rely on insulation to ensure their thermoregulation have insulating layers that they can take advantage of to reduce heat loss. Most terrestrial mammals and many birds react to the cold by inflating their fur or feathers. In doing so, they trap a thicker layer of air, which significantly increases the insulating capacity of the plumage or fur. To repel water that would reduce the insulating capacity of their feathers or their hair, some animals secrete oily substances, such as those that birds apply to their feathers when smoothing. Insulation is particularly important for marine mammals such as whales and walruses. These animals swim in water whose temperature is much colder than that of the inside of their body. Many of these species spend at least part of the year in polar seas where the water almost reaches freezing point. Their thermoregulation is all the more difficult since, in water, the loss of heat by conduction is 50 to 100 times faster than in air. This is why marine mammals have a very thick layer of insulating fat under their skin, called bacon. This bacon is so effective that it maintains a body temperature of the order of 36 to 38 ° C and its metabolism is comparable to that of terrestrial mammals.

- **Regulation of blood circulation :**

The circulatory systems play an important role in the heat exchange between the internal medium and the environment. Adaptations that regulate the circulation of blood close to the surface of the body or that keep the heat in the center of the body are essential for thermoregulation. In response to variations in the temperature of their environment, many animals can modify the amount of blood (and therefore heat) that circulates between the internal parts of their body and their skin. A high blood supply to the skin normally results from vasodilation, i.e. the increase in the diameter of the superficial blood vessels. Vasodilation is triggered by nerve impulses that produce a relaxation of the muscle fibers of the vessel wall. These expand, then leading to an increase in blood circulation. In endotherms, vasodilation generally warms the skin, which increases the transfer of heat from the body to the environment by radiation, conduction and convection (see Figure 2). The reverse process is vasoconstriction, which reduces blood supply and heat transfer by decreasing the diameter of the superficial vessels. It is the mechanism of vasoconstriction in the ears that allows the hare not to suffer from heat stroke under the sun from the desert.

To reduce heat loss, many birds and Mammals have to rely on countercurrent heat exchange, that is, on the transfer of heat (or solutes) between liquids that circulate in opposite directions. In a countercurrent heat exchanger, the arteries and veins pass close to each other (Fig. 3). Thanks to this arrangement of blood vessels, the warm blood that arrives from the center of the body through the arteries is found to transfer its heat to the less warm blood that returns from the extremities through the veins. Since the blood from the veins and arteries flows in opposite directions, heat transfer takes place along the entire length of the exchanger, which maximizes the exchange process.

Sharks, fish and insects also use the heat exchanger against the current. Although sharks and fish are heat-tolerant animals, some of them, including the great white shark, bluefin tuna and swordfish, have countercurrent heat exchangers. This adaptation favors the vigorous and sustained activity of these animals, because it allows them to keep their main swimming muscles at a temperature a few degrees higher than that of the tissues on the surface of the body. Similarly, many endothermic insects (bumblebees, honeybees) have a countercurrent heat exchange mechanism that maintains a high temperature in their thorax, where their wing muscles are located.



Picture 03 : the countercurrent heat exchangers

- In the fins of a dolphin, each artery is surrounded by several veins.forming a countercurrent heat exchanger, this perm device and an efficient heat transfer between the arterial blood and the venous blood.
- The arteries transporting hot blood along the animal's limbs are in close proximity to the veins transporting cooler blood in the reverse direction, toward the center of the body. This mechanism facilitates heat transfer from the arteries to the veins throughout the length of the blood vessels.
- Close to the extremity of a limb or fin, where the arterial blood has cooled down to a temperature much lower than the animal's normal internal body temperature, the artery can still transmit heat to the colder blood flowing in a nearby vein. The venous blood keeps.

absorbing heat because it travels alongside warmer and warmer arterial blood moving in the opposite direction.

- Near the end of a limb or fin, where the arterial blood has cooled, so that it reaches a temperature significantly lower than the normal internal body temperature of the animal, the artery can still transfer heat to the colder blood passing in an adjacent vein. The venous blood continues to absorb heat because it moves in proximity to the increasingly warmer arterial blood flowing in the opposite direction.

3.3.4. Cooling by heat loss due to vaporization :

Many mammals and birds live in environments where thermoregulation involves cooling and warming mechanisms. If the temperature of the medium is higher than that of its body, the animal acquires heat, because the environment transmits it to it even while its metabolism continues to produce it. In this case, evaporation is the only way for him to prevent his body temperature from rising rapidly. Terrestrial animals lose water by evaporation through the skin and by breathing.

Some animals benefit from adaptations that can significantly increase this cooling effect. Panting plays an important role in birds and in many Mammals (the dog, for example). Some birds are provided with a specialized bag, very vascularized, in the floor of their oral cavity, and whose swelling and rapid deflation favor vaporization.

3.3.5. Behavioral reactions :

Endotherms and ectotherms modulate their body temperature by adapting their behaviors to environmental changes. Many ectotherms maintain an almost constant body temperature through simple behaviors. Hibernation or migration to a more favorable climate constitute behavioral adaptations to extreme temperature conditions.

The regulation of the body temperature of ectotherms depends mainly on their behavior. When they are cold, these animals look for warm places ; in addition, to increase their heat supply, they adopt a position that allows them to expose most of their body surface to the heat source. On the contrary, when they are hot, they retreat to cooler areas or orient themselves differently.

Many terrestrial invertebrates modify their internal temperature by using behavioral mechanisms similar to those of ectothermic vertebrates. For example, the desert locust (Schistocerca gregaria) must reach a certain temperature before it can take flight; on cold days, it positions itself in such a way as to optimize its exposure to solar rays. Other terrestrial invertebrates adopt certain postures that give them the ability to increase or lower their absorption of solar heat.

Honeybees (Apis mellifera) use a thermoregulatory mechanism that depends on social behavior. When it gets cold, they increase their heat production and pile on top of each other to preserve it better. Some of them move, going from the periphery of the grouping to the center, where it is warmer, which makes it possible to circulate and distribute the heat. Even when they pile up, bees have to expend considerable energy to maintain a vital temperature during long periods of cold weather. When it's hot, the bees also regulate the temperature of the hive by transporting water there and flapping their wings to facilitate vaporization and convection. Thus, a bee colony uses many thermoregulation mechanisms observed in other organisms living in solitary.

Despite their many homeostatic adaptations, animals are occasionally forced to face situations that push them to the limits of their ability to balance their energy allocations. For example, during certain seasons of the year (or certain times of the day), the temperature can reach very high or very low values, or food may be missing. To save energy while avoiding being in difficult or dangerous circumstances, some animals enter a state of torpor, that is to say a physiological state characterized by reduced activity to a minimum and by a slowing down of metabolism.

Many small mammals and birds present a daily torpor that seems adapted to their mode of feeding. Thus, some bats feed at night and fall into a state of torpor during the day, when they are inactive. Tits and hummingbirds feed during the day and usually enter a state of torpor during cool nights; the body temperature of the tit falls to 10 °C, at night, while that of some hummingbirds can rise from 40 °C, during the day, to 15 °C, at night. All endotherms that manifest daily torpor are relatively small, large mammals being unable to quickly lower their internal temperature. When they are active, the speed of their metabolism is accelerated and they consume a lot of energy.

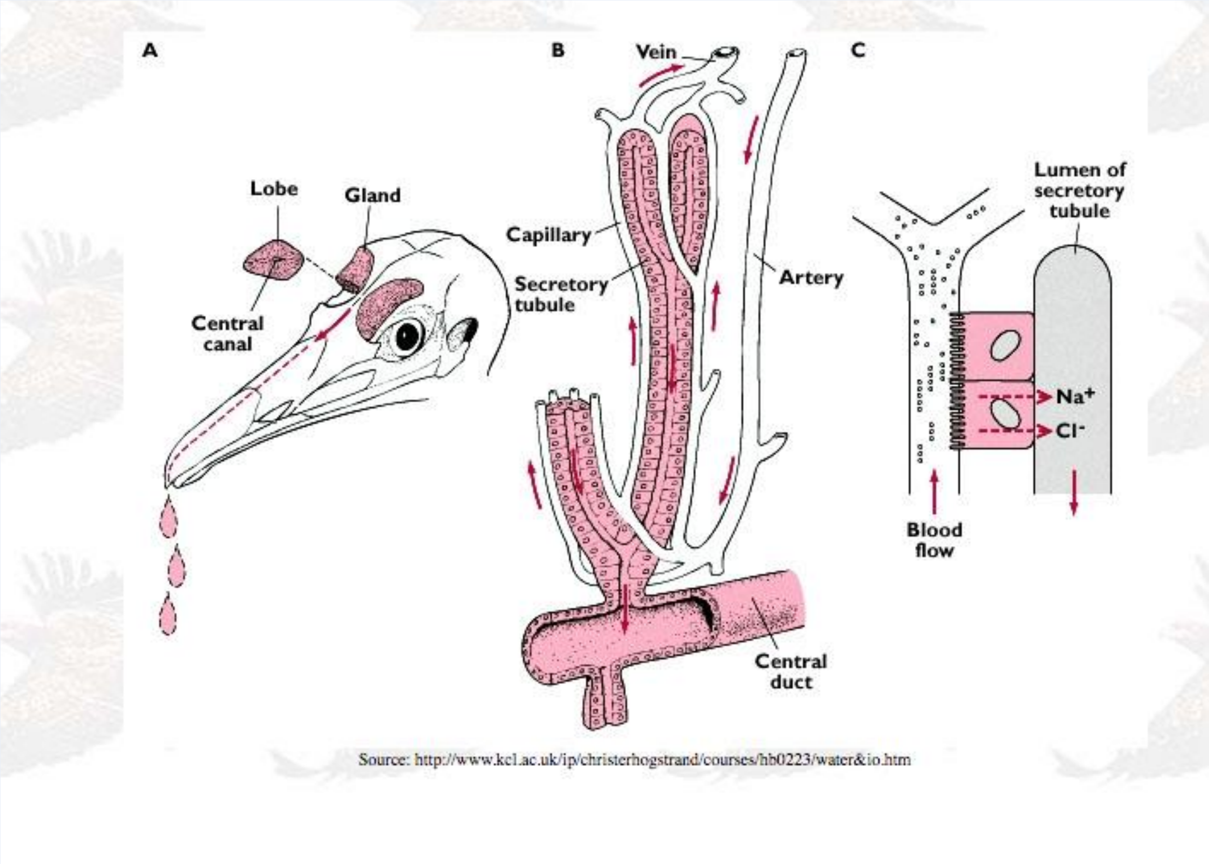
Hibernation is a state of prolonged torpor, which is an adaptation to the winter cold and the shortage of food during this season. When a mammal goes into hibernation, its body temperature decreases. The temperature reduction can be considerable and can be done quite quickly (in a few hours): some mammals in hibernation maintain a temperature of 1 to 2 ° C; in at least one case, that of the Arctic ground squirrel (Spermophilus parryii), the body temperature can even drop slightly below 0 °C. Hibernating animals, such as ground squirrels, are able to survive the long winter months by having limited reserves of energy, stored in the tissues of their body or piled up in their burrow. In the same way, the slowing down of metabolism and inactivity that characterize estivation, or summer torpor, allow some animals to survive long periods of heat by relying on limited water reserves.

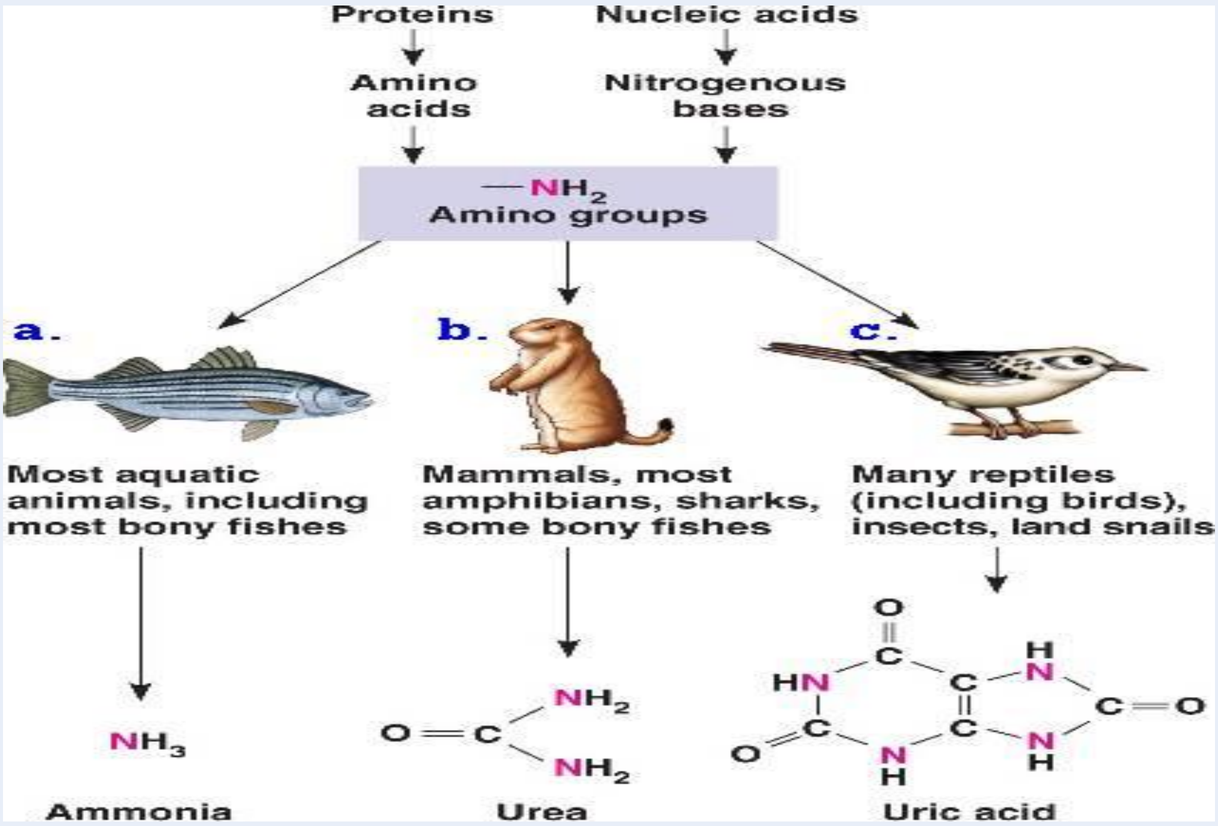
3.4. Water balance and waste disposal :

The water balance and the elimination of waste are carried out via the transport epitheliums. Layers of specialized cells regulate the movement of solutes necessary to eliminate waste and to stabilize the composition of body fluids.

In most animals, the transport epitheliums are arranged in complex tubular networks, offering an extensive exchange surface. The salt glands of seabirds, which spend months or years at sea and which must obtain food and water from the ocean, constitute one of the best examples of this type of structure (pic 4).

Animals produce nitrogenous waste products that correlate with their phylogenesis and their habitat (Fig. 5). The metabolism of proteins and nucleic acids generates ammonia, a toxic waste excreted in three forms. Most aquatic animals excrete ammonia through the body surface or the epithelium of their gills into the surrounding water. The liver of Mammals and most adult Amphibians converts ammonia into urea, a less toxic substance. This is transported into the kidneys, concentrated and excreted with minimal water loss. Uric acid is an insoluble precipitate excreted in the pasty urine of Land Snails, Insects, Birds and many Reptiles.





Picture 03 : Nitrogenous waste

(A) : Many seabirds, such as this albatross, are capable of living for extended periods at sea by drinking saltwater. This is made possible by a pair of nasal glands that secrete a fluid significantly more saline than seawater. Thus, even though consuming seawater provides the albatross with a large amount of salt, it can still achieve a net water gain. In contrast, when humans drink seawater, they must use more water than they have consumed to excrete the excess salt, leading to dehydration. The salt glands of seabirds empty through a duct that leads to the nostrils, where the salty solution either drips along the beak or is exhaled as à fine mist.

(B) : This diagram illustrates one of the thousands of secretory tubules found within à salt gland. Each tubule is lined with a transport epithelium, surrounded by capillaries, and drains into a central duct.

(c) : The secretory cells of the transport epithelium actively transport salt from the blood into the tubules. You will observe that the blood flows in the opposite direction to the saline secretion. By maintaining à salt concentration gradient within the tubules (represented by the pale blue gradient), this countercurrent exchanger facilitates the transfer of salt from the blood into the lumen of the tubules.

Cells require a balancé between water gain and loss through osmosis. Water absorption and loss must be regulated by various osmoregulatory mechanisms, depending on the environment. Osmoregulators expend energy to control their internal osmolarity, while osmoconformers are generally iso-osmotic with their surroundings. Osmoconformers, which do not regulate their osmolarity, include most marine invertebrates. Osmoregulators manage water loss and acquisition in hyperosmotic or hypoosmotic environments. Sharks maintain a slightly higher osmolarity than seawater because they retain urea. Marine bony fish lose water to their hyperosmotic environment and compensate by drinking seawater.

Marine vertebratesexcrete excess salts through their rectal glands, gills, salt-excreting glands or kidneys. Freshwater animals, which constantly absorb water from the hypoosmotic medium, excrete diluted urine. The loss of salts is replaced by the salts absorbed in the food, or by the capture of ions via the gills. Terrestrial animals fight dehydration through behavioral adaptations and thanks to water-conserving excretory organs. They also do this by consuming liquids and solids containing a high proportion of water.