

## Thermoregulation

- In its simplest definition, thermoregulation is the maintenance of an organism's body temperature.
  - Thermoregulation involves physiological and behavioral adjustments that balance heat gain and loss.
  - An **ectotherm** has such a low metabolic rate that the amount of heat that it generates is too small to have much effect on body temperature.
    - Consequently, ectotherm body temperatures are almost entirely determined by the temperature of the surrounding environment.
    - Most invertebrates, fishes, amphibians, and reptiles are ectotherms.
  - In contrast, an **endotherm's** high metabolic rate generates enough heat to keep its body temperature substantially warmer than the environment.
    - Mammals, birds, some fishes, a few reptiles, and numerous insect species are endotherms.
  - For endotherms and for those ectotherms that thermoregulate, the essence of thermoregulation is management of the heat budget so that rates of heat gain are equal to rates of heat loss.
    - If the heat budget gets out of balance, the animal will either become warmer or colder.
- (1) *Adjusting the rate of heat exchange between the animal and its surroundings.*
- Insulation, such as hair, feathers, and fat located just beneath the skin, reduces the flow of heat between an animal and its environment.
  - Other mechanisms usually involve adaptations of the circulatory system.
  - **Vasodilation**, expansion of the diameter of superficial blood vessels, elevates blood flow in the skin and typically increases heat transfer to a cool environment.
  - **Vasoconstriction** reduces blood flow and heat transfer by decreasing the diameter of superficial vessels.
- Another circulatory adaptation is a special arrangement of blood vessels called a **countercurrent heat exchanger** that helps trap heat in the body core and reduces heat loss.
    - For example, marine mammals and many birds living in cold environments face the problem of losing large amounts of heat from their extremities as warm arterial blood flows to the skin.
    - However, arteries carrying warm blood are in close contact with veins conveying cool blood back toward the trunk.
    - This countercurrent arrangement facilitates heat transfer from arteries to veins along the entire length of the blood vessels.
    - By the end of the extremity, the arterial blood has cooled far below the core temperature, and the venous blood has warmed close to core temperature as it nears the core.
- (2) *Cooling by evaporative heat loss.*
- Terrestrial animals lose water by evaporation across the skin and when they breathe.
  - Water absorbs considerable heat when it evaporates.
  - Some organisms can augment this cooling effect.
    - For example, most mammals and birds can increase evaporation from the lungs by panting.
    - Sweating or bathing to make the skin wet also enhances evaporative cooling.
- (3) *Behavioral responses.*
- Both endotherms and ectotherms use behavioral responses, such as changes in posture or moving about in their environment, to control body temperature.

- Many terrestrial animals will bask in the sun or on warm rocks when cold or find cool, shaded, or damp areas when hot.
- More extreme behavioral adaptations in some animals include hibernation or migration to a more suitable climate.
- Heat production is increased by muscle activity during moving or shivering.
  - In some mammals, **nonshivering thermogenesis (NST)** is induced by certain hormones to increase their metabolic activity and produce heat instead of ATP.
- The regulation of body temperature in humans and other mammals is a complex system facilitated by feedback mechanisms.
- Nerve cells that control thermoregulation, as well as those controlling other aspects of homeostasis, are concentrated in the hypothalamus of the brain.
- A group of neurons in the hypothalamus functions as a thermostat, responding to changes in body temperature above and below a set point by activating mechanisms that promote heat loss or gain.

### **Torpor reserves energy during environmental extremes**

- Despite their many adaptations for homeostasis, animals may periodically encounter conditions that severely challenge their abilities to balance heat, energy, and materials budgets.
  - One way that animals can save energy while avoiding difficult and dangerous conditions is to use **torpor**, a physiological state in which activity is low and metabolism decreases.
- **Hibernation** is long-term torpor that evolved as an adaptation to winter cold and food scarcity.
- **Estivation**, or summer torpor, also characterized by slow metabolism and inactivity, enables animals to survive long periods of high temperatures and scarce water supplies.

### **Water Balance and Disposal of Metabolic Wastes**

- Animals must regulate the chemical composition of their body fluids by balancing the uptake and loss of water and fluids.
- Management of the body's water content and solute composition, **osmoregulation**, is largely based on controlling movements of solutes between internal fluids and the external environment.
- In most animals, osmotic regulation and metabolic waste disposal depend on the ability of a layer or layers of **transport epithelium** to move specific solutes in controlled amounts in particular directions.
- In most animals, transport epithelia are arranged into complex tubular networks with extensive surface area.
- The molecular structure of plasma membranes determines the kinds and directions of solutes that move across the transport epithelium.
  - For example, the salt-excreting glands of the albatross remove excess sodium chloride from the blood.
  - By contrast, transport epithelia in the gills of freshwater fishes actively pump salts from the dilute water passing by the gill filaments.
  - Transport epithelia in excretory organs often have the dual functions of maintaining water balance and disposing of metabolic wastes.

## An animal's nitrogenous wastes are correlated with its phylogeny and habitat

- Because most metabolic wastes must be dissolved in water when they are removed from the body, the type and quantity of waste products may have a large impact on water balance.
  - Nitrogenous breakdown products of proteins and nucleic acids are among the most important wastes in terms of their effect on osmoregulation.
  - During their breakdown, enzymes remove nitrogen in the form of **ammonia**, a small and very toxic molecule.
- In general, the *kinds* of nitrogenous wastes excreted depend on an animal's evolutionary history and habitat - especially water availability.
- Animals that excrete nitrogenous wastes as ammonia need access to lots of water.
  - This is because ammonia is very soluble but can only be tolerated at very low concentrations.
  - Therefore, ammonia excretion is most common in aquatic species.
- Ammonia excretion is much less suitable for land animals and even many marine fishes and turtles.
  - Because ammonia is so toxic, it can only be transported and excreted in large volumes of very dilute solutions.
  - Most terrestrial animals and many marine organisms (which tend to lose water to their environment by osmosis) do not have access to sufficient water.
- Instead, mammals, most adult amphibians, and many marine fishes and turtles excrete mainly **urea**.
  - Urea is synthesized in the liver by combining ammonia with carbon dioxide and excreted by the kidneys.
- The main advantage of urea is its low toxicity, about 100,000 times less than that of ammonia.
  - Urea can be transported and stored safely at high concentrations.
- The main disadvantage of urea is that animals must expend energy to produce it from ammonia.
- Land snails, insects, birds, and many reptiles excrete **uric acid** as the main nitrogenous waste.
  - Like urea, uric acid is relatively nontoxic.
  - But unlike either ammonia or urea, uric acid is largely insoluble in water and can be excreted as a semisolid paste with very small water loss.
  - While saving even more water than urea, it is even more energetically expensive to produce.
- Uric acid and urea represent different adaptations for excreting nitrogenous wastes with minimal water loss.

## Animal Excretory Systems

- Most excretory systems produce urine in a two-step process.
  - First the body fluid (blood or hemolymph) is collected.
  - Then the composition of the fluid is adjusted by *selective reabsorption* of solutes.
- Insects and terrestrial arthropods like the grasshopper have *Malpighian tubules* that remove nitrogenous wastes.
  - They open into the digestive tract and dead-end at points in the hemolymph. The tubules secrete nitrogenous wastes and salts into the lumen, and water follows by osmosis.
- Mammals have two *kidneys*, and each is supplied with a *renal artery* and a *renal vein*.
  - *Urine* leaves the kidneys through the *ureters*, which drain into the urinary bladder. Urine is expelled from the body through the *urethra*.

- The kidney has two regions, the **outer renal cortex** and the **inner renal medulla**.
- These two regions are packed with nephrons, which are the functional units of the kidney.
- Nephrons are made up of a single long tubule and the glomerulus, a ball of capillaries.
  - At the end of the tubule is the Bowman's capsule, a c-shaped capsule that surrounds the glomerulus.
- The filtrate flows through the **proximal tubule**, the descending **loop of Henle**, the loop of Henle, the ascending loop of Henle, and the distal tubule.
  - The distal tubule empties into a **collecting duct**, which receives wastes from many nephrons.
  - The filtrate empties into the renal pelvis.
- In the human kidney, most of the nephrons are **cortical nephrons**; these are in the renal cortex.
- The rest are **juxtamedullary nephrons**, with long loops of Henle that extend into the renal medulla.
- Capillaries called **afferent arterioles** are associated with the nephrons, and as they leave the glomerulus, the capillaries converge into an **efferent arteriole**.
- This vessel subdivides again to form **peritubular capillaries**, which surround the proximal and distal tubules.
- In the proximal tubule, secretion and reabsorption changes the volume and composition of the filtrate.
  - The pH of body fluids is controlled, and bicarbonate is absorbed, as are NaCl and water.
- In the descending loop of Henle, reabsorption of water continues.
- In the ascending loop of Henle, the filtrate loses salt without giving up water and becomes more dilute.
- In the distal tubule, K<sup>+</sup> and NaCl levels are regulated, as is filtrate pH.
- The collecting duct carries the filtrate through the medulla to the renal pelvis, and the filtrate becomes more concentrated by the movement of salt.
- Antidiuretic hormone is an important hormone in the regulation of water balance. It is produced in the hypothalamus and stored in and released from the pituitary gland.
  - Two other hormones involved in regulation of water balance are angiotensin and aldosterone.