9.4 Water Balance

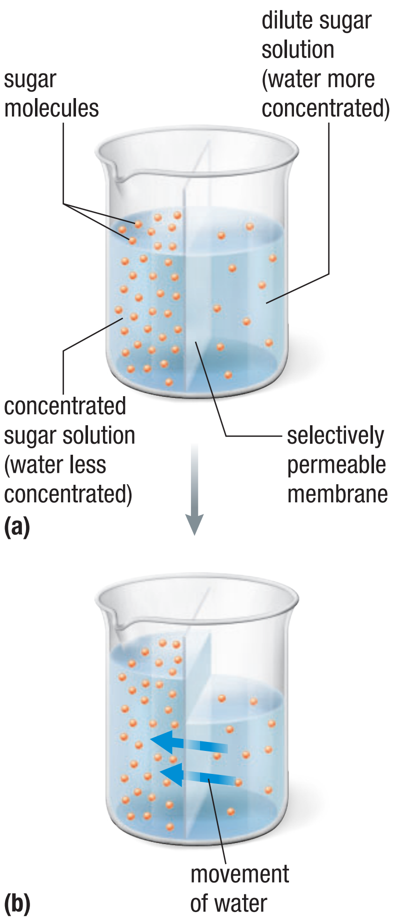

Figure 1 (a) Two solutions have different concentrations. (b) Osmosis occurs when water moves across a selectively permeable membrane from an area of high concentration to an area of low concentration.

osmotic pressure the pressure that results from a difference in solute concentration between the two sides of a selectively permeable membrane

hyperosmotic the property of the solution on one side of a selectively permeable membrane that has the lower concentration of water

hypoosmotic the property of the solution on one side of a selectively permeable membrane that has the higher concentration of water

isoosmotic the property of two solutions that have equal water concentrations

The body's internal environment of extracellular fluid must maintain a constant volume, solute content, and often temperature. Humans and many other terrestrial vertebrates require a stable aqueous environment to survive. They carry this aqueous environment inside their body, and they must continuously replenish and maintain it.

Aquatic organisms must also maintain their internal environment, since the conditions of the external environment change in terms of solutes and temperature. The Atlantic salmon (*Salmo salar*) spends part of its life cycle in both freshwater and saltwater environments. For the first two or three years of its life, the salmon lives in freshwater rivers and lakes, where the solute concentration (about 0.1 %) is less than the concentration within its body (about 1.0 %). This concentration gradient results in the uptake of water into the salmon's internal environment, and therefore homeostatic mechanisms must expel the excess water from the body. As the salmon matures, it abandons the freshwater environment for the salt water of the Atlantic Ocean, where the concentration of solutes is about 3.5 %. In this saltwater environment, the salmon experiences a continuous loss of water from its body, which it must replenish.

In addition to changing solute concentrations, there are other important differences between terrestrial and aquatic environments. Because water is not as abundant on land as it is in aquatic environments, terrestrial organisms require mechanisms to conserve water and maintain a homeostatic balance of solutes within their body. In this section, you will consider the following questions: Why do animals need to maintain a water balance? Why do animals need an excretory system?

Osmosis

In Chapter 2, you learned about the role of osmosis in the homeostatic water balance of cells. During osmosis, water molecules move from a region where they are highly concentrated to a region where their concentration is lower. This movement occurs across a selectively permeable membrane, which allows water but very few solute molecules to flow through. The different water concentrations on the two sides of the membrane are produced by different numbers of solute molecules (**Figure 1(a)**). The side with a lower concentration of solutes has a higher concentration of water molecules. The water moves osmotically across the membrane to the other side, where the water concentration is lower (**Figure 1(b)**). Selective permeability is a key factor in osmosis because it helps to maintain differences in solute concentration on the two sides of biological membranes, such as cell membranes. Proteins are among the most important solutes in establishing the conditions that produce osmosis.

Osmotic pressure is the pressure that results from a difference in water concentration, or a water concentration gradient, between the two sides of a selectively permeable membrane. The greater the water concentration gradient, the greater the osmotic pressure difference between the two sides. A solution with a higher concentration of solute molecules on one side of a selectively permeable membrane is said to be **hyperosmotic** (hypertonic) to a solution with a lower concentration of solutes on the other side. Water tends to move to the hyperosmotic side. The solution with a lower solute concentration is said to be **hypoosmotic** (hypotonic) to the solution with the higher solute concentration. Water tends to move from the hypoosmotic solution. Solutions with the same solute and water concentrations are **isoosmotic** (isotonic).

Water moves across the membrane when the two solutions have different water concentrations. This movement tends to continue until the two solutions are isoosmotic. Water still moves across the membrane even when the solutions are isoosmotic, but the water movement is equal in both directions so there is no net movement.

Another factor that determines whether osmosis will occur is hydrostatic, or water, pressure. If the hydrostatic pressure on one side of a membrane (such as a plant cell membrane) is equal to the osmotic pressure on the other side of the membrane, there is no net flow of water. As water continues to cross the membrane, the internal hydrostatic pressure begins to build until it balances the external osmotic pressure and osmosis comes to a stop. This occurs despite the fact that the outside of the membrane may have a higher concentration of water molecules. The interplay of osmotic and hydrostatic pressures is important for the structure of plant cells. The water surrounding most plant roots is hypoosmotic relative to the inside of the plant cells. Therefore, water flows into the root cells and then into the cells of stems and leaves. This inflow of water causes the cells to expand and press against the insides of their cell walls, like a balloon blowing up inside a wire-mesh cage. The hydrostatic pressure exerted against the cell walls, known as turgor pressure, gives a plant its rigidity and allows it to stand erect. If the surrounding fluid becomes hyperosmotic in relation to the insides of the cells, or if there is a shortage of water, there will be a drop in turgor pressure and the plant will wilt.

Hydrostatic pressure cannot build in animal cells because they do not have strong cell walls. If an animal cell is surrounded by a very dilute, or hypoosmotic, solution, water molecules will continue to enter the cell until it swells and bursts. If an animal cell is surrounded by a hyperosmotic solution, water molecules will leave the cell by osmosis and the cell will shrink. Both of these situations present serious problems for animals.

Osmoregulation and Excretion

Osmosis is a crucial and ongoing process in the establishment and maintenance of homeostasis. To ensure the chemical and structural stability of the body cells, the internal environment—the extracellular fluid—must be isoosmotic with the intracellular fluid inside of the cells. The process of actively regulating the osmotic pressure of bodily fluids and cells is known as **osmoregulation**. The concentrations of water and solutes, both inside and outside of the cells, must be kept in a constant balance. This requires the continuous movement of water by osmosis and the movement of solutes by diffusion and active processes into and out of the cells.

osmoregulation the process of actively regulating the osmotic pressure of bodily fluids and cells

All organisms need to keep their intracellular and extracellular fluids isoosmotic, but some animals require different levels of active upkeep than others. Many marine animals (such as sponges, jellyfish, sea urchins, squid, and lobsters) do not need to regulate the concentration of their extracellular fluid. The concentrations of their intracellular and extracellular fluids are identical to the concentrations in the external environment (that is, salt water), and water flows in and out of their body freely. In contrast, plants must keep a certain minimum osmotic and hydrostatic pressure within their cells to maintain rigidity and transport nutrients. Many animals (including almost all vertebrates) require more complex control mechanisms to keep the concentrations of intracellular and extracellular fluids constant, but at levels different from the concentrations in the external environment. Some of the most important factors that affect these concentrations are the waste products of metabolism and cell functions, which are continuously eliminated from the body to maintain aqueous homeostasis.

Excretion

To maintain homeostasis, cells regulate their ionic balance and pH balance, in addition to their osmotic concentration. Therefore, certain ions and toxic compounds, such as the metabolites of nitrogenous compounds (for example, amino acids and nucleic acids) must be eliminated. The body's aqueous internal environment acts as a solvent for these wastes, and their elimination helps maintain osmotic pressure and concentration. This is why excretion is so closely tied to the process of osmoregulation. For most terrestrial animals, the maintenance of osmotic concentration while eliminating nitrogenous wastes can be difficult, since it requires significant amounts of water, which may not be readily available depending on the season or geographical location.

Animals maintain their ionic and pH balance through the process of excretion. Excretion is the elimination of waste products and foreign matter from the body.

It serves to maintain the ionic and osmotic equilibrium that is necessary for cell functions. The body system that regulates the removal of wastes is the excretory (or urinary) system, and its main organs are the kidneys and the bladder. As the body processes proteins during metabolism, it produces waste molecules, which the liver converts into soluble metabolites. The kidneys can filter out these metabolites and eliminate them from the body with other aqueous waste, maintaining the water and pH balance of the internal environment.

Waste nitrogen is produced in different forms for different groups of animals (**Figure 2**). Bony fishes produce ammonia, mammals and cartilaginous fishes (sharks, skates, rays) produce urea, and most birds produce uric acid as nitrogenous waste.

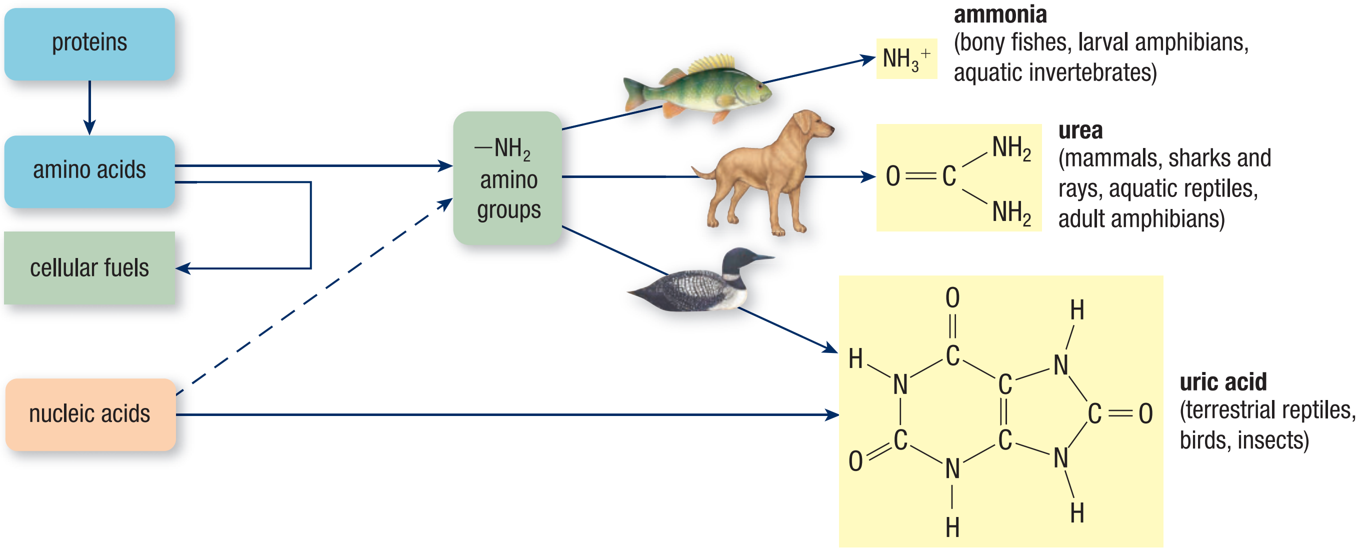

Figure 2 Nitrogenous wastes excreted by different animal groups

As you learned in Chapter 1, the building blocks of proteins are amino acids. An amino acid contains a nitrogen atom bonded to two hydrogen atoms, called an amino group. In the process of deamination, which occurs in the liver, the amino group is removed from each amino acid that comes from the breakdown of a protein. The amino group is then converted to ammonia. The rest of the amino acid, which is mostly carbon and hydrogen, is oxidized to produce energy.

Ammonia, NH_3, the by-product of deamination, is a highly toxic substance. A buildup of as little as 0.005 mg/L can kill a human. It can be transported and secreted only in very dilute solutions. Animals with an abundant supply of water (such as bony fish and marine invertebrates) are able to secrete ammonia directly from the body in this very dilute form. In mammals, some reptiles, and most amphibians, the liver combines ammonia with HCO_3^- to create urea, a very soluble substance with 0.001 % the toxicity of ammonia. In fact, 33 mg of urea can be dissolved in just 100 mL of blood with no toxic effects. Although the chemical reactions that produce urea require more energy than the reactions that produce ammonia, urea can be eliminated from the body with less water, allowing terrestrial animals to maintain their water balance.

Other animals conserve water even more efficiently. For example, birds and some terrestrial invertebrates produce uric acid as their nitrogenous waste product. Uric acid is not toxic, but its key feature for these smaller animals is its low solubility. As urine is concentrated in its final stages, the uric acid forms crystals that are expelled from the body with a minimal amount of water. (The white substance in bird droppings is uric acid crystals.) Most animals are able to form all three of these nitrogen compounds, but the primary method of excretion depends on a balance among water conservation, toxicity, and energy requirements. You will learn about the excretory system and the functions of its organs in humans in Section 9.5.

UNIT TASK **BOOKMARK**

You may want to consider thermoregulation (Section 9.3) or water balance (Section 9.4) as a factor for your Unit Task on page 566.

9.4 Review

Summary

- All organisms must maintain a balance between their internal aqueous environment and the external environment.
- Osmoregulation ensures that the intracellular and extracellular fluids are isoosmotic, and it keeps the internal concentrations of water and ions different from the concentrations in the external environment.
- Osmoregulation is closely linked to the process of excretion, in which animals expel the waste products of metabolism to the external environment.
- The excretory system removes nitrogenous waste, excess water, and toxic compounds from the body. The main organs in the excretory system are the liver and the kidney.

Questions

1. (a) Describe the similarities and differences between diffusion and osmosis.
   (b) Why is osmosis particularly important for biological functions? K/U
2. Why do cells need to use osmoregulation? K/U
3. What is the relationship between osmoregulation and excretion? K/U
4. Explain the advantages and disadvantages for terrestrial animals of creating urea rather than other forms of nitrogenous waste. K/U
5. Why is it an advantage for birds to create uric acid as their nitrogenous waste compound? (Think in terms of birds' specialized adaptation of flight.) K/U T/I
6. What animals do you think would produce more urea: carnivores with a high-protein diet or herbivores with a high-carbohydrate diet? Which would require more water? Why? K/U T/I
7. Predict what would happen if a cell found in an ocean with a high concentration of salt was suddenly placed in a beaker of fresh water. T/I A
8. Excretion is studied in Grade 8 science. Describe to a Grade 8 student the importance of excretion in relation to osmoregulation. K/U C
9. Describe why a walleye living in Lake Ontario cannot survive in the Bay of Fundy (**Figure 3**). In your description, refer to hypoosmoticity, hyperosmoticity, and isoosmoticity. K/U T/I C

Figure 3 A walleye from Lake Ontario

10. Explain the difference between the terms "hypertonic" and "hyperosmotic." K/U
11. How do mineral salts and other particles such as glucose, urea, and proteins participate in osmotic regulation? K/U T/I
12. Why do you think sugar and salt are used in the drying of fruit and meat? K/U T/I A