

Chapter 42 Water and Electrolyte Balance in Animals

- I. Challenges to Water and Electrolyte Balance in Different Environments
- A. Osmotic stress—cells can undergo osmotic stress with changes in their environment. If unopposed, osmotic stress will impair cell function and may lead to death.
 1. Water moves to the area of highest solute concentration via osmosis.
 2. If an animal's body is hypertonic (has a higher solute concentration) to its environment, the animal will take on water.
 3. If an animal's body is hypotonic (has a lower solute concentration) to its environment, the animal will lose water.
 - B. Osmotic stress may occur with either an imbalance in the water and/or electrolyte content of body fluids.
 - C. Freshwater, marine, and terrestrial habitats impose different forms of osmotic stress on the animals inhabiting them; those animals have adaptations allowing them to achieve homeostasis.
 1. Marine invertebrates . . .
 - a. Are isotonic relative to seawater
 - b. Are considered osmoconformers because they do not osmoregulate
 2. Marine fish . . .
 - a. Are hypotonic to their environment and tend to lose water and gain excess ions
 - b. Must osmoregulate by drinking water and excreting excess electrolytes
 3. Freshwater animals..
 - a. Are hypertonic to their environment and tend to gain excess water and lose electrolytes
 - b. Must osmoregulate by excreting excess water and obtaining electrolytes from their environment and food
 4. Terrestrial animals . . .
 - a. Run the risk of dehydration due to evaporation of water from their body surfaces, including respiratory organs
 - b. Must osmoregulate by drinking and excreting excess electrolytes.
- II. Osmoregulation is the ability to counteract osmotic stress and maintain homeostasis with respect to water and electrolyte balance.
- A. All organs of osmoregulation possess transport epithelium for exchange of water and electrolytes with the environment.
 1. Shark rectal gland—specialized for NaCl secretion
 2. Chloride cells—found in abundance in the gill epithelia of marine fish
 3. Nasal salt glands of marine birds and reptiles
 4. Mammalian kidney
 - B. All such organs use a common molecular mechanism for salt transport.
 1. Na^+/K^+ -ATPase, located in the basolateral membrane, pumps Na^+ out of epithelial cell into extracellular fluid, creating a low intracellular Na^+ concentration.
 2. Na^+ moves across the basolateral membrane from the extracellular to the intracellular fluid down its concentration gradient, using a $\text{Na}^+/2\text{Cl}^-/\text{K}^+$ cotransport mechanism and bringing Cl^- and K^+ into the cell.
 3. Cl^- leaves the cell through apical chloride channels, creating an electrical charge gradient for Na^+ transport.
 4. Na^+ moves down its concentration and electrical charge gradients from the extracellular fluid to the environment between the epithelial cells.
 - C. Migratory fishes like salmon which move from freshwater to seawater back to freshwater during their life span, make physiological adjustments to maintain water and electrolyte balance during these transitions.
- III. The Impact of Forms of Nitrogenous Waste Products on Water Balance
- A. Deamination of amino acids generates the toxic compound ammonia.

- B. In aquatic organisms, ammonia diffuses from the extracellular fluid into the environment, thus avoiding the buildup of this toxic molecule.
- C. Terrestrial organisms convert ammonia to a less toxic compound for excretion.
 1. Uric acid has very low solubility in water, allowing birds, reptiles, and insects to excrete semisolid urine. More energy is required for synthesis of this molecule.
 2. Urea is the primary nitrogenous waste of mammals. It is more water soluble than uric acid, so more water is required to excrete this form, but its synthesis requires less energy.

IV. Terrestrial Invertebrates Are Subject to Dehydration

- A. The large surface area/volume ratios and the use of air as a respiratory medium present challenges to maintenance of water balance in insects.
 1. A water-impermeable waxy coating on the exoskeleton minimizes evaporation from the body surface.
 2. The openings to the insect tracheal system, used for gas exchange, are called spiracles; they can close to prevent excessive water loss from respiration.
- B. The Malpighian tubule system allows insects to produce concentrated urine, conserving water loss and maintaining water and electrolyte balance of the hemolymph.
 1. Pre-urine is formed in the Malpighian tubules. K^+ is pumped into the tubule lumen; water and solutes, other electrolytes and wastes, follow.
 2. The pre-urine flows into the hindgut for processing. Cl^- and Na^+/K^+ -ATPase pumps are critical for reabsorption of water and needed electrolytes, including K^+ . The degree of reabsorption of these substances is based on the water and electrolyte balance of the insect and is under hormonal regulation.
 3. Malpighian tubule system allows hydrated insects to produce urine hypotonic to their hemolymph and dehydrated insects to produce hypertonic urine.

V. The mammalian kidney is an important adaptation to life on land; its functional unit is the nephron.

- A. The high blood pressures of closed circulatory systems allow for the formation of pre-urine by filtration of the blood.
 1. A filtrate of blood is formed in the renal corpuscle of the nephron as water and smaller solutes, but not large proteins and cells, are forced through glomerular capillary slits into Bowman's capsule.
 2. This pre-urine is processed by remaining segments of the nephron, primarily via reabsorption. In order, these segments are proximal tubule, descending and ascending limbs of the loop of Henle, distal tubule, and collecting duct. Any substance that is filtered, but not reabsorbed, is lost in the urine.
- B. The transport activity of the proximal tubule accounts for two-thirds of the water, sodium, and chloride and all of the amino acid and glucose reabsorption.
 1. The apical membranes of the proximal tubule epithelial cells have microvilli to increase the surface area for reabsorption.
 2. Na^+/K^+ -ATPase creates a driving Na^+ concentration gradient for cotransport of valuable solutes. Water follows by osmosis through aquaporins.
- C. The loop of Henle creates an osmotic gradient within the renal medulla, allowing for the production of hyperosmotic urine.
 1. Kuhn hypothesized that the loop of Henle acts as a countercurrent multiplier, a model supported by other researchers.
 2. The descending limb of the loop of Henle is water permeable, but salt impermeable. The ascending limb of the loop of Henle is salt permeable, but water impermeable.
 3. Water moves out of the descending limb into the surrounding tissues, concentrating the salts that remain behind.
 4. Salts (Na^+ , Cl^- , and K^+) move passively down their concentration gradient into the surrounding tissue in the thin ascending limb and are actively pumped out in the thick ascending limb.
 5. The presence of these salts in the medullary tissue accounts for 60% of the high osmolarity of that region.

- D. The distal tubule is the final site for adjustments to the chemical composition of the urine. Much of its activity is under hormonal regulation.
1. The amount of Na^+ lost in the urine is under regulation by the hormone aldosterone. If blood Na^+ levels are low, aldosterone will stimulate the reabsorption of Na^+ .
 2. Cl^- and water follow as Na^+ is reabsorbed in this region.
- E. The water permeability of the collecting duct is under hormonal regulation by the hypothalamus.
1. When blood osmolarity is high (indicating dehydration) ADH is released, increasing the water permeability of the collecting duct through the insertion of aquaporins. Water moves by osmosis into the medullary tissue and is reabsorbed. Hyperosmotic urine is formed, thus conserving water.
 2. When blood osmolarity indicates a well-hydrated state, the absence of ADH keeps the water permeability of the collecting duct low. Hypo-osmotic urine is produced.
 3. The collecting duct is responsible for depositing urea into the medulla, contributing to the high osmolarity of that region.

Chapter Vocabulary

homeostasis

water balance
osmolarity

osmosis
hypertonic
hypotonic
isotonic
osmotic stress
osmoregulation
osmoconformers
osmoregulators

electrolytes
electrolyte balance

diffusion

concentration gradient
solute
selectively permeable membrane
equilibrium

facilitated diffusion
channels
carriers
active transport
cotransporter
antiporter

urea
TMAO (trimethylamine oxide)
shark rectal gland
lumen
basolateral membrane
apical membrane
Na⁺/K⁺-ATPase (sodium-potassium pump)
electrochemical gradient

ouabain
chloride channel
CFTR (cystic fibrosis transmembrane regulator)

anadromous
chloride cells
gill filaments
gill lamellae
chloride-cell-switch hypothesis

ammonia
ammonium ion
strong base
pH
nitrogenous wastes
urea
uric acid

tracheal system
spiracles
chitin
wax
hemolymph
Malpighian tubules
pre-urine
hindgut
reabsorption
kidney
nephron
renal corpuscle
proximal tubule
loop of Henle
distal tubule
collecting duct
cortex
medulla
ureter
urethra
renal artery
bladder

filtration
glomerulus
Bowman's capsule
filtrate
positive feedback

microvilli
aquaporins
osmotic gradient
countercurrent multiplier
descending limb
thin ascending limb
thick descending limb
vasa recta
aldosterone
ADH (antidiuretic hormone)
diabetes insipidus
metabolic water
nasal countercurrent exchange