CAMPBELL BIOLOGY IN FO

URRY • CAIN • WASSERMAN • MINORSKY • REE

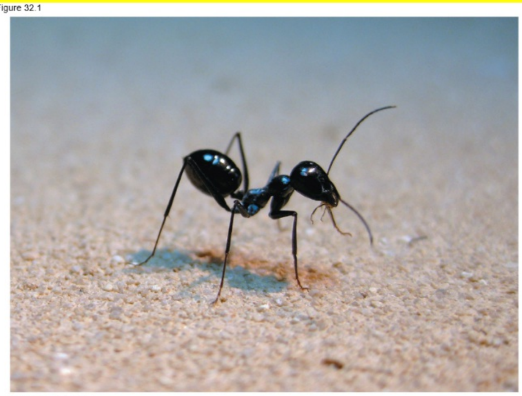
32

The Internal Environment of Animals: Organization and Regulation

Overview: Diverse Forms, Common Challenges

- **Anatomy** is the study of the biological form of an organism
- **Physiology** is the study of the biological functions an organism performs
- Form and function are closely correlated

Figure 32.1



Concept 32.1: Animal form and function are correlated at all levels of organization

- Multicellularity allows for cellular specialization with particular cells devoted to specific activities
- Animal bodies are characterized by layers of organization

- Cells form a functional animal body through emergent properties that arise from levels of structural and functional organization
- Cells are organized into
  - **Tissues**, groups of cells with similar appearance and common function
  - **Organs**, different types of tissues organized into functional units
  - **Organ systems**, groups of organs that work together

- The specialized, complex organ systems of animals are built from a limited set of cell and tissue types
- Animal tissues can be grouped into four categories
  - Epithelial
  - Connective
  - Muscle
  - Nervous

Figure 32.2 Exploring Structure and Function in Animal Tissues

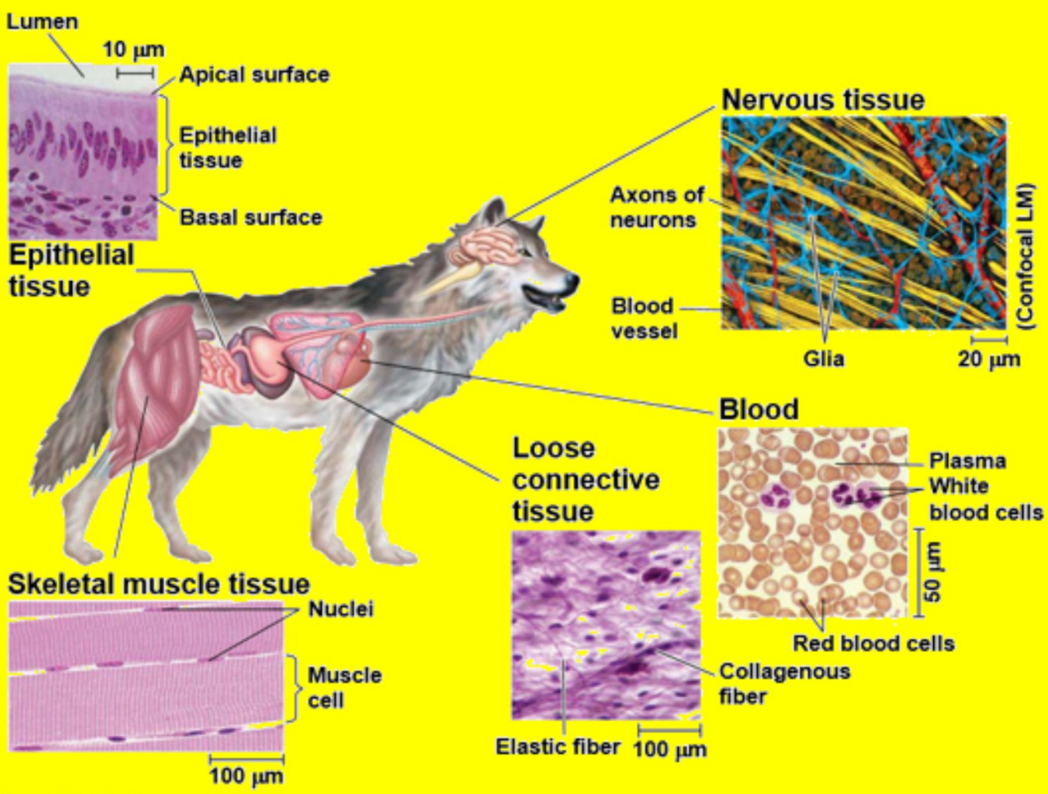


Table 32.1-1

Table 32.1 Organ Systems in Mammals

Organ System	Main Components
Digestive	Mouth, pharynx, esophagus, stomach, intestines, liver, pancreas, anus
Circulatory	Heart, blood vessels, blood
Respiratory	Lungs, trachea, other breathing tubes
Immune and lymphatic	Bone marrow, lymph nodes, thymus, spleen, lymph vessels, white blood cells
Excretory	Kidneys, ureters, urinary bladder, urethra
Endocrine	Pituitary, thyroid, pancreas, adrenal, and other hormone-secreting glands
Reproductive	Ovaries or testes and associated organs
Nervous	Brain, spinal cord, nerves, sensory organs
Integumentary	Skin and its derivatives (such as hair, claws, sweat glands)
Skeletal	Skeleton (bones, tendons, ligaments, cartilage)
Muscular	Skeletal muscles

Table 32.1-2

Table 32.1 Organ Systems in Mammals

Organ System	Main Functions
Digestive	Food processing (ingestion, digestion, absorption, elimination)
Circulatory	Internal distribution of materials
Respiratory	Gas exchange (uptake of oxygen; disposal of carbon dioxide)
Immune and lymphatic	Body defense (fighting infections and virally induced cancers)
Excretory	Disposal of metabolic wastes; regulation of osmotic balance of blood
Endocrine	Coordination of body activities (such as digestion and metabolism)
Reproductive	Reproduction
Nervous	Coordination of body activities; detection of stimuli and formulation of responses to them
Integumentary	Protection against mechanical injury, infection, dehydration; thermoregulation
Skeletal	Body support, protection of internal organs, movement
Muscular	Locomotion and other movement

Figure 32.3-1 Make Connections: Life Challenges and Solutions in Plants and Animals (Part 1)

MAKE CONNECTIONS: Life Challenges and Solutions

Environmental Response

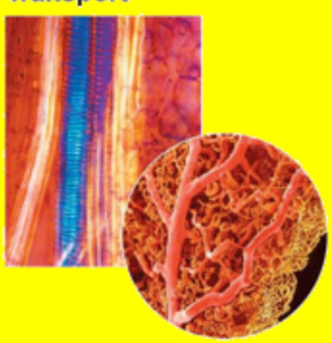
Nutritional Mode

Growth and Regulation

Figure 32.3-2 Make Connections: Life Challenges and Solutions in Plants and Animals (Part 2)

MAKE CONNECTIONS: Life Challenges and Solutions

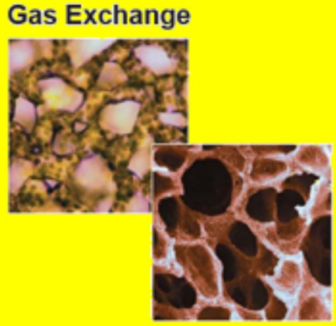
Transport



Reproduction

Absorption

Gas Exchange



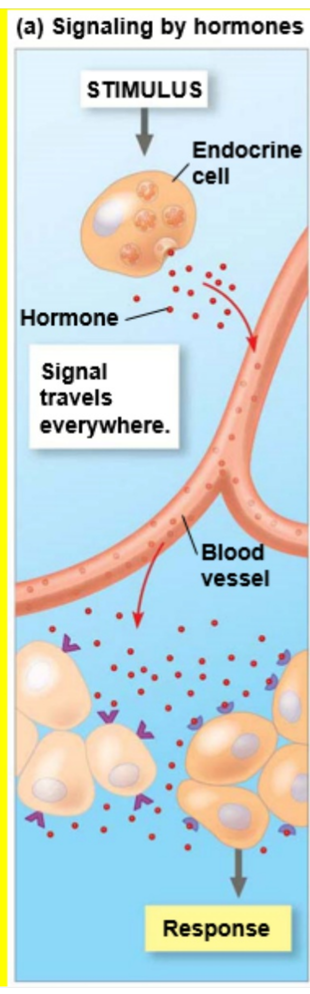
Concept 32.2: The endocrine and nervous systems act individually and together in regulating animal physiology

- For an animal's tissues and organ systems to perform their specialized functions correctly, they must act in concert with one another

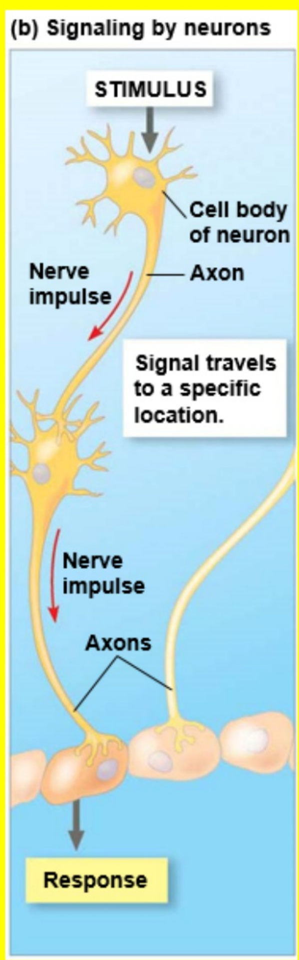
An Overview of Coordination and Control

- In the **endocrine system**, signaling molecules released into the bloodstream by endocrine cells reach all locations in the body
- In the **nervous system**, neurons transmit signals along dedicated routes, connecting specific locations in the body

- Signaling molecules sent out by the endocrine system are called **hormones**
- Hormones may have effects in a single location or throughout the body
- Only cells with receptors for a certain hormone can respond to it
- The endocrine system is well adapted for coordinating gradual changes that affect the entire body



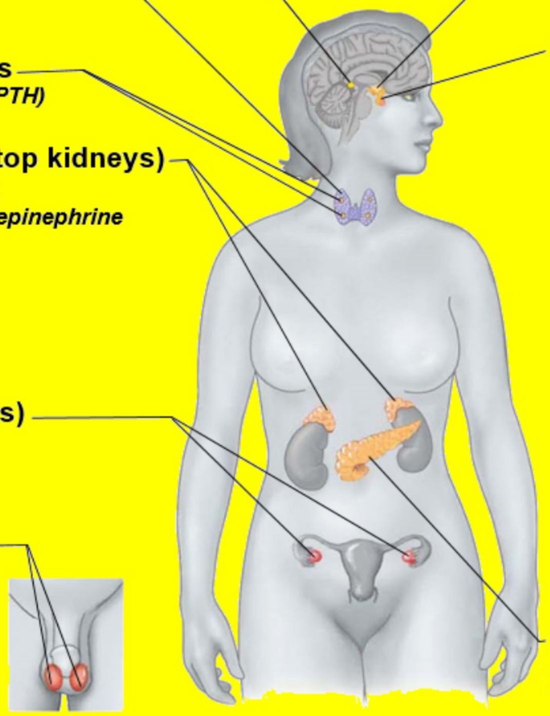
- In the nervous system, signals called nerve impulses travel along communication lines consisting mainly of axons
- Other neurons, muscle cells, and endocrine and exocrine cells can all receive nerve impulses
- Nervous system communication usually involves more than one type of signal
- The nervous system is well suited for directing immediate and rapid responses to the environment



Endocrine Glands and Hormones

- Endocrine cells are often grouped in ductless organs called **endocrine glands**
- Endocrine glands and cells secrete hormones directly into the surrounding fluid, from which the hormones enter the bloodstream
- By contrast, exocrine glands have ducts that carry enzymes or secreted substances into body cavities or onto body surfaces

Figure 32.5



Regulation of Endocrine Signaling

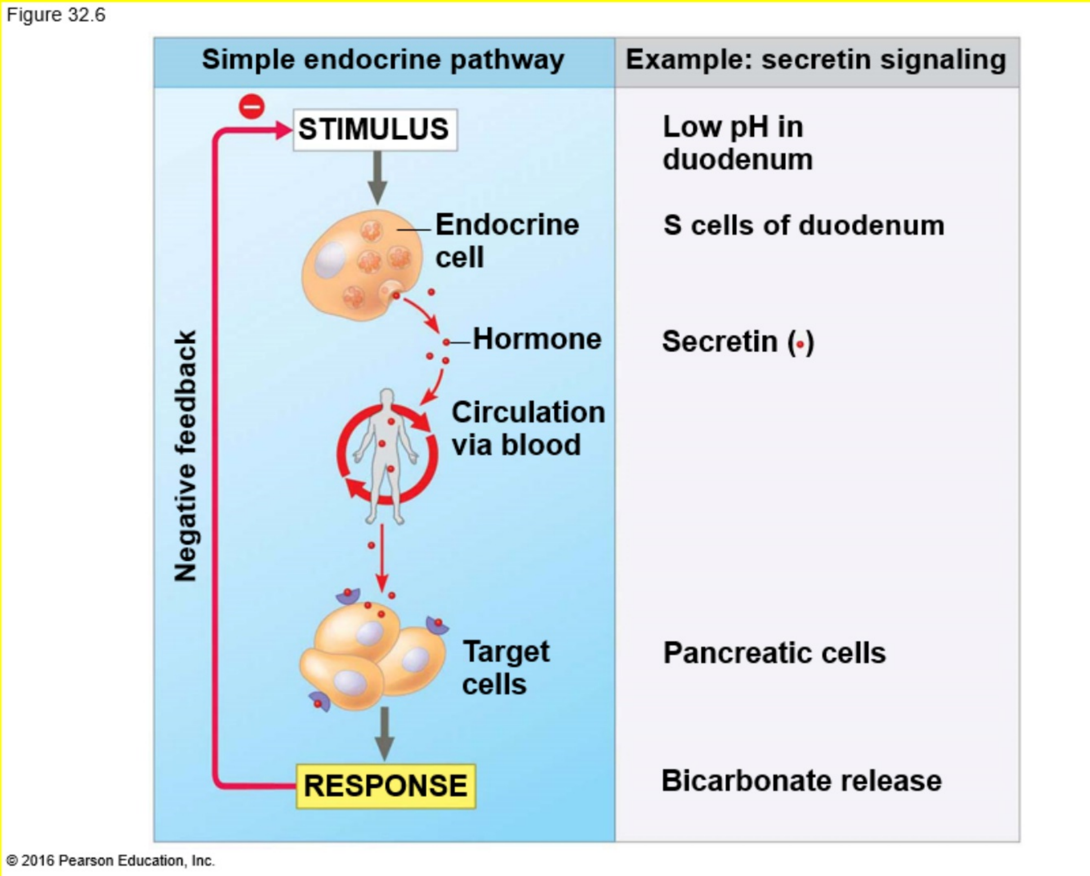
- Stimuli that cause endocrine cells and glands to release hormones are varied
- Hormones can be released in response to organic molecules, nervous system signals, or other hormones
- The **hypothalamus**, an almond-sized region of the brain, controls most neuroendocrine signaling in mammals

- Regulation of a signaling process involves both initiation and termination
- While **negative feedback** dampens a stimulus, **positive feedback** reinforces a stimulus to increase the response

Simple Endocrine Pathways

- Digestive juices in the stomach are extremely acidic and must be neutralized before the remaining steps of digestion take place
- Coordination of pH control in the duodenum relies on an endocrine pathway

- The release of acidic stomach contents into the duodenum stimulates endocrine cells there to secrete the hormone secretin
- This causes target cells in the **pancreas** to raise the pH in the duodenum



Neuroendocrine Signaling

- For many hormones, secretion is triggered when the nervous system detects and processes a stimulus
- In vertebrates, neuroendocrine signaling involves the hypothalamus and the **pituitary gland**, found at its base

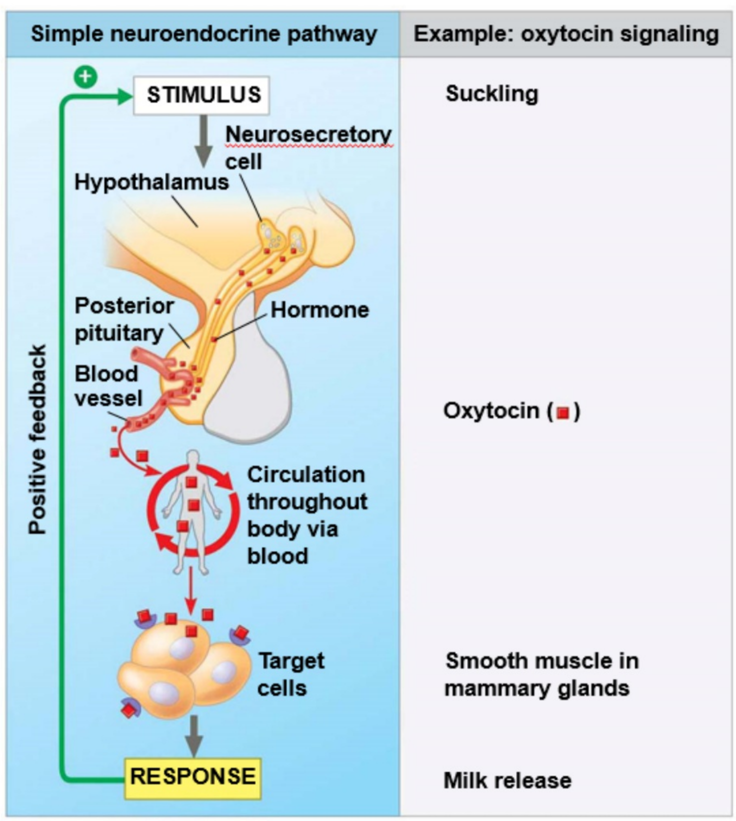
- The pituitary is actually two glands:
  - The **posterior pituitary** is an extension of the hypothalamus that stores and secretes hormones synthesized by the hypothalamus
  - The **anterior pituitary** is an endocrine gland that synthesizes and secretes hormones

Posterior Pituitary Pathways

- Regulation of milk release during nursing in mammals is an example of a neuroendocrine pathway
- Suckling stimulates sensory neurons in the nipples to generate nerve impulses that reach the hypothalamus
- The hypothalamus stimulates release of **oxytocin** from the posterior pituitary, which stimulates further release of milk
- This positive feedback cycle continues until the baby stops suckling

- Another posterior pituitary hormone is **antidiuretic hormone** (**ADH**), also called **vasopressin**

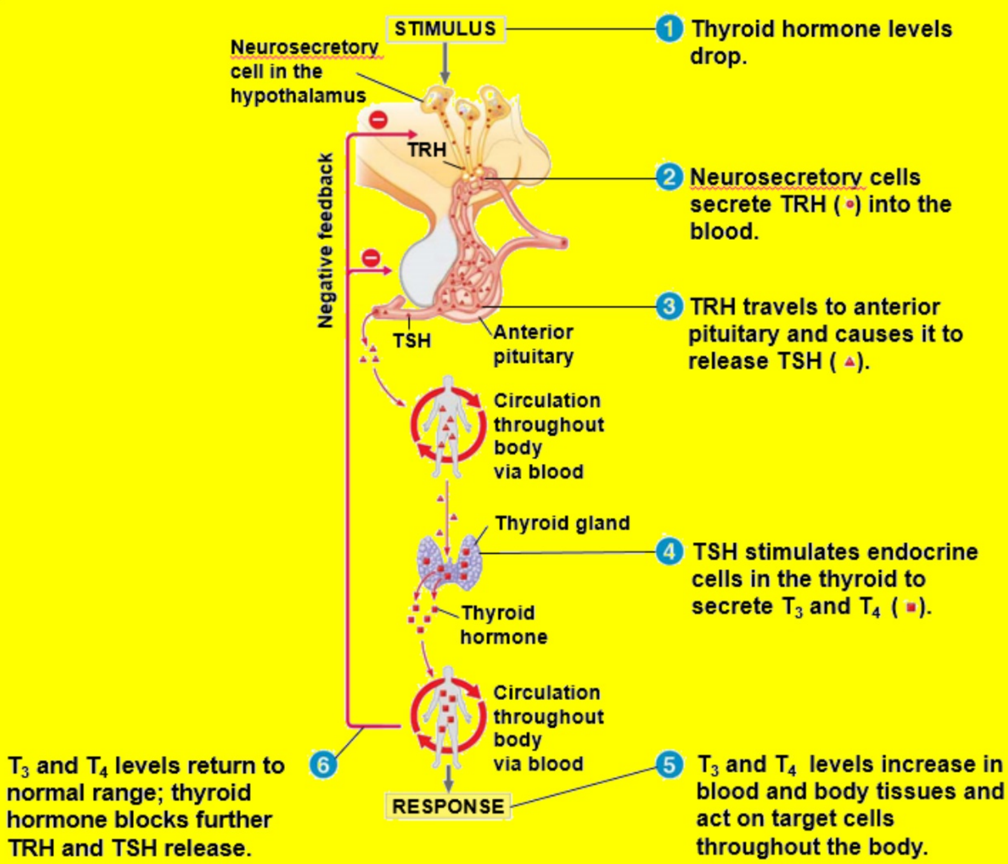
Figure 32.7



Anterior Pituitary Pathways

- The anterior pituitary synthesizes and secretes a diverse set of hormones
- The functions of these hormones range from reproduction to metabolism and stress response
- Anterior pituitary hormones often form part of a hormone cascade
- Anterior pituitary hormones in these cascades are called tropic hormones
- Feedback regulation occurs at multiple levels in hormone cascades

Figure 32.8



Hormone Solubility

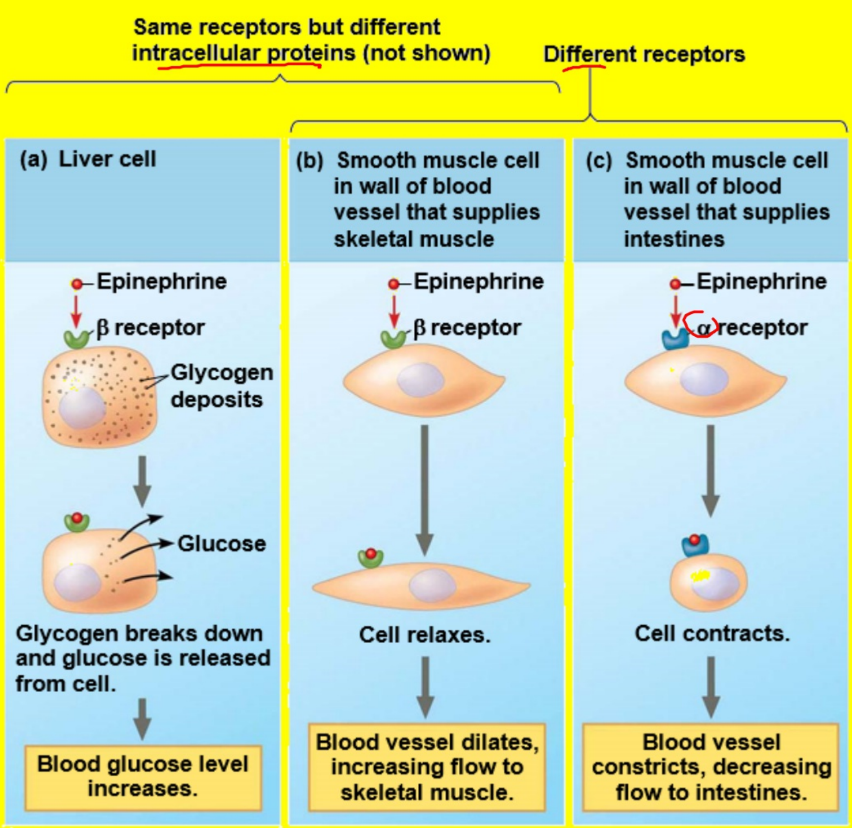
- Many hormones are soluble in water but not in lipids
- These hormones cannot pass through the plasma membrane of target cells
- Instead, they bind to cell-surface receptors, and that triggers events leading to a cellular response
- The intracellular response is called signal transduction
- A signal transduction pathway typically has multiple steps

- Lipid-soluble hormones bind to receptors inside cells
- When bound by the hormone, the hormone-receptor complex moves into the nucleus
- There, the receptor alters transcription of particular genes

Multiple Effects of Hormones

- Many hormones elicit more than one response
- For example, **epinephrine** is secreted by the adrenal glands and can raise blood glucose levels, increase blood flow to muscles, and decrease blood flow to the digestive system
- Target cells vary in their response to a hormone because they differ in their receptor types or in the molecules that produce the response

Figure 32.9



Evolution of Hormone Function

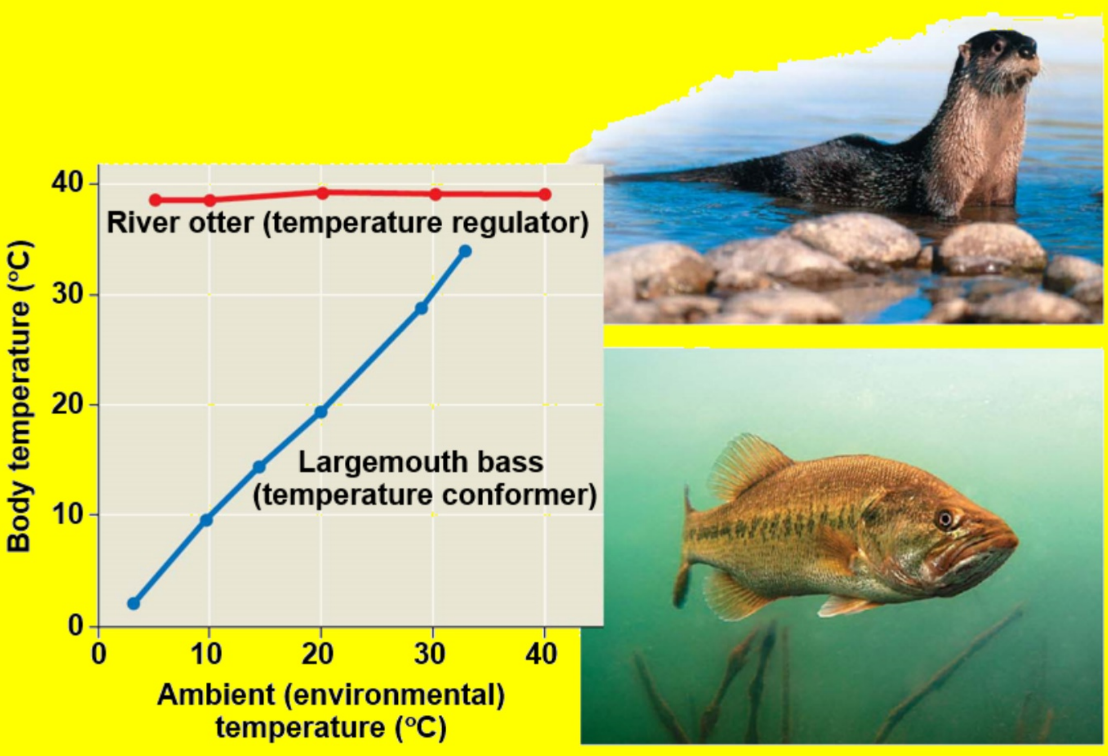
- Over the course of evolution, the functions of a given hormone often diverge between species
- For example, thyroid hormone plays a role in metabolism across many lineages, but in frogs it has taken on a unique function: stimulating the resorption of the tadpole tail during metamorphosis
- Prolactin also has a broad range of activities in vertebrates

Concept 32.3: Feedback control maintains the internal environment in many animals

- Faced with environmental fluctuations, animals manage their internal environment by either regulating or conforming

Regulating and Conforming

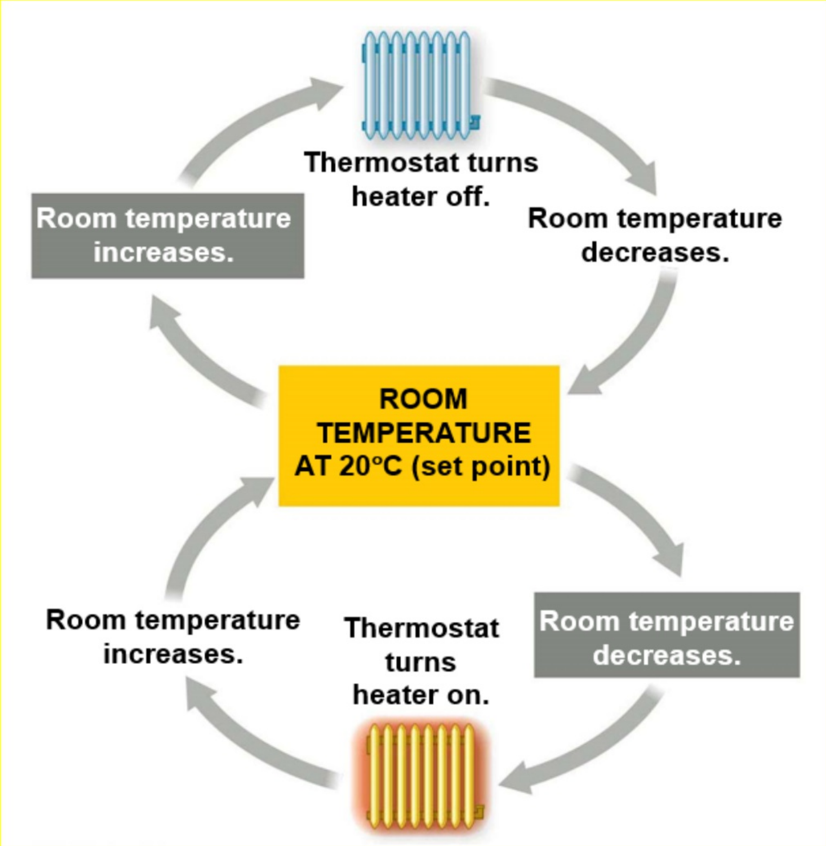
- An animal that is a **regulator** uses internal mechanisms to control internal change despite external fluctuation
- An animal that is a **conformer** allows its internal condition to change in accordance with external changes



- An animal may regulate some internal conditions and not others
- For example, a fish may conform to surrounding temperature in the water, but it regulates solute concentrations in its blood and **interstitial fluid** (the fluid surrounding body cells)

Homeostasis

- Organisms use **homeostasis** to maintain a “steady state” or internal balance regardless of external environment
- In humans, body temperature, blood pH, and glucose concentration are each maintained at a constant level
- Regulation of room temperature by a thermostat is analogous to homeostasis



- Animals achieve homeostasis by maintaining a variable at or near a particular value, or **set point**
- Fluctuations above or below the set point serve as
- a **stimulus**; these are detected by a **sensor** and trigger a **response**

The response returns the variable to the set point

- Homeostasis in animals relies largely on negative feedback, a control mechanism that reduces the stimulus
- Homeostasis moderates, but does not eliminate, changes in the internal environment
- Set points and normal ranges for homeostasis are usually stable, but certain regulated changes in the internal environment are essential

Thermoregulation: *A Closer Look*

- **Thermoregulation** is the process by which animals maintain an internal temperature within a normal range

Endothermy and Ectothermy

- **Endothermic** animals generate heat by metabolism; birds and mammals are endotherms
- **Ectothermic** animals gain heat from external sources; ectotherms include most invertebrates, fishes, amphibians, and nonavian reptiles

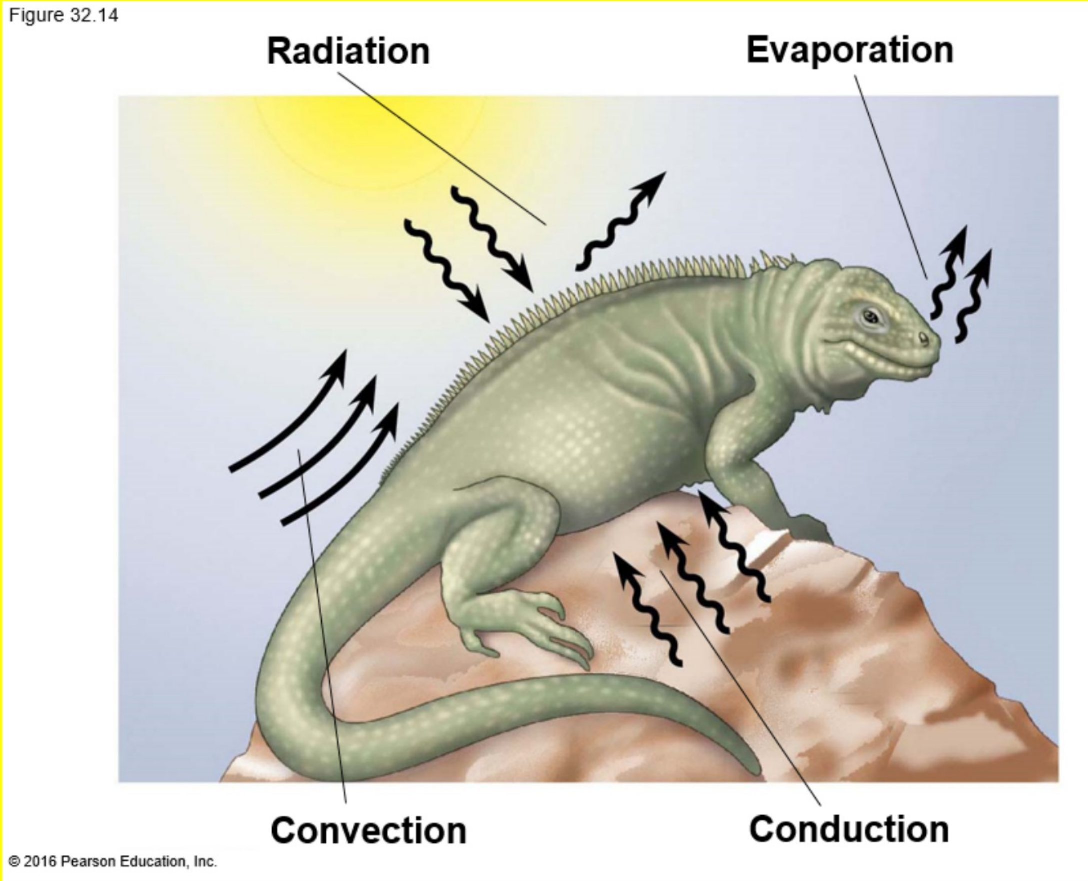
- Endotherms can maintain a stable body temperature in the face of large fluctuations in environmental temperature
- Ectotherms may regulate temperature by behavioral means
- Ectotherms generally need to consume less food than endotherms because their heat source is largely environmental

(a) A walrus, an endotherm

(b) A lizard, an ectotherm

Balancing Heat Loss and Gain

- Organisms exchange heat by four physical processes
  - Radiation
  - Evaporation
  - Convection
  - Conduction
- Heat is always transferred from an object of higher temperature to one of lower temperature

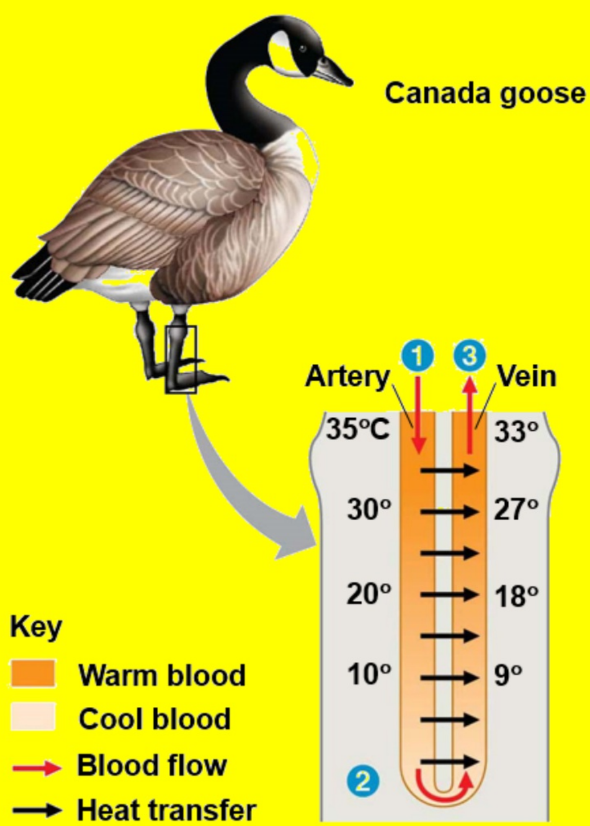


Circulatory Adaptations for Thermoregulation

- In response to changes in environmental temperature, animals can alter blood (hence heat) flow between their body core and surface
- Vasodilation, the widening of the diameter of superficial blood vessels, promotes heat loss
- Vasoconstriction, the narrowing of the diameter of superficial blood vessels, reduces heat loss

- The arrangement of blood vessels in many marine mammals and birds allows for **countercurrent exchange**
- Countercurrent heat exchangers transfer heat between fluids flowing in opposite directions and reduce heat loss

Figure 32.15



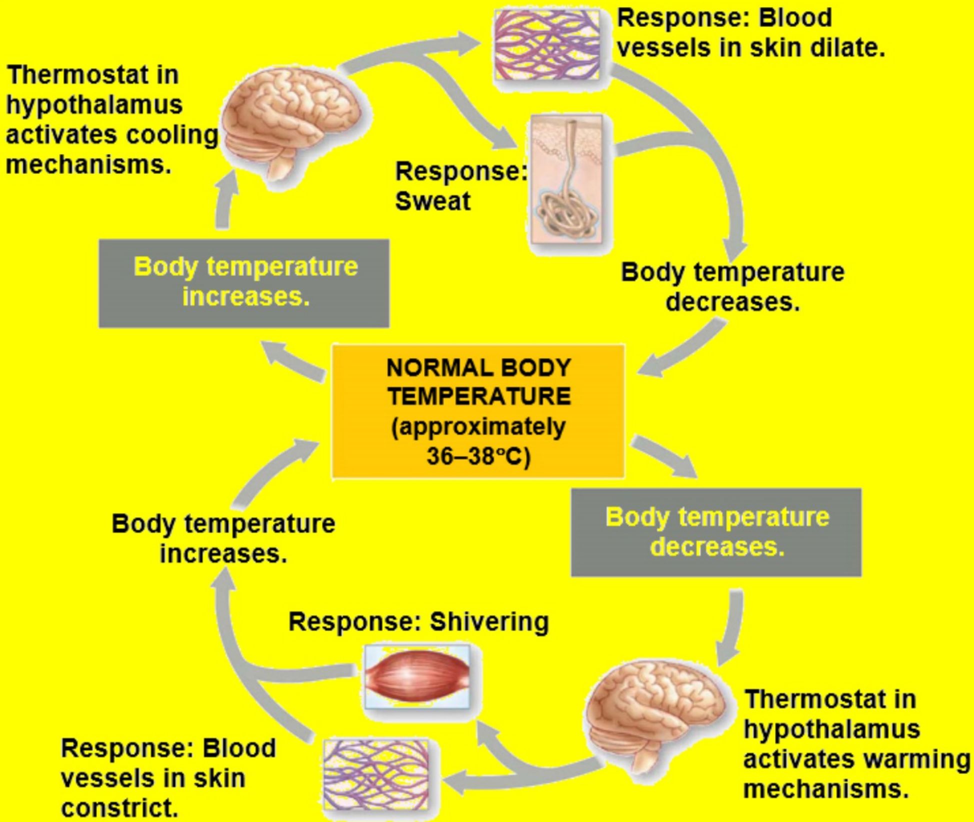
Acclimatization in Thermoregulation

- Birds and mammals can vary their insulation to acclimatize to seasonal temperature changes
- Acclimatization in ectotherms often includes adjustments at the cellular level
- Some ectotherms that experience subzero temperatures can produce "antifreeze" compounds to prevent ice formation in their cells

Physiological Thermostats

- Thermoregulation in mammals is controlled by the hypothalamus, in which a group of nerve cells functions as a thermostat
- The hypothalamus triggers heat loss or heat-generating mechanisms
- Fever is the result of a change to the set point for a biological thermostat

Figure 32.16



Concept 32.4: A shared system mediates osmoregulation and excretion in many animals

- **Osmoregulation** is the general term for the processes by which animals control solute concentrations in the interstitial fluid and balance water gain and loss
- Several mechanisms have evolved for **excretion**, the process that rids the body of nitrogenous metabolites and other metabolic waste products

Osmosis and Osmolarity

- **Osmolarity**, the solute concentration of a solution, determines the movement of water across a selectively permeable membrane
- If two solutions are isoosmotic, the movement of water is equal in both directions
- If two solutions differ in osmolarity, the net flow of water is from the hypoosmotic (lower solute concentration) to the hyperosmotic (higher solute concentration) solution

Water Potential

$$\text{Water Potential} = \Psi = \Psi_s + \Psi_p$$

$$\Psi_s = -iCRT$$

- i = The number of particles the molecule will make in water; for NaCl this would be 2; for sucrose or glucose, this number is 1
- C = Molar concentration
  (from your experimental data; where the line of best fit crosses the x-axis)
- R = Pressure constant = 0.0831 liter bar/mole K
- T = Temperature in degrees Kelvin = 273 + °C of solution

Sample Problem

The molar concentration of a sugar solution in an open beaker has been determined to be 0.3M. Calculate the solute potential at 27 ºC. Round your answer to the nearest tenths.

If a baby carrot with a water potential of 5.2 bars is put into this solution, what will happen? Why?

Plants must be able to balance water uptake and loss to survive. In animal cells the direction of osmosis is easily predicted based on solute concentration. Water will flow from the hypotonic (high concentration) region to the hypertonic (low concentration) region in the cellular environment. In plant cells, this is only half the story. Plants have rigid cell walls that affect the cells' physical pressure. The effects of both solute concentration and physical pressure are incorporated into a single measurement called *water potential,* represented by the Greek letter *psi* (ψ). Water potential is defined in terms of the free energy per mole of water and is measured in bars. The total water potential (ψ) may be determined by adding the water potential due to pressure (ψ_P) and the water potential due to solute concentration (ψ_S) (see Equation 1).

$$\psi = \psi_P + \psi_S \qquad \textit{Equation 1}$$

The key to understanding water potential is that water spontaneously moves from an area of higher potential (higher free energy, more water molecules) to an area of lower water potential (lower free energy, fewer water molecules). In basic terms water potential measures the tendency of water to diffuse from one area to another.

Solute potential, ψ_S, is dependent on solute concentration. The solute concentration in the area surrounding the cell influences the properties of the cell. Solutes decrease the water potential in a solution, thus causing water to diffuse into an area with a higher solute concentration. If the solute concentration is higher outside the cell, water will leave the cell and enter the surrounding solution. The solute potential is calculated using Equation 2.

$$\psi_S = -iCRT \qquad \textit{Equation 2}$$

where "i" is the ionization constant (for sucrose this is 1.0 because it does not ionize in water)

C is the molar concentration

R is the pressure constant (R = 0.0831 liter·bar/mole·K)

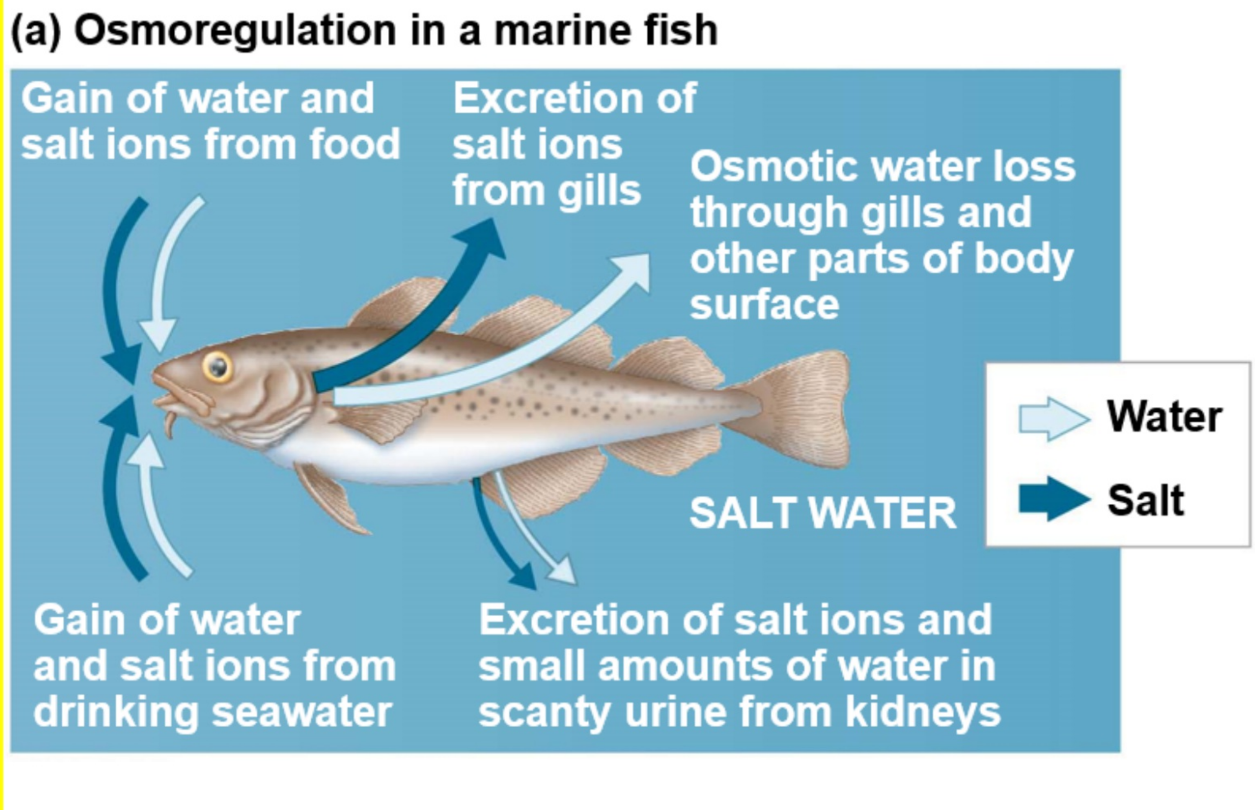
T is the absolute temperature of solution in Kelvin (K = 273 + °C)

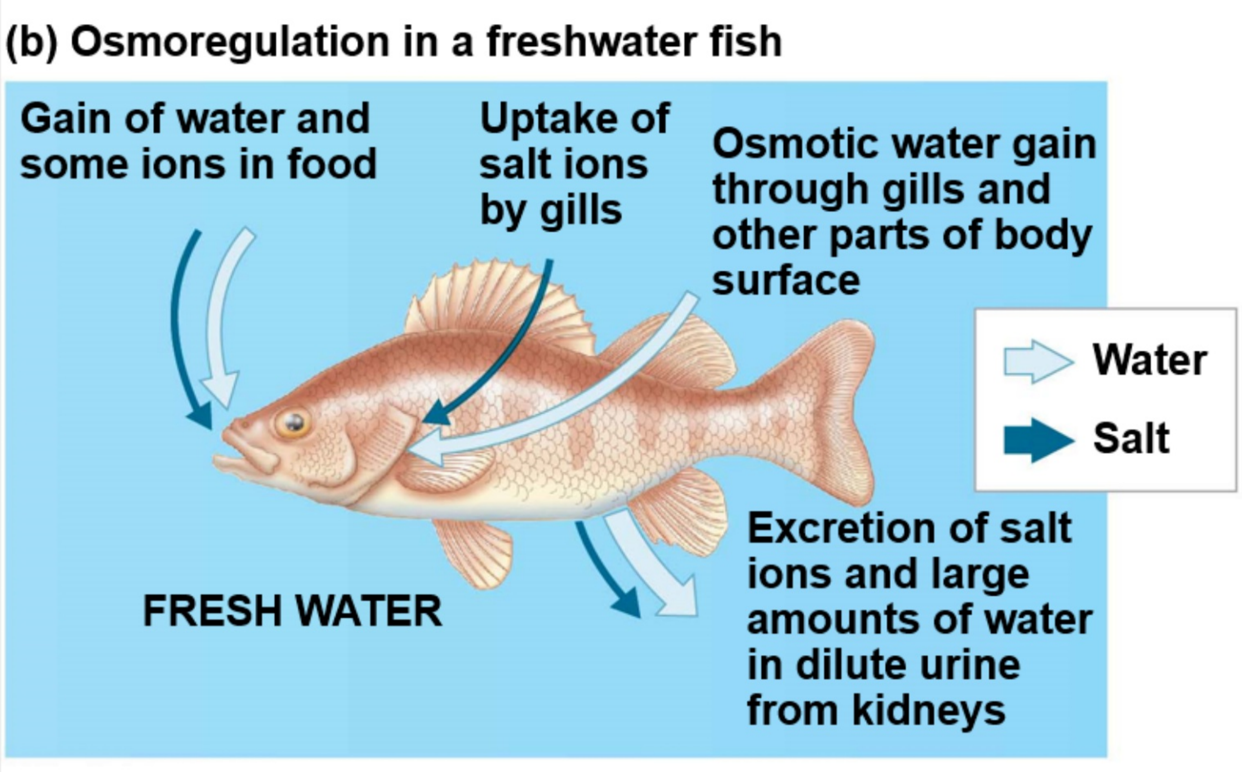
Osmoregulatory Challenges and Mechanisms

- **Osmoconformers**, consisting of some marine animals, are isoosmotic with their surroundings and do not regulate their osmolarity
- **Osmoregulators** expend energy to control water uptake and loss in a hyperosmotic or hypoosmotic environment

- Marine and freshwater organisms have opposite challenges
- Marine fish drink large amounts of seawater to balance water loss and excrete salt through their
- gills and kidneys

Freshwater fish drink almost no water and replenish salts through eating; some also replenish salts by uptake across the gills

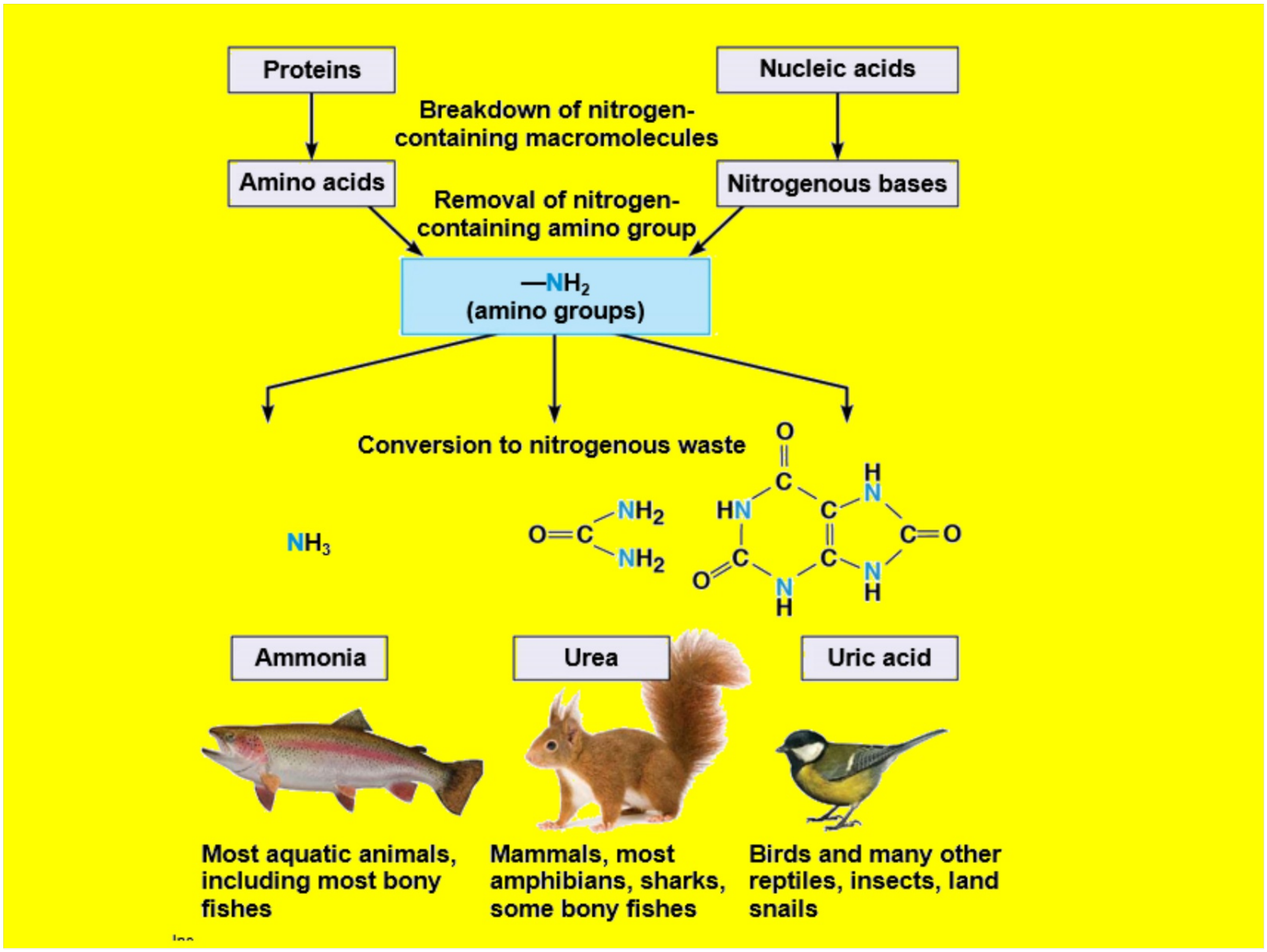

(a) Osmoregulation in a marine fish
Gain of water and salt ions from food
Excretion of salt ions from gills
Osmotic water loss through gills and other parts of body surface
Water
Salt
SALT WATER
Gain of water and salt ions from drinking seawater
Excretion of salt ions and small amounts of water in scanty urine from kidneys

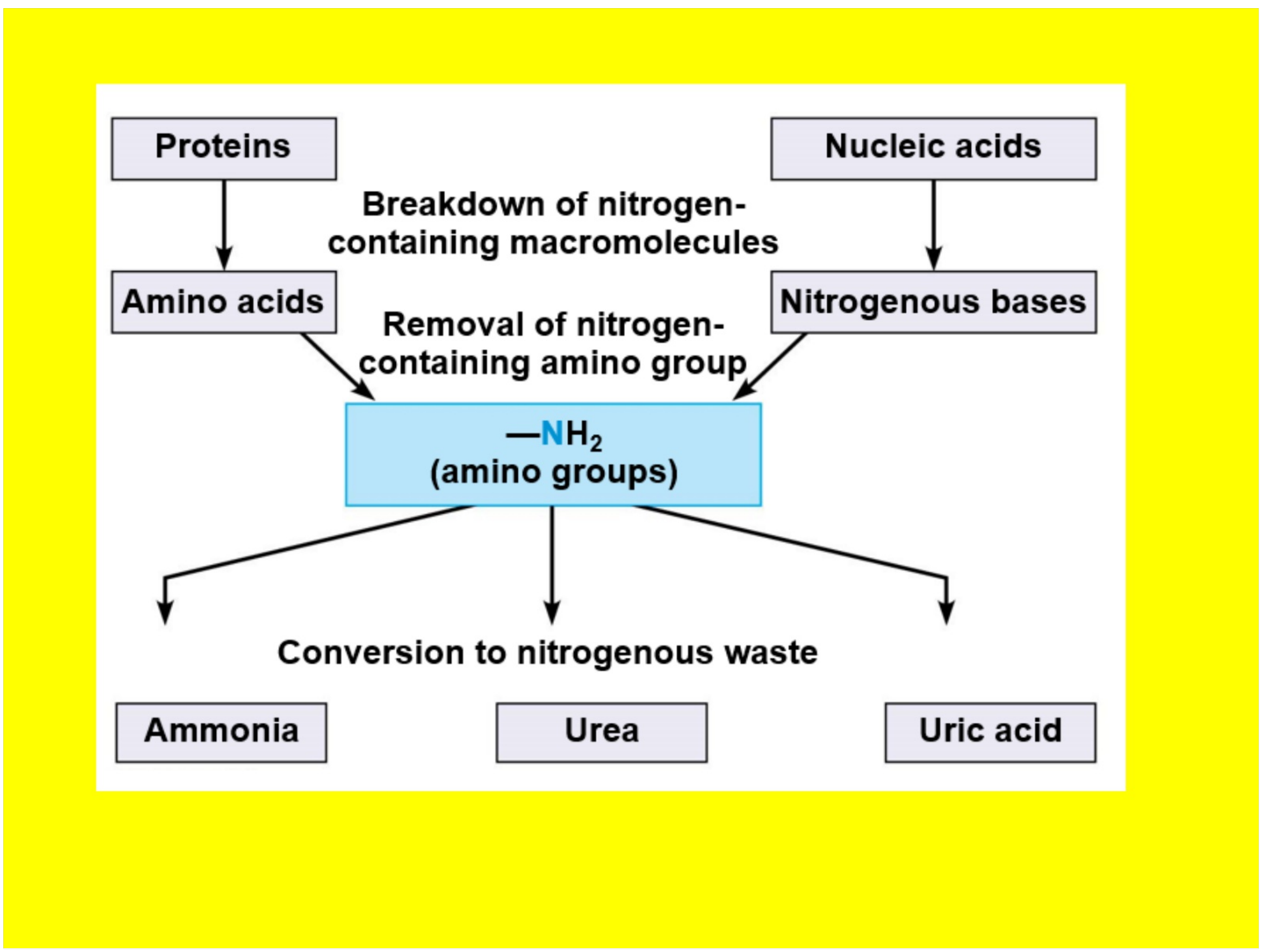

(b) Osmoregulation in a freshwater fish
Gain of water and some ions in food
Uptake of salt ions by gills
Osmotic water gain through gills and other parts of body surface
Water
Salt
FRESH WATER
Excretion of salt ions and large amounts of water in dilute urine from kidneys

- Land animals have mechanisms to prevent dehydration
- Most have body coverings that help reduce water loss
- They drink water and eat moist foods, and they produce water metabolically

Nitrogenous Wastes

- The type and quantity of an animal's waste products may greatly affect its water balance
- Among the most significant wastes are nitrogenous breakdown products of proteins and nucleic acids
- Some animals convert toxic **ammonia** (NH_3) to less toxic compounds prior to excretion


Proteins
Nucleic acids
Breakdown of nitrogen-containing macromolecules
Amino acids
Nitrogenous bases
Removal of nitrogen-containing amino group
—NH2 (amino groups)
Conversion to nitrogenous waste
NH3
Ammonia
Urea
Uric acid
Most aquatic animals, including most bony fishes
Mammals, most amphibians, sharks, some bony fishes
Birds and many other reptiles, insects, land snails


Proteins
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—NH2 (amino groups)
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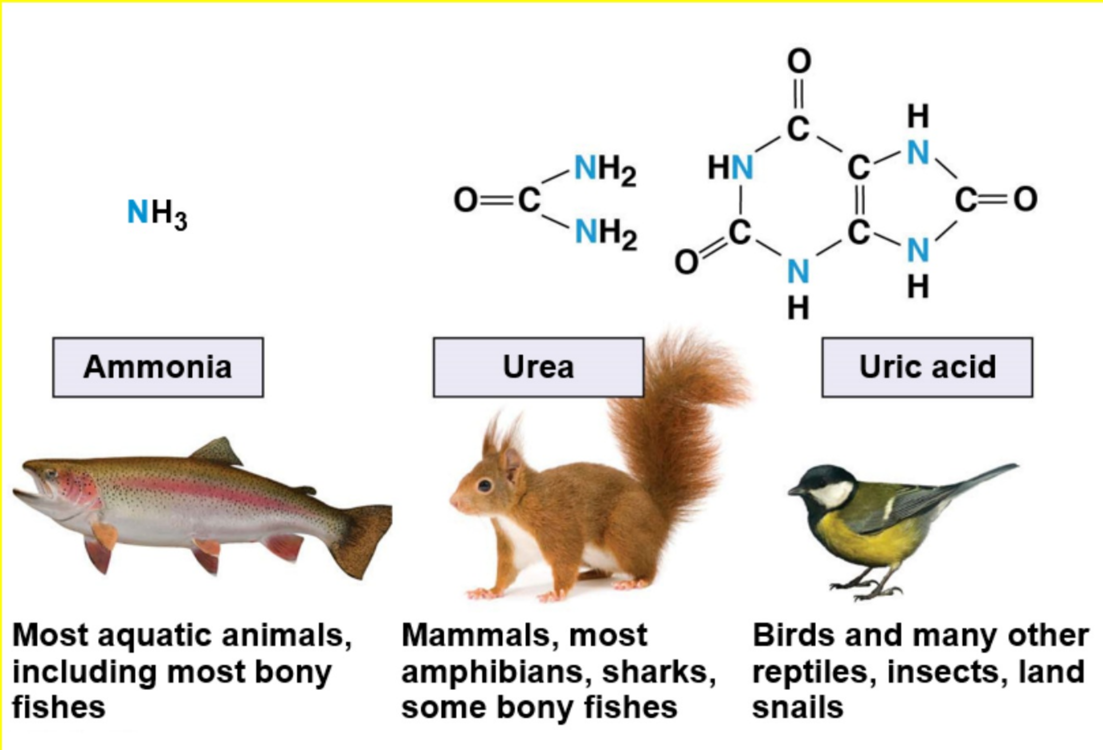
Ammonia
Urea
Uric acid

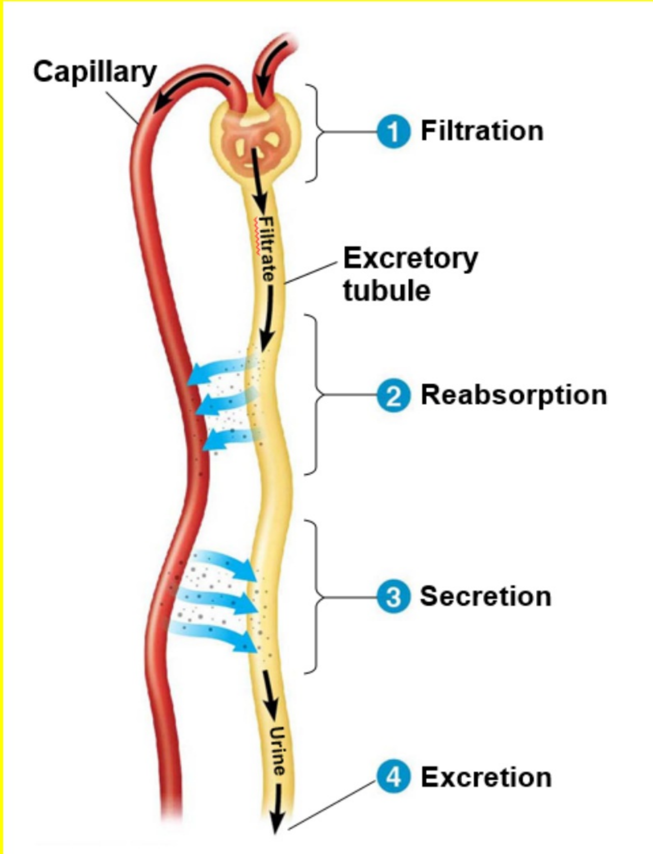


- Ammonia excretion is most common in aquatic organisms
- Most terrestrial animals and many marine species excrete **urea**, a conversion product of ammonia, which is much less toxic
- Insects, land snails, and many reptiles including birds excrete **uric acid** as a semisolid paste
- It is less toxic than ammonia and generates very little water loss, but it is energetically more expensive to produce than urea

Excretory Processes

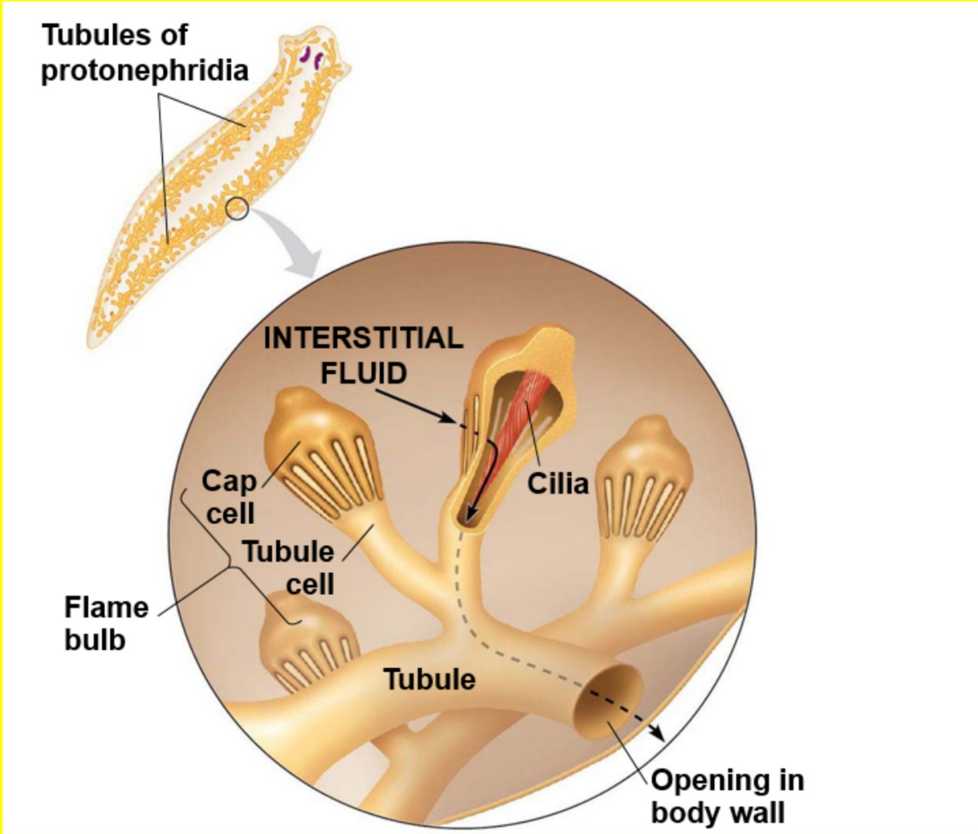
- In most animals, osmoregulation and metabolic waste disposal rely on **transport epithelia**
- These layers of epithelial cells are specialized for moving solutes in controlled amounts in specific directions

- Many animal species produce a fluid waste by refining a **filtrate** derived from body fluids
- Key functions of most excretory systems
  - **Filtration**: Filtering of body fluids
  - **Reabsorption**: Reclaiming valuable solutes
  - **Secretion**: Adding nonessential solutes and wastes from the body fluids to the filtrate
  - Excretion: Releasing processed filtrate containing nitrogenous wastes from the body



Invertebrates

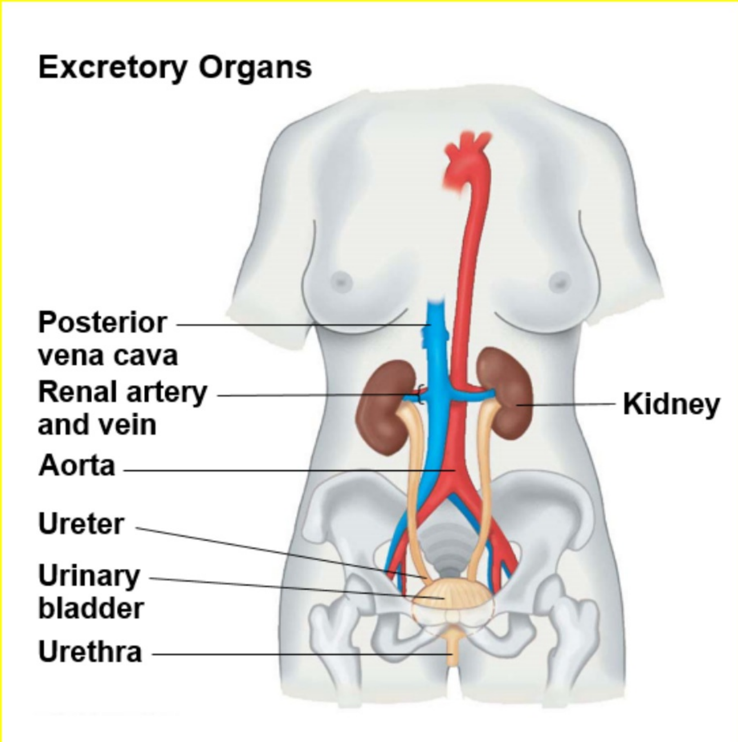
- Flatworms have excretory systems called protonephridia, networks of tubules connected to external openings
- The smallest branches of the network are capped by a cellular unit called a flame bulb
- The dilute urine produced is emptied into the external environment



- In insects and other terrestrial arthropods, Malpighian tubules remove nitrogenous wastes from hemolymph without a filtration step
- Insects produce a relatively dry waste matter, mainly uric acid

Vertebrates

- In vertebrates and some other chordates, the **kidney** functions in both osmoregulation and excretion
- The kidney consists of tubules arranged in an organized array and in contact with a network of capillaries
- The excretory system includes ducts and other structures that carry urine from the tubules out of the body



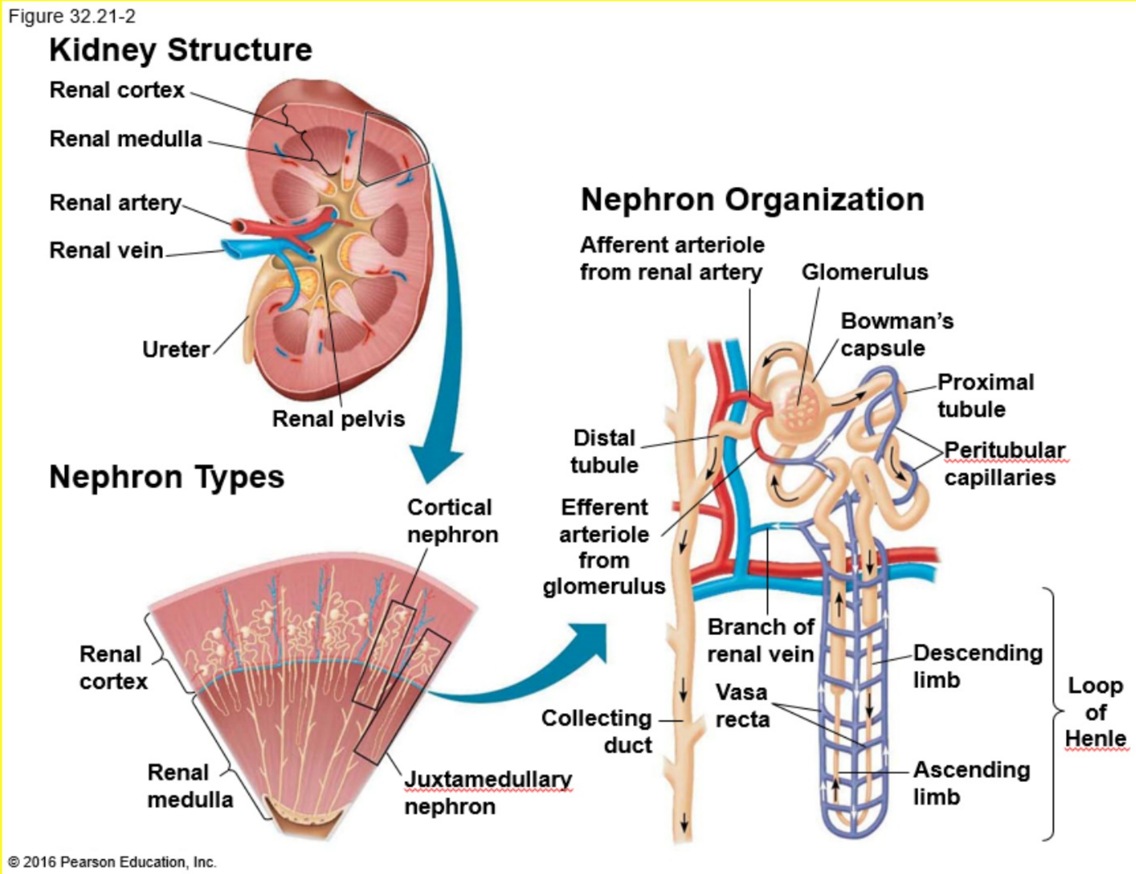


Figure 32.21-2
Kidney Structure
Renal cortex
Renal medulla
Renal artery
Renal vein
Ureter
Renal pelvis
Nephron Types
Cortical nephron
Renal cortex
Renal medulla
Juxtamedullary nephron
Nephron Organization
Afferent arteriole from renal artery
Glomerulus
Bowman's capsule
Proximal tubule
Peritubular capillaries
Distal tubule
Efferent arteriole from glomerulus
Branch of renal vein
Descending limb
Vasa recta
Loop of Henle
Collecting duct
Ascending limb
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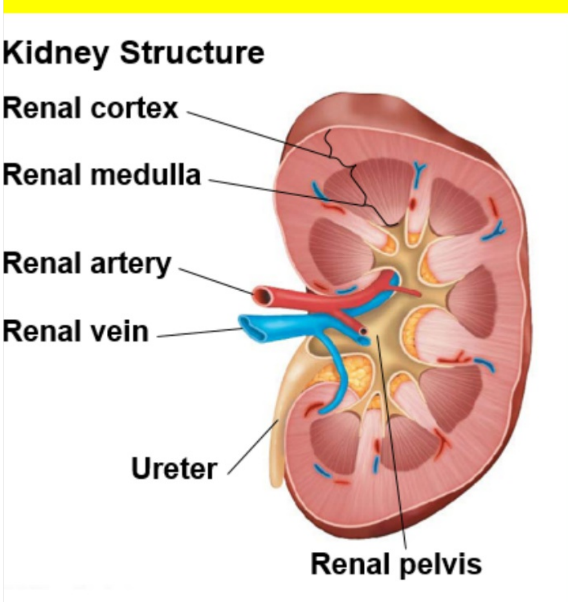

Kidney Structure
Renal cortex
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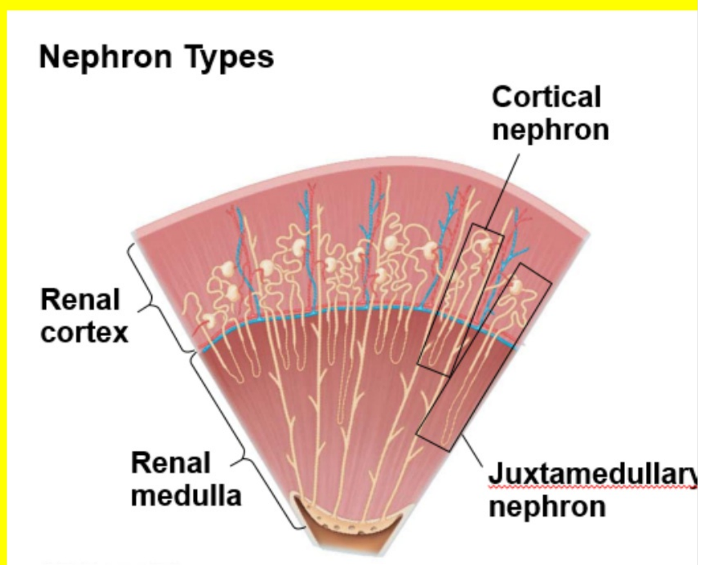
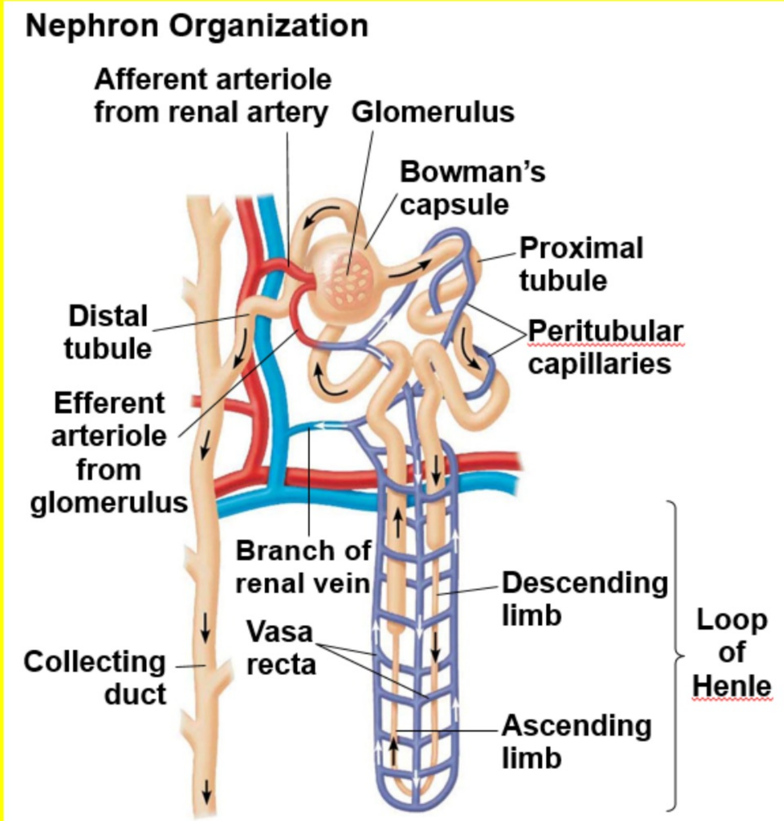
Renal pelvis



Nephron Types
Cortical nephron
Renal cortex
Renal medulla
Juxtamedullary nephron



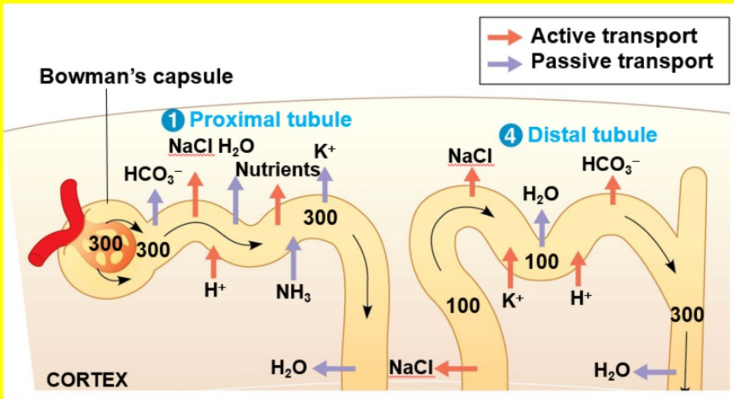
Concept 32.5: The mammalian kidney's ability to conserve water is a key terrestrial adaptation

- The basic unit of the mammalian kidney is a nephron
- In the human kidney, filtrate forms when fluid passes from the bloodstream to the lumen of Bowman's capsule in each nephron
- Roughly 1,600 L of blood flows through a pair of human kidneys each day, yielding about 180 L of initial filtrate
- About 99% of the water and nearly all of the sugars, amino acids, vitamins, and other organic nutrients are reabsorbed into the blood

From Blood Filtrate to Urine: *A Closer Look*

Proximal tubule

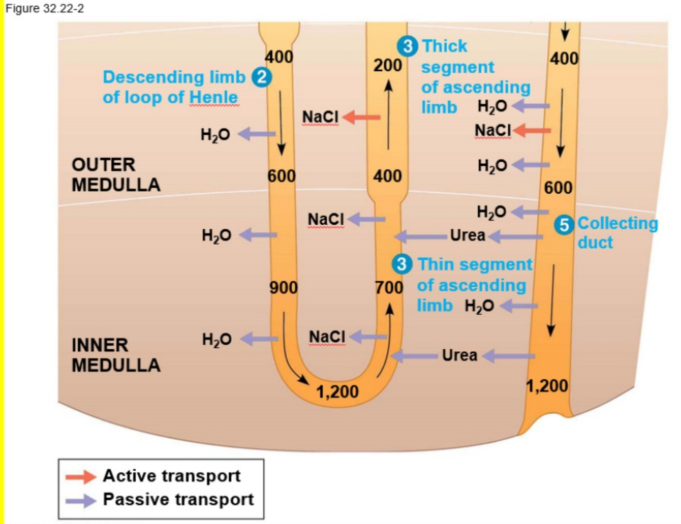
- Reabsorption of ions, water, and nutrients takes place in the proximal tubule
- Molecules are transported actively and passively from the filtrate into the interstitial fluid and then capillaries
- Some toxic materials are actively secreted into the filtrate



Descending limb of the loop of Henle

- Reabsorption of water continues through channels formed by **aquaporin** proteins
- Movement is driven by the high osmolarity of the interstitial fluid, which is hyperosmotic to the filtrate
- The filtrate becomes increasingly concentrated all along its journey down the descending limb

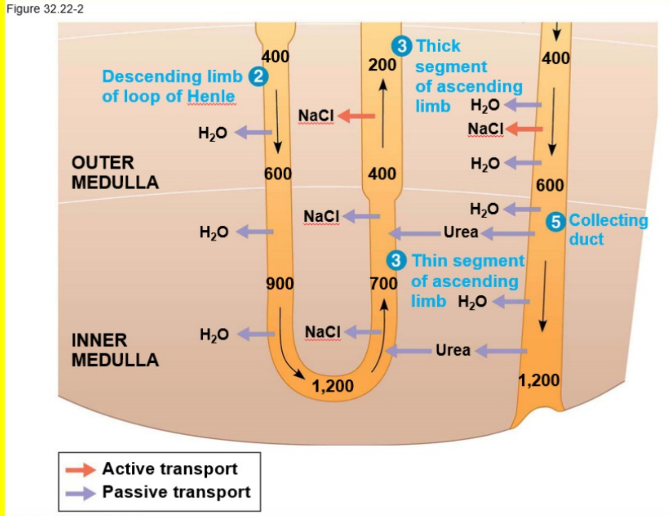
Figure 32.22-2



Ascending limb of the loop of Henle

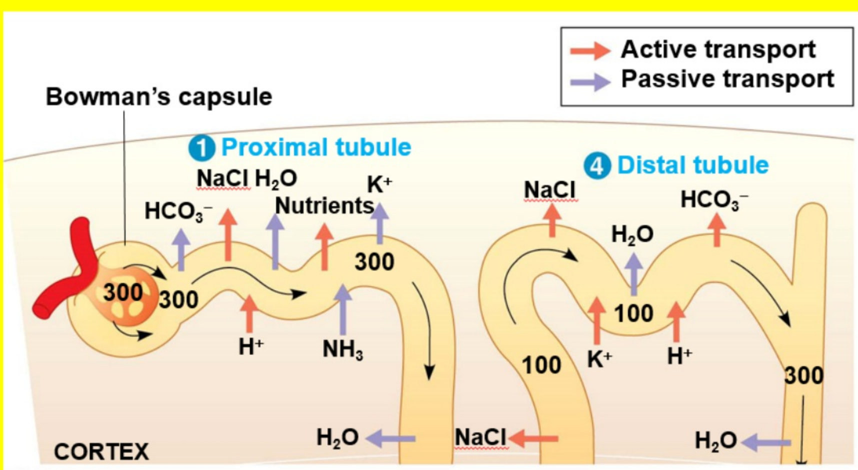
- The ascending limb has a transport epithelium that lacks water channels
- Here, salt but not water is able to move from the tubule into the interstitial fluid
- The filtrate becomes increasingly dilute as it moves up to the cortex

Figure 32.22-2



Distal tubule

- The distal tubule regulates the K^+ and NaCl concentrations of body fluids
- The controlled movement of ions contributes to pH regulation



Collecting duct

- The collecting duct carries filtrate to the renal pelvis
- As filtrate passes along the transport epithelium of the collecting duct, regulation of permeability and transport across the epithelium determines the concentration of the urine

Figure 32.22-2

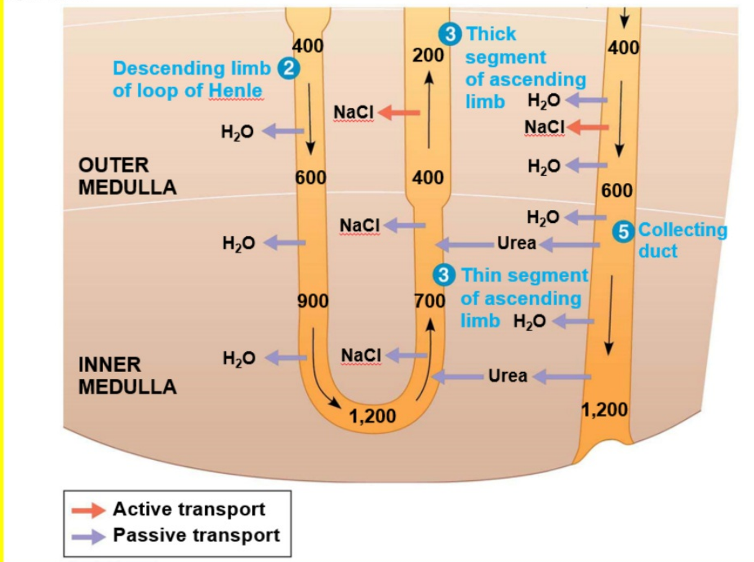
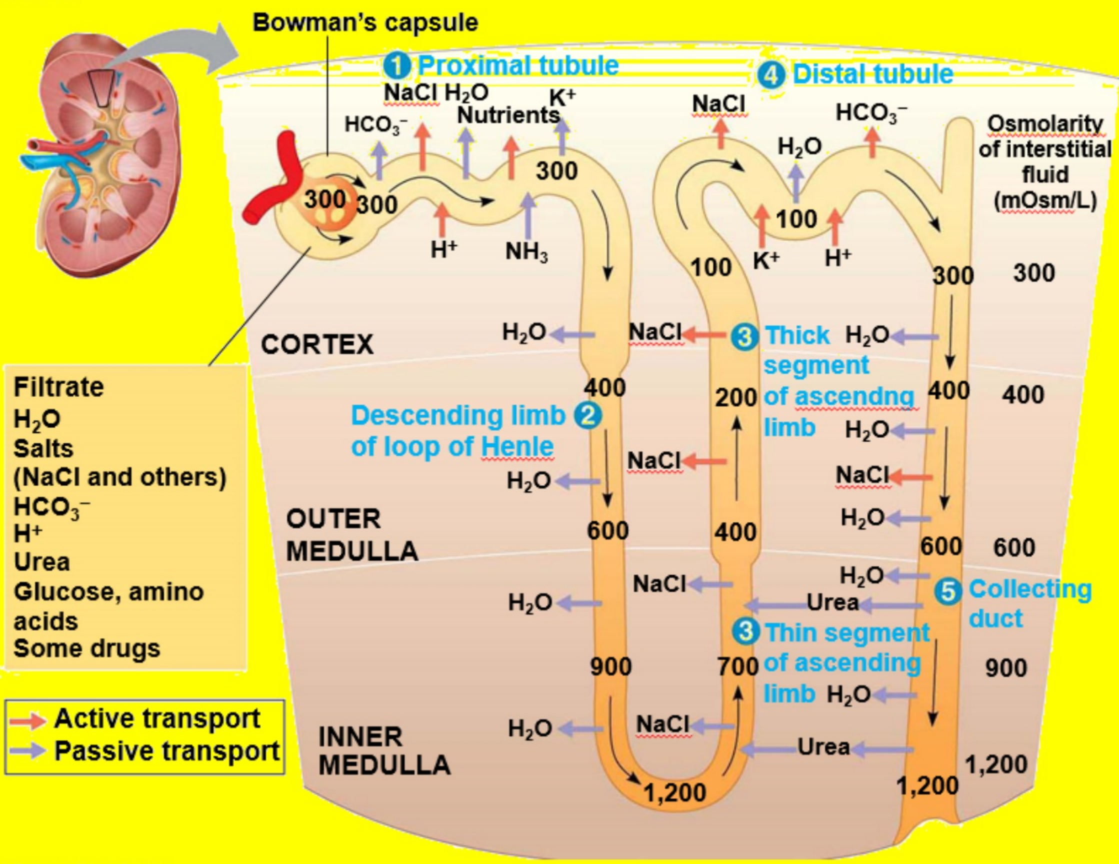


Figure 32.22



Concentrating Urine in the Mammalian Kidney

- The mammalian kidney’s ability to conserve water is a key terrestrial adaptation
- The loop of Henle and surrounding capillaries act as a type of countercurrent system
- This system involves active transport and thus an expenditure of energy
- Such a system is called a **countercurrent multiplier system**

Adaptations of the Vertebrate Kidney to Diverse Environments

- Variations in nephron structure and function equip the kidneys of different vertebrates for osmoregulation in their various habitats

- Desert-dwelling mammals excrete the most hyperosmotic urine and have long loops of Henle
- Birds have shorter loops of Henle but conserve water by excreting uric acid instead of urea

- Mammals control the volume and osmolarity of urine
- The kidneys of the South American vampire bat can produce either very dilute or very concentrated urine
- This allows the bats to reduce their body weight rapidly or digest large amounts of protein while conserving water

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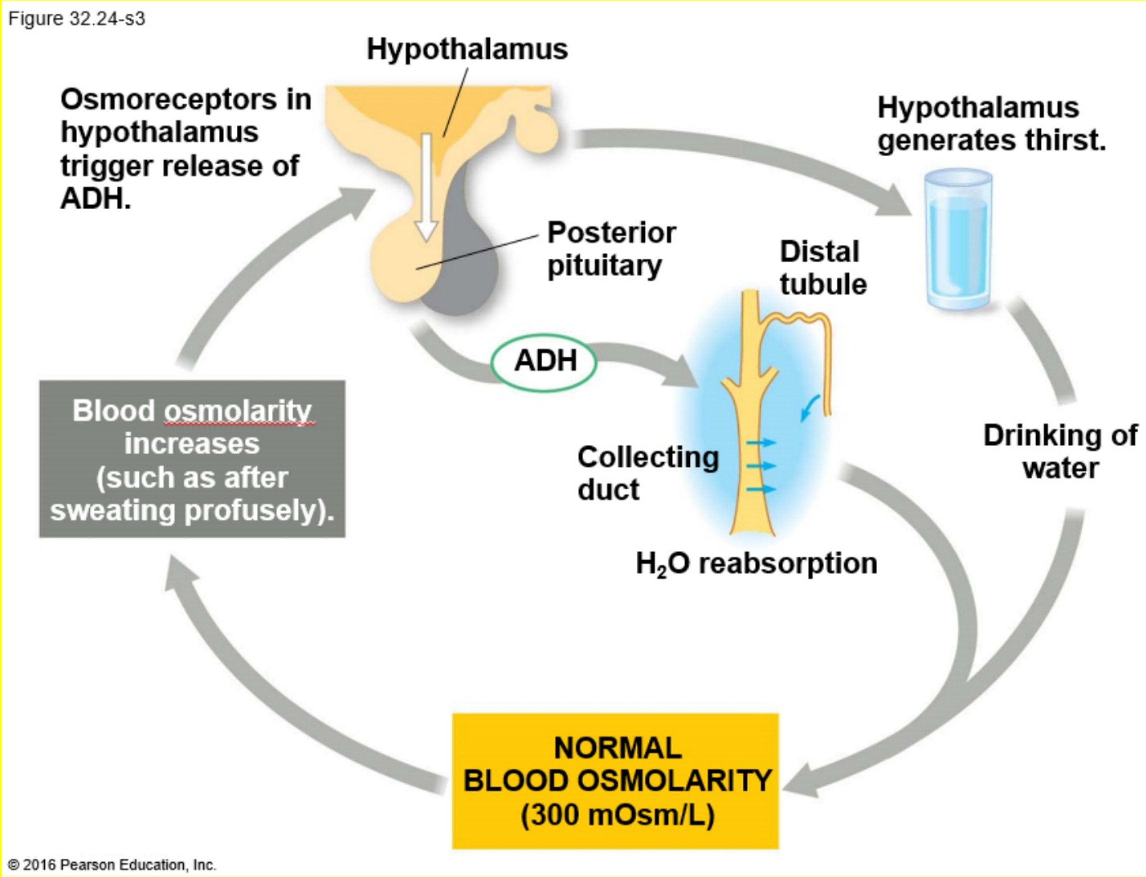
Homeostatic Regulation of the Kidney

- A combination of nervous and hormonal inputs regulates the osmoregulatory function of the kidney
- These inputs contribute to homeostasis for blood pressure and volume

Antidiuretic Hormone

- Antidiuretic hormone (ADH) makes the collecting duct epithelium temporarily more permeable to water
- An increase in blood osmolarity above a set point triggers the release of ADH, which helps to conserve water

Decreased osmolarity causes a drop in ADH secretion and a corresponding decrease in permeability of collecting ducts



Coordination of Kidney Regulation

- The renin-angiotensin-aldosterone system (RAAS) also regulates kidney function
- A drop in blood volume and pressure causes the RAAS to increase water and Na^+ reabsorption
- A peptide called angiotensin II is a product of the RAAS

- Angiotensin II raises blood pressure and decreases blood flow to capillaries in the kidney
- Drugs that block angiotensin II production are used to treat hypertension (chronic high blood pressure)