LECTURE PRESENTATIONS
For CAMPBELL BIOLOGY, NINTH EDITION
Jane B. Reece, Lisa A. Urry, Michael L. Cain, Steven A. Wasserman, Peter V. Minorsky, Robert B. Jackson

Chapter 44

Osmoregulation and Excretion

Lectures by
Erin Barley
Kathleen Fitzpatrick

Overview: A Balancing Act

- Physiological systems of animals operate in a fluid environment
- Relative concentrations of water and solutes must be maintained within fairly narrow limits
- **Osmoregulation** regulates solute concentrations and balances the gain and loss of water

- Freshwater animals show adaptations that reduce water uptake and conserve solutes
- Desert and marine animals face desiccating environments that can quickly deplete body water
- **Excretion** gets rid of nitrogenous metabolites and other waste products

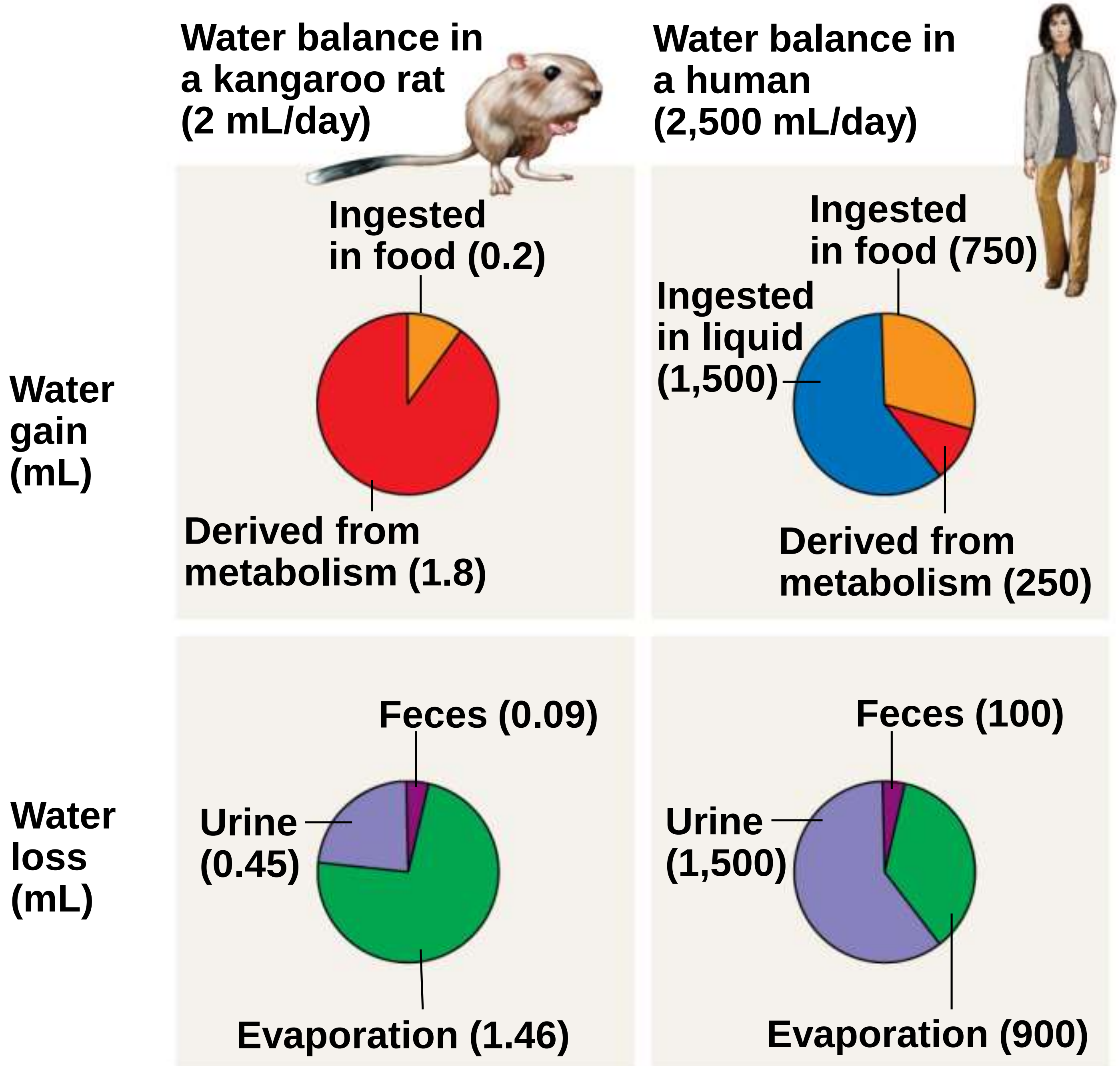
Concept 44.1: Osmoregulation balances the uptake and loss of water and solutes

- Osmoregulation is based largely on controlled movement of solutes between internal fluids and the external environment

Land Animals

- Adaptations to reduce water loss are key to survival on land
- Body coverings of most terrestrial animals help prevent dehydration
- Desert animals get major water savings from simple anatomical features and behaviors such as a nocturnal lifestyle
- Land animals maintain water balance by eating moist food and producing water metabolically through cellular respiration

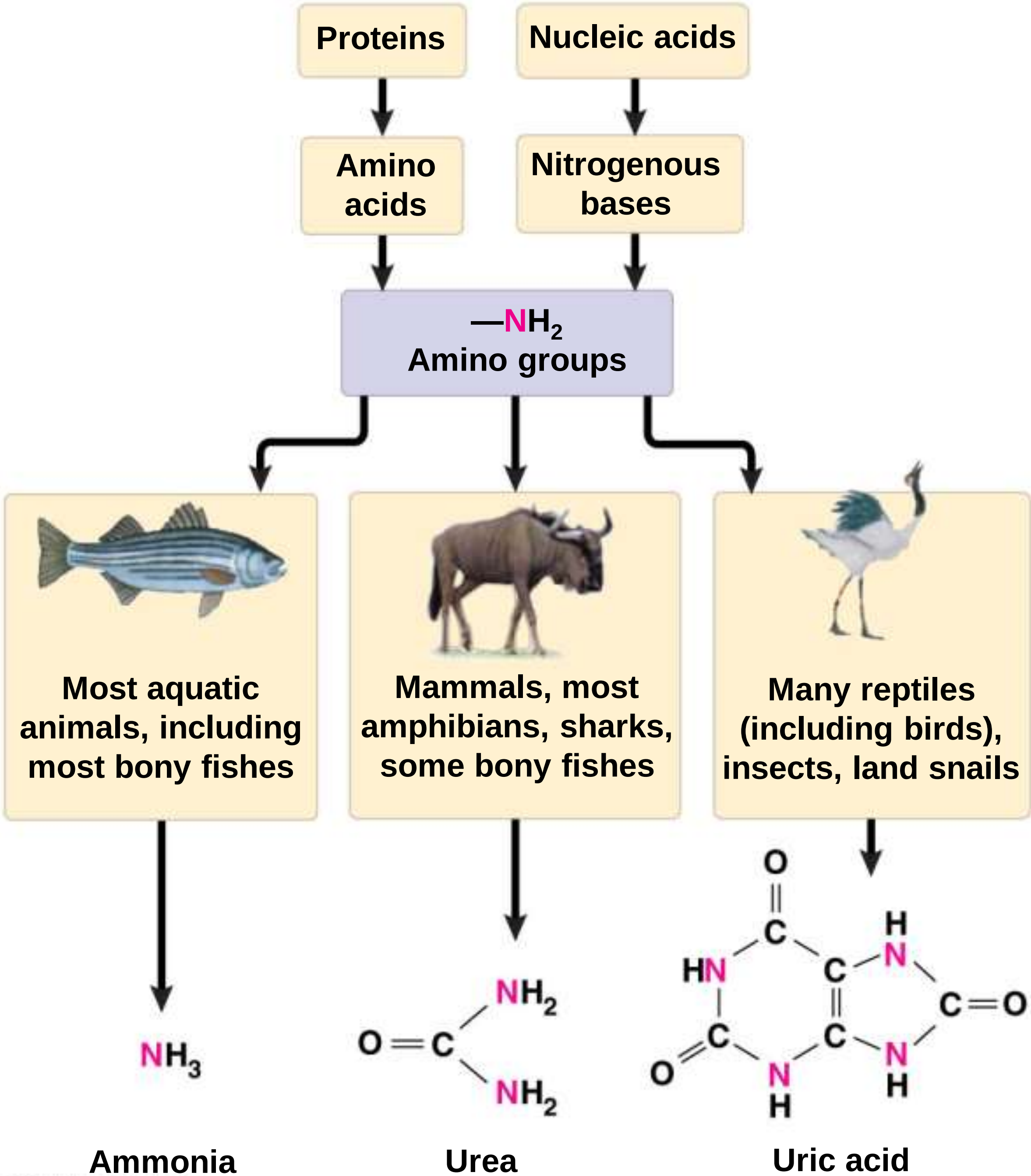
Figure 44.6


Water balance in a kangaroo rat (2 mL/day)
Water balance in a human (2,500 mL/day)
Water gain (mL)
Ingested in food (0.2)
Derived from metabolism (1.8)
Ingested in food (750)
Ingested in liquid (1,500)
Derived from metabolism (250)
Water loss (mL)
Feces (0.09)
Urine (0.45)
Evaporation (1.46)
Feces (100)
Urine (1,500)
Evaporation (900)

Concept 44.2: An animal's nitrogenous wastes reflect its phylogeny and habitat

- 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

Figure 44.8



Proteins
Nucleic acids
Amino acids
Nitrogenous bases
—NH2
Amino groups
Most aquatic animals, including most bony fishes
Mammals, most amphibians, sharks, some bony fishes
Many reptiles (including birds), insects, land snails
NH3
Ammonia
Urea
Uric acid

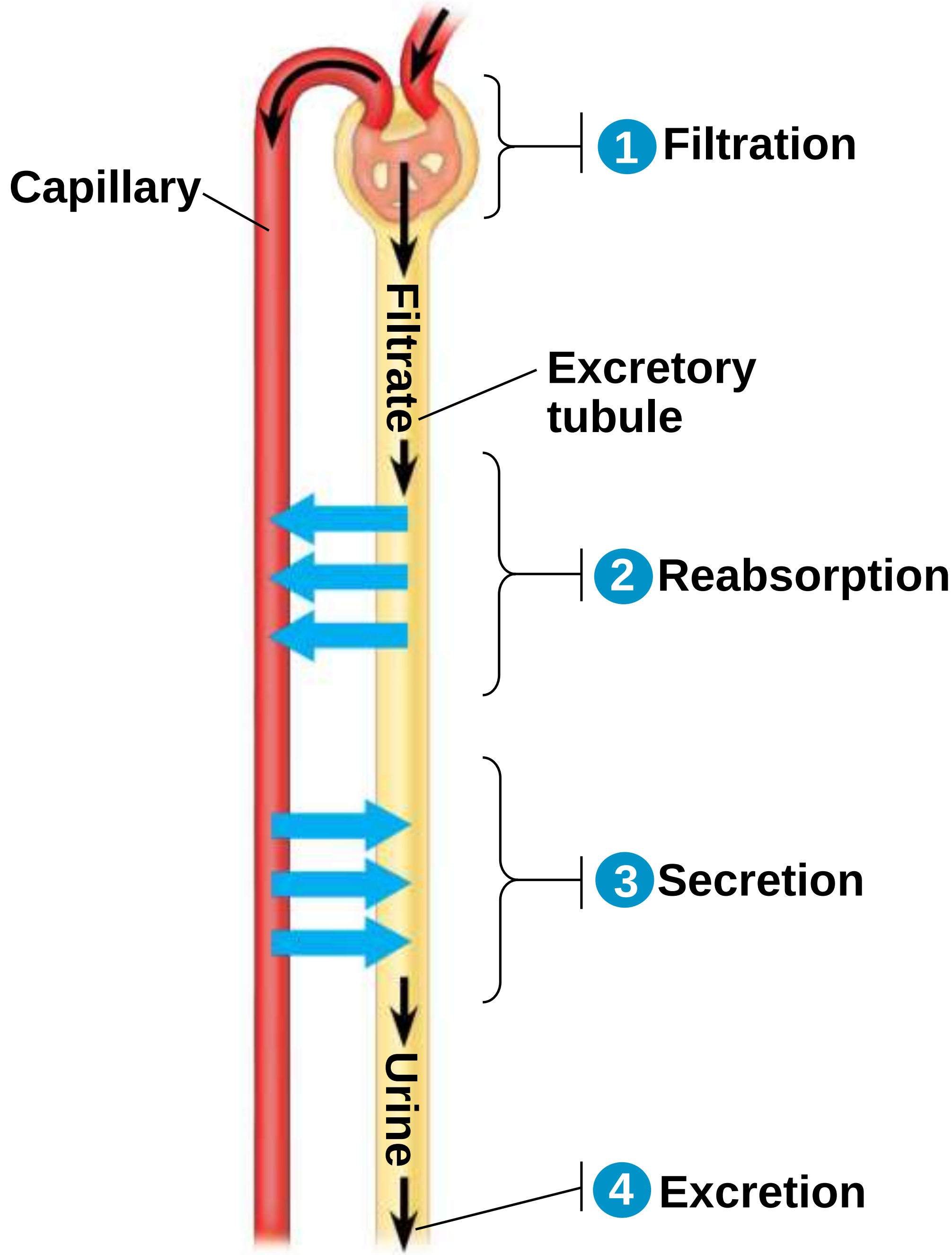
Concept 44.3: Diverse excretory systems are variations on a tubular theme

- Excretory systems regulate solute movement between internal fluids and the external environment

Excretory Processes

- Most excretory systems produce **urine** 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**: Processed filtrate containing nitrogenous wastes, released from the body

Figure 44.10



Capillary
1 Filtration
Filtrate
Excretory tubule
2 Reabsorption
3 Secretion
Urine
4 Excretion

Figure 44.14a

Excretory Organs

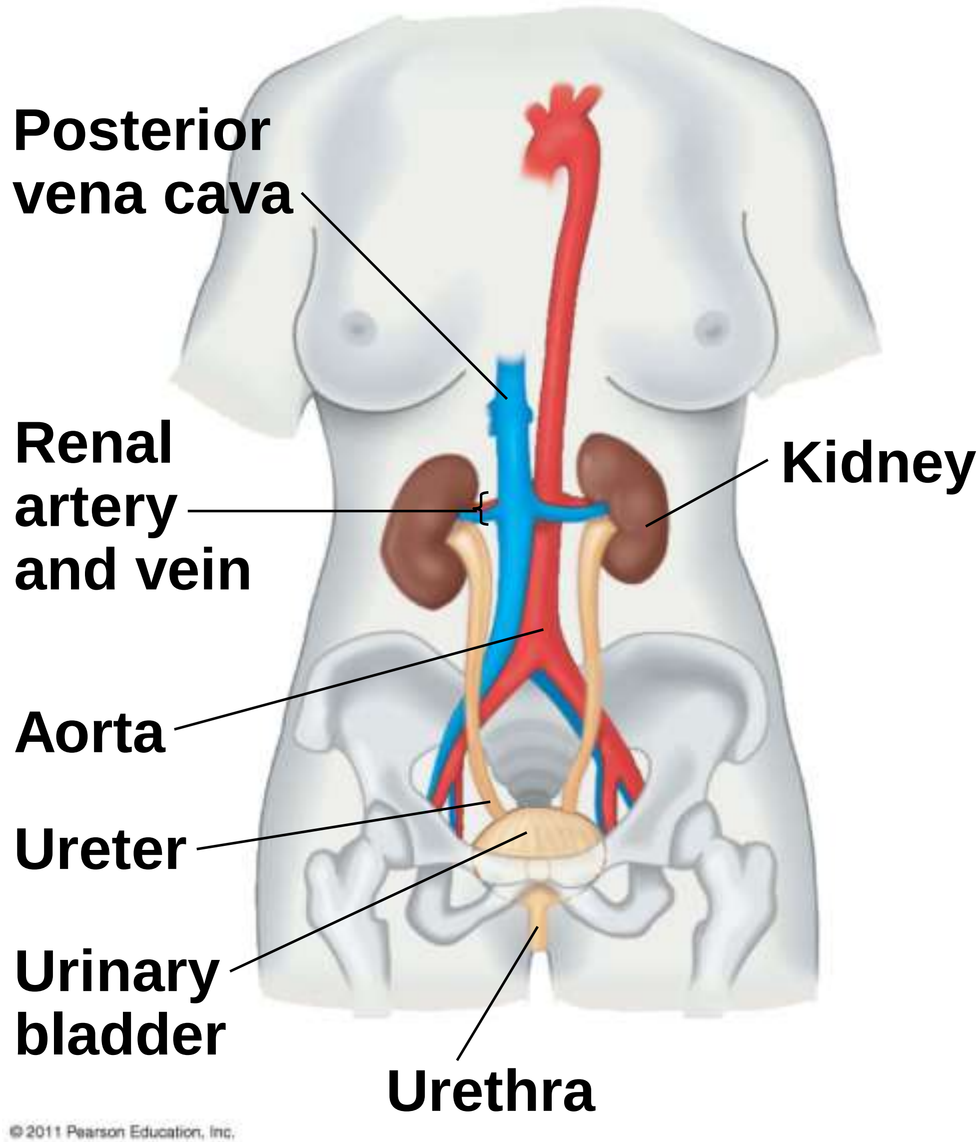


Figure 44.14b

Kidney Structure

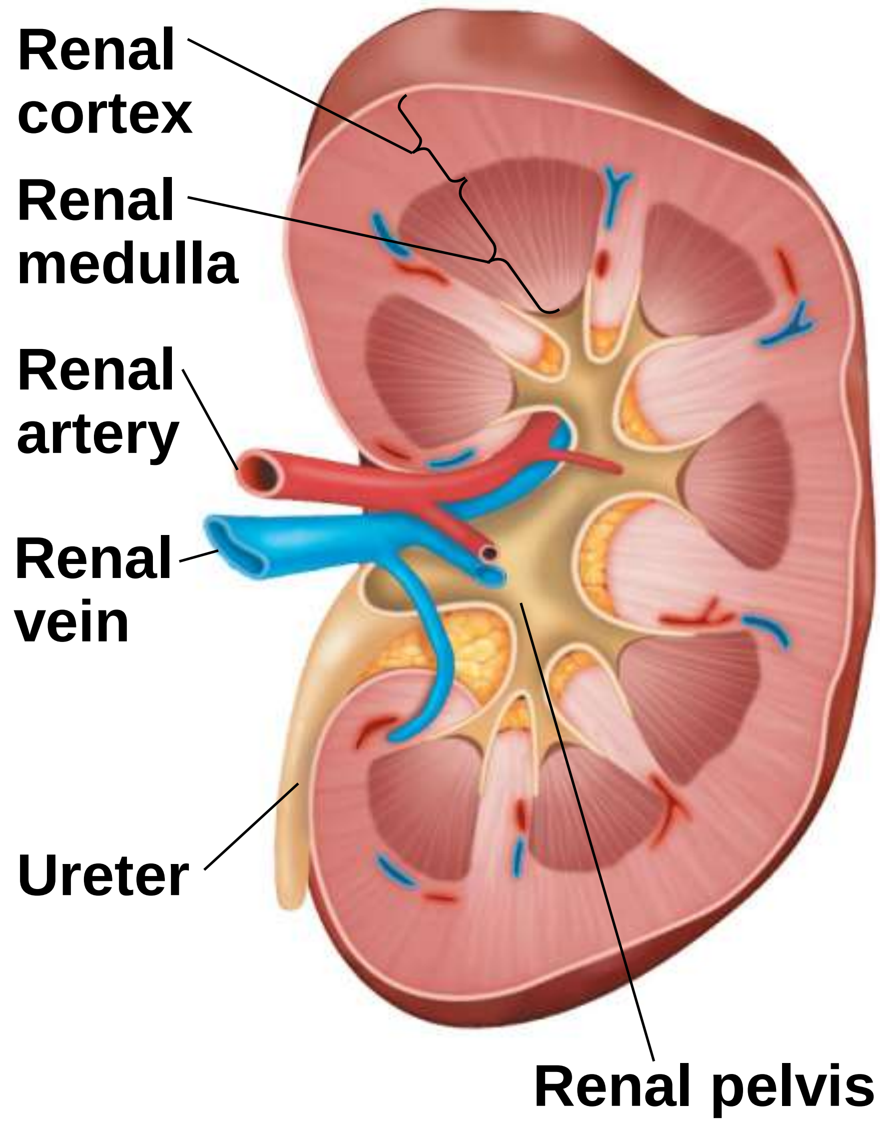


Figure 44.14c

Nephron Types

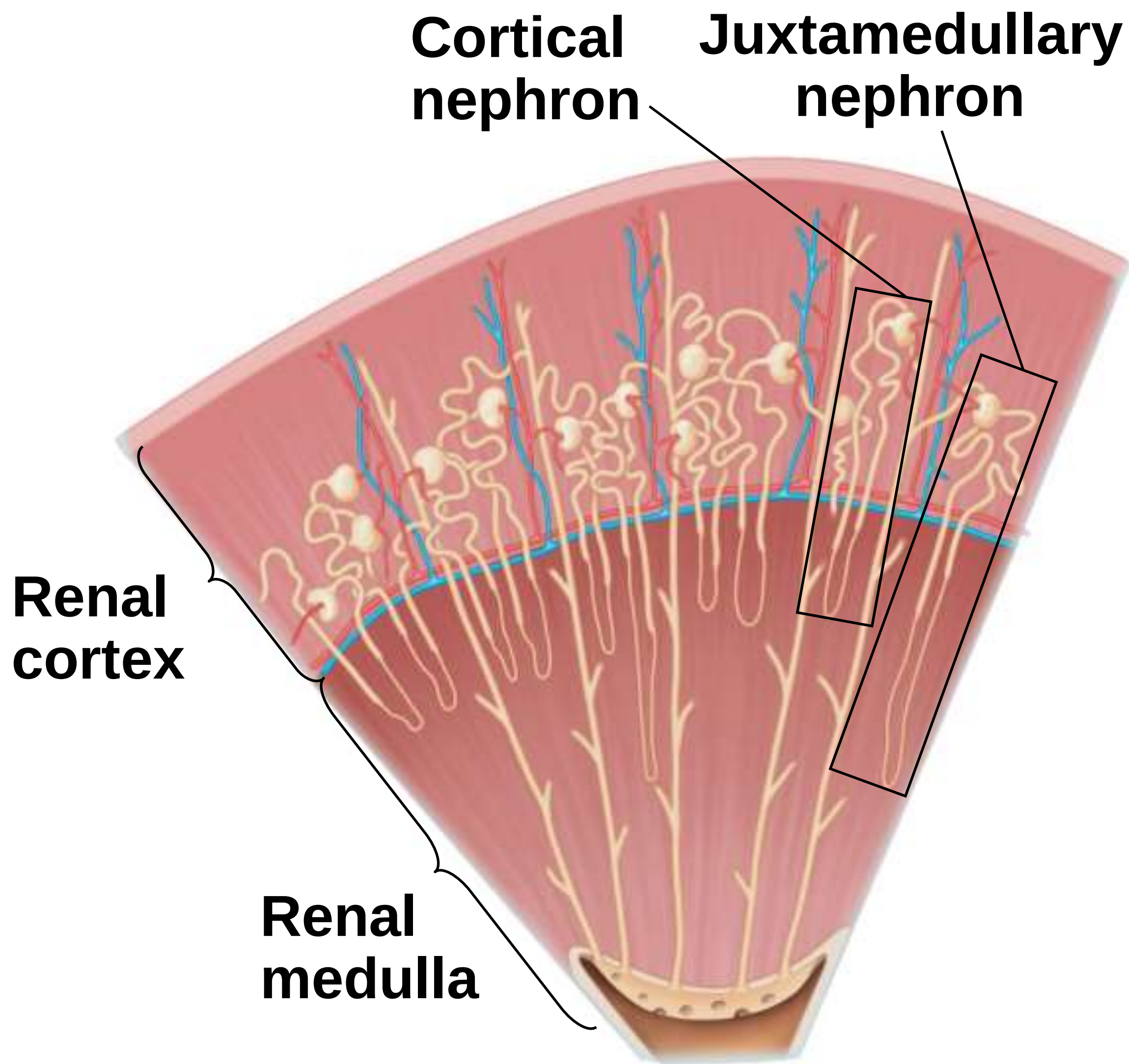


Figure 44.14d

Nephron Organization

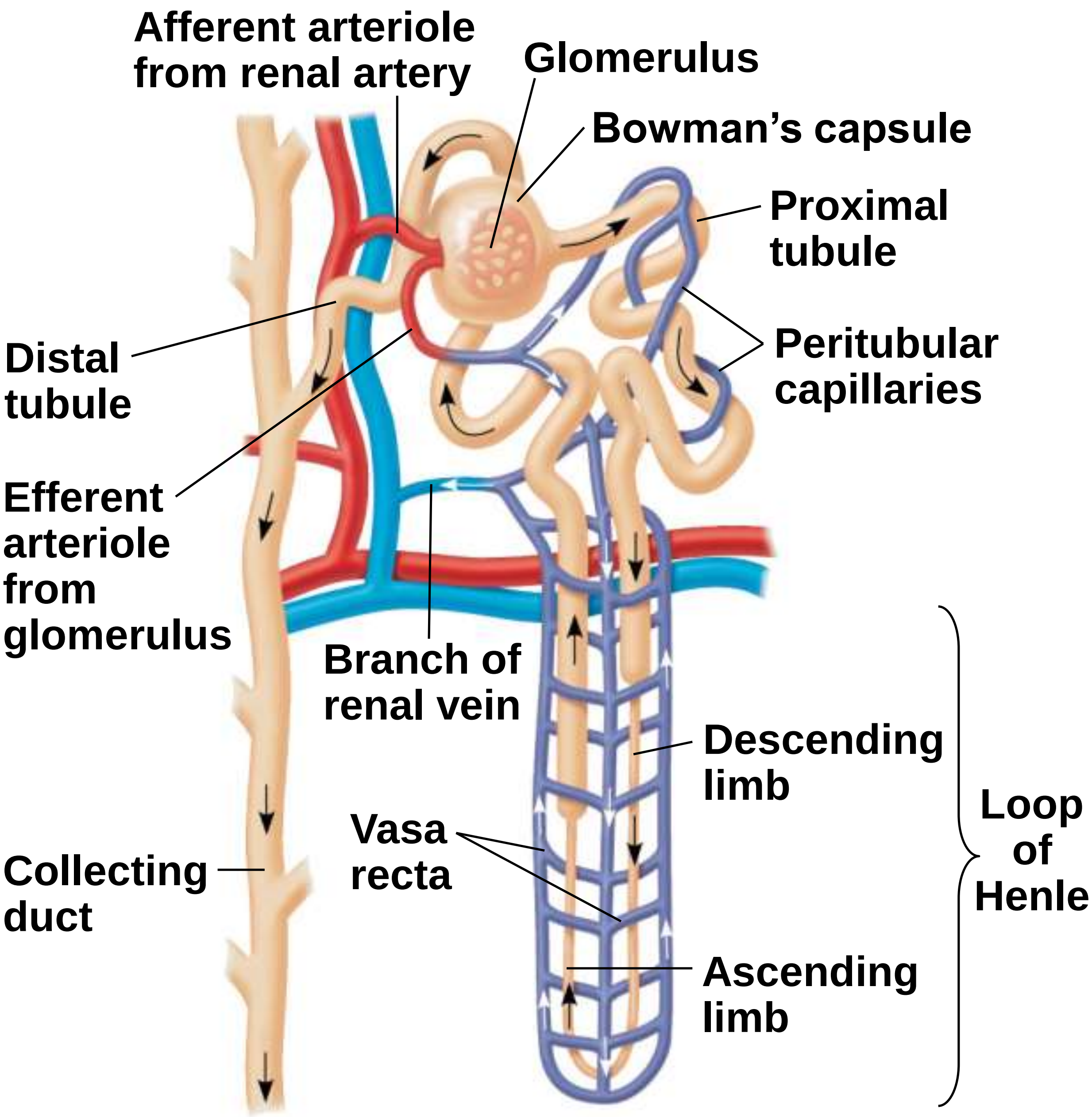


Figure 44.14e

Blood vessels from a human kidney. Arterioles and peritubular capillaries appear pink; glomeruli appear yellow.

Concept 44.4: The nephron is organized for stepwise processing of blood filtrate

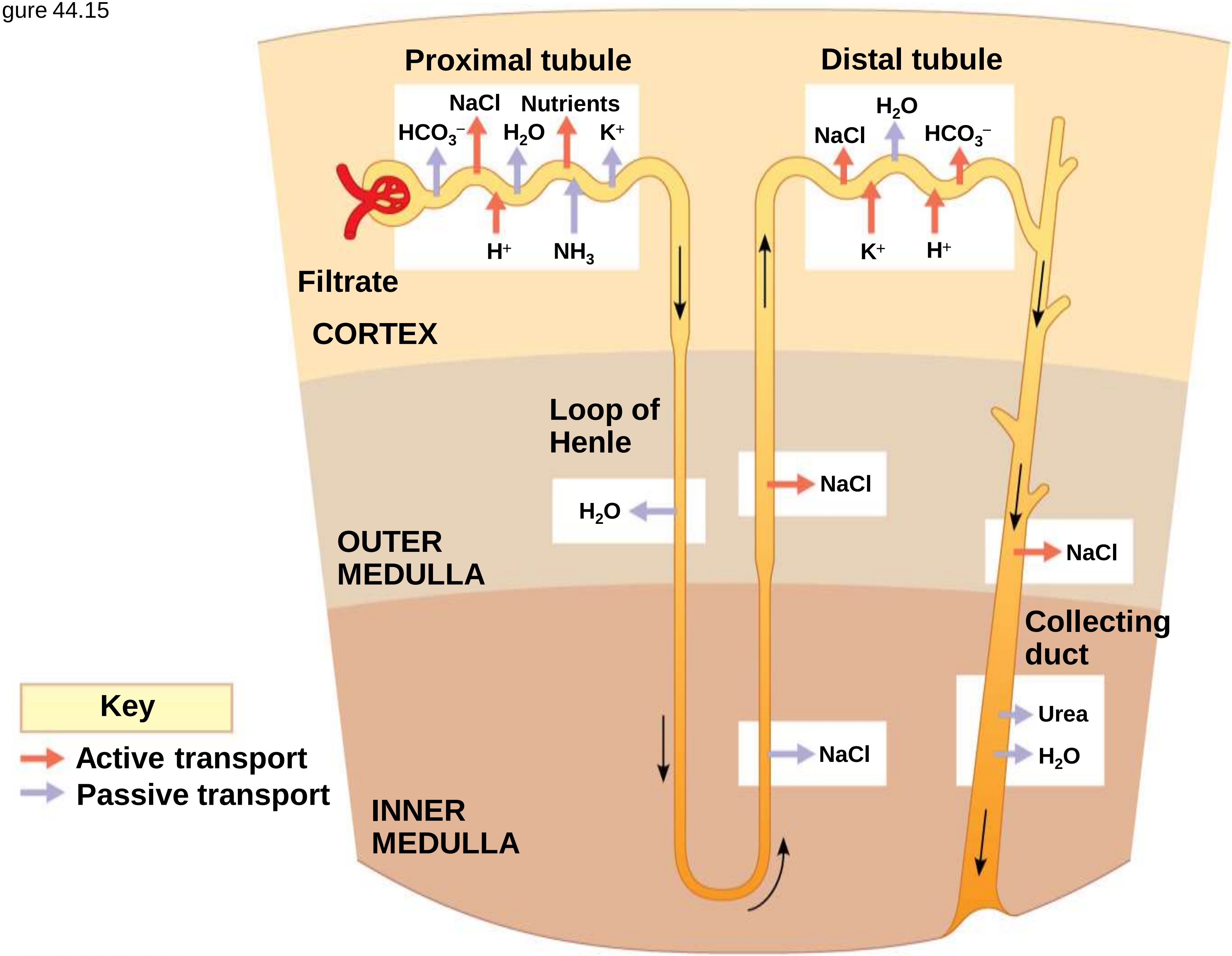
- The filtrate produced in Bowman's capsule contains salts, glucose, amino acids, vitamins, nitrogenous wastes, and other small molecules

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
- As the filtrate passes through the proximal tubule, materials to be excreted become concentrated

Figure 44.15


Proximal tubule
NaCl
Nutrients
HCO_3^-
H_2O
K^+
H^+
NH_3
Distal tubule
H_2O
NaCl
HCO_3^-
K^+
H^+
Filtrate
CORTEX
Loop of Henle
H_2O
NaCl
OUTER MEDULLA
NaCl
Collecting duct
Urea
H_2O
NaCl
INNER MEDULLA
Key
Active transport
Passive transport

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

Ascending Limb of the Loop of Henle

- In the ascending limb of the loop of Henle, **salt but not water is able to diffuse from the tubule into the interstitial fluid**
- The filtrate becomes increasingly dilute

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 through the medulla to the renal pelvis
- **One of the most important tasks is reabsorption of solutes and water**
- **Urine is hyperosmotic to body fluids**

Solute Gradients and Water Conservation

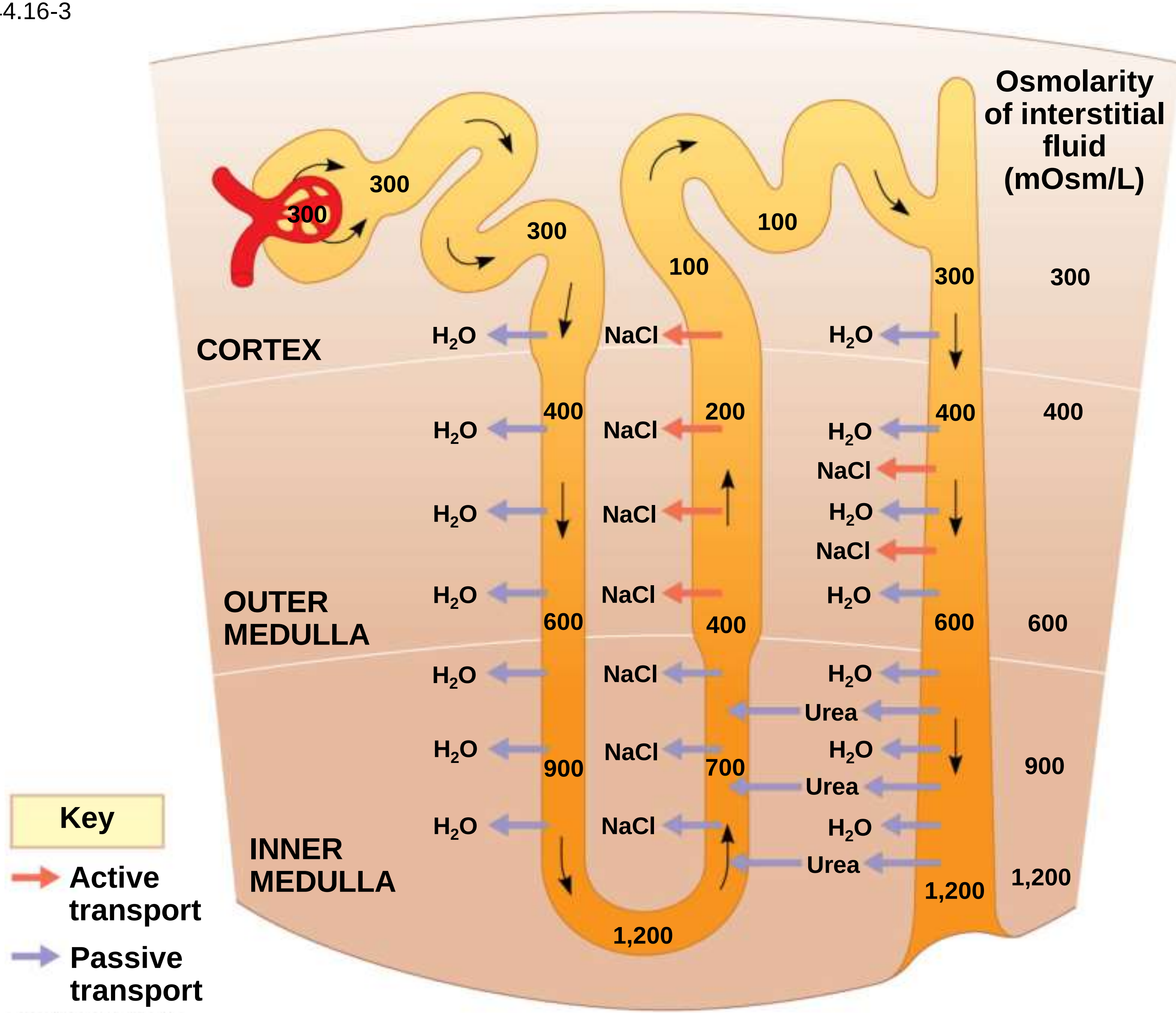
- The mammalian kidney's ability to conserve water is a key terrestrial adaptation
- Hyperosmotic urine can be produced only because considerable energy is expended to transport solutes against concentration gradients
- **The two primary solutes affecting osmolarity are NaCl and urea**

The Two-Solute Model

- In the proximal tubule, filtrate volume decreases, but its osmolarity remains the same
- The **countercurrent multiplier system** involving the loop of Henle maintains a high salt concentration in the kidney
- This system allows the vasa recta to supply the kidney with nutrients, without interfering with the osmolarity gradient
- Considerable energy is expended to maintain the osmotic gradient between the medulla and cortex

- The collecting duct conducts filtrate through the osmolarity gradient, and more water exits the filtrate by osmosis
- **Urea diffuses out of the collecting duct as it traverses the inner medulla**
- Urea and NaCl form the osmotic gradient that enables the kidney to produce urine that is hyperosmotic to the blood

Figure 44.16-3



Adaptations of the Vertebrate Kidney to Diverse Environments

- The form and function of nephrons in various vertebrate classes are related to requirements for osmoregulation in the animal’s habitat

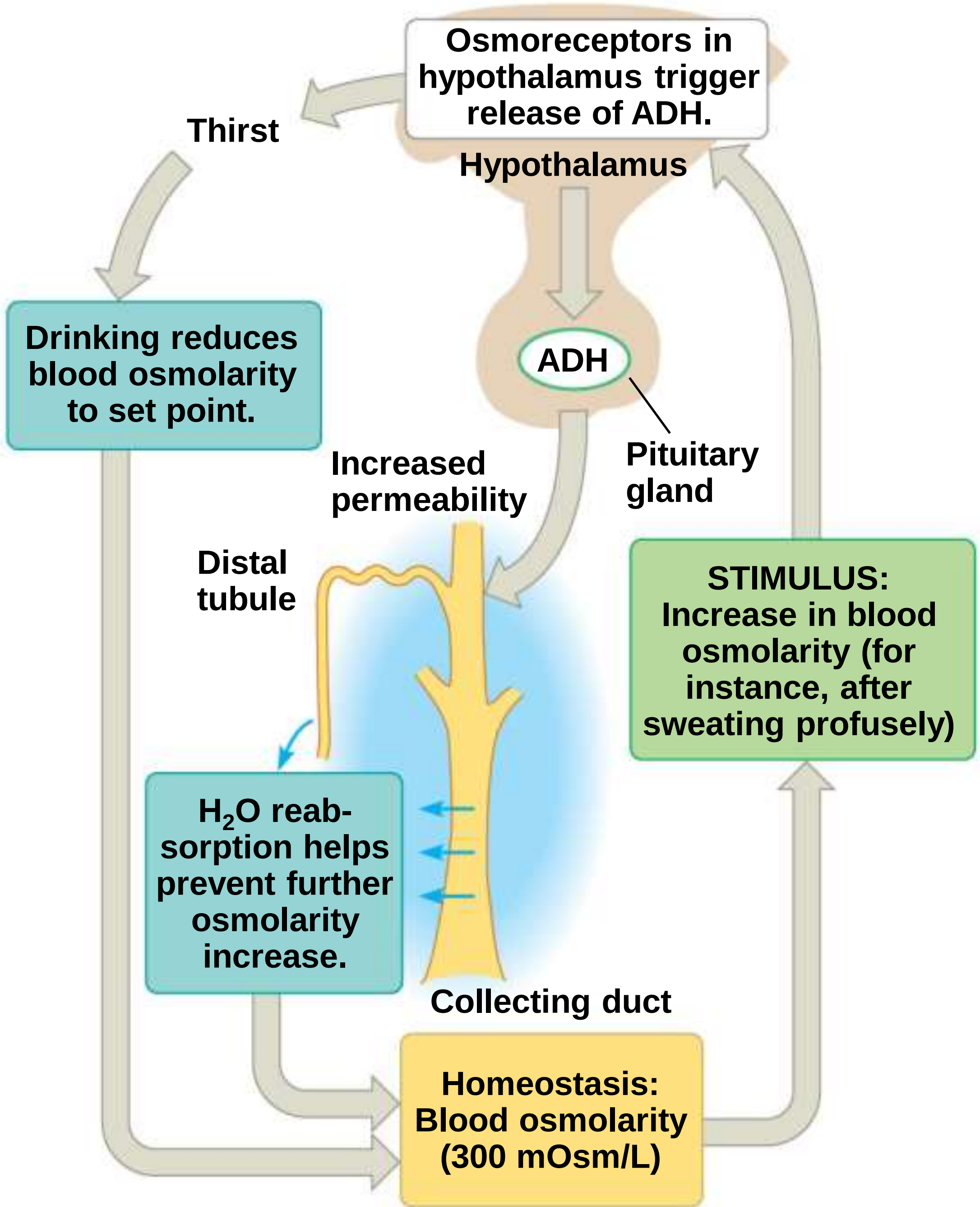
Mammals

- The juxtamedullary nephron is key to water conservation in terrestrial animals
- Mammals that inhabit dry environments have long loops of Henle, while those in fresh water have relatively short loops

Antidiuretic Hormone

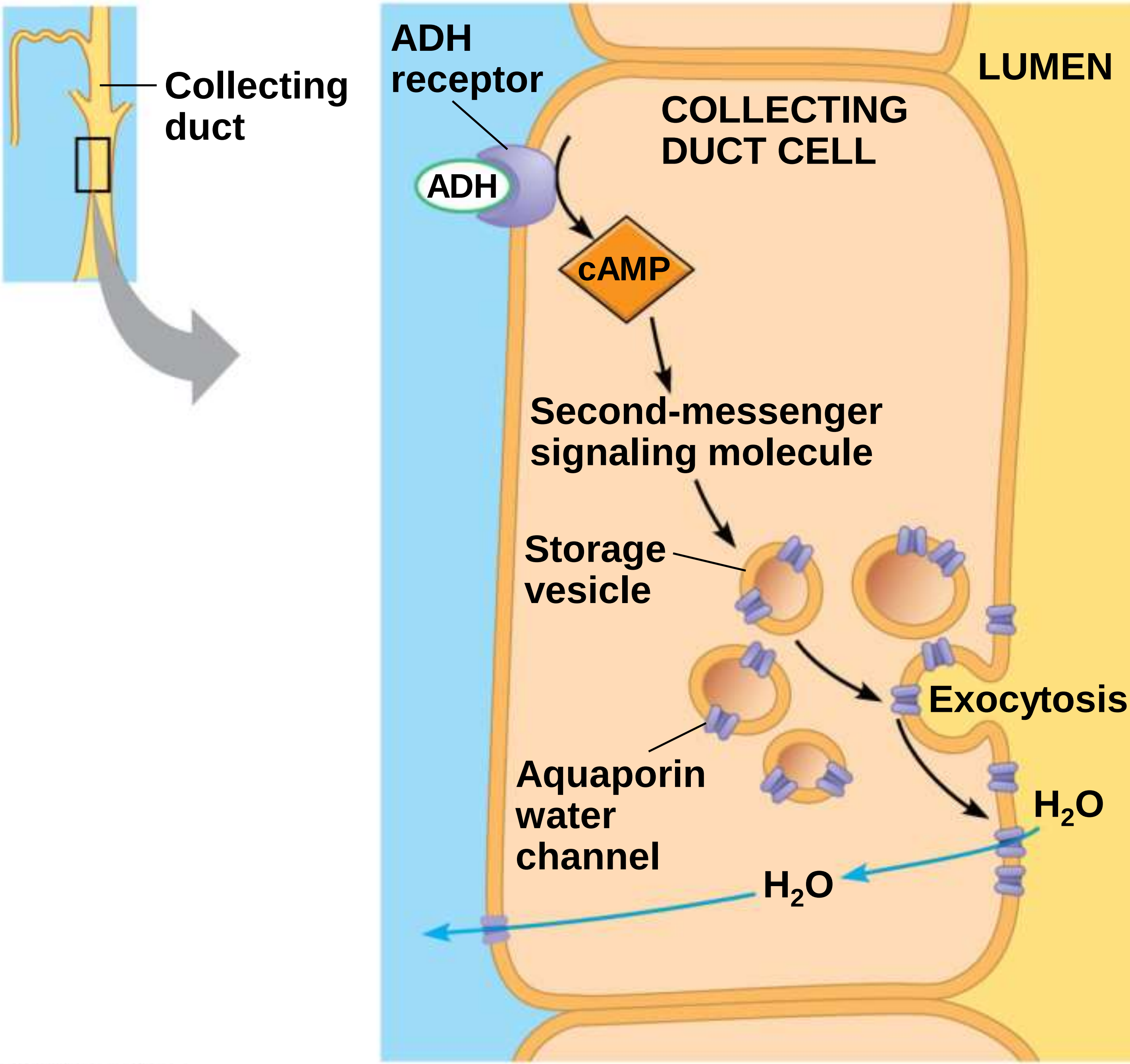
- The osmolarity of the urine is regulated by nervous and hormonal control
- **Antidiuretic hormone (ADH)** makes the collecting duct epithelium more permeable to water
- An increase in osmolarity triggers the release of ADH, which helps to conserve water

Figure 44.19-2



- Binding of ADH to receptor molecules leads to a temporary increase in the number of aquaporin proteins in the membrane of collecting duct cells

Figure 44.20



Collecting duct
ADH receptor
ADH
LUMEN
COLLECTING DUCT CELL
cAMP
Second-messenger signaling molecule
Storage vesicle
Exocytosis
Aquaporin water channel
H_2O
H_2O

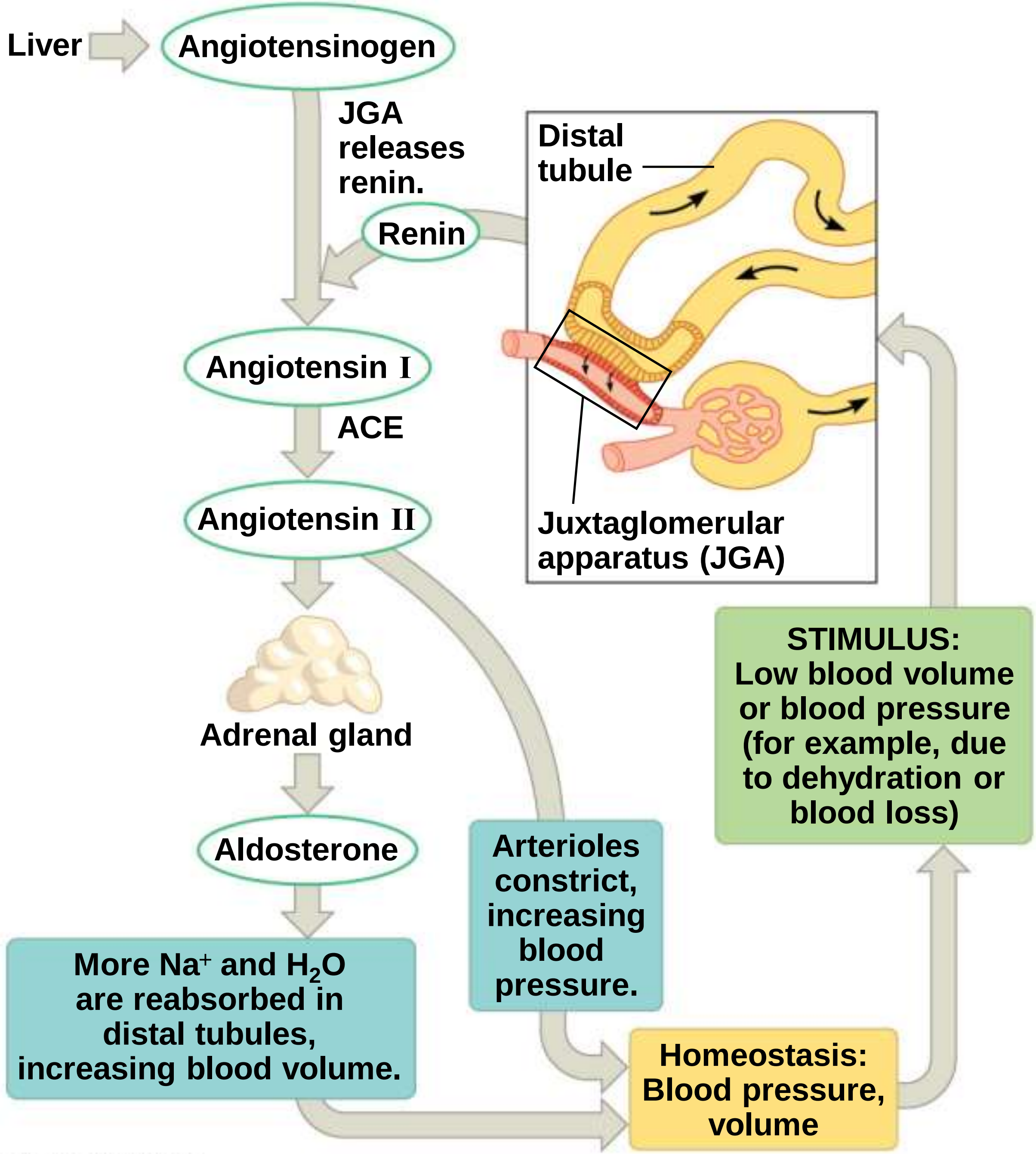
- Mutation in ADH production causes severe dehydration and results in diabetes insipidus
- Alcohol is a diuretic as it inhibits the release of ADH

The Renin-Angiotensin-Aldosterone System

- The **renin-angiotensin-aldosterone system (RAAS)** is part of a complex feedback circuit that functions in homeostasis
- A drop in blood pressure near the glomerulus causes the **juxtaglomerular apparatus (JGA)** to release the enzyme renin
- Renin triggers the formation of the peptide **angiotensin II**

- Angiotensin II
  - Raises blood pressure and decreases blood flow to the kidneys
  - Stimulates the release of the hormone **aldosterone**, which increases blood volume and pressure

Figure 44.22-3



Homeostatic Regulation of the Kidney

- ADH and RAAS both increase water reabsorption, but only RAAS will respond to a decrease in blood volume
- Another hormone, **atrial natriuretic peptide (ANP)**, opposes the RAAS
- ANP is released in response to an increase in blood volume and pressure and inhibits the release of renin

Figure 44.UN01

Animal	Inflow/Outflow	Urine
Freshwater fish. Lives in water less concentrated than body fluids; fish tends to gain water, lose salt	Does not drink water Salt in (active transport by gills) H_2O in  Salt out	 ▶ Large volume of urine ▶ Urine is less concentrated than body fluids
Marine bony fish. Lives in water more concentrated than body fluids; fish tends to lose water, gain salt	Drinks water Salt in H_2O out  Salt out (active transport by gills)	 ▶ Small volume of urine ▶ Urine is slightly less concentrated than body fluids
Terrestrial vertebrate. Terrestrial environment; tends to lose body water to air	Drinks water Salt in (by mouth)  H_2O and salt out	 ▶ Moderate volume of urine ▶ Urine is more concentrated than body fluids

Figure 44.UN01a

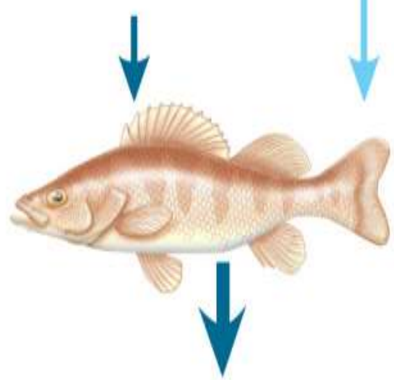
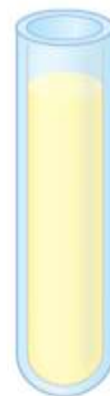
Animal	Inflow/Outflow	Urine
Freshwater fish. Lives in water less concentrated than body fluids; fish tends to gain water, lose salt	Does not drink water Salt in (active transport by gills) H_2O in  Salt out	 ▶ Large volume of urine ▶ Urine is less concentrated than body fluids

Figure 44.UN01b

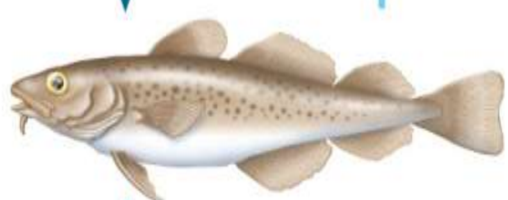
Animal	Inflow/Outflow	Urine
Marine bony fish. Lives in water more concentrated than body fluids; fish tends to lose water, gain salt	Drinks water Salt in H_2O out  Salt out (active transport by gills)	 ▶ Small volume of urine ▶ Urine is slightly less concentrated than body fluids

Figure 44.UN01c

Animal	Inflow/Outflow	Urine
Terrestrial vertebrate. Terrestrial environment; tends to lose body water to air	Drinks water Salt in (by mouth)  H_2O and salt out	 ▶ Moderate volume of urine ▶ Urine is more concentrated than body fluids

Figure 44.UN02