Chapter 44

Osmoregulation and Excretion

Overview: A Balancing Act

- **Osmoregulation** regulates solute concentrations and balances the gain and loss of water

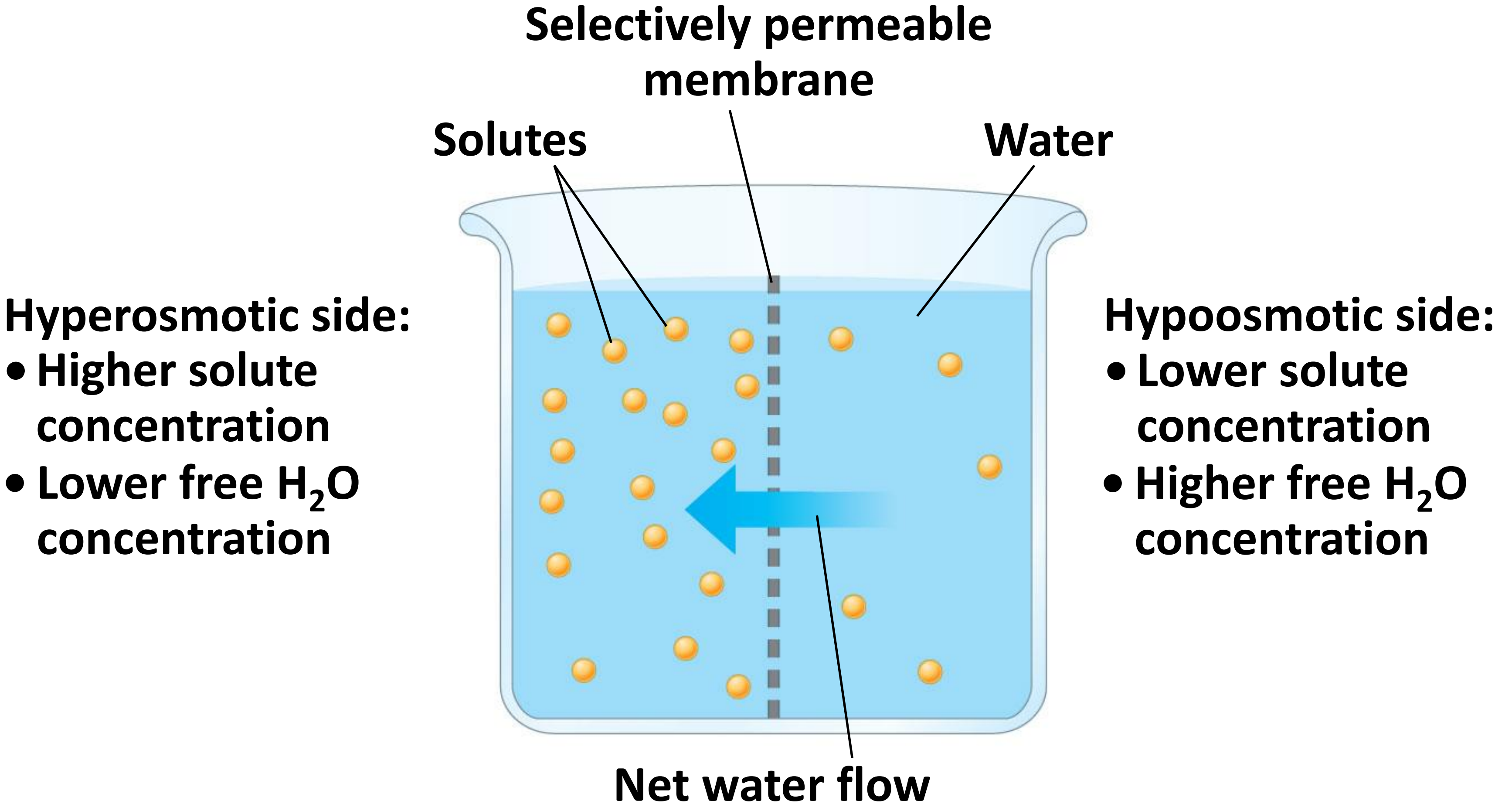
- **Osmoregulation** is based largely on controlled movement of solutes between internal fluids and the external environment

- **Excretion** gets rid of nitrogenous metabolites and other waste products

Osmosis and Osmolarity

- **Osmolarity**, the solute concentration of a solution, determines the movement of water across a selectively permeable membrane
- **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** to the **hyperosmotic** solution

Figure 44.2



Selectively permeable membrane
Solutes
Water
Hyperosmotic side:
• Higher solute concentration
• Lower free H_2O concentration
Hypoosmotic side:
• Lower solute concentration
• Higher free H_2O concentration
Net water flow

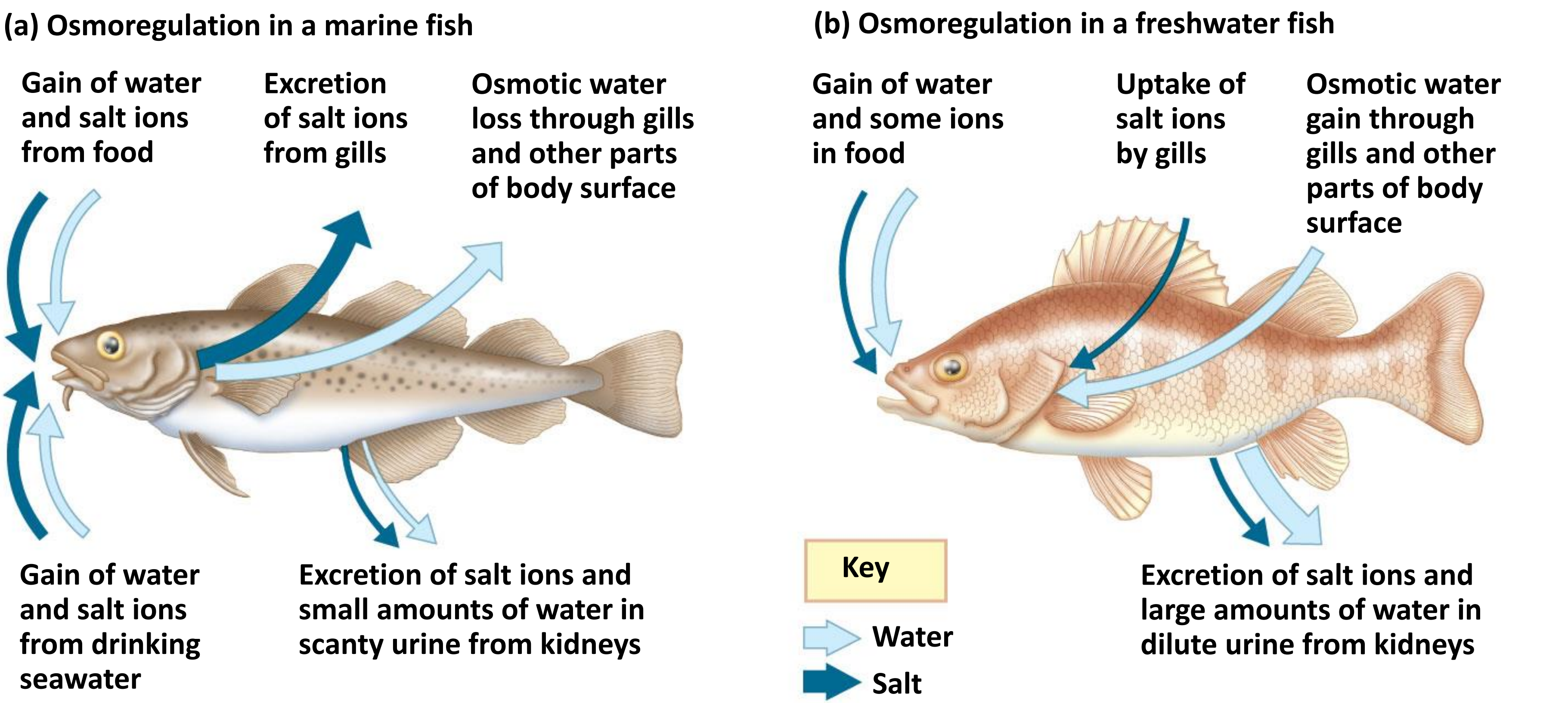
Osmotic Challenges

- **Osmoconformers**, consisting only 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 Animals

- Most marine invertebrates are osmoconformers
- Most marine vertebrates and some invertebrates are osmoregulators
- Marine bony fishes are hypoosmotic to sea water
- They lose water by osmosis and gain salt by diffusion and from food
- They balance water loss by drinking seawater and excreting salts

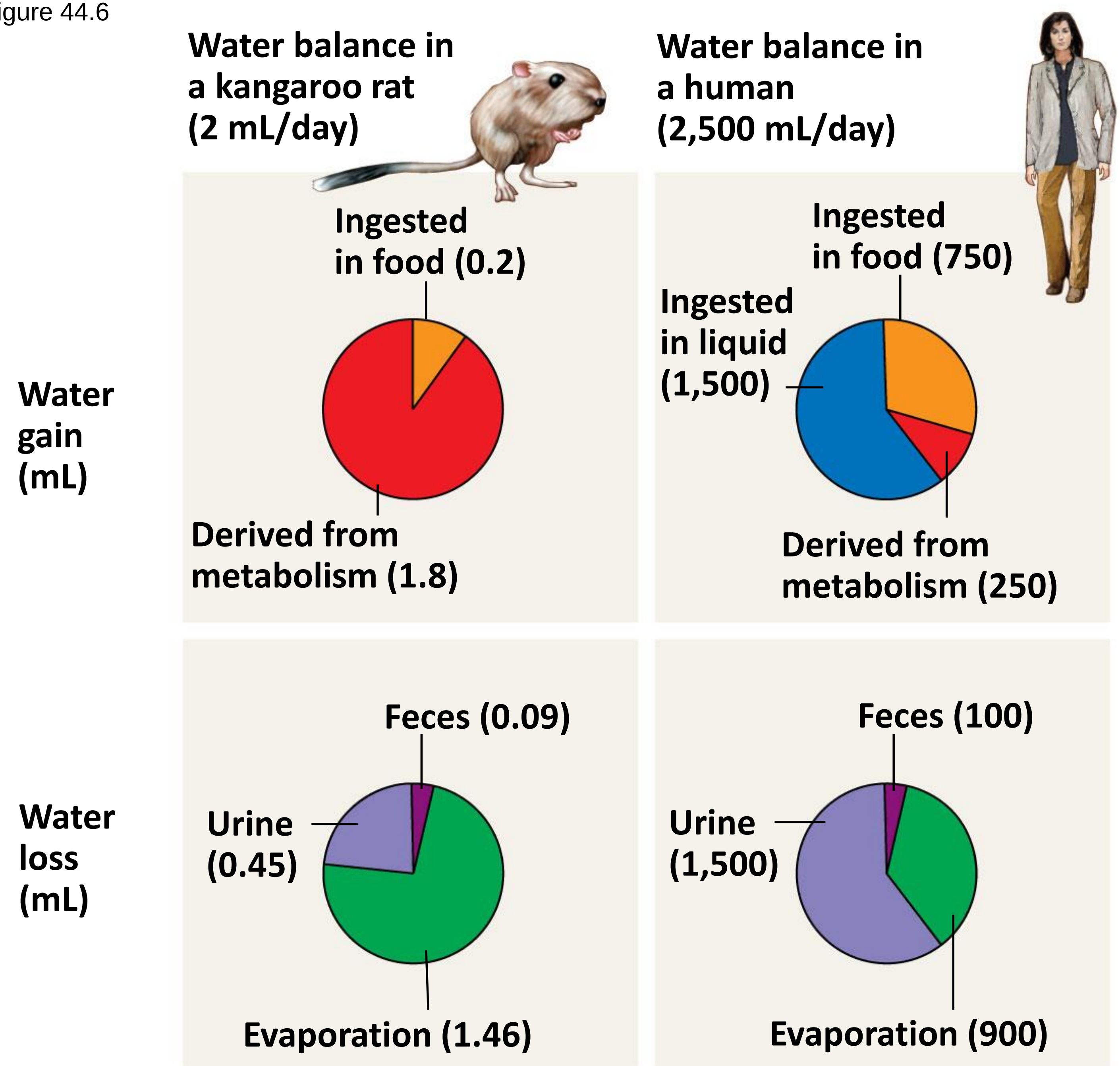
Figure 44.3


(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
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
Excretion of salt ions and large amounts of water in dilute urine from kidneys
Key
Water
Salt

Land Animals

- Body coverings
- Desert animals get major water savings
  -nocturnal life style
- 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)

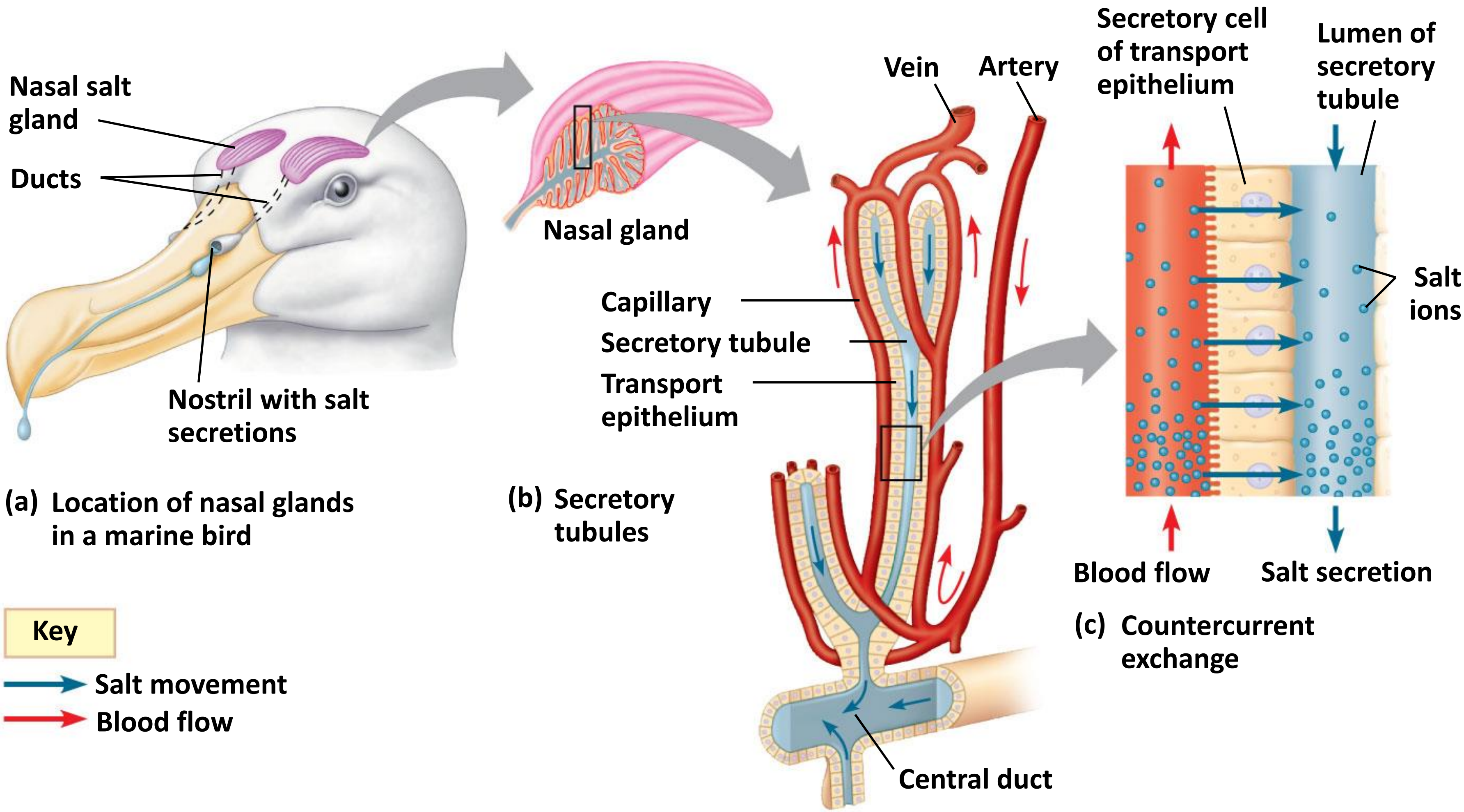
Energetics of Osmoregulation

- Osmoregulators must expend energy to maintain osmotic gradients
- The amount of energy differs based on
  - surroundings
  - How easily water and solutes move across the animal's surface
  - The work required to pump solutes across the membrane

Transport Epithelia in Osmoregulation

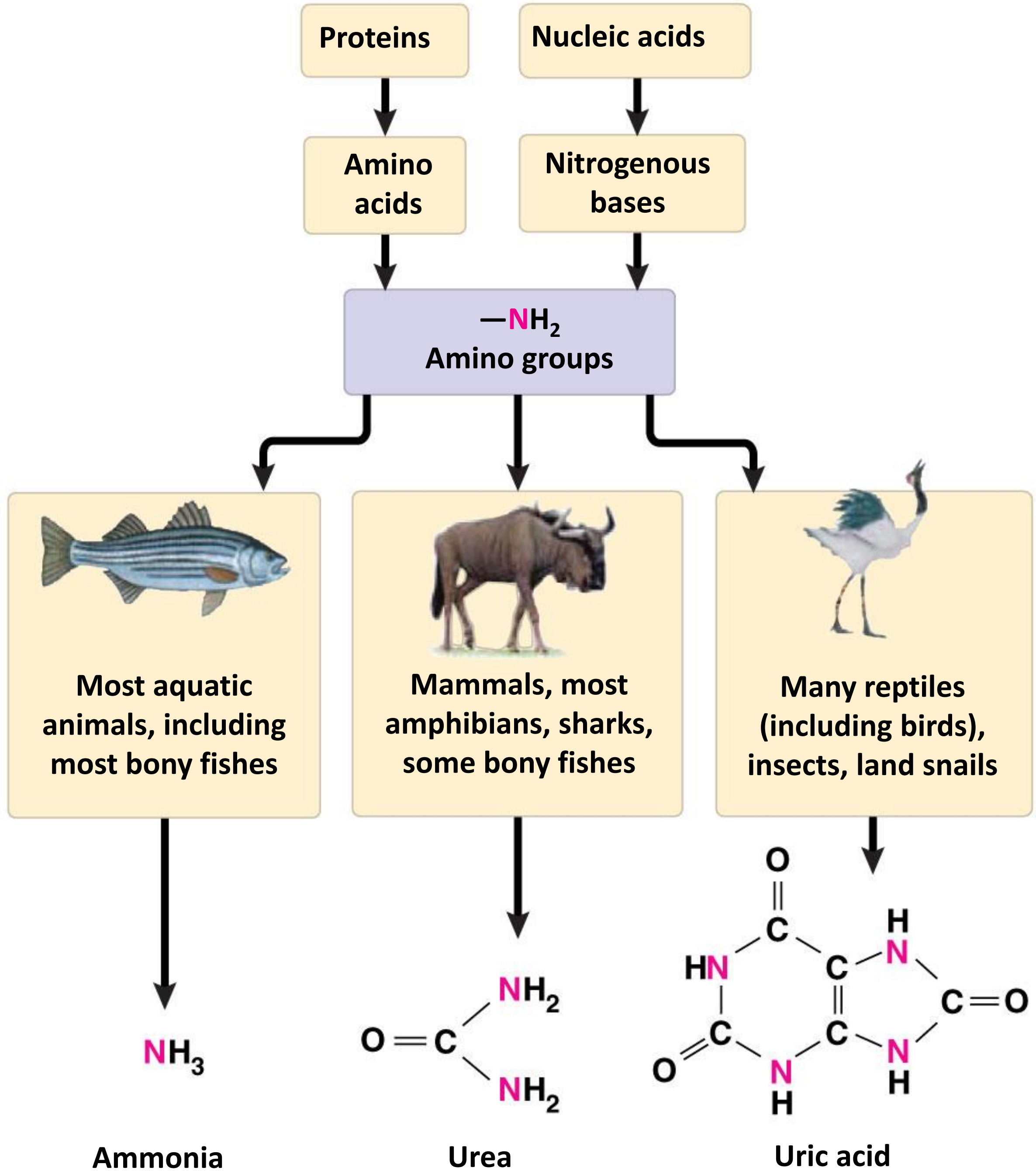
- **Transport epithelia** are epithelial cells that are specialized for moving solutes in specific directions
- arranged in complex tubular networks
- An example is in nasal glands of marine birds, which remove excess sodium chloride from the blood

Figure 44.7


Nasal salt gland
Ducts
Nostril with salt secretions
(a) Location of nasal glands in a marine bird
Nasal gland
Vein
Artery
Capillary
Secretory tubule
Transport epithelium
Central duct
(b) Secretory tubules
Secretory cell of transport epithelium
Lumen of secretory tubule
Salt ions
Blood flow
Salt secretion
(c) Countercurrent exchange
Key
Salt movement
Blood flow

- waste products may greatly affect its water balance
- 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.



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

Forms of Nitrogenous Wastes

- Animals excrete nitrogenous wastes in different forms: ammonia, urea, or uric acid
- These differ in toxicity and the energy costs of producing them

Ammonia

- Animals that excrete nitrogenous wastes as ammonia need access to lots of water
- They release ammonia across the whole body surface or through gills

Urea

- The liver of mammals and most adult amphibians converts ammonia to the less toxic **urea**
- The circulatory system carries urea to the kidneys, where it is excreted
- Conversion of ammonia to urea is energetically expensive; excretion of urea requires less water than ammonia

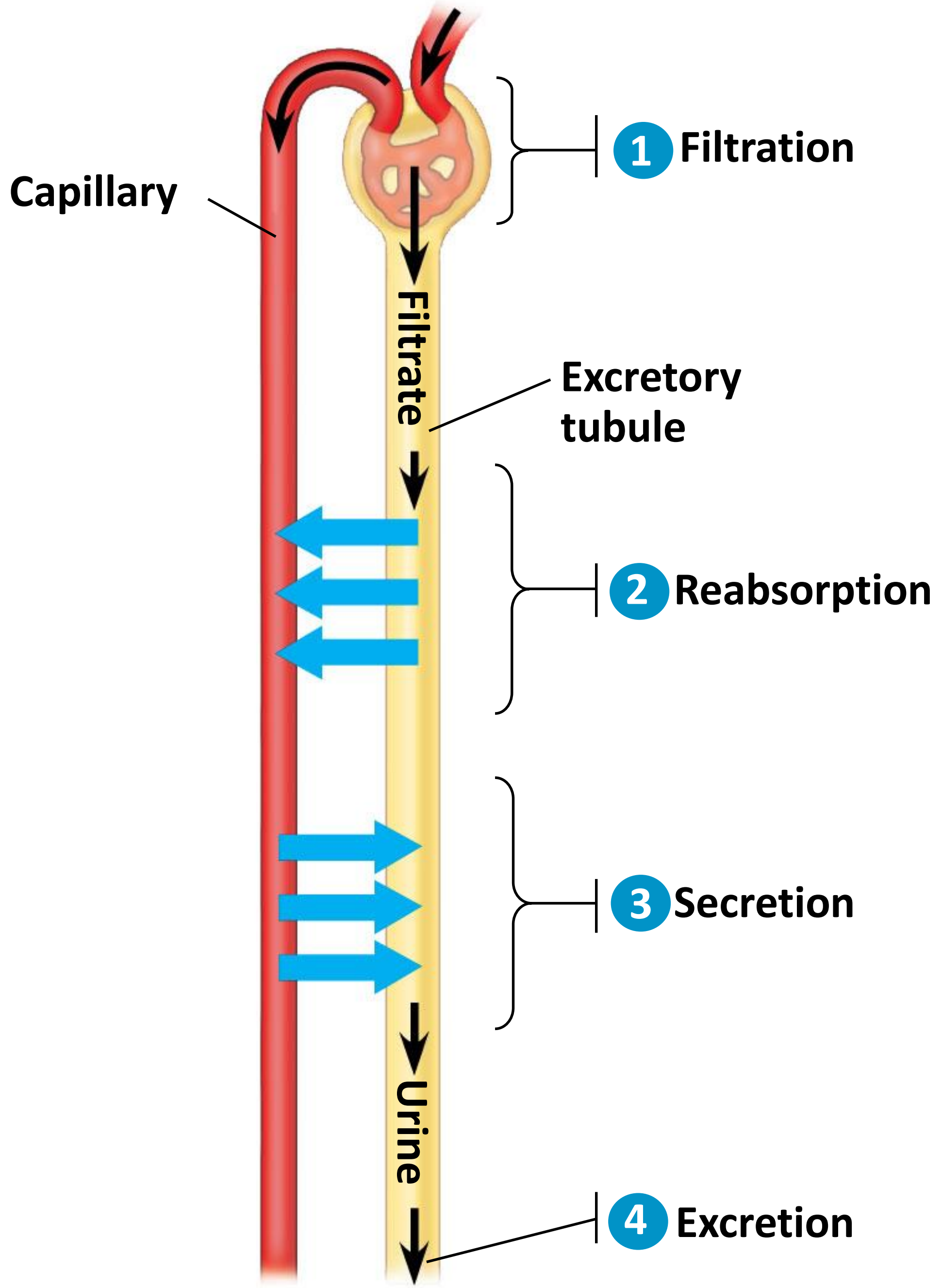
Uric Acid

- Insects, land snails, and many reptiles, including birds, mainly excrete **uric acid**
- Uric acid is relatively nontoxic and does not dissolve readily in water
- It can be secreted as a paste with little water loss
- Uric acid is more energetically expensive to produce than urea

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

Protonephridia

- A **protonephridium** is a network of dead-end tubules connected to external openings - flatworms
- The smallest branches of the network are capped by a cellular unit called a flame bulb
- These tubules excrete a dilute fluid and function in osmoregulation

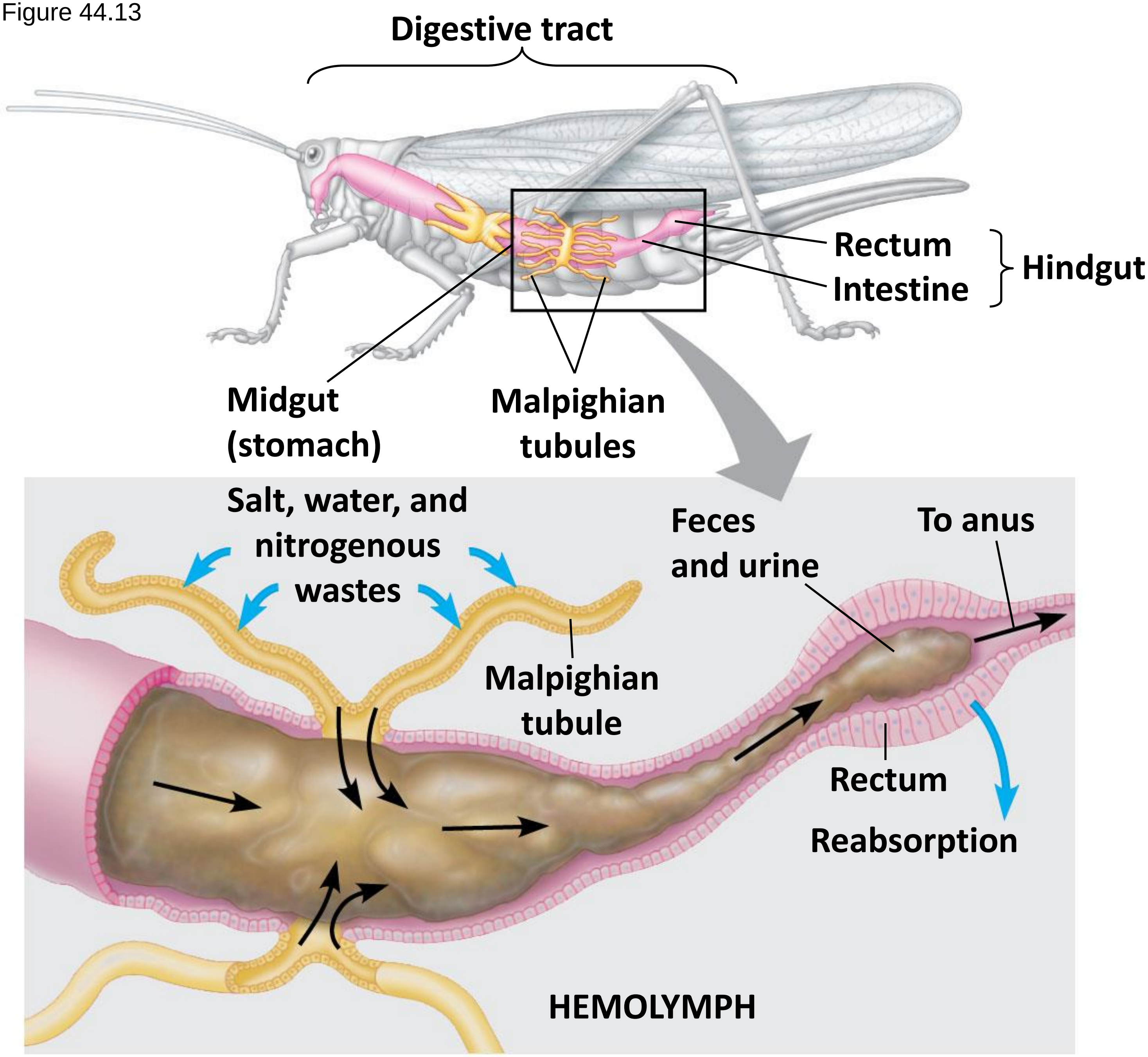
Metanephridia

- Each segment of an earthworm has a pair of open-ended **metanephridia**
- Metanephridia consist of tubules that collect coelomic fluid and produce dilute urine for excretion

Malpighian Tubules

- In insects and other terrestrial arthropods, **Malpighian tubules** remove nitrogenous wastes from hemolymph and function in osmoregulation
- Insects produce a relatively dry waste matter, mainly uric acid, an important adaptation to terrestrial life
- Some terrestrial insects can also take up water from the air

Figure 44.13



Digestive tract
Rectum
Intestine
Hindgut
Midgut (stomach)
Malpighian tubules
Salt, water, and nitrogenous wastes
Feces and urine
To anus
Malpighian tubule
Rectum
Reabsorption
HEMOLYMPH

Kidneys

- Kidneys, the excretory organs of vertebrates, function in both excretion and osmoregulation

Figure 44.14-a

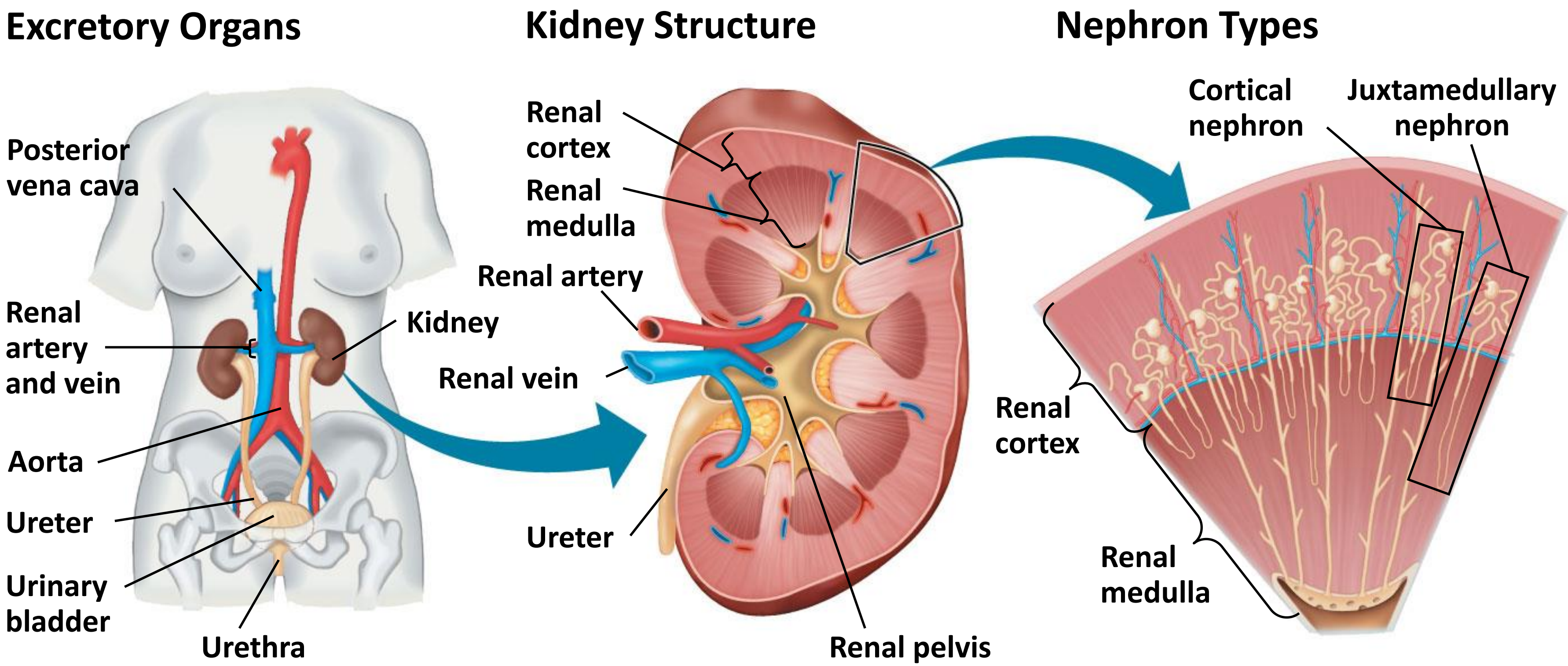
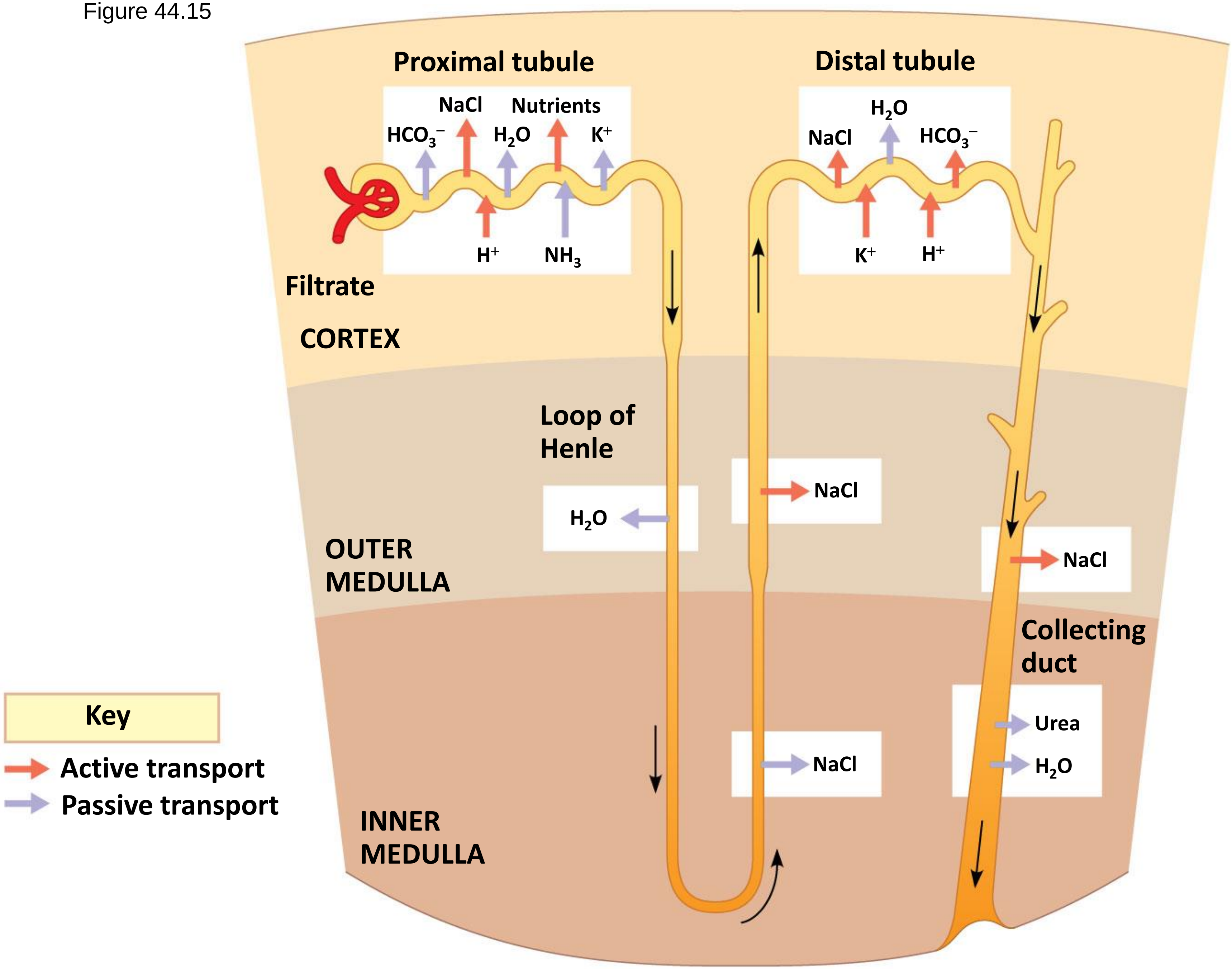
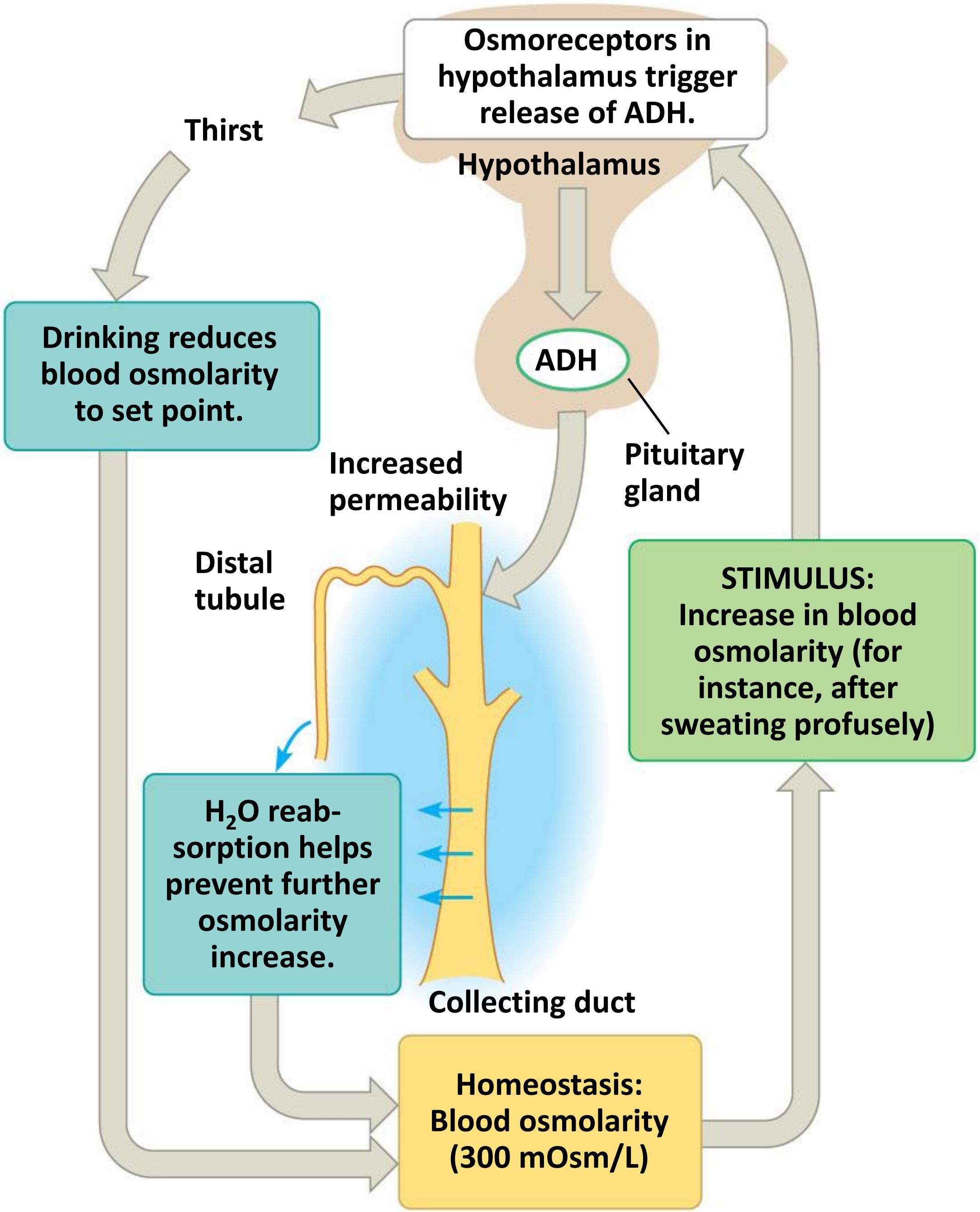


Figure 44.15



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

Figure 44.19-2



The Renin-Angiotensin-Aldosterone System

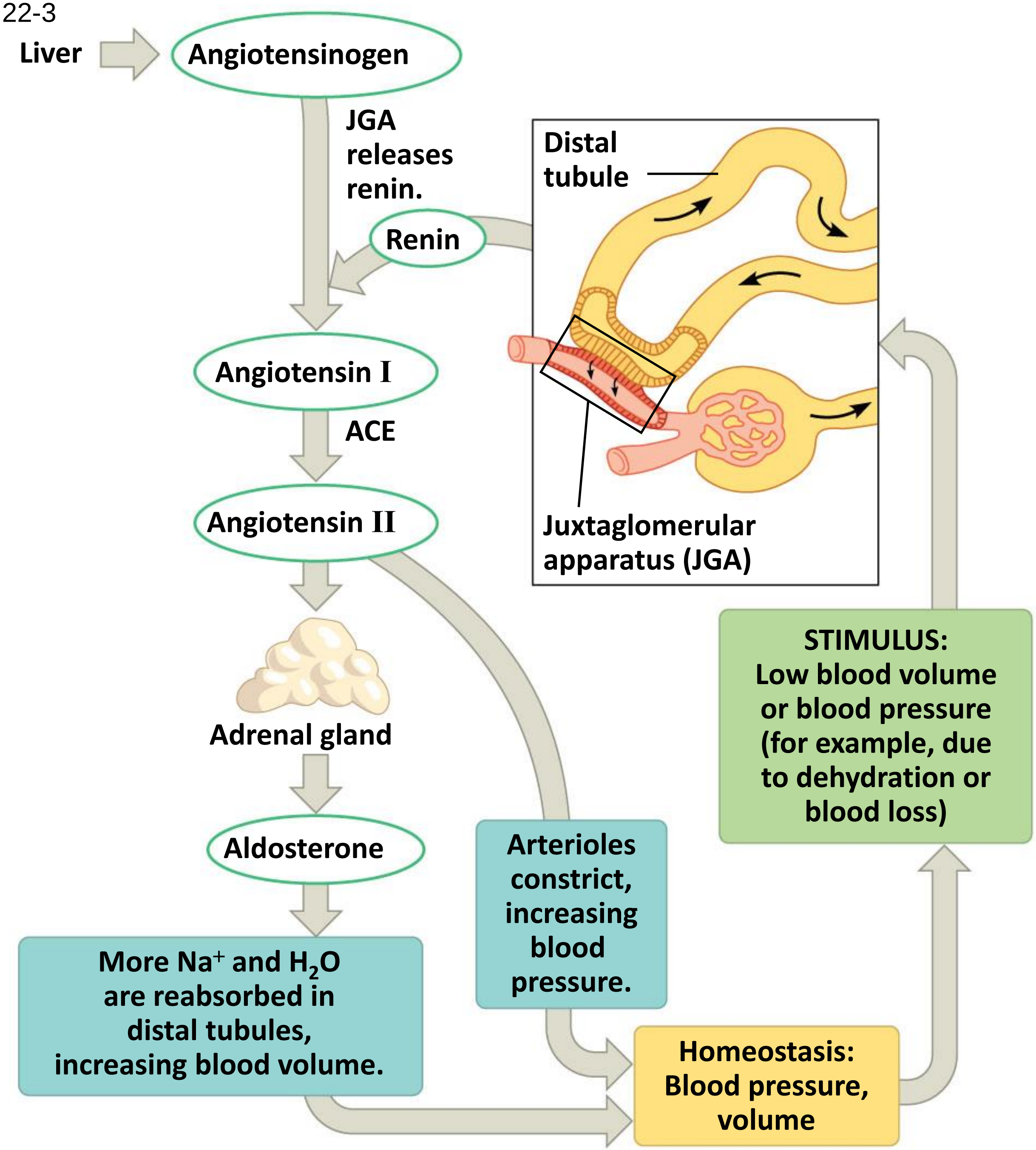
- The **renin-angiotensin-aldosterone system (RAAS)** is part of a complex feedback circuit that functions in homeostasis

1. A drop in blood pressure near the glomerulus
2. **juxtaglomerular apparatus (JGA)** to release the enzyme **renin**
3. Renin triggers the formation of the peptide **angiotensin II**

Angiotensin II

1. Raises blood pressure and decreases blood flow to the kidneys
2. 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