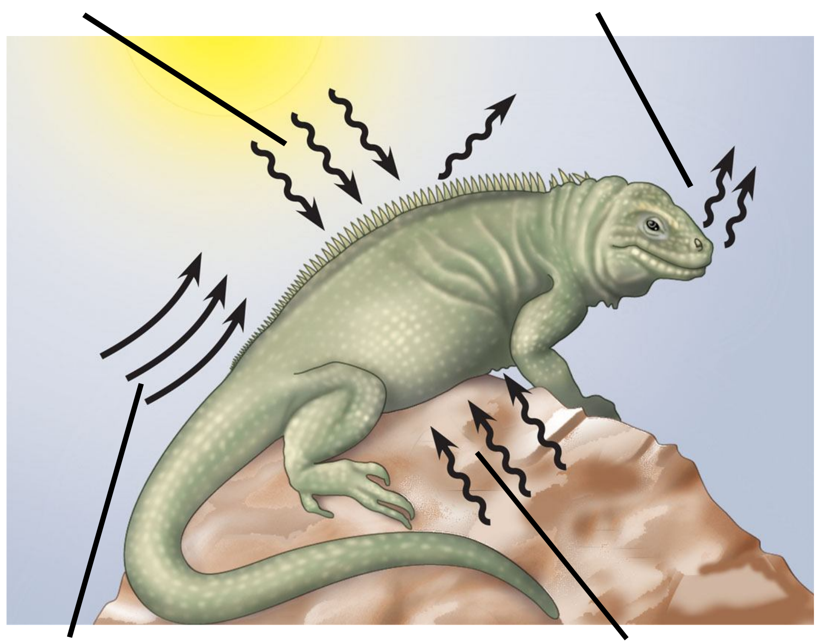
Regulating the Internal Environment

Thermoregulation

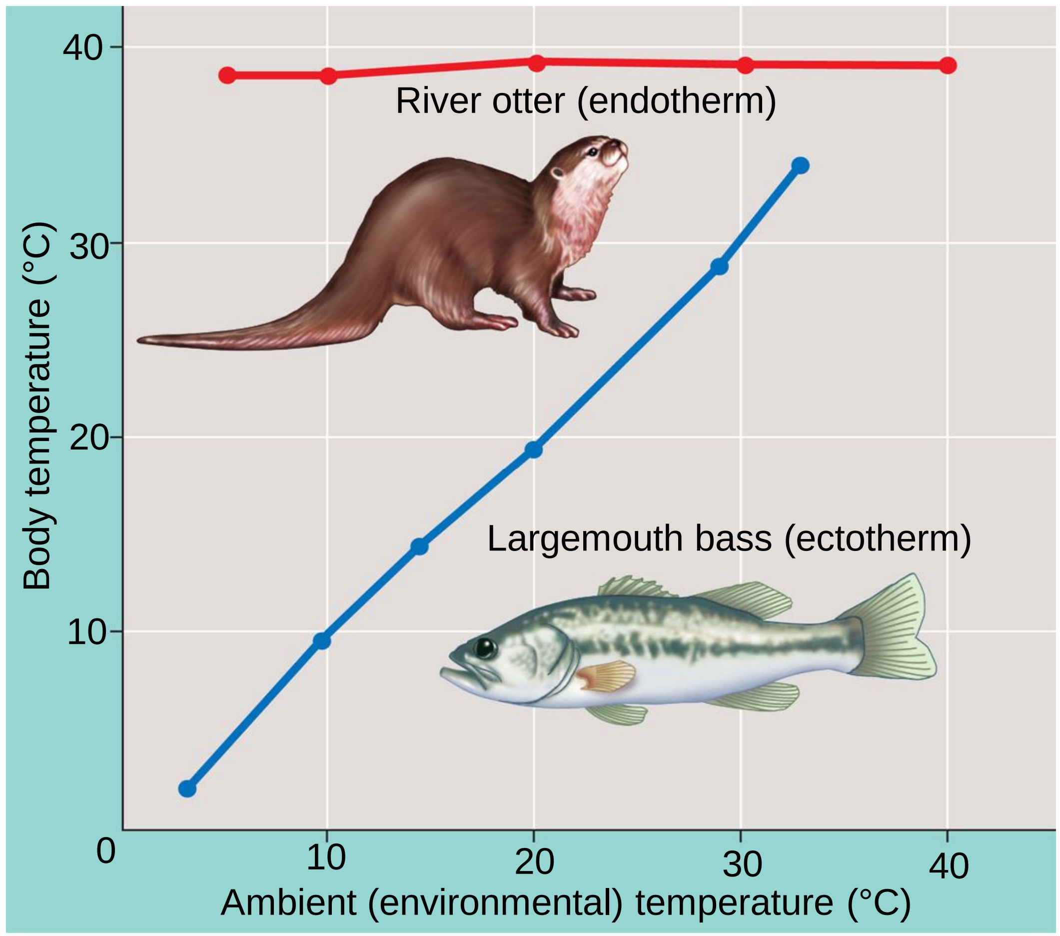
Modes of Heat Exchange

- **Organisms exchange heat by 4 physical processes:**



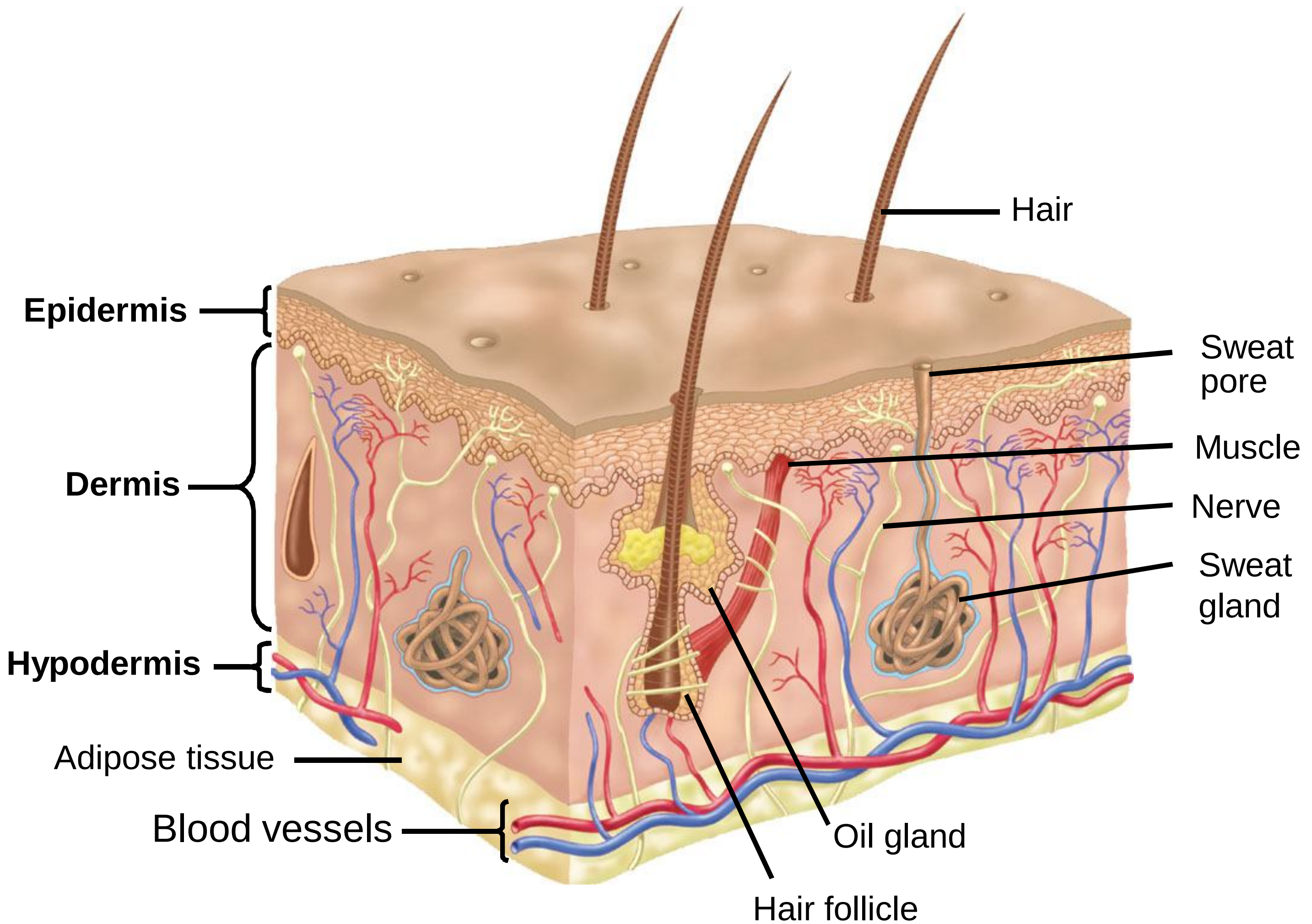
Ectotherms vs. endotherms

- **In general, ectotherms tolerate greater internal temperature variation than endotherms**



Insulation

- **In mammals, the integumentary system (skin) acts as insulating material**

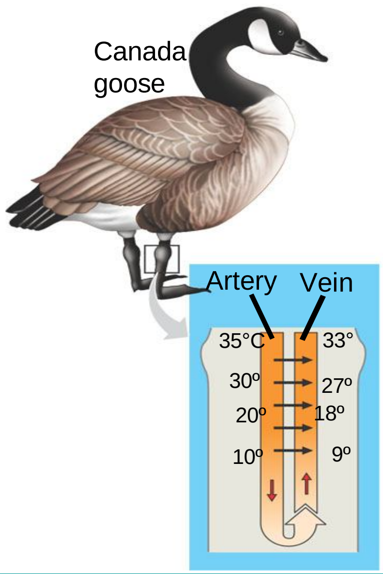


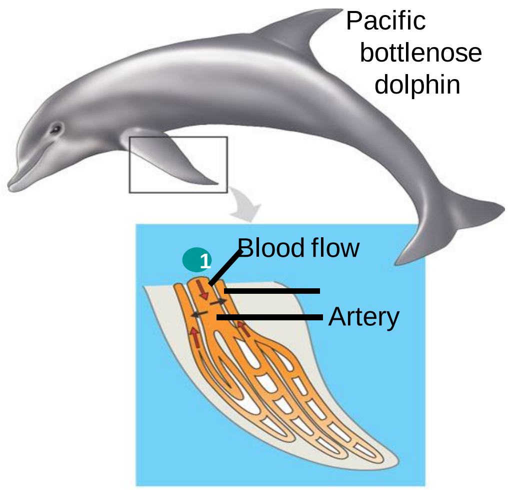
Circulatory Adaptations

- **Many endotherms and some ectotherms can regulate blood flow between body core & skin**
  - **Vasodilation – increases heat loss by increasing blood flow to skin**
  - **Vasoconstriction – decreases heat loss by decreasing blood flow to skin**

Countercurrent exchange

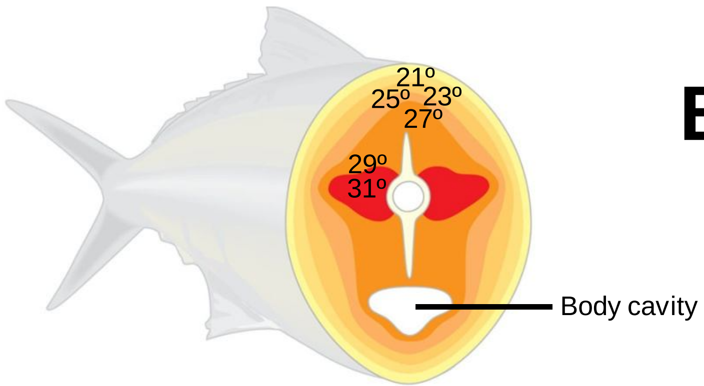
- **Countercurrent heat exchangers = arrangements of blood vessels that minimize heat loss**
  - **Found in many marine mammals and birds**
  - **Heat in arteries transferred back to body by veins instead of being lost to environment**



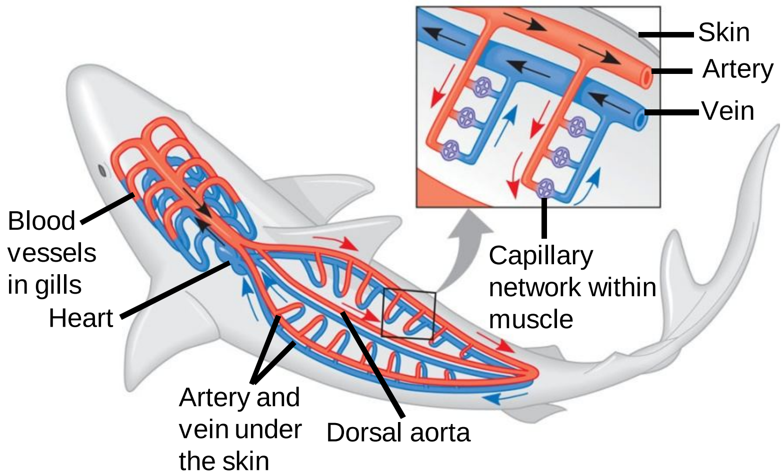


Countercurrent exchange

- **countercurrent heat exchangers are also found in some specialized bony fishes & sharks**



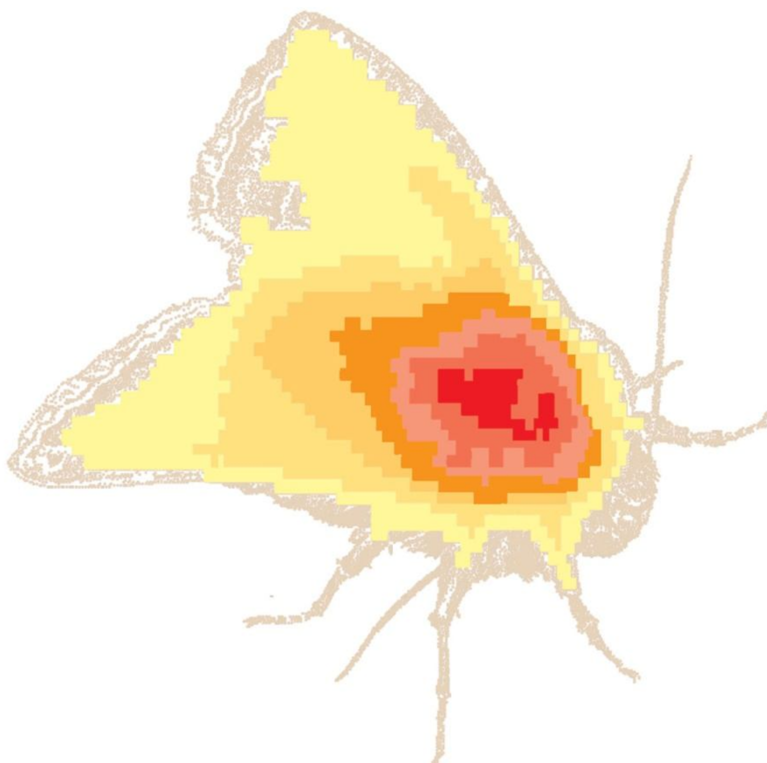
Bluefin tuna



Great white shark

Countercurrent exchange

- **Many endothermic insects have countercurrent heat exchangers that help maintain a high temperature in the thorax**
  - **Keep flight muscles warmed**



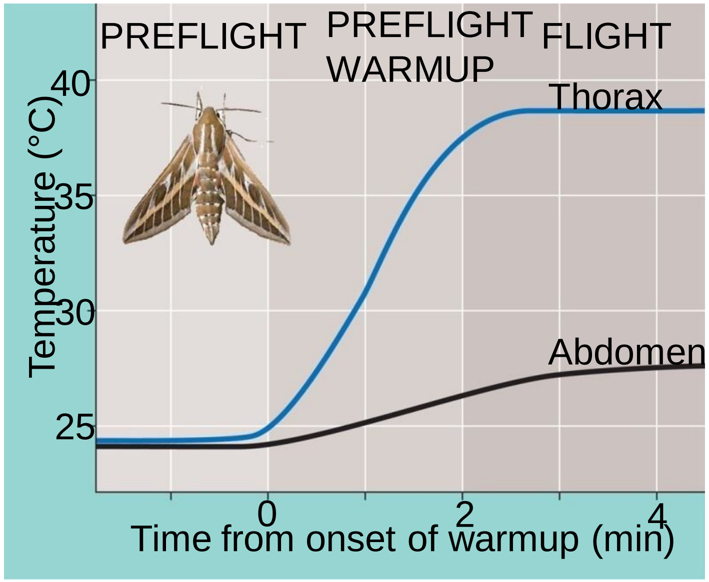
Cooling by Evaporative Heat Loss

- **Many types of animals lose heat through evaporation of water by:**
  - **Sweating**
  - **Panting**
  - **Bathing**

Behavioral Responses

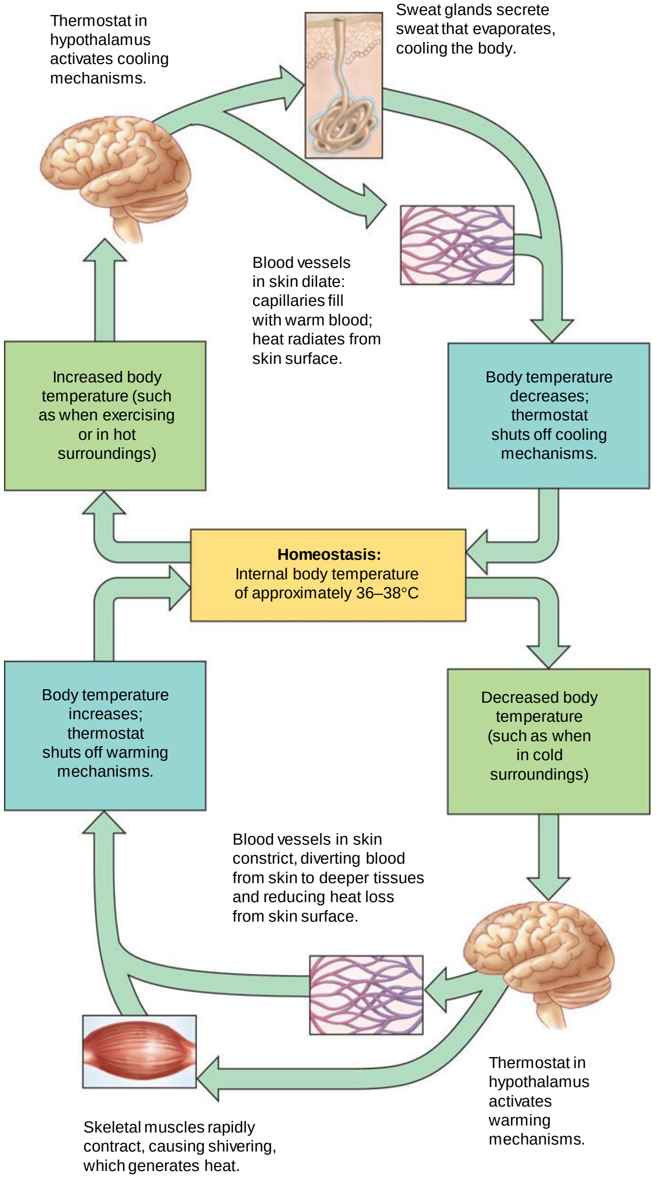
- **Assuming specific postures help minimize or maximize heat absorption from the sun**

- **Shivering warms up flight muscles in many species of flying insects**



Feedback Mechanisms in Thermoregulation

- In humans, the **hypothalamus** contains a group of nerve cells that function as a thermostat



Torpor

- physiological state in which activity is low and metabolism decreases to conserve energy while avoiding difficult and dangerous conditions
- daily torpor
  - small mammals & birds
  - seems to be adapted to their feeding patterns
- long-term torpor
  - Hibernation – winter torpor; adaptation to cold & food scarcity
  - Estivation – summer torpor; adaptation to heat & water scarcity

Osmoregulation

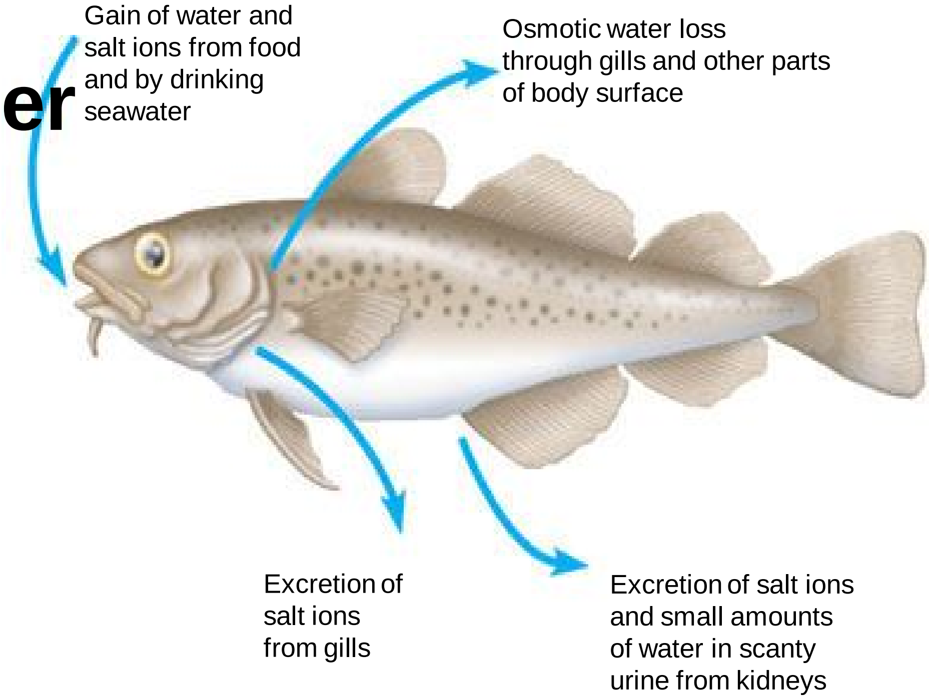
- **Osmoregulation**
  - **Regulates solute concentrations**
    - **controlled movement of solutes between internal fluids & external environment**
  - **Balances gain & loss of water**
- **Excretion**
  - **Gets rid of metabolic wastes**

Opposite problems

- **Freshwater animals**
  - **must reduce water uptake & conserve solutes**
- **Desert & marine animals**
  - **must conserve water & excrete solutes**

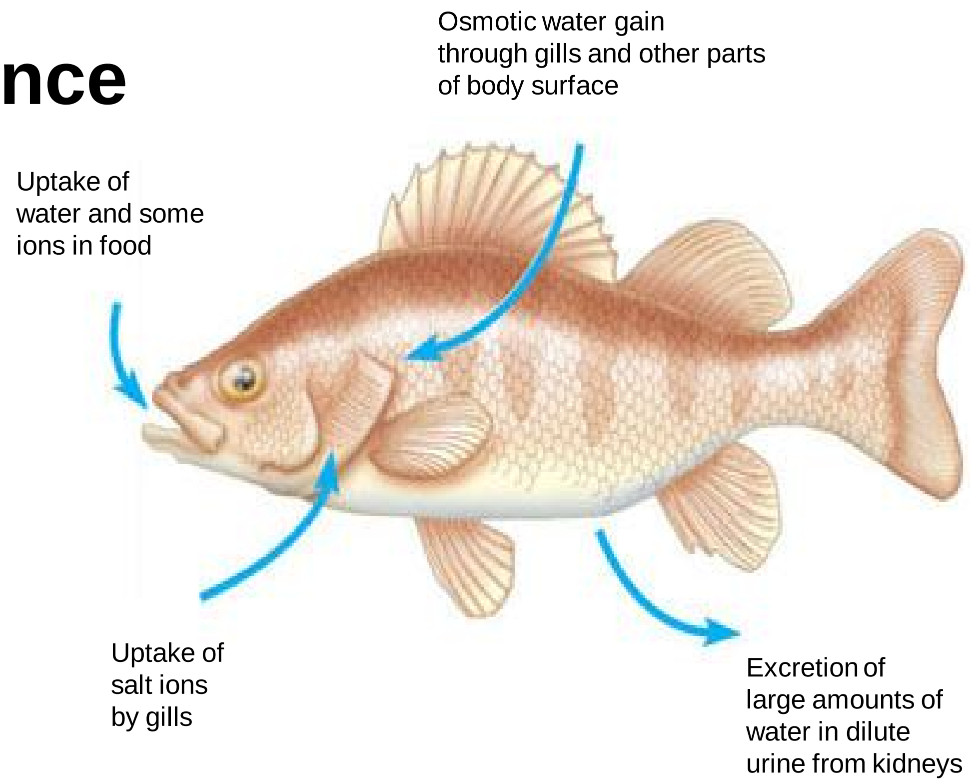
Osmoregulation in saltwater fish

- <u>hypo</u>osmotic to sea water
  - lose water by osmosis
  - gain salt by diffusion & from food they eat
- balance water loss by drinking seawater
- balance ions by excreting salt



Osmoregulation in freshwater fish

- Hyperosmotic to freshwater
  - Constantly take in water from environment
  - Lose salts by diffusion
- maintain water balance by excreting large amounts of dilute urine
- replace salts by foods & uptake across gills



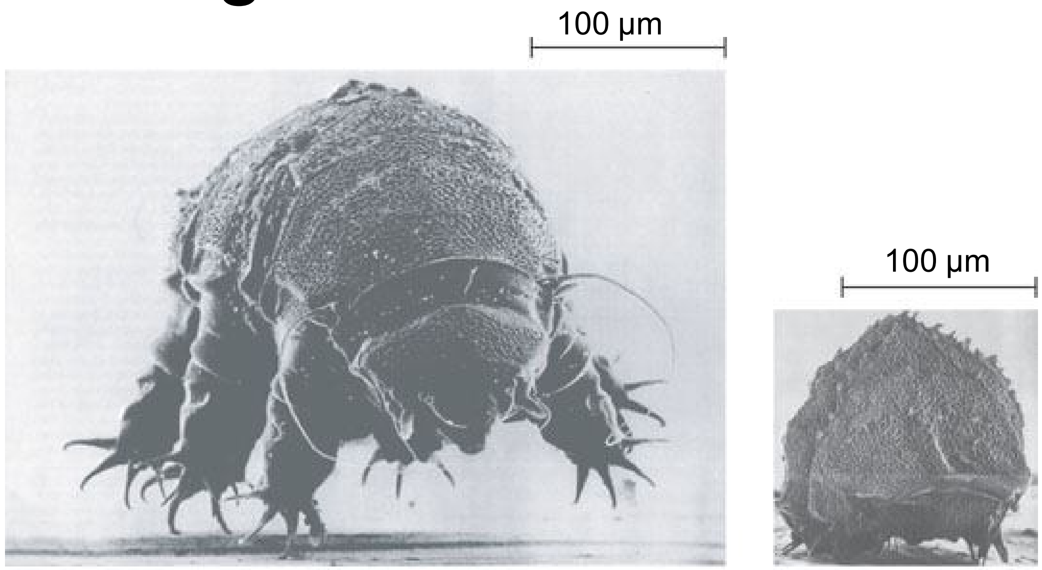
Osmotic Challenges

- Osmoconformers
  - only marine animals
  - isoosmotic with environment; do not regulate osmolarity
- Osmoregulators
  - expend <u>energy</u> to control water uptake & loss
  - hyperosmotic or hypoosmotic environment

- **Stenohaline (narrow salinity range)**
  - **cannot tolerate substantial changes in external osmolarity**
  - **most animals**
- **Euryhaline (wide salinity range)**
  - **can survive large fluctuations in external osmolarity**
  - **salmon, tilapia**

anhydrobiosis

- **Ability to lose almost all body water & survive in dormant state when habitat dries up**
  - **some aquatic invertebrates (tardigrades) in temporary ponds**
  - **desert frogs**



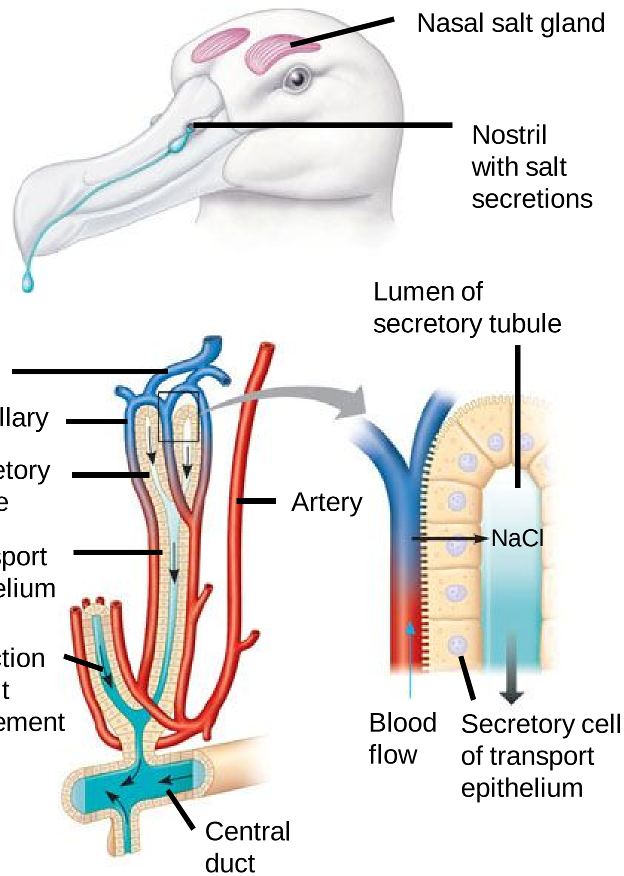
(a) Hydrated tardigrade **(b) Dehydrated tardigrade**

Transport Epithelia

- **specialized cells**
- **regulate solute movement**
- **essential components of osmotic regulation & metabolic waste disposal**
- **arranged into complex tubular networks**

Transport epithelia

- **found in the salt glands of marine birds**
- **remove excess NaCl from blood**



(a) An albatross's salt glands empty via a duct into the nostrils, and the salty solution either drips off the tip of the beak or is exhaled in a fine mist.

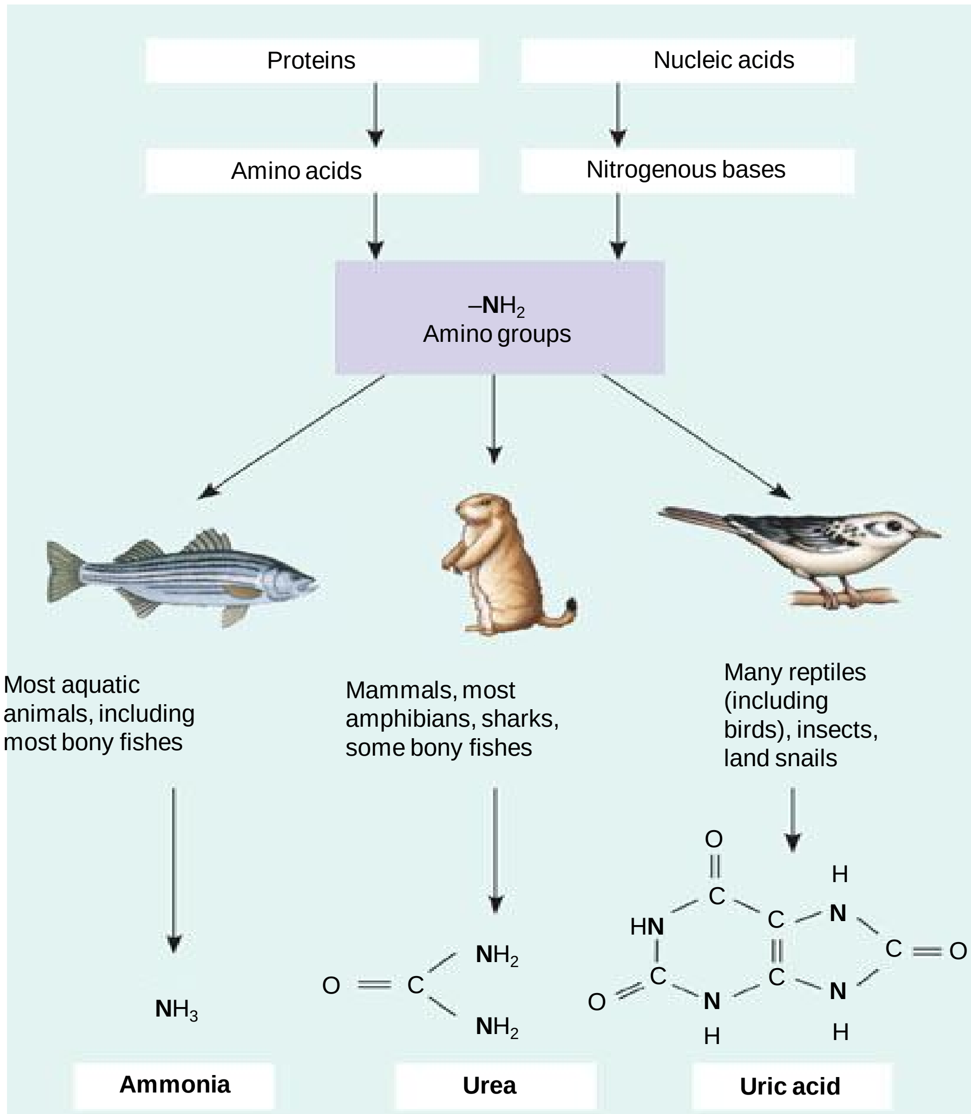
(b) One of several thousand secretory tubules in a salt-excreting gland. Each tubule is lined by a transport epithelium surrounded by capillaries, and drains into a central duct.

(c) The secretory cells actively transport salt from the blood into the tubules. Blood flows counter to the flow of salt secretion. By maintaining a concentration gradient of salt in the tubule (aqua), this countercurrent system enhances salt transfer from the blood to the lumen of the tubule.

Nitrogenous wastes

- type & quantity of nitrogenous waste
  - reflect animal's phylogeny & habitat
  - may have a large impact on animal's water balance
- breakdown products of proteins & nucleic acids
- 3 major types: ammonia, urea, uric acid

Types of Nitrogenous Wastes



Ammonia

- **Highly toxic**
- **Animals need lots of water to excrete it**
- **Release it across whole body surface or through gills**

Urea

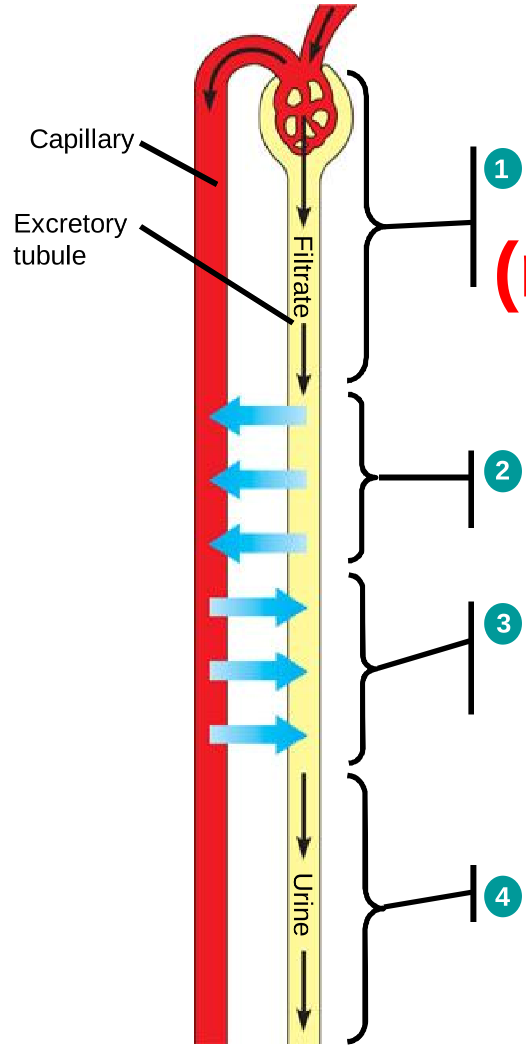
- less toxic
- produced in liver of mammals & most adult amphibians (by converting ammonia to urea)
- carried to the kidneys, concentrated, & excreted with minimal loss of water

Uric Acid

- largely insoluble in water (so less toxic)
- can be secreted as a paste with little water loss
- main form of nitrogenous waste excreted by insects, land snails, & many reptiles, including birds
  - guano
  - gout

Excretory processes overview

- **4 major processes produce urine**
  - **vary widely among animal groups**
  - **generally built on complex network of tubules**

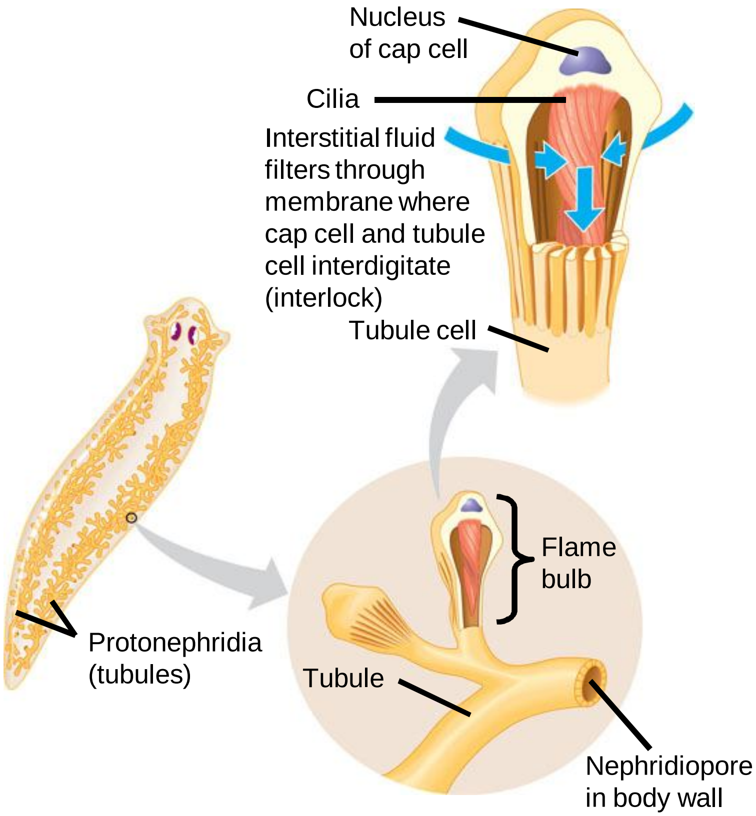


Excretory processes

- **Filtration**
  - **pressure-driven; blood cells & large molecules stay behind; produces filtrate**
- **Reabsorption**
  - **valuable solutes reclaimed from the filtrate**
- **Secretion**
  - **addition of toxins & other solutes from body fluids to filtrate**
- **Excretion**
  - **filtrate leaves the system**

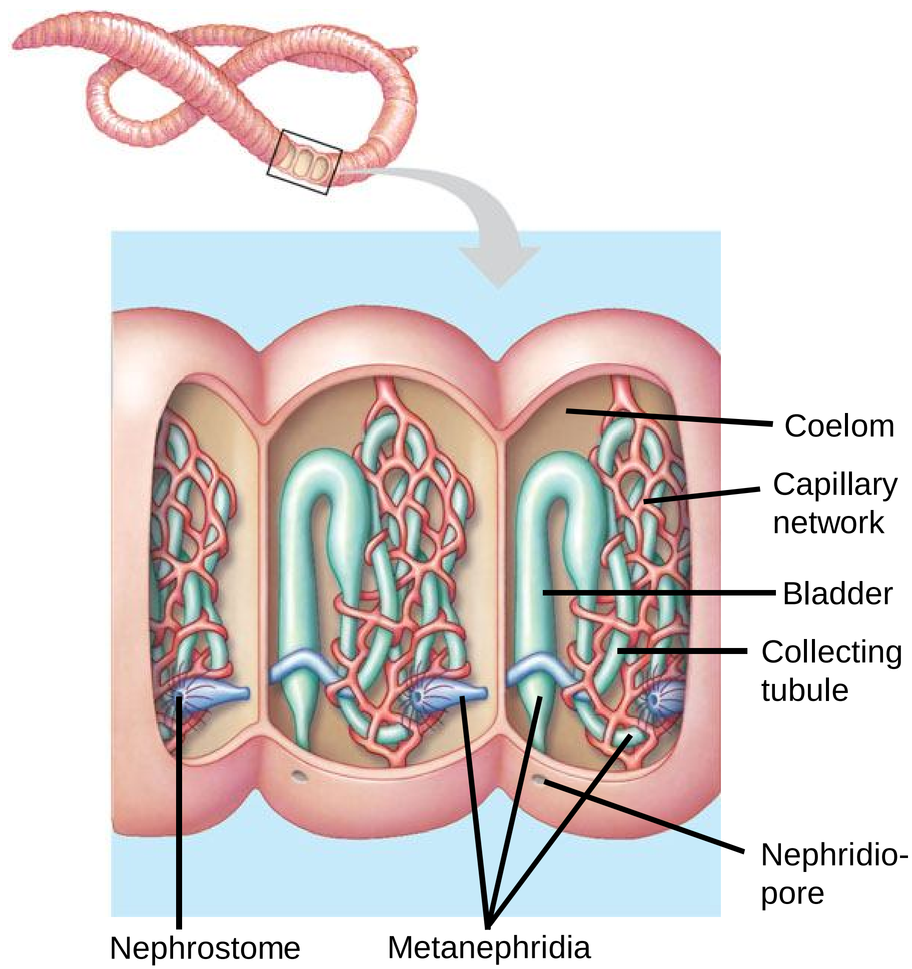
Survey of Excretory Systems

- Protonephridium (w/ flame bulb)
  - network of <u>dead-end tubules</u> lacking internal openings; end in flame bulb
  - excrete dilute fluid & function in osmoregulation
  - Platyhelminthes (flatworms)



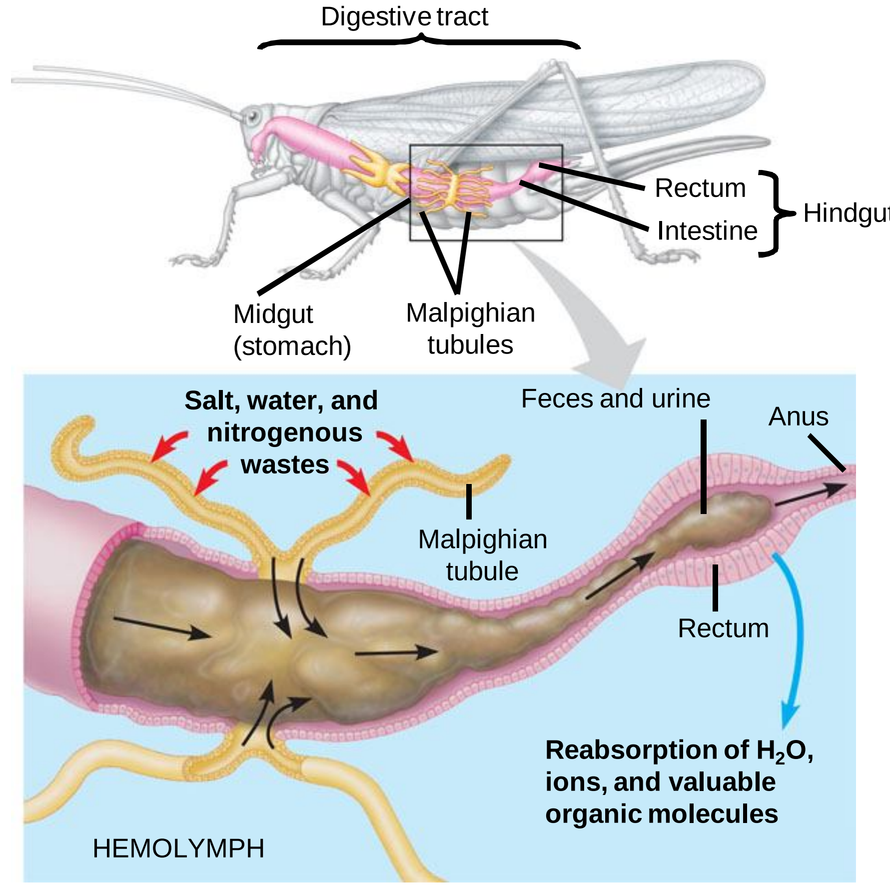
Survey of Excretory Systems

- **Metanephridia - system of open-ended tubules that collect coelomic fluid & produce dilute urine for excretion**
  - **annelids**
  - **one pair of metanephridia per segment**



Survey of Excretory Systems

- **Malpighian tubules** – **outfoldings of digestive tract that remove nitrogenous wastes from hemolymph & function in osmoregulation**
  - **insects & other terrestrial arthropods**
  - **produce relatively dry waste matter**
  - **terrestrial adaptation!**

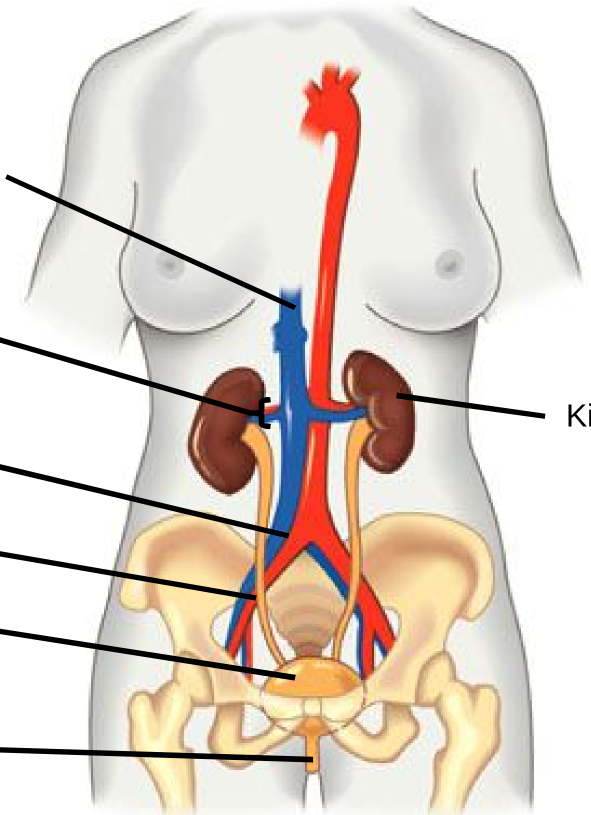


Survey of Excretory Systems

- **Kidneys**
  - **excretory organs of vertebrates**
  - **function in both excretion & osmoregulation**
  - **Functional unit = nephron**

Mammalian kidney

- **Each kidney supplied with blood by a renal artery & drained by a renal vein**
- **Renal = kidney**
- **Urine exits each kidney through ureter**
- **Both ureters drain into urinary bladder**



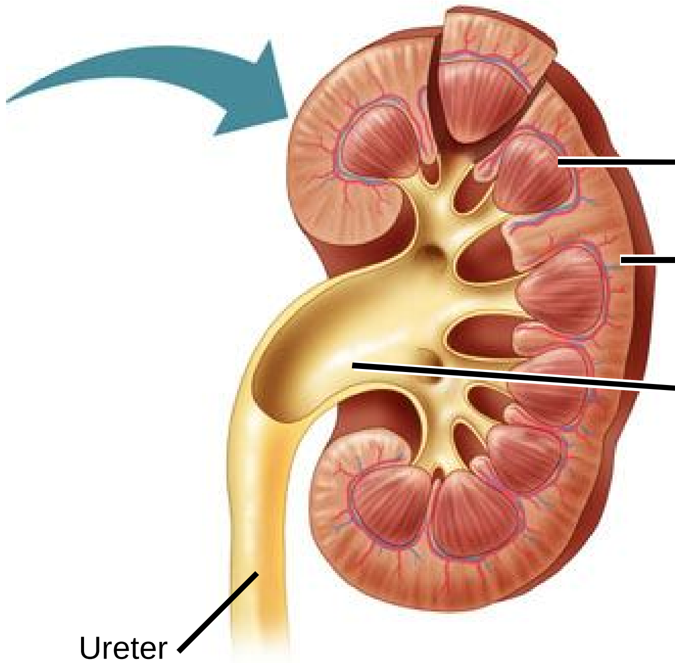
(a) Excretory organs and major associated blood vessels

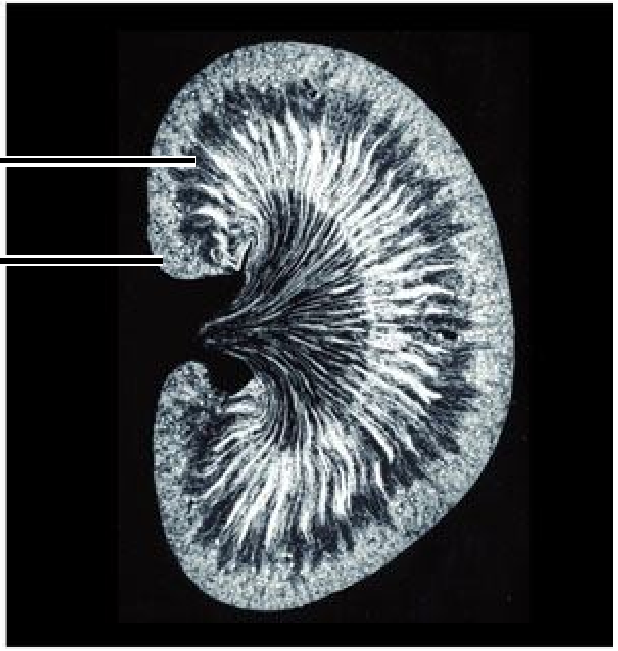
How is mammalian kidney adaptive?

- conserves water
- can produce urine much more concentrated than body fluids
- key terrestrial adaptation

Kidney structure

- two distinct regions
  - renal cortex = outer
  - renal medulla = inner

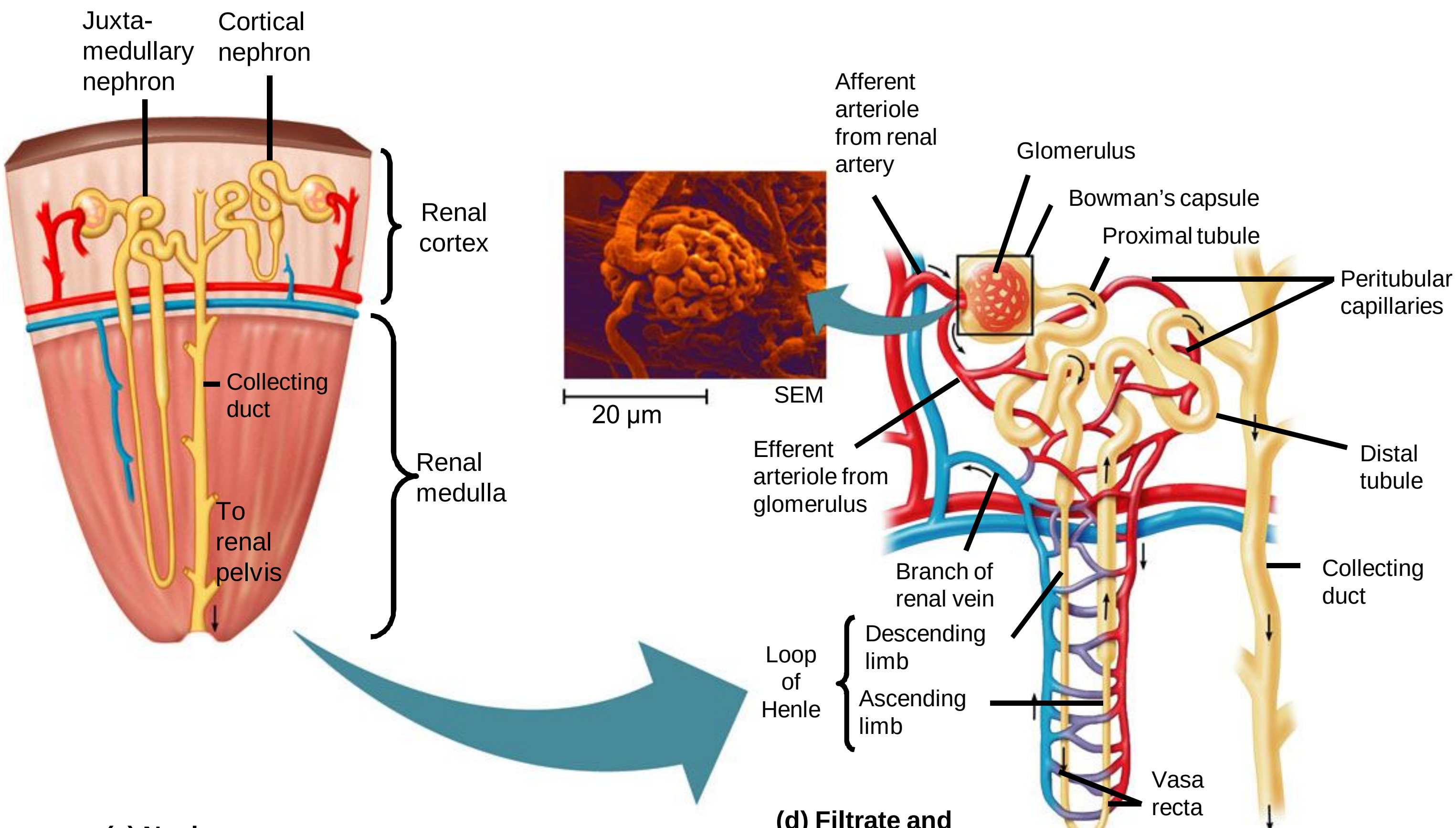




Section of kidney from a rat

Kidney structure

- **Nephron consists of a single long tubule and a ball of capillaries called the glomerulus**



(c) Nephron

(d) Filtrate and blood flow

Filtration of the Blood

- occurs as blood pressure forces fluid from the blood in the glomerulus into the lumen of Bowman's capsule
  - filtration of small molecules
  - nonselective
  - concentration of filtrate in Bowman's capsule similar to blood plasma

Pathway of the Filtrate

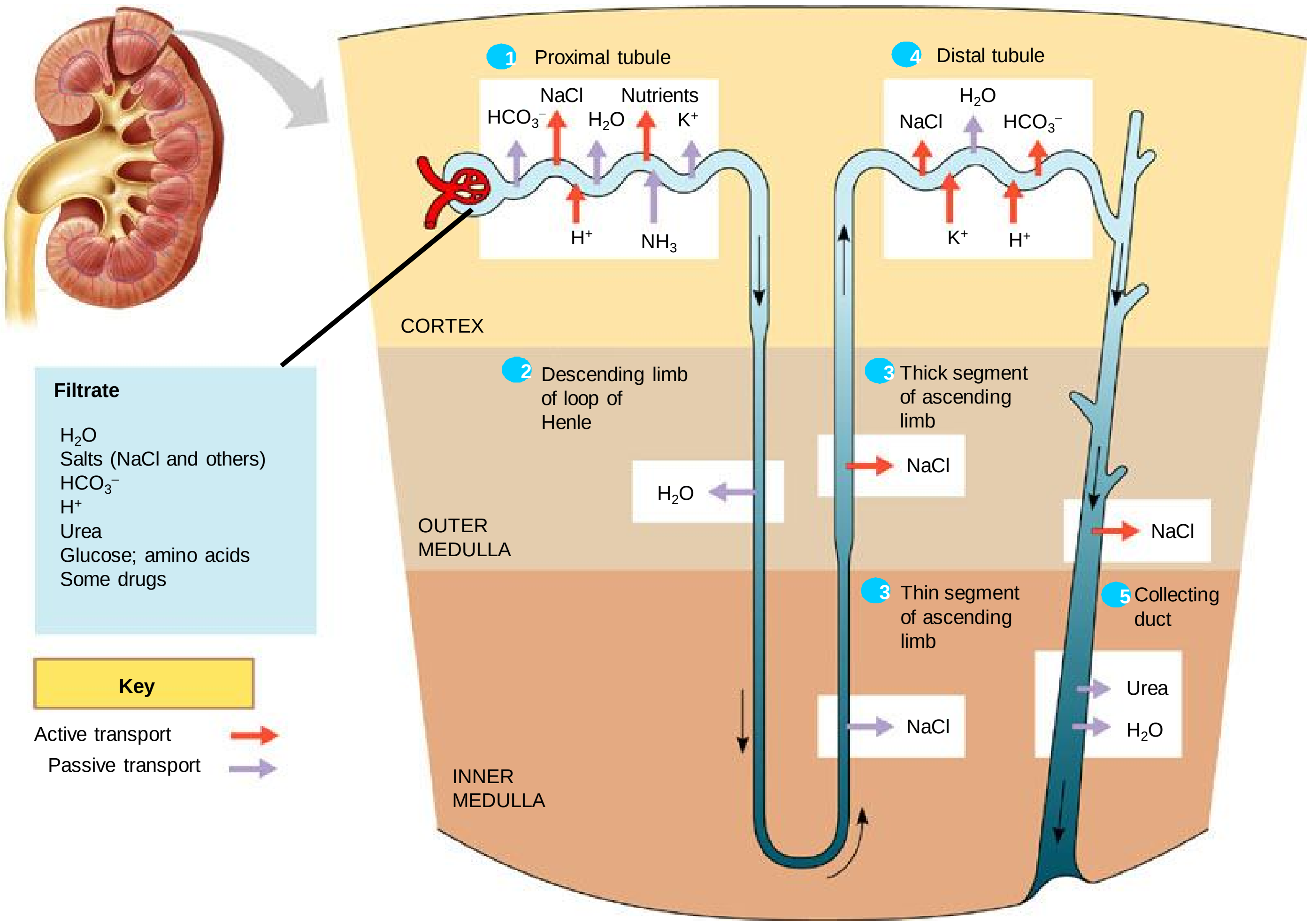
- **From Bowman's capsule, filtrate passes through 3 regions of nephron:**
  - **proximal tubule**
  - **loop of Henle**
  - **distal tubule**
- **volume & composition of filtrate altered by secretion & reabsorption of H_2O & NaCl in different regions**
- **Fluid from several nephrons flows into a collecting duct**

Blood Vessels Associated with Nephrons

- **afferent arteriole – branch of renal artery that supplies glomerulus in nephron (“arriving”)**
- **efferent arteriole – convergence of capillaries that drains glomerulus (“exiting”)**
- **peritubular capillaries – after leaving glomerulus, vessels subdivide again forming net of capillaries that surround proximal and distal tubules**

From Blood Filtrate to Urine: A Closer Look

- **Filtrate becomes urine as it flows through the mammalian nephron and collecting duct**



What happens to filtrate in each region of a nephron?

- **Proximal tubule**
  - **Regulates pH by reabsorbing bicarbonate (HCO_3^-)**
  - **Reduces filtrate volume by reabsorbing most of NaCl & H_2O**
    - **Active transport moves NaCl out; H_2O follows by osmosis**
- **Descending limb of the loop of Henle**
  - **Reabsorption of H_2O continues by osmosis**
  - **Transport epithelium permeable to H_2O, but not to NaCl**

What happens to filtrate in each region of a nephron?

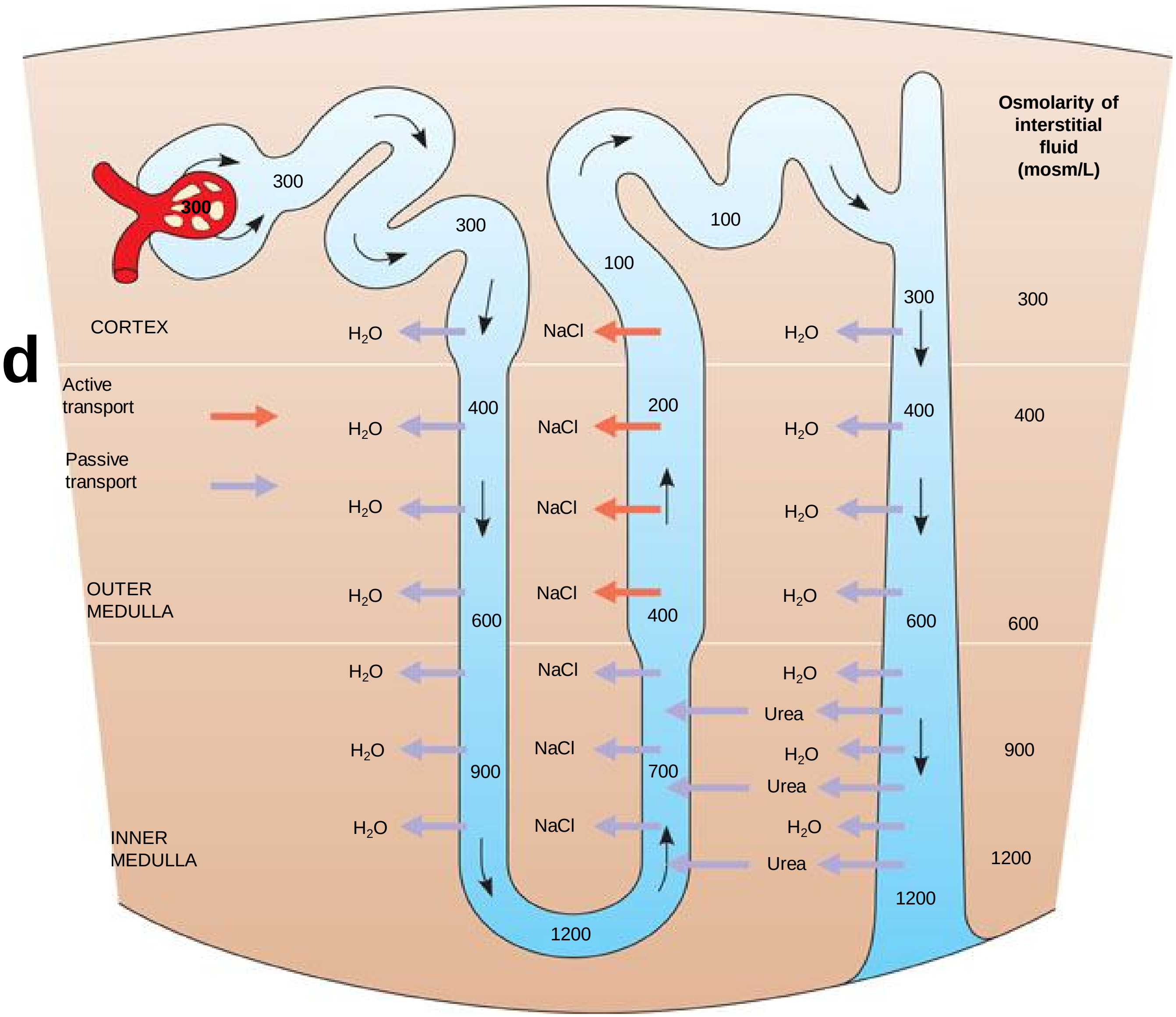
- Ascending limb of the loop of Henle
  - In thin segment, NaCl diffuses out of the tubule into the interstitial fluid
    - Transport epithelium permeable to NaCl, but not to H_2O
  - In thick segment, actively transports NaCl into interstitial fluid
- Distal tubule
  - Plays key role in regulating the K^+ & NaCl concentration of body fluids
- Collecting duct
  - Carries filtrate through medulla to renal pelvis & reabsorbs NaCl

Why does this work?

- Cooperative action & precise arrangement of the loops of Henle & collecting ducts
- Countercurrent exchange!
- Osmotic gradient established within kidney
  - Cortex – low osmolarity
  - Medulla – high osmolarity (higher than rest of body!)
- Selective permeability & active transport by transport epithelium

Osmotic gradient

- **NaCl & urea increase osmolarity of interstitial fluid**
- **causes reabsorption of water in kidney & concentrates urine**



Collecting duct

- **permeable to water but not salt**
  - **conducts the filtrate through the kidney's osmolarity gradient**
  - **more water exits the filtrate by osmosis**

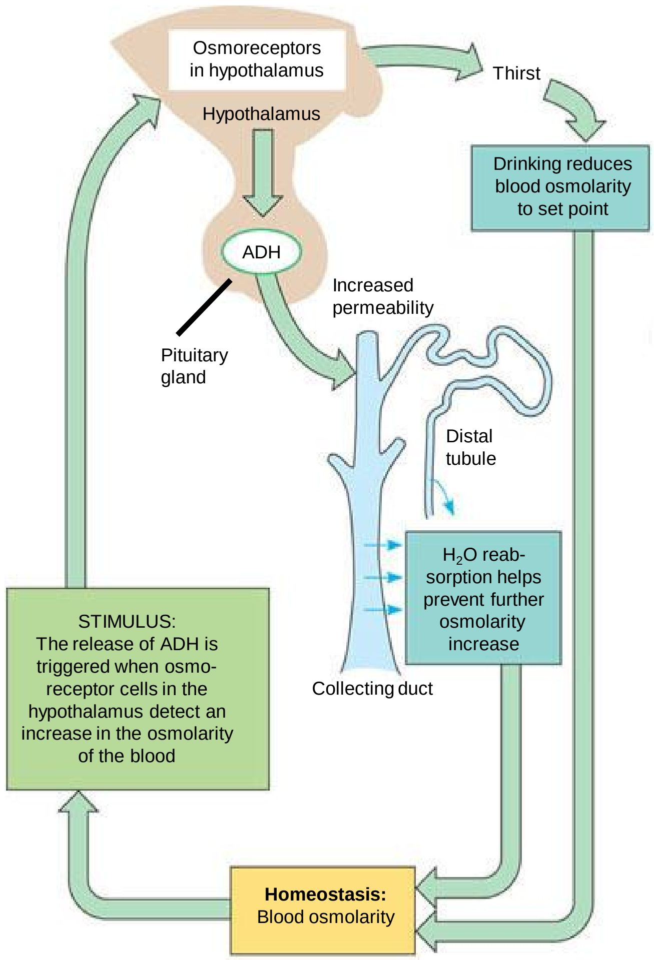
- **Urea**
  - **diffuses out of the collecting duct as it traverses the inner medulla**
- **Urea and NaCl**
  - **form the <u>osmotic gradient</u> that enables the kidney to produce urine that is <u>hyperosmotic</u> to the blood**

Regulation of Kidney Function

- **osmolarity of urine is regulated by nervous & hormonal control of water and salt reabsorption in the kidneys**

Regulation of Kidney Function

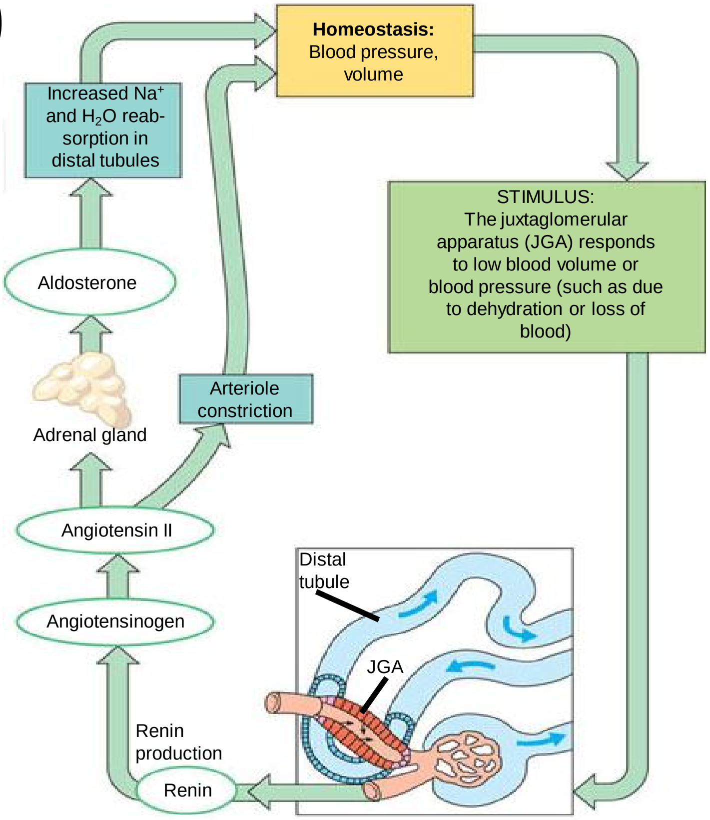
- **Antidiuretic hormone (ADH)**
  - Increases water reabsorption in the **distal tubules** and **collecting ducts** of the kidney
  - Triggered by **decrease in osmolarity** (ex. dehydration)



(a) Antidiuretic hormone (ADH) enhances fluid retention by making the kidneys reclaim more water.

Regulation of Kidney Function

- **renin-angiotensin-aldosterone system (RAAS)**
  - **partners with ADH to maintain homeostasis**
  - **also increases reabsorption of water**
  - **triggered by drop in blood volume & pressure**



(b) The renin-angiotensin-aldosterone system (RAAS) leads to an increase in blood volume and pressure.

Regulation of Kidney Function

- **atrial natriuretic factor (ANF)**
  - **in walls of atrium**
  - **opposes the RAAS**
  - **inhibits NaCl reabsorption**
  - **triggered by increase in blood pressure & volume**