

Chapter 44

Osmoregulation and Excretion

Controlling the internal environment

Osmoregulation

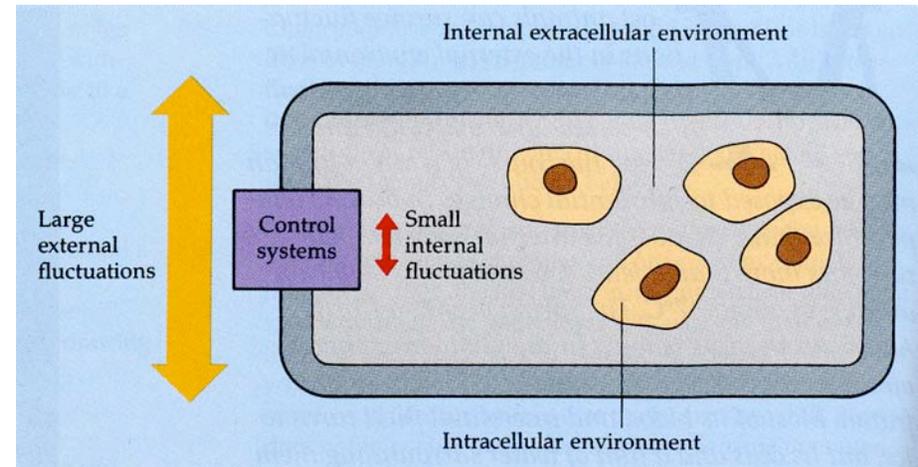
Nitrogenous wastes

Excretory systems

Mammalian excretory systems

Controlling the Internal Environment

Most animals survive in external environments that are much too extreme for an individual cell to tolerate.



2 processes of homeostasis:

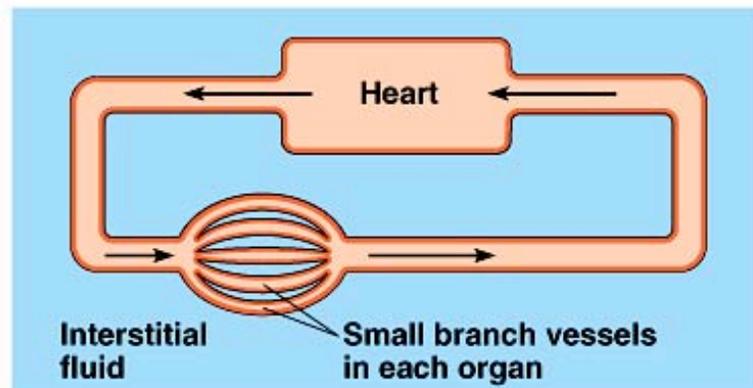
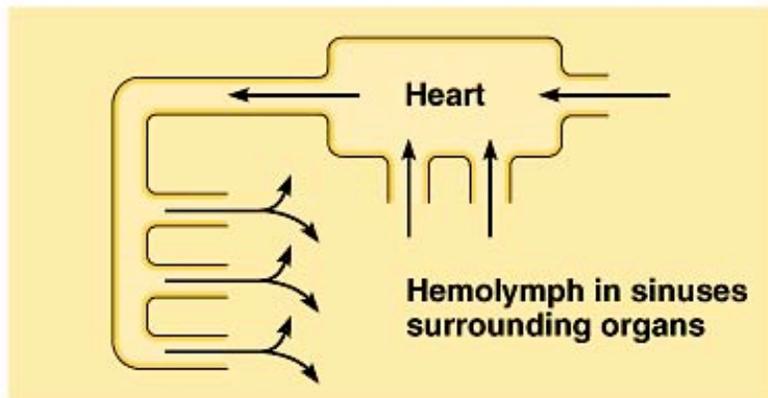
1. Osmoregulation - regulation of solute balance and the gain and loss of water.
2. Excretion of nitrogen containing waste products of metabolism.

Animals with open circulations (ex. insects):

Circulatory fluid escapes the vasculature and bathes all the cells of the body = hemolymph. No distinction between blood and interstitial fluid.

Animals with closed circulation (ex. vertebrates):

Blood is confined to vessels and is not in direct contact with tissue cells. Interstitial fluid bathes cells, and is served by plasma of the circulatory system for transport.



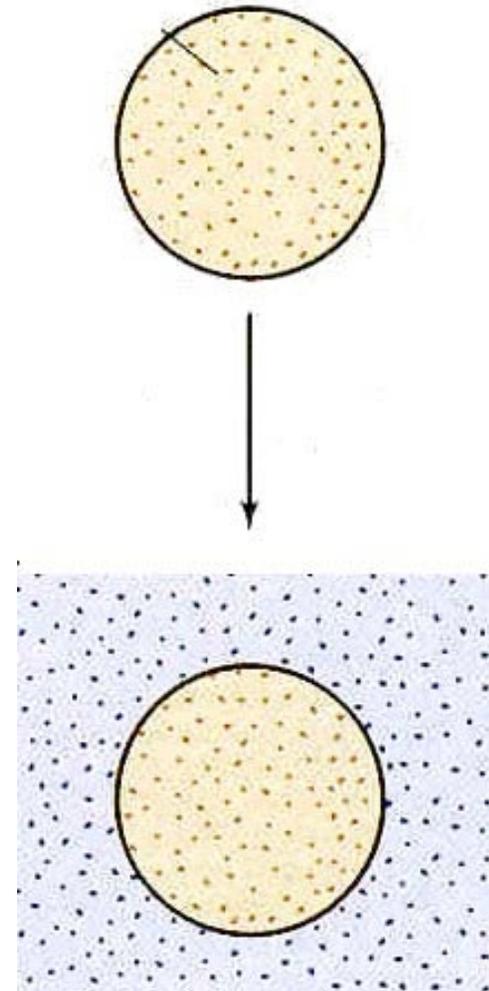
Osmosis between intracellular and extracellular fluids:

Isotonic solutions

The cell does not swell or shrink.

A solution of **impermeant solutes** with an osmolarity of **280 mOsm/liter**.

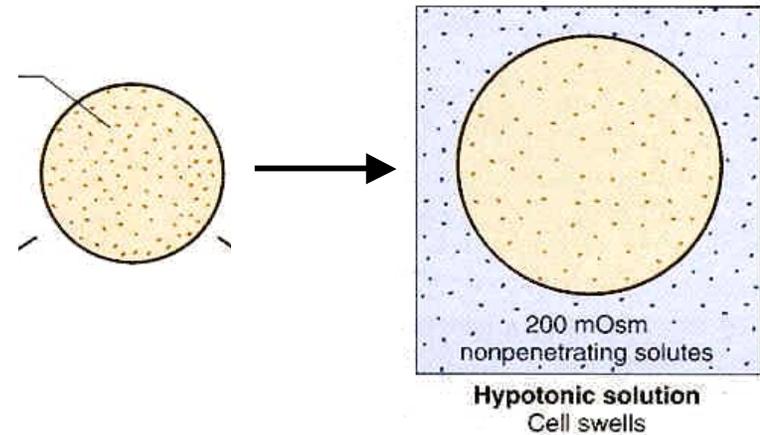
A 0.9% solution of NaCl or a 5% solution of glucose.



Hypotonic solutions

The concentration of impermeant solutes is less than 280 mOsm/liter.

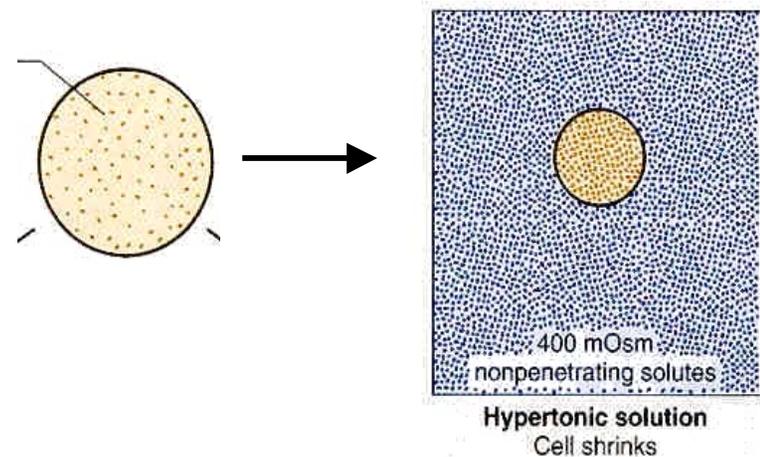
Water will diffuse into the cell causing the cell to swell.



Hypertonic solutions

The concentration of impermeant solutes is greater than 280 mOsm/liter.

Water will diffuse out of the cell into the extracellular fluid, causing the cell to shrink.



Isosmotic solutions

Two solutions that have the **same osmolarity**, whether or not the solute can pass the cell membrane.

Hypo-osmotic solution

Solution with a **lower osmolarity**.

Hyperosmotic solution

Solution with a **higher osmolarity**.

Osmoconformers: some marine animals

Animals whose body fluids are isotonic to their environment. They do not actively adjust the internal osmolarity.

Osmoregulators: terrestrial animal, freshwater animals, many marine animals

Animals whose body fluids are *hypotonic*. They will gain water from the environment and must continuously eliminate excess water.

Animals whose body fluids are *hypertonic*. They will lose water to the environment and must continuously take in excess water.

Osmoregulators must expend energy to maintain osmotic balance (5% to 30% of metabolic rate).

The external environment determines the mechanism of maintaining water balance:

Marine Animals:

1. Osmoconformers – most marine invertebrates

May still need to regulate internal composition of specific ions. Usually slight, but may be significant.



2. Osmoregulators – most marine vertebrates
 - a. Cartilaginous fish (ex, sharks)
 - b. Bony fish

Cartilagenous fish (ex. shark)

Maintain a lower osmolarity **for salt** than seawater.

Salt diffuses through gills.

Excrete salt

a. kidneys excrete some salt

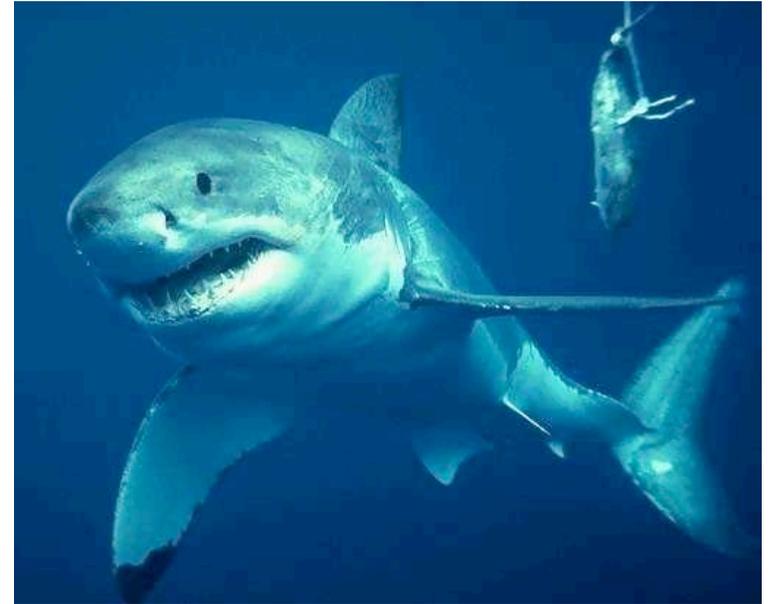
b. rectal glands (salt excretory glands) excrete NaCl.

Animal fluids still slightly **hypertonic** to seawater

Due to accumulation of urea and trimethylamine oxide (TMAO) in fluids.

Water slowly enters body by osmosis.

Excretory organs (kidneys) eliminate excess water as urine.



Bony fishes: ex. cod

Body fluids are *hypotonic* to seawater.

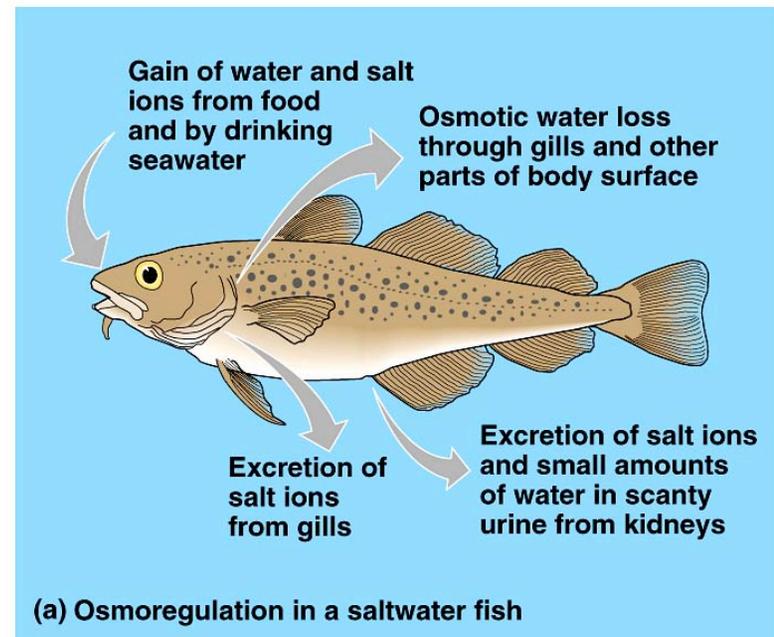
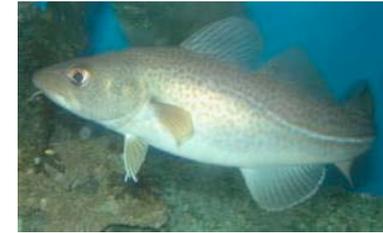
Constant loss of water to surroundings by osmosis.

Constant gain of salt by diffusion and in food.

Compensate by drinking large quantities of seawater and pumping out excess salt through gills and skin.

Chloride cells in gills pump chloride ions out, sodium follows passively.

Kidneys excrete only small amounts of water.



Freshwater Animals: ex. perch

Body fluids are *hypertonic* to fresh water.

Constantly taking water in by osmosis.

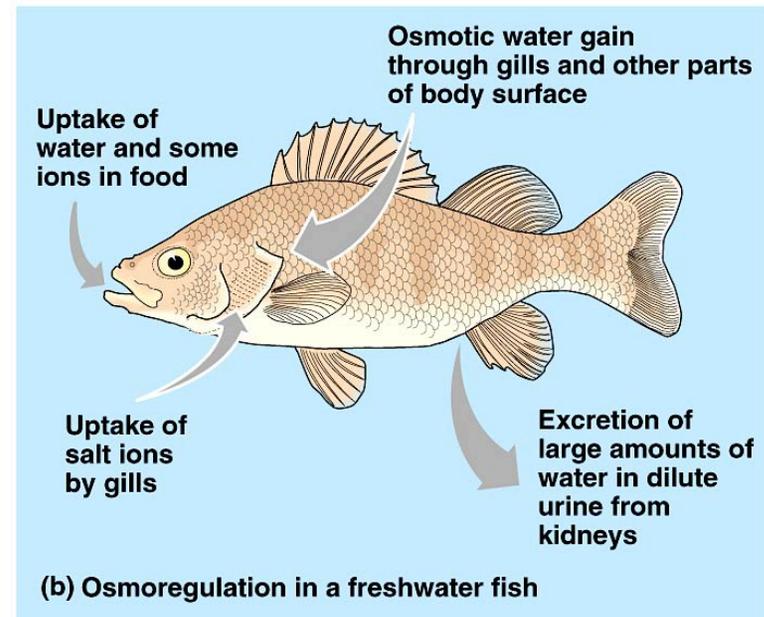
Constantly losing salt by diffusion.



Compensate by excrete large volumes of dilute urine and regaining lost salts.

Chloride cells in gills pump chloride ions in, sodium follows passively.

Ingest salt in food.



Terrestrial animals:

Covered by relatively impervious surfaces to prevent dehydration:

Waxy layer in insects

Shells of land snails

Keratinization of skin of terrestrial vertebrates

Most still lose water from moist surfaces (respiratory), in urine and feces, and across skin.



Desert lynx,
caracal

Balance water budget

Nervous and hormonal mechanisms to control *thirst*.

Kidneys exhibit adaptations to conserve water and *concentrate urine*.

Behavior: Nocturnal animals, especially in the desert.

Nitrogenous Wastes:

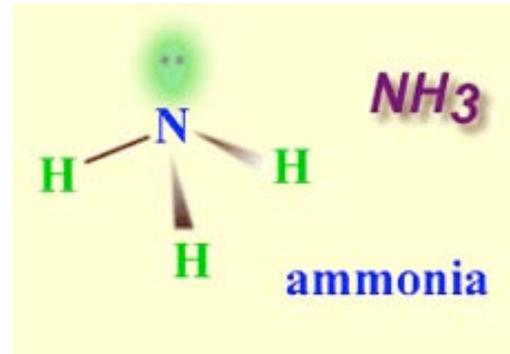
Metabolism of proteins and nucleic acid produces nitrogenous waste = ammonia

Ammonia is eliminated as

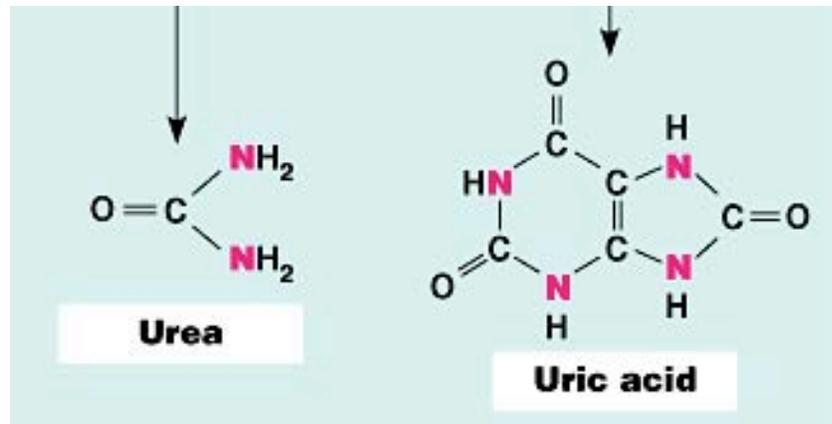
Ammonia – very toxic

Urea } less toxic

Uric acid }



Excreted dissolved in water; excretion has a great effect on osmoregulation.



Ammonia:

Most aquatic animals

Very soluble in water.

Easily permeates membranes.

Diffuses out of entire body surface into surrounding water of invertebrates.

Excreted out of gills and a minor amount from kidneys of fish.



Ammonia is so toxic it can only be transported and excreted in very dilute concentrations, so terrestrial animals cannot eliminate it fast enough.

Urea:

Excreted by animals that *conserve water*.

Produced in the liver by combining ammonia with CO_2 .
Excreted by kidney in urine.

Uses energy.

Urea is 100,000 times less toxic than ammonia.

Tolerated in more concentrated form; sacrifice less water.



Uric acid:

Excreted by land snails, insects, birds, and many reptiles.

More energy to produce than urea.

Relatively non toxic.

1,000 times less soluble in water than ammonia or urea.

Can be excreted as a precipitate.

Vertebrates that produce uric acid produce shelled eggs. Uric acid precipitates out of solution and can be stored in the egg as a solid.



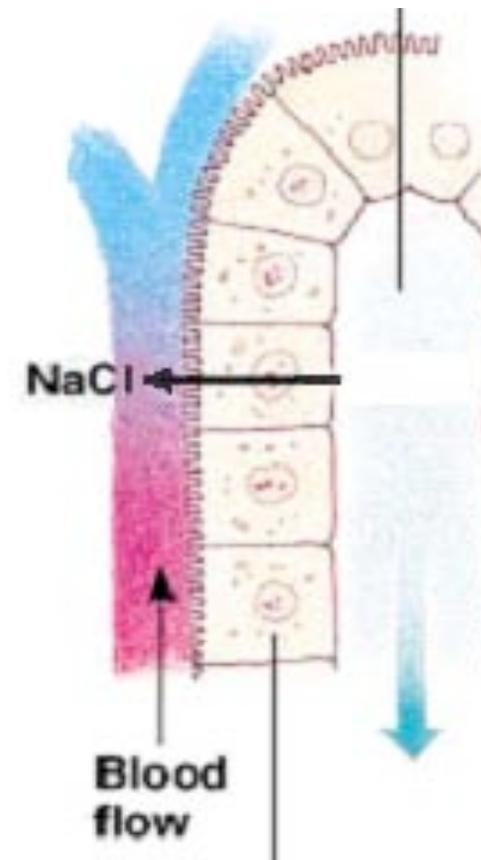
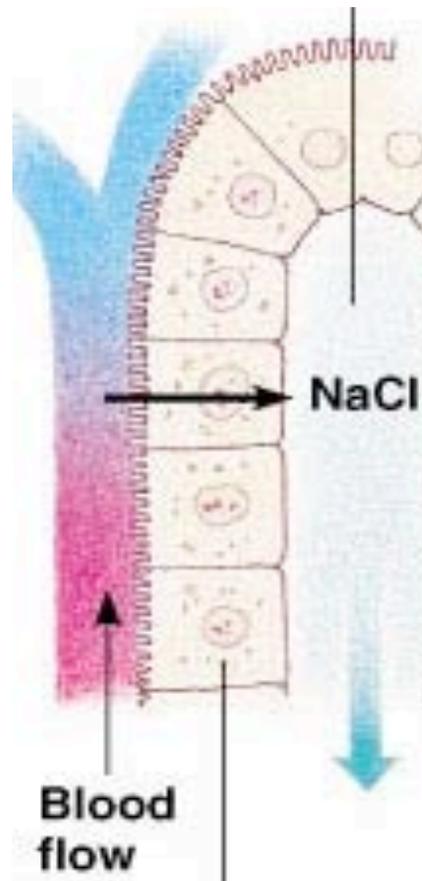
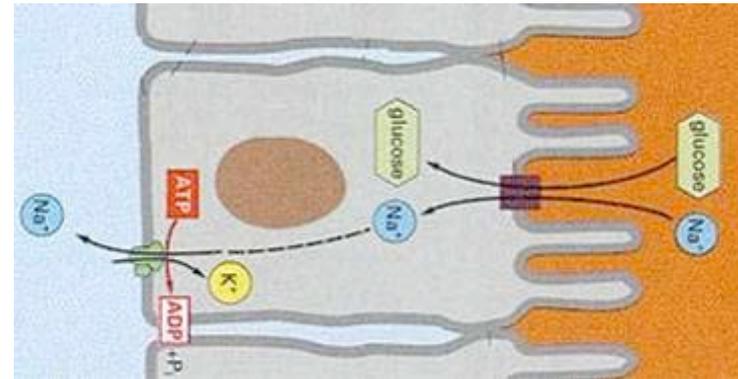
Excretory Systems:

Transport epithelia

regulate solute movement, and therefore water movement by osmosis.

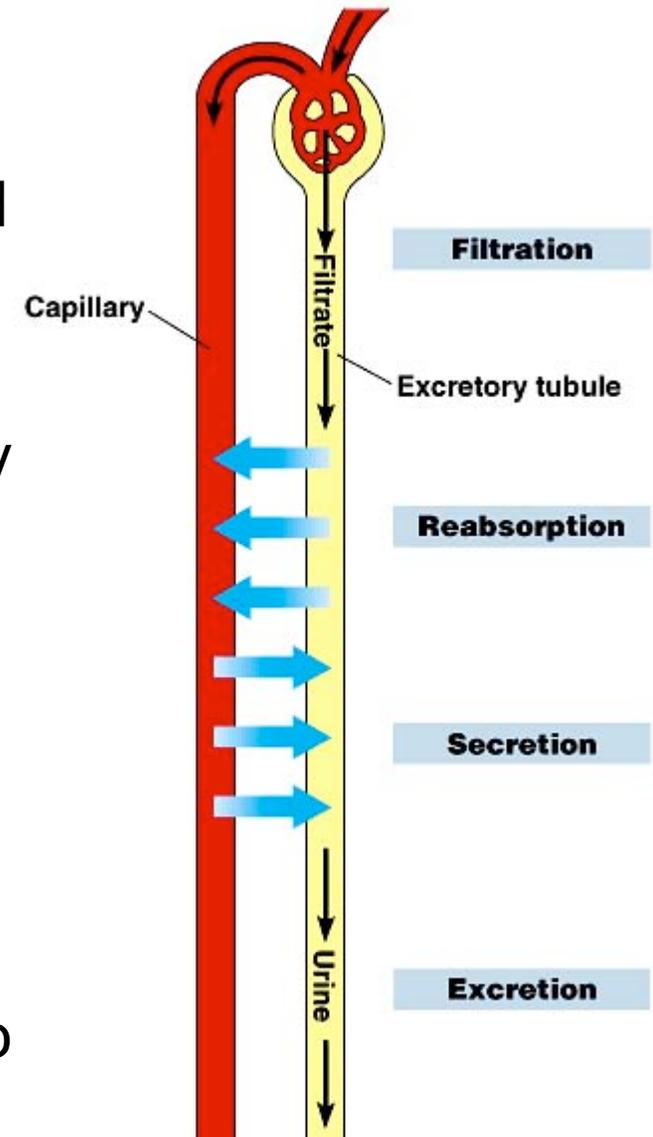
Regulate what passes and in which direction by the placement of carrier proteins on the membrane.

ex. Marine fish pump chloride out while freshwater fish pump chloride in.



Excretory processes:

1. Body fluid is collected, usually by *filtration*, into a tubular system. Fluid = filtrate.
2. Essential small molecules (glucose, amino acids, salts) are recovered by active transport = *selective reabsorption*.
3. Non-essential solutes and wastes (excess salts & toxins) are left in filtrate and added to filtrate by *secretion*.
4. Water is adjusted by osmosis due to pumping of various solutes.
5. Remaining filtrate excreted as urine.



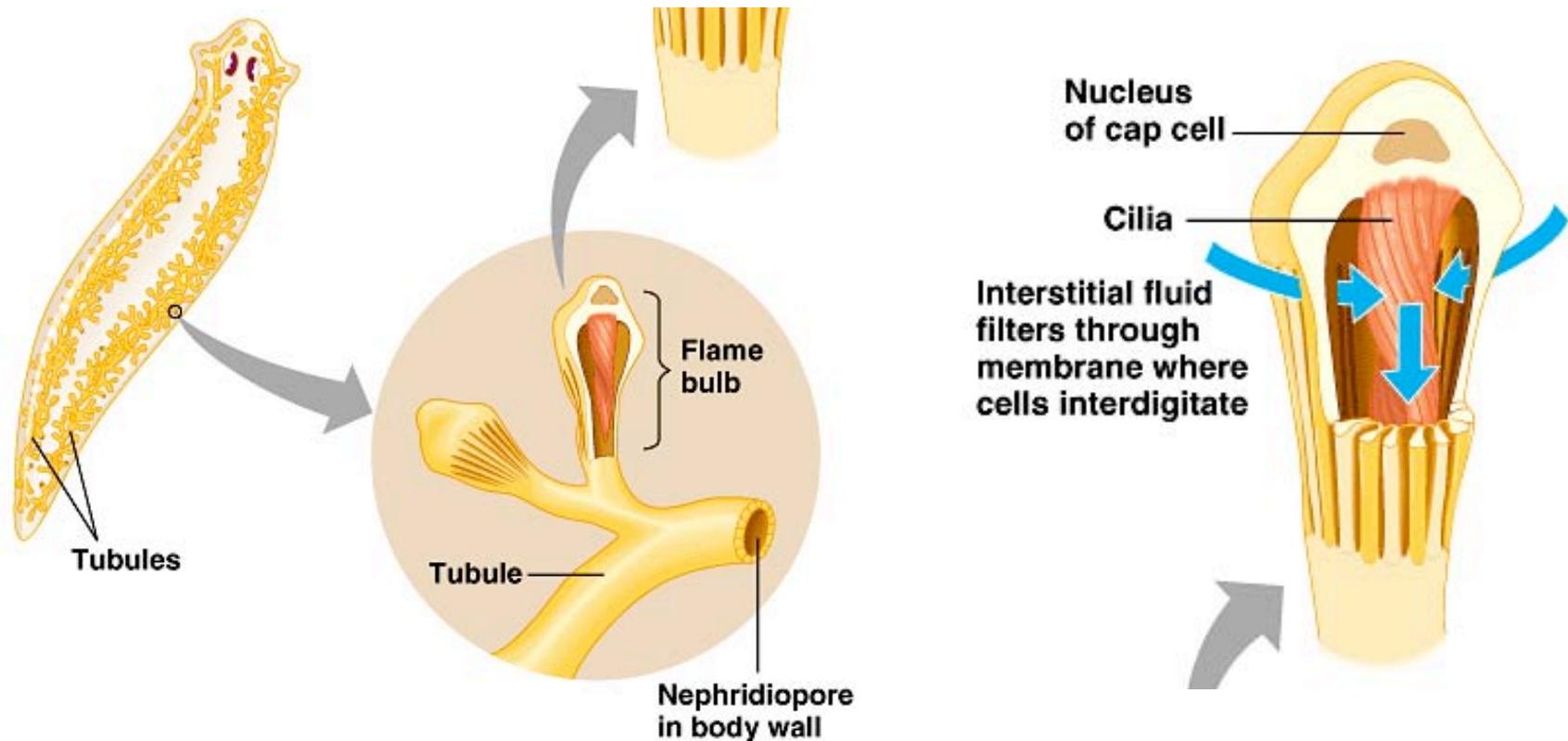
Excretory Systems:

1. Protonephridia
2. Metanephridia
3. Malphigian tubules of insects
4. Kidneys (nephrons) of most vertebrates

Protonephridia: flatworms, rotifers, some annelids, larvae of mollusks, lancets

Network of closed tubules branch throughout the body.

Interstitial fluid filters into lumen at **flame bulb** between adjacent cells



Freshwater flatworms:

Function mainly in *osmoregulation*.

Most metabolic wastes diffuse out of the body surface or to the gastrovascular cavity.



Parasitic flatworms (tapeworm):

In isotonic environment.

Function mainly in excretion of *nitrogenous wastes*.

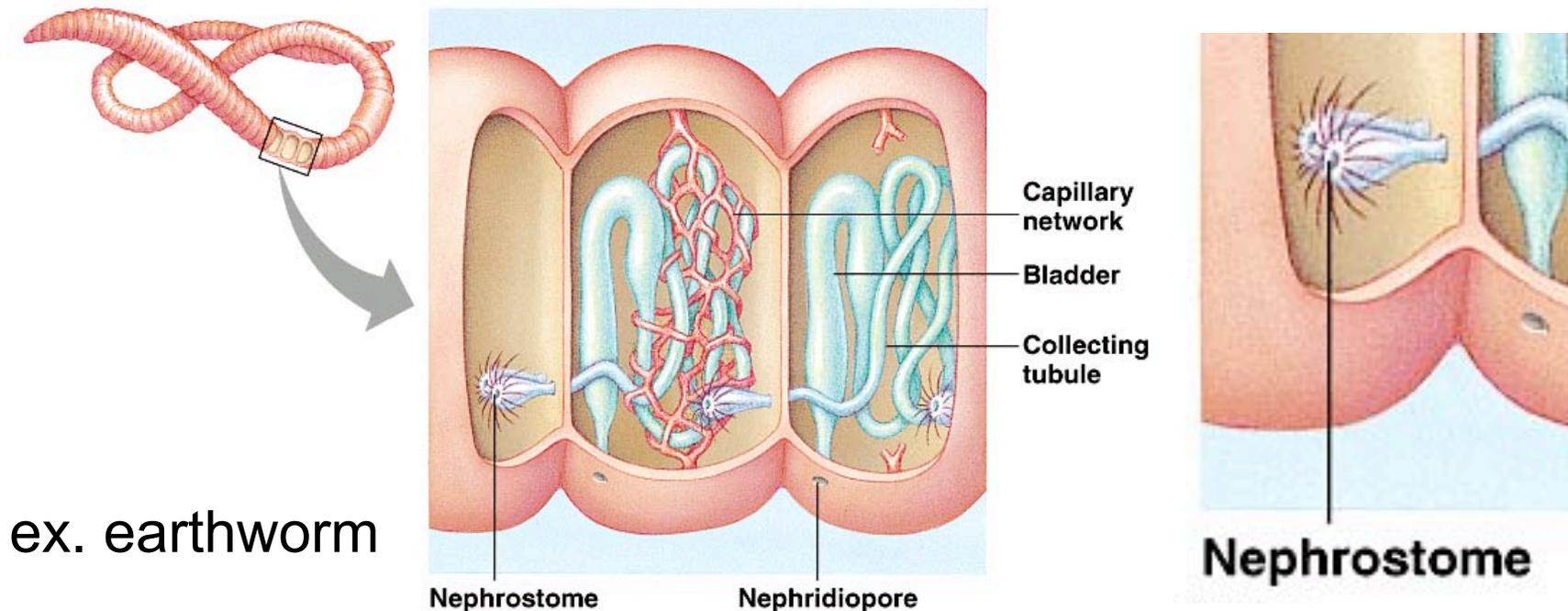


Metanephidia: most annelids

Tubules are immersed in coelomic fluid and surrounded by a network of capillaries (closed circulatory system).

Internal openings collect coelomic fluid.

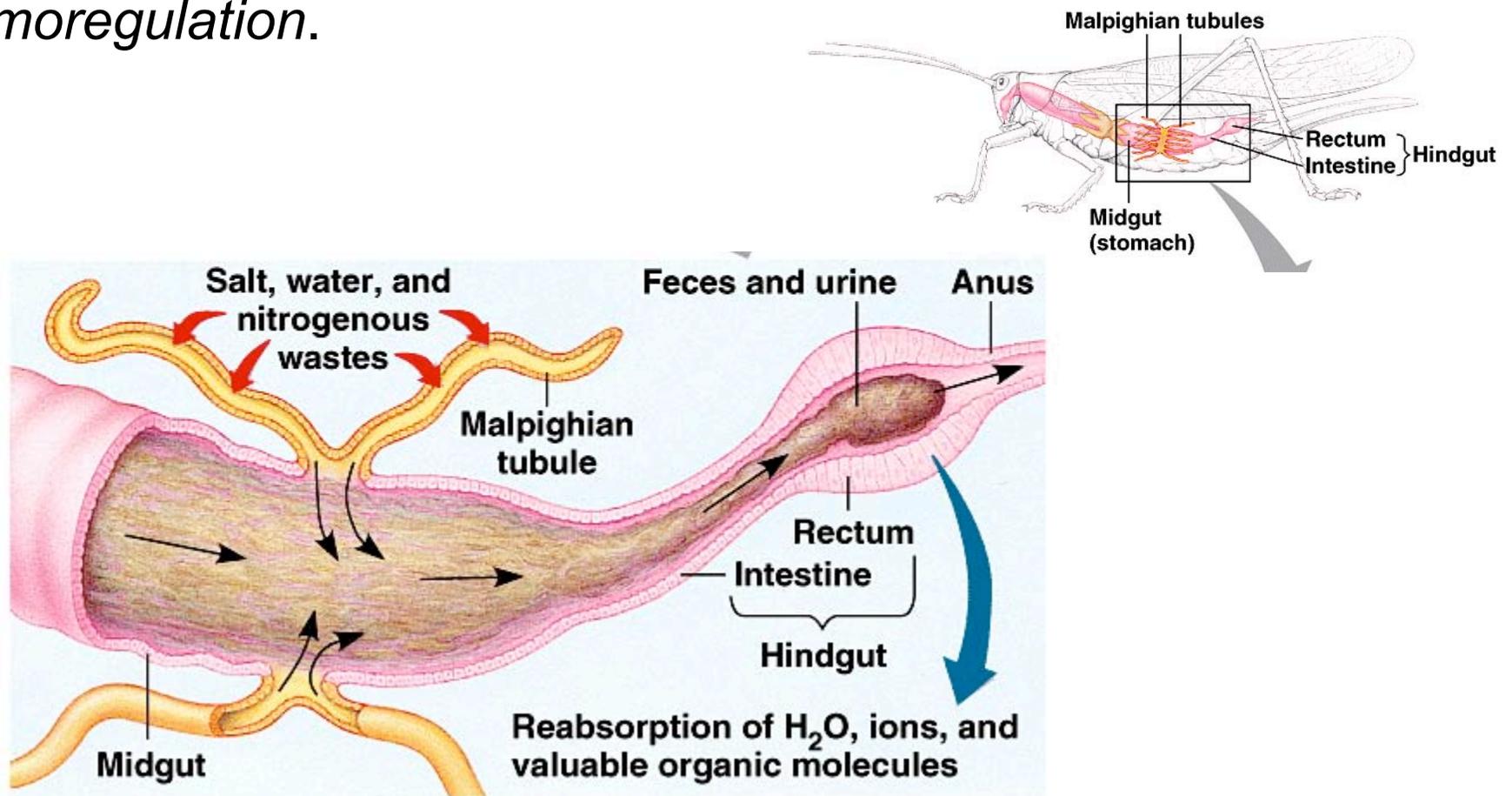
Both excretion of *nitrogenous wastes* and *osmoregulatory* functions.



Malpighian tubules: insects and terrestrial arthropods

Outfoldings of the digestive tract. Bathed directly in hemolymph (open circulation).

Function in both removal of *nitrogenous wastes* and *osmoregulation*.

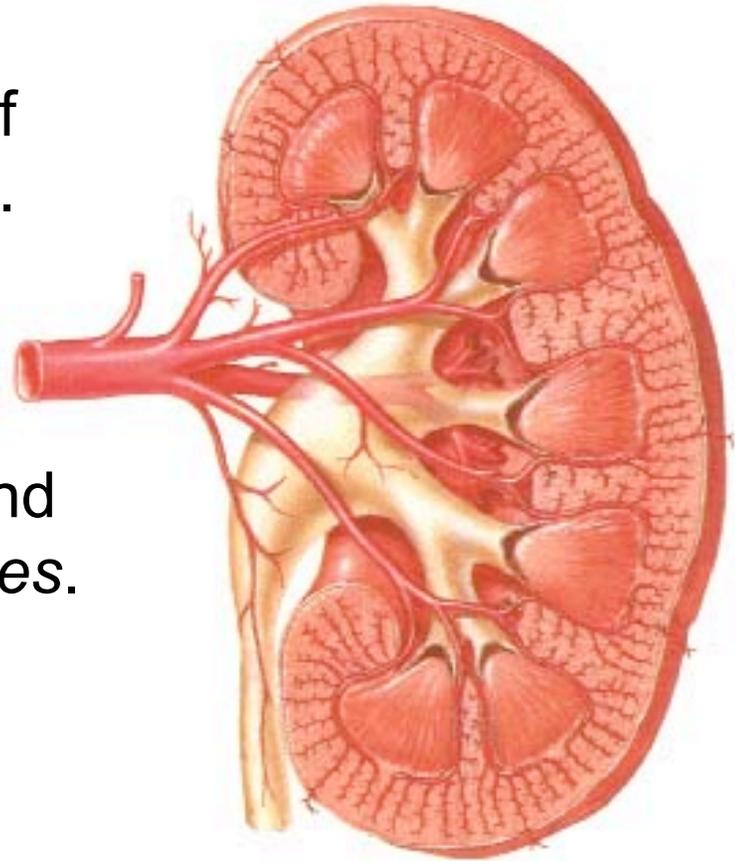


Kidneys: most vertebrates:

Compact organs composed of tubular structures = nephrons.

Dense network of capillaries associated with tubules.

Function in *osmoregulation* and *excretion of nitrogenous wastes*.



Mammalian Excretory System

Regulates:

- Osmolarity

 - Total body water

 - Volume of extracellular fluid

 - Cell volume (osmotic pressure)

- Individual ions

- Acid-base balance

Eliminates:

- Metabolic waste products

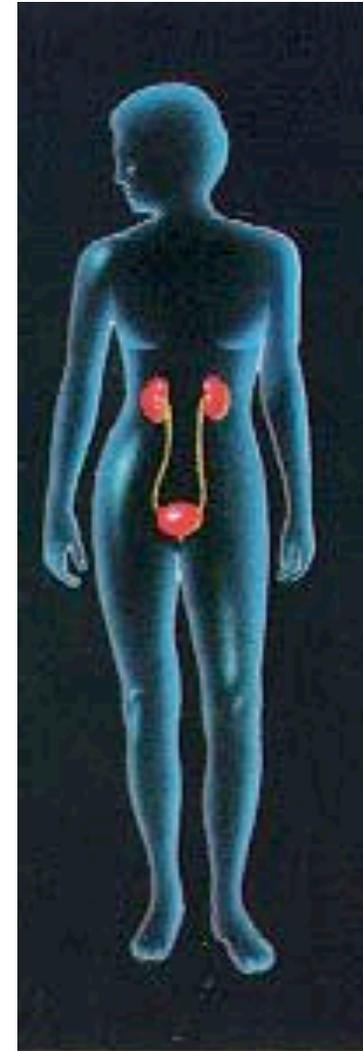
 - Urea

 - Uric acid

 - Creatinin (from muscle)

- Foreign chemicals

 - Drugs, pesticides, food additives, etc.

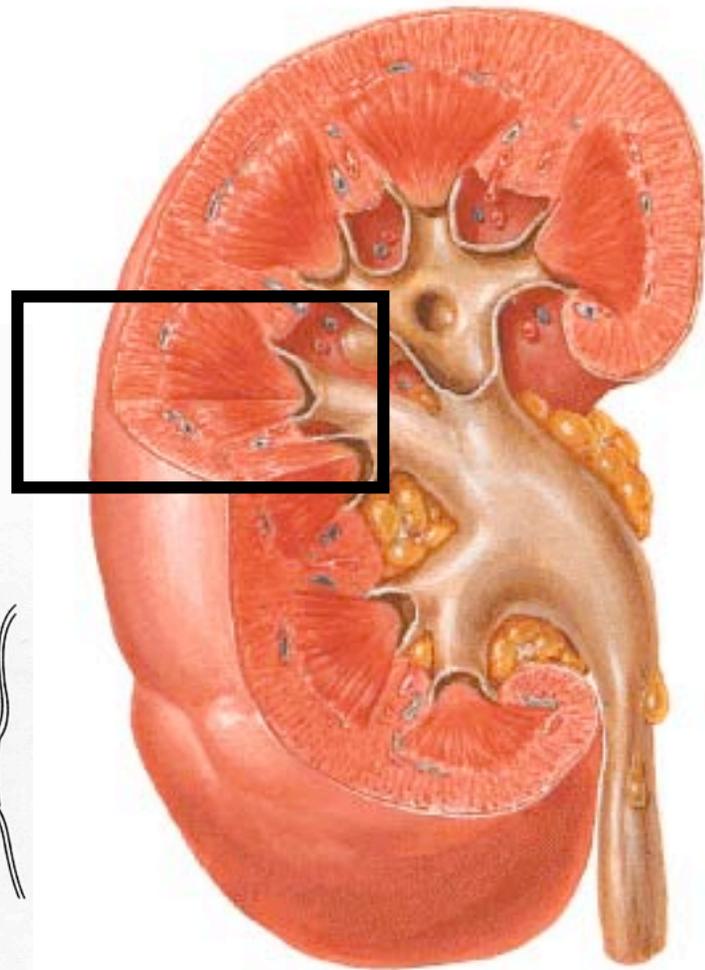
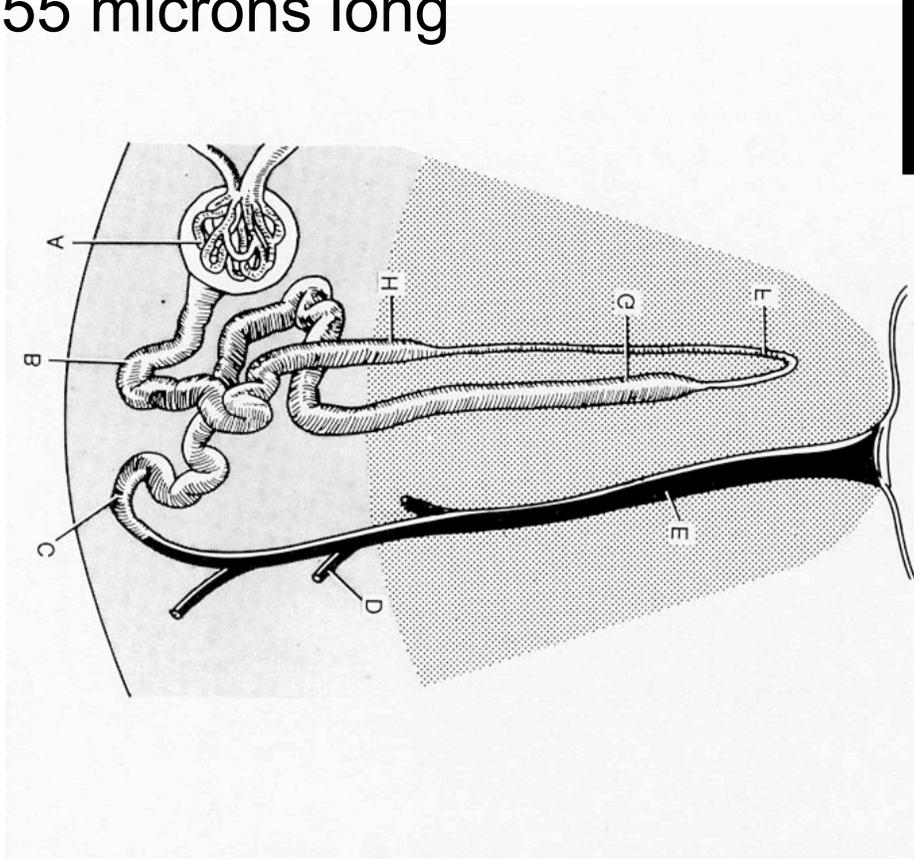


Functional unit =

- 1) Nephron &
- 2) Collecting duct

1 million per kidney

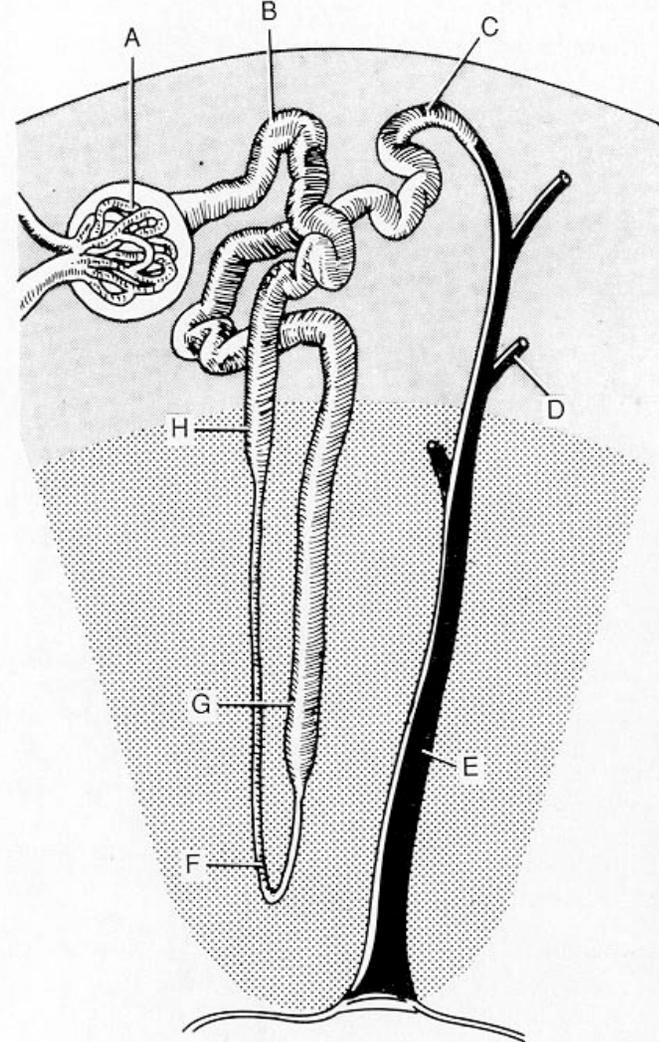
50-55 microns long



Nephron – mainly simple cuboidal epithelium

- 1) a. Glomerulus - tuft of capillaries
b. Bowman's capsule – double walled cup surrounding glomerulus
- 2) Proximal convoluted tubule
- 3) Loop of Henle
- 4) Distal convoluted tubule

Collecting duct– mainly simple cuboidal epithelium



Cortex

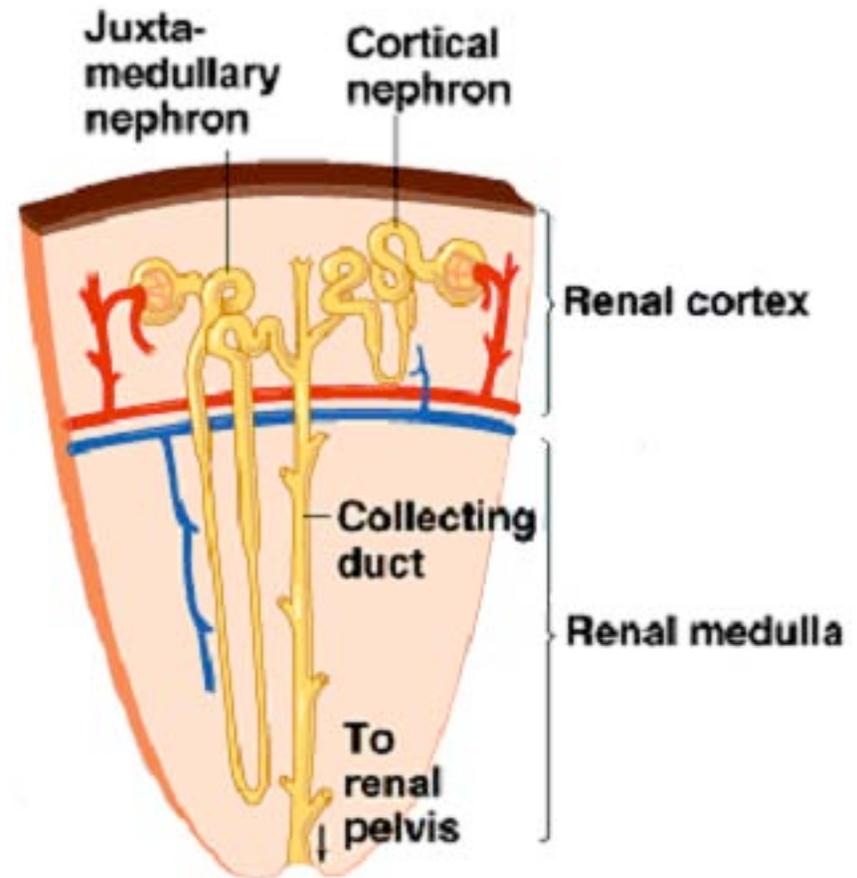
Glomeruli & Bowman's capsules

Convolved tubules

Medulla

Long loops of Henle

Collecting ducts



Only mammals and birds have loops of Henle. They allow production of hypertonic urine to conserve water.

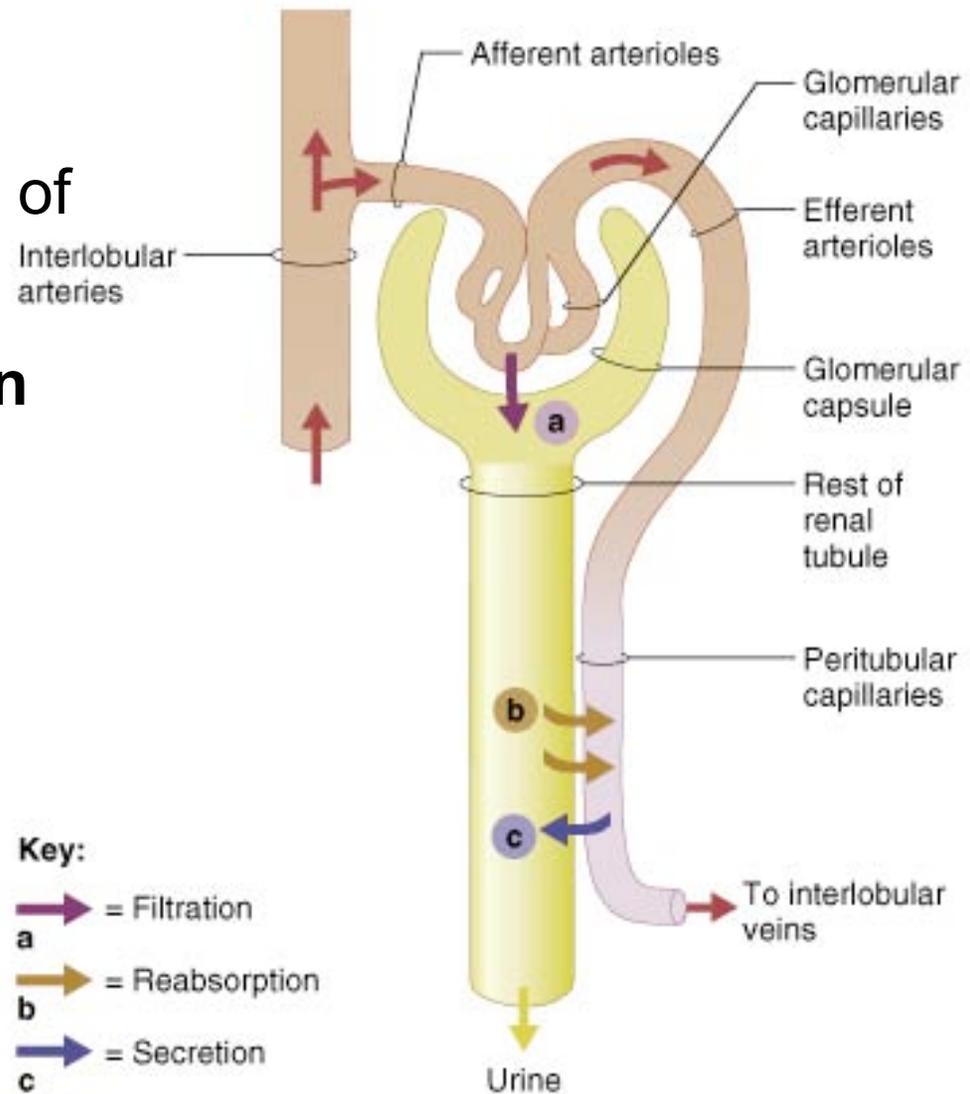
In humans 80% of nephrons are short and located within the cortex. 20% have long loops of Henle that extend into the medulla.

Urine – formed by 3 processes

1) **Glomerular filtration** of blood plasma

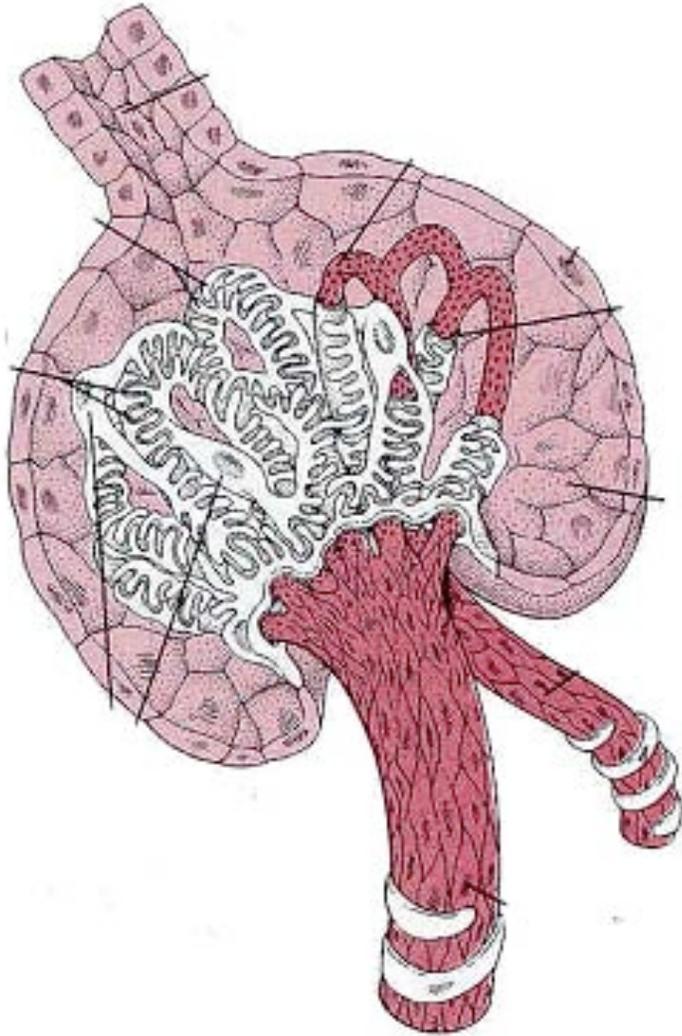
2) **Tubular reabsorption** (filtrate > plasma)

3) **Tubular secretion** (plasma > filtrate)



Glomerular filtration:

Bulk flow of protein free plasma from glomerular capillaries to space of Bowman's capsule.



Bowman's capsule: 2 walls

Inner wall – *podocytes* coat
capillaries

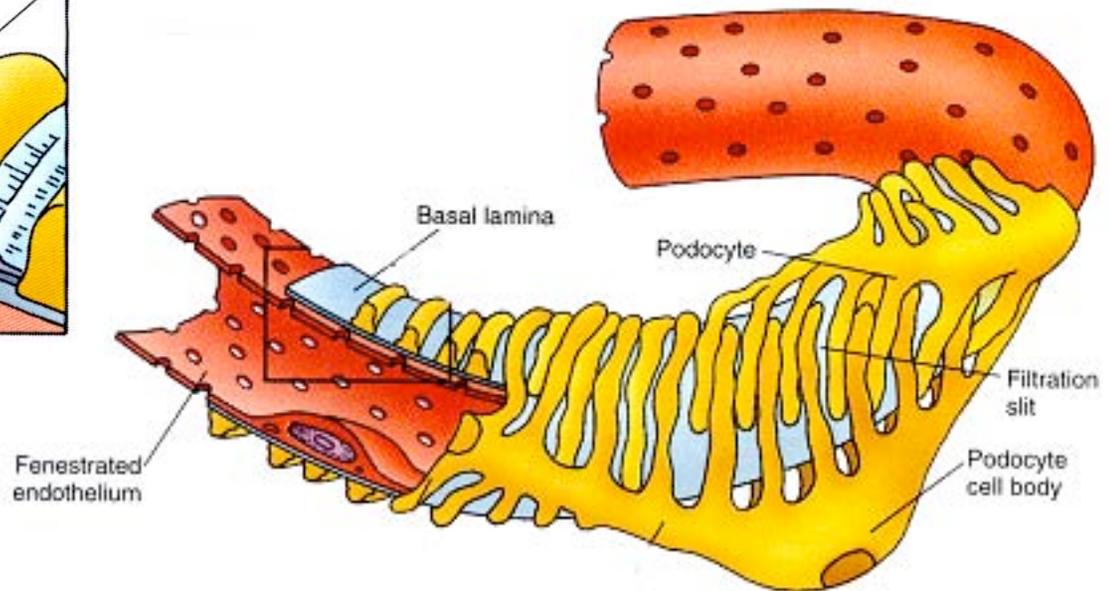
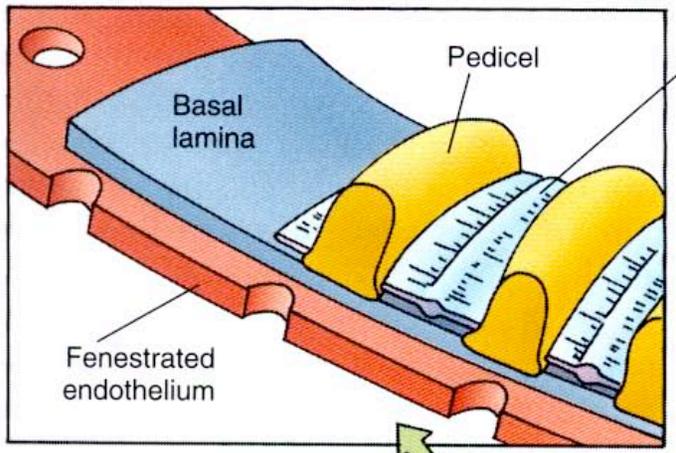
Glomerular capillaries

Tuft of capillaries
surrounded by
Bowman's space

Podocytes

Specialized epithelial cells have branching cytoplasmic processes that completely coat the glomerular capillaries.

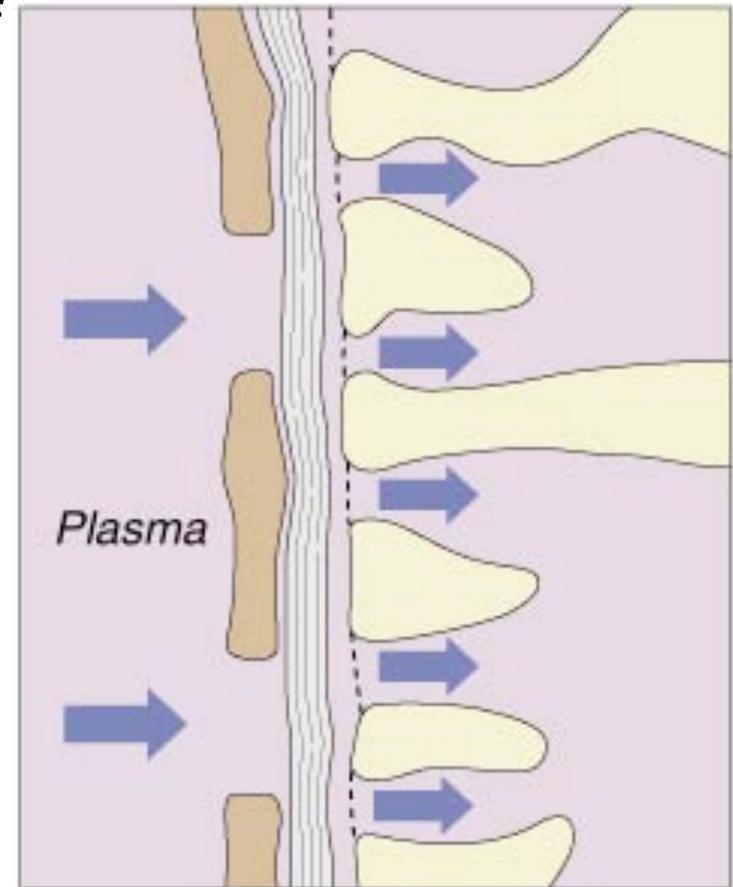
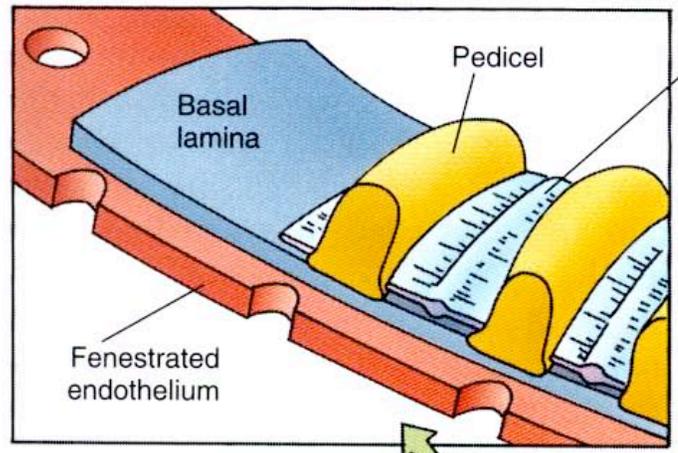
Filtration slits = narrow slits between the pedicels of adjacent processes



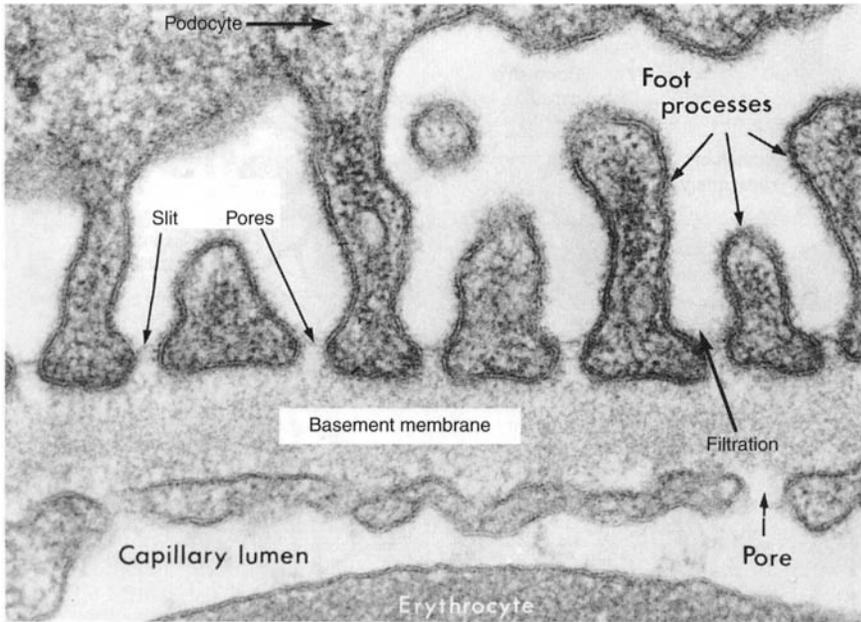
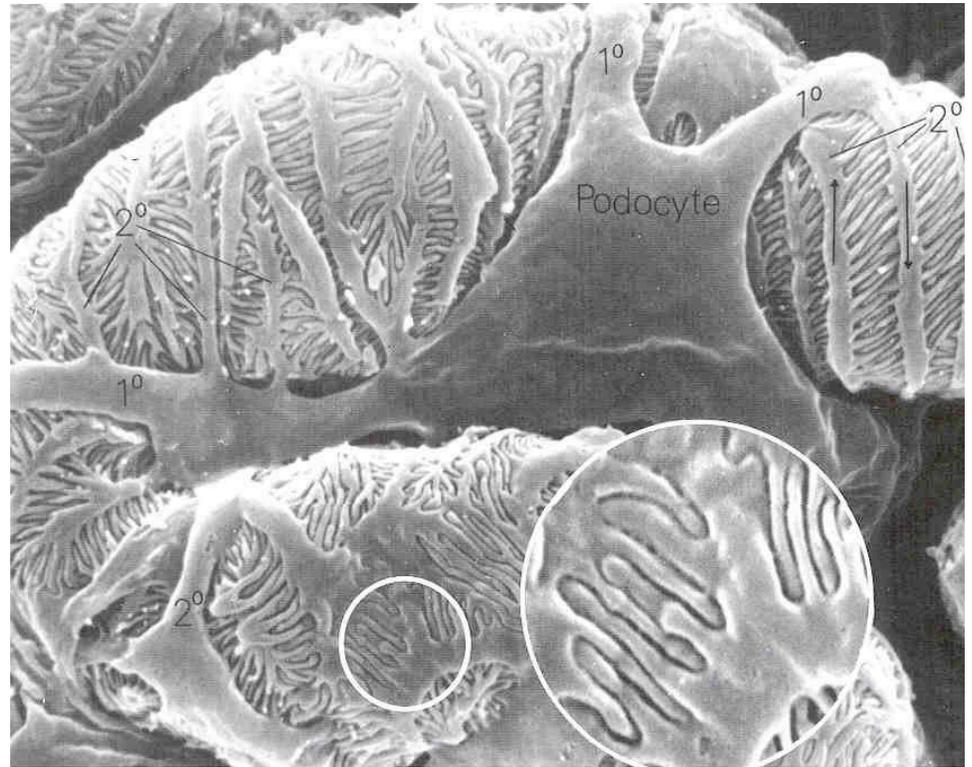
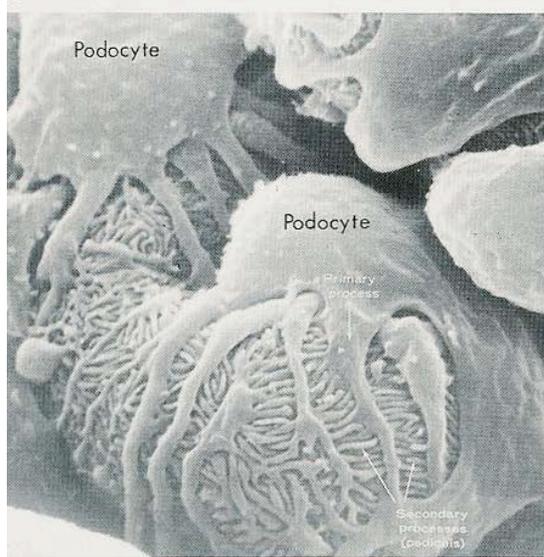
Filtration barrier

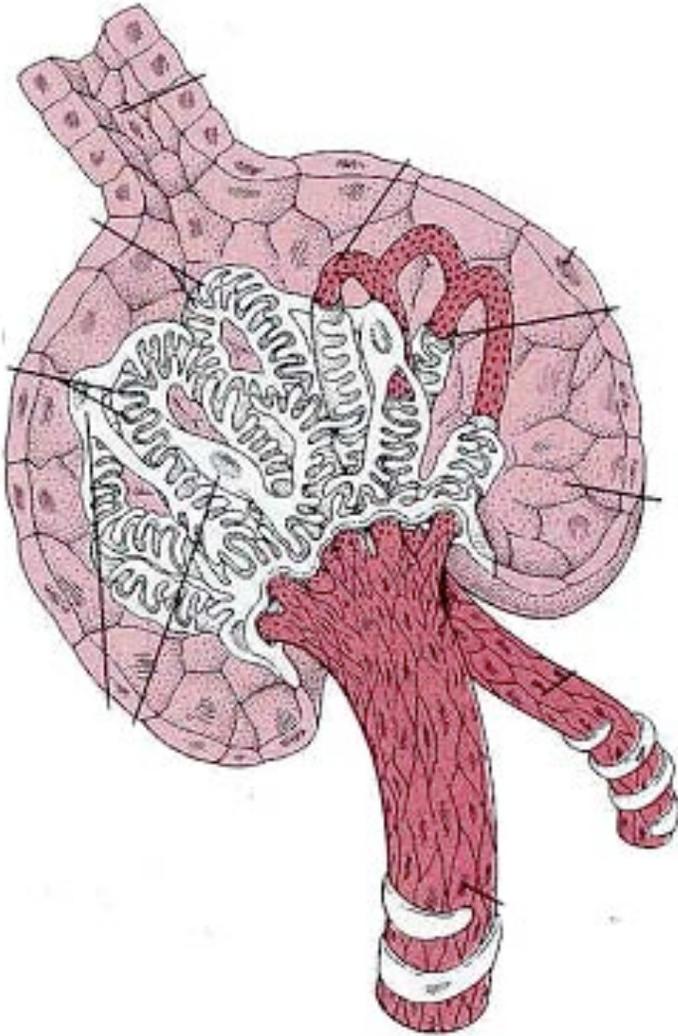
From glomerular capillary to lumen of Bowman's capsule

- 1) Fenestrated capillaries
- 2) Basement membrane
- 3) Filtration slits



Cells, platelets, and large plasma proteins cannot pass.
Filtrate contains salts, glucose, amino acids, vitamins, nitrogenous wastes, other small molecules.





Afferent arteriole

Short and wide with high
blood pressure

Favors filtration

180 liters/day filtered

20 to 25% of cardiac output
to kidneys = 1,100 to 2,000
liter/day

3 liter plasma volume is
filtered 60 times a day

Tubular transport:

Peritubular capillary network

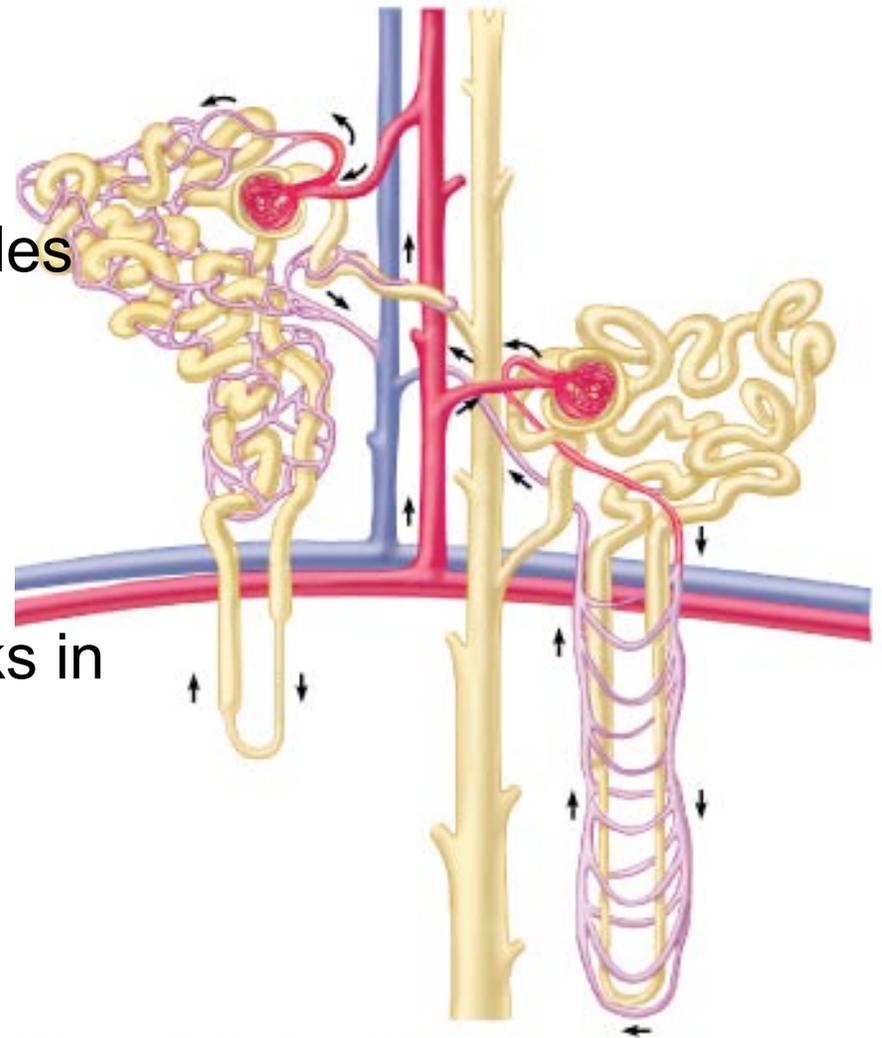
Supplies the convoluted tubules
in the cortex

Drain from efferent arterioles

Vasae rectae

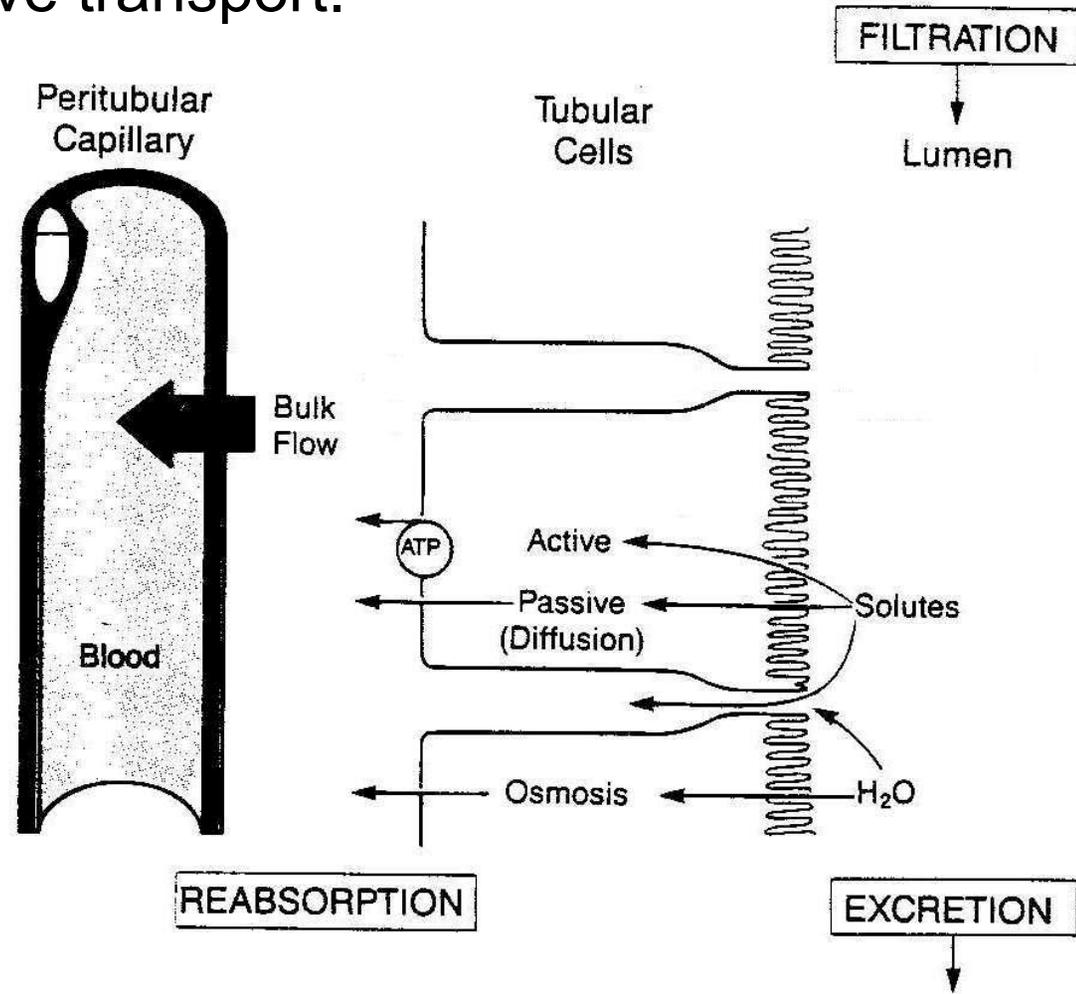
Fenestrated capillary networks in
the medulla

Drain from efferent arterioles



Tubular reabsorption:

Movement from filtrate to plasma via passive or active transport.

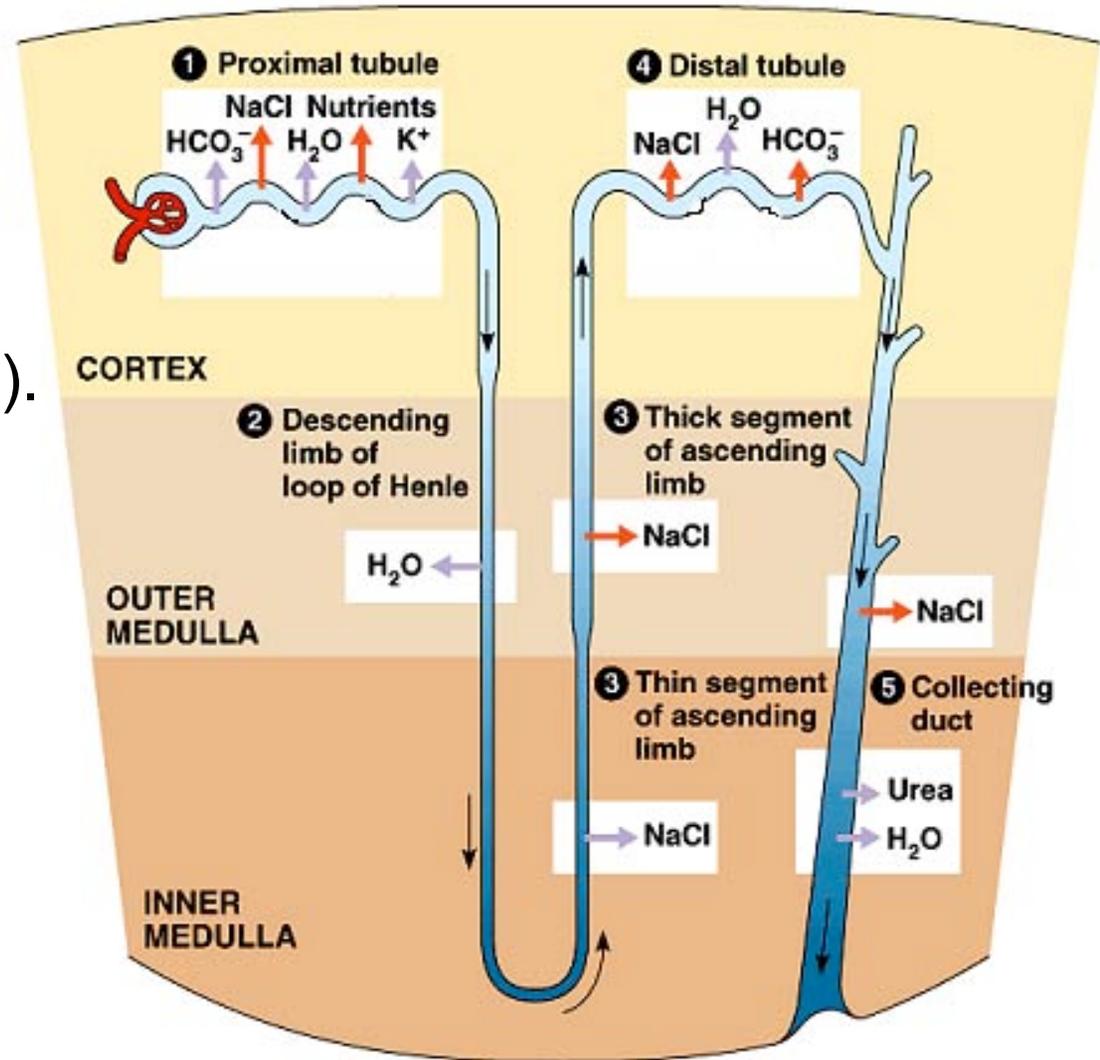


Tubular reabsorption:

Regulated or not regulated.

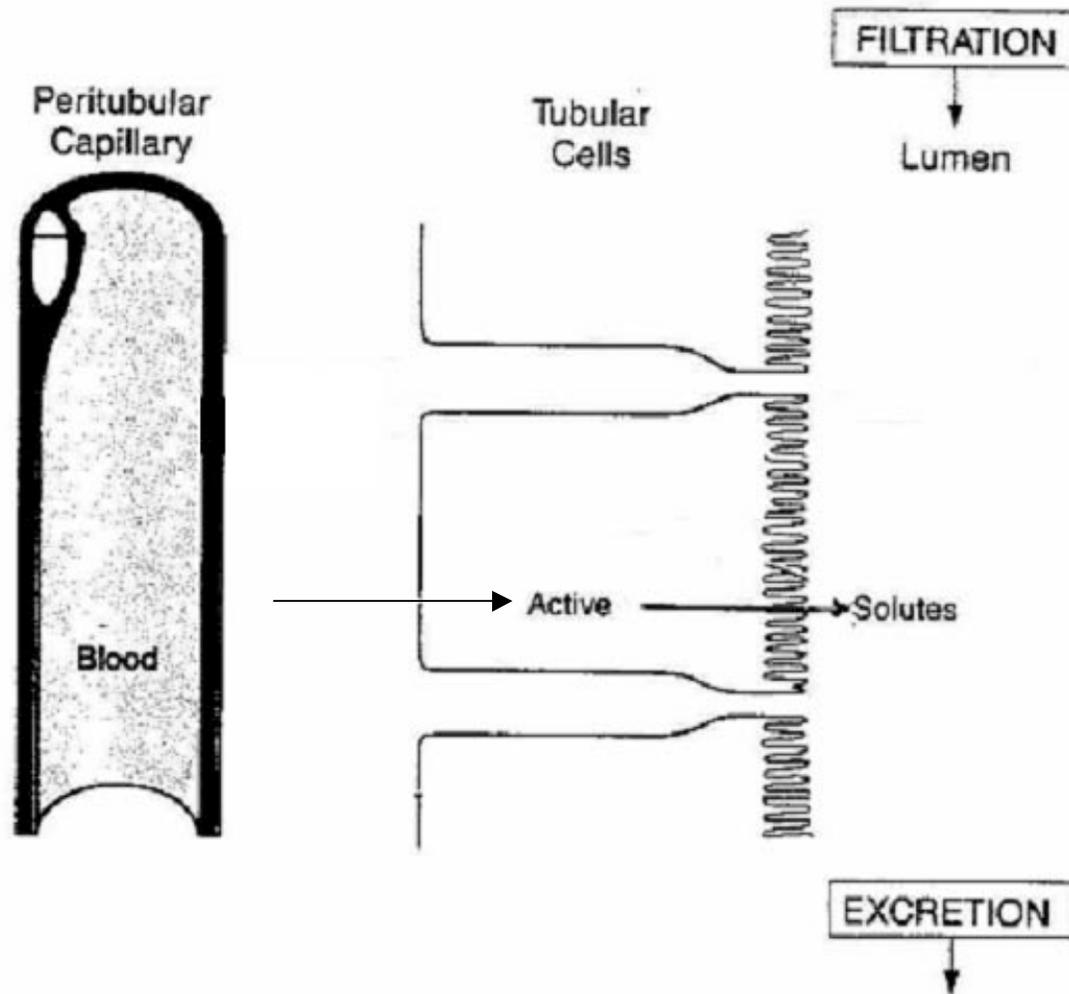
Most reabsorption in proximal convoluted tubule (80% of volume).

Most regulation in distal convoluted tubule.



Tubular secretion:

Movement from plasma to filtrate to via active transport.

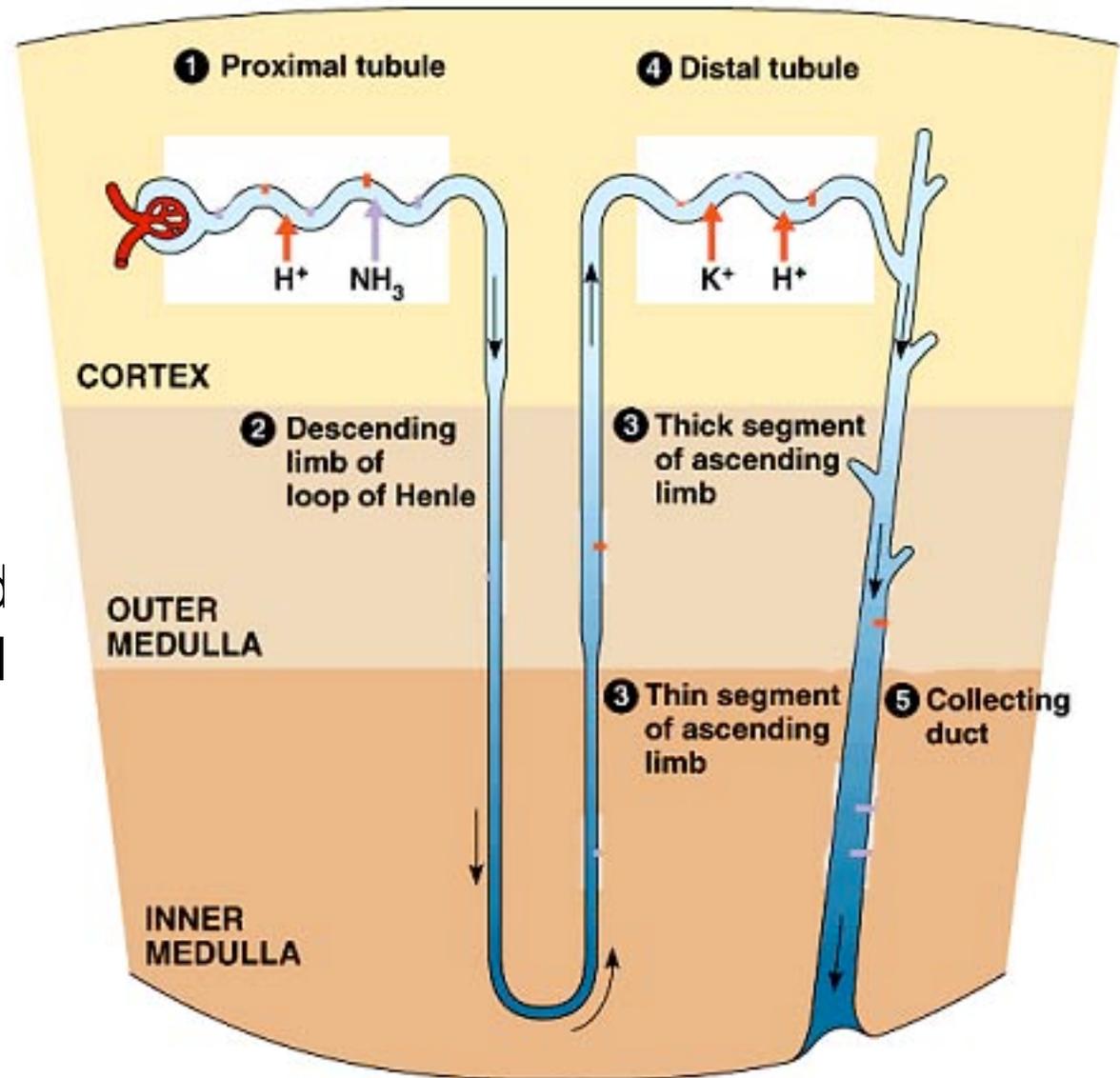


Tubular secretion:

Regulated or not regulated.

Secretion of waste products in proximal convoluted tubule.

Regulation of K^+ and H^+ secretion in distal convoluted tubule.

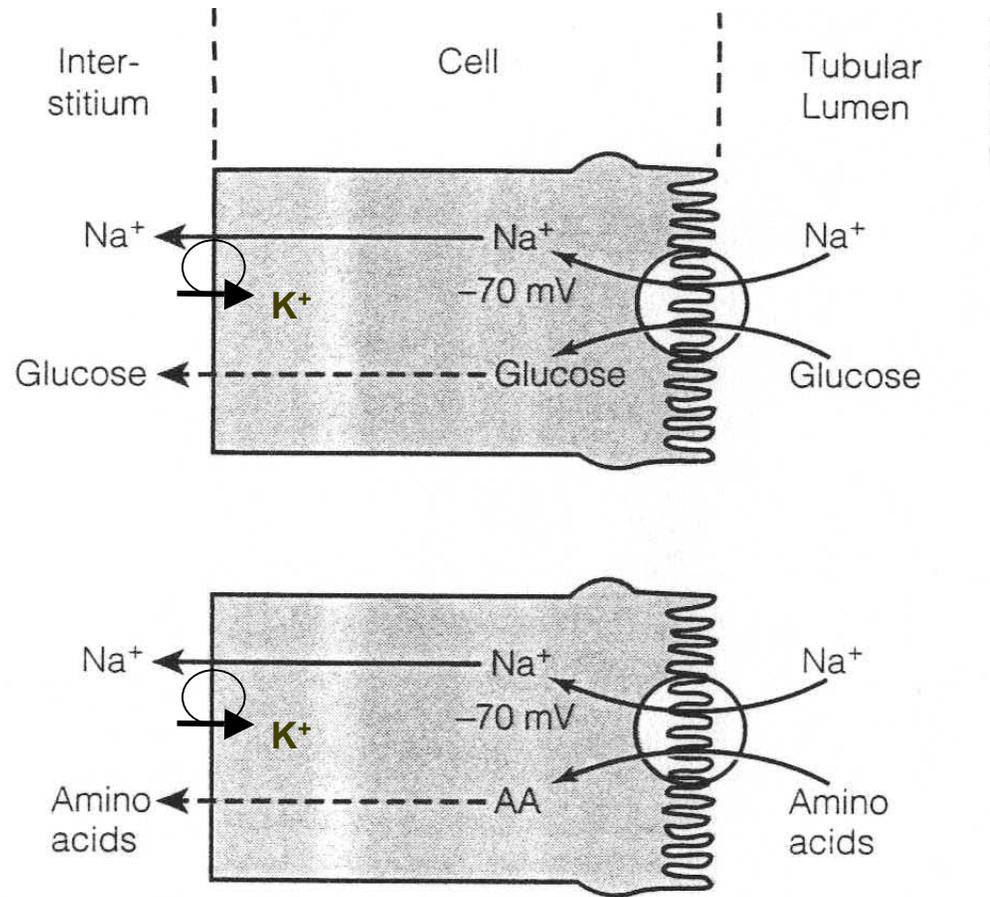


Reabsorption of Sodium, Glucose and Amino Acids by Active Transport in the Proximal Tubule

70% of Na^+

100% of glucose
and amino acids

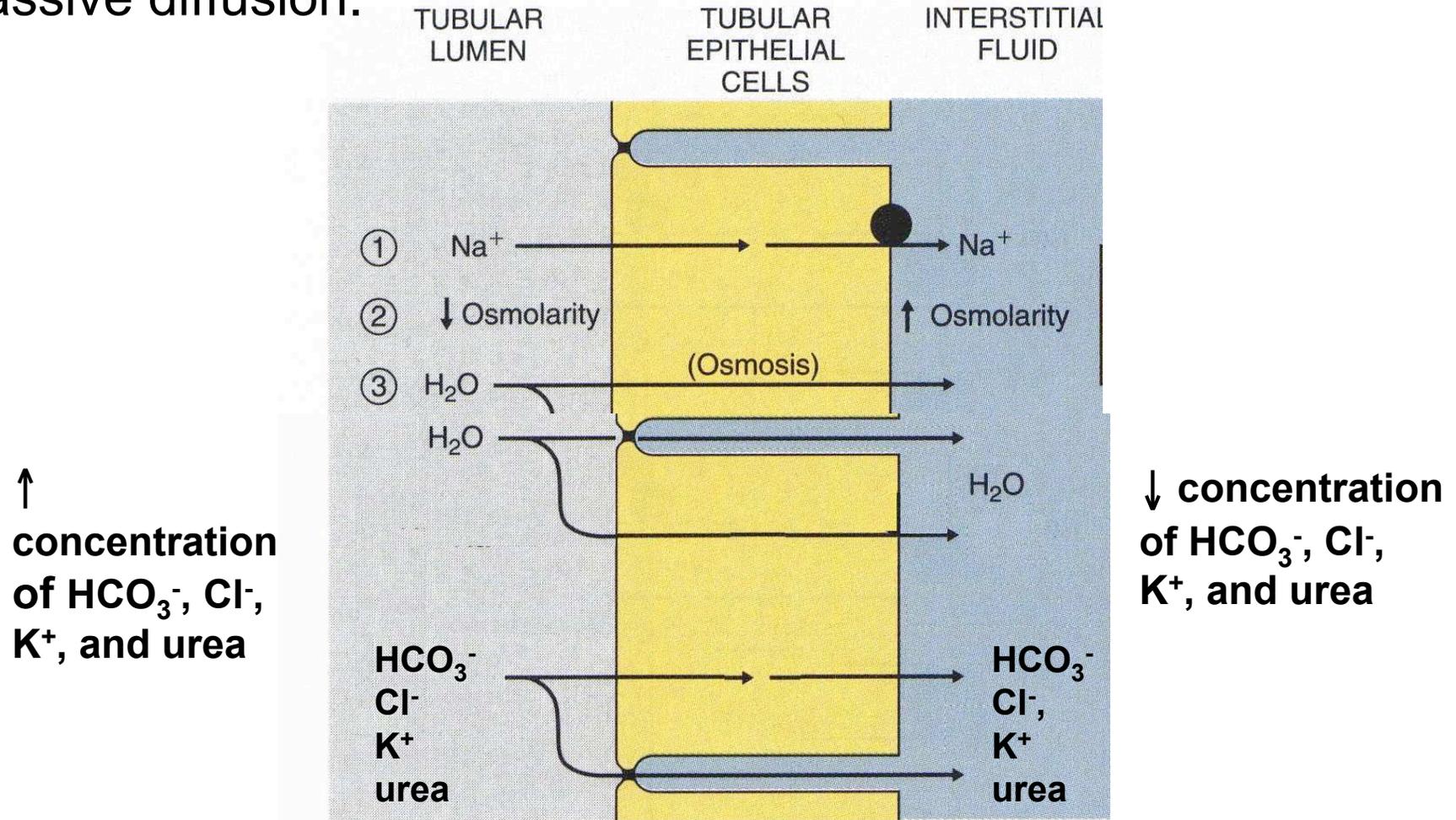
Considerable
amount of energy
used in transport.



facilitated diffusion

secondary active transport
co-transport

Water, HCO_3^- , Cl^- , K^+ , and urea are all reabsorbed by passive diffusion.



Water is always reabsorbed by osmosis.

80% volume reabsorbed in PCT, over 99% reabsorbed total.

Formation of concentrated urine

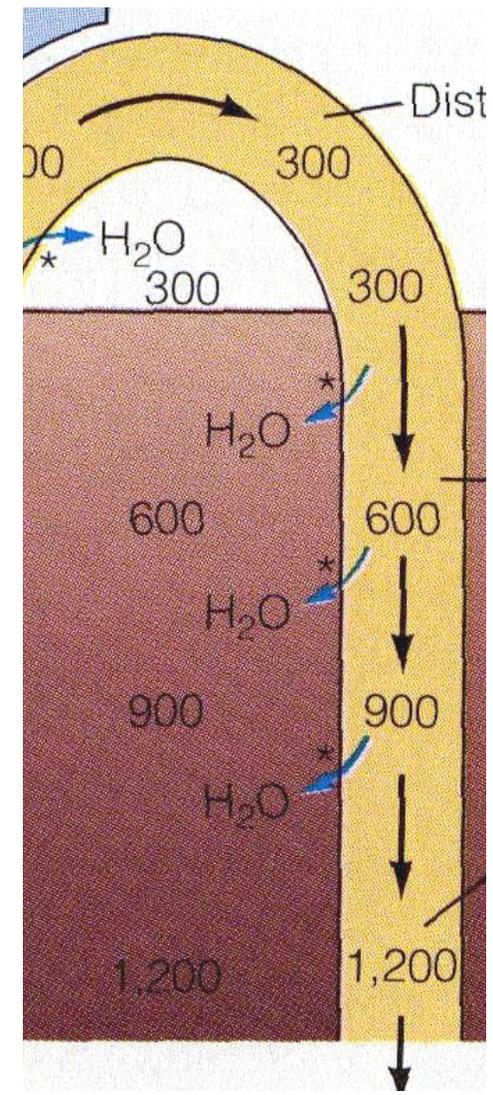
Decreased volume of filtrate via increased water reabsorption.

Increased osmolarity to a maximum concentration of 1200 to 1400 mOsm/liter

The basic requirements

- (1) permeability of CD to water:
hormonally regulated
- (2) a high osmolarity in the renal medullary interstitium

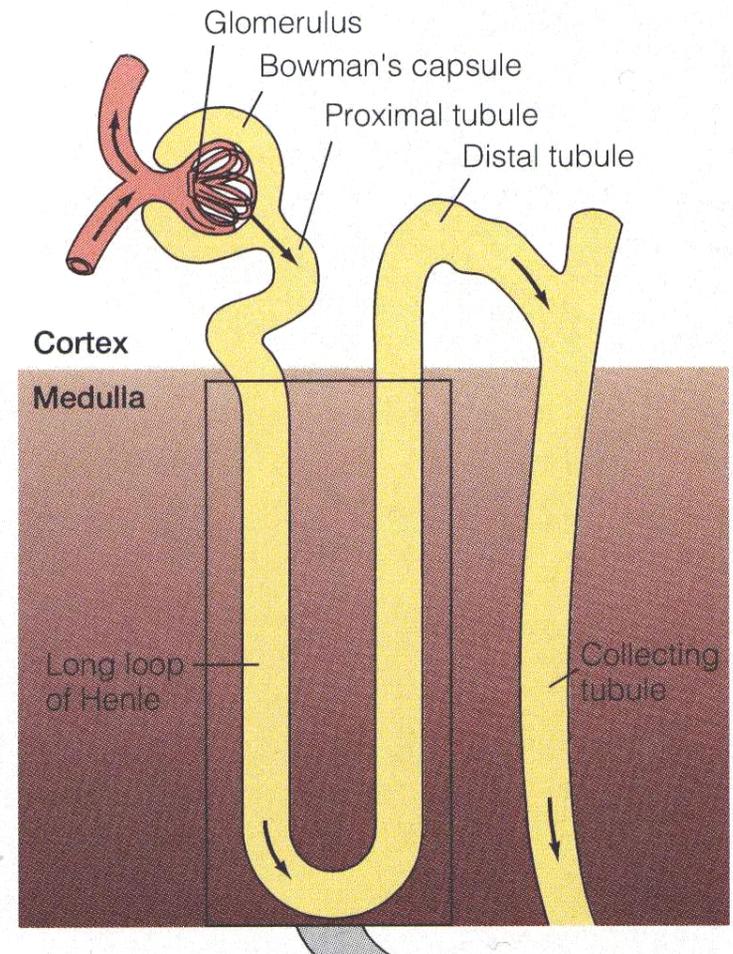
As filtrate passes through the CD, water is reabsorbed by osmosis.



Hyperosmotic interstitium:

Osmolarity of interstitial fluid in the medulla of the kidneys increases progressively

1. The urea cycle
2. The counter current multiplier
3. The counter current exchanger

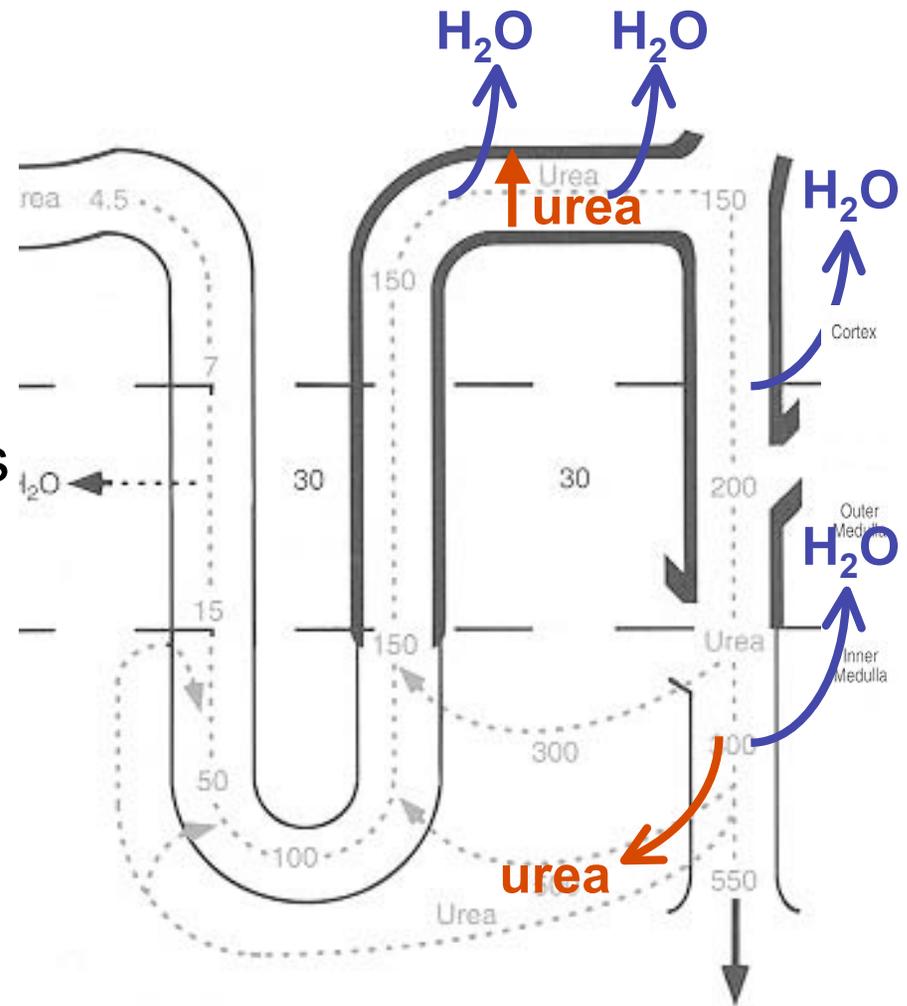


Urea cycle

Ascending loop of Henle, Distal tubule, Cortical collecting duct:
Not permeable to urea.

Distal tubule, Collecting duct:
Water reabsorption increases
filtrate urea concentration.

Inner medullary collecting ducts:
Permeable to urea.
Urea diffuses into the
interstitium, helping create a
hyperosmotic interstitium.

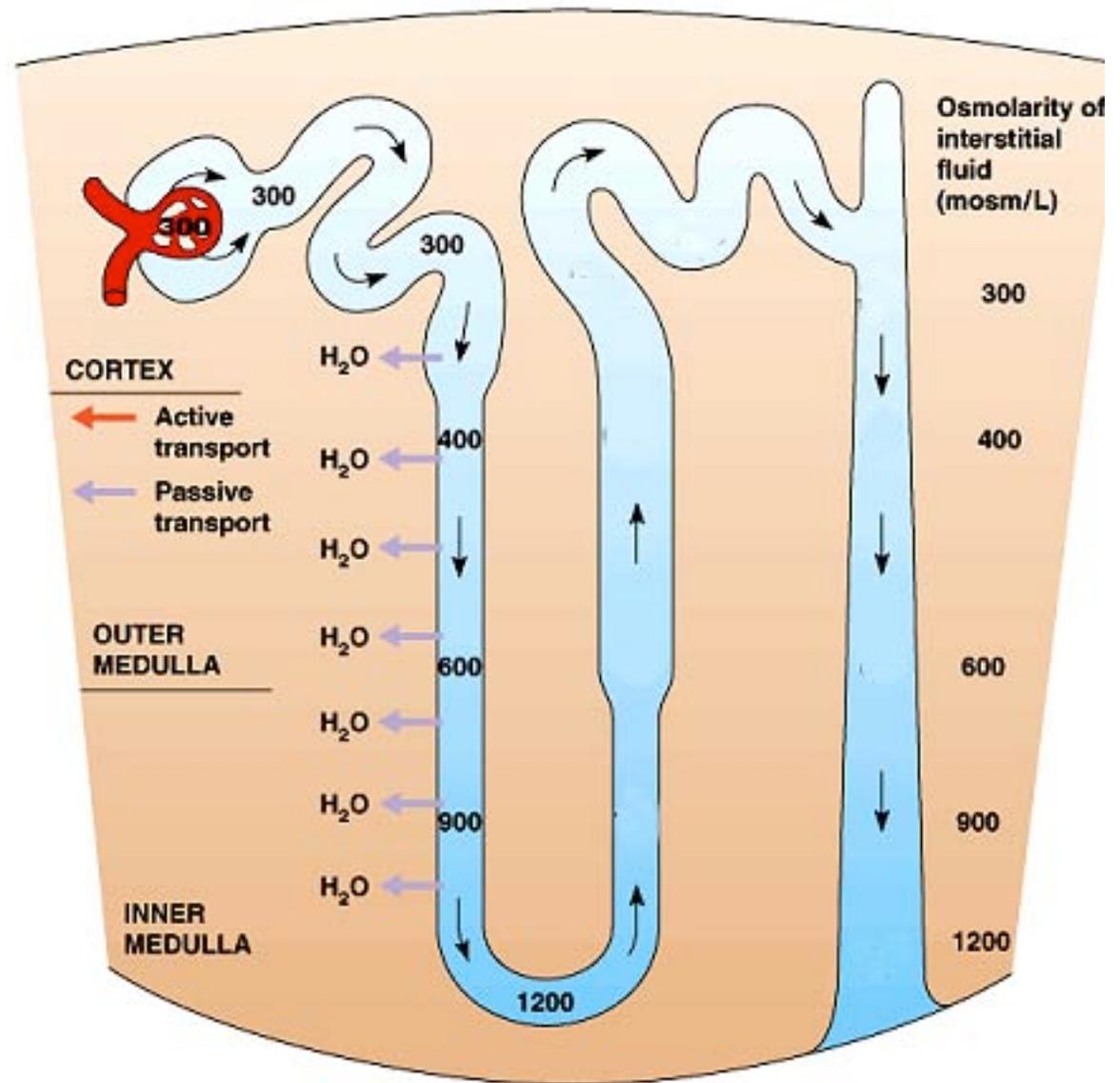


The counter current multiplier:

The descending limb of the loop of Henle is permeable to water, but not solute.

Water is reabsorbed by osmosis to the hyperosmotic interstitium.

The filtrate becomes progressively hyperosmotic.



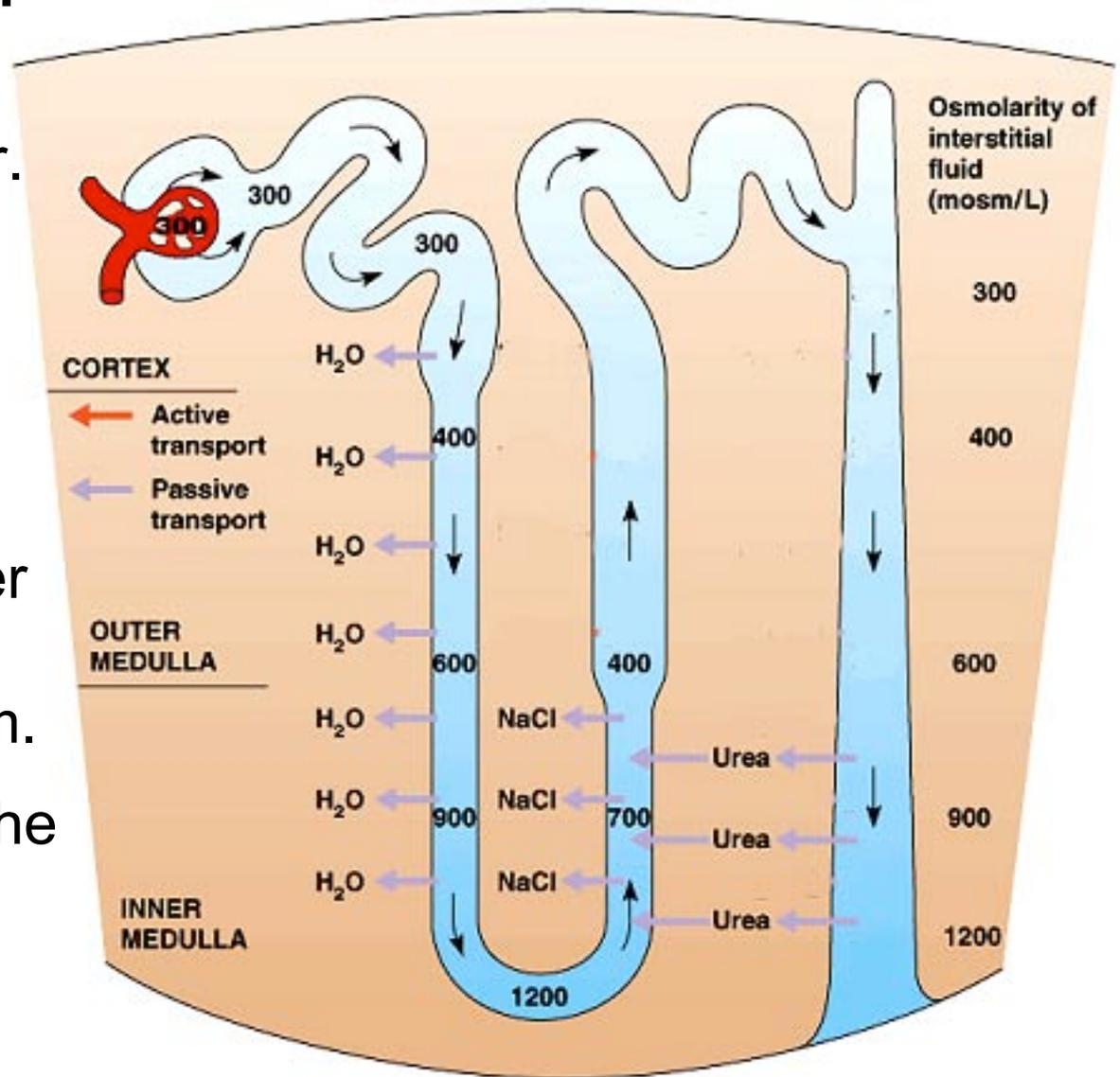
The ascending limb of the loop of Henle:

Not permeable to water.

Medullary region is permeable to salt and urea.

NaCl is reabsorbed by diffusion from the higher concentration in the filtrate to the interstitium.

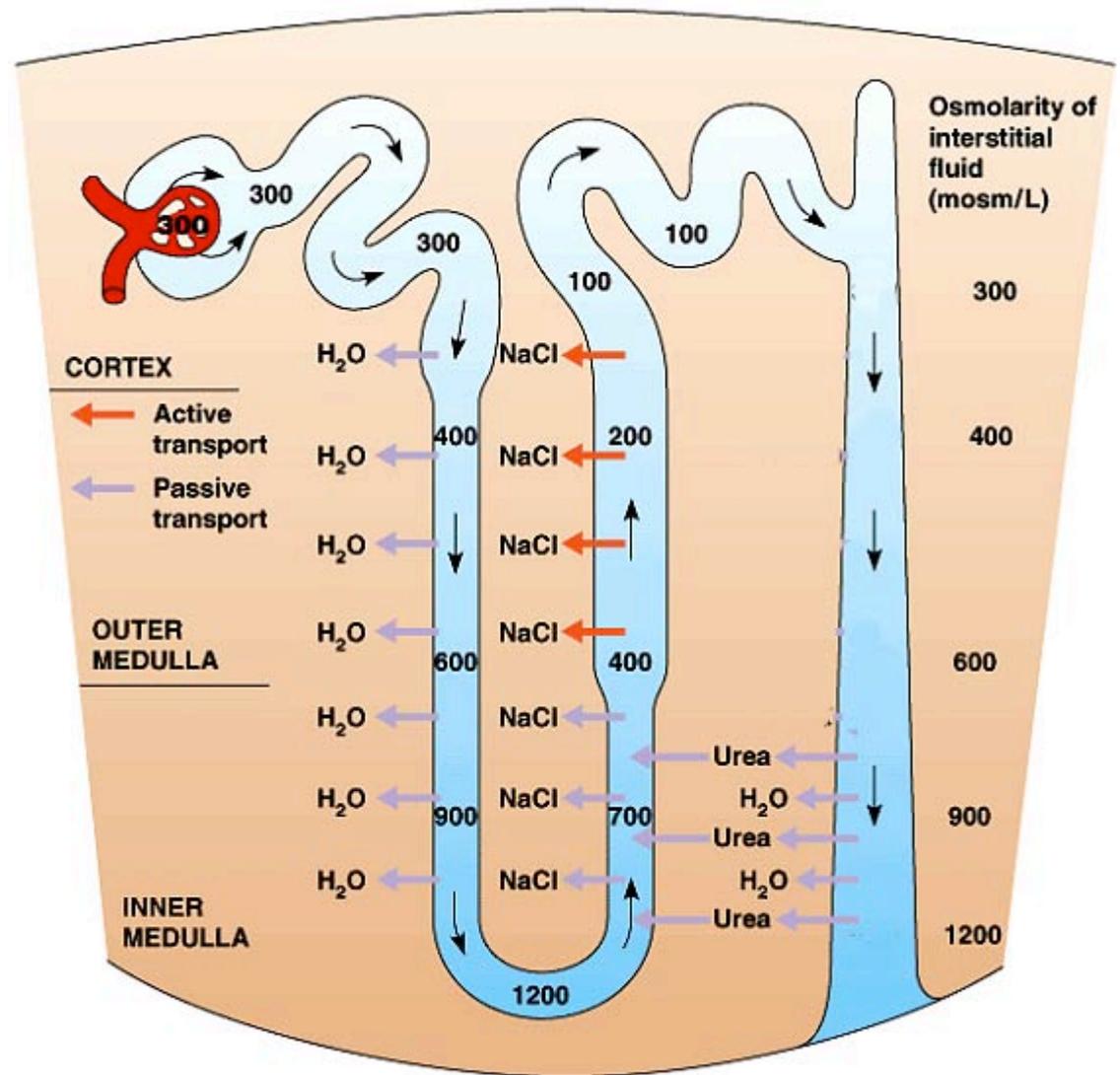
Urea is secreted from the higher concentration in the interstitium to the filtrate.



The ascending limb of the loop of Henle:

Cortical region is not permeable to water, salt or urea.

NaCl is reabsorbed by active transport, increasing the osmolarity of the interstitium and decreasing the osmolarity of the filtrate.

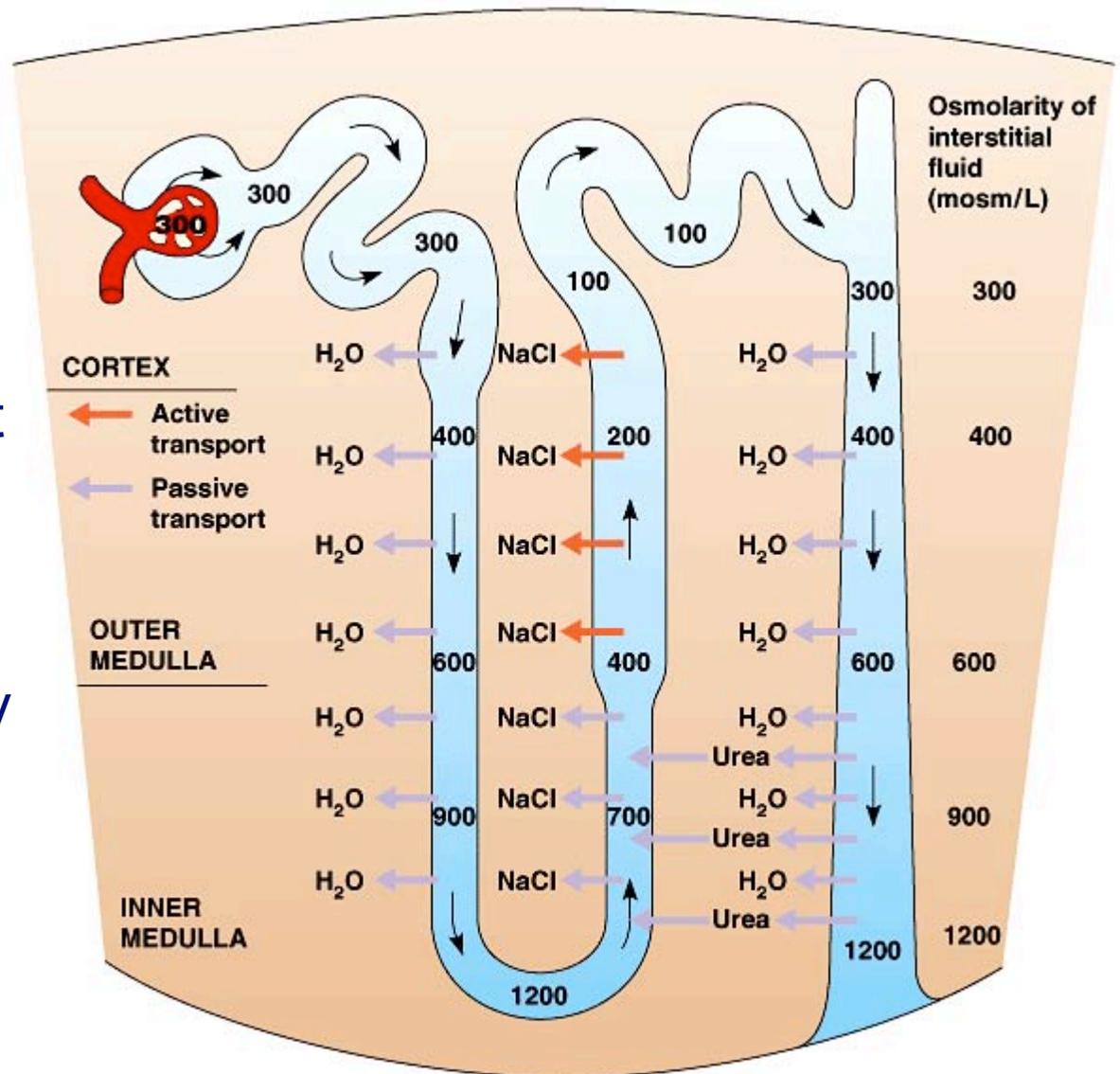


Medullary collecting duct:

Water permeability is dependent on ADH.

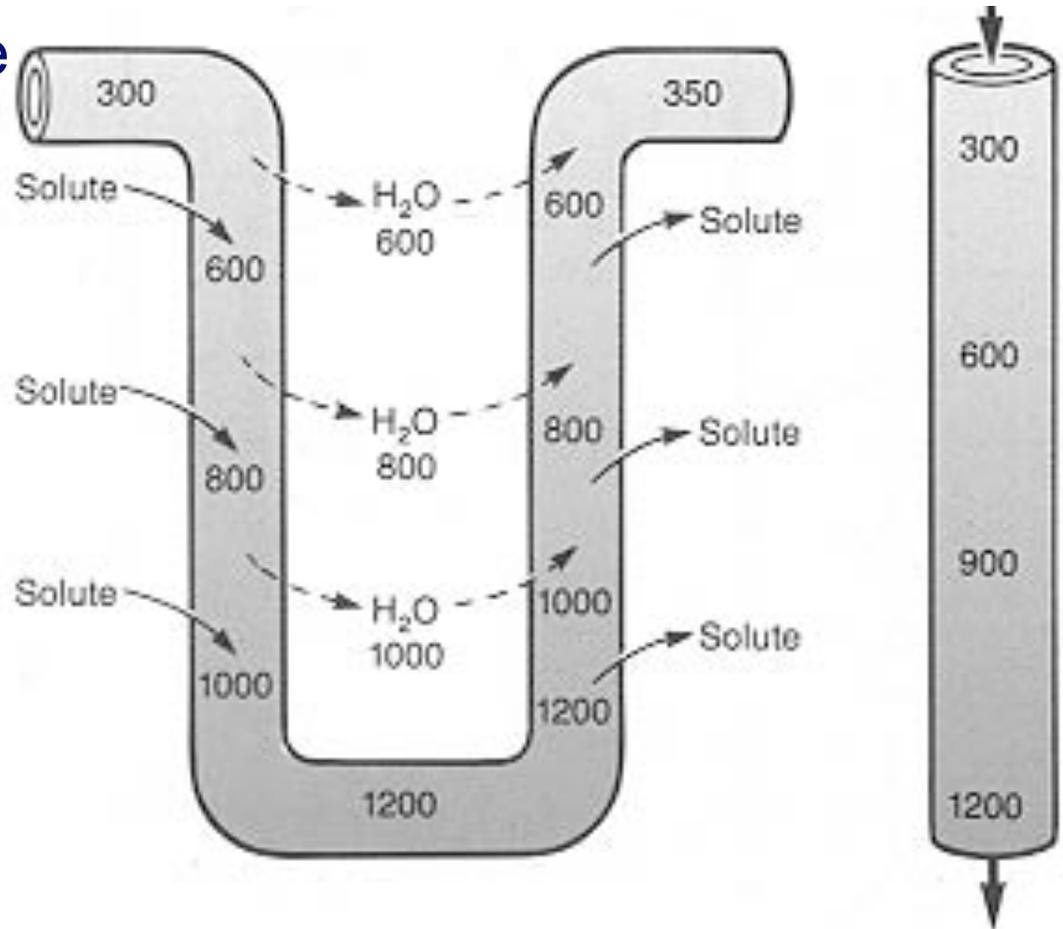
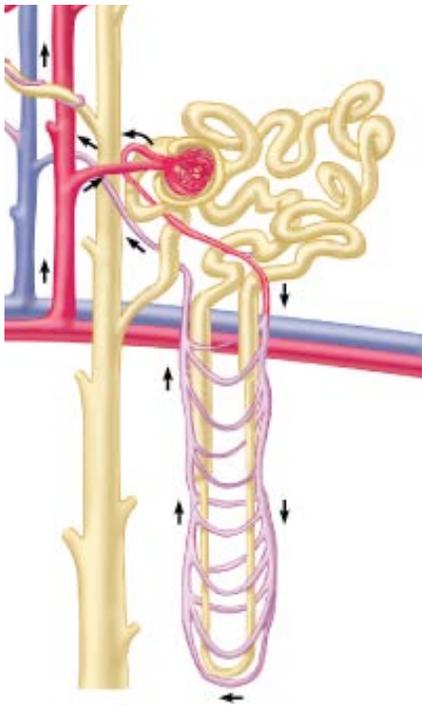
When permeability is high, water diffuses out of the collecting ducts until the tubular fluid osmolarity is the same as that of the medullary interstitium.

High ADH, filtrate at end of the collecting ducts about 1200 to 1400 mOsm/liter.



Counter current exchanger

Vasa recta serve as counter current exchangers to minimize the washout of solutes from the medullary interstitium.



Regulation of blood volume and blood pressure:

Must increase reabsorption of *both water and salt* to increase blood volume and blood pressure (maintain iso-osmotic).

Regulate Na^+ reabsorption, and water follows by osmosis.

Hormonal regulation of Na^+ reabsorption:

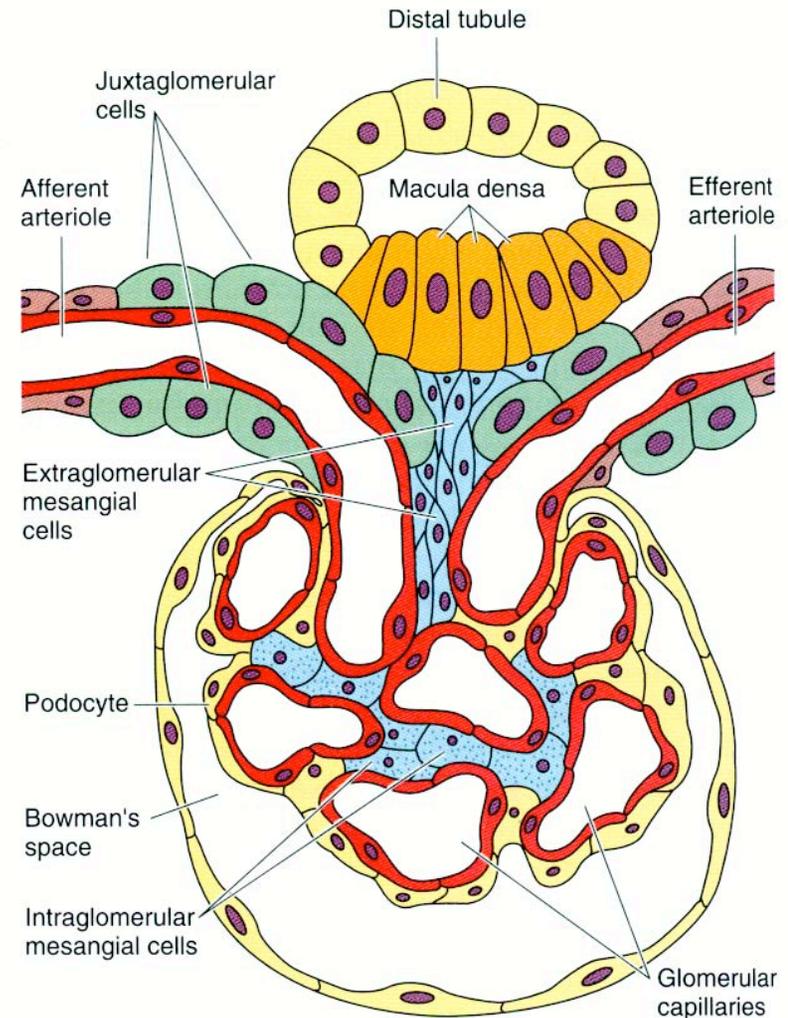
70% in PCT – regulated by angiotensin II

20% in loop of Henle – not regulated

10% in DCT and CD – regulated by aldosterone and ANF

Angiotensin II and aldosterone increase Na⁺ and water reabsorption.

1. A decrease in blood pressure (or in Na⁺ concentration) causes JG cells to secrete the enzyme **renin**.
2. Renin promotes the conversion of an inactive plasma protein (angiotensinogen) to active **angiotensin II**.
3. Angiotensin II stimulates secretion of **aldosterone** from the adrenal glands.



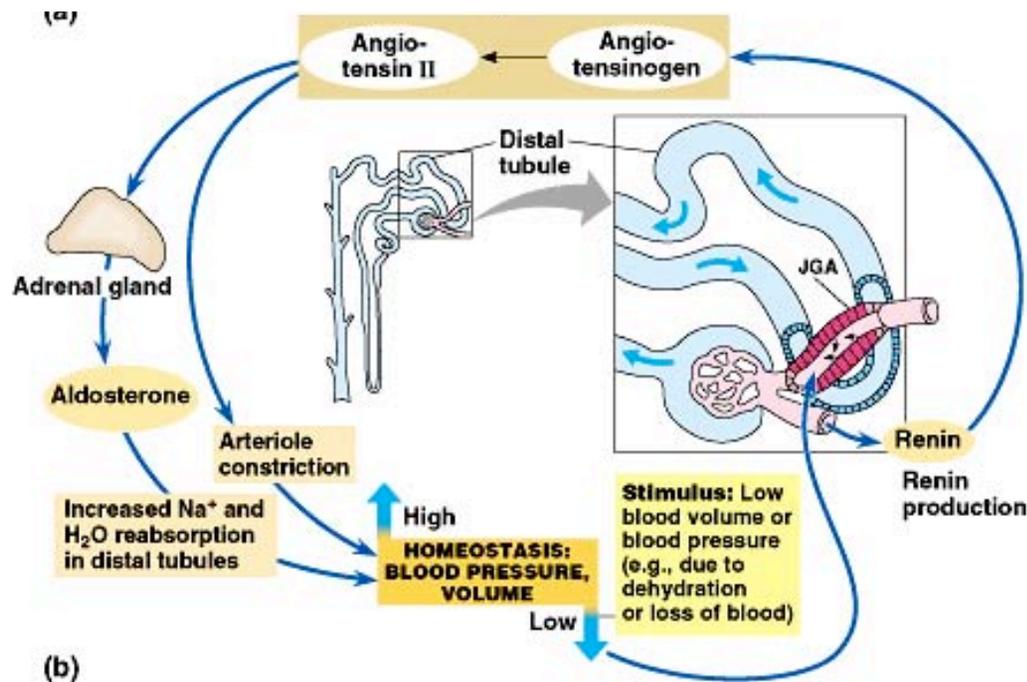
1. Angiotensin II:

Increases Na^+ and water reabsorption.

Causes vasoconstriction to increase blood pressure.

2. Aldosterone:

Increases Na^+ and water reabsorption.



Regulation of body fluid osmolarity:

Must increase reabsorption of *water without salt* to decrease body fluid osmolarity.

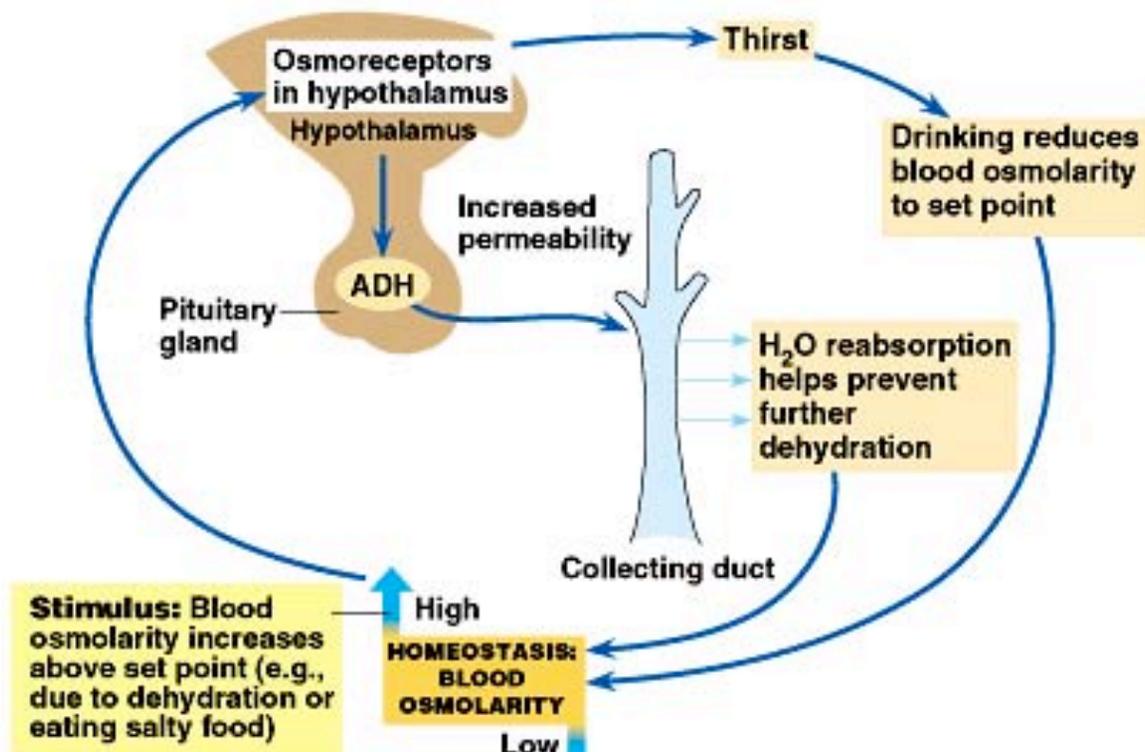
Hormonal regulation by antidiuretic hormone (ADH).

Water reabsorption:

In PCT and loop of Henle – unregulated, follows Na^+ , does **not** change osmolarity

20% in DCT and collecting ducts – regulated, reabsorbed *without* Na^+ , **does** change osmolarity

1. Increased ECF osmolarity activates osmoreceptor cells in the hypothalamus.
2. Increased secretion of ADH from the pituitary.
3. Increasing water permeability in the DCT and CD.
4. Increased reabsorption of water without salt.
5. Decreased osmolarity.



Adaptation of Vertebrate Kidneys:

Length of loop of Henle related to need for water conservation – longer loops, greater ability to conserve water.

