Excretory System

Metabolic Waste
Mammalian System
Anatomy & Physiology

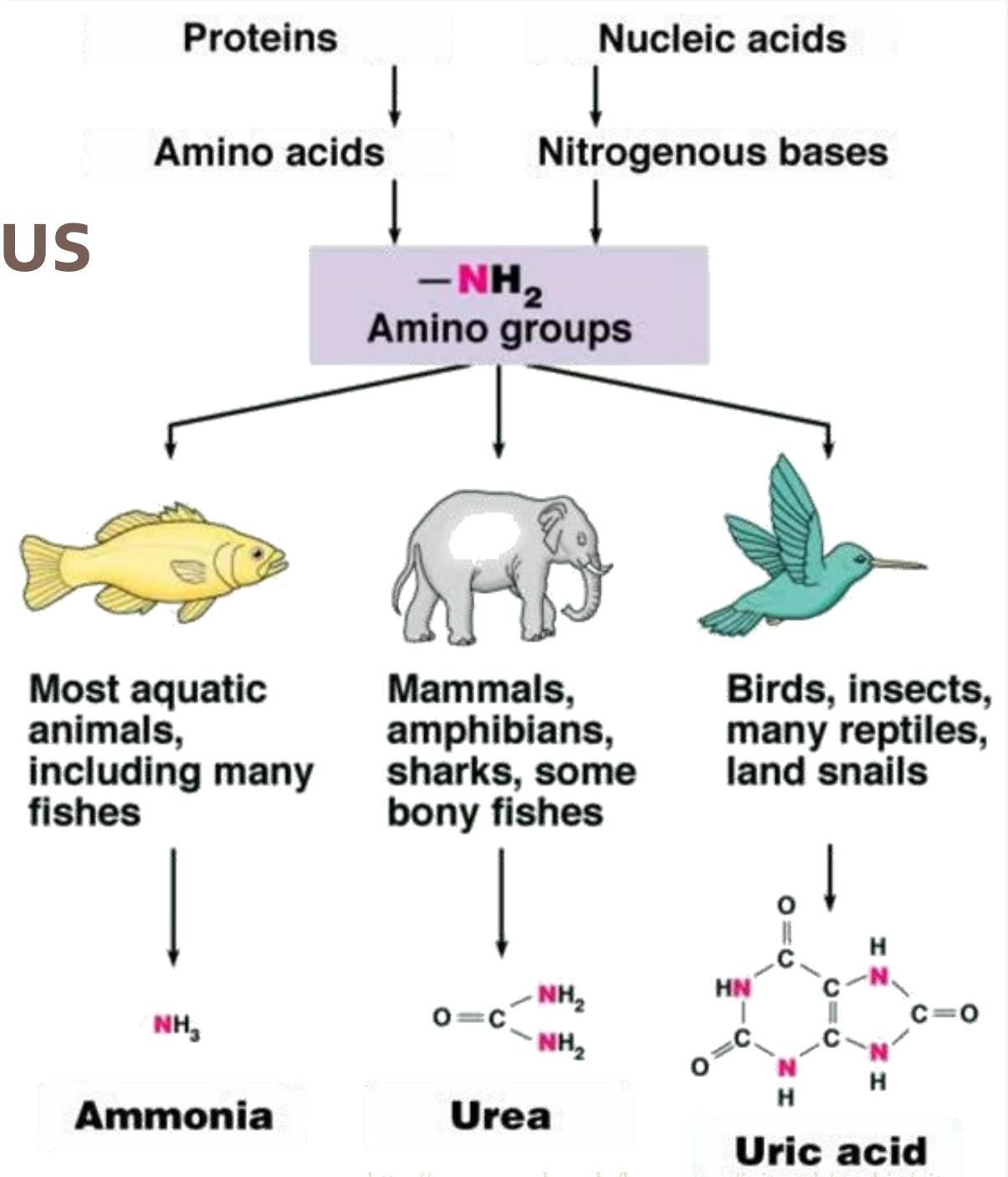
Excretory System Function: Osmoregulation

- Excretion of metabolic waste
- Controls composition of body fluids (metabolite concentration)
- Regulates blood pH
- Regulated blood pressure and blood volume

Metabolic Waste

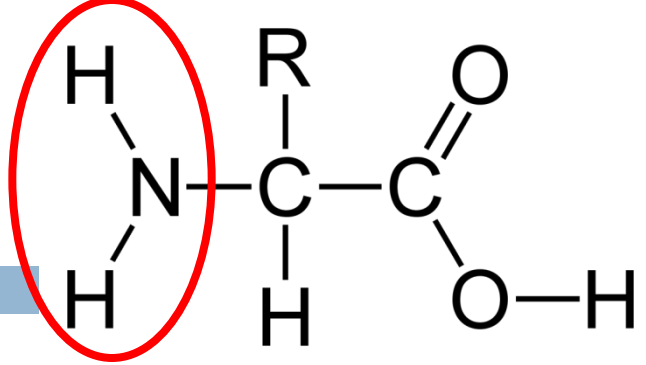
- Produced by metabolism
  - by-products in cellular reactions
  - breakdown of proteins and nucleic acids for energy and when converted to carbohydrates and fats
  - does not include feces (feces is what your body never absorbed)
- Major waste product: nitrogenous waste
- Waste converted to:
  - Ammonia
  - Urea
  - Uric acid

Nitrogenous Waste



http://www.anselm.edu/homepage/jpitocch/genbio/nitrowaste.JPG

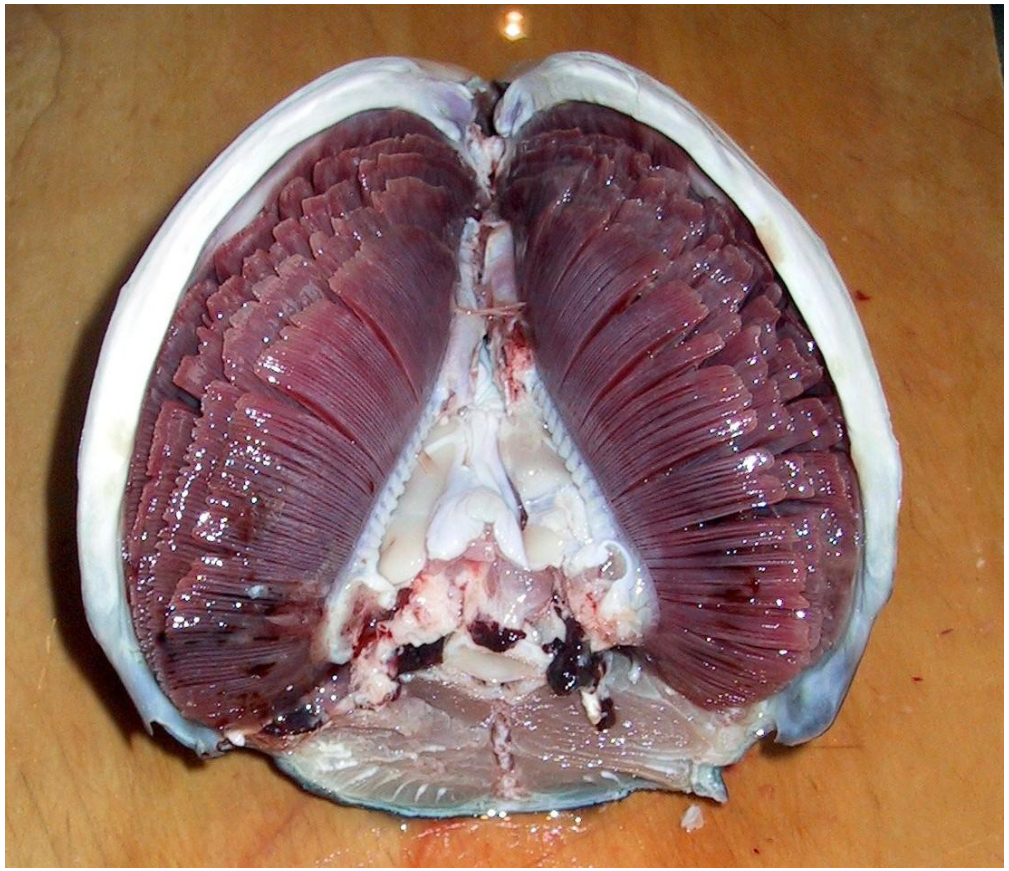
Ammonia



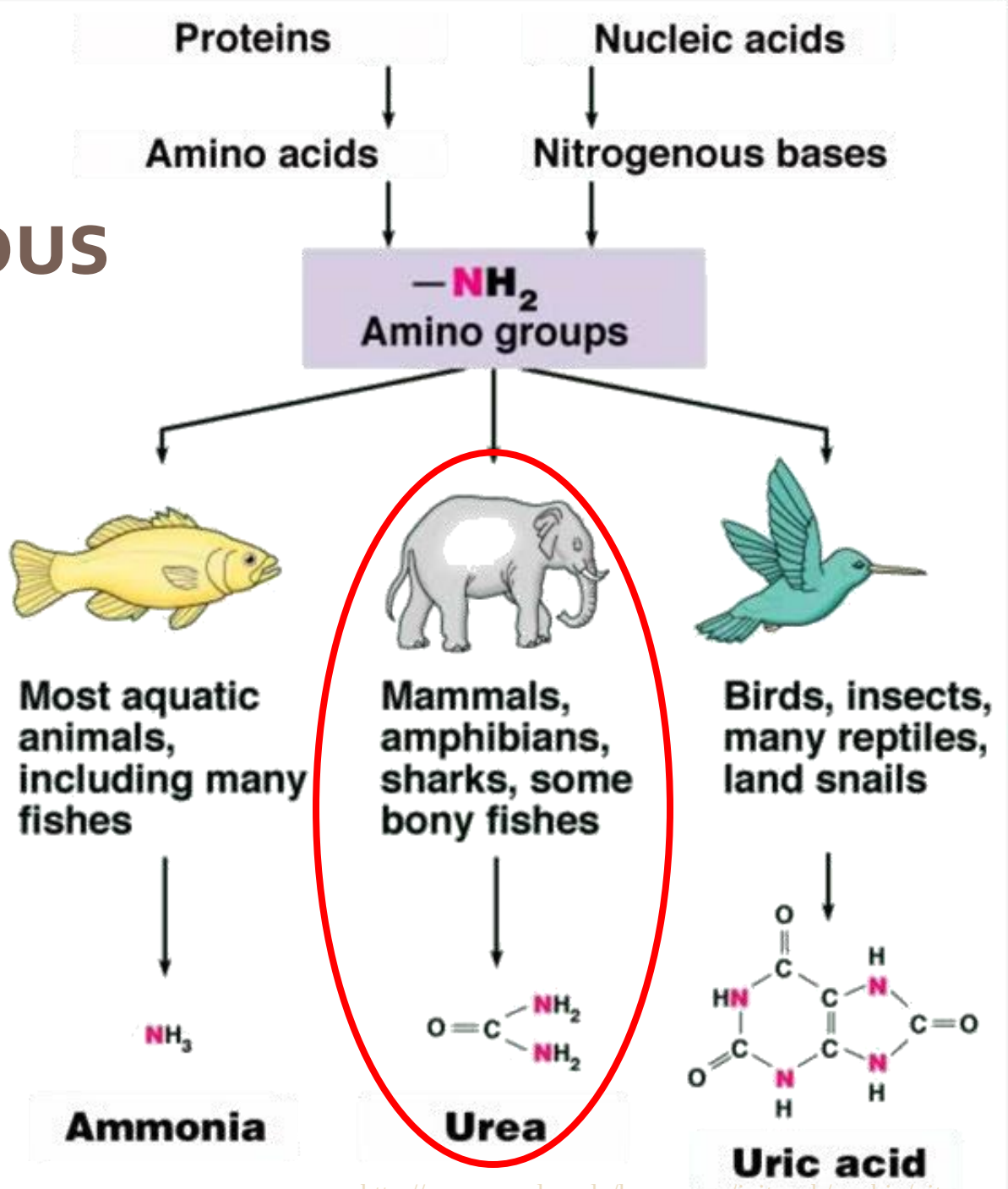
- Released when liver breaks down proteins (amino acids) by deamination (removal of amine group)
- Very soluble
- Very toxic, can only tolerate low concentrations (0.005 mg NH_3 is lethal)
- Must be diluted with water
  - excretion requires a large volume of water
- Common in aquatic species

Excretion: Fish

- Fish can excrete ammonia directly through their gills.
- Q: Why is it safe for fish to excrete ammonia?
- Q: If other organisms were to change to excrete ammonia, what would be the disadvantage that isn't applicable to fish?



Nitrogenous Waste



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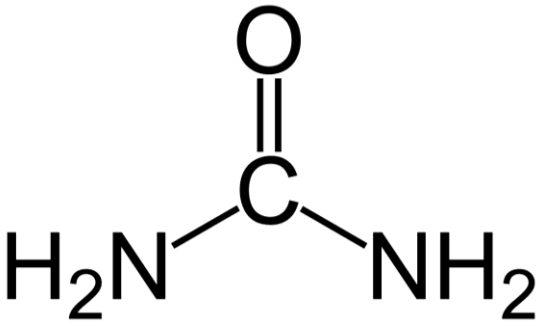
Urea



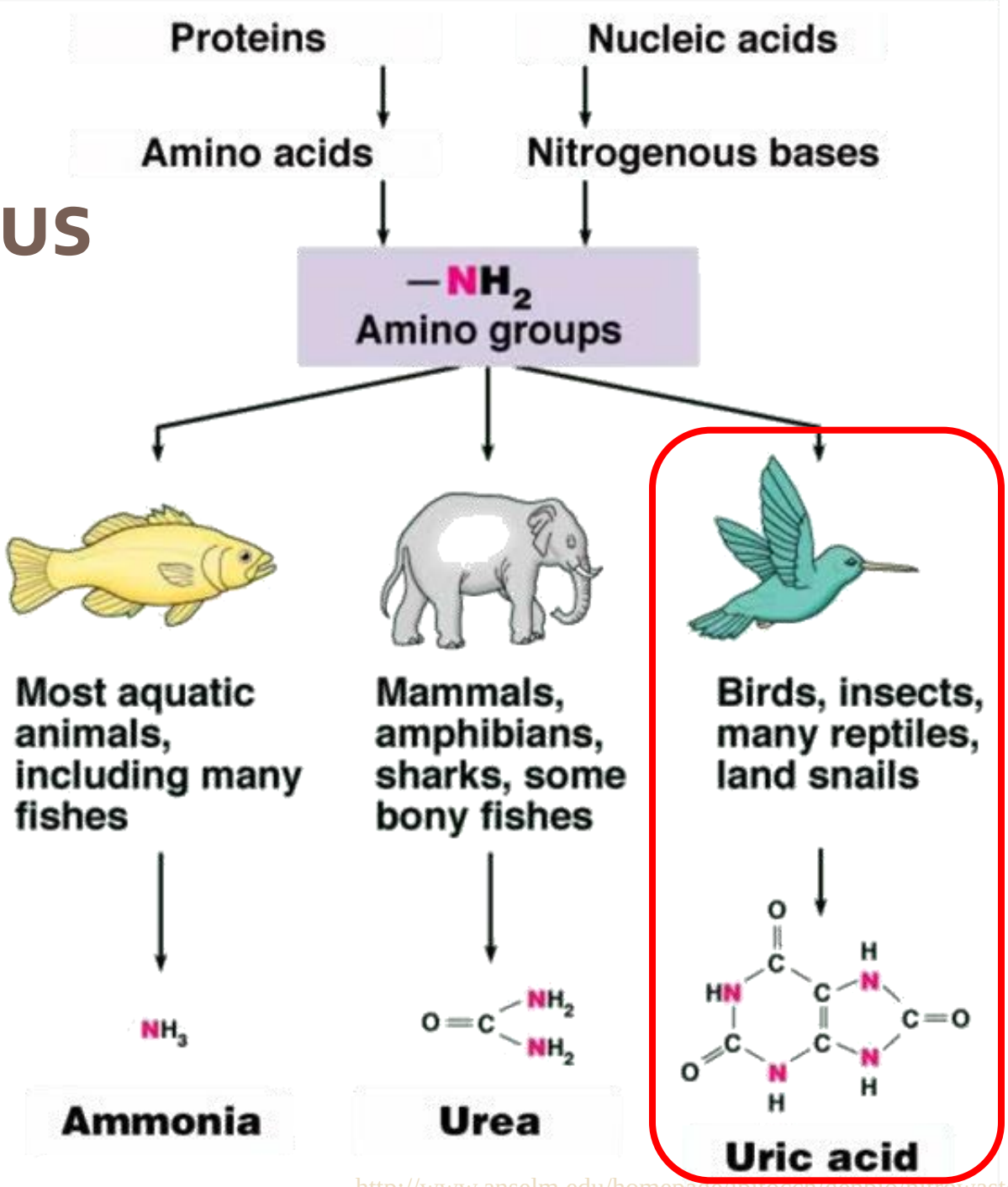
- Product of two waste molecules
  - ammonia, NH_3
  - carbon dioxide, CO_2
- Conversion occurs in the liver
  - requires energy
- Low toxicity
  - (100,000x less than ammonia)
  - Can safely store and transport urea
  - Reduces amount of water required for excretion

Excretion: Mammals

- Why can't mammals excrete urine in the form of ammonia?
- How would our lifestyle be different if we excreted ammonia?

Public urinals: Barcelona & Amsterdam

Nitrogenous Waste



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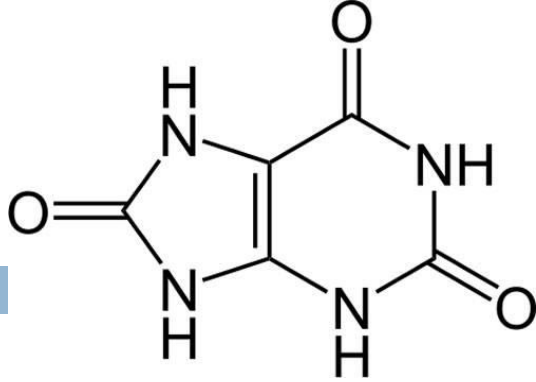
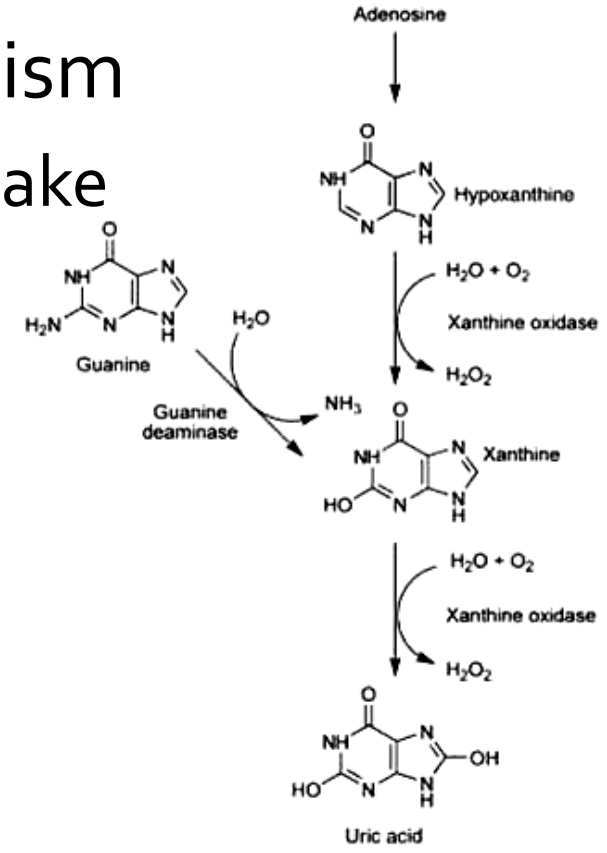
Uric Acid



- Product of nucleic acid breakdown
  - specifically of purine bases (A and G)
- Released through liver metabolism
  - Very energetically expensive to make
- Nontoxic
- Insoluble in water
  - Excreted as semisolid paste
  - Little water loss



Excretion: Birds

- Birds excrete uric acid directly with feces.

Excretion: Birds

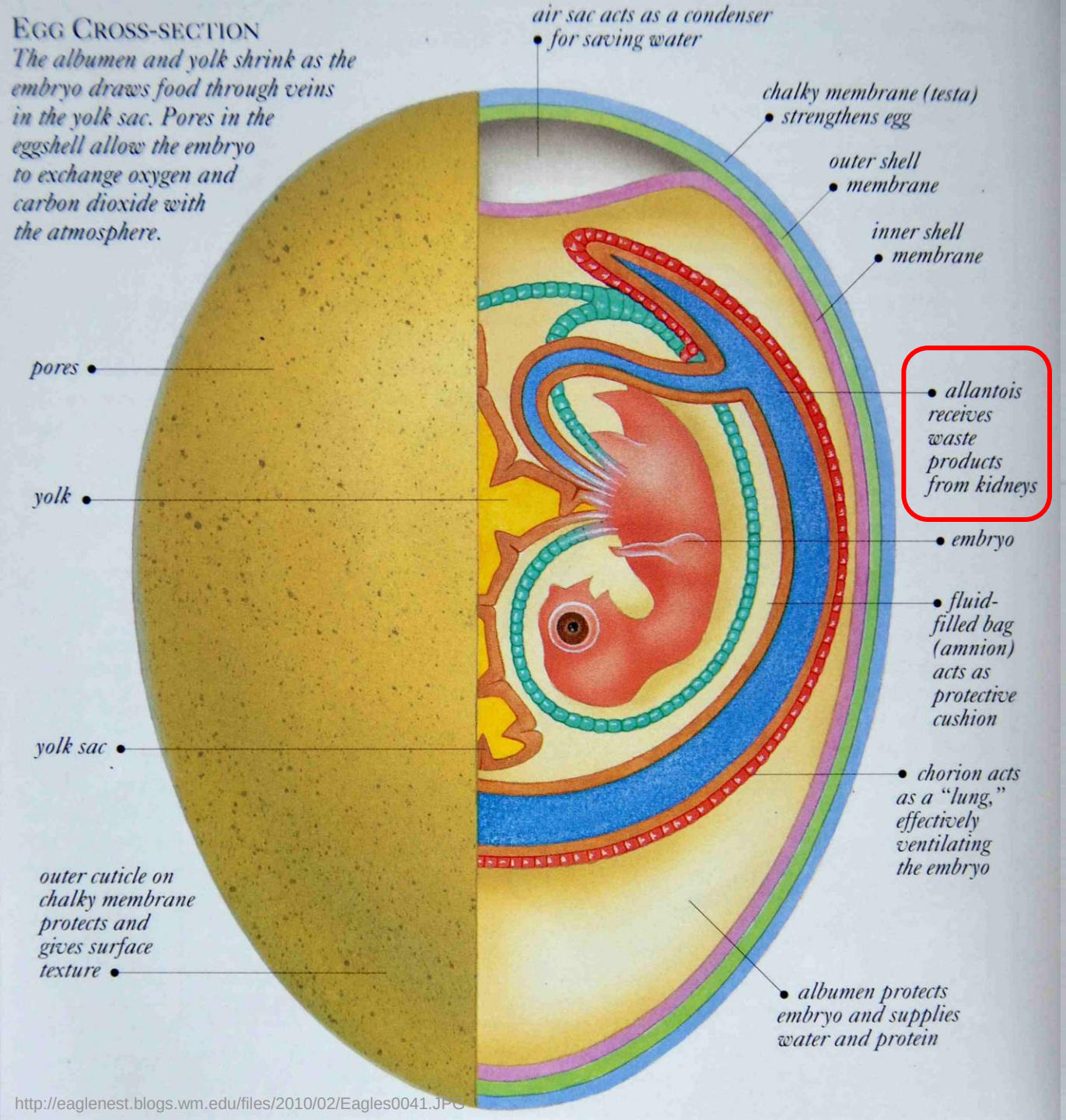
- Q: Why would birds need to excrete urine as uric acid as opposed to urea when it is so energetically expensive to make?
- A1: Flight & weight
- A2: Migration & water loss

http://cezl.files.wordpress.com/2012/07/bird_poop.jpg

Excretion: Reptiles

- Q: Why would reptiles need to excrete urine as uric acid as opposed to urea?
- A1: Water retention in hot climate
- A2: Embryos store nitrogenous waste inside egg. Prevent diffusion of waste and thus self-poisoning. (also applies to birds)

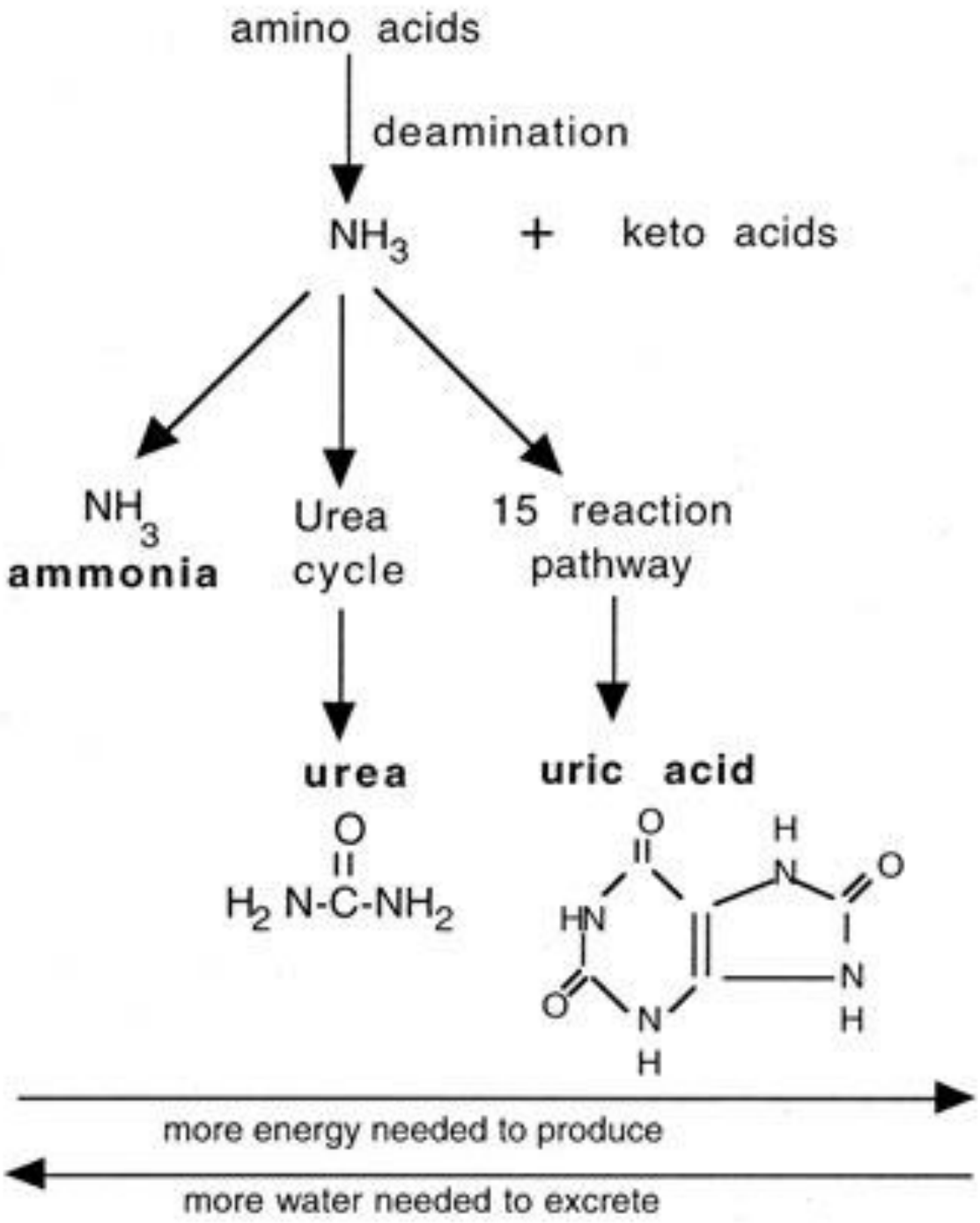
http://www.goodwp.com/large/20110719263.jpg



Uric acid stored in eggs

http://eaglenest.blogs.wm.edu/files/2010/02/Eagles0041.JPG

Comparing Nitrogenous Waste



http://www.biog1105-1106.org/demos/105/unit7/media/nitrogenouswastes.1.jpg

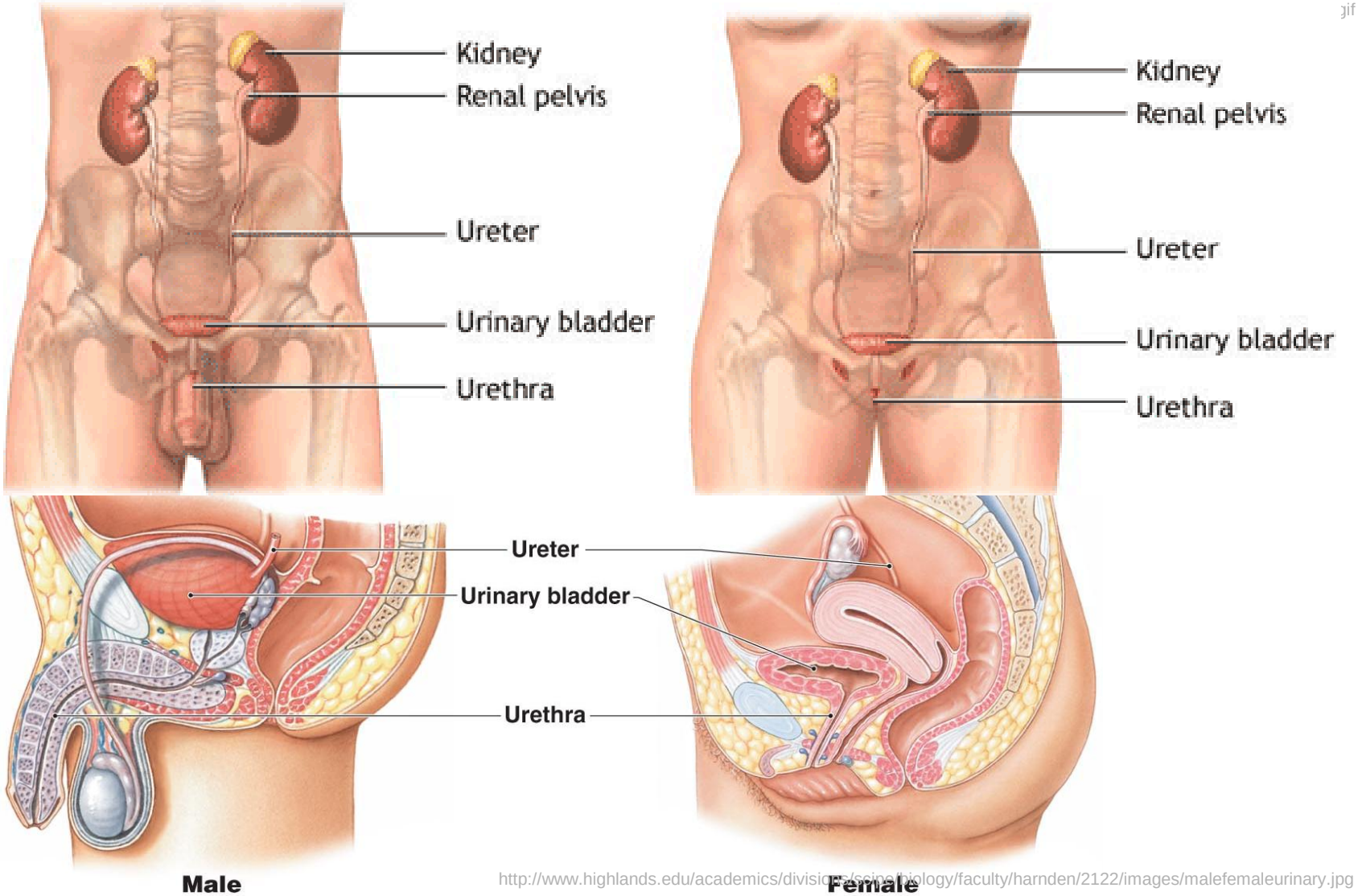
Summary Chart of N-waste

	Ammonia	Urea	Uric acid
Toxicity			
Solubility			
Synthesis			
Organism			

Summary Chart of N-waste

	Ammonia	Urea	Uric acid
Toxicity	High	Low	Nontoxic
Solubility	Very soluble	Soluble	Insoluble
Synthesis	Deamination of amino acid	Combining NH_3 and CO_2	Nucleic acid breakdown
Organism	Fish	Mammals	Birds, reptiles

Mammalian Excretory System Structures



http://www.highlands.edu/academics/divisions/scipt/biology/faculty/harnden/2122/images/malefemaleurinary.jpg

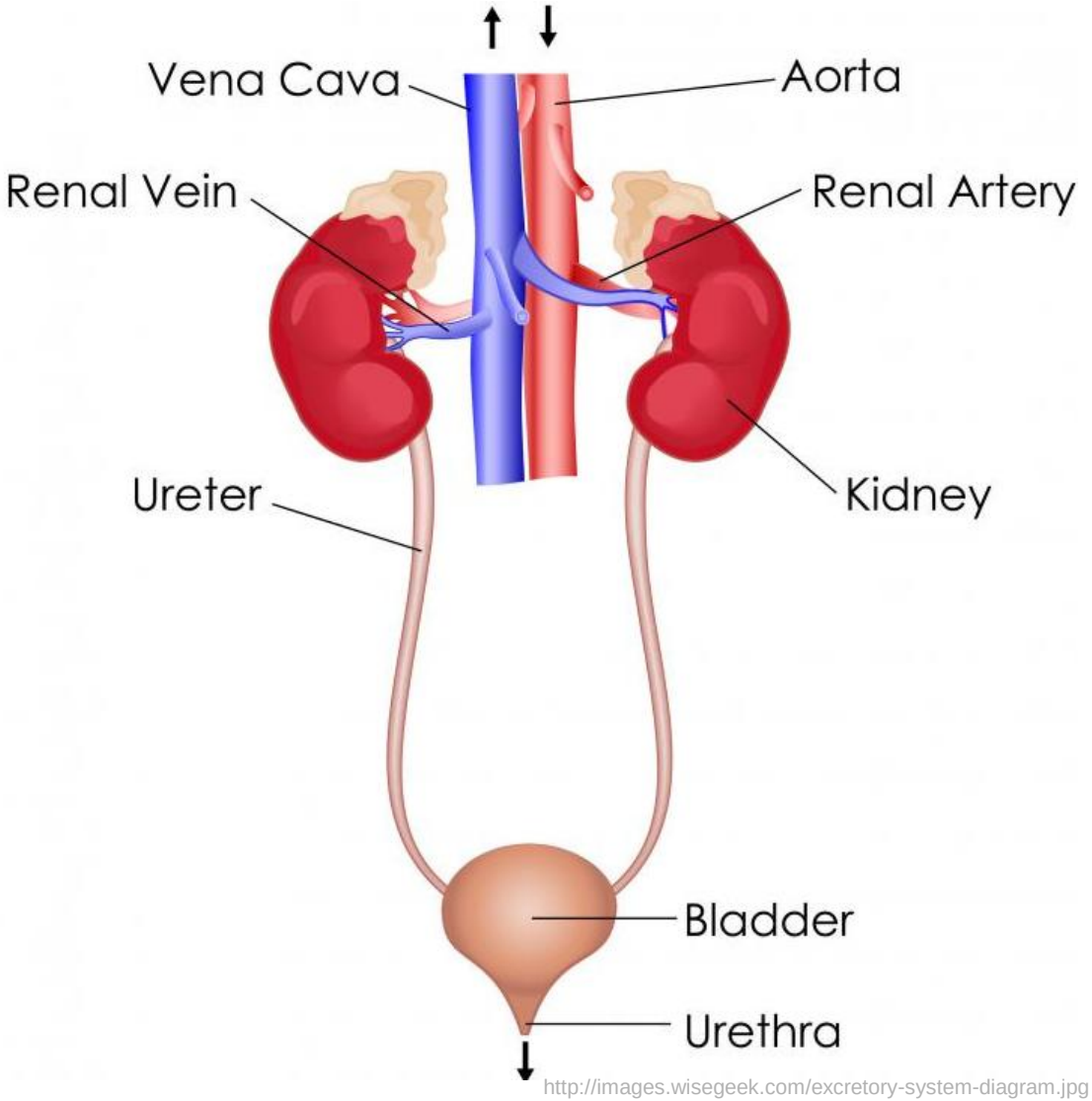
Urine Pathway

Kidneys

Ureter (duct)

Urinary bladder

Urethra (duct)



http://images.wisegeek.com/excretory-system-diagram.jpg

Urinary Tract Infection (UTI)

- Caused by bacterial growth in the urethra or bladder
- Symptoms:
  - frequent urination
  - sensation of needing to urinate (even is there is little to pass)
  - blood in urine
  - discharge in urine (cloudiness)

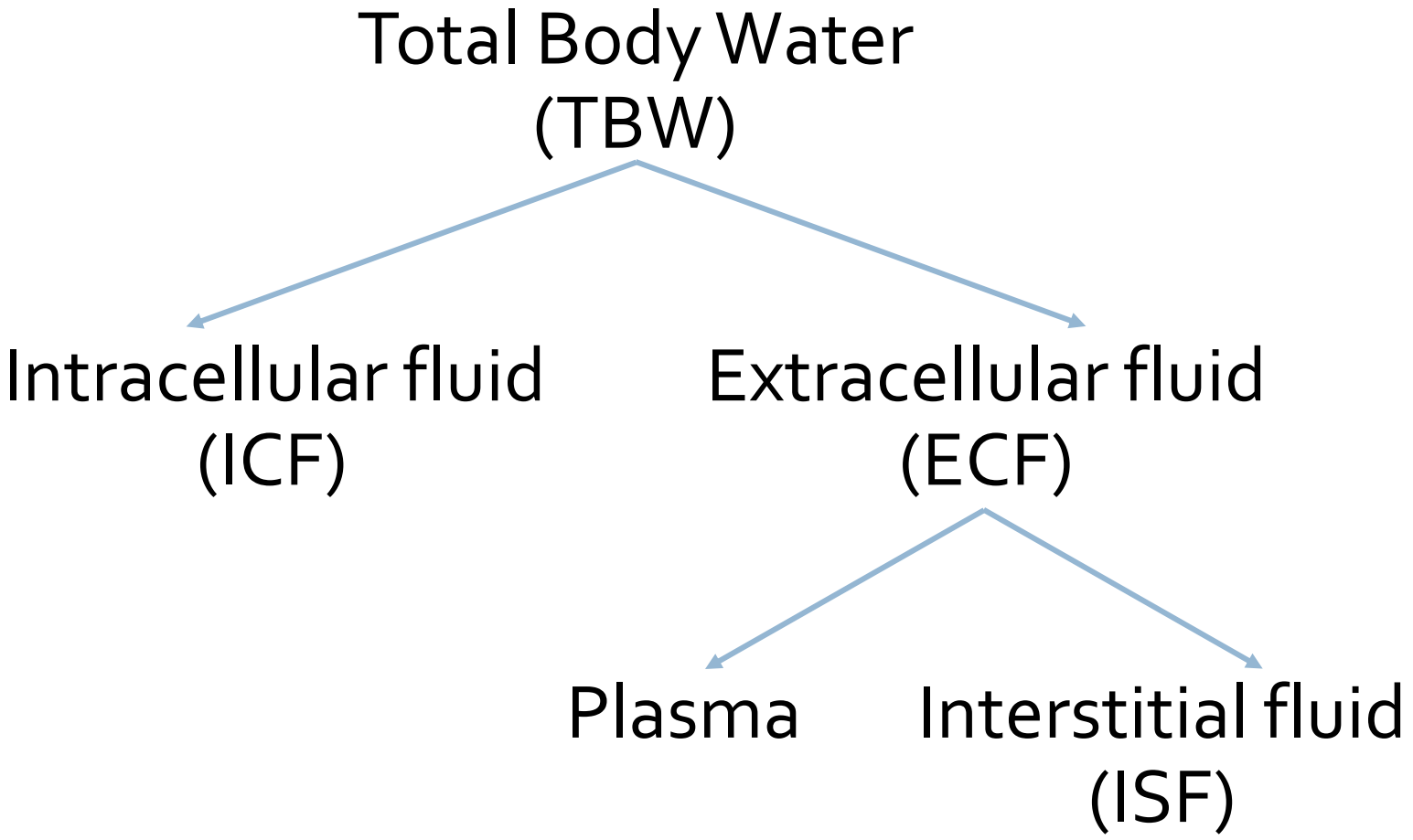
Kidney Stones

- crystallization of some urine solutes
- a 2 – 3 mm stone can obstruct flow to the ureter
- Treatment:
  - increased water consumption
  - surgery

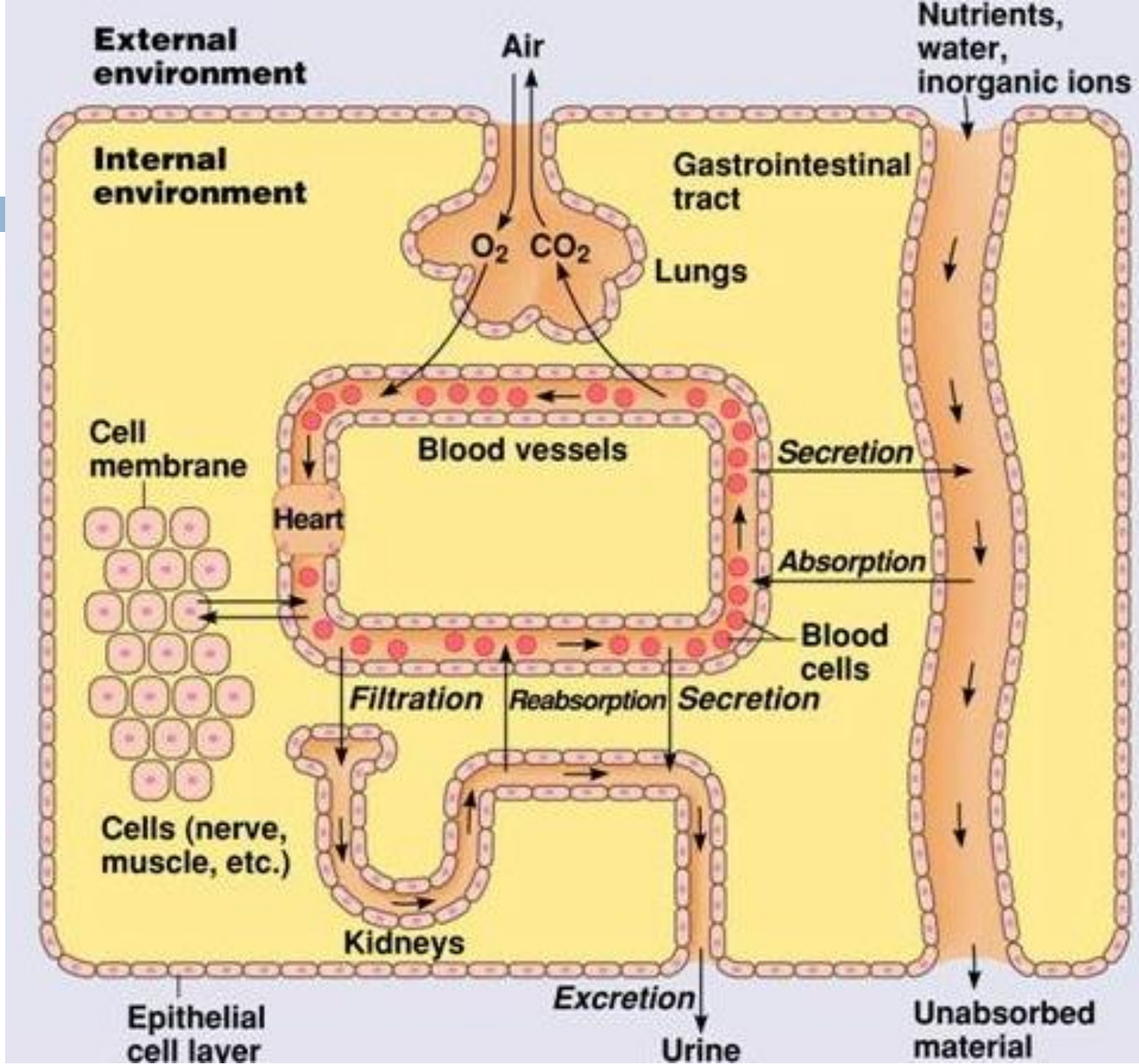
Urine

- Urine is 4x more concentrated than blood
- fluid for urine comes from extracellular fluid (ECF): filtered blood (plasma) and interstitial fluid (ISF)
- solution of metabolic waste
  - water
  - salts
  - organic compounds
  - urea and uric acid
  - other wastes / toxins

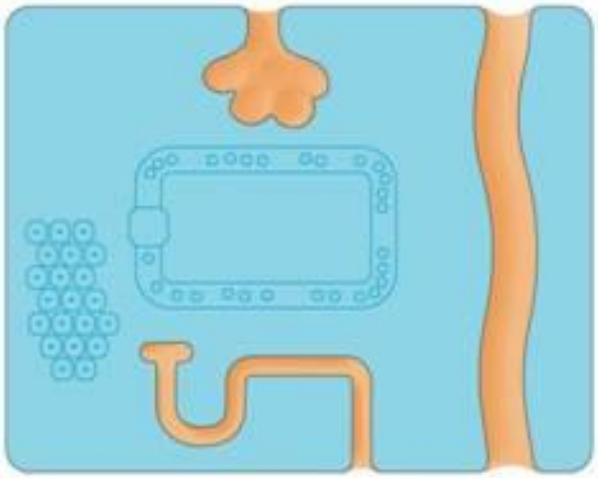
Body Fluids


Total Body Water
(TBW)
Intracellular fluid
(ICF)
Extracellular fluid
(ECF)
Plasma
Interstitial fluid
(ISF)

A simplified body plan



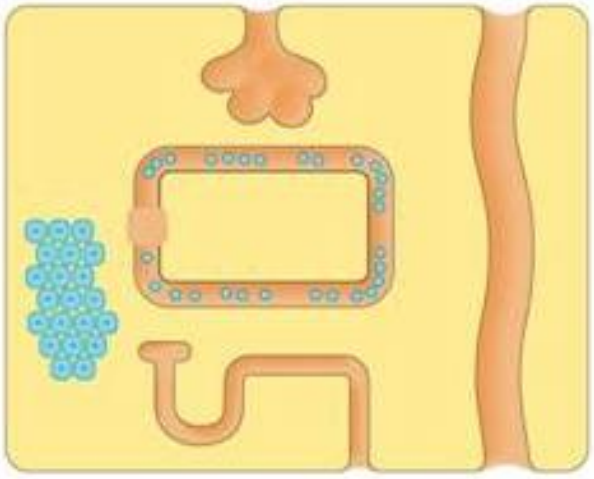
Body Fluids



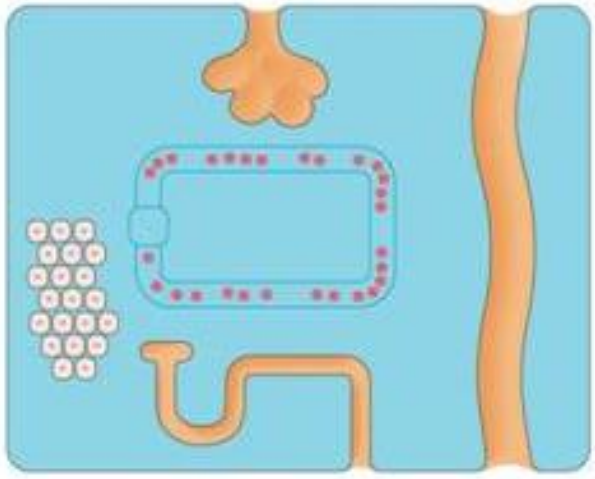
(a) Total body water (TBW)

Blue colour = fluid

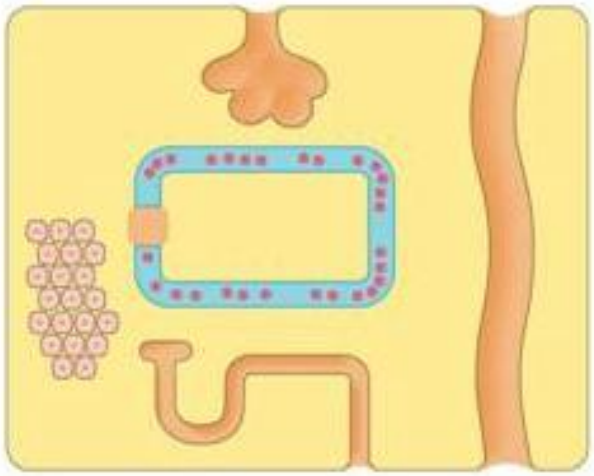
- All liquid inside body
- Liquids inside cell (cytoplasm)
- Liquid inside body, outside cell
- Liquid of bloodstream
- Liquid inside body, bathing body cells



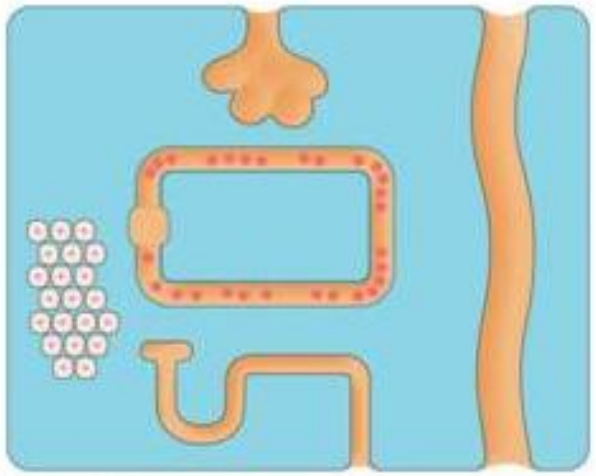
(b) Intracellular fluid (ICF)



(c) Extracellular fluid (ECF)



(d) Plasma



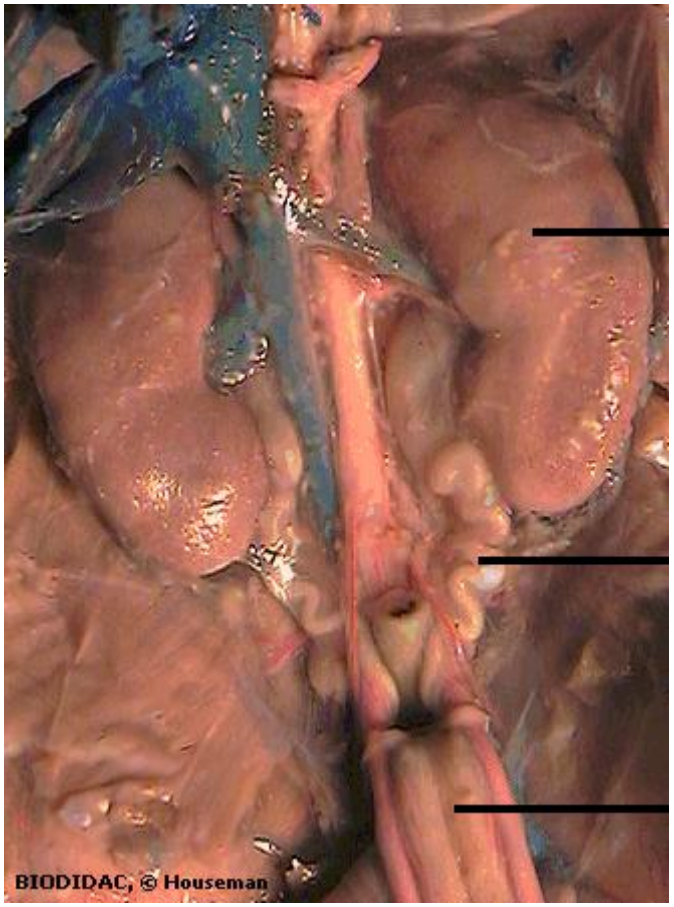
(e) Interstitial fluid (ISF)

Urine Excretion

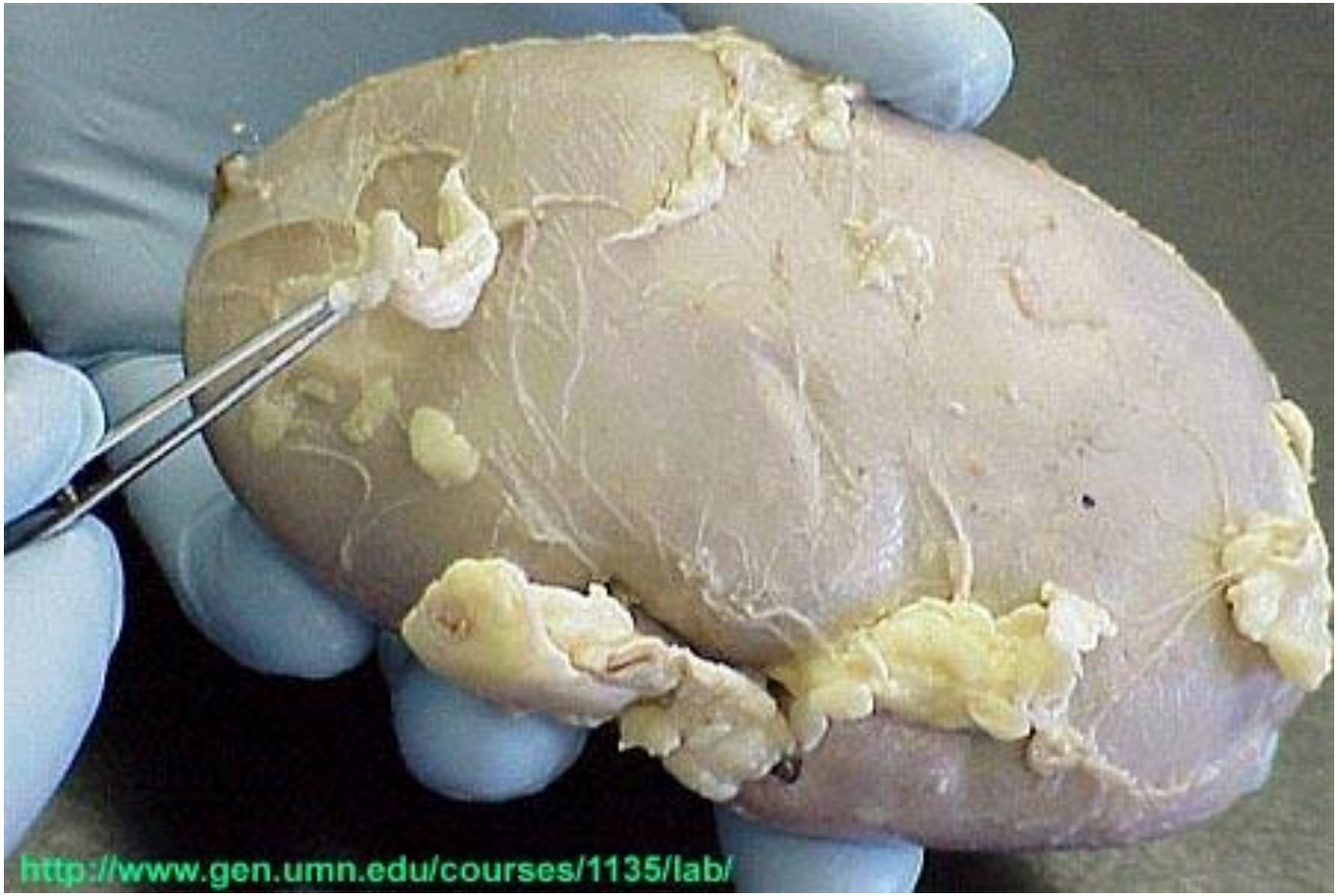
- When ~200 mL of urine has collected in the bladder, the walls stretch and signals are sent to the brain.
- At ~600 mL, urine will involuntarily be released.
- average person loses 2L of liquids a day
- suggested to consume 2L H_2O / day

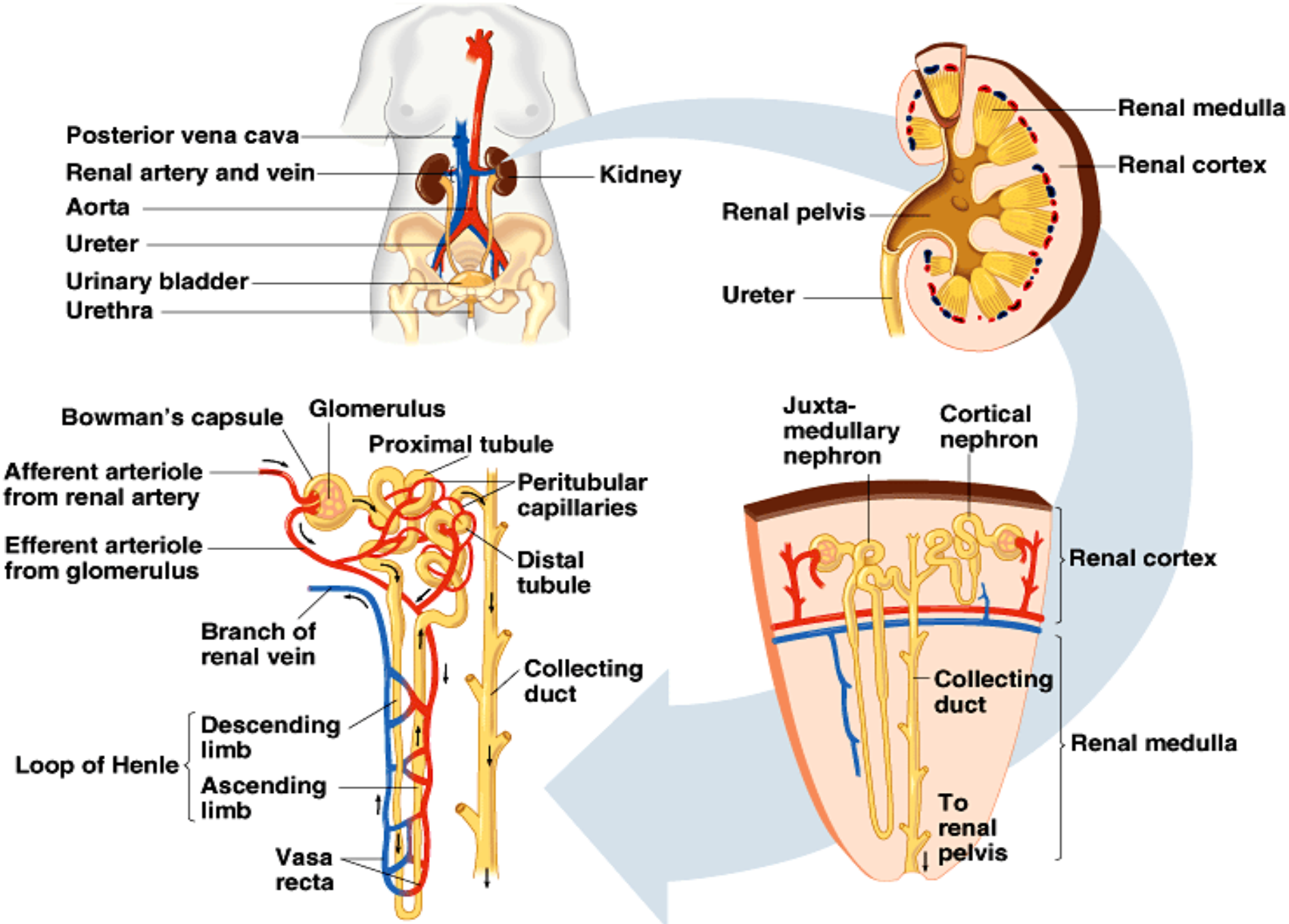
Mammalian Kidney

- A pair
- Bean-shaped
- 10 cm long
- Built of tubules and ducts that carry urine
- Contains a dense network of capillaries

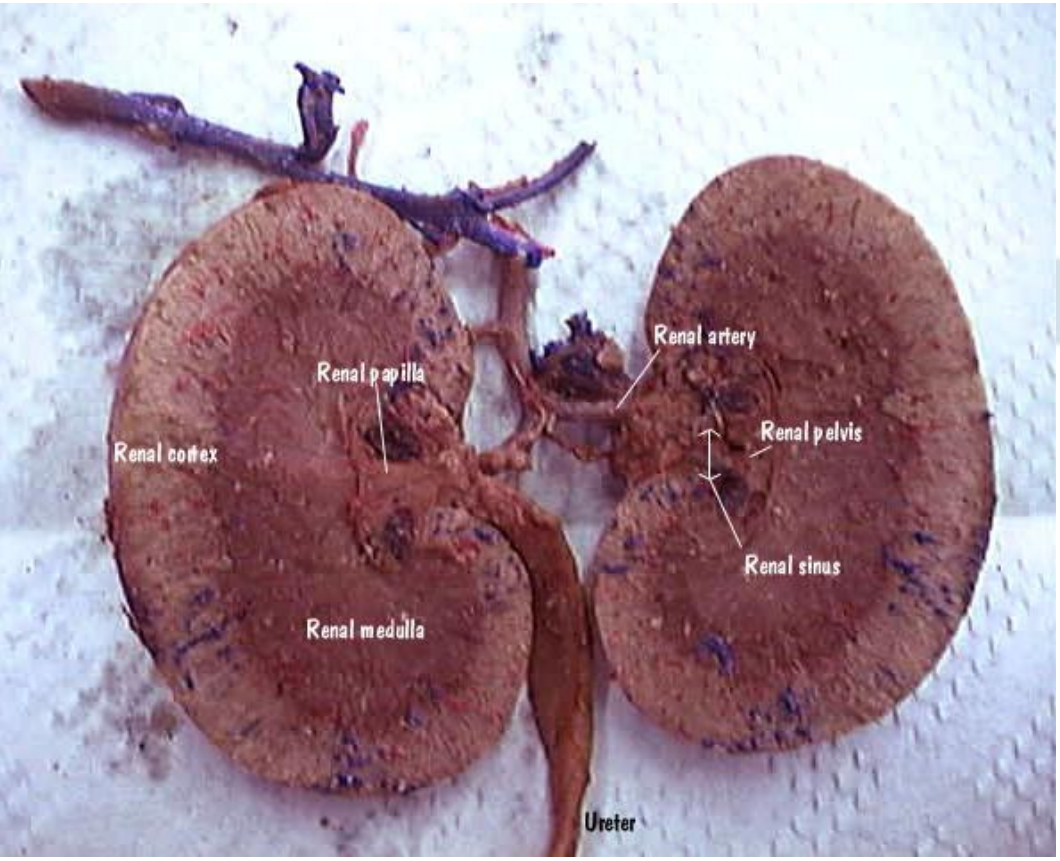


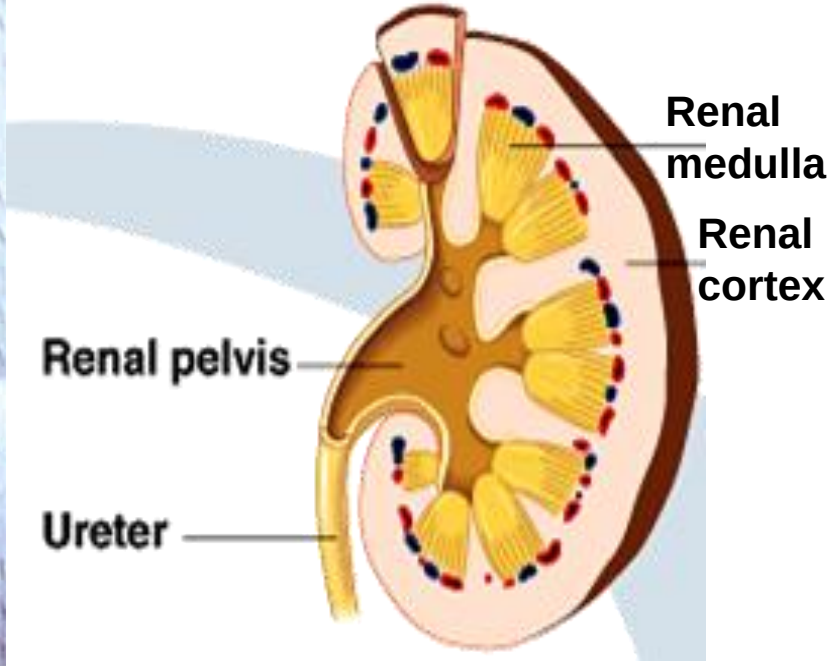
Mammalian Kidney





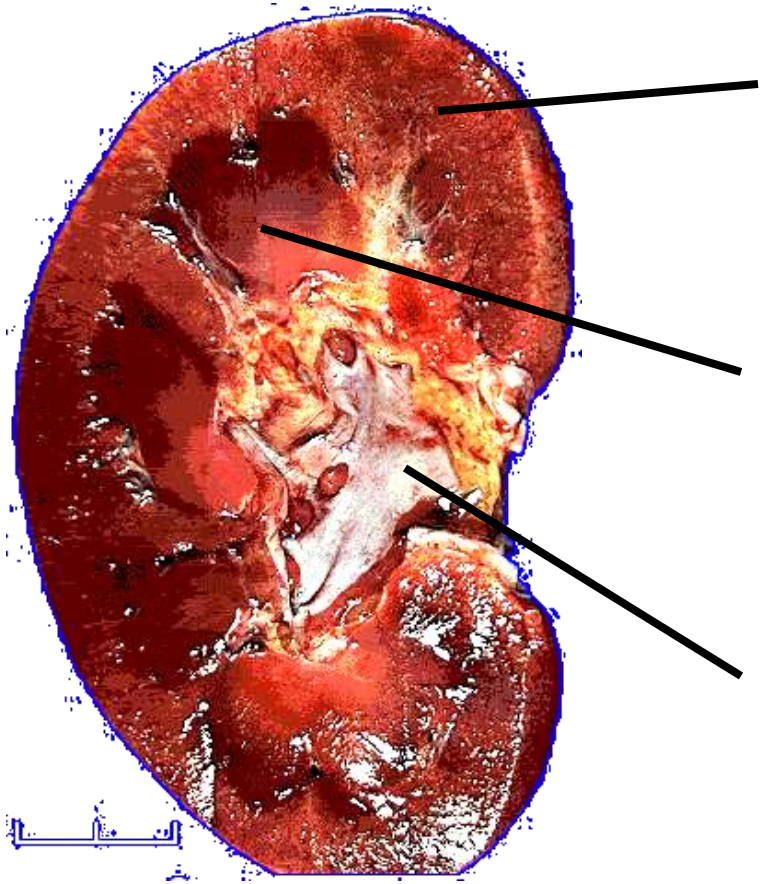
Internal Kidney Anatomy





http://www.gisbornesc.vic.edu.au/home/jans/home/kidney.htm

Kidney Structure



- renal **cortex:** outside of kidney
- renal **medulla:** middle of kidney
- renal **pelvis:** inner portion of kidney

Nephron Anatomy

- Nephron: functional unit
- About a million nephrons make up the kidney.

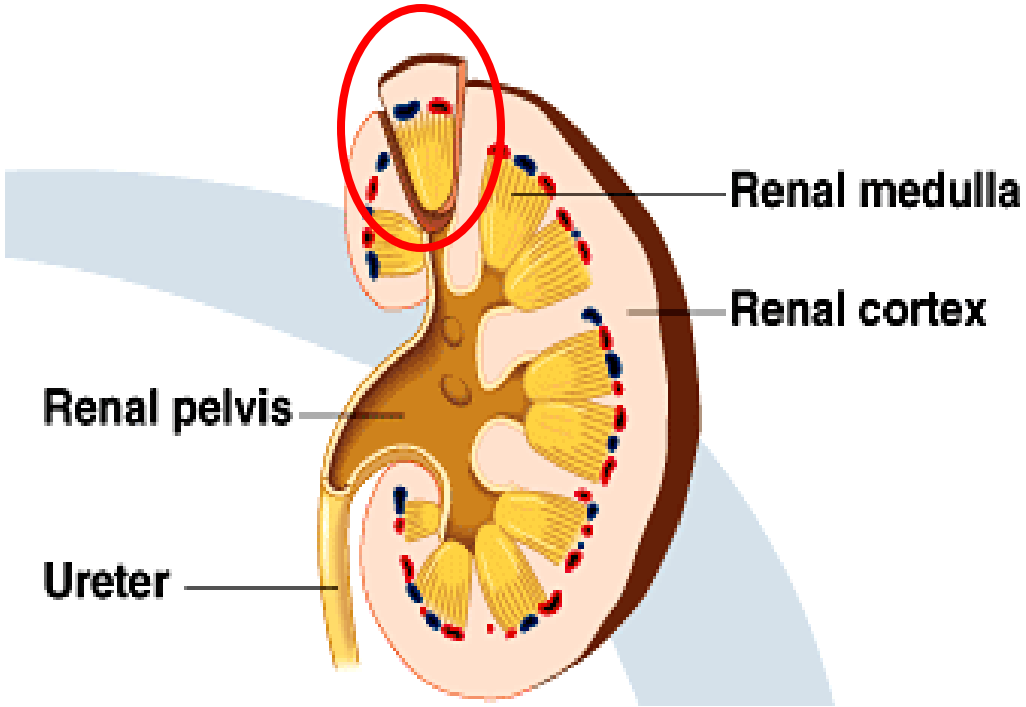


Fig. 44.21

Nephron Anatomy

- Consists of tubules/ducts surrounded by blood vessels.

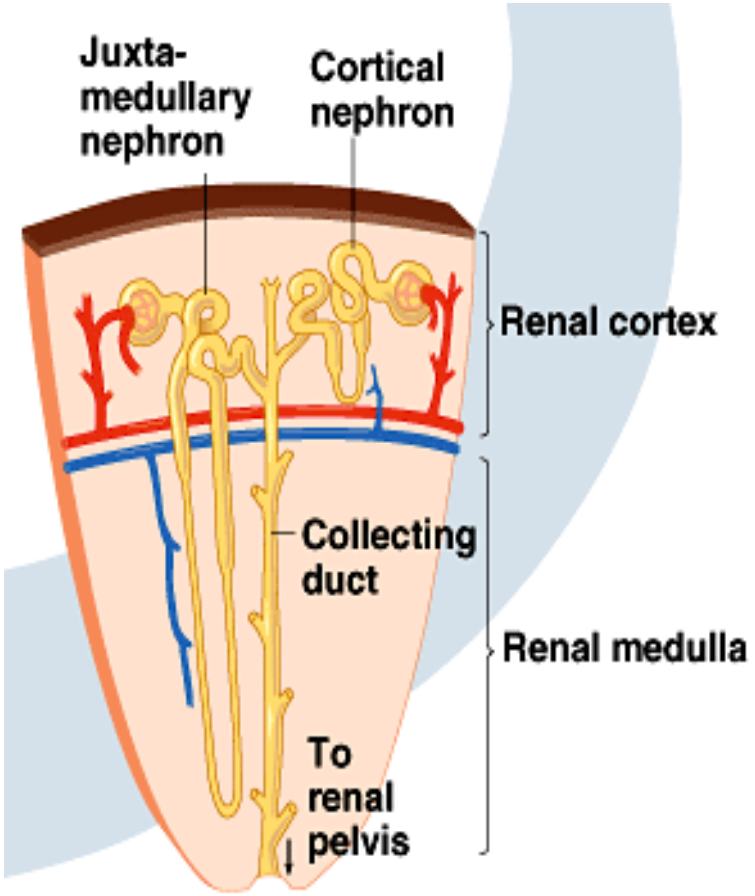
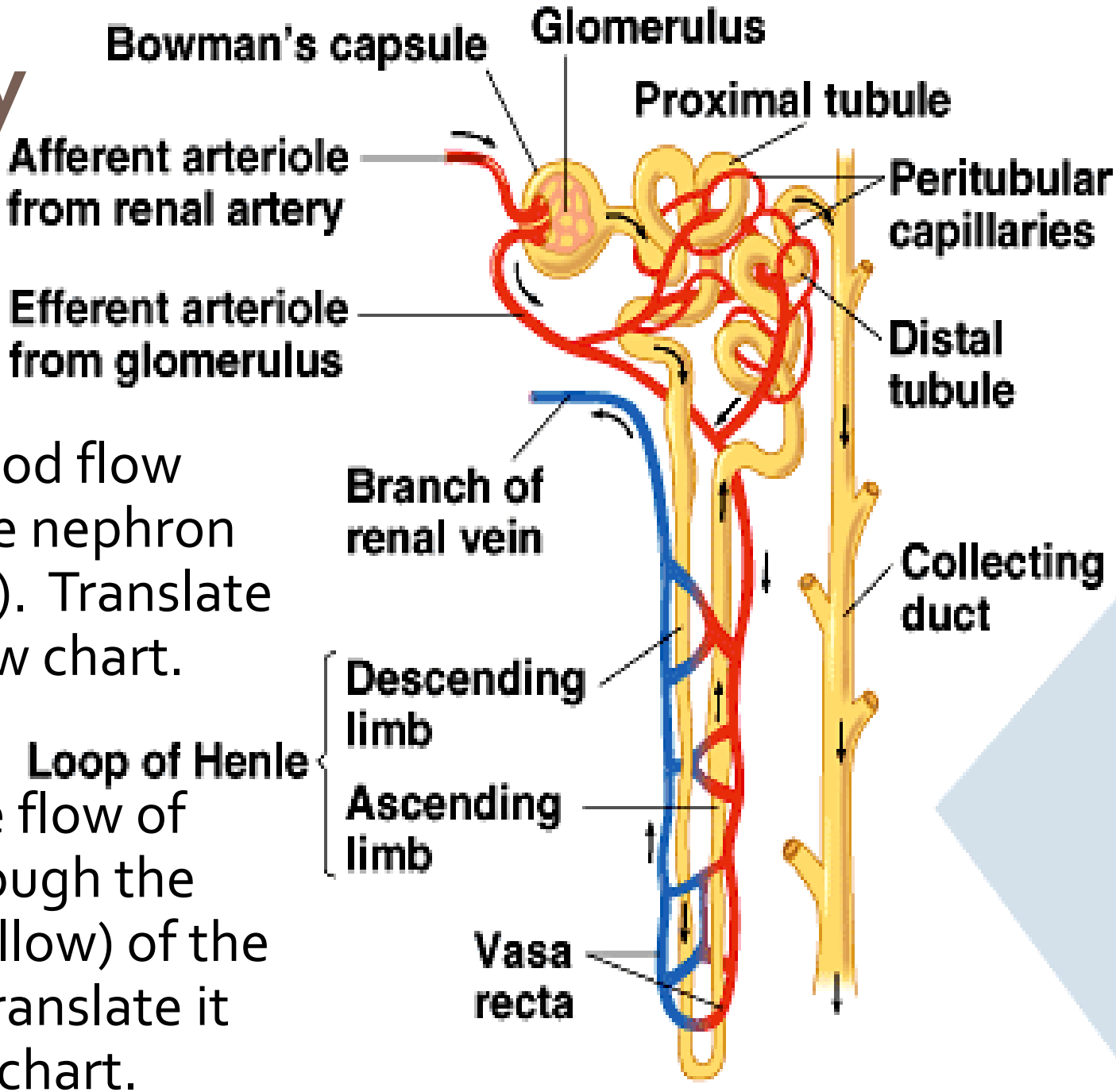


Fig. 44.21

Activity

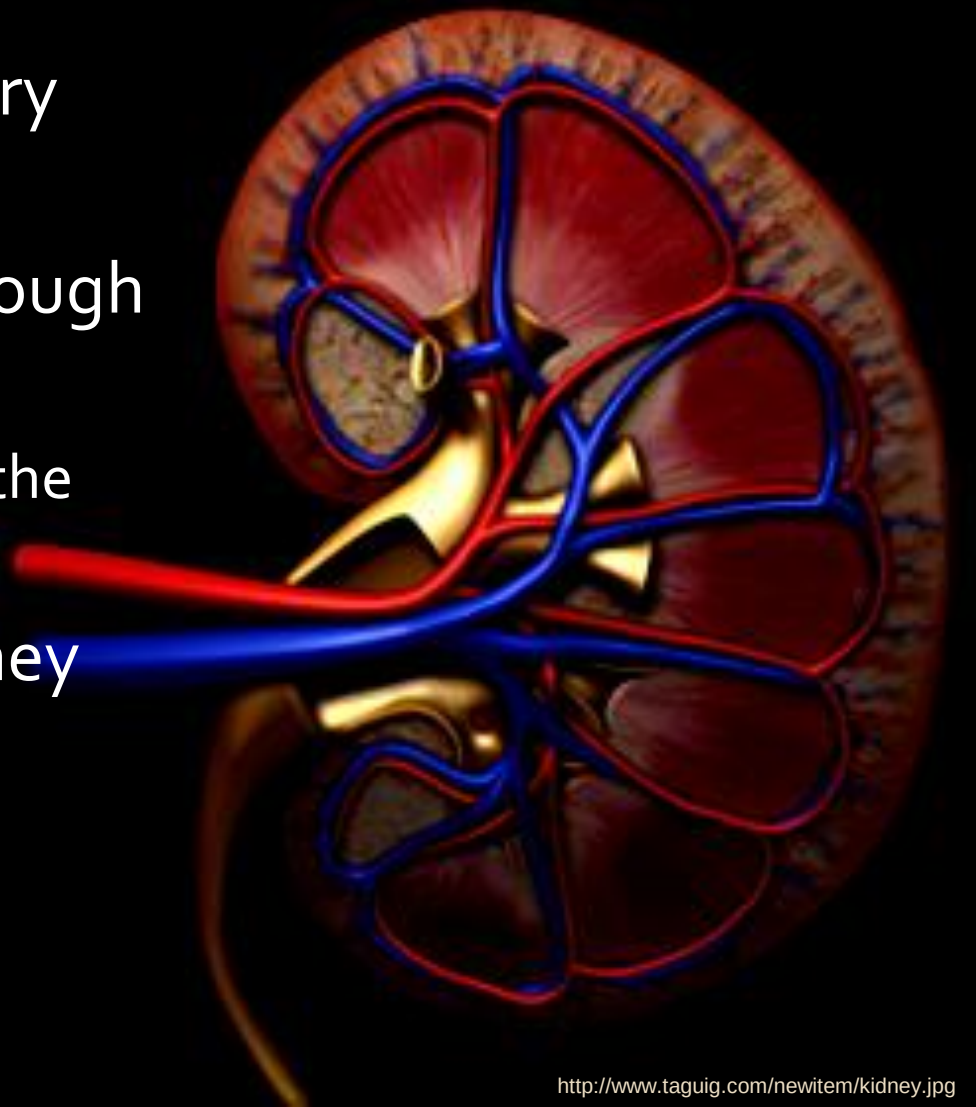
1. Look at blood flow through the nephron (red & blue). Translate it into a flow chart.

2. Look at the flow of filtrate through the tubules (yellow) of the nephron. Translate it into a flow chart.



Blood Flow in Kidney

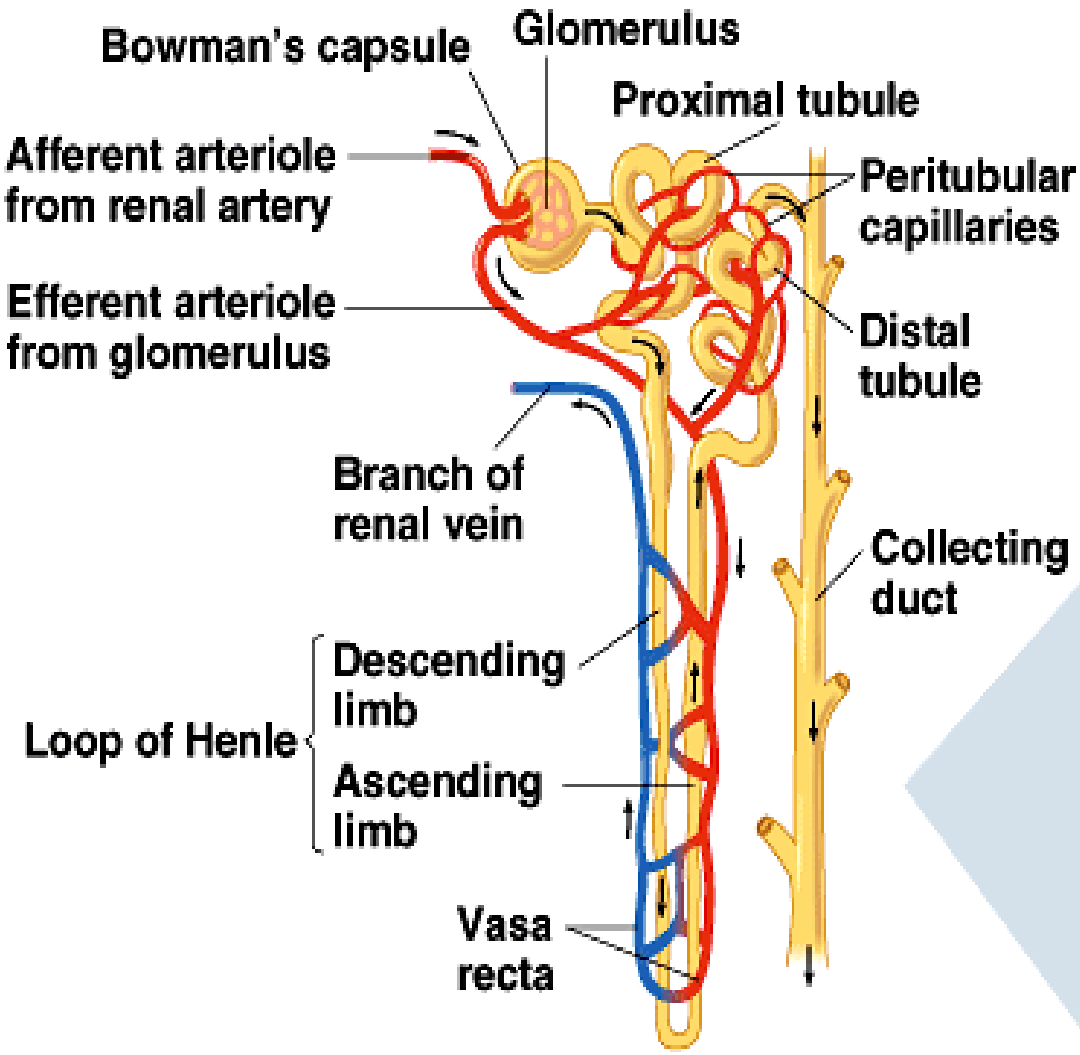
- Blood supply: renal artery and vein
- Blood enters kidney through **renal artery**
  - renal arteries stem from the **aorta**
- Filtered blood exits kidney through **renal vein**
  - renal veins flow into the **inferior vena cava**



http://www.taguig.com/newitem/kidney.jpg

Blood Flow in Nephron

- Renal artery
- Afferent arteriole
- Capillaries of glomerulus
- Efferent arteriole
- Peritubular capillaries
- Vasa recta
- Renal vein

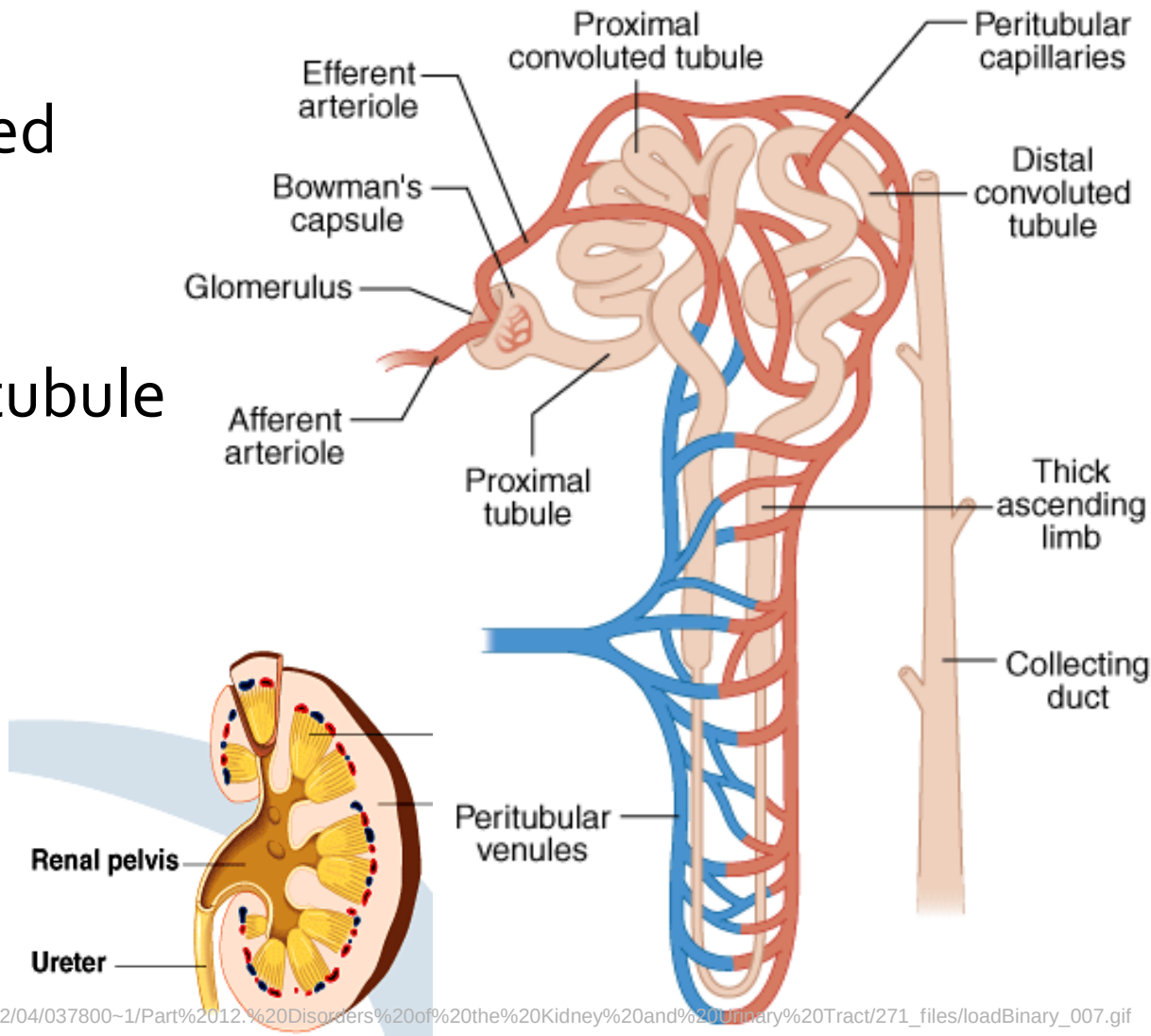


Blood Vessels in the Nephron

Vessels	Location
Afferent arteriole	From renal artery to glomerulus.
Capillaries of the glomerulus	Capillaries in the Bowman's capsule.
Efferent arteriole	Capillaries converge. Exit glomerulus.
Peritubular capillaries	Surrounds proximal and distal tubules.
Vasa recta	Surrounds loop of Henle. Countercurrent. To renal vein.

Pathway of Filtrate

- Bowman's capsule
- Proximal convoluted tubule
- Loop of Henle
- Distal convoluted tubule
- Collecting duct
- Renal pelvis
- Ureter
- Bladder
- Urethra



Filtrate & Blood flow

Pathway of filtrate	Function	Blood vessel
Bowman's capsule	Filtration	Capillaries of glomerulus
Proximal tubule	Reabsorption & secretion	Peritubular capillaries
Loop of Henle	Reabsorption	Vasa Recta
Distal tubule	Reabsorption & secretion	Peritubular capillaries
Collecting Duct	Reabsorption & excretion	

Introductory Video

- Biology Crash Course
  - Excretory system (12:20)
  - http://www.youtube.com/watch?v=WtrYotjYvtU (watch until 3:40)

Nephron Processes

- **Filtrate**: portion that is inside tubules
- Processes:
  - Filtration of blood
  - Reabsorption of valuable substances
  - Secretion of toxins and excess ions
  - Excretion of the contents of tubule

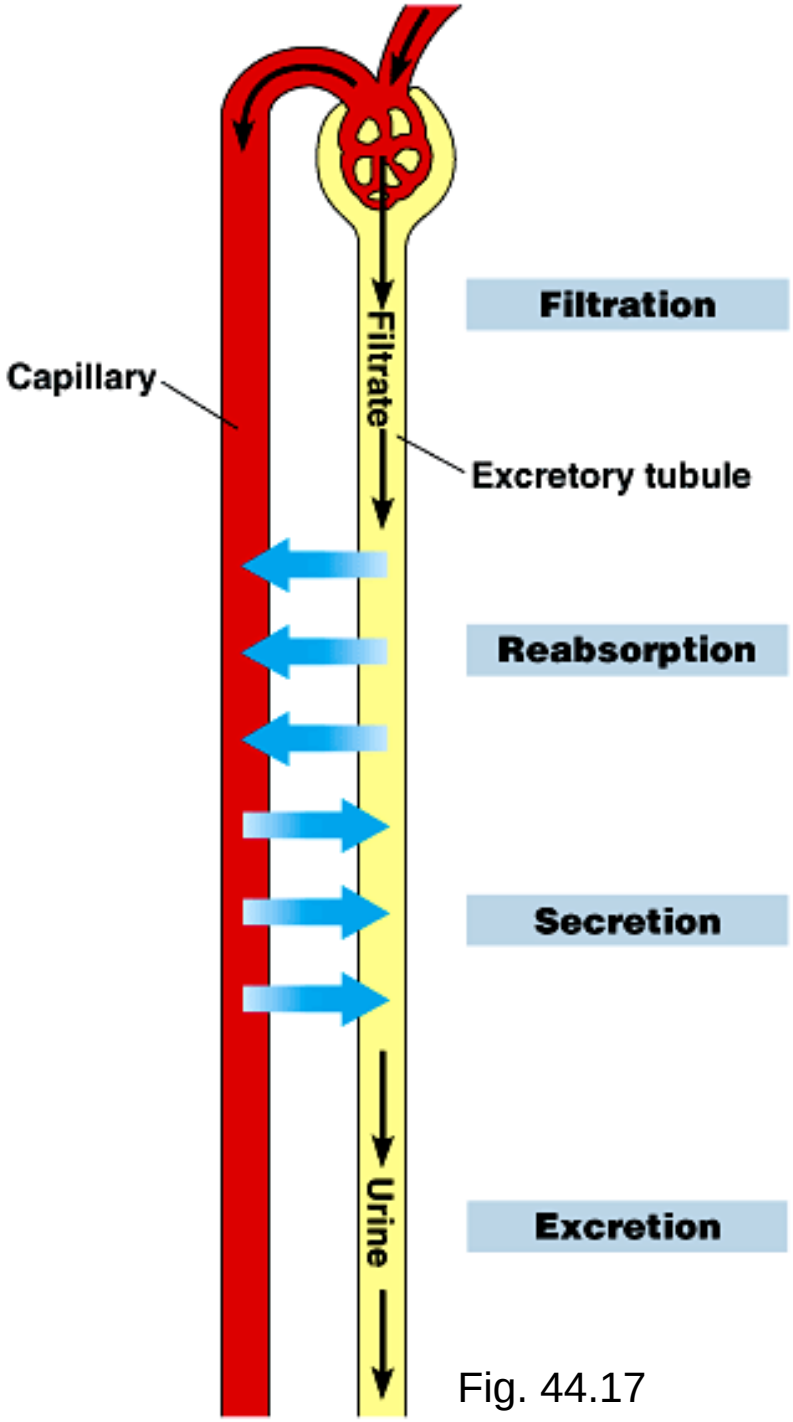
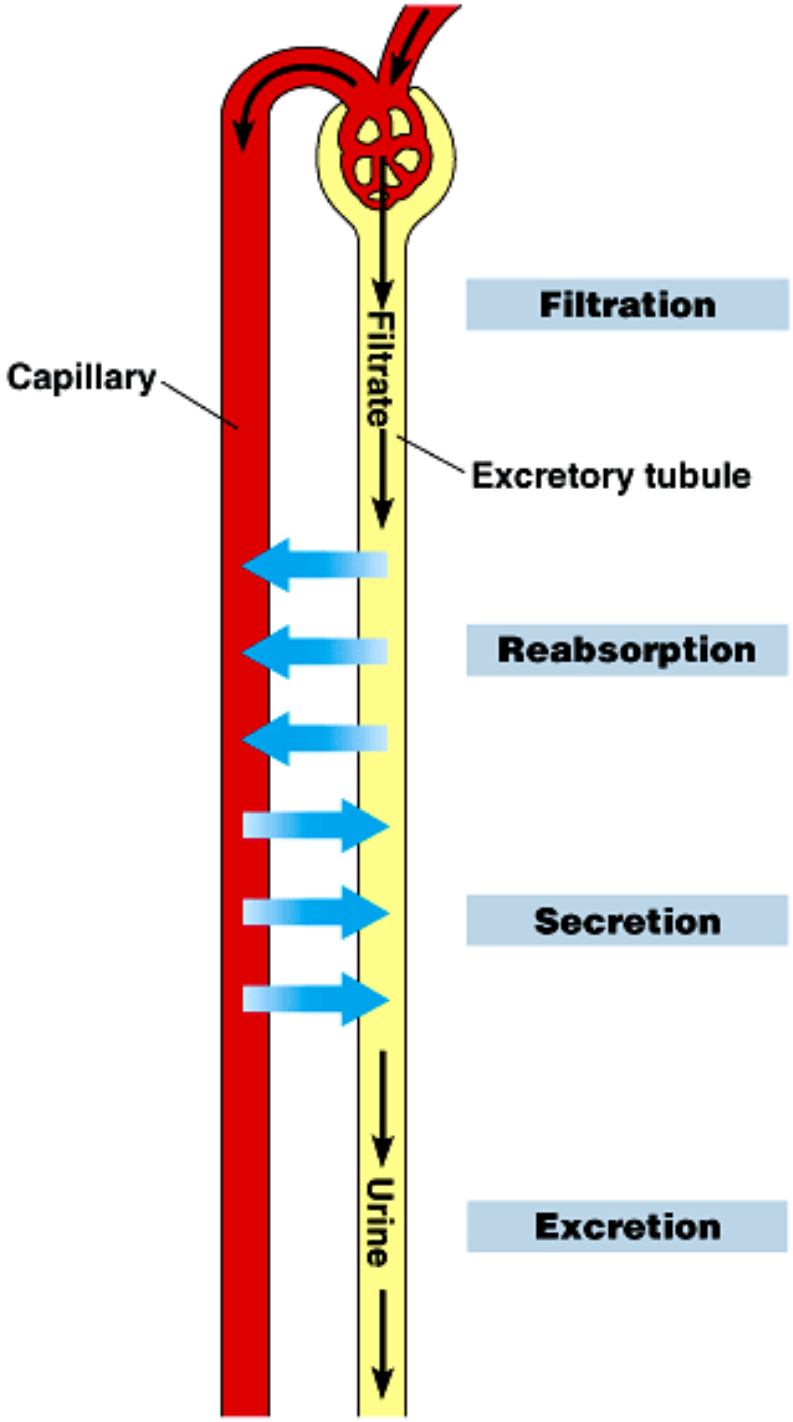


Fig. 44.17

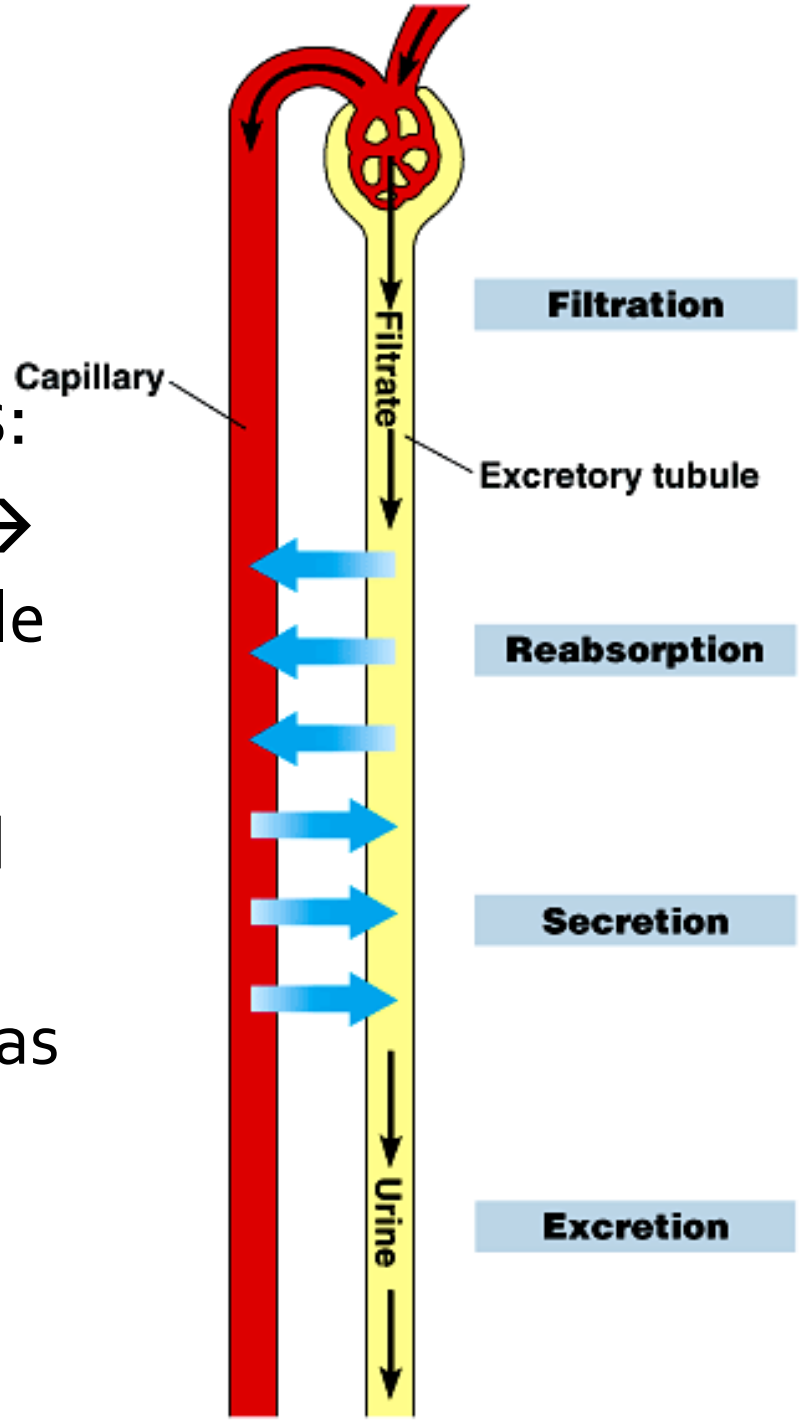
Excretion

- Exit of filtrate out of body
- Filtrate is now called urine



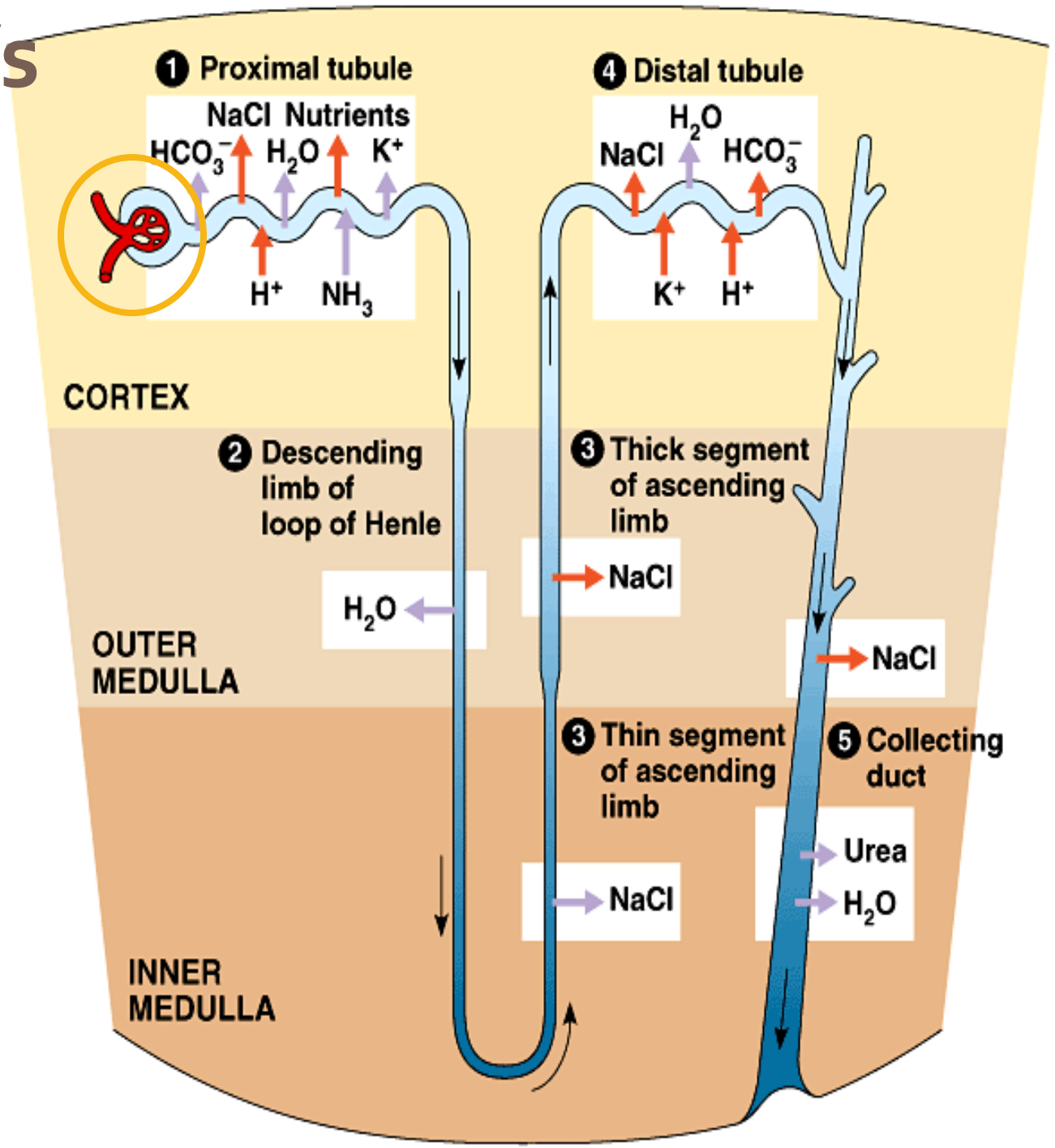
Filtration

- Movement of substances:
  - Capillaries of glomerulus → lumen of Bowman's capsule
- Filtering blood
  - Blood pressure forces fluid through filter
  - Transport epithelium acts as filter



1. Bowman's Capsule

- Active transport
- Passive transport



1. Bowman's Capsule

- **Glomerulus**: ball of capillaries
- **Bowman's capsule**: blind end of tubule that surrounds glomerulus

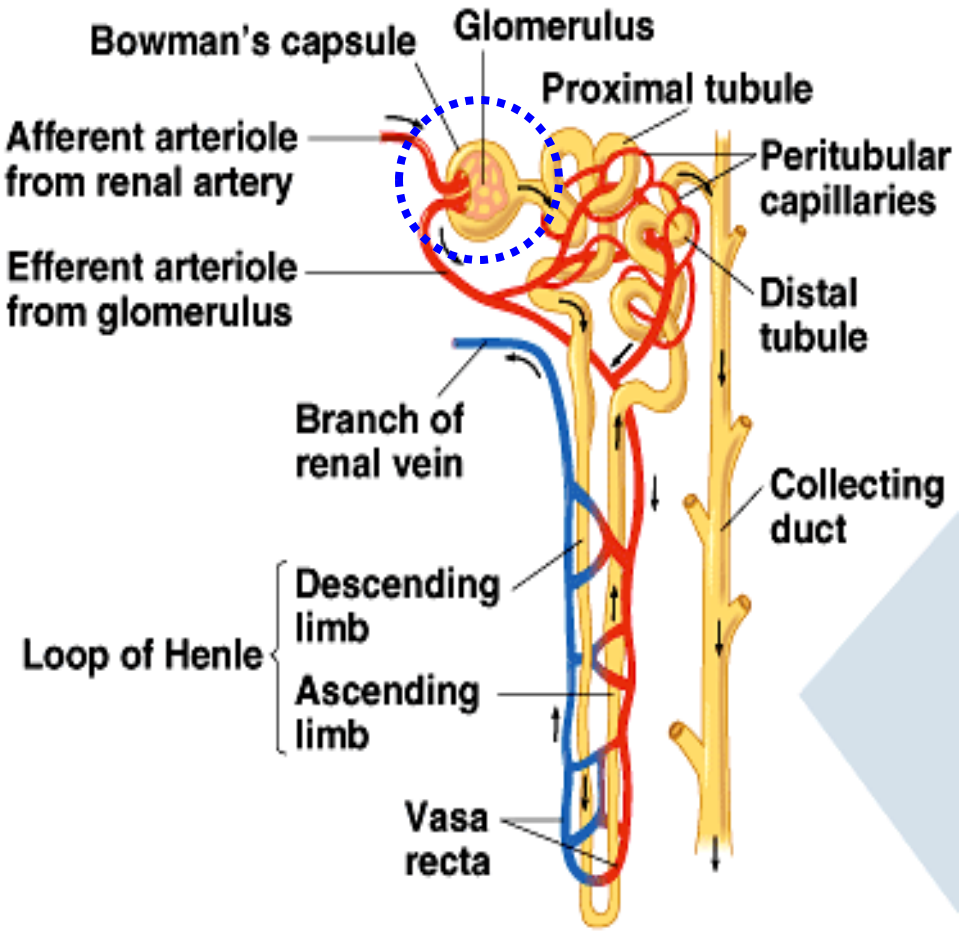
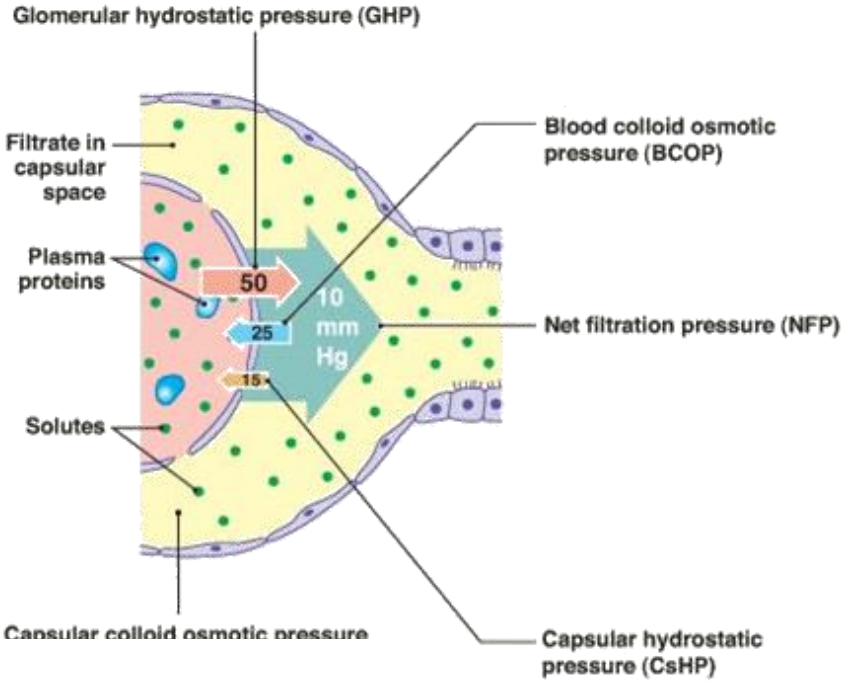
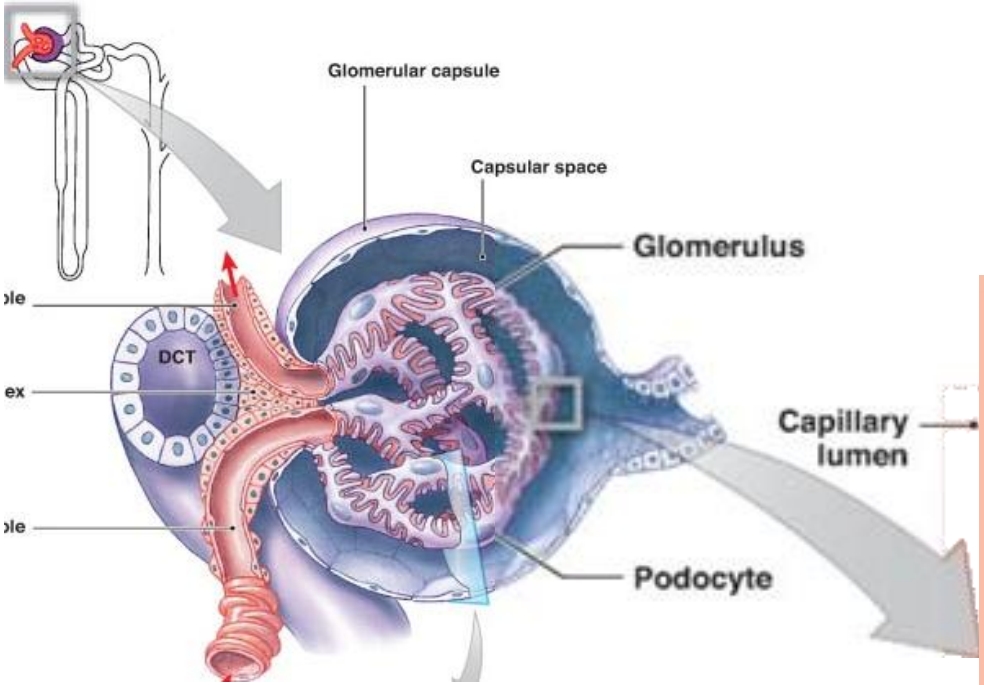
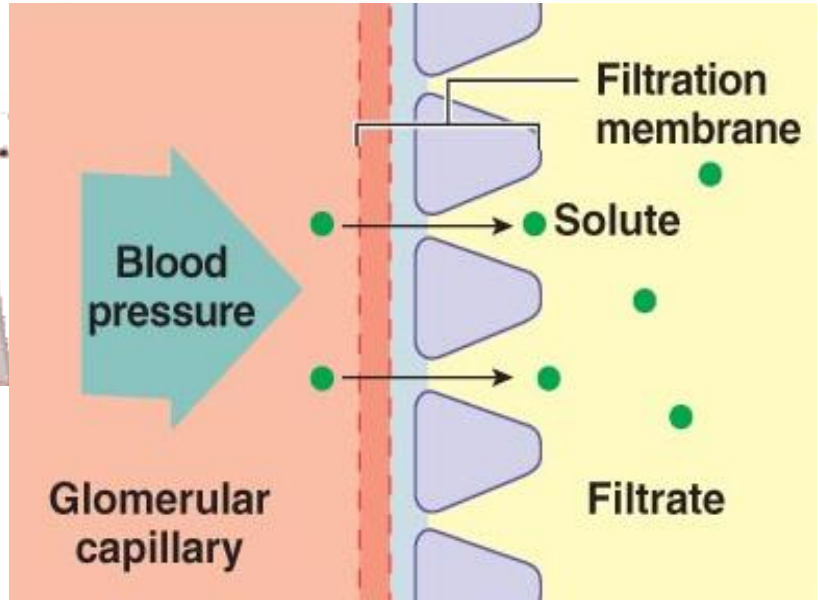


Fig. 44.21

Filtration







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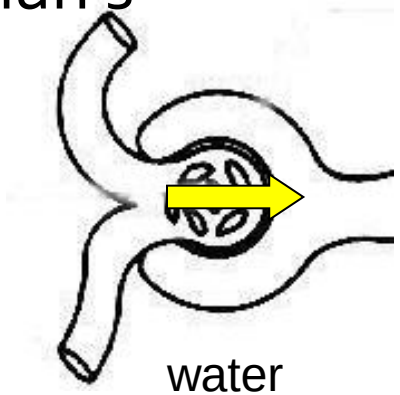
Glomerulus & Bowman's Capsule

1. Bowman's Capsule

- Nutrients flow from glomerulus into Bowman's capsule due to **high blood pressure**
  - 65 mm Hg; normal ~ 25 mm Hg
- Retain large molecules:
  - Cells
  - protein etc.
- Filter is non-selective for small molecules
  - water
  - small solutes: salt/ions, sugar/glucose, amino acid, vitamins, minerals
  - nitrogenous waste



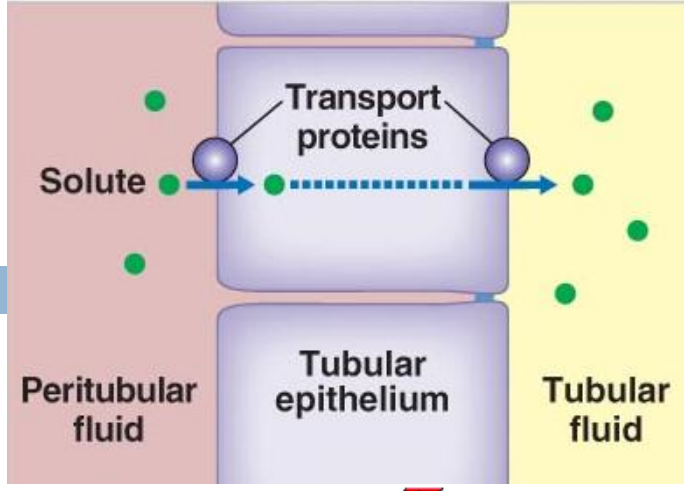
water
Na^+
H^+
Cl^-
glucose
amino acids
vitamins
minerals
urea
uric acid

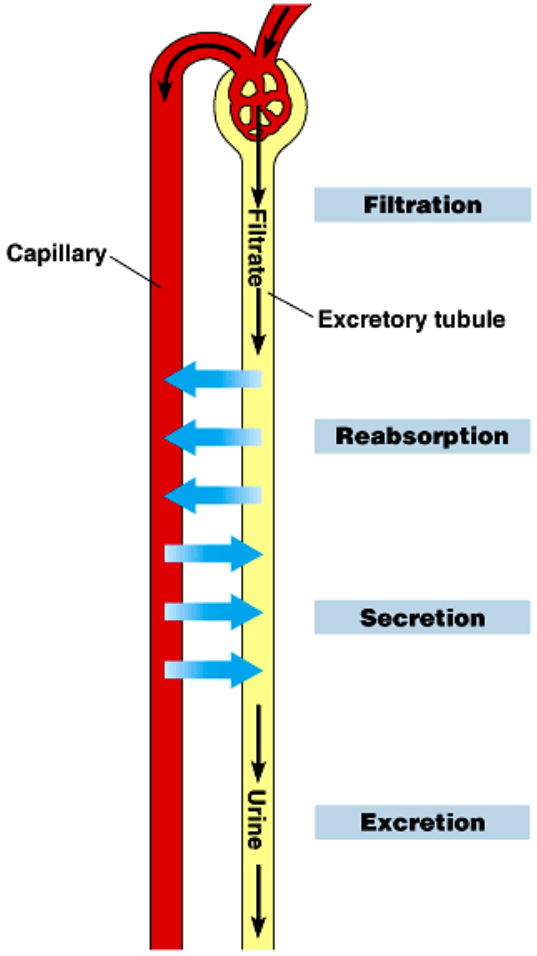
Filtration

Solute	Bowman's Capsule
water	Yes
NaCl	Yes
H^+	Yes
HCO_3-	Yes
glucose	Yes
amino acids	Yes
vitamins / minerals	Yes
urea / uric acid	Yes
plasma proteins	No
red blood cells	No
platelets	No

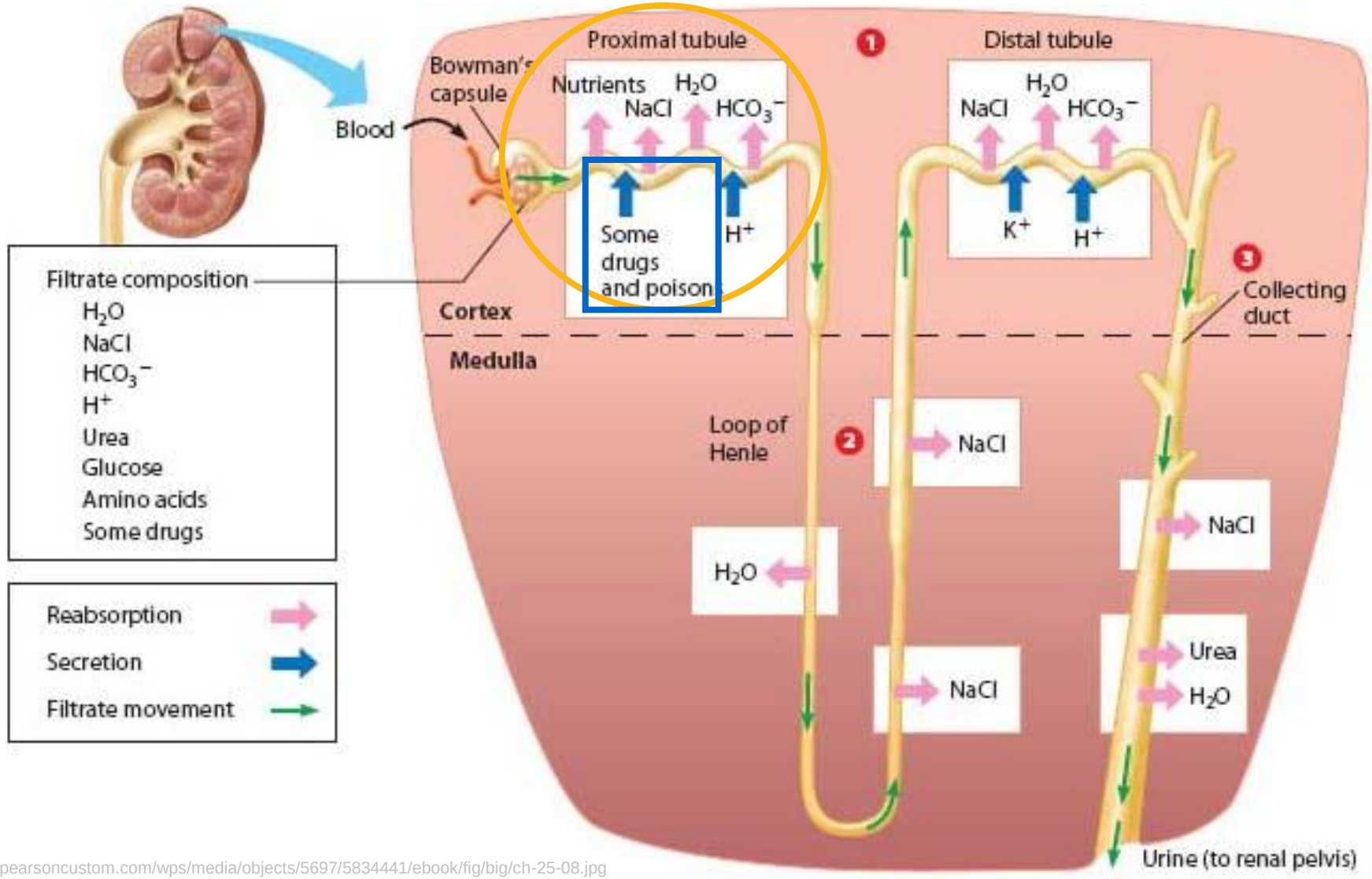
Secretion

- Movement of substances:
  - blood →interstitial fluid → filtrate
  - Opposite of reabsorption
  - materials will eventually be excreted from body
- Protein transporters move substances:
  - Nonessential or excess solutes
  - Waste
  - toxins





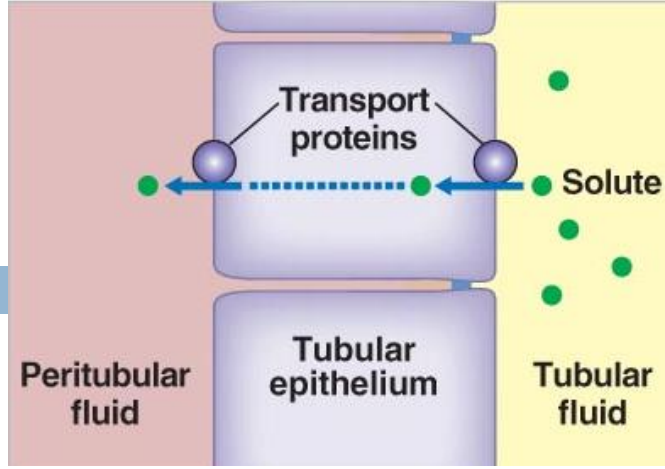
2. Proximal Tubule

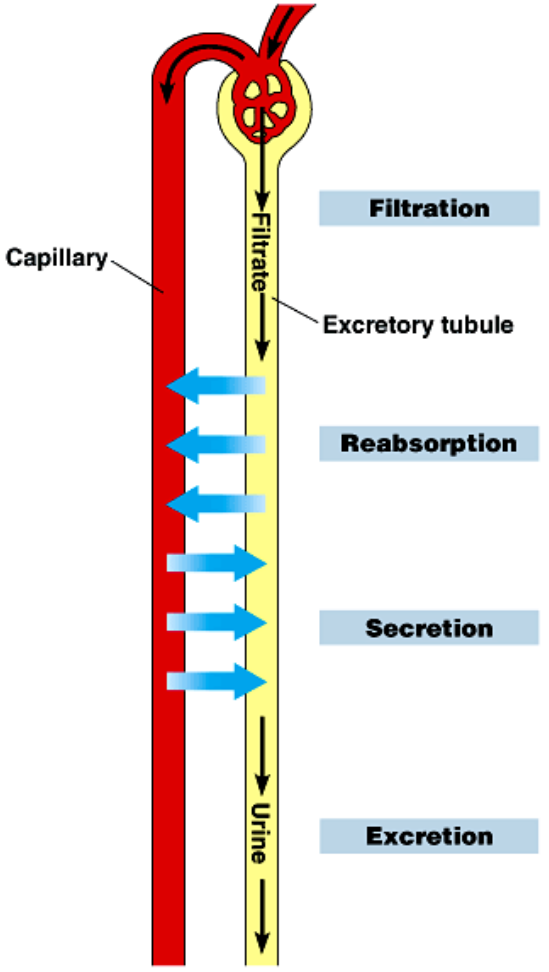


http://wps.pearsoncustom.com/wps/media/objects/5697/5834441/ebook/fig/big/ch-25-08.jpg

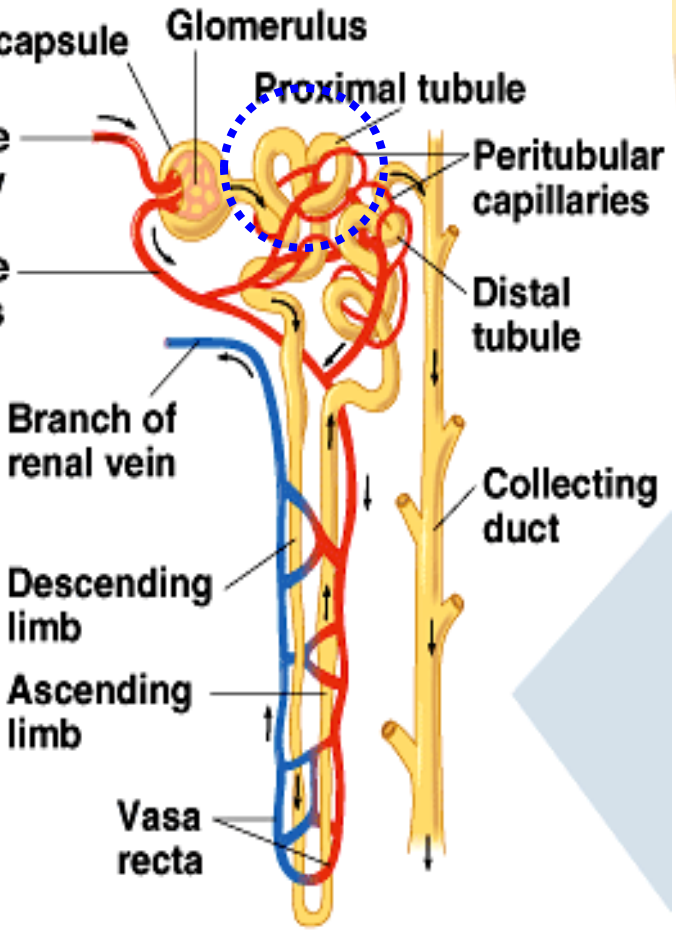
Reabsorption

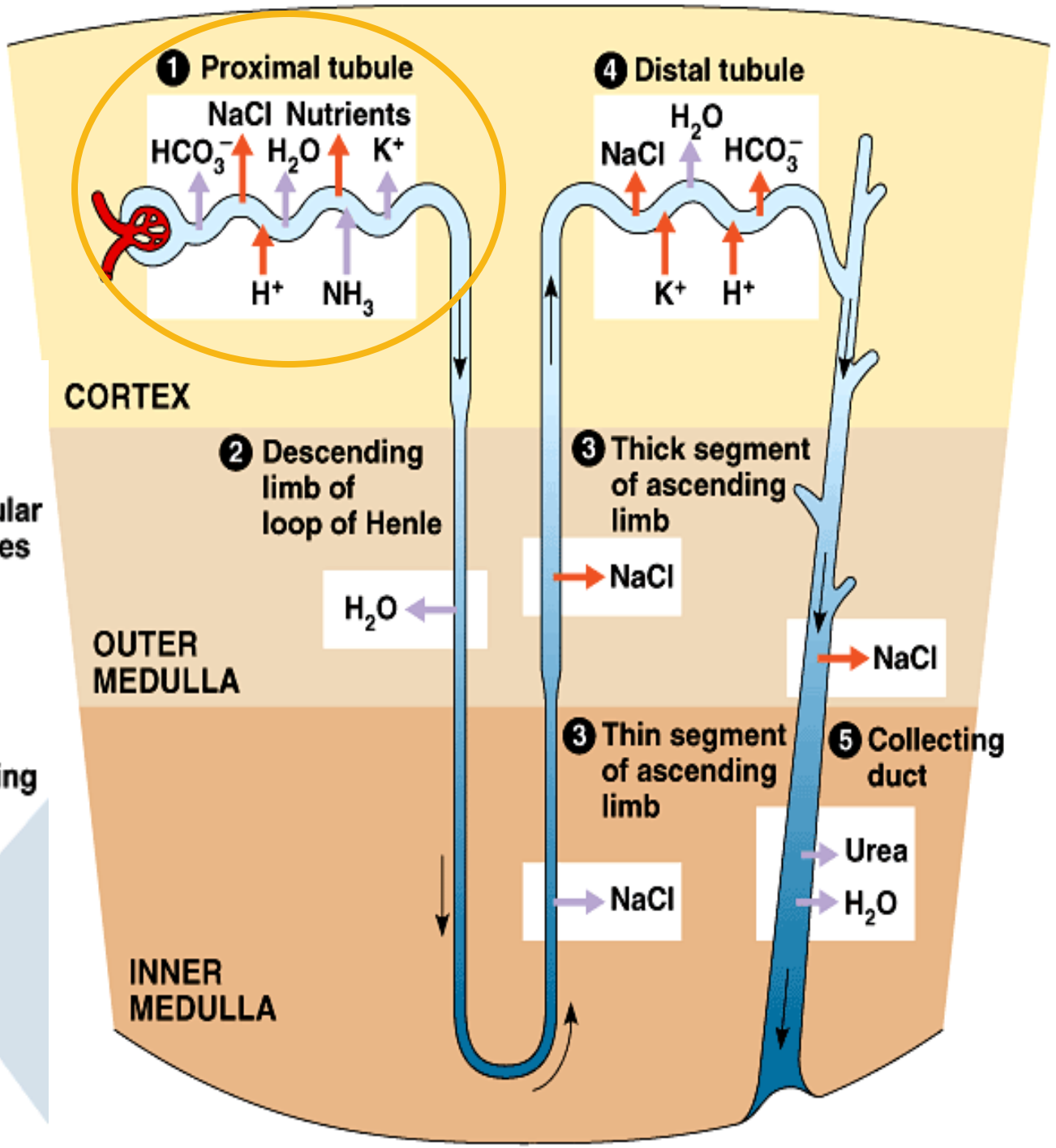
- Movement of substances:
  - filtrate → interstitial fluid →blood
  - About 99% of the substances in the filtrate are returned back into the body
- Protein transporters move substances
- Reabsorption saves us from having to continuously replenish our body with fluid





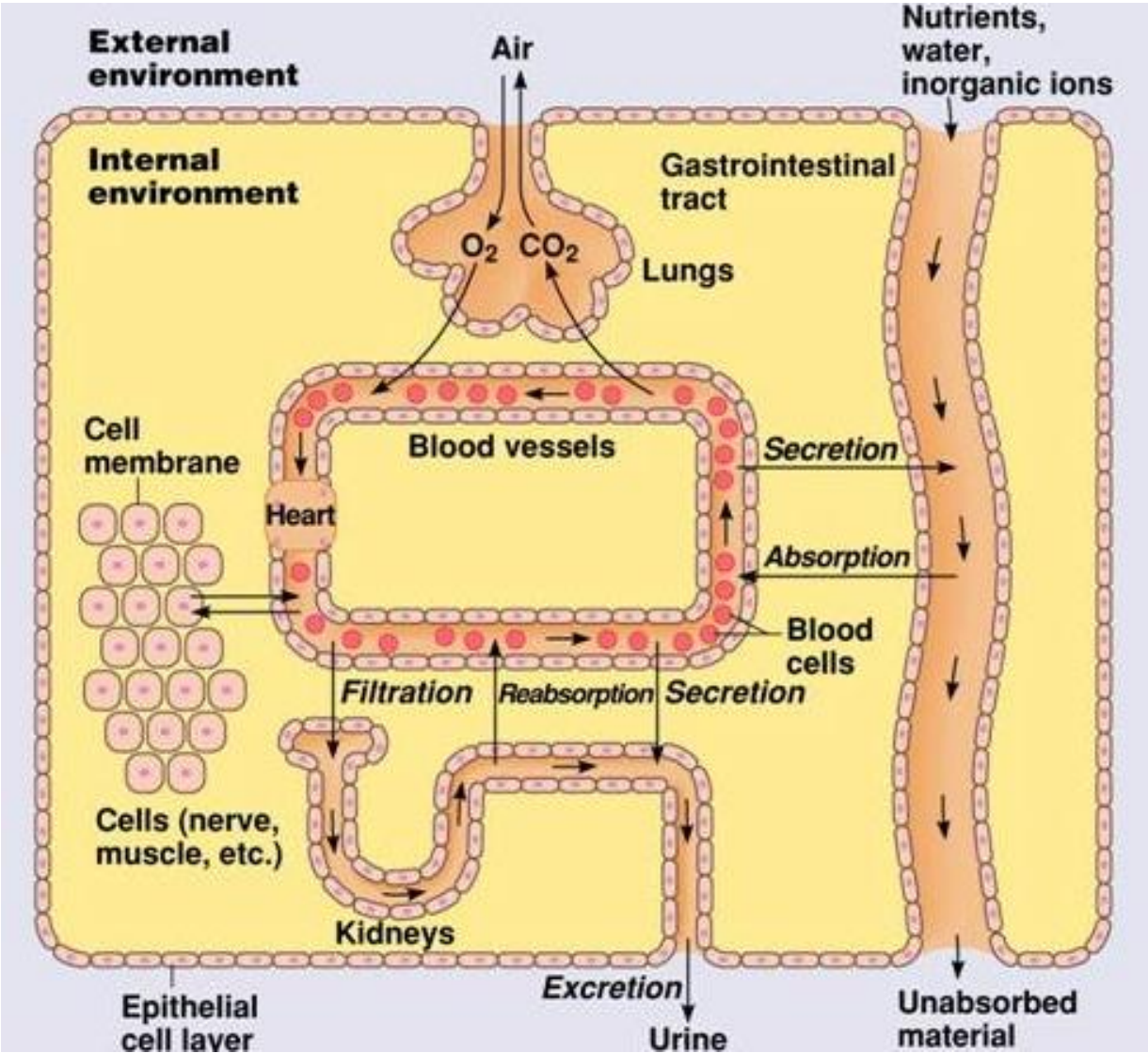
2. Proximal Tubule

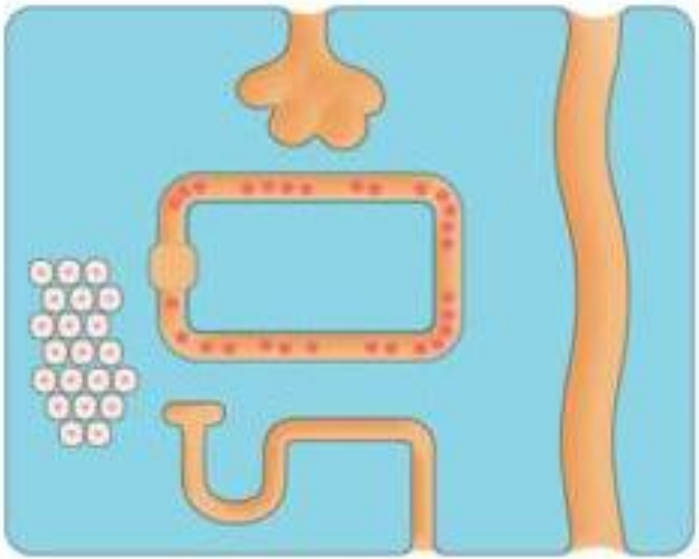




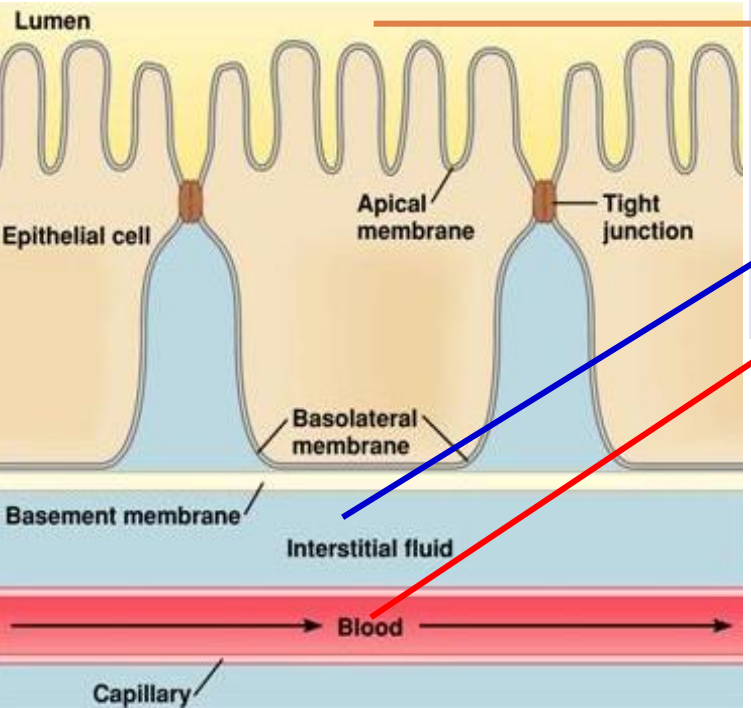
A simplified body plan

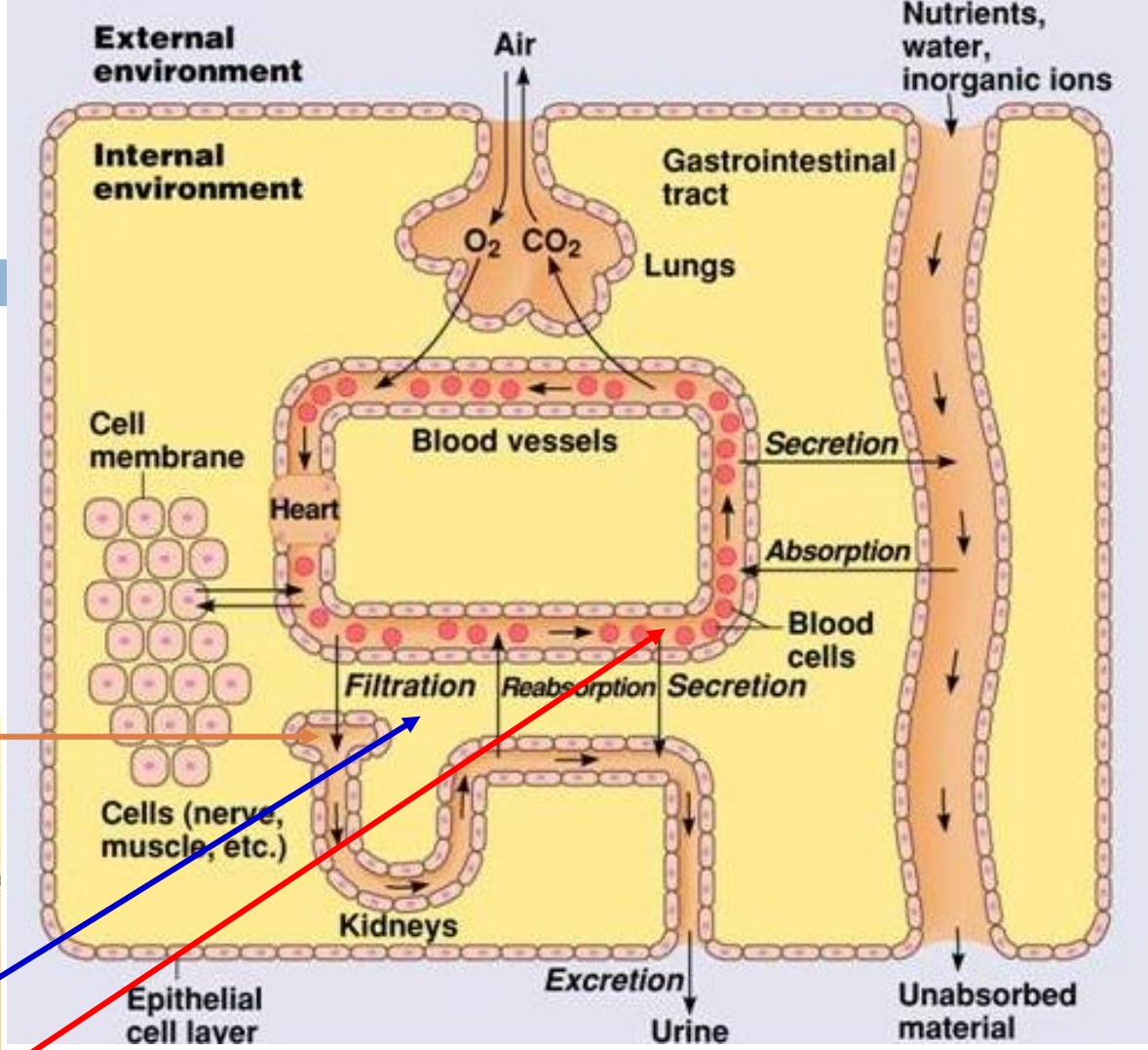
- Closer look at how reabsorption of water works
- Key terms:
  - transport epithelium
  - Interstitial fluid
  - Secondary transport





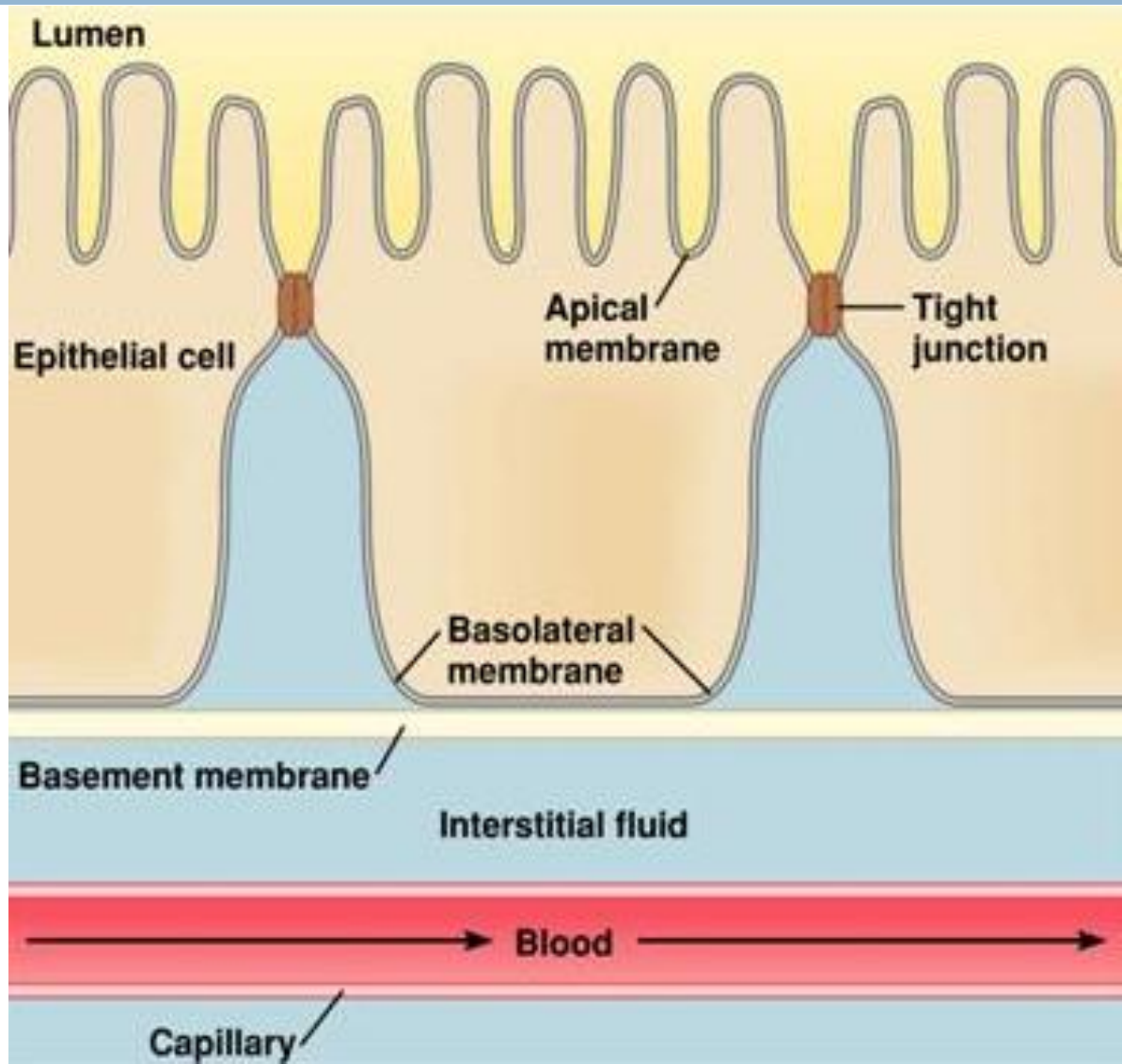
(e) Interstitial fluid (ISF)





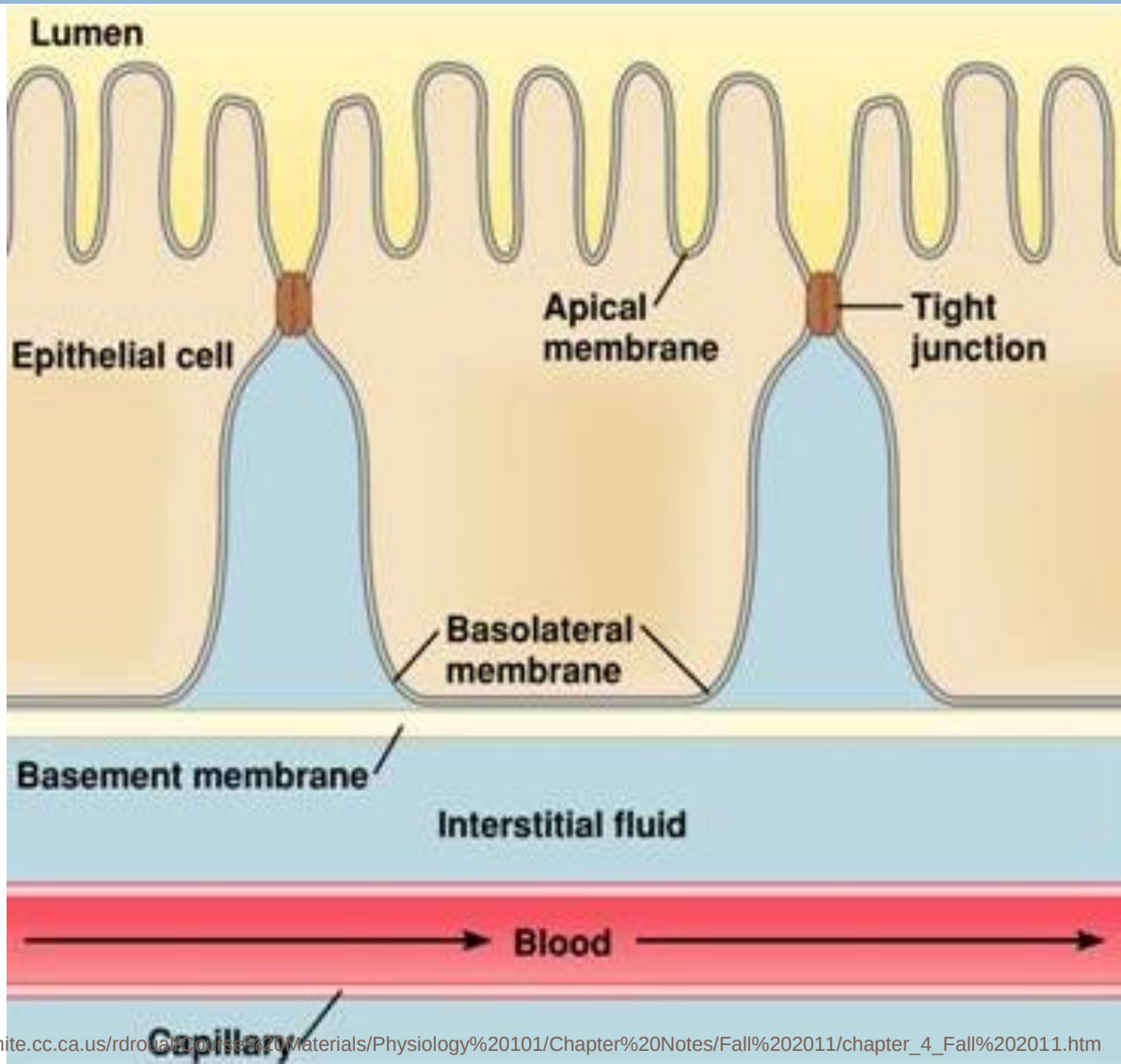
Transport Epithelium

- Layer of epithelial cells that regulate solute movement
- Lines the alveoli, intestine and kidney tubules
- Controls movement of specific solutes in controlled amounts in a particular direction



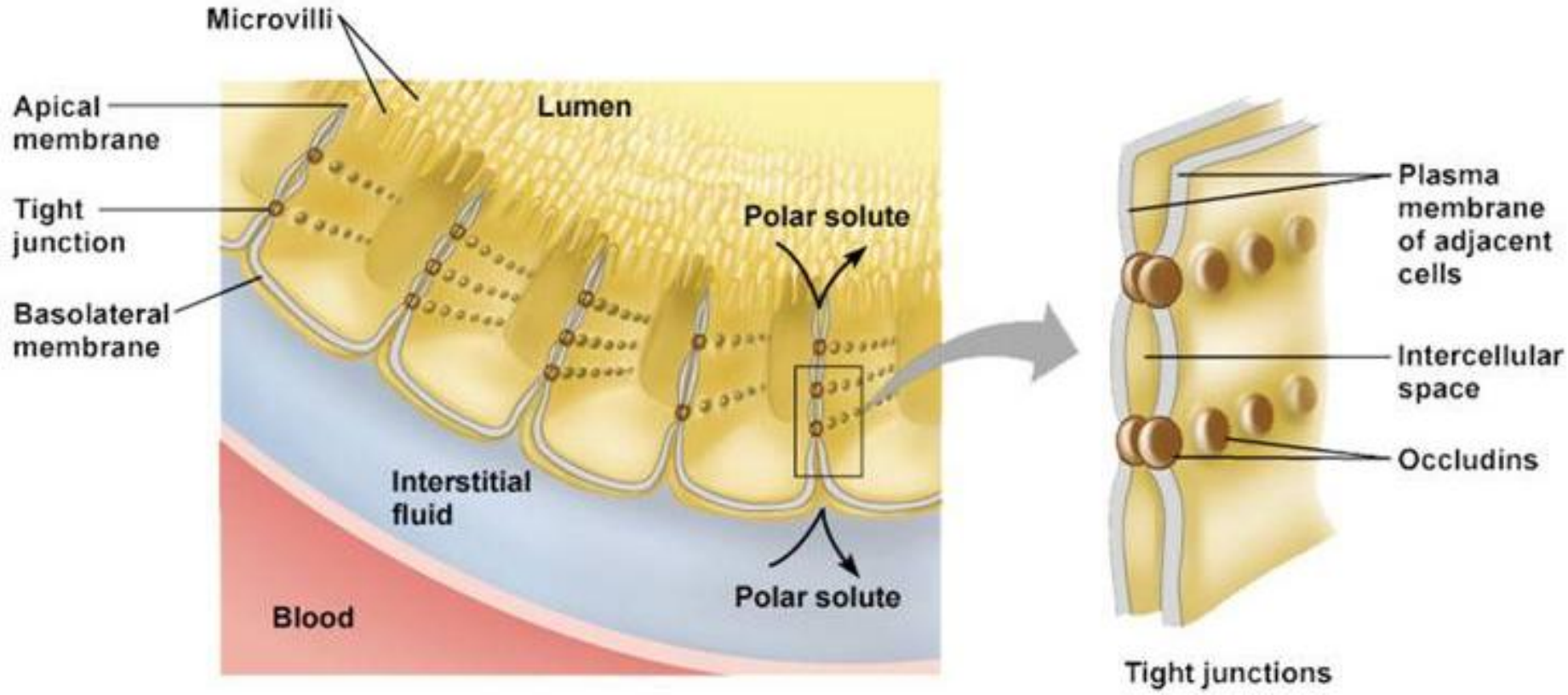
Transport Epithelium

- **Apical** membrane: faces the lumen of a body cavity
- **Basolateral** (base & sides) membrane: facing the interstitial fluid
- **Basement** membrane: anchors the basolateral membrane and supports the epithelial layer

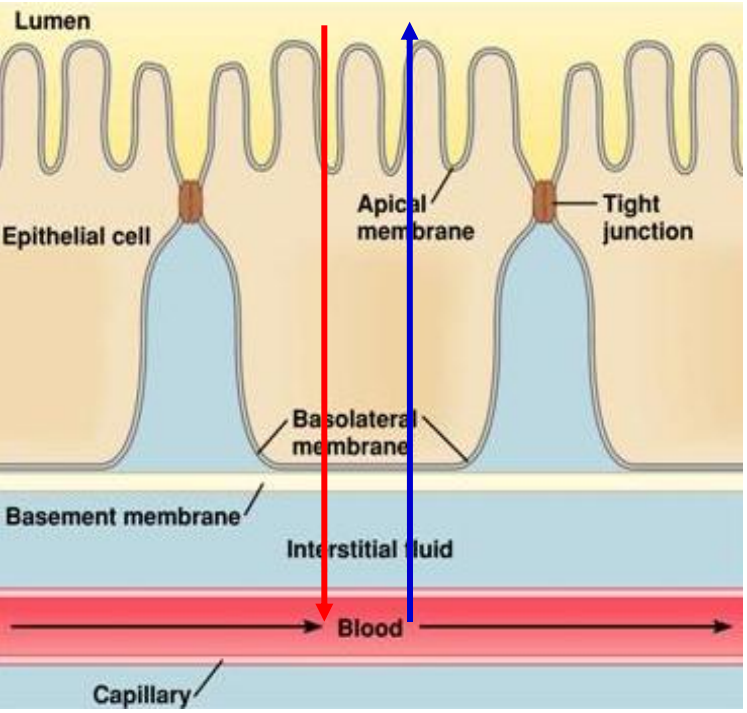


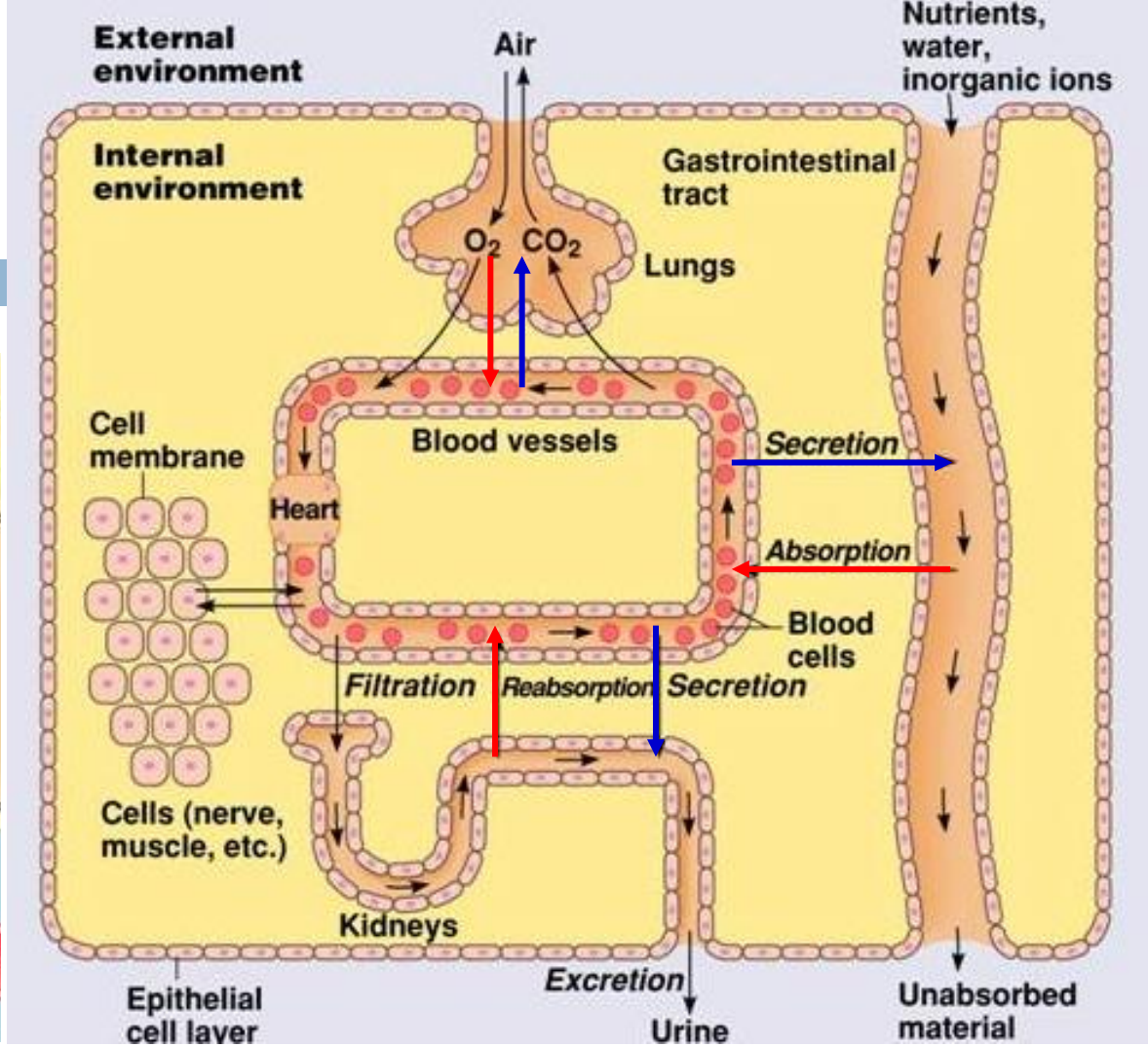
Tight Junctions

- Cells joined by tight junctions that form an impermeable barrier between internal cells and environment
- Limit passage of material through the spaces between the cells



Transport

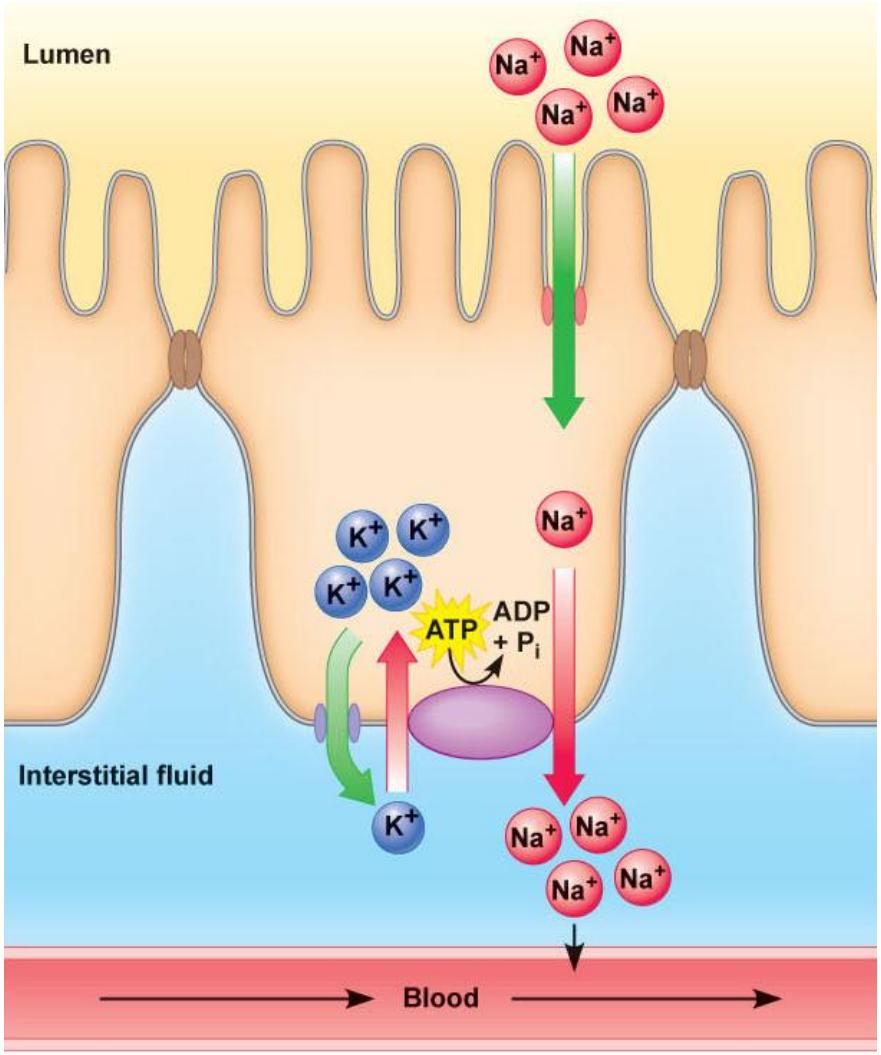




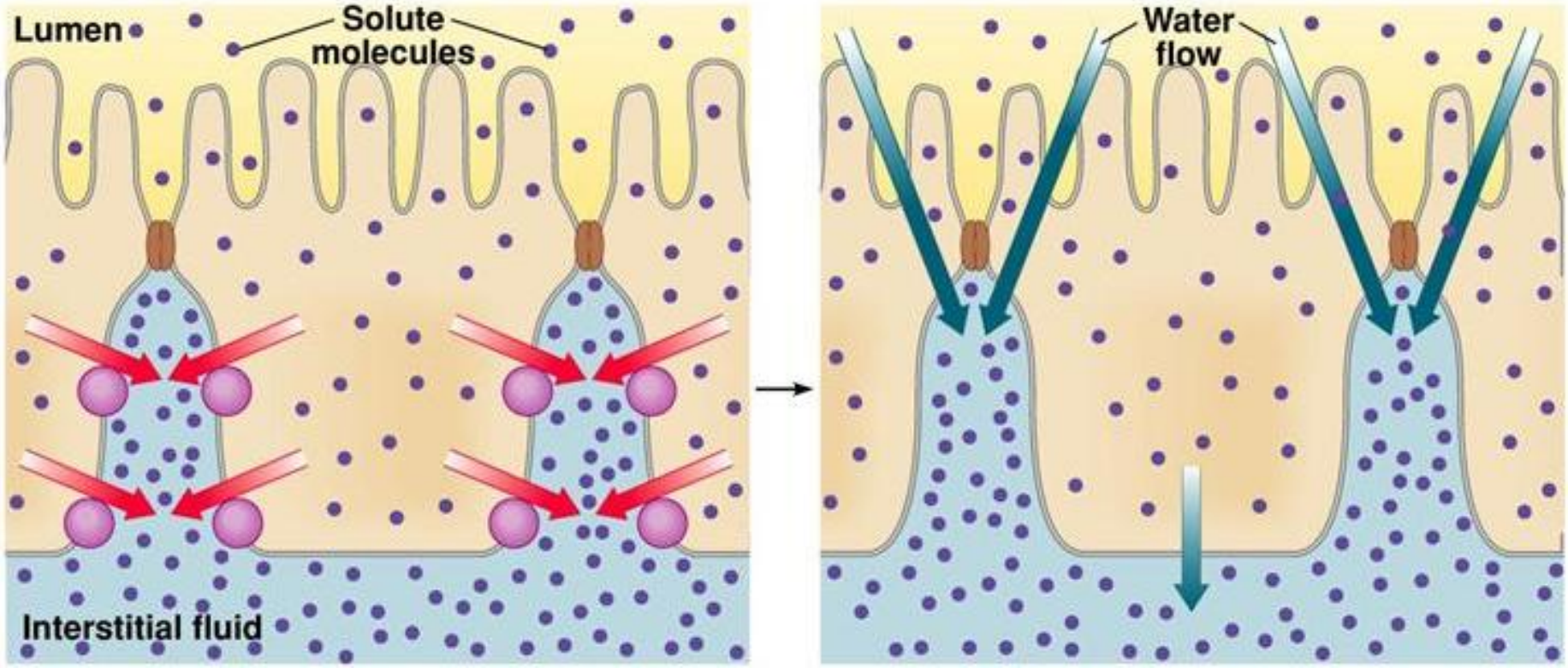
- **(Re)Absorption**: process of transporting material from the outside into the internal environment
- **Secretion**: process of transporting material from the internal environment to the outside

Polarized Epithelial Cells

- Transport across a cell is possible because the membrane on one side has transport systems that are different from the other side.
- This means that epithelial cells are **polarized**.



Water transport across epithelium is secondary to solute transport



- Active transport solute molecules increases the solute concentration in the interstitial fluid.
- Water flows from the lumen through the cells and to the interstitial fluid.

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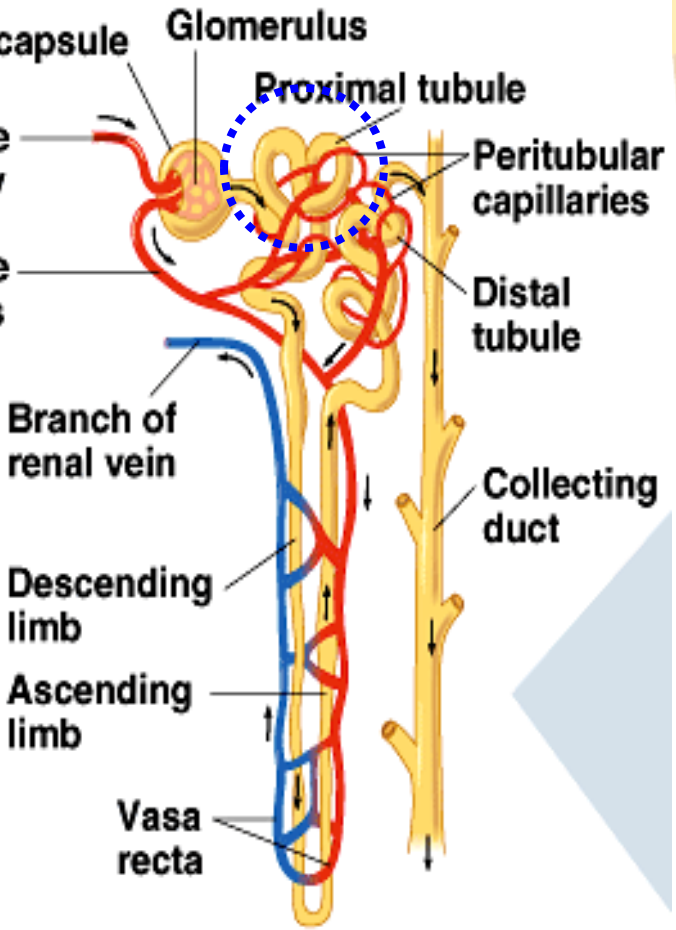
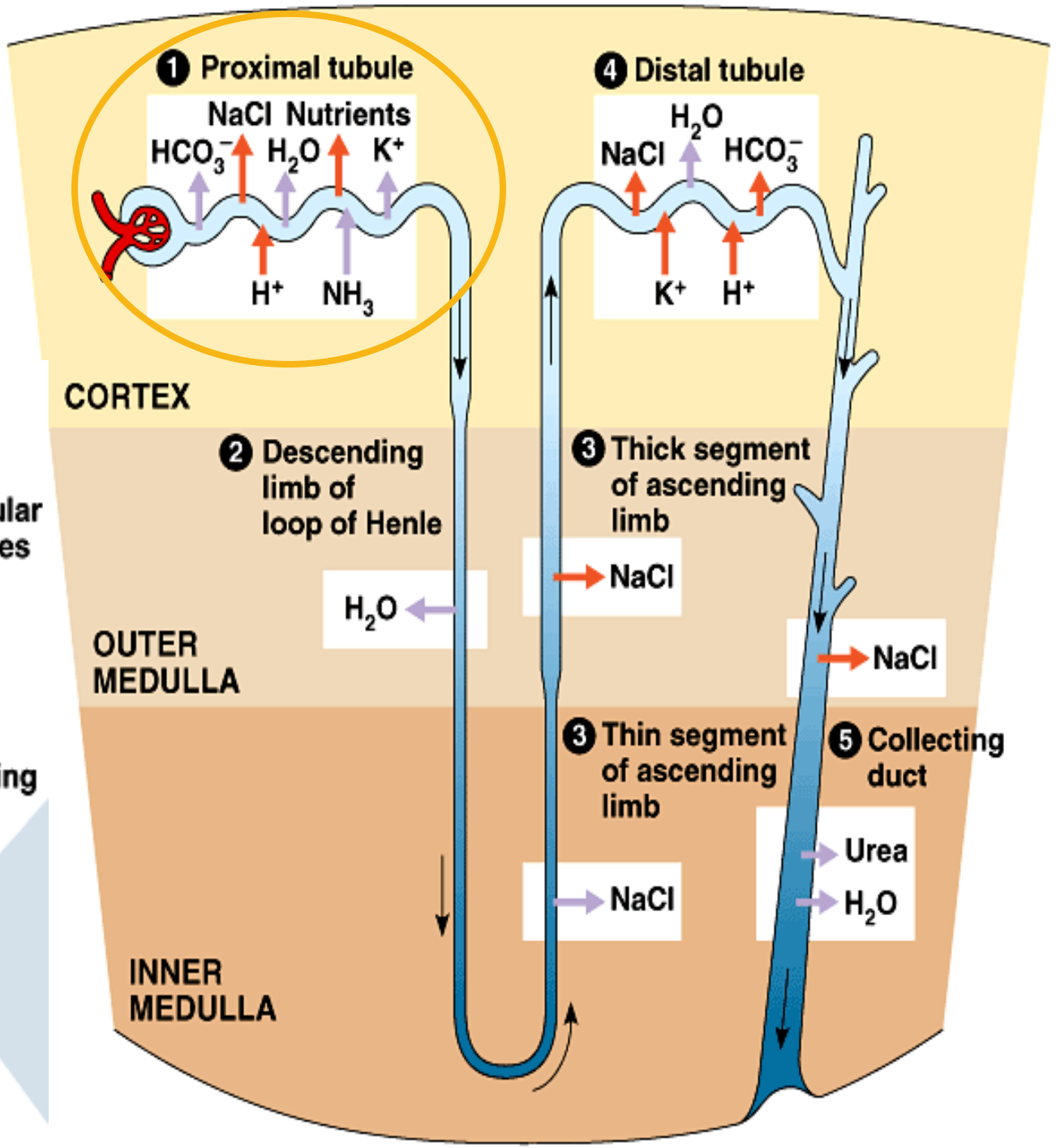
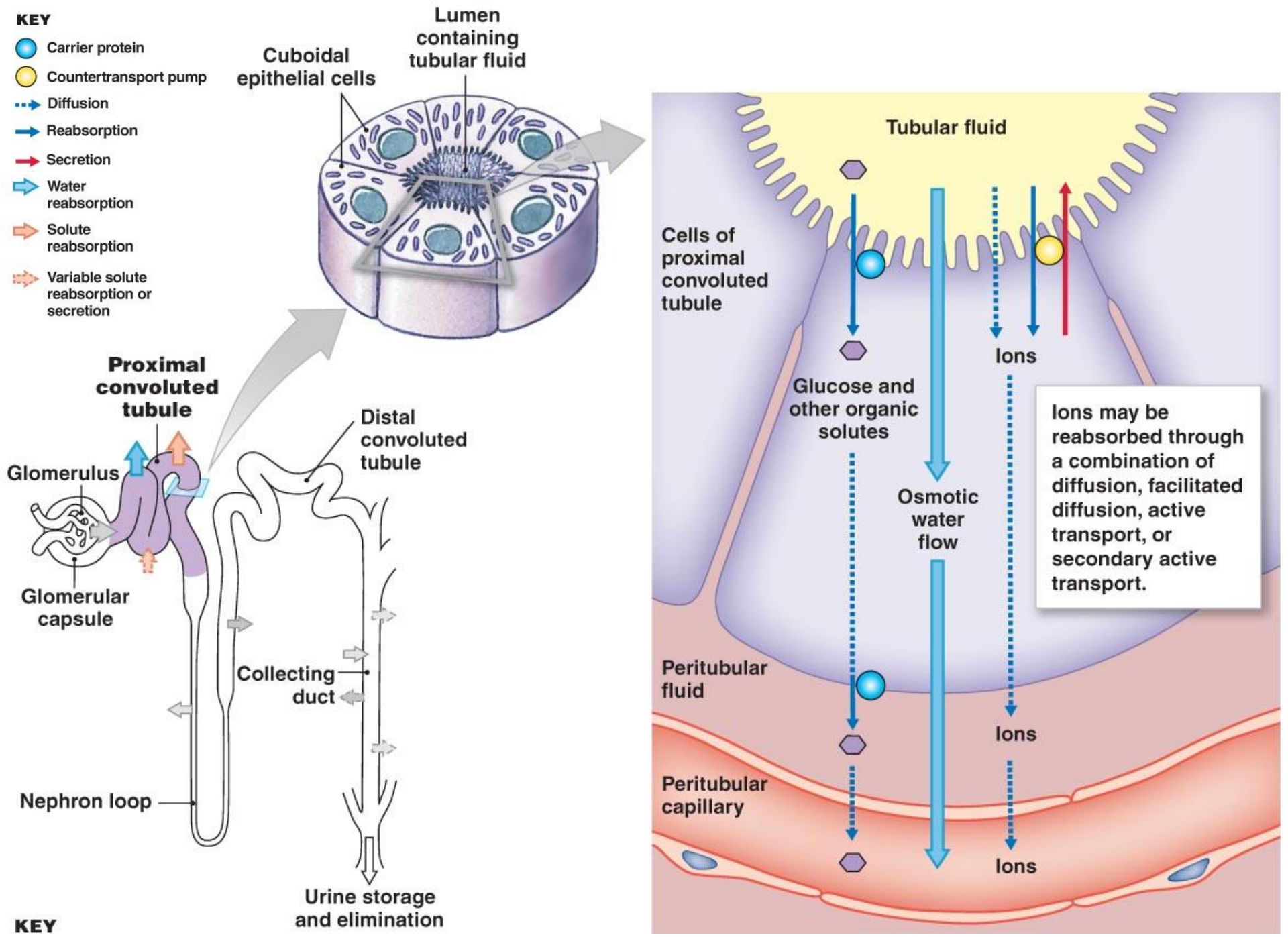
2. Proximal Tubule

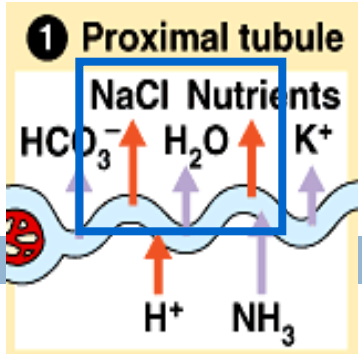




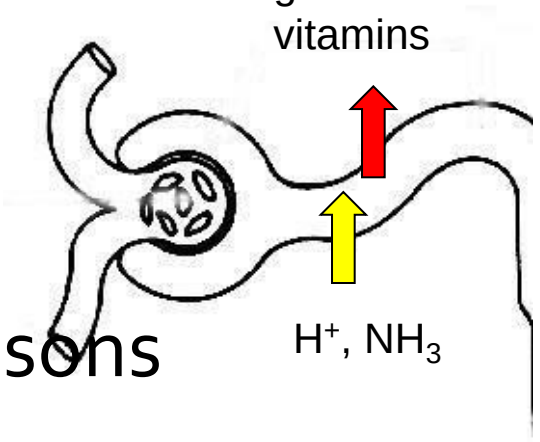


http://www.highlands.edu/academics/divisions/scipe/biology/faculty/harnden/2122/images/pct.jpg

2. Proximal Tubule



- Selective reabsorption of nutrients into capillaries (peritubular)
  - Active transport of valuable nutrients (glucose, amino acids, vitamins) and salt (NaCl)
  - Passive transport of water by osmosis
- pH determined by:
  - HCO3- reabsorption
  - H+ and NH3 secretion
- Secretion of drugs and other poisons



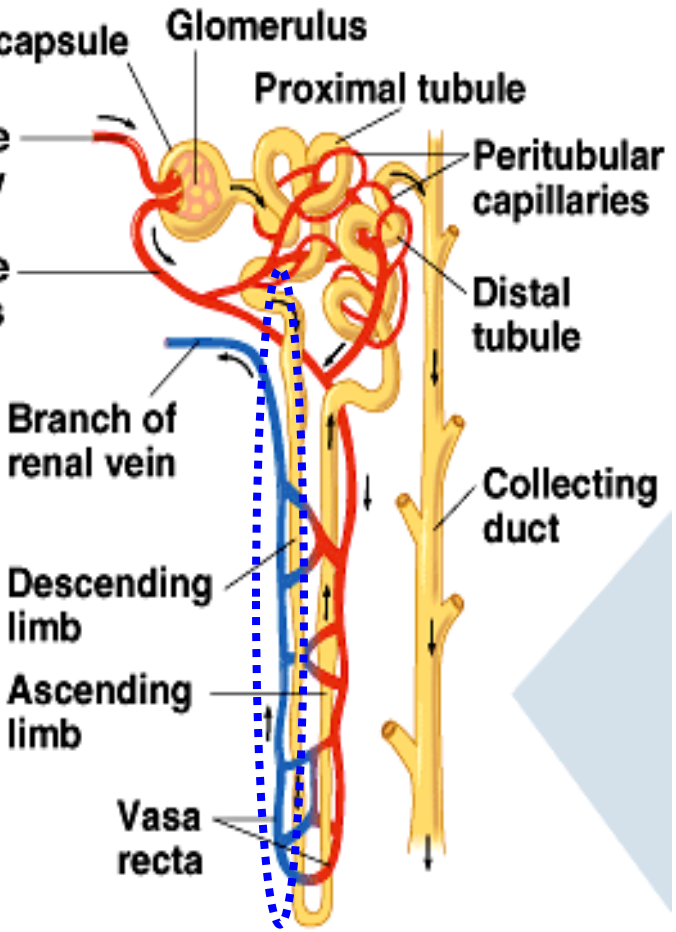
Nutrient Flow

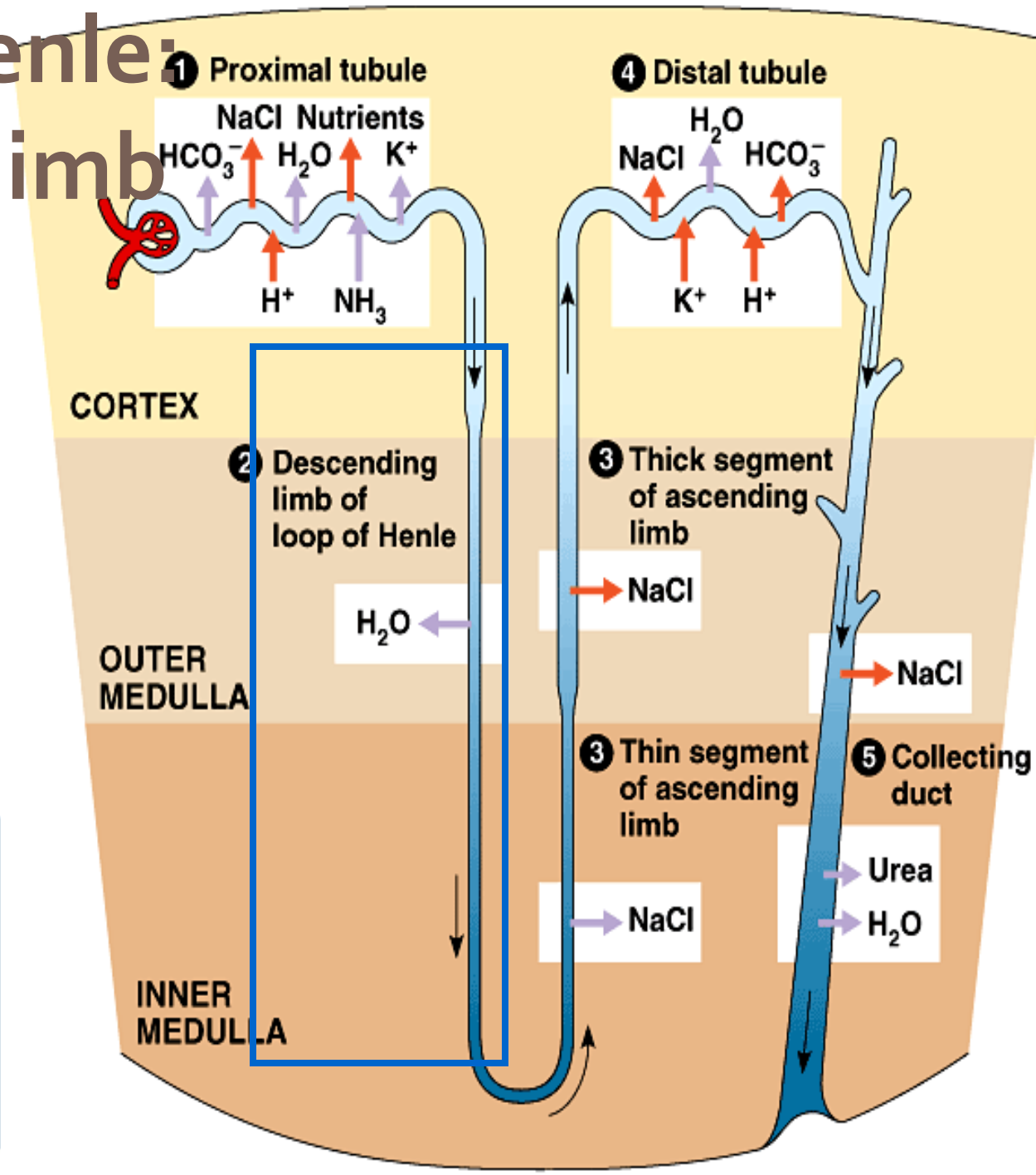
Solute	Proximal tubule	Loop of Henle	Distal tubule	Collecting duct
water				
NaCl				
H^+				
HCO_3-				
glucose				
amino acids				
vitamins / minerals				
urea / uric acid				

Nutrient Flow

Solute	Proximal tubule	Loop of Henle	Distal tubule	Collecting duct
water	R			
NaCl	R			
H^+	S			
HCO_3-	R			
glucose	R			
amino acids	R			
vitamins / minerals	R			
urea / uric acid	S			

3. Loop of Henle: Descending limb





Filtrate Concentration

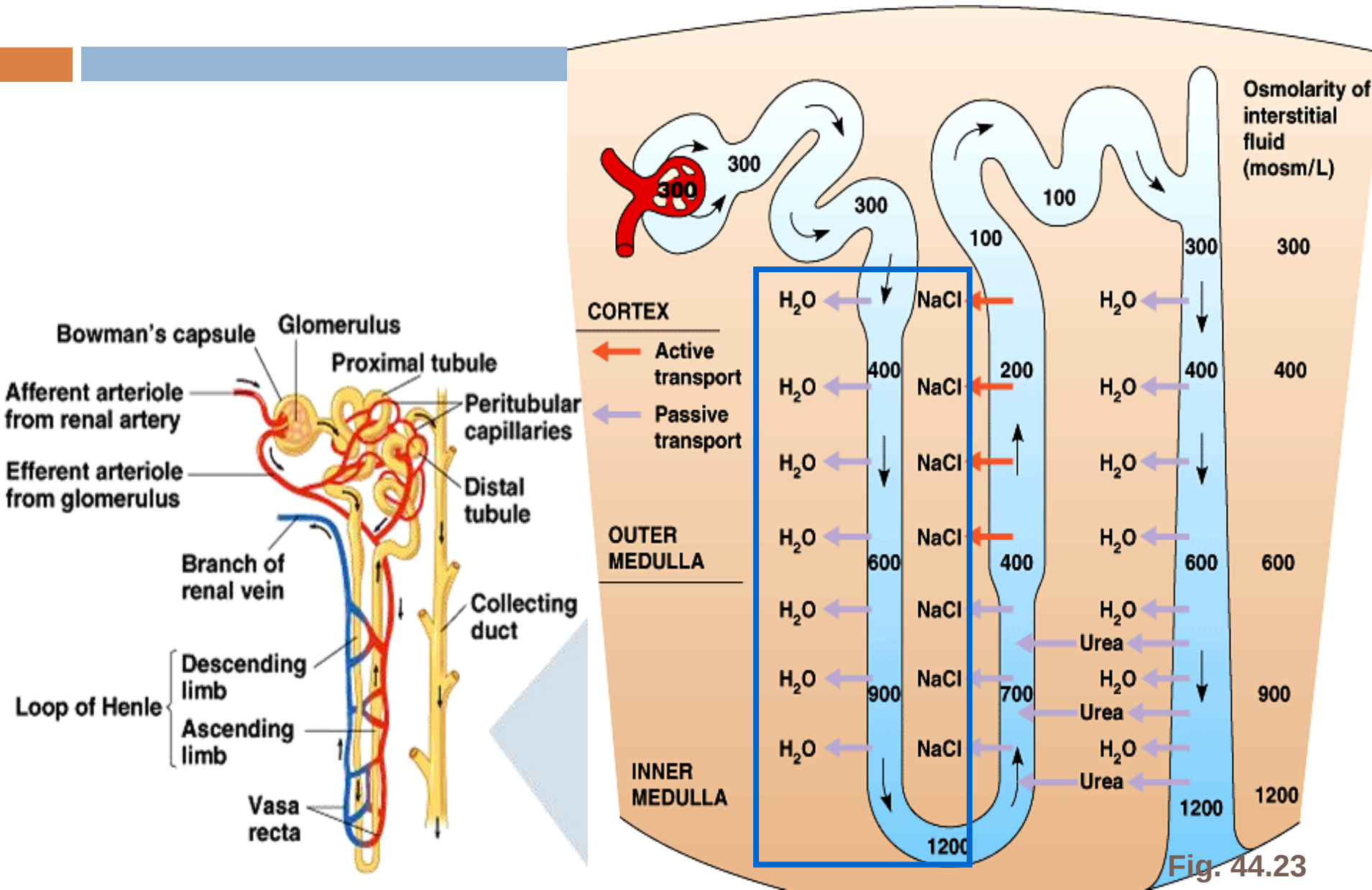
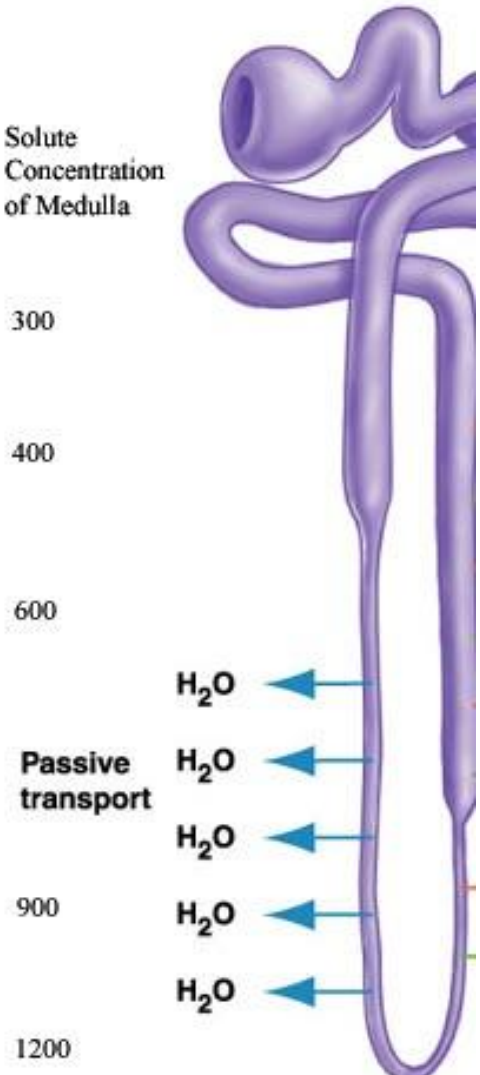


Fig. 44.23

3. Loop of Henle: Descending Limb



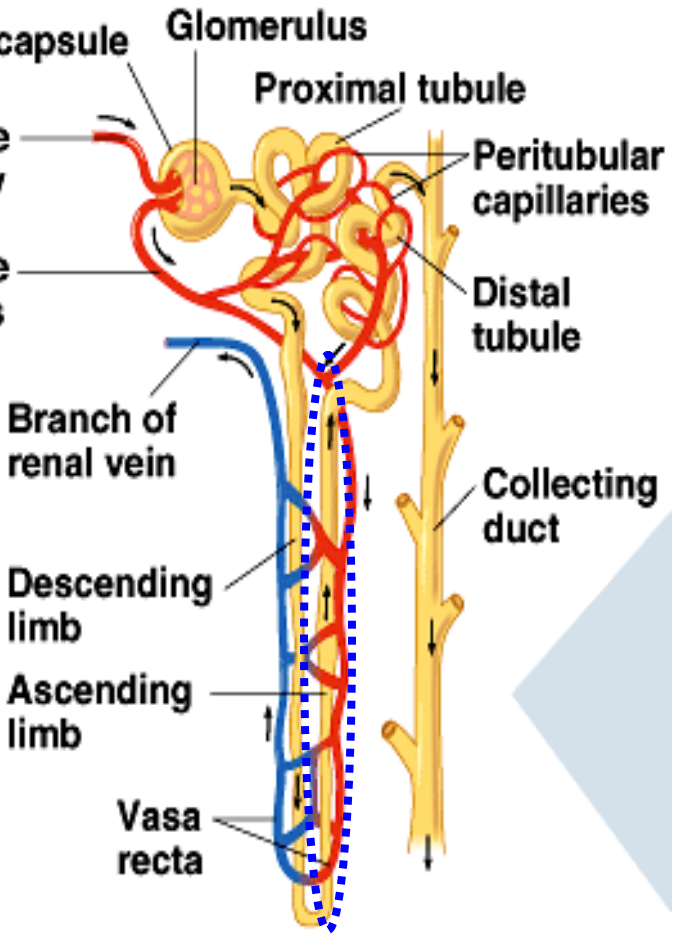
- Transport epithelium is only permeable to water
- Impermeable to salt and other small solutes
- Reabsorption of water by osmosis
  - Interstitial fluid is hyperosmotic
  - Osmolarity of interstitial fluid becomes progressively greater from outer cortex to inner medulla
- Filtrate becomes more concentrated as it moves down into the medulla

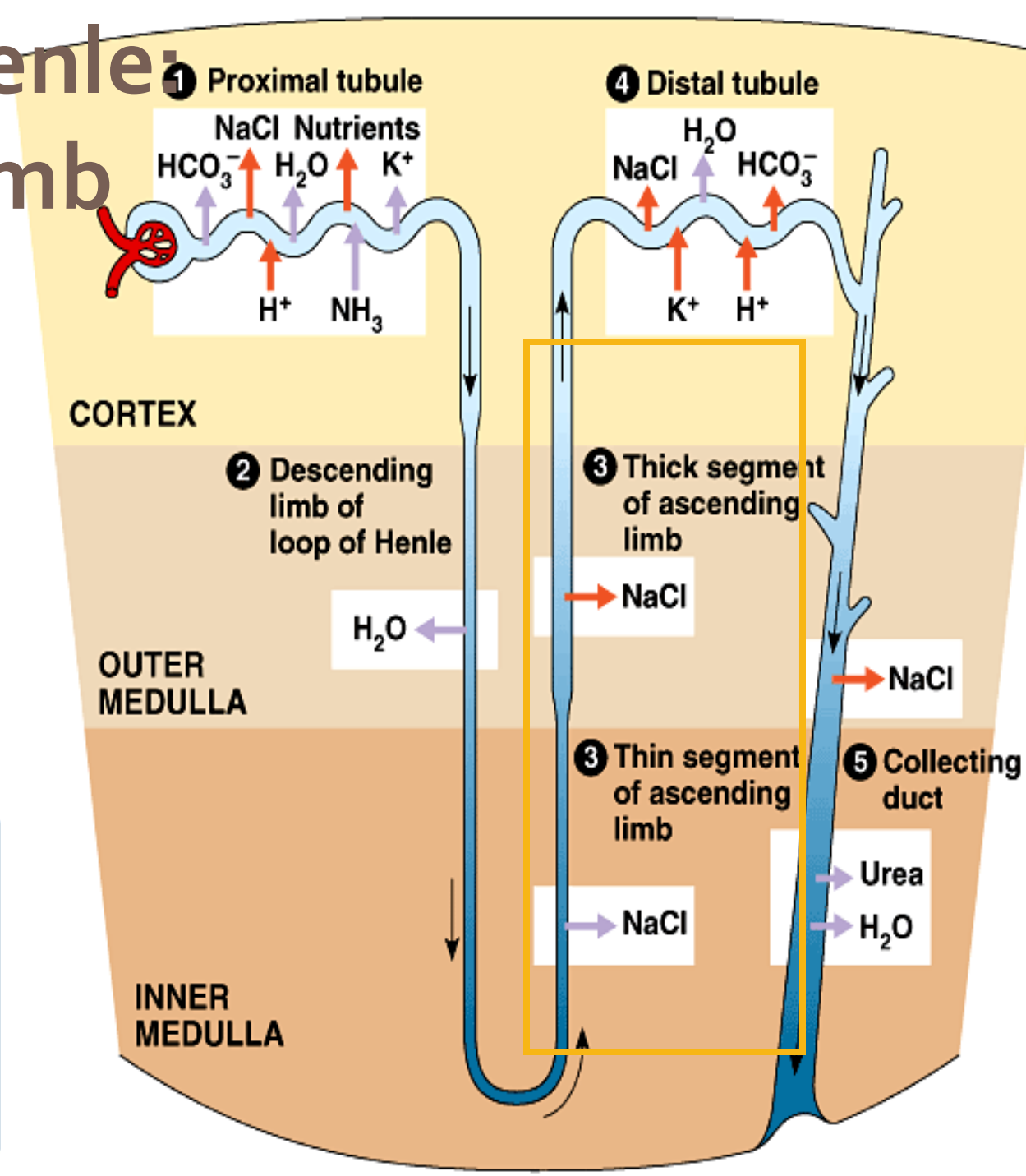
http://www.uic.edu/classes/bios/bios100/lecturesf04am/loopofhenle03b.jpg

Things to keep in mind

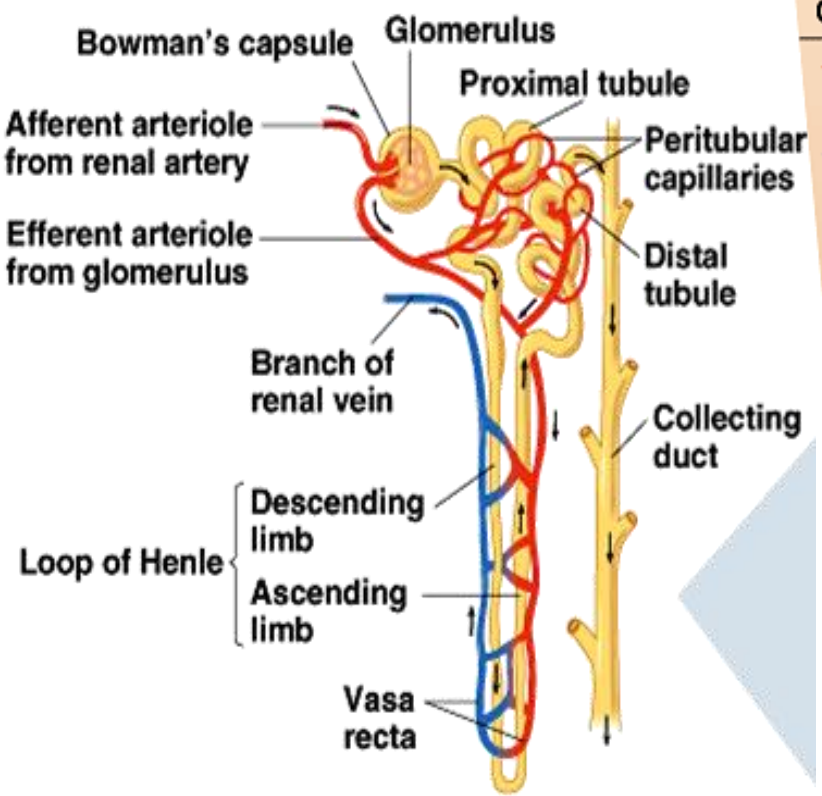
- What is the mechanism that maintains the osmolarity difference in the nephron?
- What keeps the osmolarity of the interstitial fluid to become progressively greater from the outer cortex to the inner medulla?

4. Loop of Henle: Ascending limb





Filtrate Concentration



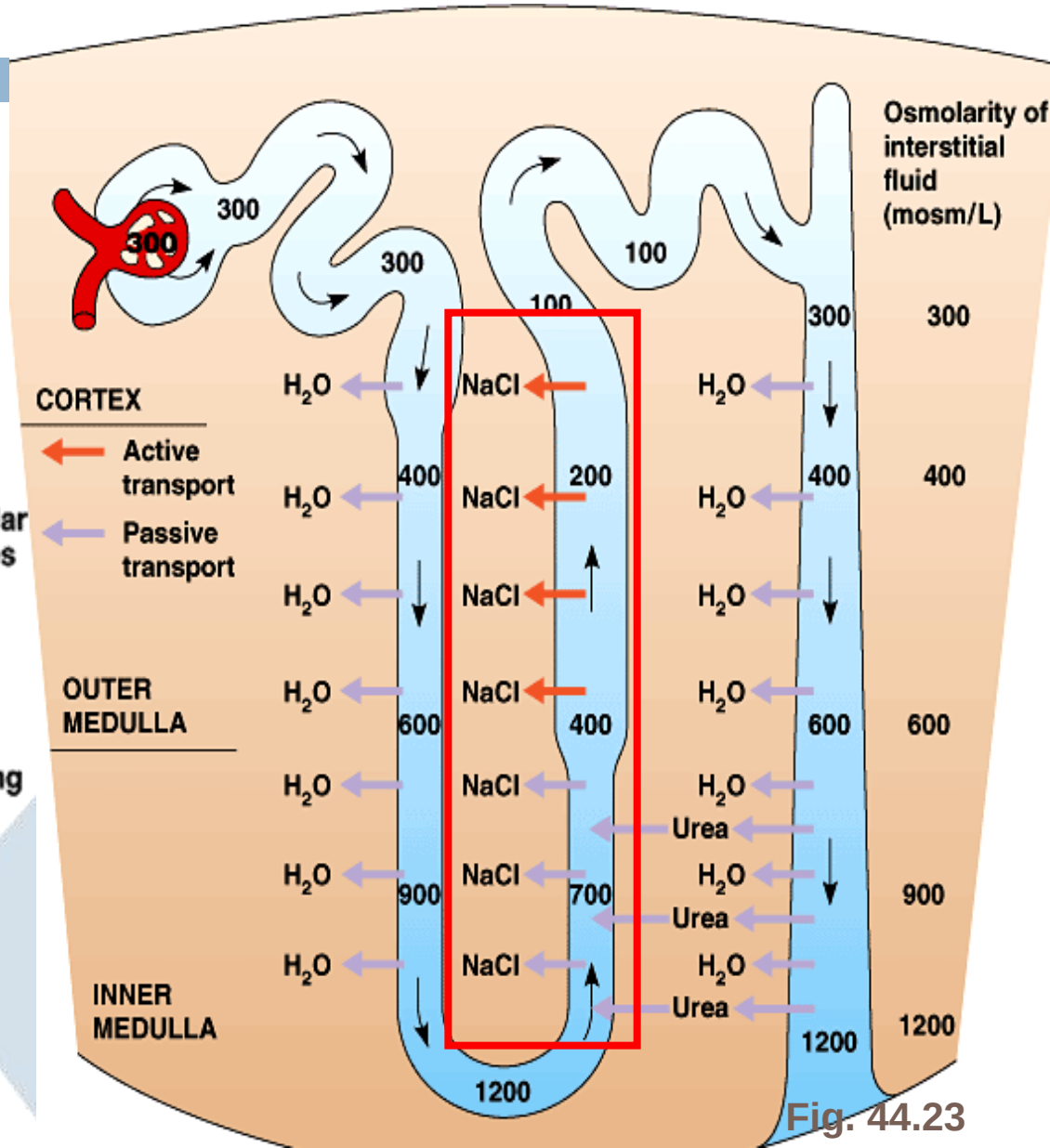
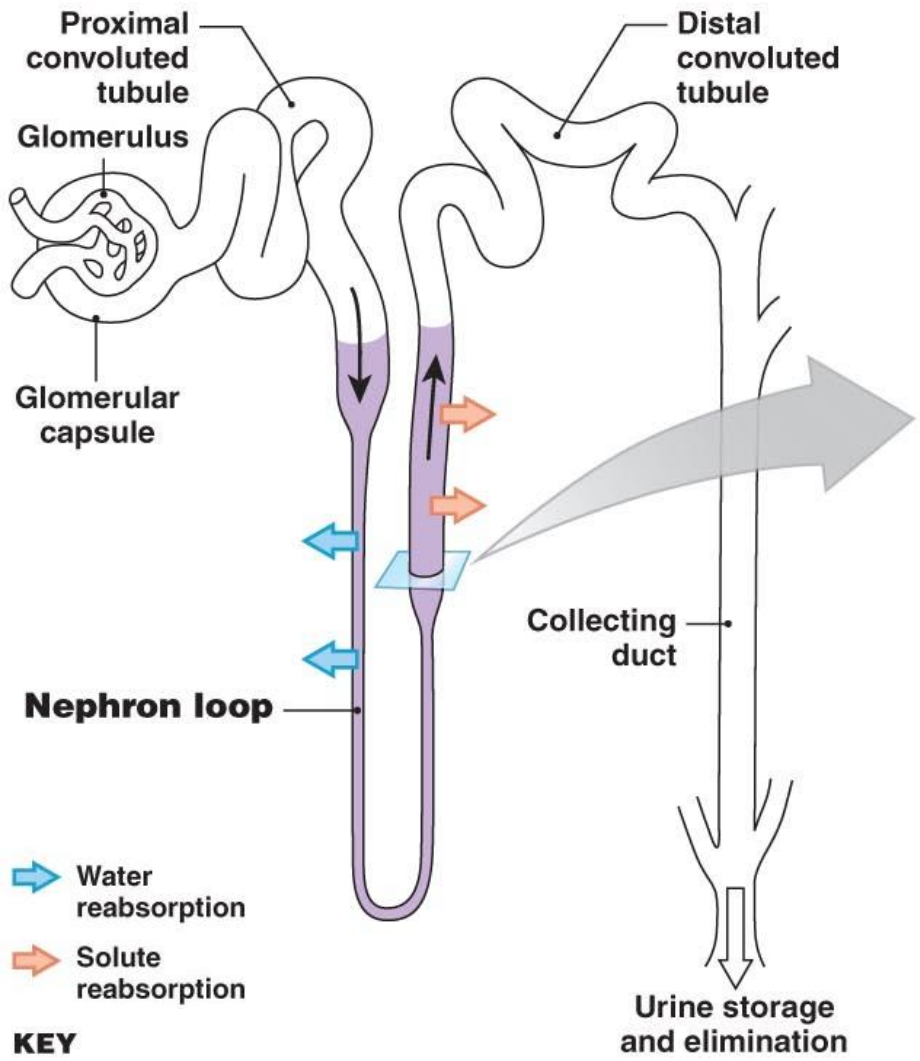
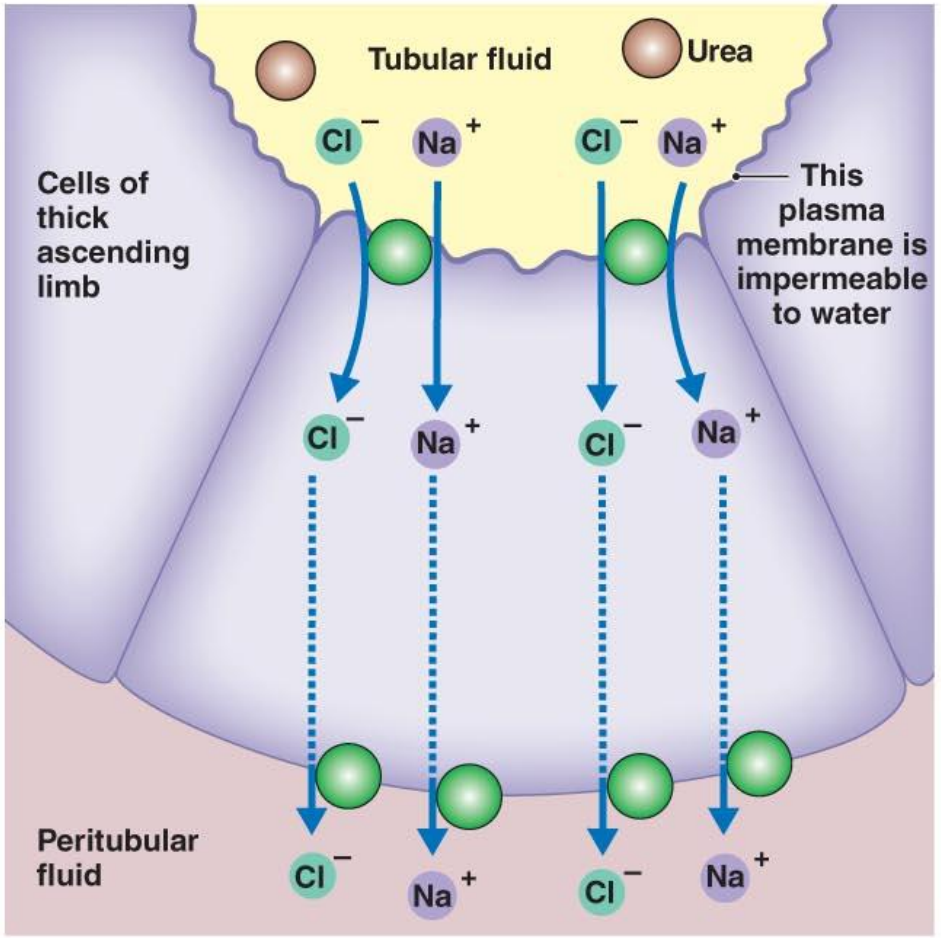


Fig. 44.23

The close proximity of the thin descending and the thick ascending limbs of the nephron loop, which enables the exchange called countercurrent multiplication

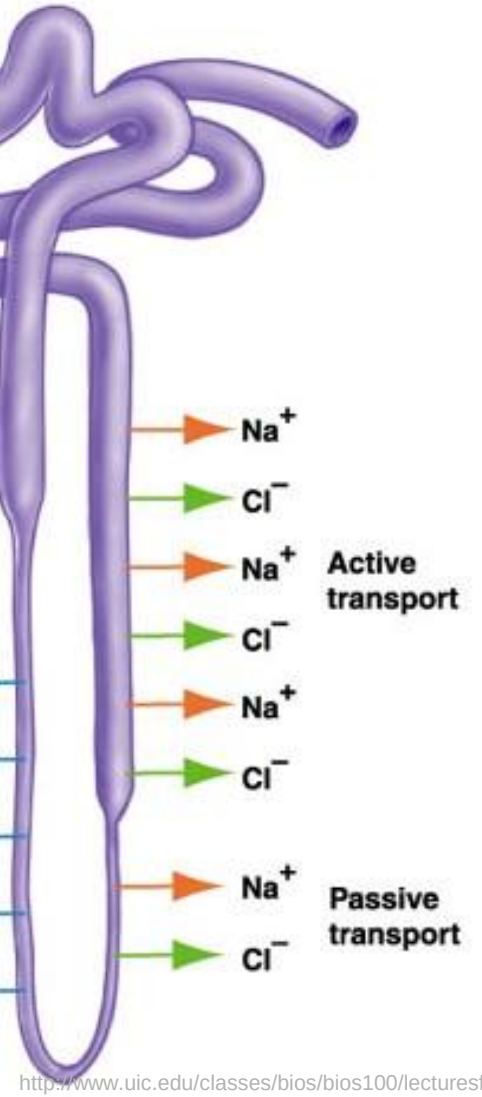


The transport activities performed by cells of the thick ascending limb



http://www.highlands.edu/academics/divisions/scipe/biology/faculty/harnden/2122/images/loop.jpg

4. Loop of Henle: Ascending Limb



- Transport epithelium is permeable to salt but not water
- Thin segment: NaCl passive transport
  - Diffusion possible due to concentrated filtrate
  - Increases osmolarity of the inner medulla
- Thick segment: NaCl active transport
- Filtrate becomes more dilute as it moves up towards the cortex

http://www.uic.edu/classes/bios/bios100/lecturesf04am/loopofhenle03b.jpg

Nutrient Flow

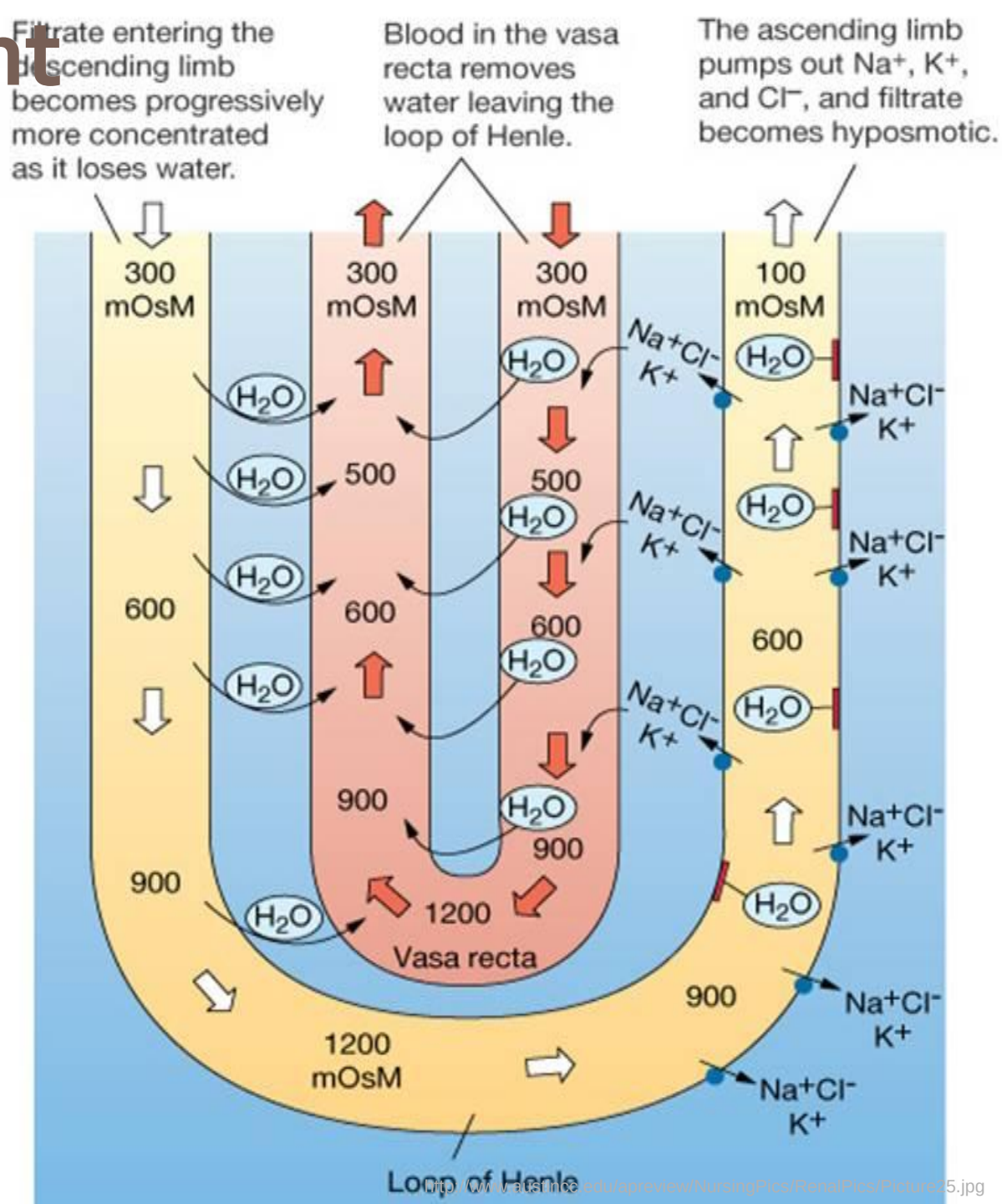
Solute	Proximal tubule	Loop of Henle	Distal tubule	Collecting duct
water	R			
NaCl	R			
H^+	S			
HCO_3-	R			
glucose	R			
amino acids	R			
vitamins / minerals	R			
urea / uric acid	S			

Nutrient Flow

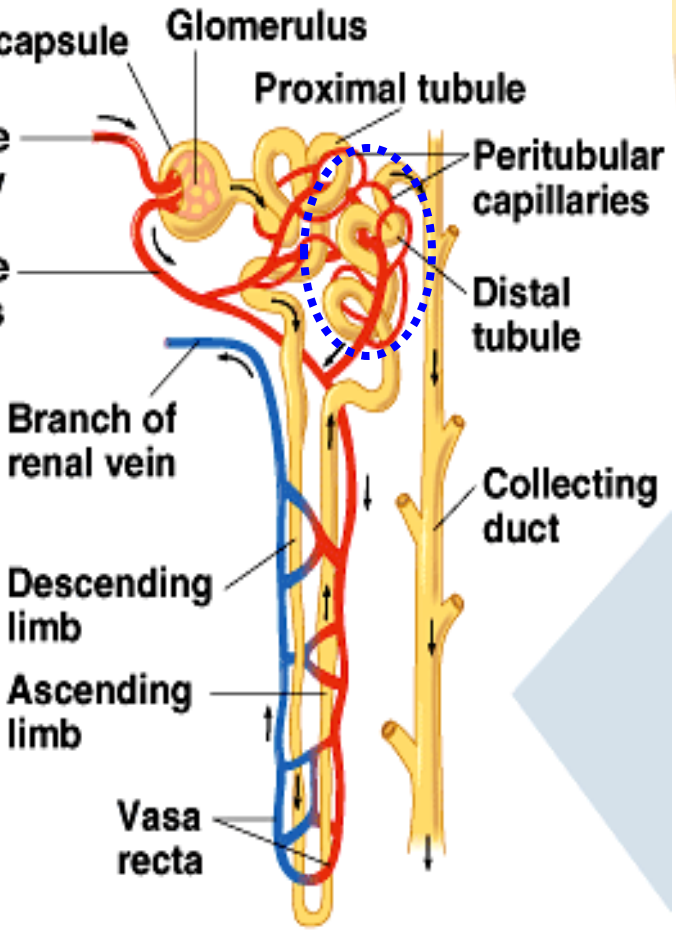
Solute	Proximal tubule	Loop of Henle	Distal tubule	Collecting duct
water	R	R (desc)		
NaCl	R	R (ascn)		
H^+	S			
HCO_3-	R			
glucose	R			
amino acids	R			
vitamins / minerals	R			
urea / uric acid	S			

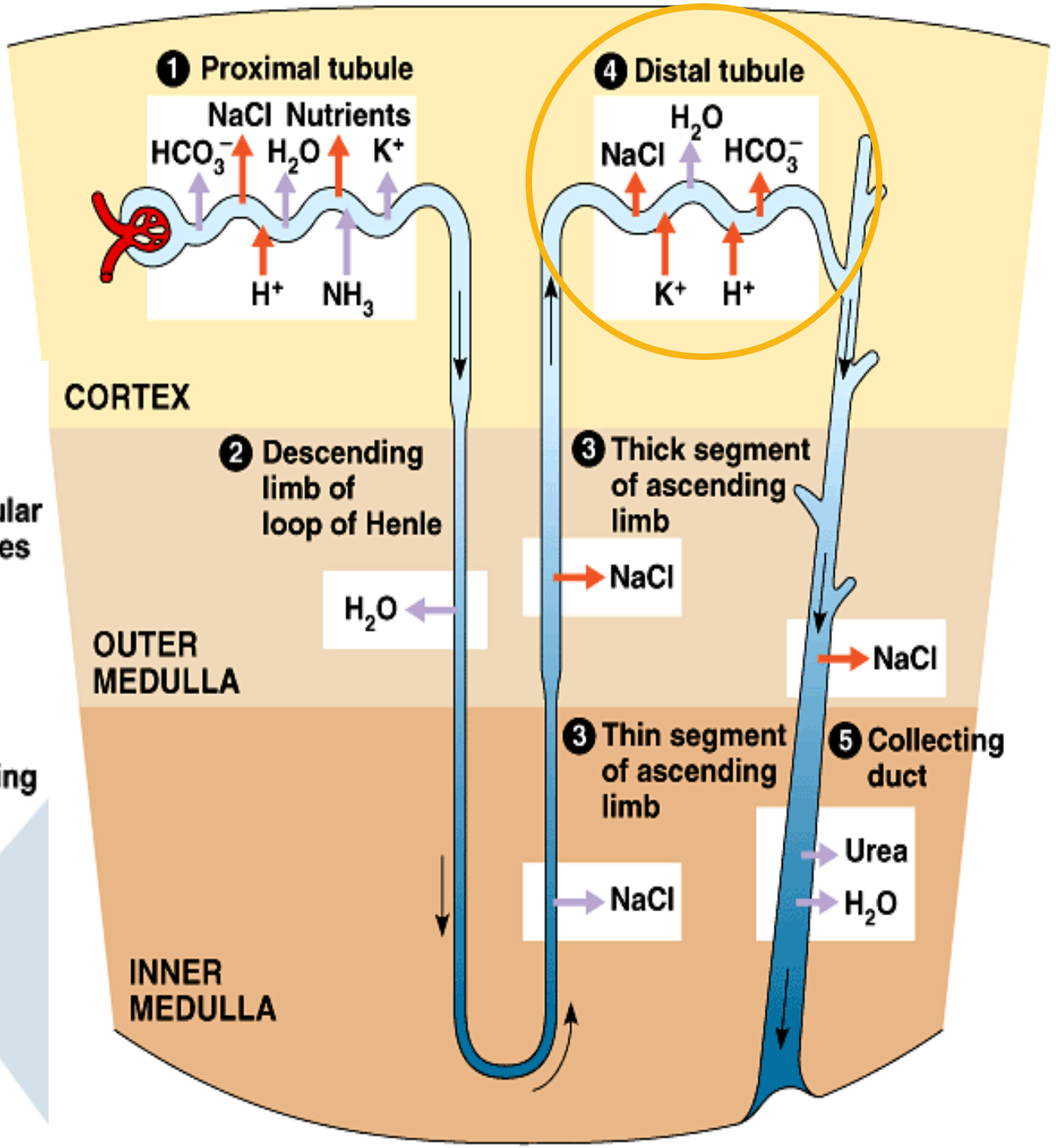
Countercurrent Flow

- Flow of filtrate in the loop of Henle and flow of blood in the vasa recta are in opposite directions
- Allows the less concentrate filtrate to be next to the less concentrated blood (and vice versa)
- Contributes to establishing the osmotic gradient
- Increase the efficiency of reabsorption

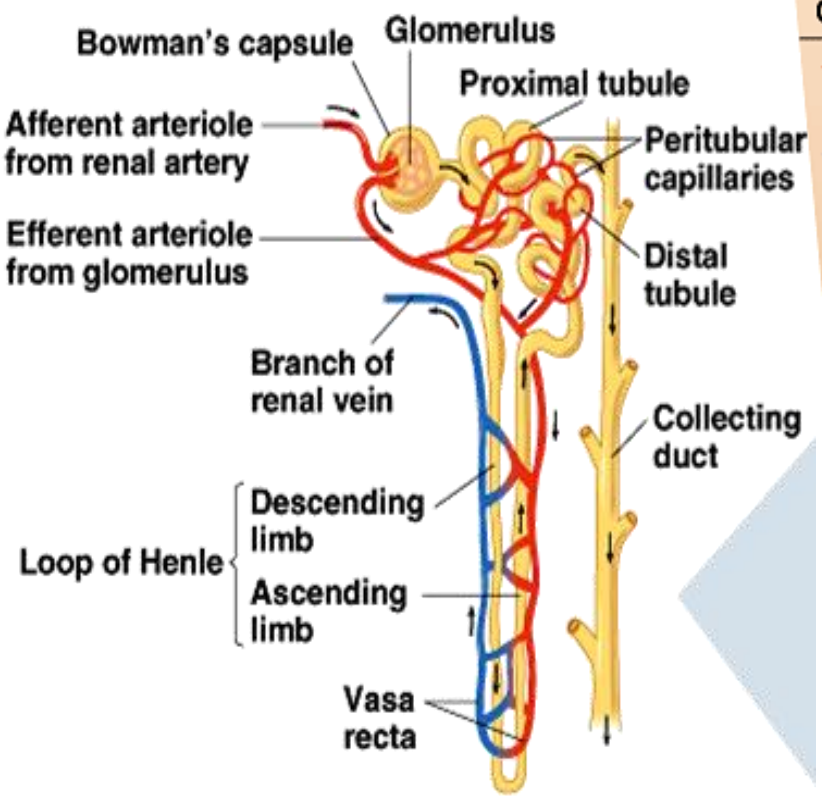


5. Distal Tubule





Filtrate Concentration



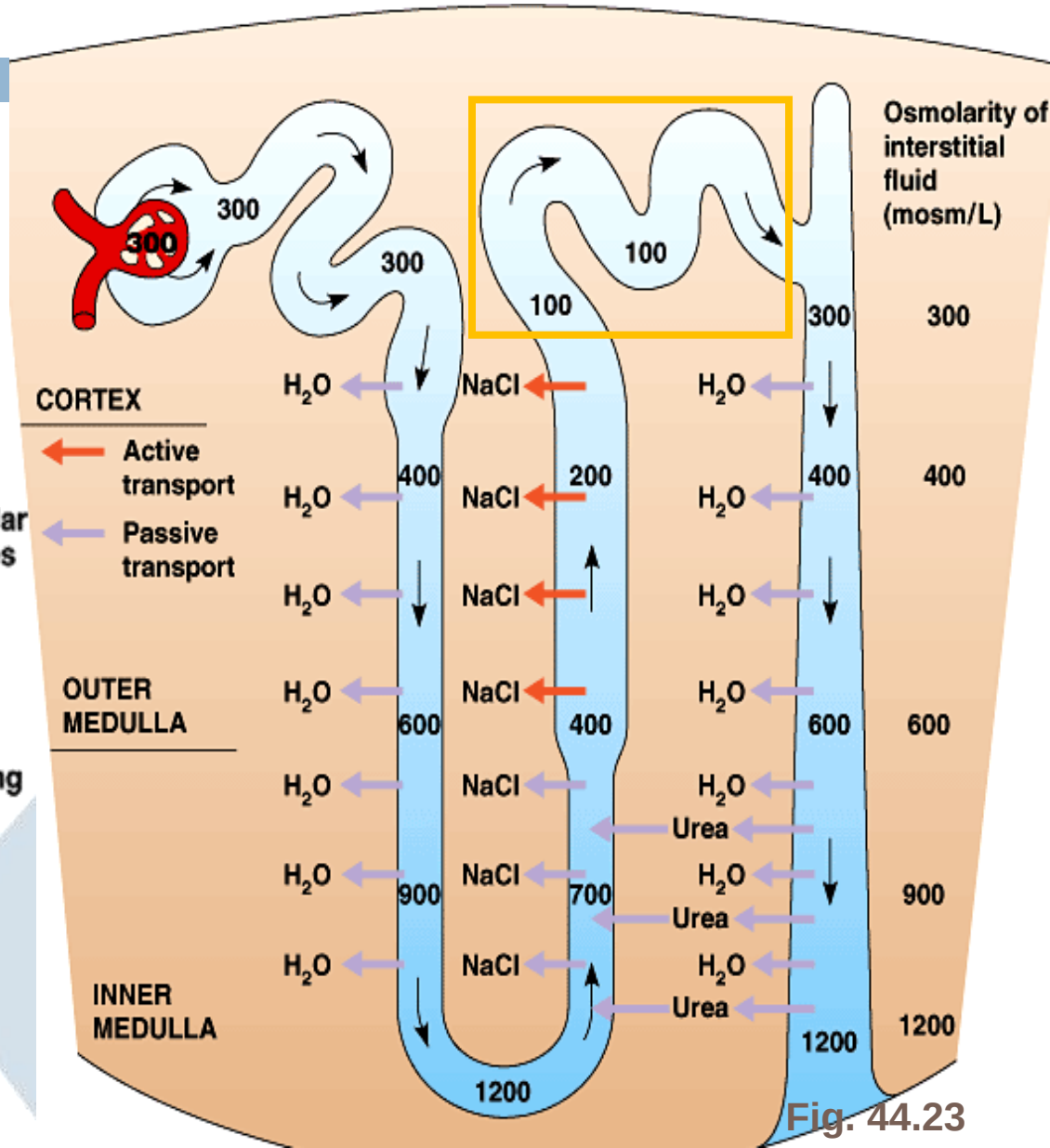
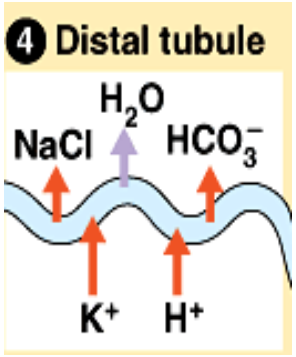
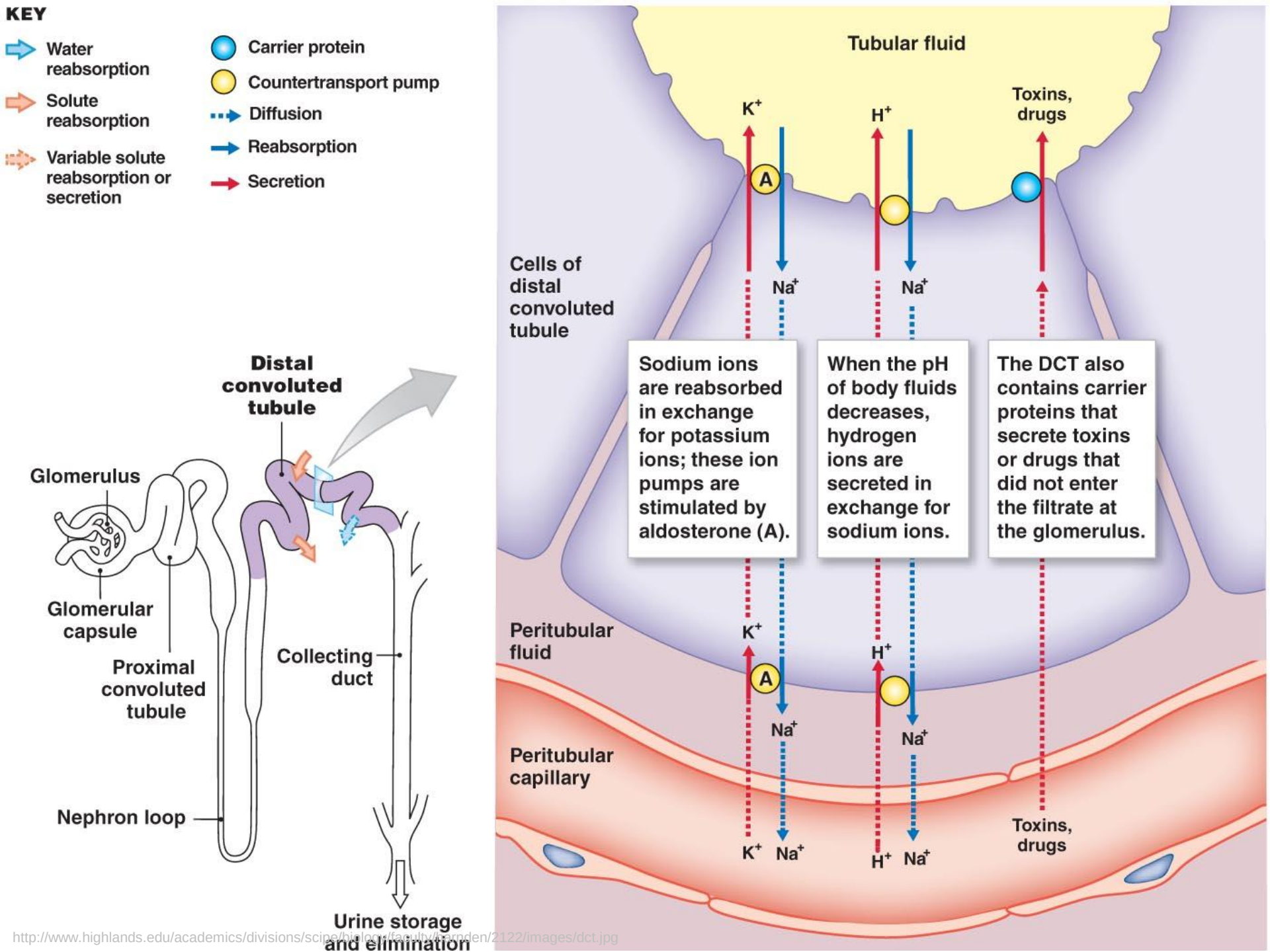


Fig. 44.23

5. Distal tubule

- Water reabsorption is passive and secondary
- Regulates K+ and NaCl concentrations by controlling active transport of:
  - K+ secretion
  - NaCl reabsorption
- Contributes to pH regulation
  - secretion of H+
  - reabsorption of bicarbonate (HCO3-)





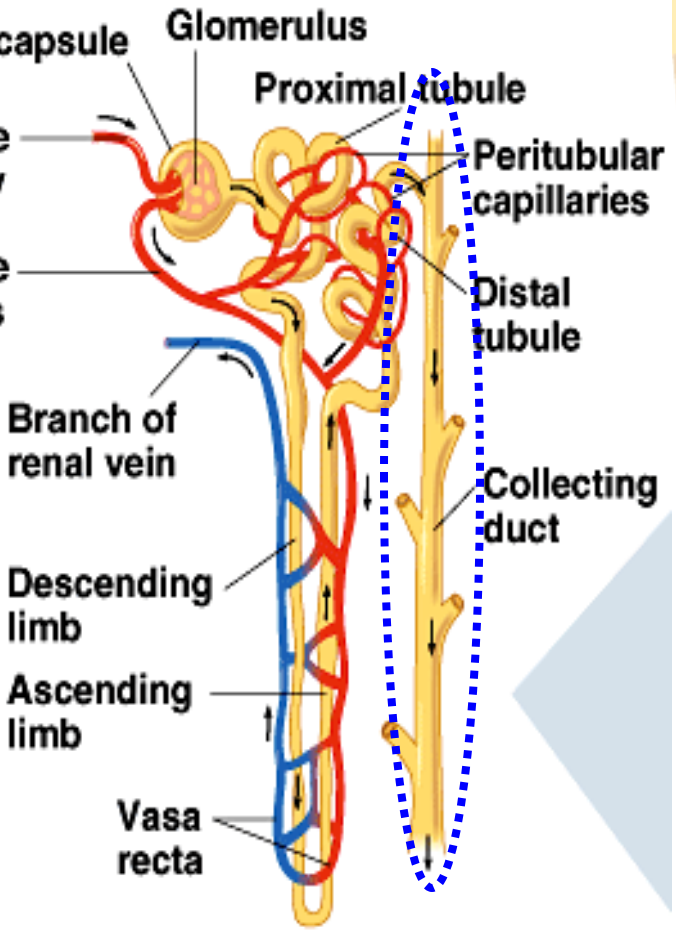
Nutrient Flow

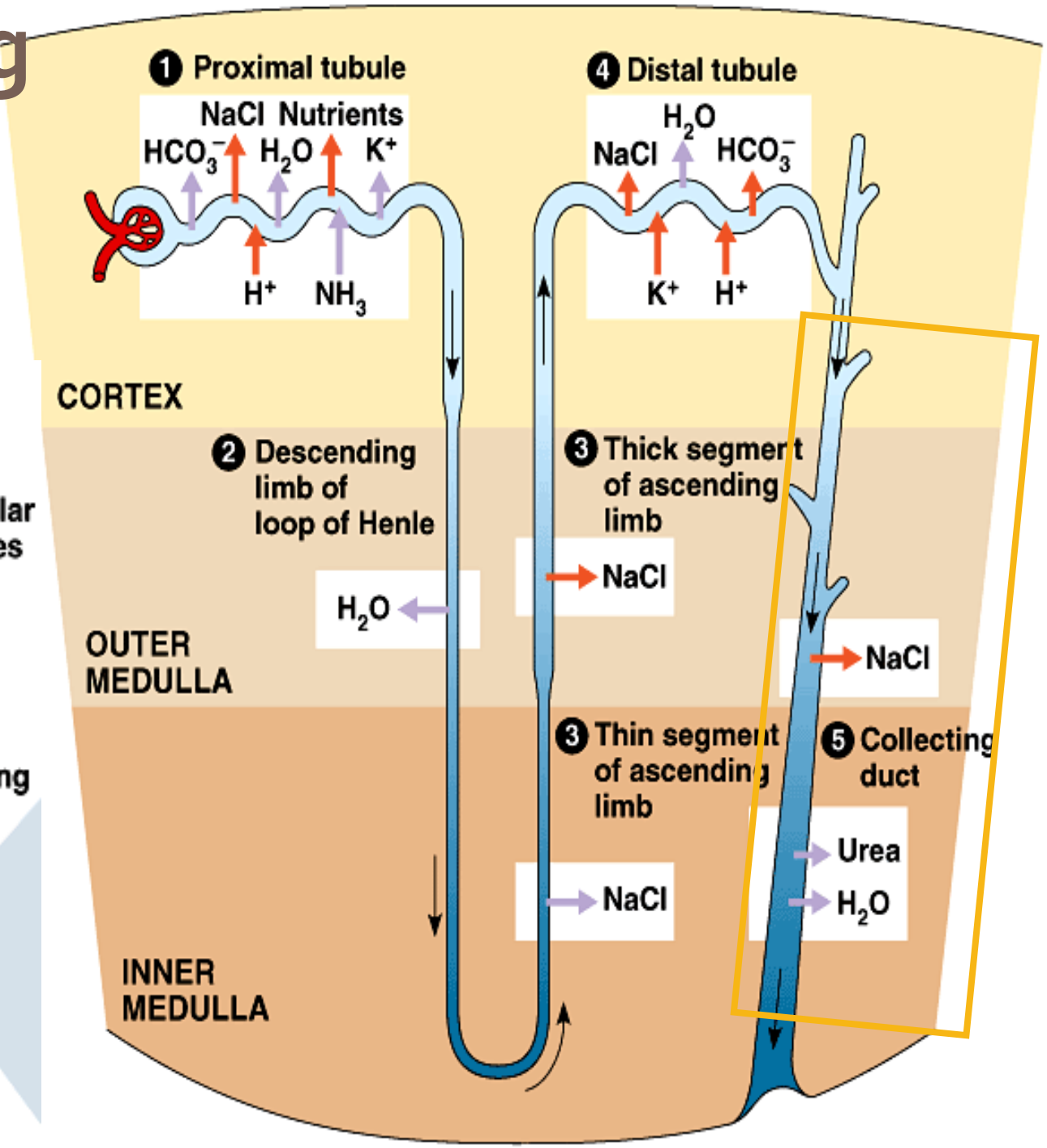
Solute	Proximal tubule	Loop of Henle	Distal tubule	Collecting duct
water	R	R (desc)		
NaCl	R	R (ascn)		
H^+	S			
HCO_3-	R			
glucose	R			
amino acids	R			
vitamins / minerals	R			
urea / uric acid	S			

Nutrient Flow

Solute	Proximal tubule	Loop of Henle	Distal tubule	Collecting duct
water	R	R (desc)	R	
NaCl	R	R (ascn)	R	
H^+	S		S	
HCO_3-	R		R	
glucose	R		R	
amino acids	R		R	
vitamins / minerals	R		R	
urea / uric acid	S		S	

6. Collecting Duct

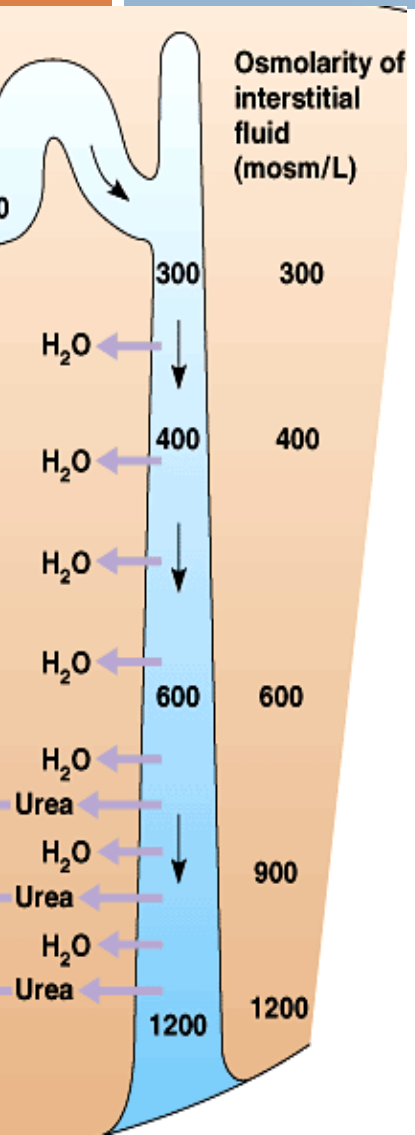




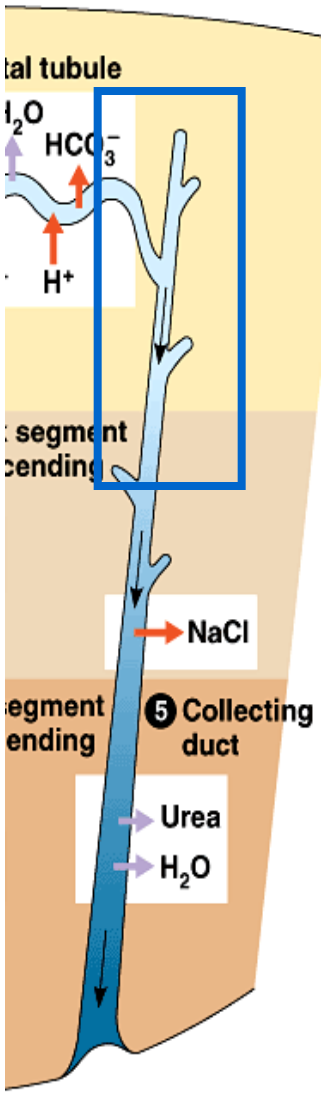
6. Collecting Duct

- Collects from several nephrons
- Main function to concentrate filtrate
- 3 sections have different permeabilities
  - Cortex: permeable to water
  - Outer medulla: permeable to water & NaCl
  - Inner medulla: permeable to water and urea

6. Collecting duct

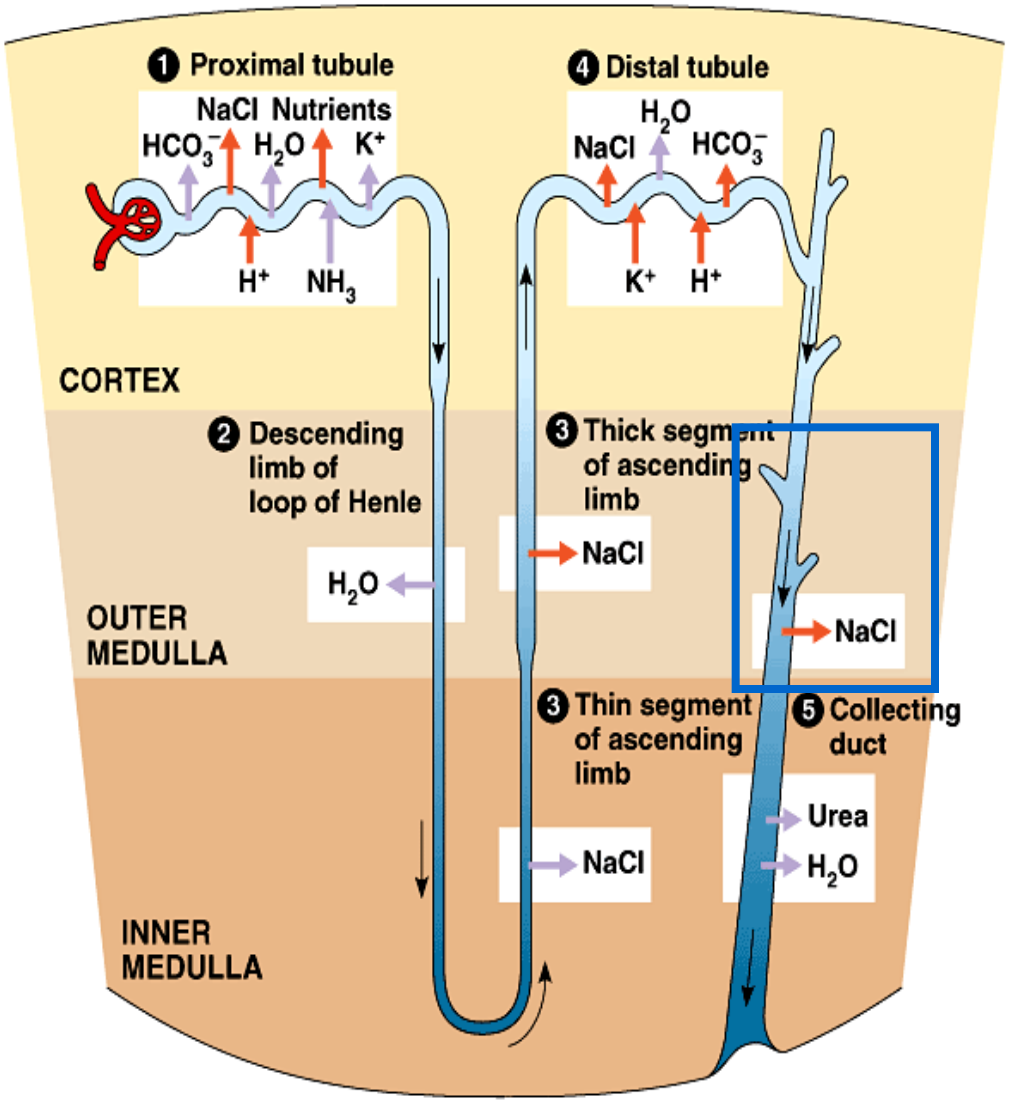


- Permeable to water throughout duct
- First part is only permeable to water and no other solutes
- Filtrate becomes increasingly concentrated
  - Enables conservation of water

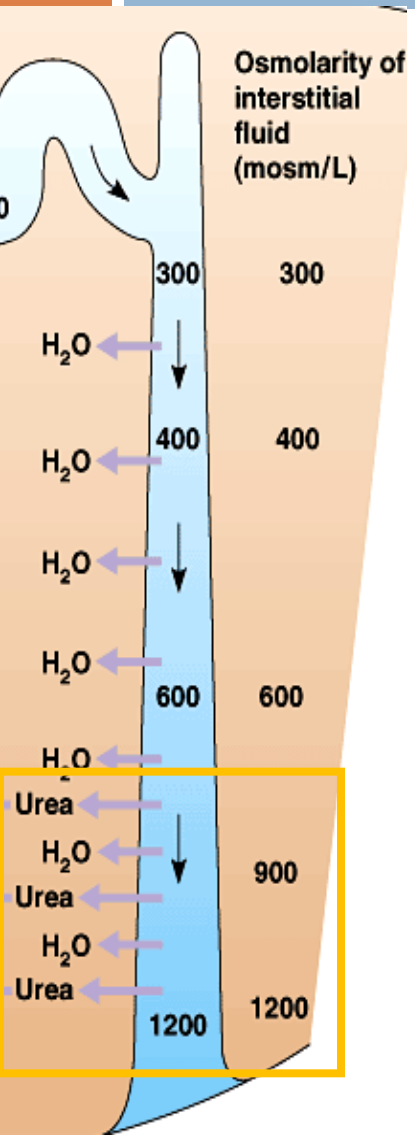


6. Collecting duct

- Duct is permeable to **NaCl** only in **outer medulla**
- Regulates amount of NaCl in urine
  - Reabsorption of NaCl by active transport
- Results in further reabsorption of water



6. Collecting duct



- Duct is permeable to **urea** only in **inner medulla**
  - Urea can diffuse out to the interstitial fluid due to high urea concentration in filtrate
  - any urea and urine that is reabsorbed is less than that was filtered into nephron
- Contributes to hyperosmotic environment
  - Drives reabsorption of water by osmosis
  - Enables conservation of water
  - Filtrate becomes increasingly concentrated

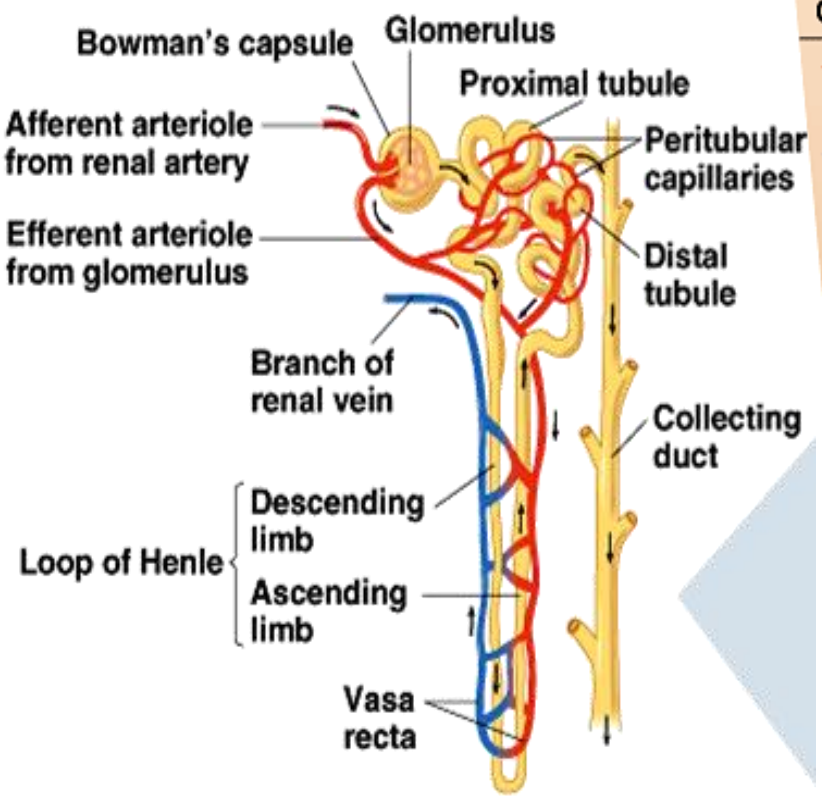
Nutrient Flow

Solute	Proximal tubule	Loop of Henle	Distal tubule	Collecting duct
water	R	R (desc)	R	
NaCl	R	R (ascn)	R	
H^+	S		S	
HCO_3-	R		R	
glucose	R		R	
amino acids	R		R	
vitamins / minerals	R		R	
urea / uric acid	S		S	

Nutrient Flow

Solute	Proximal tubule	Loop of Henle	Distal tubule	Collecting duct
water	R	R (desc)	R	R
NaCl	R	R (ascn)	R	R (outer medulla)
H^+	S		S	
HCO_3-	R		R	
glucose	R		R	
amino acids	R		R	
vitamins / minerals	R		R	
urea / uric acid	S		S	R (inner medulla)

Urine Concentration



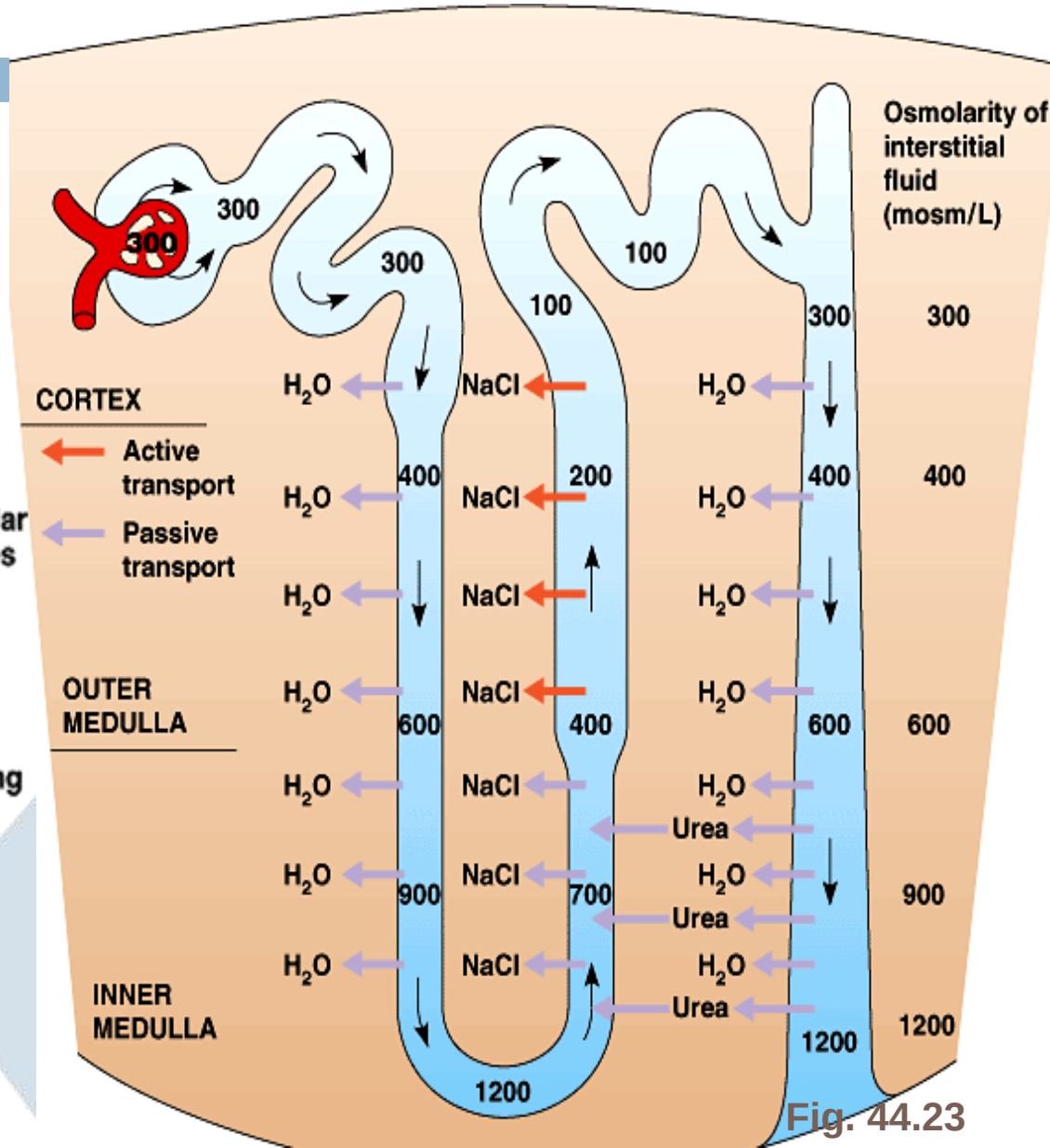


Fig. 44.23

Video Summarizing Function

- Biology Crash Course
  - Excretory system (12:20)
  - http://www.youtube.com/watch?v=WtrYotjYvtU (start at 2:54 for focus on kidney)