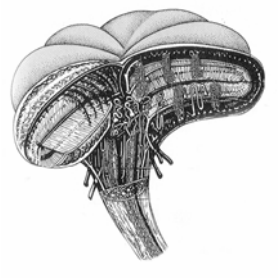
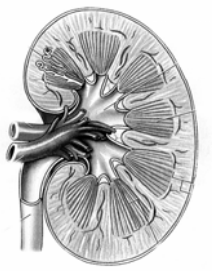
Excretory Systems

Ionic and Osmotic Balance

Animal Physiology

April, 2008





Homeostasis

Maintaining relative stable environment for animal cells

The problem!!!

How do animals maintain an ionic and osmotic balance in a wide variety of environments?

Functions of Excretory systems:

1. To adjust the quantity of water and various plasma constituents to be conserved by the body or eliminated in the urine
2. Responsible for eliminating potentially toxic metabolic waste and foreign compounds from an animal's body.

Definitions

Osmoregulators:

Animals that maintain an internal osmolarity different from the medium surrounding them.

Osmoconformers:

Animals that maintain an internal osmolarity similar to the osmolarity of the surrounding medium.

The rate of transfer for water and salts from an environment depends on:

Surface area of animal

Size of gradient

Permeability of the surface

Every animal has its own unique water problem!!

- **Frog skin is very permeable to water**
- **Reptiles, birds and many mammals have impermeable skin**
- **Other mammals perspire and lose water through their skin**
- **Insects have a waxy cuticle that is impermeable to water.**

Every animal has its own unique feeding problem!!

- **Most terrestrial vertebrates (especially birds and mammals) produce hyperosmotic urine to eliminated unwanted solutes**
- **Reptiles and amphibians have kidneys but can't produce hyperosmotic urine.**
- **Fish contain kidneys but also control osmoregulation at gills.**
- **Insects and spiders have a "kidney-like" system that produces concentrated urine**

Fish problems!

Freshwater fish are hyperosmotic to their environment

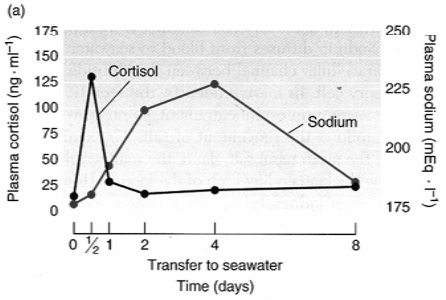
Subject to swelling as water moves into their body

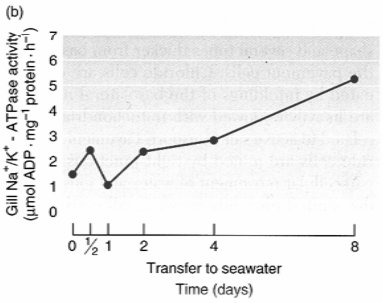
Subject to continual loss of body salts to the surrounding water

Saltwater fish are hypo-osmotic to their environment

Subject to tissue shrinking as water moves out of their body

Migratory fish are hyperosmotic to their environment during some periods and hypoosmotic at other times.

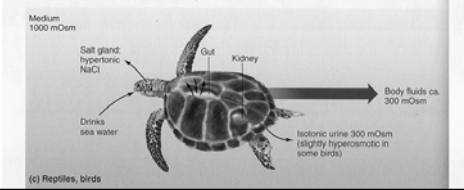




Osmoregulation problems for marine reptiles!

Marine reptiles need to drink salt water to get their water requirements.

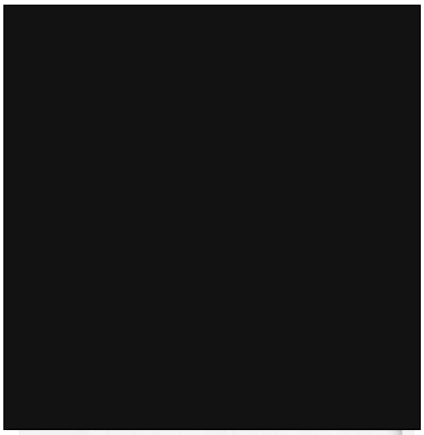
[redacted]

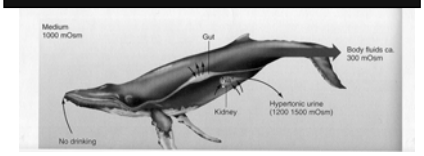


[redacted]

Osmoregulation problems for marine mammals!

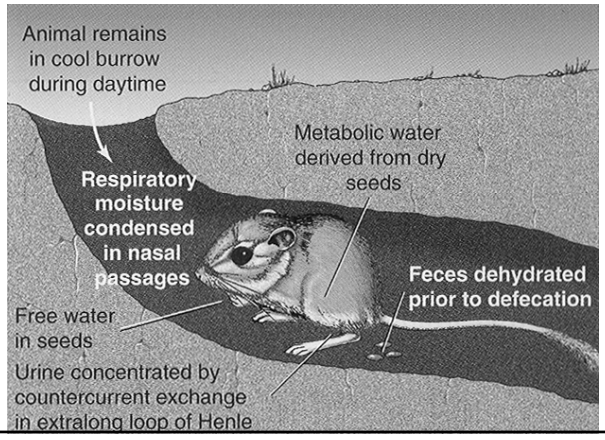
Whales, dolphins and seals don't drink salt water.

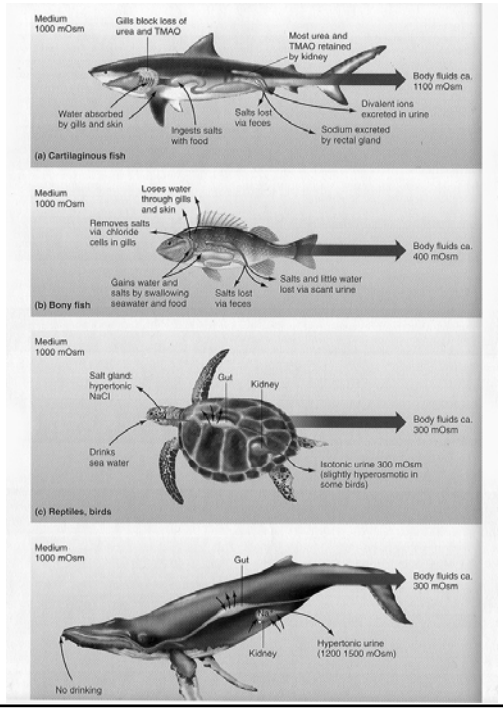


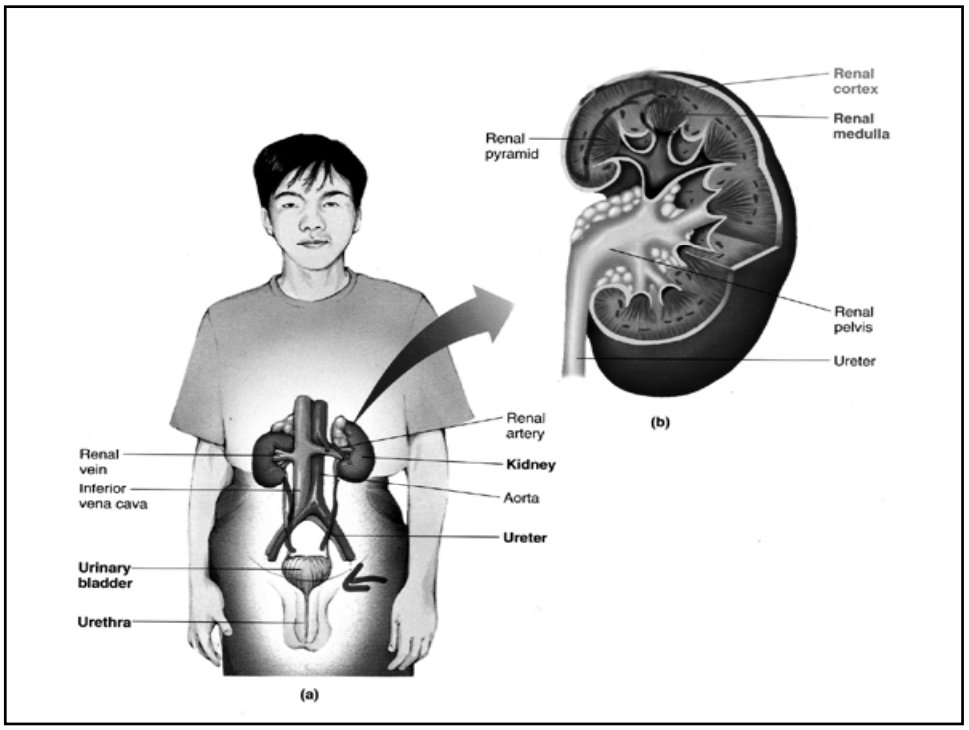


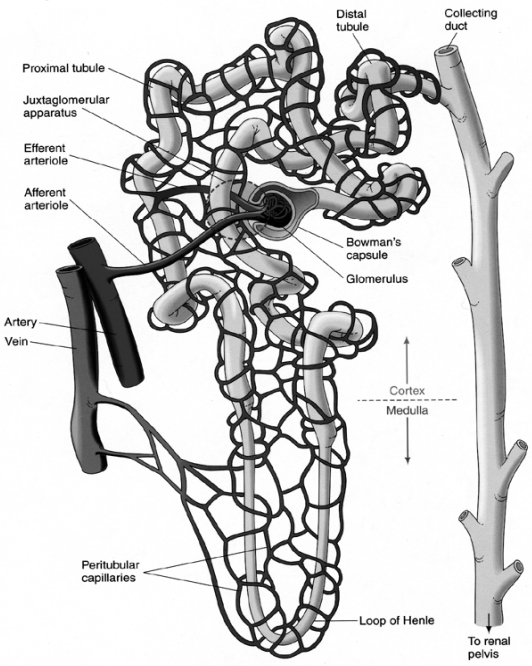
Osmoregulation problems for desert mammals!

Desert rats don't drink water.

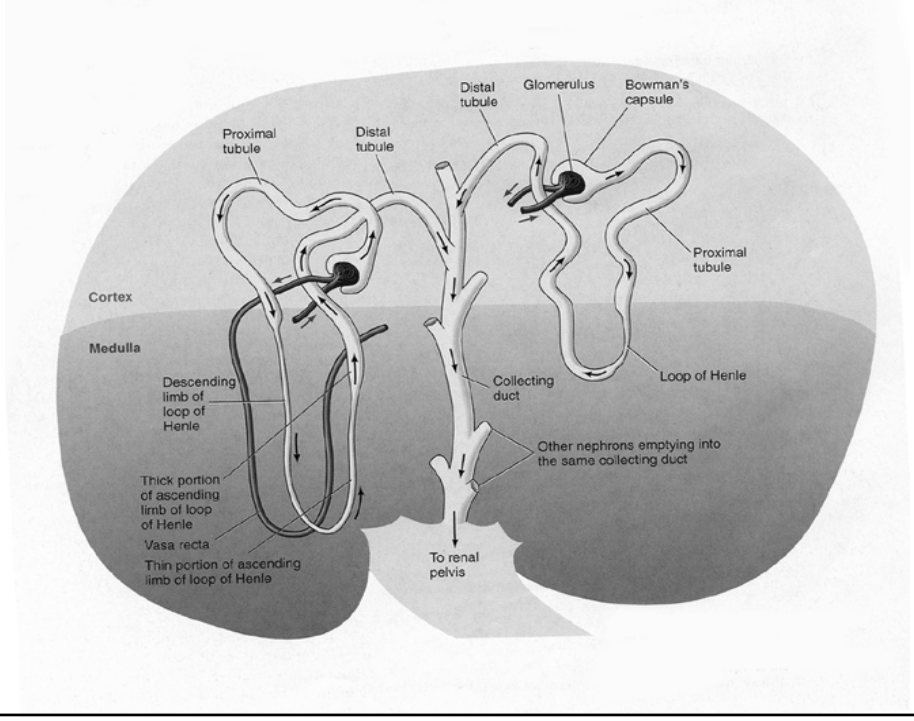



Medium
1000 mOsm
Gills block loss of urea and TMAO
Most urea and TMAO retained by kidney
Body fluids ca. 1100 mOsm
Divalent ions excreted in urine
Water absorbed by gills and skin
Ingests salts with food
Salts lost via feces
Sodium excreted by rectal gland
(a) Cartilaginous fish
Medium
1000 mOsm
Loses water through gills and skin
Removes salts via chloride cells in gills
Body fluids ca. 400 mOsm
Gains water and salts by swallowing seawater and food
Salts lost via feces
Salts and little water lost via scant urine
(b) Bony fish
Medium
1000 mOsm
Salt gland: hypertonic NaCl
Gut
Kidney
Body fluids ca. 300 mOsm
Drinks sea water
Isotonic urine 300 mOsm (slightly hyperosmotic in some birds)
(c) Reptiles, birds
Medium
1000 mOsm
Gut
Body fluids ca. 300 mOsm
Kidney
Hypertonic urine (1200 1500 mOsm)
No drinking


Renal cortex
Renal medulla
Renal pyramid
Renal pelvis
Ureter
(b)
Renal artery
Renal vein
Kidney
Inferior vena cava
Aorta
Ureter
Urinary bladder
Urethra
(a)



Overview of Functions of Parts of a Nephron

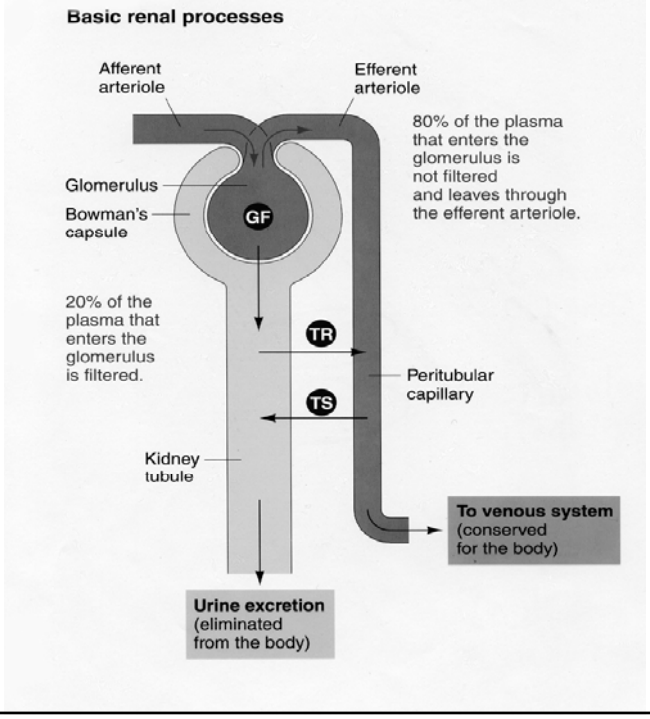


Urine Formation

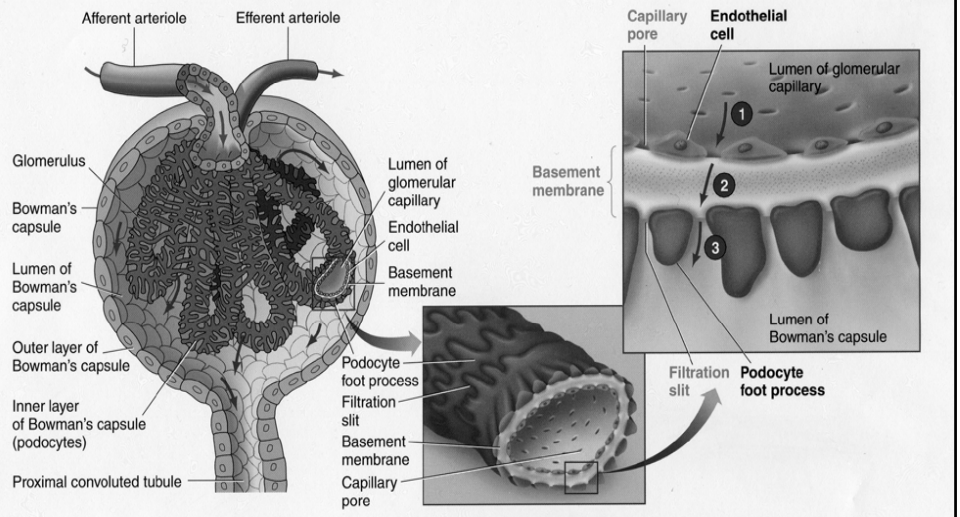
Glomerular filtration

Tubular reabsorption

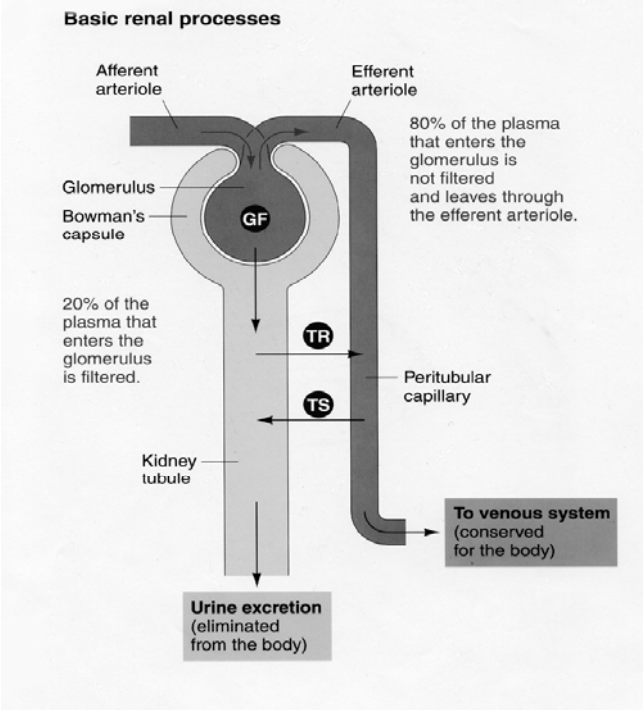
Tubular secretion



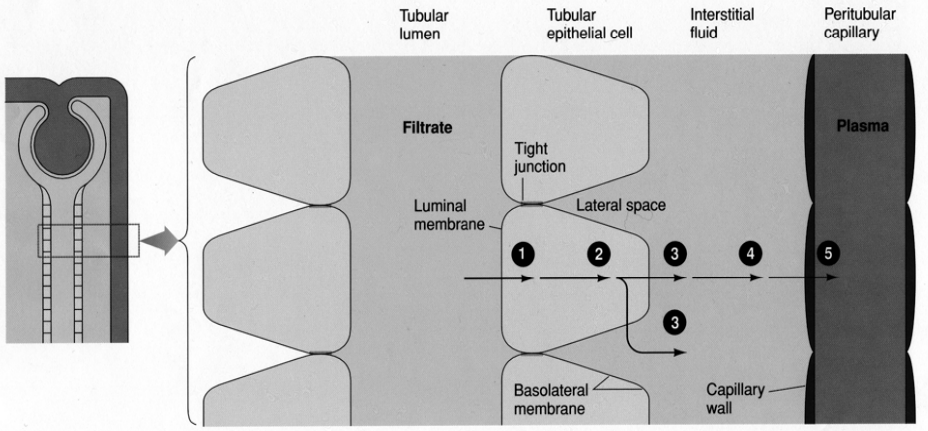
Layers of the glomerular membrane

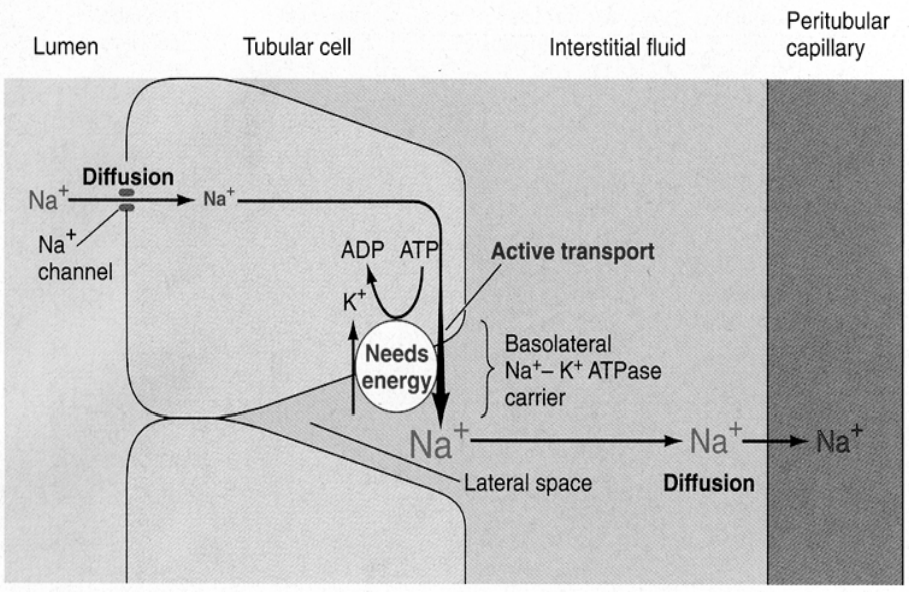


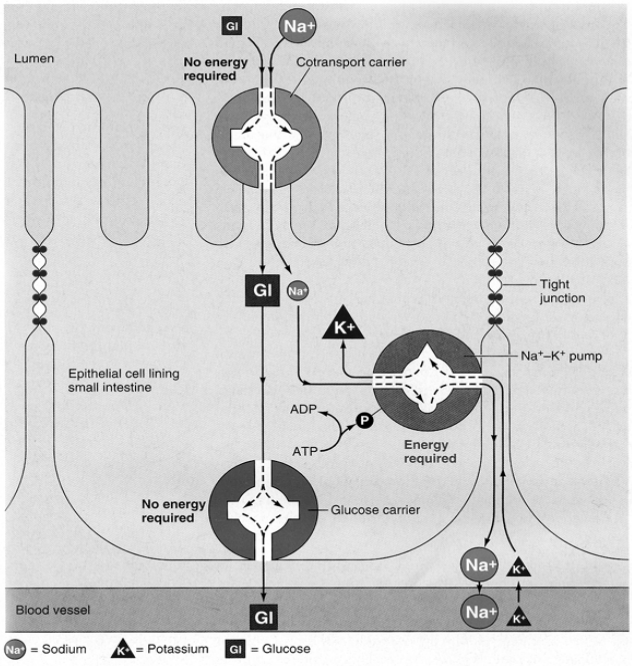
Basic renal processes

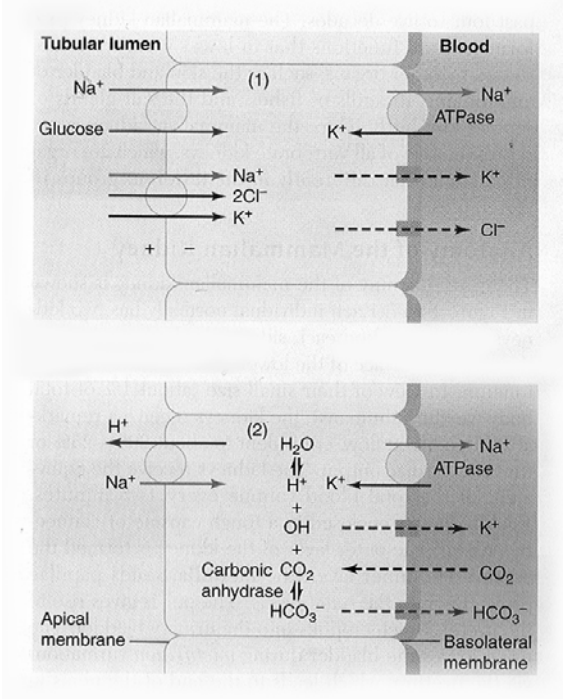


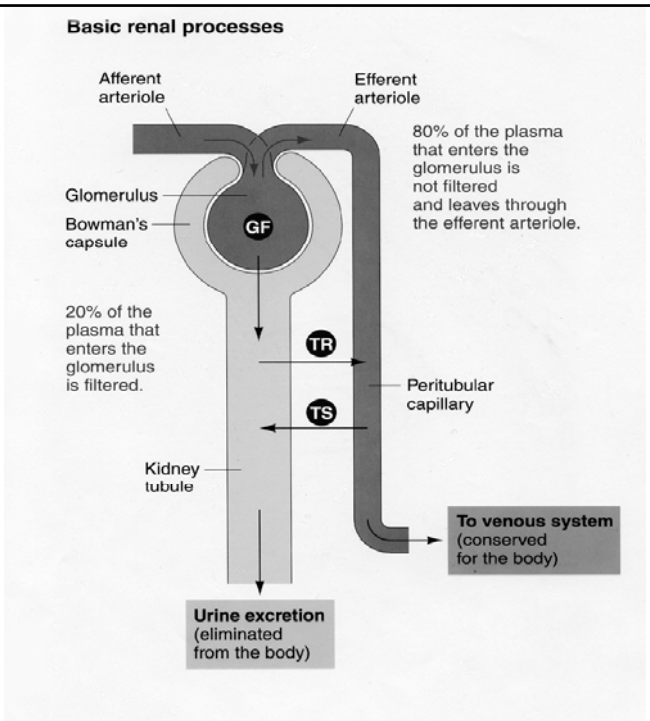
Steps of transepithelial transport






Gl
Na+
Lumen
No energy required
Cotransport carrier
Gl
Na+
Tight junction
K+
Na+–K+ pump
Epithelial cell lining small intestine
ADP
P
ATP
Energy required
No energy required
Glucose carrier
Na+
K+
Blood vessel
Gl
Na+
K+
Na+ = Sodium
K+ = Potassium
Gl = Glucose


Tubular lumen
Blood
Na+
(1)
Na+
ATPase
Glucose
K+
Na+
2Cl−
K+
K+
Cl−
+
−
H+
(2)
H2O
Na+
ATPase
Na+
H+
K+
+
OH
K+
+
Carbonic anhydrase
CO2
CO2
HCO3−
HCO3−
Apical membrane
Basolateral membrane



Hydrogen ion secretion

Important in the regulation of acid-base balance in the body

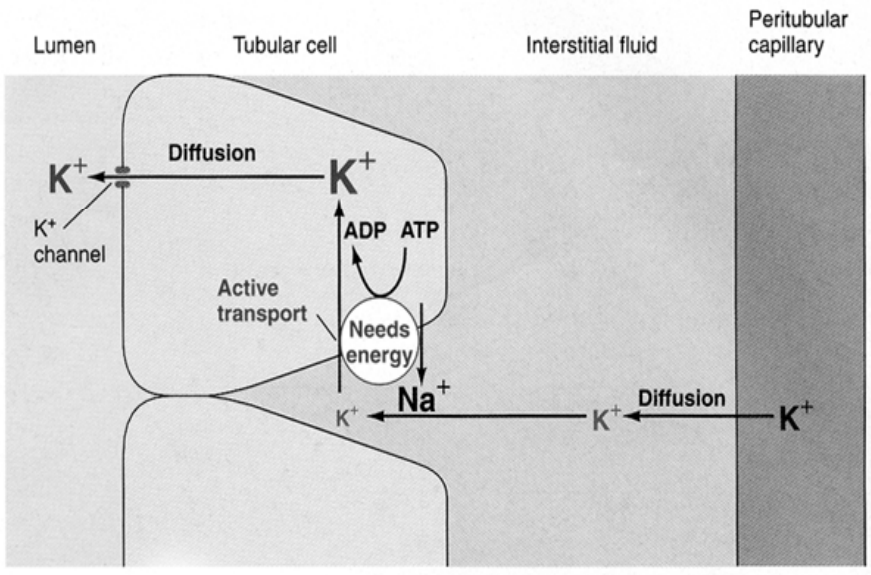
Hydrogen ions can be added to the filtered fluid in the proximal, distal and collecting tubules

The extent of hydrogen secretion depends on the acidity of the body fluids

Potassium secretion

Potassium is actively reabsorbed in the proximal tubule

Potassium is actively secreted in the distal and collecting tubules

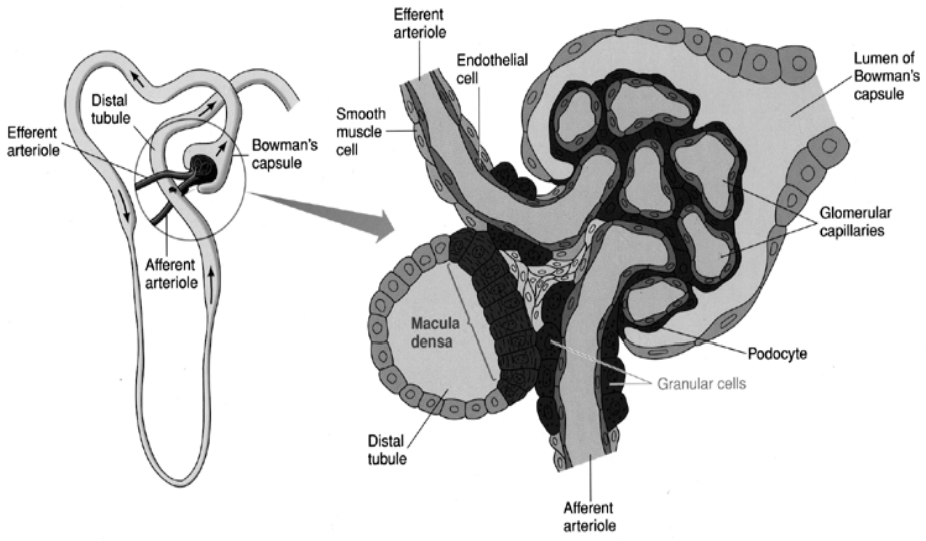


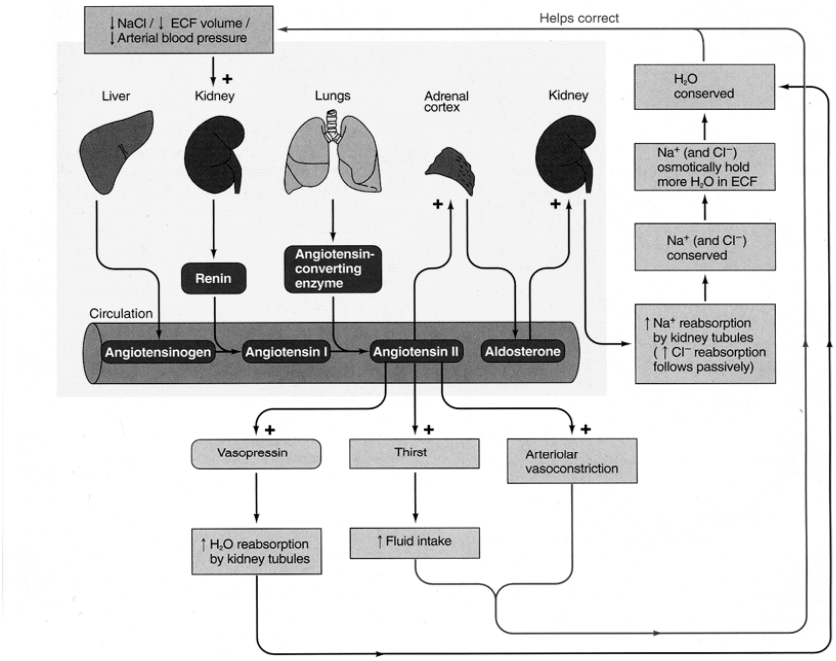
Potassium secretion

Renin-angiotension-aldosterone system

Acts to increase sodium reabsorption in the distal tubule

The juxtaglomerular apparatus



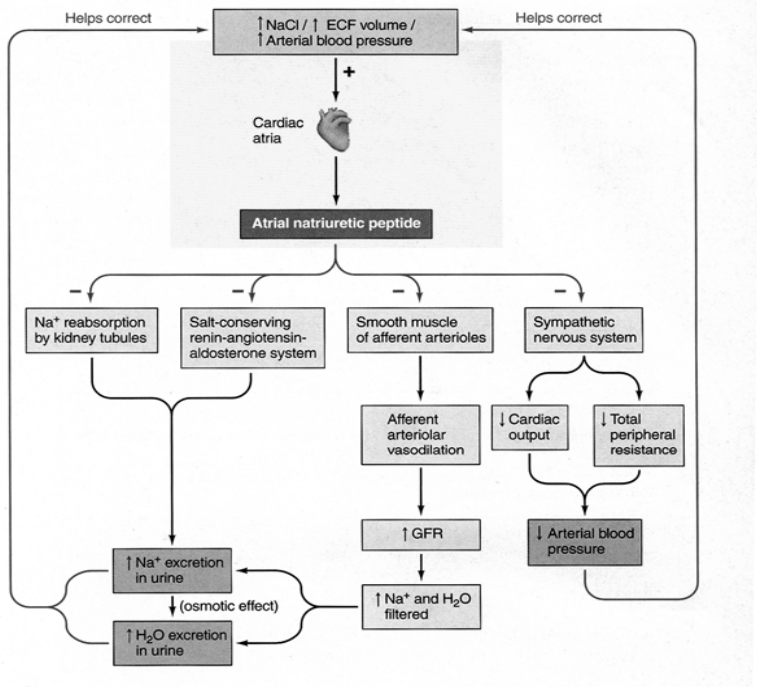


Atrial natriuretic peptide (ANP) opposes the renin-angiotension-aldosterone system

Inhibits sodium reabsorption

Inhibits renin secretion by the kidneys

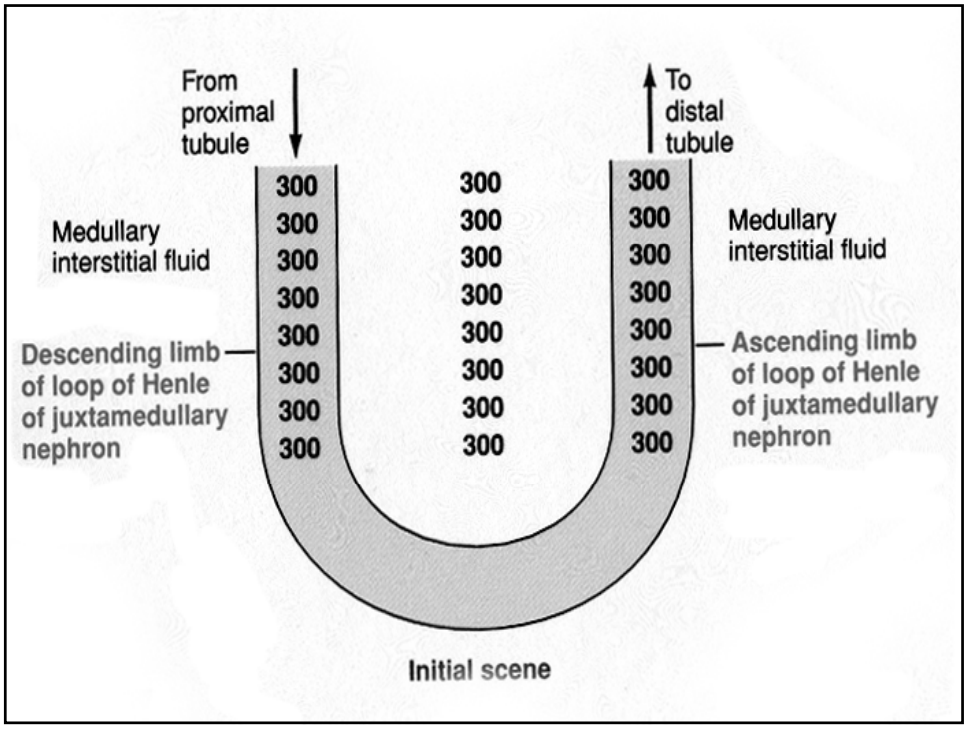
Increases GFR through dilation of the afferent arterioles

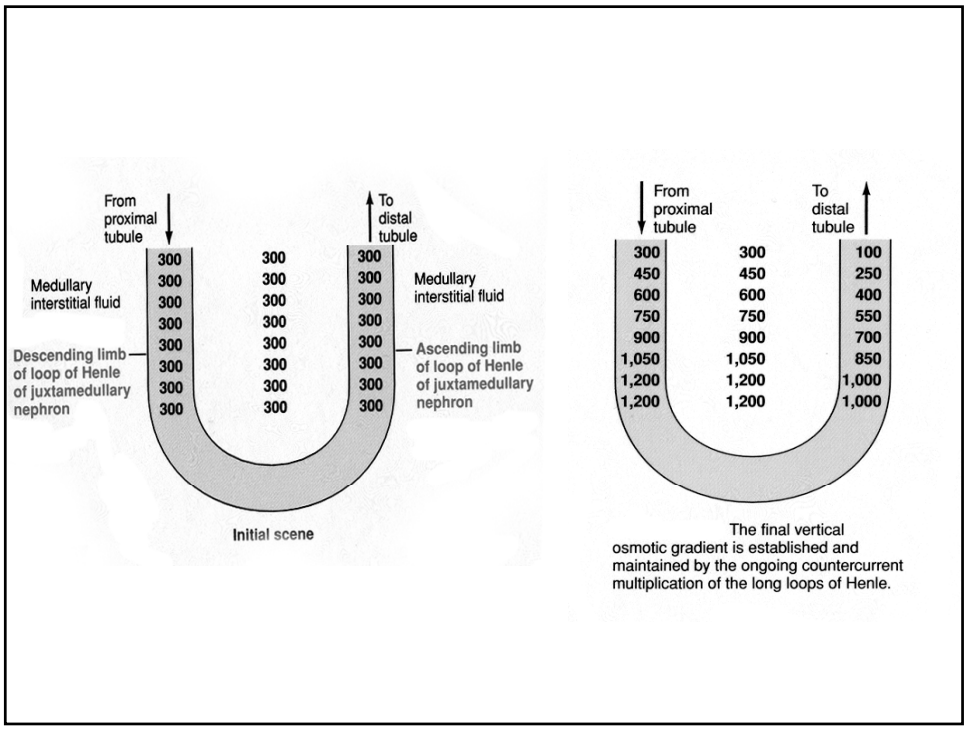


Two factors are responsible for being able to excrete urine at varying concentrations:

The medullary countercurrent system

Vasopressin (ADH; anti-diuretic hormone)


From proximal tubule
To distal tubule
Medullary interstitial fluid
Descending limb of loop of Henle of juxtamedullary nephron
Medullary interstitial fluid
Ascending limb of loop of Henle of juxtamedullary nephron
300
Initial scene


From proximal tubule
To distal tubule
Medullary interstitial fluid
Descending limb of loop of Henle of juxtamedullary nephron
Medullary interstitial fluid
Ascending limb of loop of Henle of juxtamedullary nephron
Initial scene
From proximal tubule
To distal tubule
300 300 100
450 450 250
600 600 400
750 750 550
900 900 700
1,050 1,050 850
1,200 1,200 1,000
1,200 1,200 1,000
The final vertical osmotic gradient is established and maintained by the ongoing countercurrent multiplication of the long loops of Henle.

Function of vertical osmotic gradient in loop of Henle

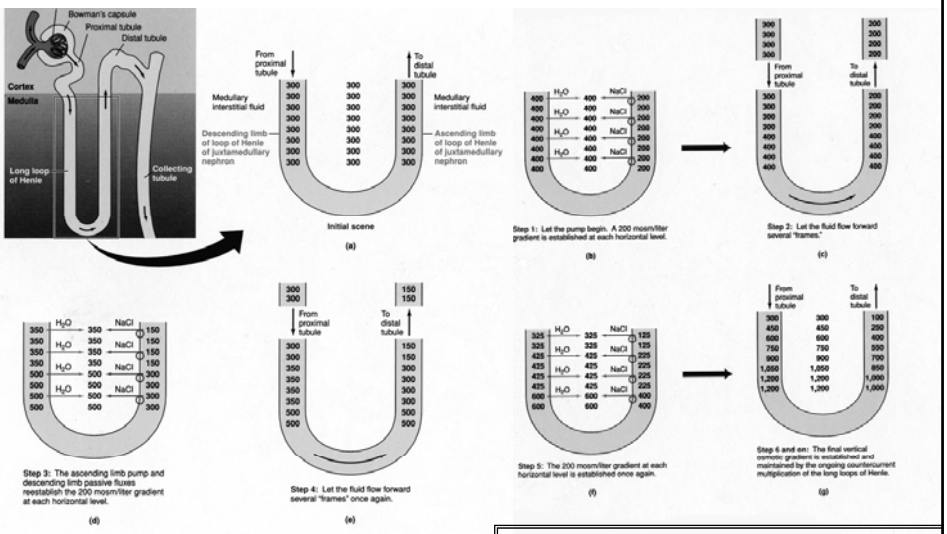
Enables the kidneys to produce urine of various concentrations from 100 to 1200 mosm/liter

Medullary countercurrent system

Loops of Henle

Vasa recta

Collecting tubules



Descending limb features:

Is highly permeable to water

Does not actively extrude sodium

Ascending limb features:

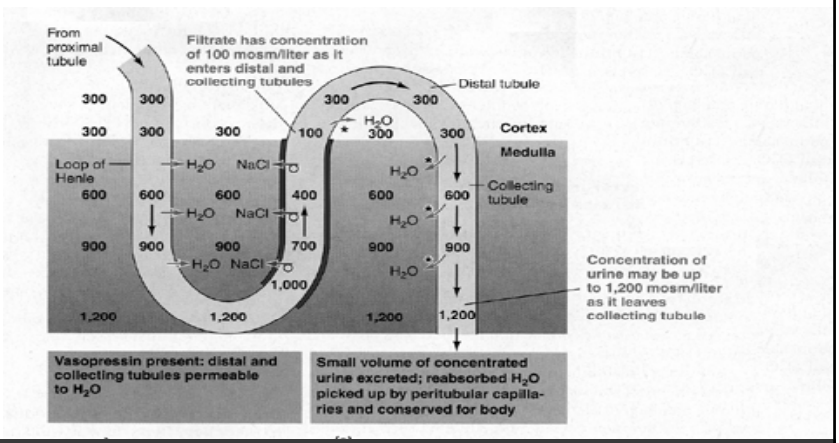
Actively transport sodium out of the tubular lumen

Is impermeable to water

What's the purpose of creating a vertical osmotic gradient?????

The vertical osmotic gradient is used by the collecting ducts to concentrate tubular fluid so that concentrated urine can be excreted.

Because the fluid is hypotonic as it enters the distal tubule, it enables the kidneys to excrete urine more dilute than normal blood fluids.



Vasopressin

Acts to increase tubules permeability to water

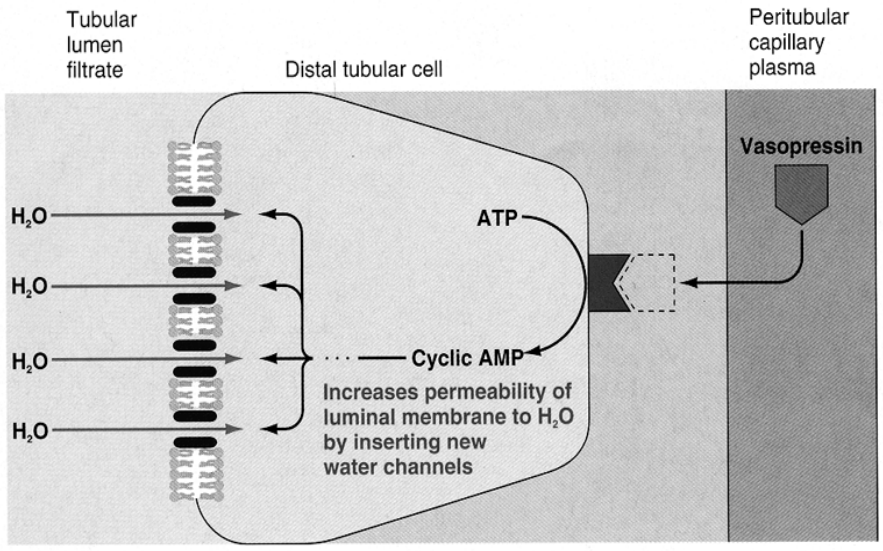
Produced in the hypothalamus and stored in the posterior pituitary gland

Hypothalamus controls the release of vasopressin from the posterior pituitary into the blood

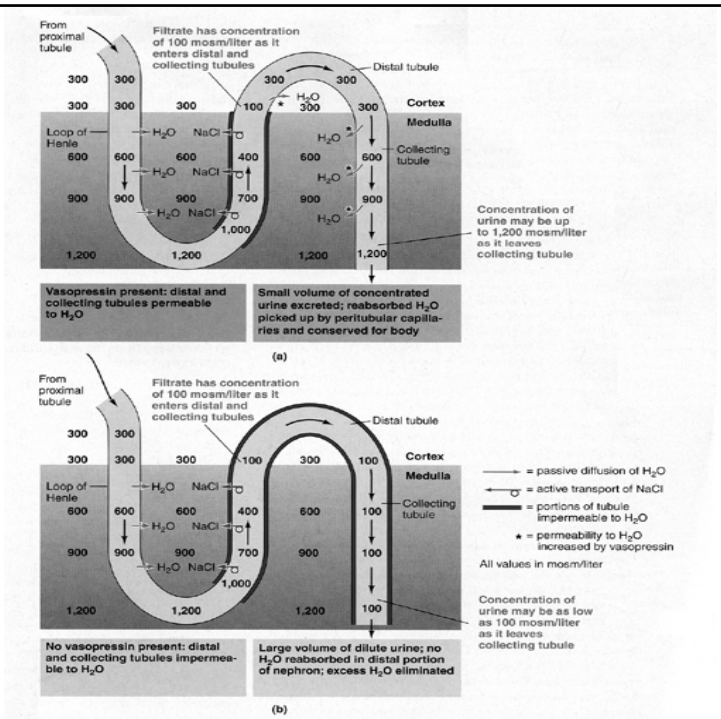
Vasopressin is released in a negative-feedback fashion

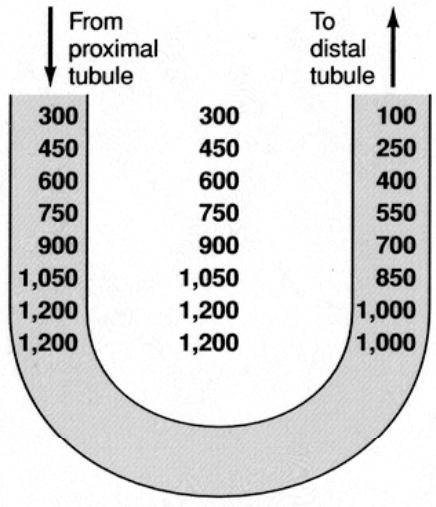
How does vasopressin increase tubule permeability to water????

Binding of vasopressin activates the cAMP second messenger system and increases the number of water channel in the membrane



Mechanism of action of vasopressin





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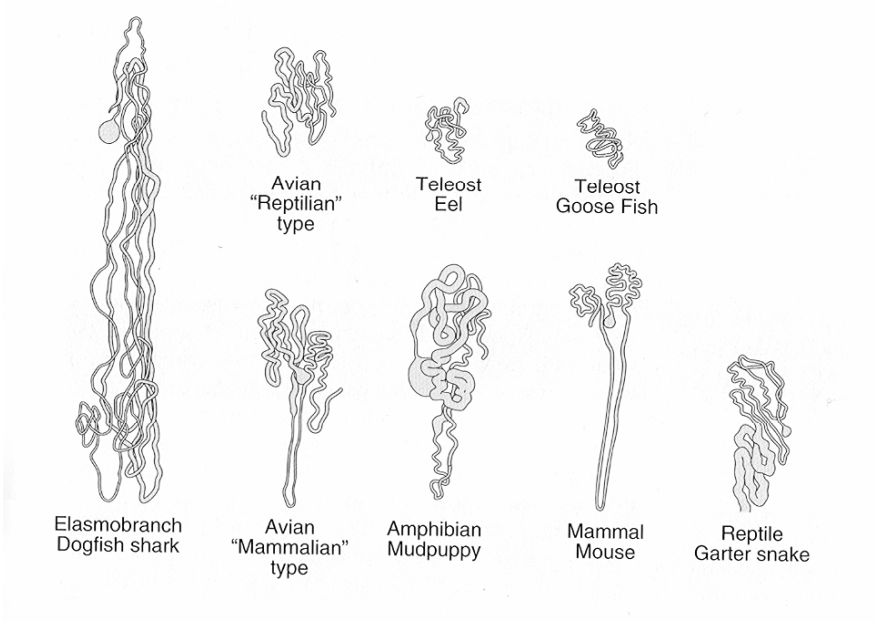
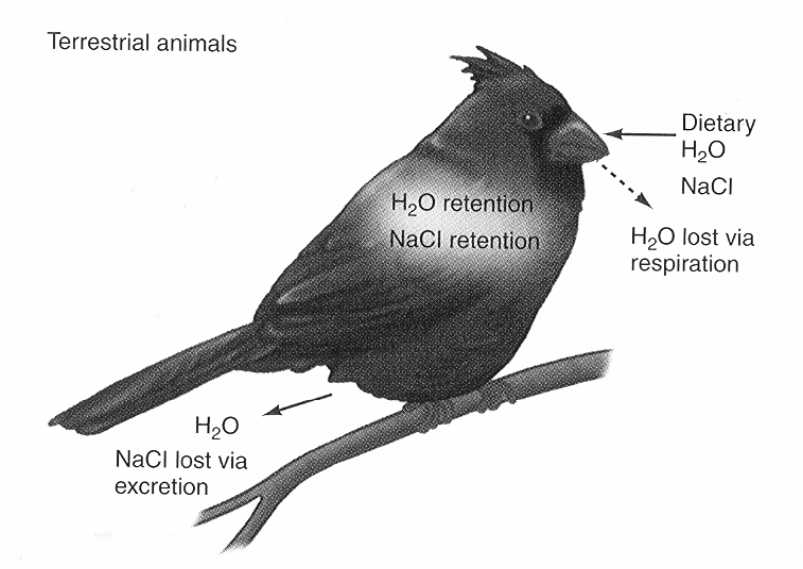
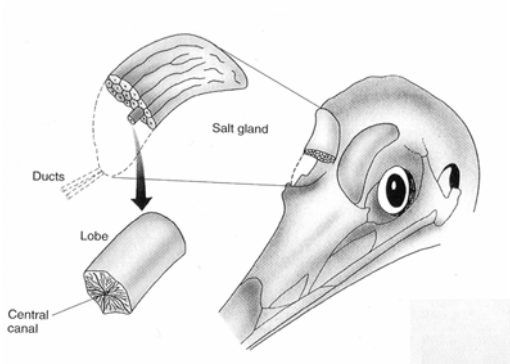
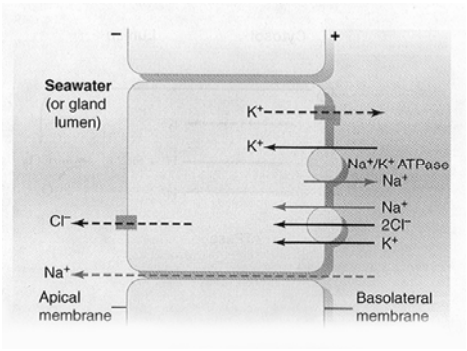
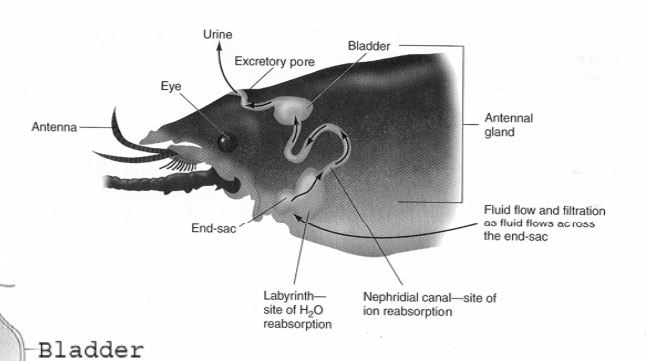
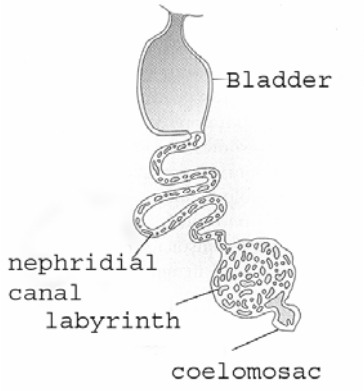

Elasmobranch
Dogfish shark
Avian
"Reptilian"
type
Avian
"Mammalian"
type
Teleost
Eel
Amphibian
Mudpuppy
Teleost
Goose Fish
Mammal
Mouse
Reptile
Garter snake

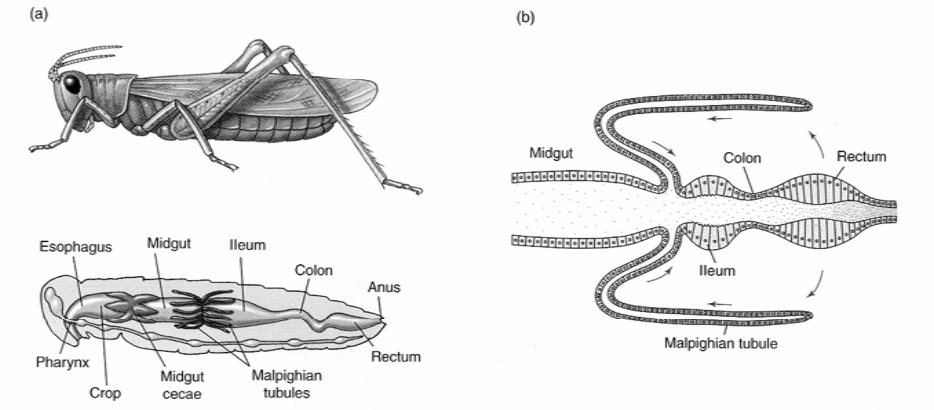

Terrestrial animals
Dietary
H_2O
NaCl
H_2O retention
NaCl retention
H_2O lost via
respiration
H_2O
NaCl lost via
excretion

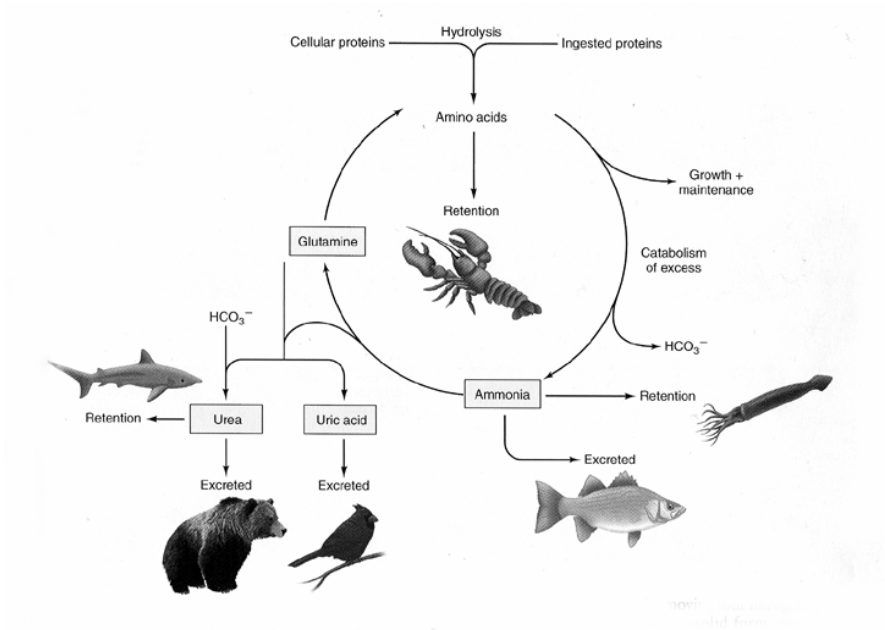

Salt gland
Ducts
Lobe
Central canal


Seawater (or gland lumen)
K+
K+
Na+/K+ ATPase
Na+
Na+
2Cl−
K+
Cl−
Na+
Apical membrane
Basolateral membrane


Urine
Excretory pore
Bladder
Eye
Antenna
Antennal gland
End-sac
Fluid flow and filtration as fluid flows across the end-sac
Labyrinth—site of H2O reabsorption
Nephridial canal—site of ion reabsorption


Bladder
nephridial canal
labyrinth
coelomosac


(a)
Esophagus
Midgut
Ileum
Colon
Anus
Pharynx
Crop
Midgut cecae
Malpighian tubules
Rectum
(b)
Midgut
Colon
Rectum
Ileum
Malpighian tubule


Cellular proteins
Hydrolysis
Ingested proteins
Amino acids
Growth + maintenance
Retention
Glutamine
Catabolism of excess
HCO_3^-
HCO_3^-
Ammonia
Retention
Retention
Urea
Uric acid
Excreted
Excreted
Excreted