Lecture 25, 14 Nov 2006

Vertebrate Physiology
ECOL 437 (MCB/VetSci 437)
Univ. of Arizona, Fall 2006

Kevin Bonine & Kevin Oh

1. Osmoregulation (Chap 25-26)
2. Kidney Function (Chap 27)

Mammalian Desert Adaptatations (Chap 28)

Amblyrhynchus cristatus

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http://eebweb.arizona.edu/eeb_course_websites.htm

Housekeeping, 14 Nov 2006

- Don't forget to do seminar write-up! (due 10 November)
- Turn in peer edits.

Upcoming Readings

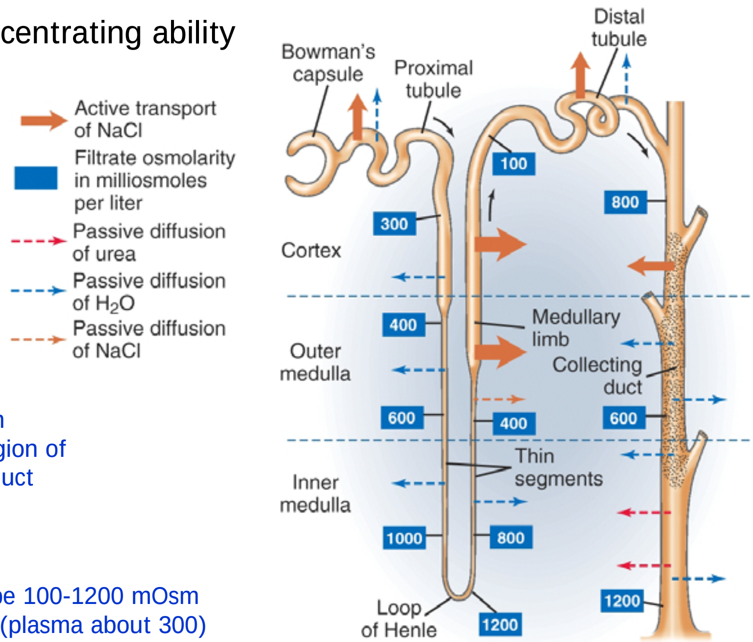
today: Text, Ch. 25-27 (osmoregulation, kidney, excretion)

Wed 15 Nov: Drought effects (Nagy 1988)
Discuss Term Paper, Prepare for Exam 3
Thurs 16 Nov: Exam 3

Lab oral presentations 15 Nov
9am – Heather Rivera
2pm – Eddie Betterton

2

Urine concentrating ability

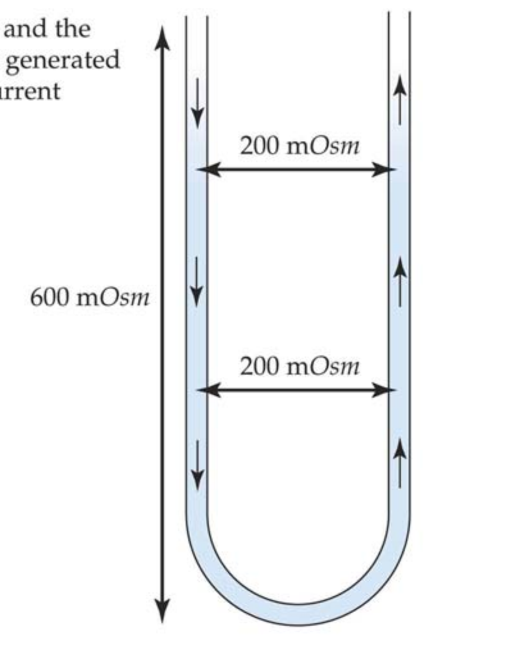


(Eckert 14-28)

ADH acts in stippled region of collecting duct

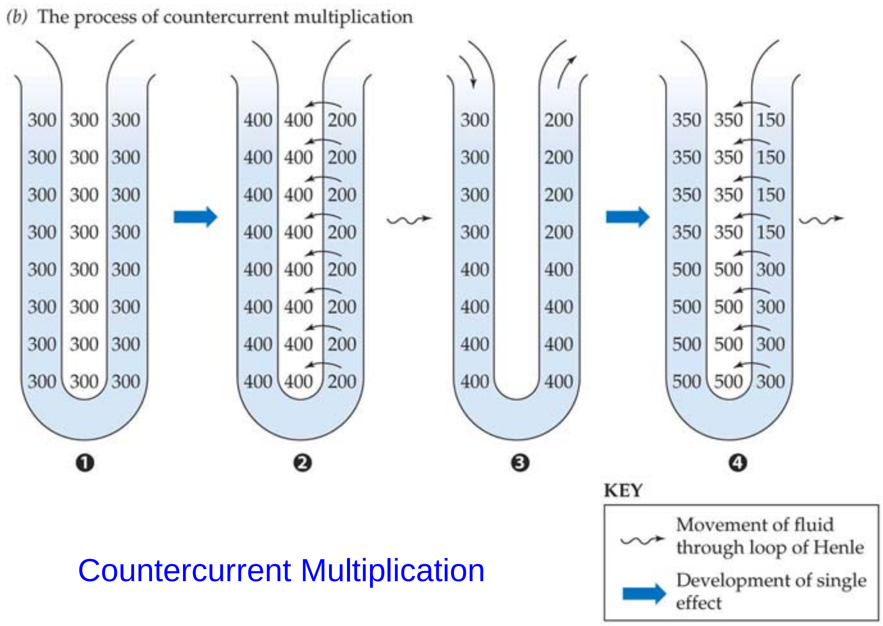
Urine can be 100-1200 mOsm in humans (plasma about 300)

(*a*) The single effect and the end-to-end gradient generated from it by countercurrent multiplication



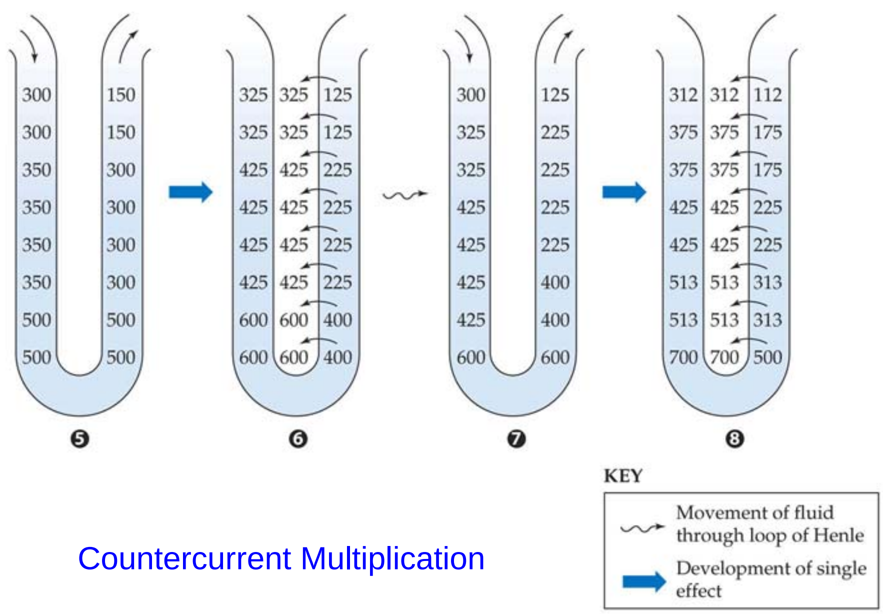
1. Single Effect
2. End-to-end Gradient

Figure 27.12
Hill et al. 2004



Countercurrent Multiplication

ANIMAL PHYSIOLOGY, Figure 27.12 (Part 2) © 2004 Sinauer Associates, Inc.



Countercurrent Multiplication

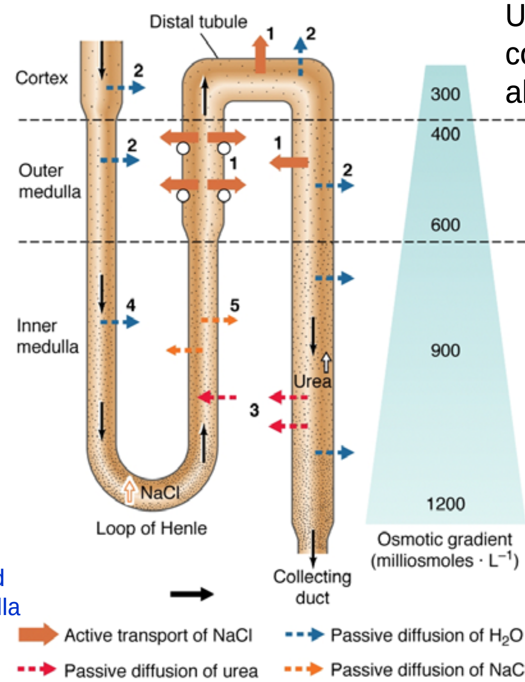
ANIMAL PHYSIOLOGY, Figure 27.12 (Part 3) © 2004 Sinauer Associates, Inc.

-Active Countercurrent Multiplier

-Dynamic

-Vasa Recta

Urine concentrating ability



Some urea "recycled"

Cortex and outer medulla →

Inner medulla

(Eckert 14-34)

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Endotherms in the COLD…

Countercurrent Heat Exchange

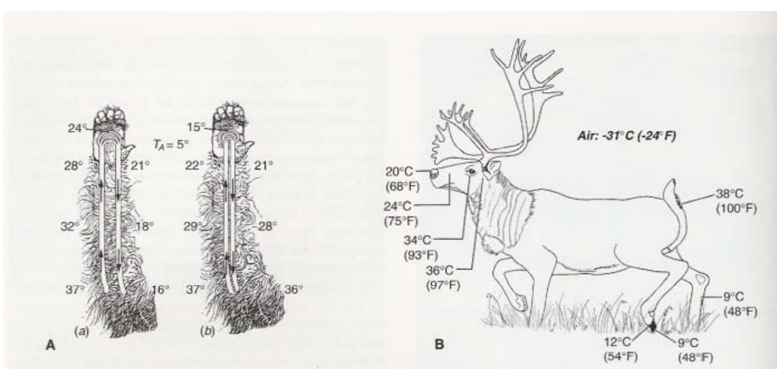

Figure 8.9 Countercurrent heat exchange. (A) A diagram representing the circulation in a limb of a mammal showing hypothetical temperature changes of the blood in the absence (a) and presence (b) of countercurrent heat exchange. Arrows indicate direction of blood flow. In (b), the venous blood takes up heat (thus cooling the arterial blood) all along its path of return because even as it becomes warmer and warmer, it steadily encounter arterial blood that is warmer yet. (B) Regulation of external body temperature in the caribou. Temperature regulation is accomplished in part by countercurrent heat exchange. An intricate meshwork of veins and arteries acts to keep the temperature of the legs near that of the environment so heat is not lost from the body.

(A) Source: Data from R.W. Hill and G.A. Wyse, Animal Physiology, 2nd edition, 1989, Harper & Row, New York. (B) Data from J.F. Merritt, "Animals of the Arctic" in Arctic Life: Challenge to Survive, (M.M. Jacobs & J.B. Richardson III, eds.), 1983, The Board of Trustees, Carnegie Institute, Pittsburgh, Pennsylvania.

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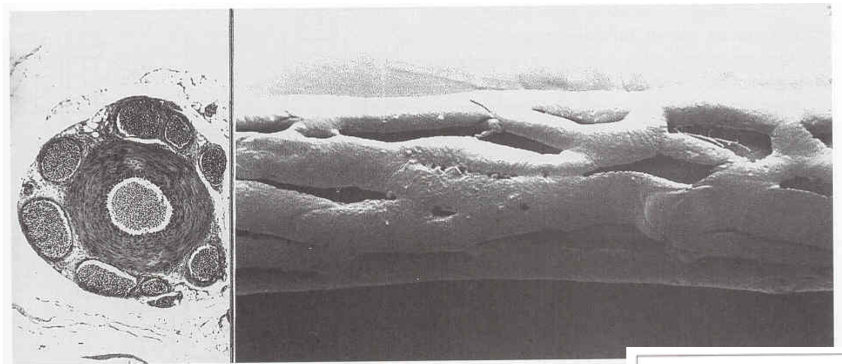


BLOOD VESSELS IN A BIRD LEG Cross section (left) and surface view of the blood vessels in the leg of a European rook (*Corvus frugilegus*), a crow-like bird. The thick-walled artery runs in the center and is surrounded by several thin-walled veins that branch and anastomose so that they virtually cover the a the structure is 2 mm. [Cour University of Copenhagen]

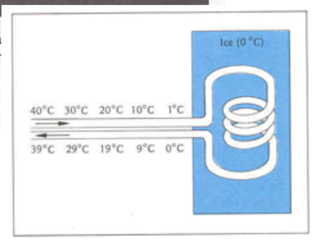
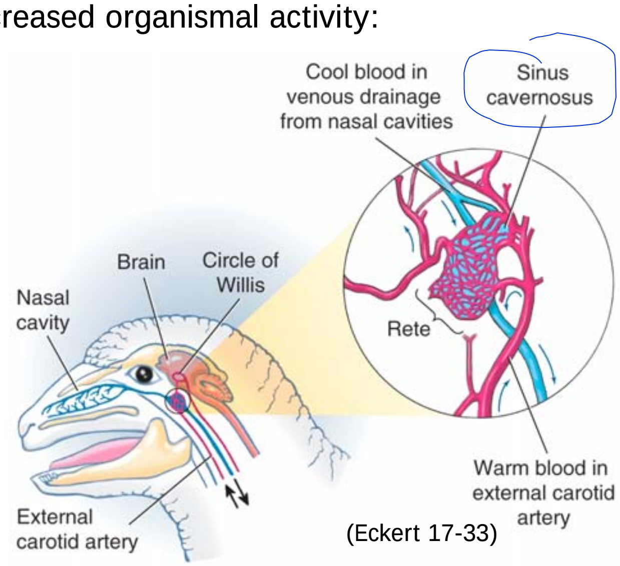


Figure 7.17 Model of a countercurrent heat exchanger. In this case heat is conducted from the incoming water to the outflowing water so that in the steady-state condition the outflowing water is pre-warmed to within 1 °C of the incoming water. For explanation, see text.

Knut Schmidt_Nielsen 1997

Hot Body, Cool Brain

Keep brain cool during prolonged increased organismal activity:



(Eckert 17-33)

-Countercurrent

-Carotid Rete

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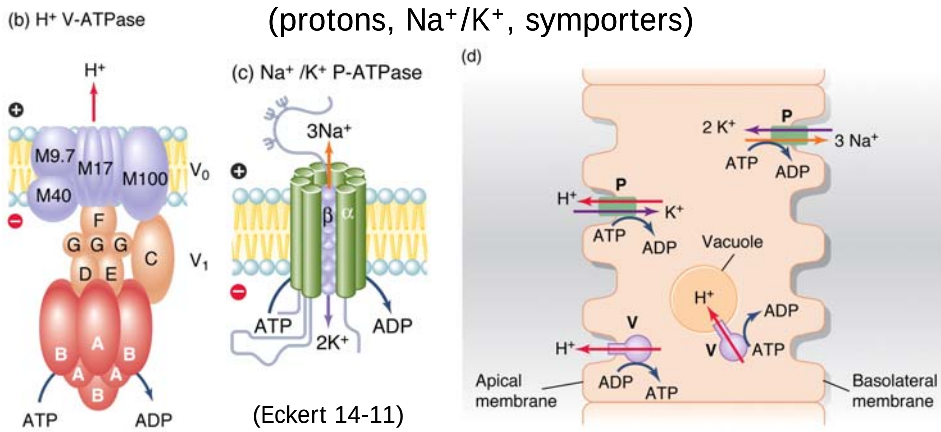
Osmoregulatory Mechanisms

-Similar mechanisms in nasal salt glands of birds and reptiles, mammalian kidney, rectal glands of sharks, gills of marine fishes, etc.

-Regulated by similar hormones as well.

(protons, Na^+/K^+, symporters)



(Eckert 14-11)

Non-mammalian kidneys:

-Only birds also have loops of henle

-Freshwater fish with more and larger glomeruli to make lots of dilute urine

-Some marine fish without glomeruli or bowman's capsule – urine formed by secretion, ammonia secreted by gills

-Osmoregulation also via extrarenal organs…

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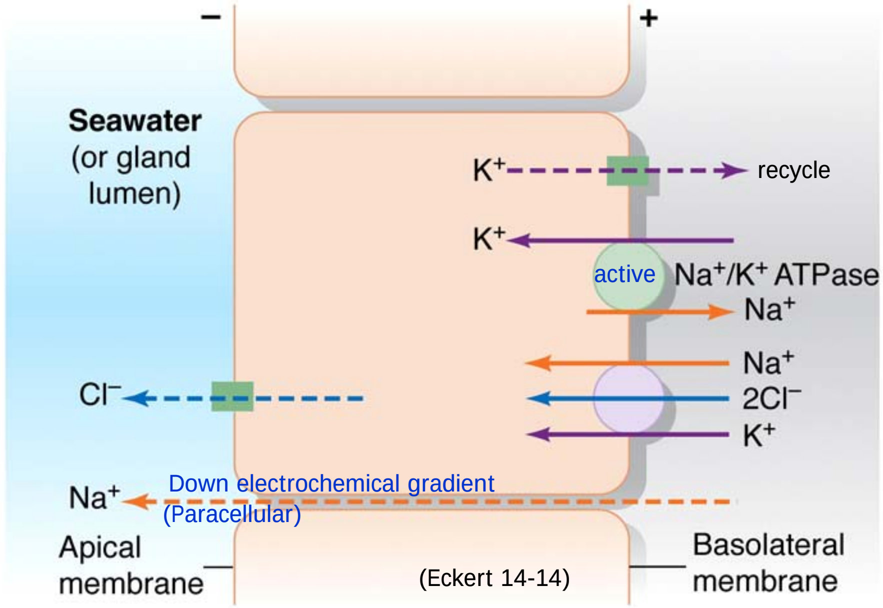
Salt Secretion:



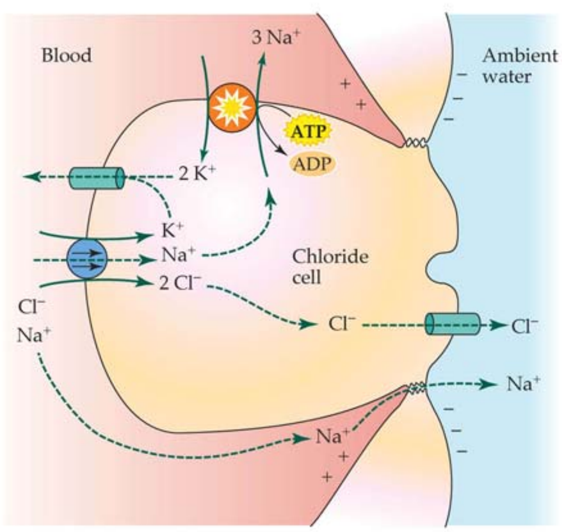
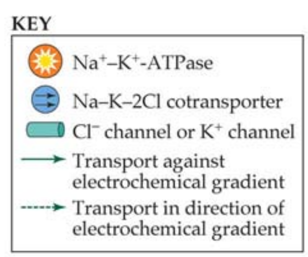


Figure in Box 26.2
Hill et al. 2004



Salt Glands

Shark rectal glands to dispose of excess NaCl

-blood hyperosmotic to seawater, but less salt
-more urea and TMAO (trimethylamine oxide)
-NaCl actively secreted

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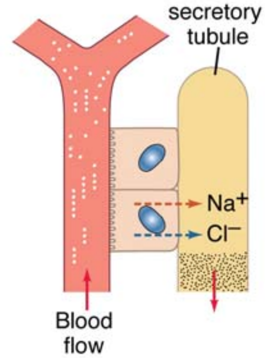
Shark Rectal Salt Glands

Salt-secreting cells:

-Na/K-ATPase pump in basolateral membrane
-generates gradient for Na+ by which $Na^+/2Cl^-/K^+$ cotransporter drives up $[Cl^-]$ in cell
-Cl^- across apical membrane
-Na^+ follows paracellularly down electrochemical gradient (and H_2O)
-apical membrane impermeable to urea and TMAO
-therefore iso-osmotic secretion with lots of NaCl

(c)

(Eckert 14-36)



… slightly different in birds and lizards →

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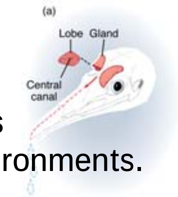
Salt Glands

(Eckert 14-36)

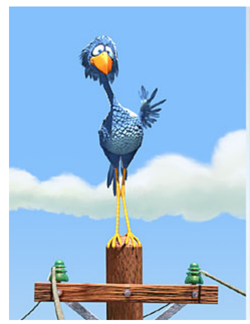


Nasal/orbital salt glands of birds and reptiles
-especially species in desert or marine environments.

Hypertonic NaCl secretions (2-3x plasma osmolarity)

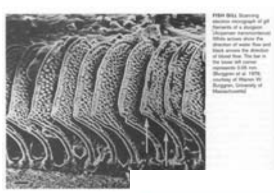
Allows some birds to drink salt water and end up with osmotically free water

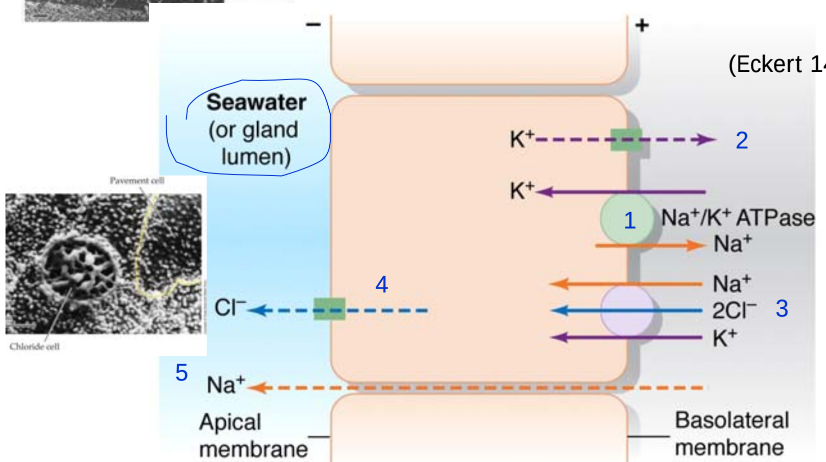
Amblyrhynchus cristatus



Fish Gills

Chloride cells involved in osmoregulation
-(recall lab paper on smolting)
-lots of mitochondria to power ATPases
-mechanism similar in nasal glands (birds and reptiles), and shark rectal gland





(Eckert 14-14)

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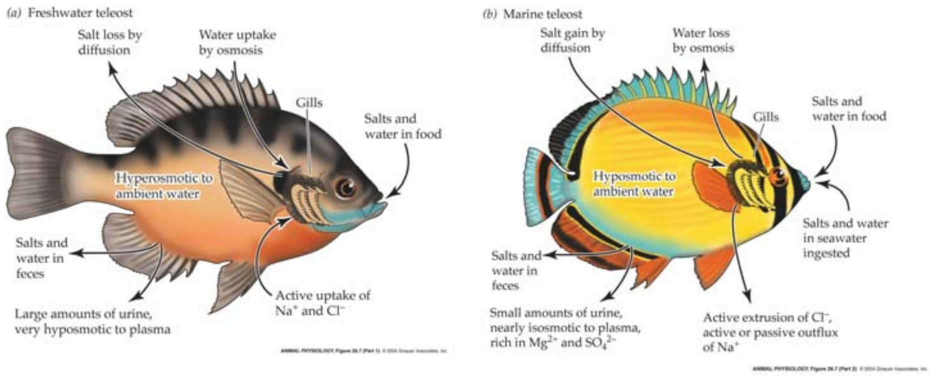

Hill et al. 2004, Fig 26.7

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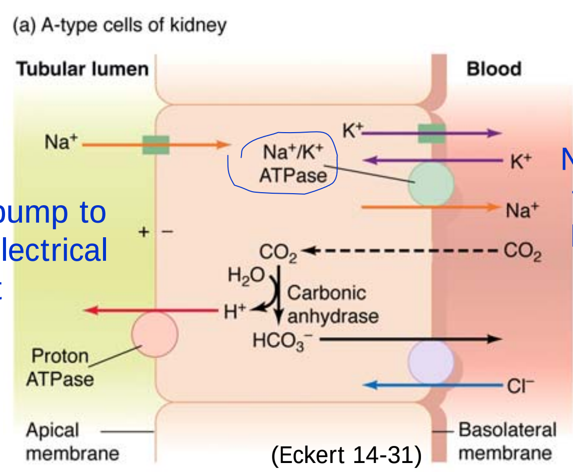
Freshwater fish:
The mechanism basically reversed to allow uptake of salt from water against concentration gradient

proton pump to create electrical gradient



(Eckert 14-31)

Na/K-ATPase to generate Na gradient

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(recall lab paper on smolting)

Sea ←→ Freshwater

Switch between getting rid of excess salt in seawater and taking up salt in freshwater

Growth hormone and cortisol for → sea
(more active chloride cells with more Na/K-ATPase activity)

Prolactin for → freshwater

Excretion of Nitrogeneous waste

-When amino acids catabolized, amino group ($-NH_2$) is released (deamination)

-If not reused, need to excrete because toxic

-Three main ways to dispose:

1-ammonia (most toxic, requires lots water)
'<u>ammonotelic</u>' (NH_3)

2-urea (need 10% of water of NH_3, but costs ATP)
'<u>ureotelic</u>' (2N)

3-uric acid (white pasty substance, low solubility, need 1% water as NH_3) '<u>uricotelic</u>' (4N), also costs ATP

-Disposal depends on water availability →

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Excretion of Nitrogeneous waste

Foodstuff		End product	
Carbohydrate	→	$CO_2 + H_2O$	
Fat	→	$CO_2 + H_2O$	
Protein	→	NH_3	↗ Urea ↘ Uric acid
Nucleic acids	→	Purines ↓ Uric acid ↓ Allantoin ↓ Allantoic acid ↓ Urea ↓ NH_3	+Pyrimidines ↓ β-Amino acids ↓ NH_3

Table 9.3 Metabolic end products of the major groups of foodstuffs. Ammonia from protein metabolism may be excreted as such or may be synthesized into other N-containing excretory products; purines from nucleic acids may be excreted as such or as any of a number of degradation products, including ammonia.

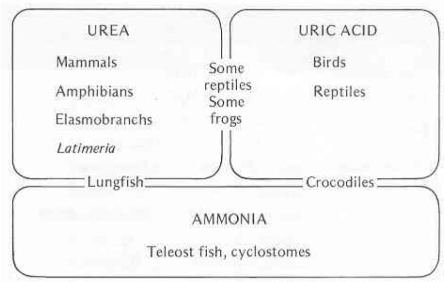
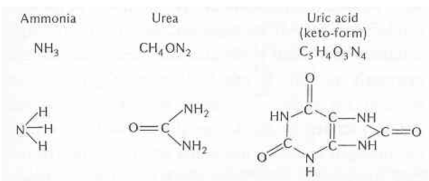


Figure 9.13 Different groups of vertebrates use different compounds as their major nitrogenous excretory product. There are many exceptions to the general pattern indicated in this diagram, most of them related to environmental factors rather than to phylogenetic relationships. See text for further details.



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Knut Schmidt_Nielsen 1997

Animal	Major end product of protein metabolism	Adult habitat	Embryonic environment
Aquatic invertebrates	Ammonia	Aquatic	Aquatic
Teleost fish	Ammonia, some urea	Aquatic	Aquatic
Elasmobranchs	Urea	Aquatic	Aquatic
Crocodiles	Ammonia, some uric acid	Semiaquatic	Cleidoic egg[a]
Amphibians, larval	Ammonia	Aquatic	Aquatic
Amphibians, adult	Urea	Semiaquatic	Aquatic
Mammals	Urea	Terrestrial	Aquatic
Turtles	Urea and uric acid	Terrestrial	Cleidoic egg
Insects	Uric acid	Terrestrial	Cleidoic egg
Land gastropods	Uric acid	Terrestrial	Cleidoic egg
Lizards	Uric acid	Terrestrial	Cleidoic egg
Snakes	Uric acid	Terrestrial	Cleidoic egg
Birds	Uric acid	Terrestrial	Cleidoic egg

[a] The role of cleidoic eggs is discussed later in this chapter.

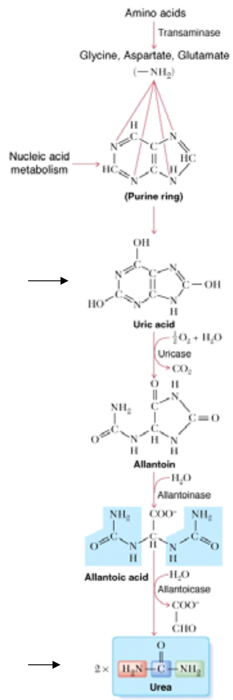
Table 9.4 Major nitrogen excretory products in various animal groups.

Knut Schmidt_Nielsen 1997

Excretion of Nitrogeneous waste

-ammonia converted to non-toxic glutamine in the body for transport

-ammonia toxic because
- -increases pH,
- -competes with K^+ for ion transport,
- -alters synaptic transmission

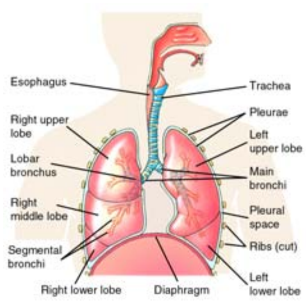


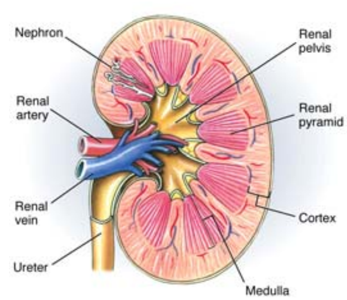
(14-31) 29

(Eckert 14-17)

pH regulation

<u>Acid Secretion</u>





CO_2 via lungs, H^+ via kidneys
(skin and gills can also play role)

Proximal tubule and loop of henle:
Na^+/H^+ antiporter (driven by Na/K-ATPase)

Distal tubule and collecting duct:
A-type cells with proton pump and anion exchanger

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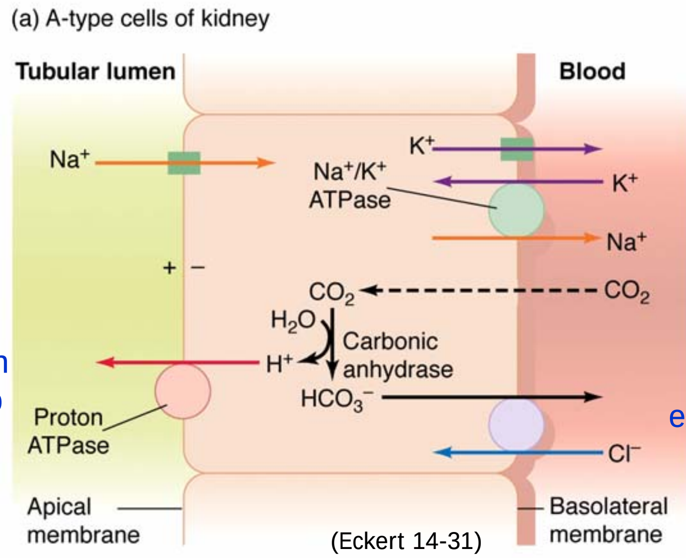

proton pump

anion exchanger

(Eckert 14-31)

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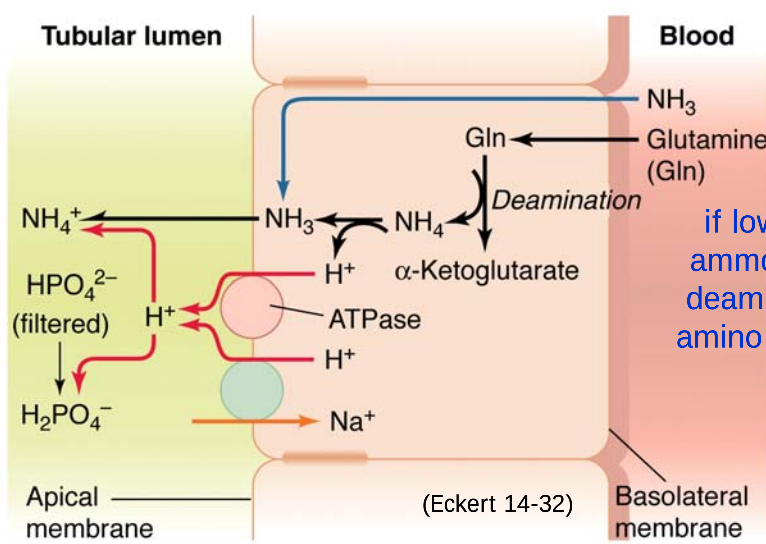
Ultrafiltrate buffered by bicarbonate, phosphates, and ammonia allowing for more acid secretion

e.g., $NH_3 + H^+ \rightarrow NH_4^+$



if low on ammonia, deaminate amino acids

(Eckert 14-32)

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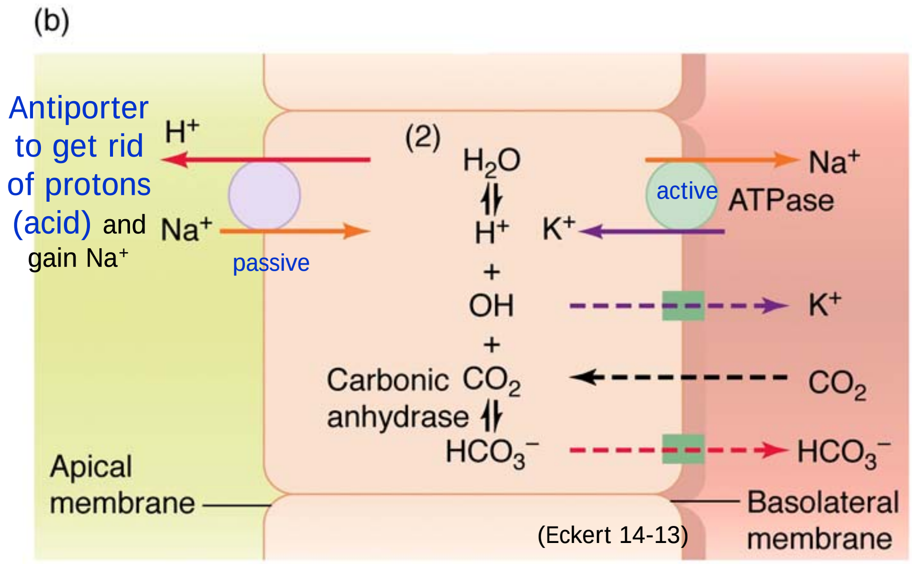
Gradients established and used:



Mammalian Kidney

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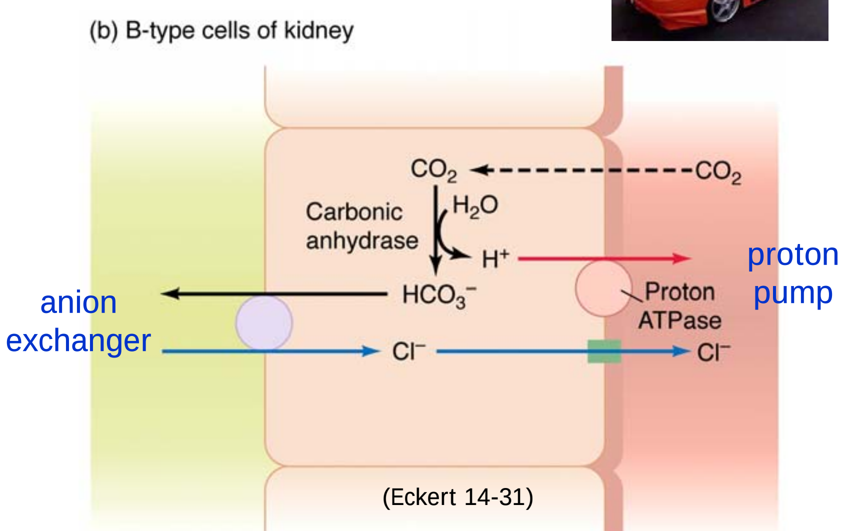
pH regulation

<u>Base Secretion</u> (opposite A-type cells)



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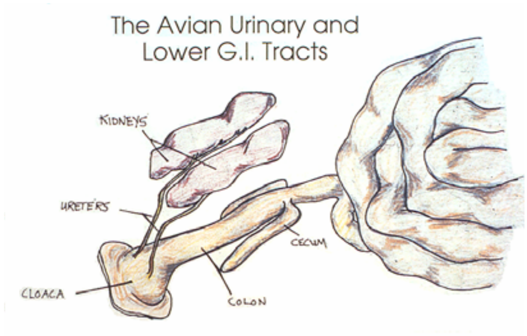
Osmoregulation by Birds

Eldon J. Braun
Department of Physiology
University of Arizona
November 2005



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Osmoregulation by birds:
Organs Involved

Kidneys

Lower gastrointestinal tract

Salt glands

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As birds do not have urinary bladders, the ureteral urine is refluxed from the cloaca into the colon

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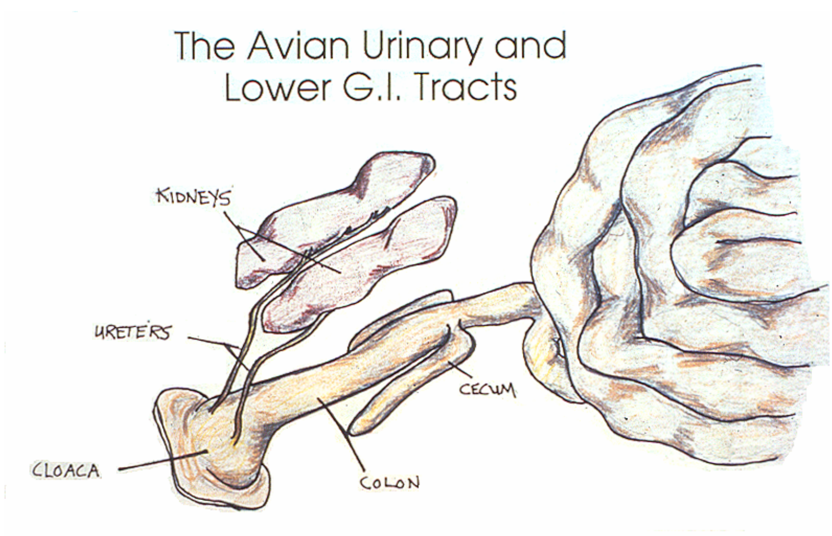

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Urine-to-Plasma Osmolar Ratios for Birds

	(U/P_{osm})
Ring-necked Pheasant	1.5
Senegal Dove	1.7
Savannah Sparrow	1.7*
King Quail	1.8
White-crowned Sparrow	1.8
Domestic Fowl	2.0
Budgerigar	2.3
House Finch	2.4
Singing Honeyeater	2.4
Stubble Quail	2.6
Mean	2.05

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Comparison of U/P_{osms} between birds and mammals

- ❖ Not valid comparison to make
  - ❖ Urine in lower GI tract
    - Effects of conc. fluid in lower GI tract
- ❖ End products of nitrogen metabolism
  - ❖ Uric acid vs. urea
    - Urea ca. 50% of solutes in urine
    - Uric acid not in solution

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Nitrogen Excretion in Birds

Compound	%
Urea	4
Ammonium	20
Uric Acid	76

Solubilites of Nitrogen-Containing Compounds

Compound	Solubility (mmol/L)
Uric Acid	0.381
Ammonium Urate	3.21
Sodium Urate	8.32
Potassium Urate	14.75
Urea	16,650

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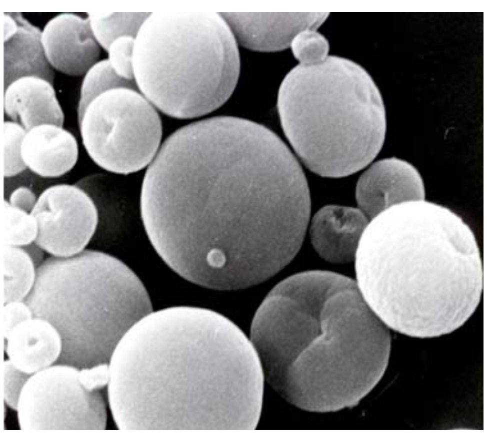
Evolutionary Rationale for this Type of Arrangement
(i.e. urine entering lower GI tract)

Physical form of uric acid in avian urine



Small spherical structures

Spheres ca. 65% uric acid

Uric acid bound To a matrix protein

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Protein in avian ureteral urine

Avian urine contains 5 mg/ml protein

Protein conc. in human urine
ca. 0.05 mg/ml

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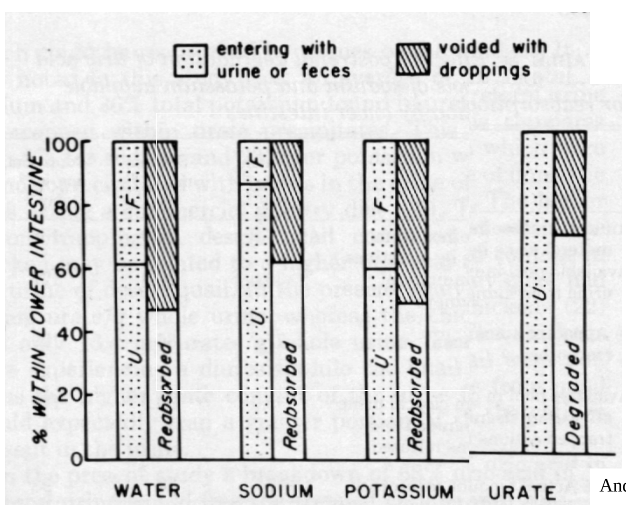
Modification of Urine in Lower GI Tract of Birds



Anderson & Braun

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Products Formed From the Breakdown of Uric Acid in Avian Lower GI tract

77% of [^{15}N]uric acid introduced into ceca of cockerels disappeared in 60 min

Labelled nitrogen appeared in plasma within glutamine

And nitrogen appeared as ammonia and rapidly absorbed

Where do these product go?

Karasawa, 1989

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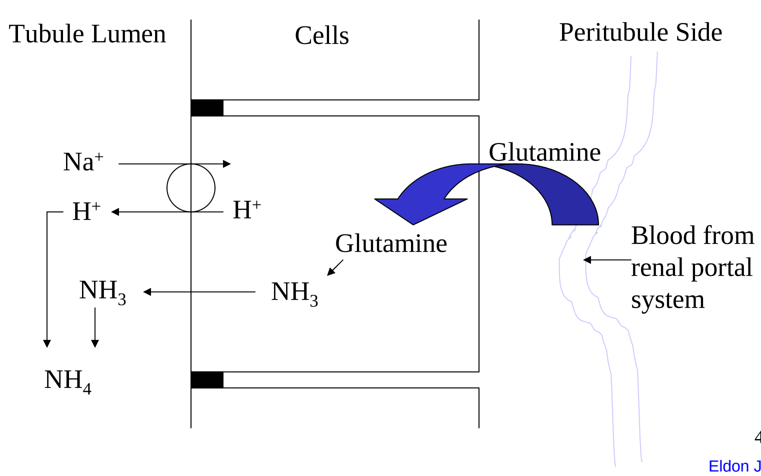
Use of glutamine by renal tubules

(To buffer hydrogen ions)



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Osmoregulation by Birds

Eldon J. Braun
Department of Physiology
University of Arizona
(08 November 2005)

What are the three fluid compartments in vertebrates?

1. Intracellular **2. Extracellular**

A. Interstitial

B. Blood Plasma

What are Colligative Properties?

Depends on Solute concentration:

Osmolality, Freezing Point, Boiling Point, Water Vapor Pressure

What is a micron?

um – 1/1,000,000 of a meter – 10^{-6}m - µm

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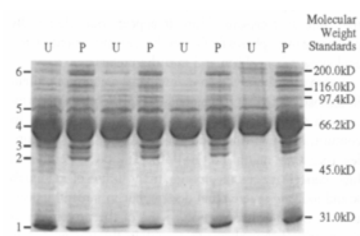
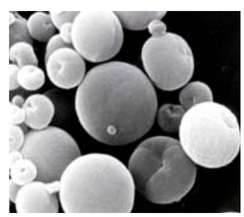
Serum Albumin

SDS PAGE of avian Urine and plasma





Albumin is the protein of the highest concentration in plasma.

Albumin transports many small molecules in the blood (for example, bilirubin, calcium, progesterone, and drugs).

It is also of prime importance in maintaining the oncotic pressure of the blood. This is because, unlike small molecules such as sodium and chloride, the concentration of albumin in the blood is much greater than it is in the extracellular fluid.

Because albumin is synthesized by the liver, decreased serum albumin may result from liver disease. It can also result from kidney disease, which allows albumin to escape into the urine. Decreased albumin may also be explained by malnutrition or a low protein diet.

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Normal Values (3.4 to 5.4 g/dL)

http://www.nlm.nih.gov/medlineplus/ency/article/003480.htm