

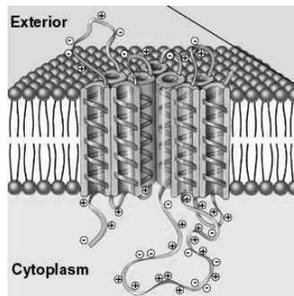
Transport across membranes

Diffusion - down a molecular gradient until reaching equilibrium

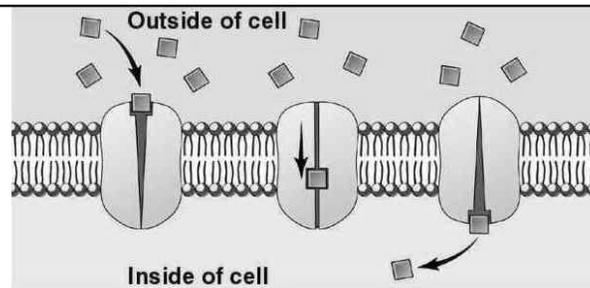
Facilitated diffusion - molecular diffusion through specific channels or gates

Passive transport - diffusion down a solute gradient

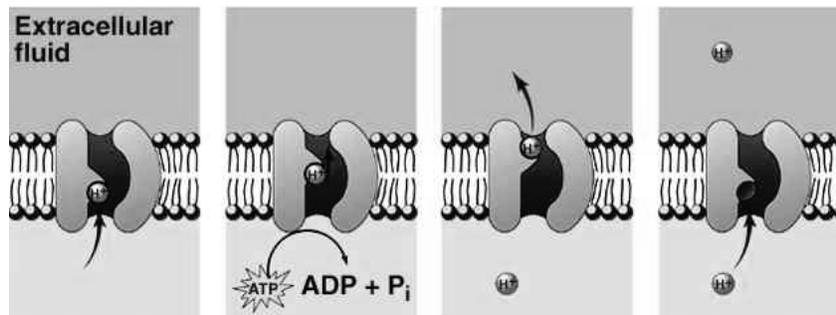
Active transport - movement of solutes from an area of lower concentration to that of a higher concentration, against a molecular gradient



Trans-membrane gate model



Single molecule transport



**TABLE 8.1** Composition of sea water. In addition to the ions listed, sea water contains small amounts of virtually all elements found on earth. [Potts and Parry 1964]

Ion	Amount per 1 liter sea water		Amount per 1 kg water <sup>a</sup>	
	mmol	g	mmol	g
Sodium	470.2	10.813	475.4	10.933
Magnesium	53.57	1.303	54.17	1.317
Calcium	10.23	0.410	10.34	0.414
Potassium	9.96	0.389	10.07	0.394
Chloride	548.3	19.440	554.4	19.658
Sulfate	28.25	2.713	28.56	2.744
Bicarbonate	2.34	0.143	2.37	0.145

<sup>a</sup>In thermodynamics concentrations are calculated per kilogram water and are referred to as the molality of the solution. A brief synopsis of the physics of solutions is found in Appendix E.

**TABLE 8.2** Typical composition of soft water, hard water, and inland saline water, given in millimoles per kilogram water

Ion	Soft lake water <sup>a</sup>	River water <sup>b</sup>	Hard river water <sup>c</sup>	Saline water <sup>d</sup>	Dead Sea <sup>e</sup>
Sodium	0.17	0.39	6.13	640	1955
Magnesium	0.15	0.21	0.66	6	2028
Calcium	0.22	0.52	5.01	32	481
Potassium	—	0.04	0.11	16	219
Chloride	0.03	0.23	13.44	630	7112
Sulfate	0.09	0.21	1.40	54	5.3
Bicarbonate	0.43	1.11	1.39	3	3.7

<sup>a</sup>Lake Nipissing, Ontario. <sup>b</sup>Mean composition of North American rivers. <sup>c</sup>Tuscarawas River, Ohio. <sup>d</sup>Bad Water, Death Valley, California. <sup>e</sup>Dead Sea, Israel. This water also contains 74 mmol per kg H<sub>2</sub>O of bromide.

1119mM  
35g

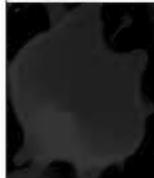
1000mOsm

1135mM  
35.6g

**Hyperosmotic solution**



**Shriveled cells**

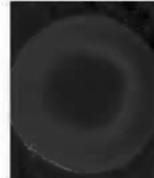


**Human red blood cells**

**Isosmotic solution**



**Normal cells**

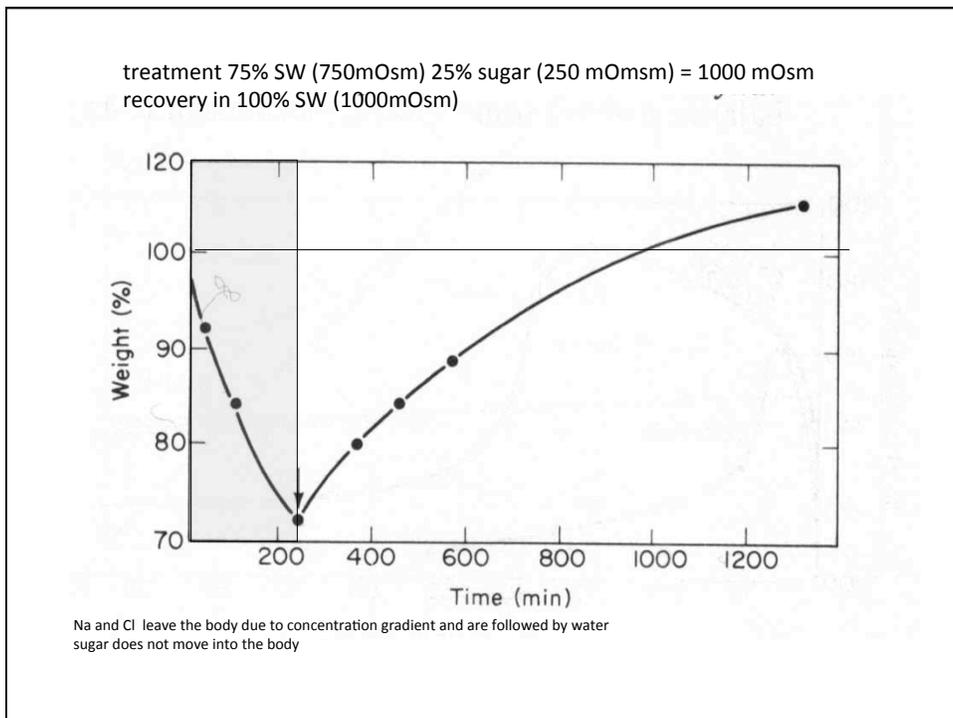
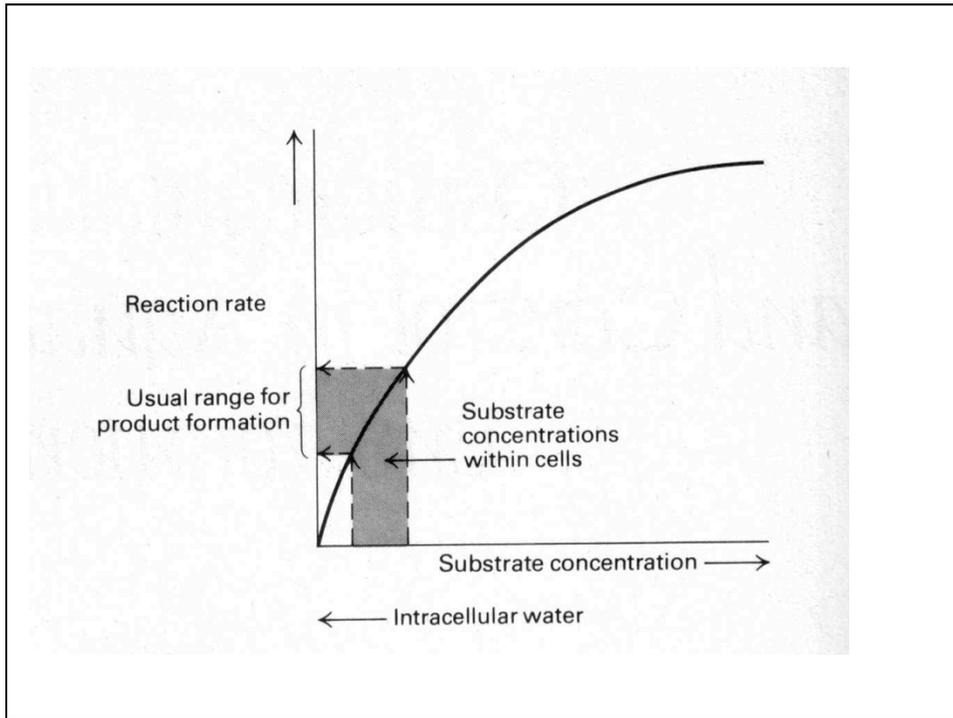


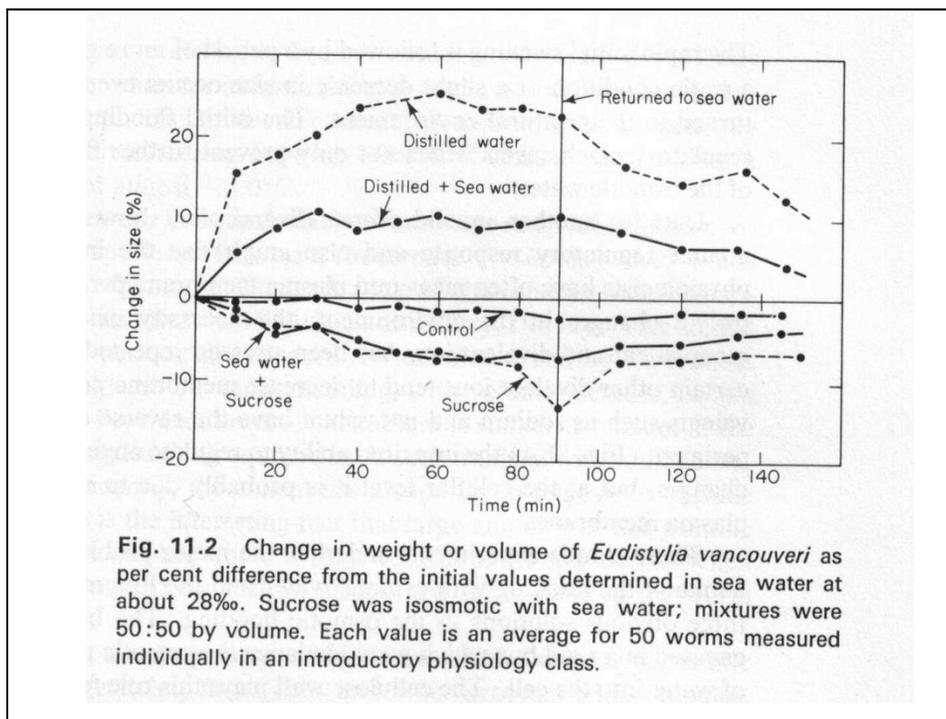
**Hypoosmotic solution**



**Cells swell and eventually burst**







**TABLE 8.3** Concentrations of common ions (in millimoles per kilogram water) in sea water and in the body fluids of some marine animals. [Potts and Parry 1964]

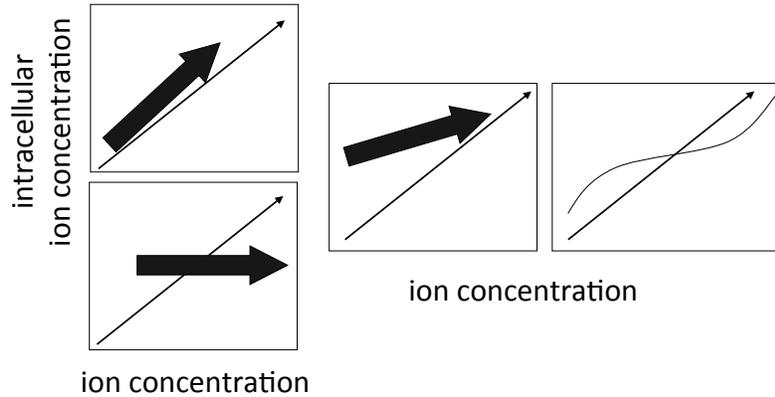
	Na	Mg	Ca	K	Cl	SO <sub>4</sub>	Protein (g liter <sup>-1</sup> )
Sea water	478.3	54.5	10.5	10.1	558.4	28.8	—
Jellyfish ( <i>Aurelia</i> )	474	53.0	10.0	10.7	580	15.8	0.7
Polychaete ( <i>Aphrodite</i> )	476	54.6	10.5	10.5	557	26.5	0.2
Sea urchin ( <i>Echinus</i> )	474	53.5	10.6	10.1	557	28.7	0.3
Mussel ( <i>Mytilus</i> )	474	52.6	11.9	12.0	553	28.9	1.6
Squid ( <i>Loligo</i> )	456	55.4	10.6	22.2	578	8.1	150
Isopod ( <i>Ligia</i> )	566	20.2	34.9	13.3	629	4.0	—
Crab ( <i>Maia</i> )	488	44.1	13.6	12.4	554	14.5	—
Shore crab ( <i>Carcinus</i> )	531	19.5	13.3	12.3	557	16.5	60
Norwegian lobster ( <i>Nephrops</i> )	541	9.3	11.9	7.8	552	19.8	33
Hagfish ( <i>Myxine</i> )	537	18.0	5.9	9.1	542	6.3	67

### Ion balance and osmoregulation

Different ionic concentrations than their environment

Highly permeable membranes (ions and water), specially gills, gut, skin.

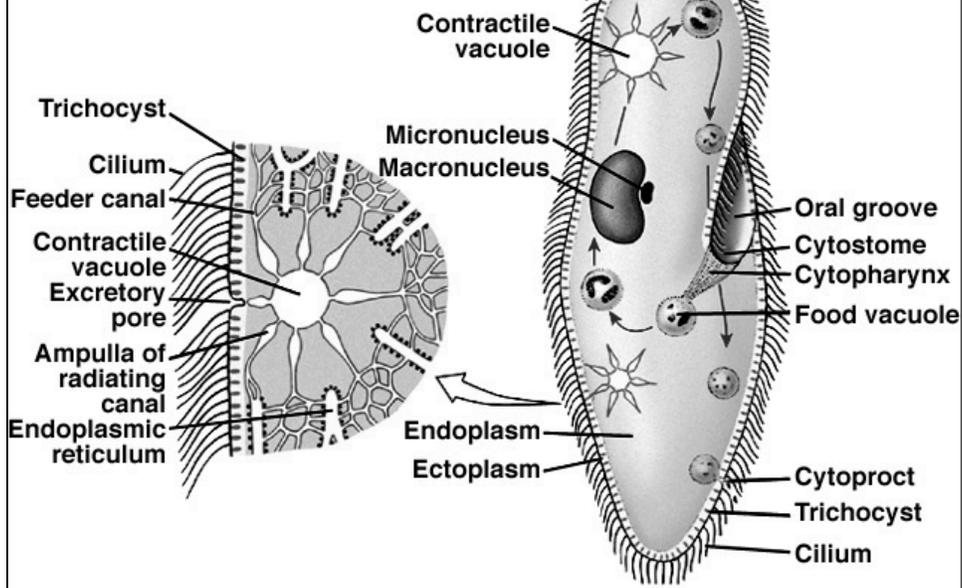
Control mechanisms: none (osmoconformers) ion balance (osmoregulators)

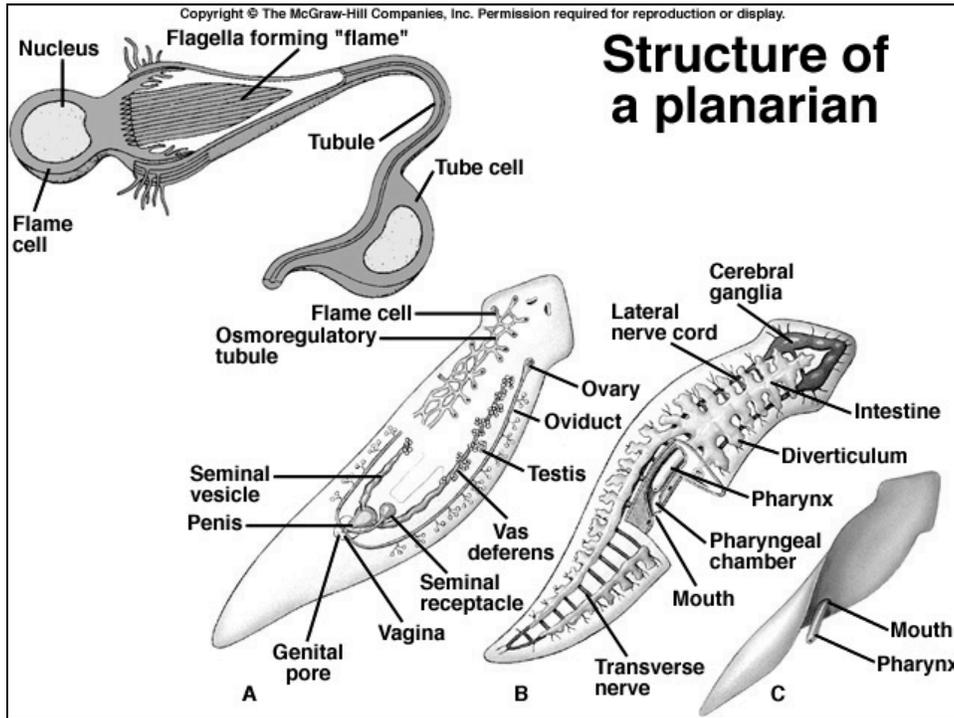


Most invertebrates are osmoconformers, some are quasi-conformers while other are osmoregulators. Most vertebrates are osmoregulators.

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### Contractile vacuole of *Paramecium*





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## A copepod

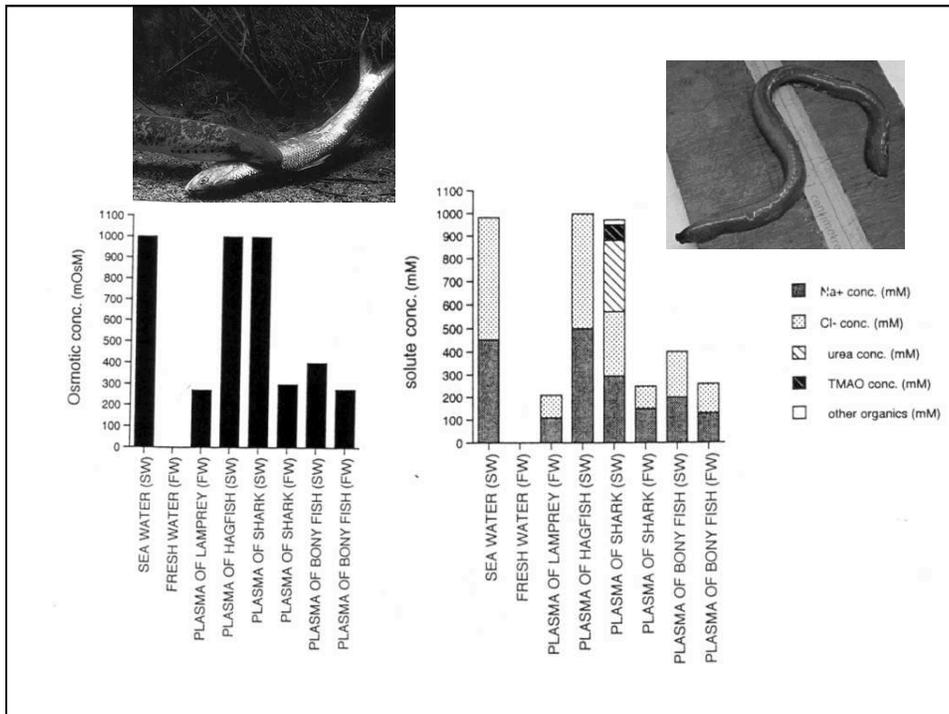
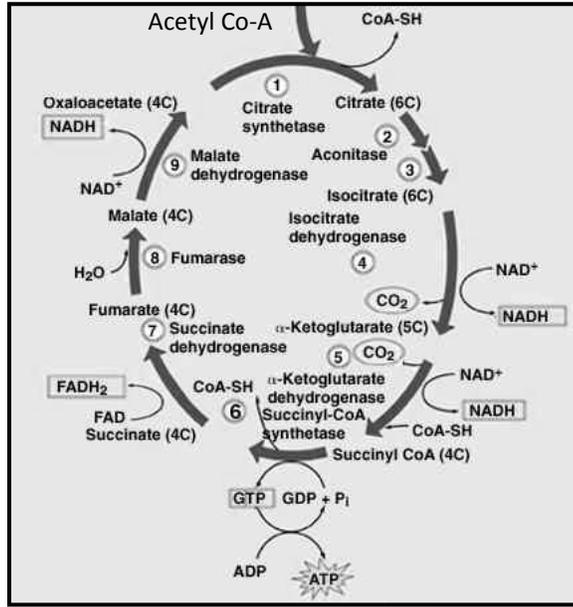
Osmotic stress response  
 build up of free amino acids

- 1) uptake from environment
- 2) uptake from extracellular fluid
- 3) protein catabolism
- 4) synthesis of 3 principal a.a.

- alanine
- glutamate
- proline

provides amino group through reductive amination

Krebs cycle leads to  $\alpha$ -ketoglutarate that leads to free a.a. synthesis and an increase in osmotic concentration

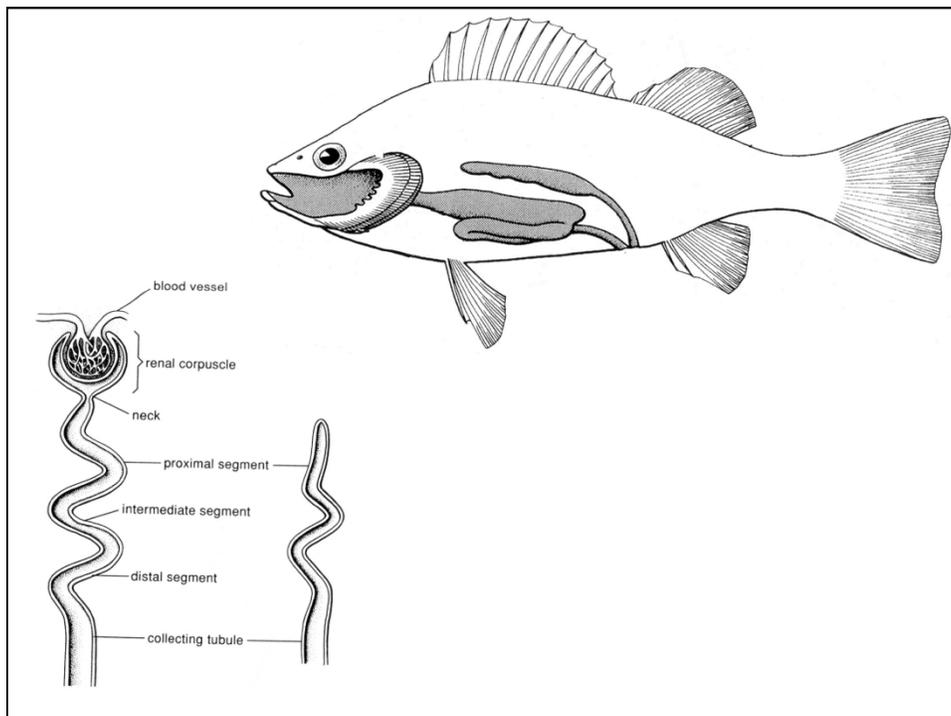


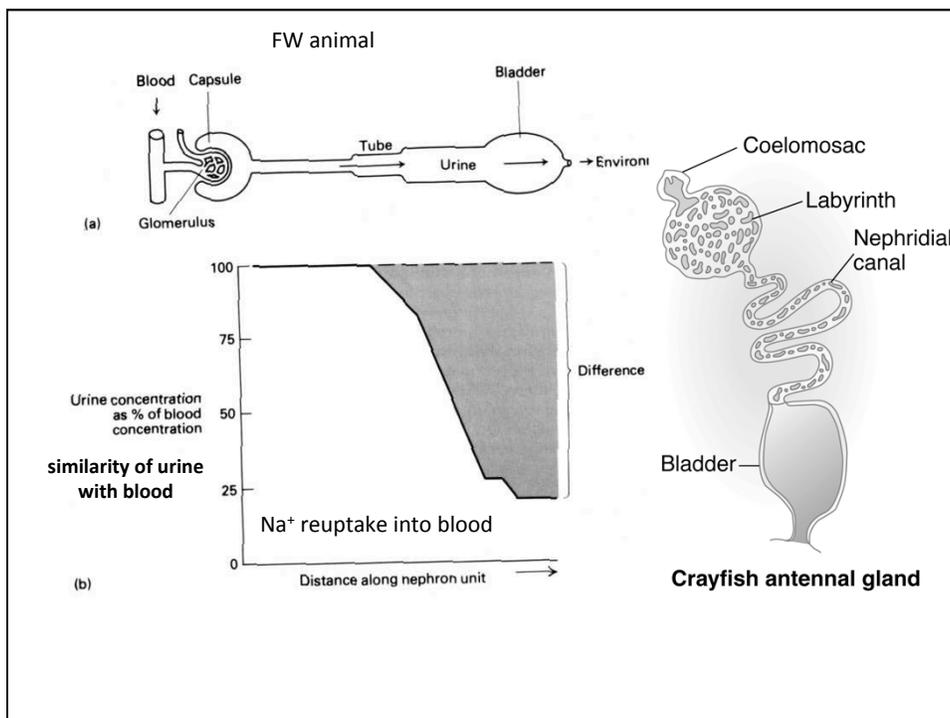
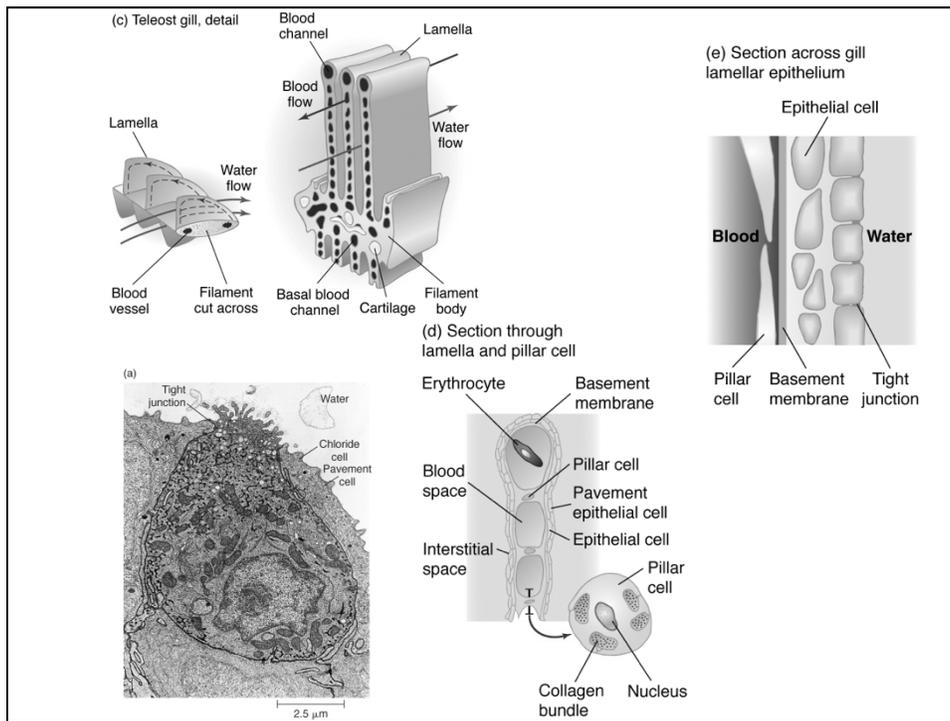
**Kidney:** functions both in excretion and ion exchange filtration of blood, resorption and secretion of ions

Nephron - glomerulus (capillary bundle, surrounded by Bowman's capsule), is where filtration occurs in the capillaries are under relatively high pressure, while the capsule interior is low pressure, water and small ions pass across membranes down the pressure gradient.

Tubules - Location for ion and water resorption and secretion, also secretion of larger waste products into filtrate from blood. Location for both passive and active transport of ions and larger compounds.

Glomerulus may be either present or absent, or there may be different elaboration of tubules, which taken together reflect different osmoregulatory strategies.





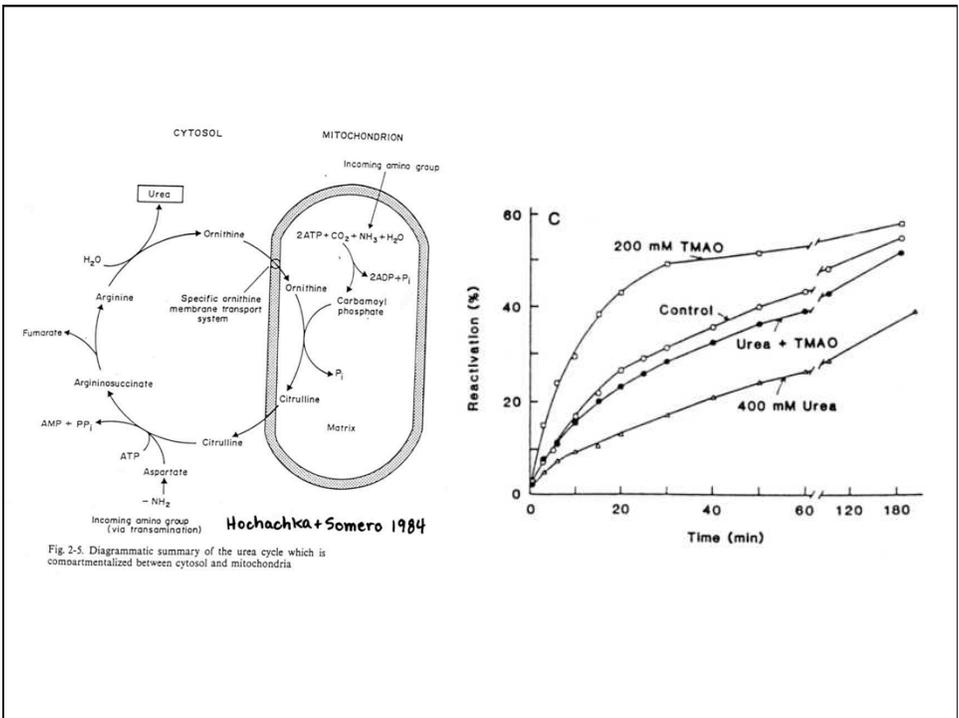
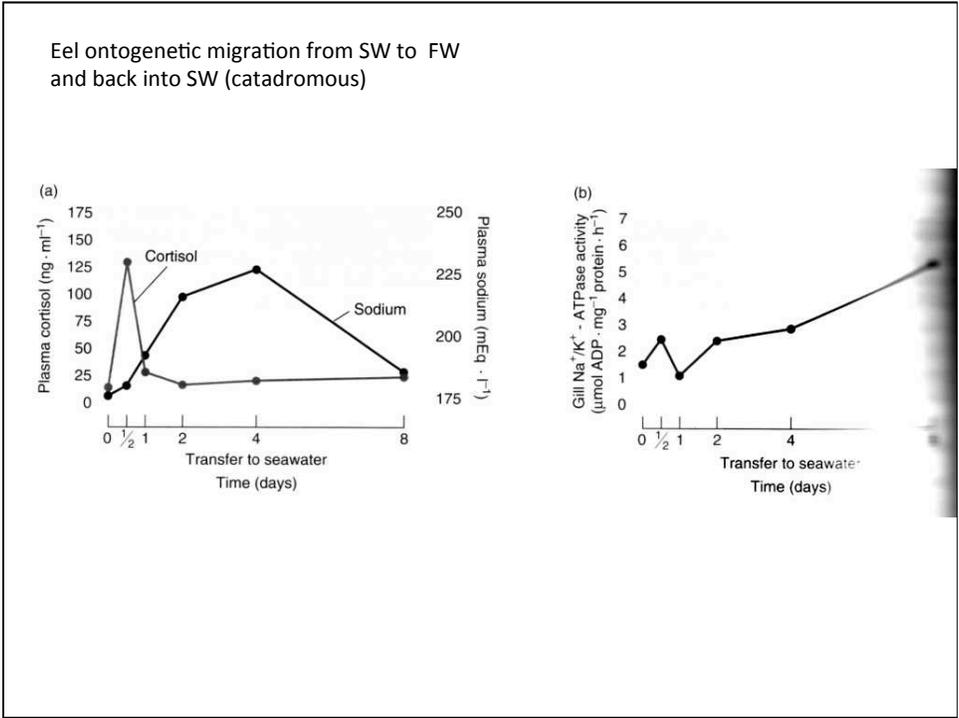
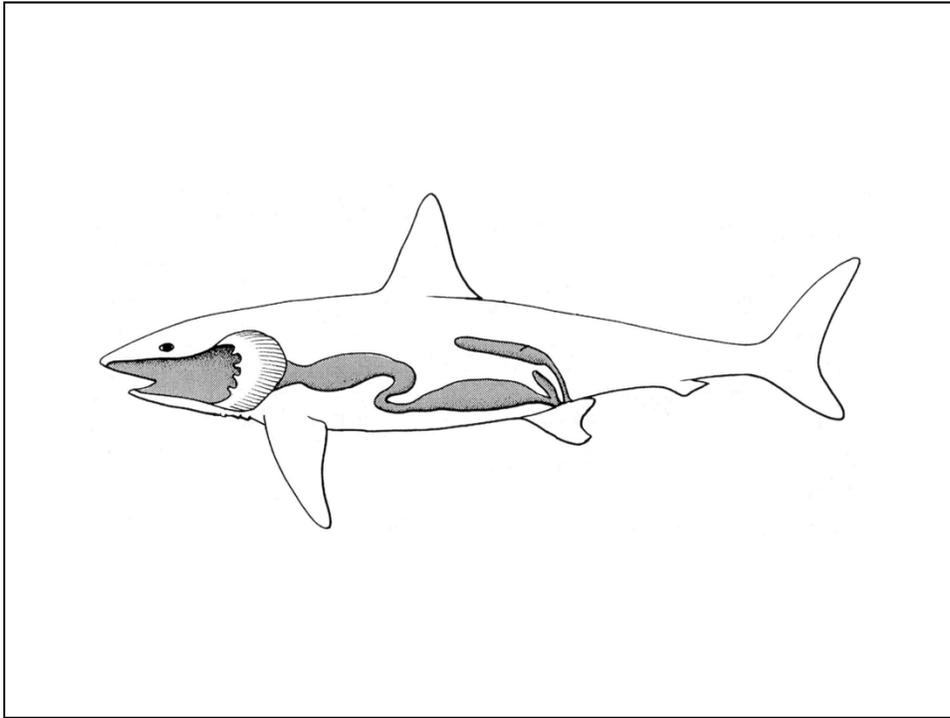


Fig. 2-5. Diagrammatic summary of the urea cycle which is compartmentalized between cytosol and mitochondria



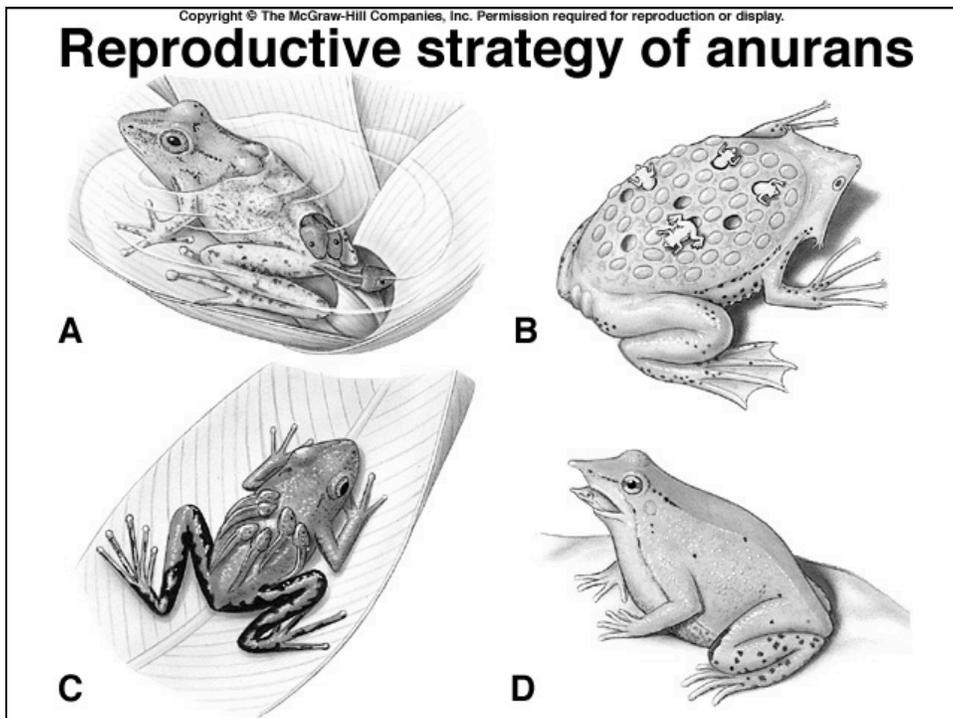
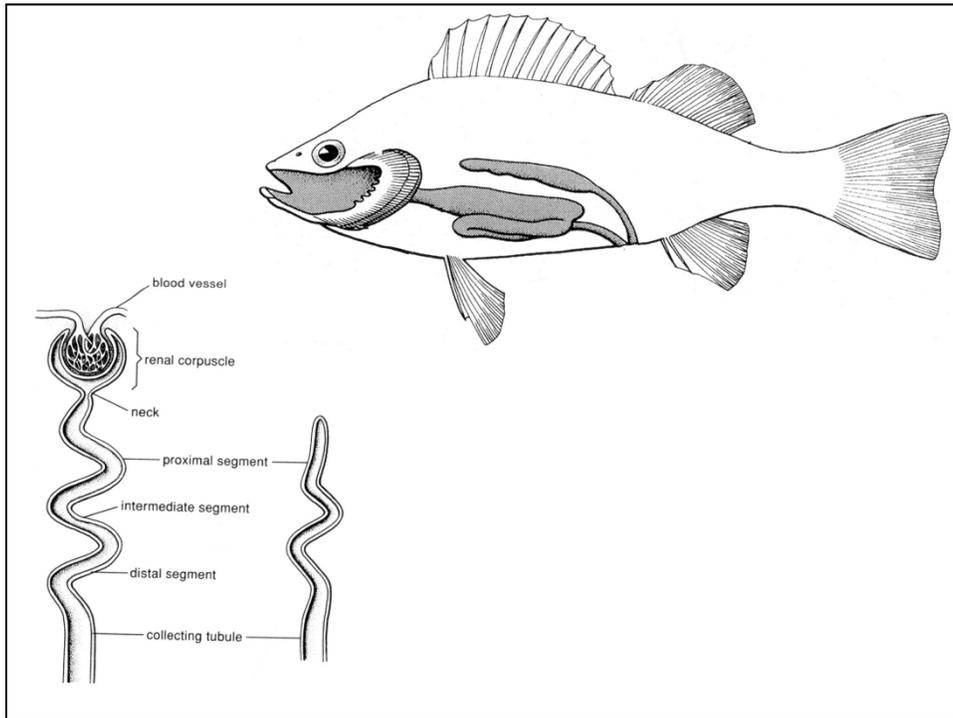
**Table 12.4** Solute constituents of a freshwater environment and of the blood of some freshwater animals (from Potts and Parry, 1963)

	$Na^+$	$K^+$	$Ca^{++}$	$Mg^{++}$	$Cl^-$	$HCO_3^-$	Others	Total
A. Average composition of North American river water (mmol/kg)	0.39	0.04	0.52	0.21	0.23	1.11	0.21 (sulfate)	2.71
B. Composition of the blood of some freshwater animals								
1) Frog ( <i>Rana</i> ) <sup>1</sup>	109	2.6	2.1	1.3	78	26.6	3.5 (lactate)	223.1
2) Trout ( <i>Salmo</i> ) <sup>2</sup>	161	5.3	6.3	0.9	119	—	1.0 (phosphate)	293.5
3) Crab ( <i>Potamon</i> ) <sup>2</sup>	259	8.4	12.7	—	242	—	—	522.1
4) Insect larva ( <i>Stalis</i> ) <sup>2</sup>	109	5.0	7.5	19	31	15	152 (amino acids)	338.5
5) Lamellibranch ( <i>Anodonta</i> ) <sup>1</sup>	15.6	0.5	6	0.2	11.7	12	0.2 (amino acids)	46.2
6) Stingray ( <i>Potamotrygon</i> ) <sup>2*</sup>	150	5.9	3.6	1.8	149	—	0.5 (urea)	310.8

<sup>1</sup> mmol/kg water

<sup>2</sup> mmol/l blood

\* From Thorson *et al.*, 1967



**TABLE 8.6** Concentrations of major solutes (in millimoles per liter) in sea water and in the blood plasma of some aquatic vertebrates.

	Habitat	Solute			Osmotic concentration (mOsm liter <sup>-1</sup> )
		Na	K	Urea <sup>a</sup>	
Sea water		~450	10	0	~1000
<i>Cyclostomes</i>					
Hagfish ( <i>Myxine</i> ) <sup>b</sup>	Marine	549	11	—	1152
Lamprey ( <i>Petromyzon</i> ) <sup>c</sup>	Marine	—	—	—	317
Lamprey ( <i>Lampetra</i> ) <sup>b</sup>	Fresh water	120	3	<1	270
<i>Elasmobranchs</i>					
Ray ( <i>Raja</i> ) <sup>b</sup>	Marine	289	4	444	1050
Dogfish ( <i>Squalus</i> ) <sup>b</sup>	Marine	287	5	354	1000
Fresh-water ray ( <i>Potamotrygon</i> ) <sup>d</sup>	Fresh water	150	6	<1	308
Coelacanth ( <i>Latimeria</i> ) <sup>e</sup>	Marine	197	7	350	954
<i>Teleosts</i>					
Goldfish ( <i>Carassius</i> ) <sup>b</sup>	Fresh water	115	4	—	259
Toadfish ( <i>Opsanus</i> ) <sup>b</sup>	Marine	160	5	—	392
Eel ( <i>Anguilla</i> ) <sup>b</sup>	Fresh water	155	3	—	323
	Marine	177	3	—	371
Salmon ( <i>Salmo</i> ) <sup>b</sup>	Fresh water	181	2	—	340
	Marine	212	3	—	400
<i>Amphibians</i>					
Frog ( <i>Rana</i> ) <sup>f</sup>	Fresh water	92	3	~1	200
Crab-eating frog ( <i>R. cancrivora</i> ) <sup>g</sup>	Marine	252	14	350	830 <sup>h</sup>

<sup>a</sup>When no value is listed for urea, the concentration is of the order of 1 mmol per liter and osmotically insignificant. Values for ray, dogfish, and coelacanth include trimethylamine oxide.  
<sup>b</sup>Bentley (1971). <sup>c</sup>Robertson (1954). <sup>d</sup>Thorson et al. (1967). <sup>e</sup>Locket (1980).  
<sup>f</sup>Mayer (1969). <sup>g</sup>Gordon et al. (1961).  
<sup>h</sup>Values for frogs kept in a medium of about 800 mOsm per liter, or four-fifths of normal sea water.

**Table 13.1** Distribution of water in the body of some vertebrates from different environments (g/100 g body weight) (from Bentley, 1971)

ENVIRONMENT	TOTAL BODY WATER	=	EXTRACELLULAR	+	INTRACELLULAR
<i>Salt water</i>					
Spiny dogfish	71.7		21.2		50.5
Parrotfish	73.1		16.6		56.5
<i>Fresh water</i>					
Freshwater shark	72.1		19.7		52.4
Paddlefish	74.0		15.6		58.4
Bowfin	74.5		18.9		55.6
Carp	74.1		15.5		55.9
<i>Terrestrial</i>					
Ornate lizard	73.6		25.7		47.9
Human	66.0		20.0		46.0
Camel	69.8		19.2		50.6

**Table 14-3** Evaporative water loss of representative animals under desert conditions

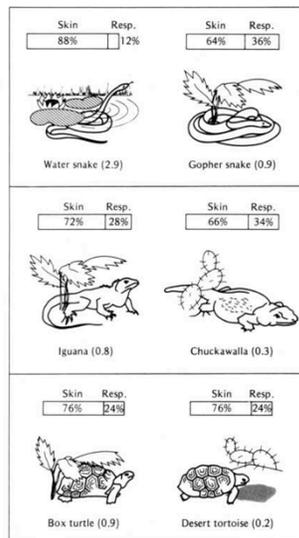
Species	Water loss (mg · cm <sup>-2</sup> · h <sup>-1</sup> )	Remarks*
<b>Arthropods</b>		
<i>Eleodes armata</i> (beetle)	0.20	30°C; 0% r.h.
<i>Hadrurus arizonensis</i> (scorpion)	0.02	30°C; 0% r.h.
<i>Locusta migratoria</i> (locust)	0.70	30°C; 0% r.h.
<b>Amphibians</b>		
<i>Cyclorana alboguttatus</i> (frog)	4.90	25°C; 100% r.h.
<b>Reptiles</b>		
<i>Cehrydra variegata</i> (gecko)	0.22	30°C; dry air
<i>Uta stansburiana</i> (lizard)	0.10	0°C

\* r.h. stands for relative humidity. Where not indicated, relative humidity is not available.  
 † The cactus mouse and African oryx are desert animals and employ various water-conservation measures. Thus their evaporative water loss is much less than that of humans.  
 Source: Hadley, 1972.

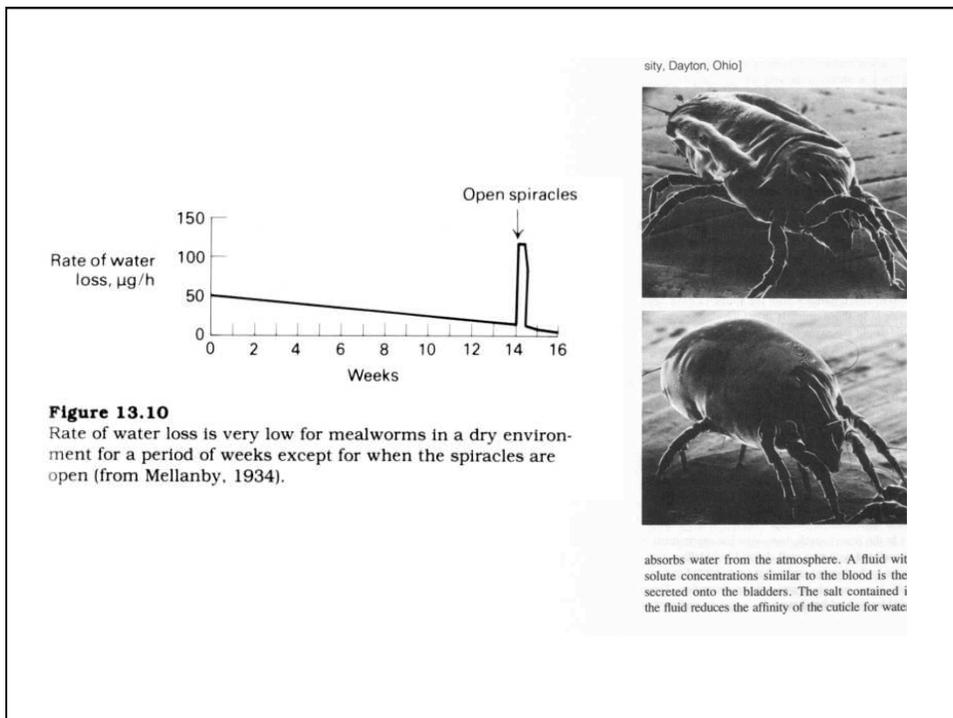
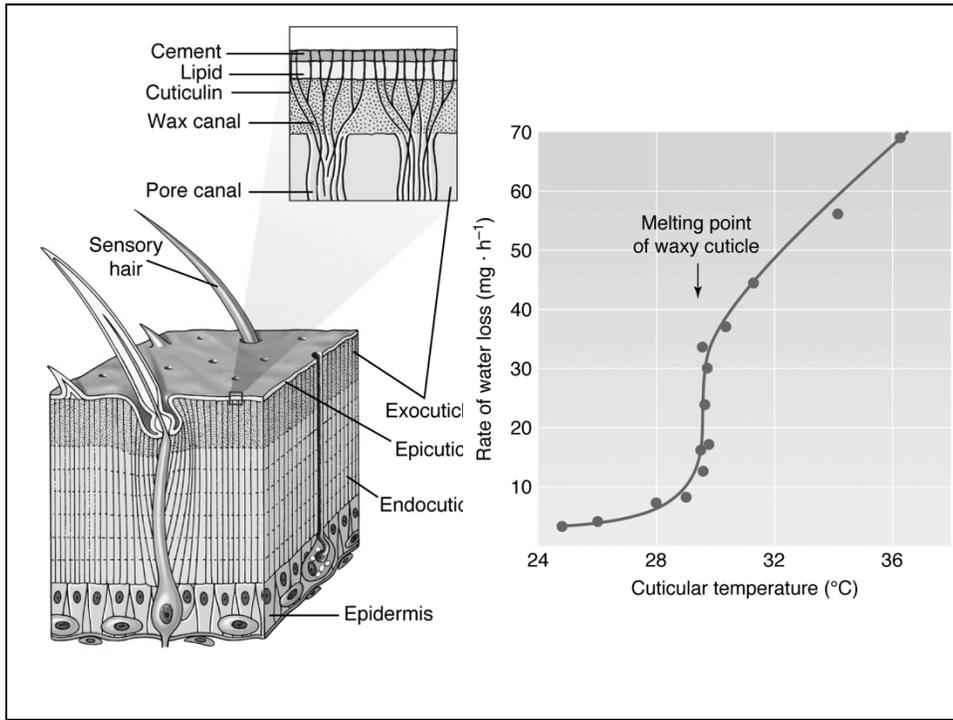
**Table 14-3** Evaporative water loss of representative animals under desert conditions

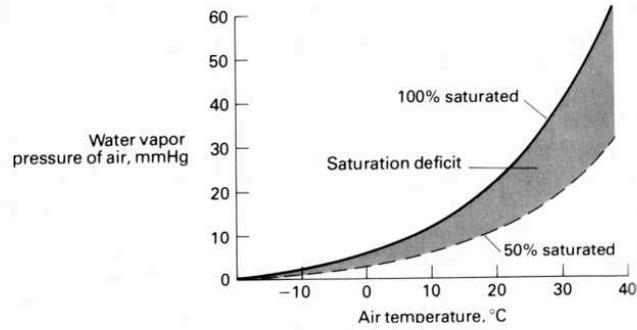
Species	Water loss (mg · cm <sup>-2</sup> · h <sup>-1</sup> )	Remarks*
<b>Birds</b>		
<i>Amphispiza belli</i> (sparrow)	1.48	30°C
<i>Phalaenpitis nutallii</i> (poorwill)	0.86	30°C
<b>Mammals†</b>		
<i>Peromyscus eremicus</i> (cactus mouse)	0.66	30°C
<i>Oryx beisa</i> (African oryx)	3.24	22°C
<i>Homo sapiens</i>	22.32	70 kg; nude, sitting in sun; 35°C

\* r.h. stands for relative humidity. Where not indicated, relative humidity is not available.  
 † The cactus mouse and African oryx are desert animals and employ various water-conservation measures. Thus their evaporative water loss is much less than that of humans.  
 Source: Hadley, 1972.



**Evaporation from skin and respiratory structures**  
 (indicates total water loss in grams for every 100 g of animal)





**Figure 13.2**  
Air 100% saturated with water vapor (upper line) contains exponentially more water vapor at higher temperatures. A saturation deficit (shaded area) is shown with respect to air 50% saturated with water vapor (lower dashed line).

Type of animal	Blood concentration relative to environment	Urine concentration relative to blood	Osmoregulatory mechanisms
Marine elasmobranch	Slightly hyperosmotic	Iso-osmotic	 Does not drink seawater Hyperosmotic NaCl from rectal gland
Marine teleost	Hypo-osmotic	Iso-osmotic	 Drinks seawater Secretes salt from gills
Freshwater teleost	Hyperosmotic	Hypo-osmotic	 Drinks no water Absorbs salt with gills
Amphibian	Hyperosmotic	Hypo-osmotic	 Absorbs salt through skin
Marine reptile	Hypo-osmotic	Iso-osmotic	 Drinks seawater Hyperosmotic salt-gland secretion
Desert mammal	-	Hyperosmotic	 Drinks no water Depends on metabolic water
Marine mammal	Hypo-osmotic	Hyperosmotic	 Does not drink seawater
Marine bird	-	Hyperosmotic	 Drinks seawater Hyperosmotic salt-gland secretion
Terrestrial bird	-	Hyperosmotic	 Drinks freshwater

