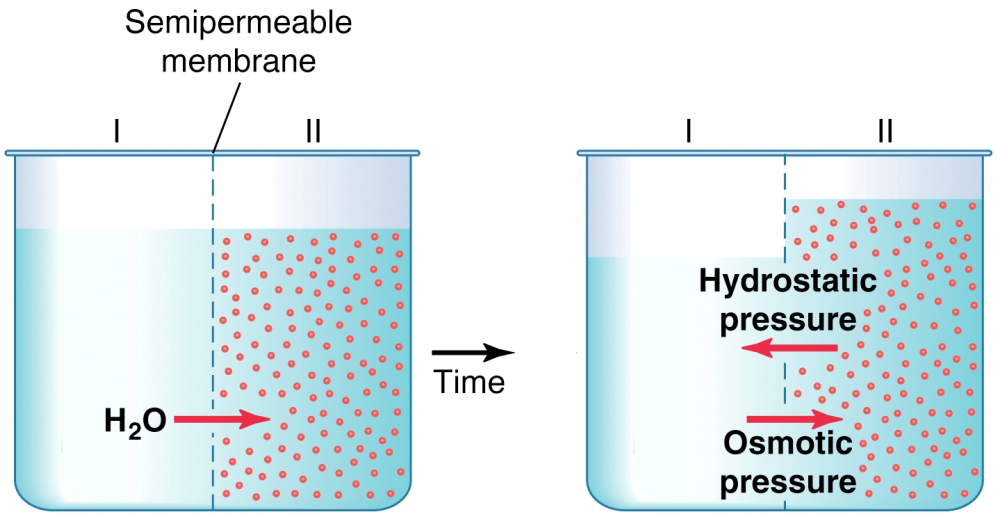
Osmotic Balance

What Happens and Why?



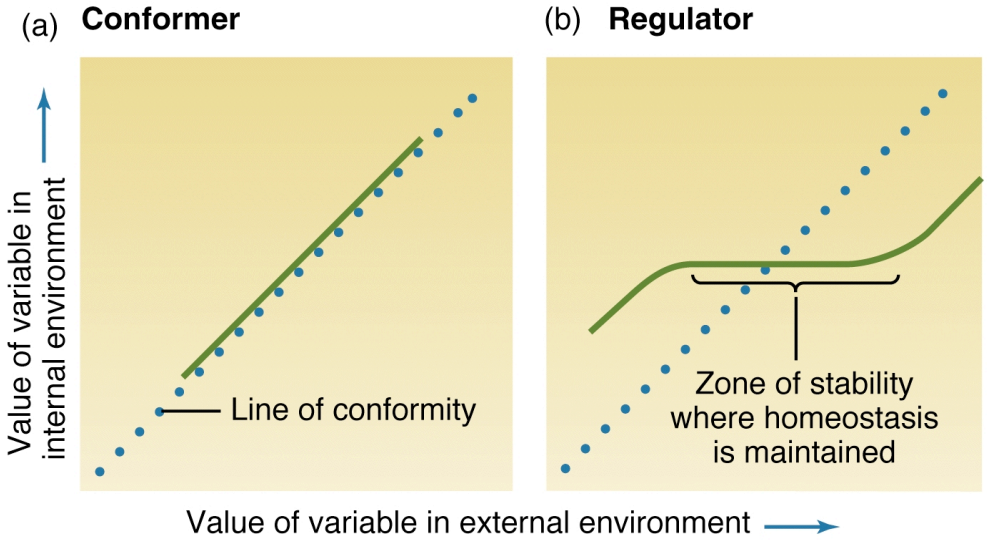
Definitions

- Osmolarity: moles of solute/liter of solvent
  - Isosmotic: two solutions with the same concentration of particles
  - Hypo-osmotic: solution that exerts less pressure, lower concentration of particles
  - Hyperosmotic: solution that exerts more pressure, higher concentration of particles
- Tonicity (of a solution): related to a particular cell/tissue
  - Isotonic: cell neither swell nor shrinks
  - Hypotonic: cell swells
  - Hypertonic: cell shrinks
- Osmolarity = tonicity for ideal cell
  - Tonicity depends on rate of accumulation of solute inside the cell and the concentration

Requirements for Life

- Maintain ionic differences AND osmotic equilibrium in cells
- Maintain balance and still allow transfer of nutrients:
  - Encycstment, eg., brine shrimp larvae can survive for years
  - Otherwise, balance requires energy = food
- Remove waste products
  - Very small aquatic animals use diffusion
  - Larger ones require blood filtering through kidney
- Osmoregulatory mechanisms
  - Many short term fluctuation but long term stability
  - Water enters and leaves through many pathways
  - Regulation requires more than managing total water; extracellular space also requires proper osmolarity
  - Many different mechanisms in the animal world

Osmoregulators vs. osmoconformer



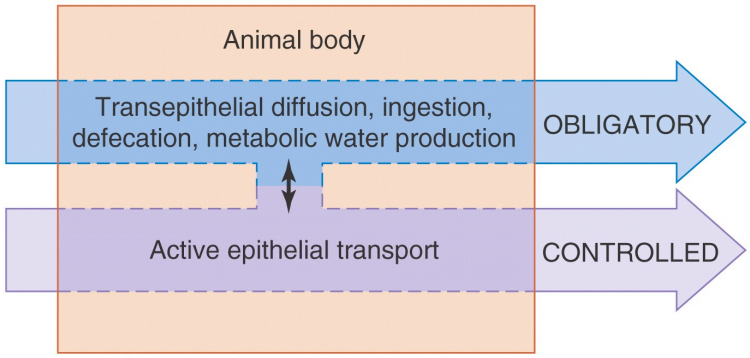
- Internal = external
- E.g., starfish (salinity) annelid worms (oxygen)

- Internal != external
- E.g., crustations (oxygen) mammals (temperature, etc.)

Osmoregulators vs. osmoconformer

- Osmoregulators: maintain different osmolarity than surroundings
- Osmoconformer: internal follows external conditions
- Most vertebrates are osmoregulators, body fluids are hypo-osmotic to sea water, hyperosmotic to freshwater
- Marine invertebrates can be either, and even limited osmoregulators
- Osmoconformers shift organic osmolytes in and out of cell to maintain osmotic balance

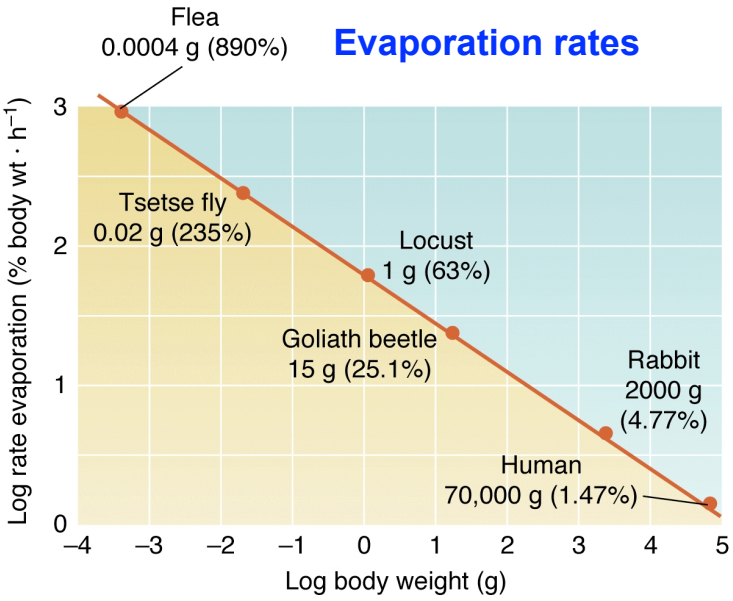
Obligatory and Controlled Exchange



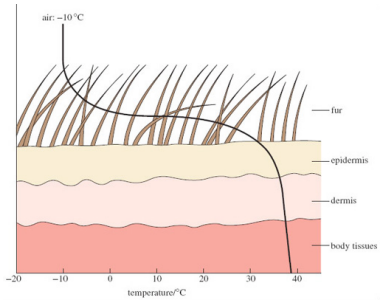
- Obligatory: in response to external factors or factors outside control of organism
- Controlled: regulated and serve to maintain homeostasis
- Regulated usually compensate for obligatory

Obligatory Exchanges

- Driving force:
  - Concentration gradients (water and solutes)
- Transfer surface
  - Larger animals have smaller surface/ volume ratio (and respiratory area)

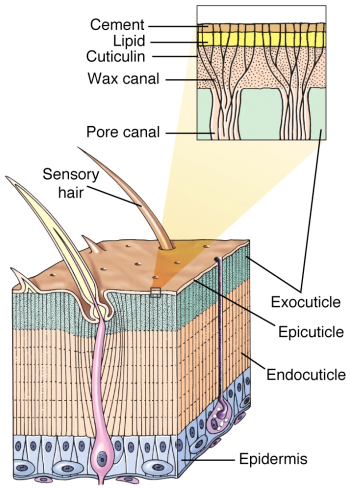


Permeability of Transfer Surface



Mammal Skin (impervious))

Amphibian Skin (porous)



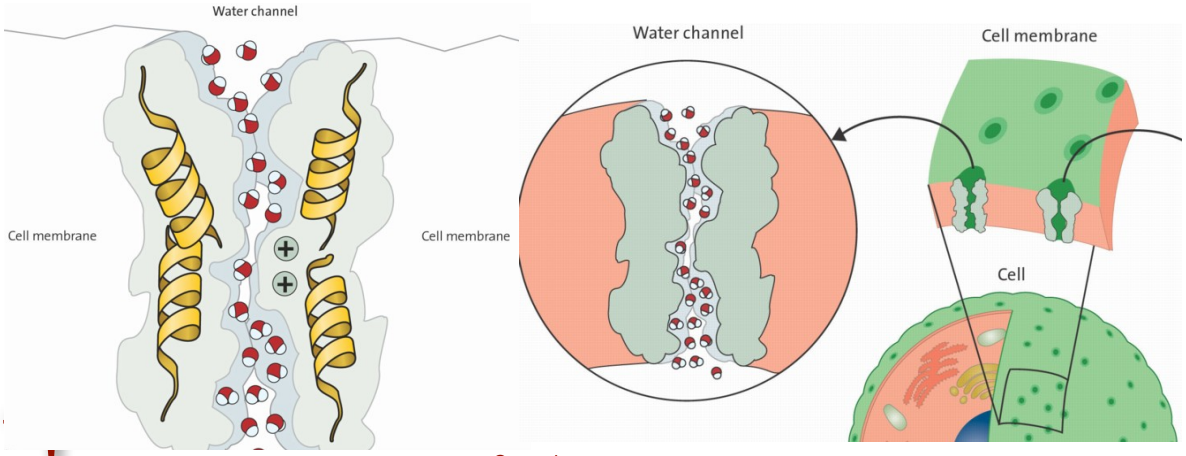
Insect Skin (waxy)

Permeability of Transfer Surface

- Water:
  - Pure phospholipids have poor permeability
  - Aquaporin in the membrane provide permeability
  - Junctions between cells control water movement in surfaces, eg., capillaries, skin
  - Amphibians have porous skin--can take up water at three times body weight per day!
  - Mammals, reptiles, birds, desert amphibians have fairly impermeable skin
  - Frogs/toads have large bladder in which to store water and salts to regulate during water loss and gain
  - Insects have waxy coating: lower water loss; they transfer water through trachea

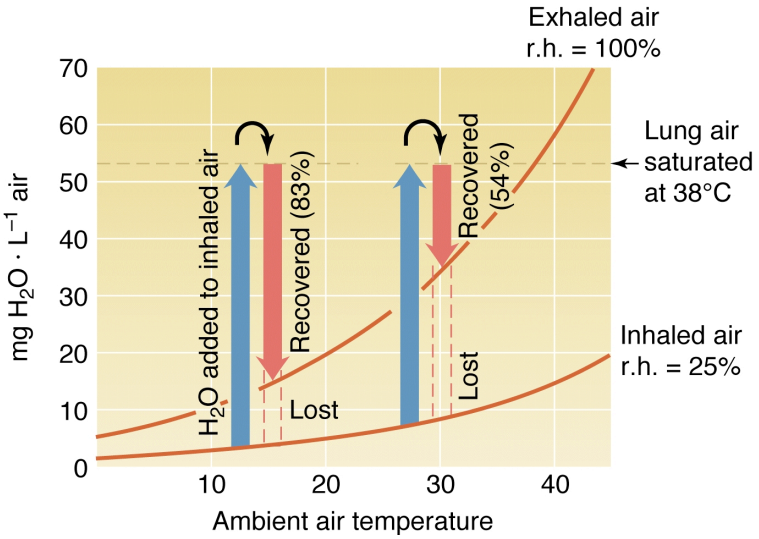
Water Channels-Aquaporins

- Peter Agre: 2003 Nobel Prize in Chemistry
  - 1950s: first known that water must pass through special channel
  - 1992: Agre discovers the structure of this channel
  - Positive charge blocks positive ions; dipolar ions flips as they pass through channel

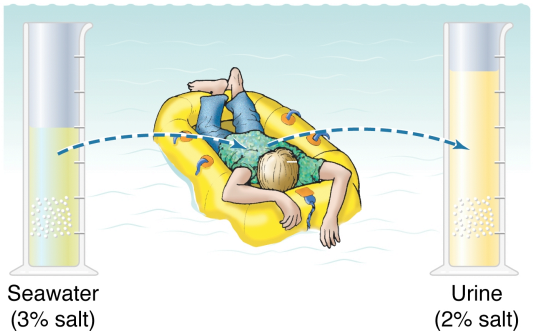


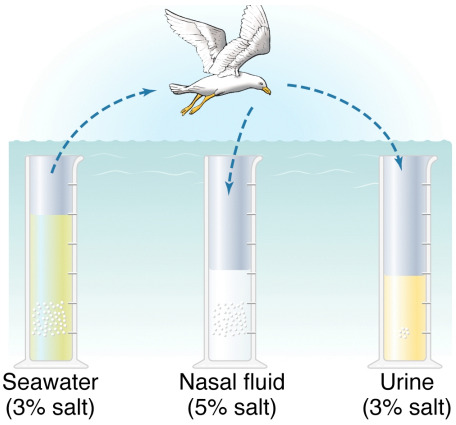
Respiratory Water Loss

- Water used for cooling: swamp cooler effect
- Warm blooded animals lose more water; warm air holds more vapor than cool
- Nose recovers moisture by staying cool
- Countercurrent blood flow keeps nose tip cool
- To observe: compare exhaled air temp from nose and mouth



Marine reptiles and birds





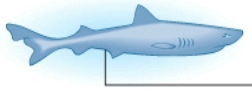
- Dehydration challenge
  - Obtaining water from seawater
- Solutions
  - Drink sea water for moisture
  - Use salt glands to eliminate salts in hyperosmotic solution (not capable of making hyperosmotic urine)

Osmoregulation in Freshwater Animals

Type of animal	Blood concentration relative to environment	Urine concentration relative to blood	Osmoregulatory mechanisms
Freshwater teleost	Hyperosmotic	Hypo-osmotic	 Drinks no water Absorbs salt with gills
Amphibian	Hyperosmotic	Hypo-osmotic	 Absorbs salt through skin

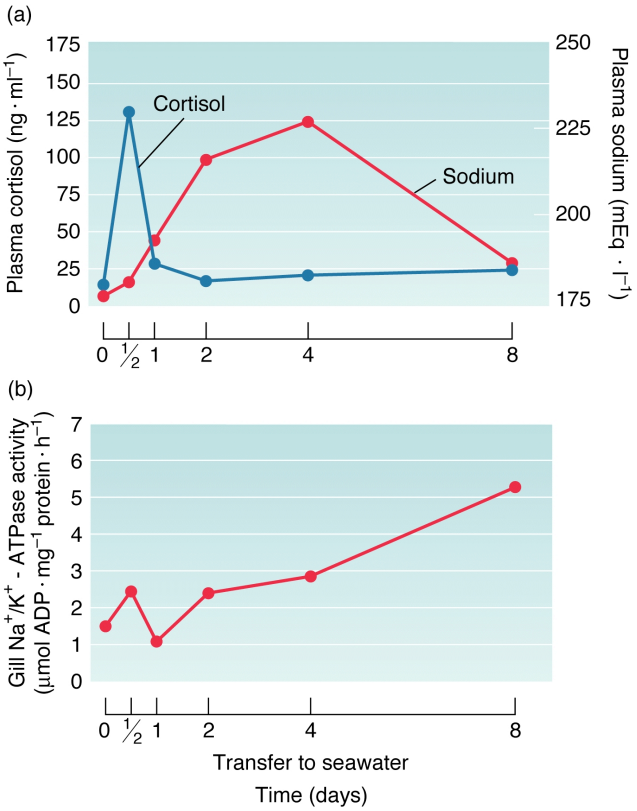
- Challenges
  - Swelling from water uptake
  - Loss of salts
- Solutions
  - Dilute urine (some loss of salts)
  - Active transport of salts (e.g., NaCl from water with only 1mM concentration against huge gradients)
  - Gills, frog skin, turtle bladder all perform active transport (gills of fish perform similar duties as kidneys in mammals)

Osmoregulation in Marine Animals

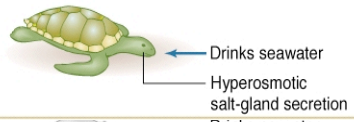
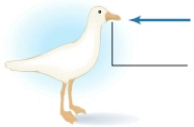
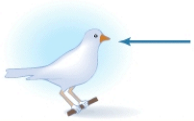
Type of animal	Blood concentration relative to environment	Urine concentration relative to blood	Osmoregulatory mechanisms
Marine elasmobranch	Slightly hyperosmotic	Iso-osmotic	 Does not drink seawater Hyperosmotic NaCl from rectal gland
Marine teleost	Hypo-osmotic	Iso-osmotic	 Drinks seawater Secretes salt from gills

- Challenges:
  - Varied, depend on animal
  - Shrinking from water loss
  - Absorbing water without salts
- Sharks, rays, skates
  - Iso-osmotic but low electrolyte concentration, higher organic osmolites, e.g., urea, trimethylamine oxid (TMAO)
  - Excess NaCl leaves via kidney and rectal gland
- Boney fish
  - Hypo-osmotic, drinks water and eliminates excess salt via gills and kidney

Migrating Fish



Air-Breathing Animals

Type of animal	Blood concentration relative to environment	Urine concentration relative to blood	Osmoregulatory mechanisms
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

- Challenge:
  - Dehydration

Marine Mammals

- Dehydration challenge:
  - Maintaining adequate hydration despite salty water
- Solutions
  - Do not drink water, take from metabolism and fish they consume
  - Retention of water
    - Elimination of salts
    - Make hypertonic urine
- Examples
    - Seals have convoluted nasal passages
    - Whales and dolphins have blowholes; high velocity of flow leads to condensation at expiration
    - Elephant seals breath sparsely (can go 10 m without breathing), derive water from metabolism and fish, go long periods without food or water

Land Mammals

- Challenges:
  - Dehydration
  - Cannot drink seawater: urine has <6 g/L Na^+ but seawater has 12 g/L Na^+
- Solutions
  - Stay cool and inactive
  - Concentrated urine and produce dry feces
  - Metabolic water
  - Tolerate wide fluctuations in hydration

Table 14-4 Production of metabolic water during oxidation of foods

	Food		
	Carbohydrates	Fats	Proteins
Grams of metabolic water per gram of food	0.56	1.07	0.40
Kilojoules expended per gram of food	17.58	39.94	17.54
Grams of metabolic water per kilojoule expended	0.032	0.027	0.023

Source: Edney and Nagy, 1976.

Humans

Source of Water Loss	Normal temperature	Hot weather	Prolonged heavy exercise
Skin	350	350	350
Lung	350	250	650
Sweat	100	1400	5000
Feces	200	200	200
Urine	1500	1200	500
Total loss	2500	3400	6700

Daily water losses [mL/day]

Desert Rodents: e.g., Kangaroo Rat

- Conservation
  - Only active at night
  - Burrows reduce heat stress and improves respiratory water retention (reduced temperature and increased humidity)
  - Highly concentrated urine, dry feces
  - Do not sweat but do produce saliva that wets fur of the chin for evaporative cooling
- Sources
  - Food (10%)
  - Metabolic water (90%)

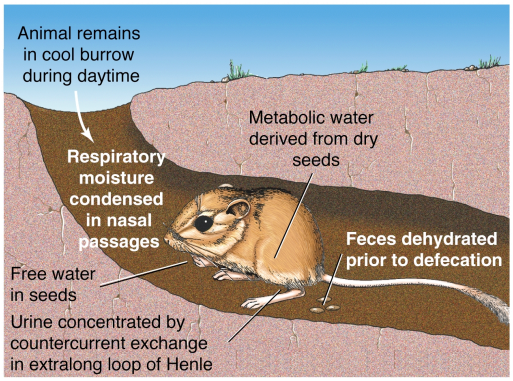


Table 14-5 Sources of water gain and loss by the kangaroo rat

Gains		Losses	
Metabolic water	90%	Evaporation and perspiration	70%
Free water in "dry" food	10%	Urine	25%
Drinking	0%	Feces	5%
	100%		100%

Source: Schmidt-Nielsen, 1972.

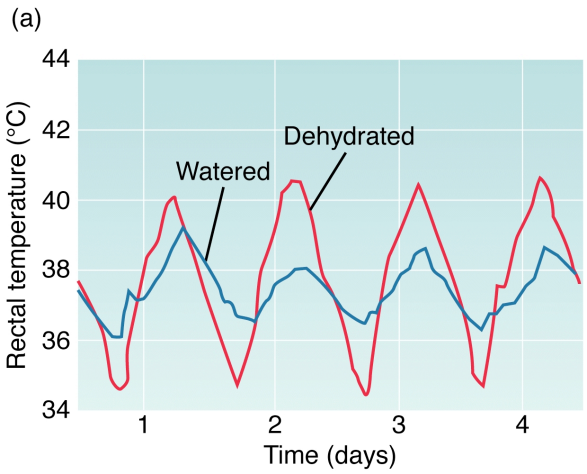
Large Desert Mammal, e.g., Camel

Large Desert Mammal, e.g., Camel

- Two types
  - Dromedary (one hump) and Bactarian (two humps)
  - Bactarian: live in mountains and colder climates (Gobi desert)
  - Dromedary: live in flat deser (Saraha, Arabian), more domesticated
- Eating
  - Herbivores, mostly hardy, thorny, salty perennials.
  - In cool season, obtain all required water from plants. How?
- Drinking
  - Tolerate salty water. How?
  - At 30-35C external temps, need to drink only every 15 days. How?
  - Only => 40C do they need any regular water.
  - Can survive the loss of 25% of body weight in water (humans die at 12%). How?
  - Can drink 200 l at a time, 130 l in a few minutes. Most animals would die from RBC rupture because of osmotic pressure. Why not camels?

Large Desert Mammal, e.g., Camel

- Challenges
  - Cannot hide in a burrow
- Capacity adaptations
  - Body temperature varies (35-41C)
  - Tolerate loss of 20-25% of body
  - Breath slowly through large noses
  - Produces concentrated urine, eventually no urine
  - Huge water capacity: 200 liters at a time
  - Slow heat loss/gain with large mass and light colored, wooly coat
  - Hump contains fat stores so that rest of body is lean for heat loss
  - Long legs keep body above the (hot) ground



Insects

- Challenges
  - Dehydration
- Solutions
  - Extract water from the air
    - Use highly concentrated salt solutions
    - Absorb through rectum (via feces) and mouth tissues (via high concentration KCl)
    - Water capillaries between hairs will also absorb water from air