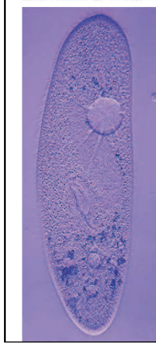
## Hydroregulation and Osmoregulation: All about $H_2O$ (and Ions):


## All About Water (and Dissolved Solutes)

Water - universal solvent for almost all biological reactions
Most organisms - well-defined, relatively constant solute conc in internal fluids (i.e., homeostasis)

Hydroregulation - the water content of an organism

Osmoregulation - the solute content of an organism

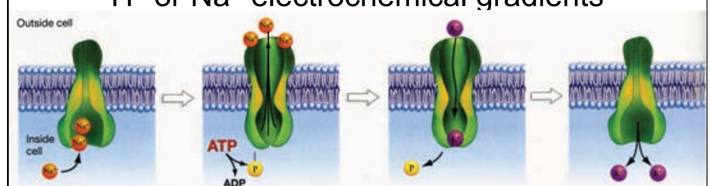

## Hydroregulation and Osmoregulation

Unity - 1) Common physical and molecular mechanisms for solute uptake (same as nutrient uptake!)
2) Osmosis - universal principle of passive water flow across membranes down its concentration gradient

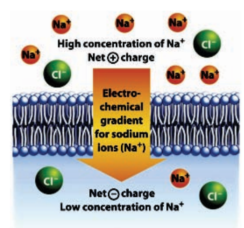
Diversity - 1) Wall-less cells – osmotic maintenance
Walled cells - turgor maintenance
2) Environmental conditions - marine, freshwater, and terrestrial




## Active transport: 1) ATP hydrolysis generates $H^+$ or $Na^+$ electrochemical gradients




Animals - $Na^+/K^+$ pump F Fig. 6.26

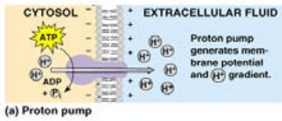



Same basic process in bacteria, protists, plants, and fungi, except they use $H^+$ pumps to generate the $H^+$ electrochemical gradient

F. Fig. 6.22

## 2) Electrochemical gradients drive the uptake of ions for osmoregulation

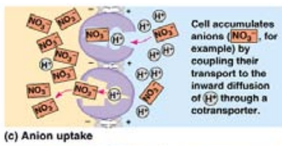
low H+
negative

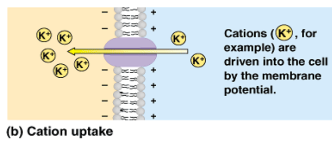



high H+
positive

ATP-dependent $H^+$ pump

C & R Fig 36.2



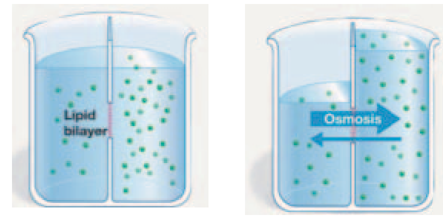

$H^+$-anion cotransporter (into the cell)

Cation uniporter (into the cell)

Animals - use $Na^+/K^+$ pump, and $Na^+$ instead of $H^+$

## Osmosis

Osmosis - passive diffusion of water molecules across a semi-permeable membrane down their concentration gradient



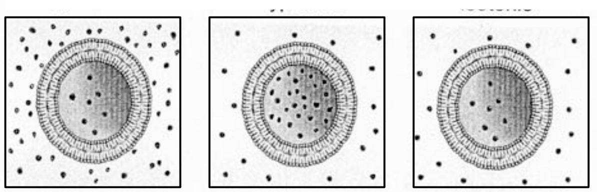

**higher $H_2O$ lower $H_2O$ concentrations**

F. Fig 6.15

Big surprise - most pure lipid biomembranes allow only slow diffusion of water molecules
Many bacterial and eukaryotic membranes have water channel proteins called **aquaporins** that mediate passive osmotic flow.

## Physical process of osmosis

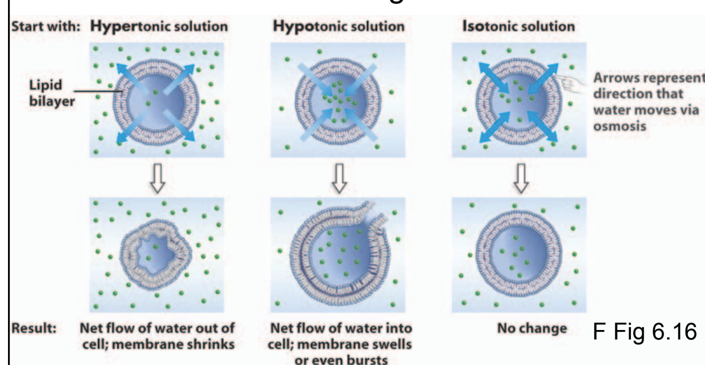
Hypertonic Hypotonic Isotonic



- Hypertonic solution - higher solute concentration in solution relative to vesicle
- Hypotonic solution - lower solute concentration in solution relative to vesicle
- Isotonic solution - same solute concentration in solution and vesicle

Group discussion: Predict the direction(s) of water flows and their consequences for vesicle membranes

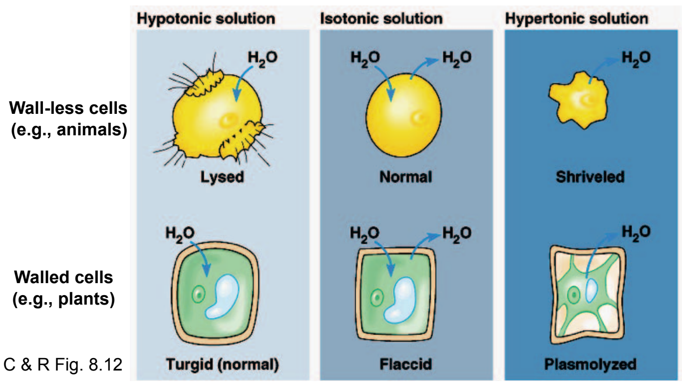
## Basic terms for describing osmotic conditions




F Fig 6.16

- Hypertonic solution - higher solute concentration in the solution relative to the vesicle
- Hypotonic solution - lower solute concentration in the solution relative to the vesicle
- Isotonic solution - same solute concentration in the solution and the vesicle

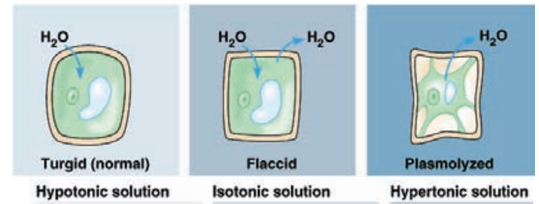
## Diversity of organisms - wall-less vs. walled cells



C & R Fig. 8.12

Organisms manipulate the physics of osmosis and the structure of their cells to carry out hydroregulation and osmoregulation

## Organisms with cell walls - prokaryotes, fungi, photosynthetic protists, and plants




Key concept - water tries to flows into turgid cells via osmosis, but wall forces water out

wall resistance is called turgor pressure

Walled cells of aquatic organisms maintain higher solute solute concentrations than the surrounding FW or SW environment.

## Organisms with cell walls - aquatic plants

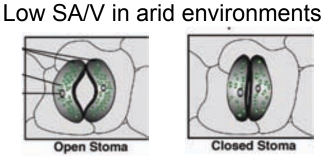




- Most photosynthetic protists ("algae") and aquatic angiosperms in FW, estuaries, and SW do not maintain constant osmolarity with changing external conditions.
- Variable osmolarity - short-term osmotic adjustments with the usual suspects aka $K^+$ and $Cl^-$, and long-term adjustments with small organic molecules such as mannitol
- Turgor maintenance = constant osmotic difference between the environment (lower) and the organism (higher)
- Turgor maintenance = constant turgor pressure (wall pressure)

## Organisms with cell walls - terrestrial plants


- Many land plants attempt to maintain internal homeostasis
- Primary emphasis on water conservation in limiting environments
- Cuticle - waxy covering on aboveground parts
- Stomates - water-sensitive pores for gas exchange
- Low SA/V in arid environments



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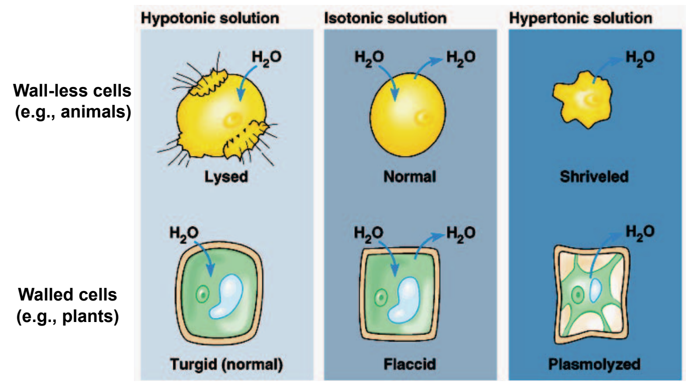
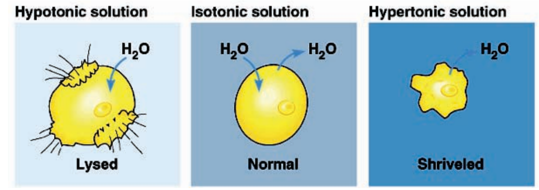
## Diversity of organisms - wall-less vs. walled cells




C & R Fig. 8.12

## Organisms lacking extracellular walls




- Many protists and all animals
- Osmolarity = total molarity of osmotically active solutes (e.g, ions, sugars, and other small molecules)
- **Different alternatives:**
- Ionocoformers – same ion and osmotic concentrations
- Osmconformers – same osmolarity as the environment but different solute composition
- Osmoregulators – different osmolarity and solute compositions

## Osmoregulation in aquatic environments

Tuna in ocean (hypertonic environment)

Beta in fresh water (hypotonic environment)

Lobster in ocean (isotonic environment)

Group discussion: Describe the osmotic challenges that these animals face in their environments and predict how they might meet those challenges:

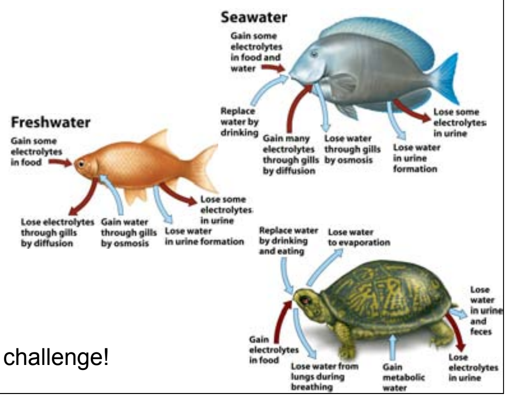
## What animals need to accomplish

- Appropriate ionic composition
- Appropriate osmotic concentration (osmolarity) – osmoles of solute/L of solution
- Often fixed relative to the environment
- Waste removal = excretion
  - Especially nitrogenous wastes

# Osmoregulation
## Three very different media

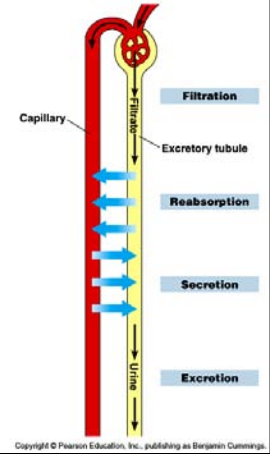
Fig. 42.2,3

- Seawater
  - Lose water
  - Gain salts
- Freshwater
  - Gain water
  - Lose salts
- Terrestrial
  - Lose water
  - Excretion a challenge!




# General tools

- Ion diffusion down the gradients
- Osmosis
- "Active" transport
  - Secretion, reabsorption
- Excretory ducts
  - Combine above with, in many cases, pressure differential -> filtration




# Life in Seawater - Most "invertebrates" (no external cell walls)

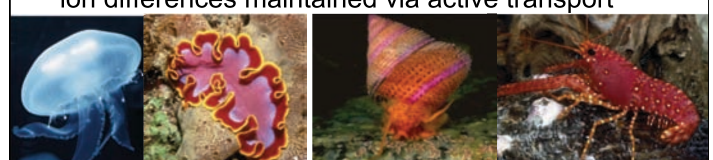
- Ions
  - Typically, ion "conforming" = ionoconformance
    - e.g. Echinoderms
    - Concentration of solutes similar inside vs. out
  - Some specific ions may be regulated

| | Na | Mg | Ca | K | Cl | $SO_4$ |
|---|---|---|---|---|---|---|
| Sea water | 478.3 | 54.5 | 10.5 | 10.1 | 558.4 | 28.8 |
| Jellyfish (*Aurelia*) | 474 | 53.0 | 10.0 | 10.7 | 580 | 15.8 |
| Polychaete (*Aphrodite*) | 476 | 54.6 | 10.5 | 10.5 | 557 | 26.5 |
| Sea urchin (*Echinus*) | 474 | 53.5 | 10.6 | 10.1 | 557 | 28.7 |
| Mussel (*Mytilus*) | 474 | 52.6 | 11.9 | 12.0 | 553 | 28.9 |
| Squid (*Loligo*) | 456 | 55.4 | 10.6 | 22.2 | 578 | 8.1 |

Schmidt-Nielsen, K. 1995. Animal Physiology. P. 304

# Life in Seawater - Most "invertebrates"

- Many marine invertebrates – ionoconformers
  internal ions = seawater ions
  ionconformers are necessarily also osmoconformers
  no ionic and osmotic gradients - no net exchange
- Almost all marine invertebrates - osmoconformers
  total internal osmolarity = total seawater osmolarity
  no osmotic gradient - no net $H_2O$ exchange
  ion differences maintained via active transport



Ionoconformers osmoconformers

## Life in Seawater - Most “invertebrates”

- Ions
- Osmolarity
- Excretion - easy
  - $NH_4^+$ soluble
  - Cell membranes permeable
  - Lots of water
  - Can flush it away before it becomes toxic

## Life in Saltwater - “Fishes”

- Osmolarity - Divergent strategies
  - Elasmobranchs - Osmoconformers
    - Isotonic
    - Retain urea (etc.). Keep total osmolarity similar to seawater
    - Reduces water flux

| | Habitat | Solute Na | K | Urea[a] | Osmotic concentration (mOsm liter$^{-1}$) |
|---|---|---|---|---|---|
| *Sea water* | | ~450 | 10 | 0 | ~1000 |
| *Cyclostomes* | | | | | |
| Hagfish (*Myxine*)[b] | Marine | 549 | 11 | | 1152 |
| Lamprey (*Petromyzon*)[c] | Marine | | | | 317 |
| Lamprey (*Lampetra*)[b] | Fresh water | 120 | 3 | <1 | 270 |
| *Elasmobranchs* | | | | | |
| Ray (*Raja*)[b] | Marine | 289 | 4 | 444 | 1050 |
| Dogfish (*Squalus*)[b] | Marine | 287 | 5 | 354 | 1000 |

## Life in Seawater - “Fishes”

- Ions
  - Tend to gain ions from environment
  - Active transport of Na, Cl out of body
    - Gills in bony fishes
    - Rectal gland in sharks
  - Some secretion into kidney tubule

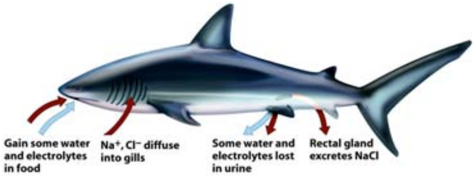
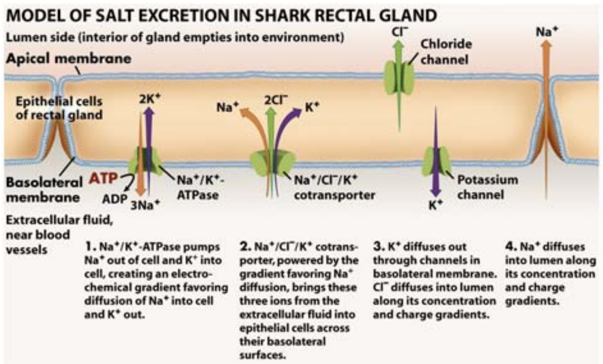



Fig. 42.4

## Life in Seawater - “Fishes”

- Ion regulation - The rectal gland

Fig. 42.5



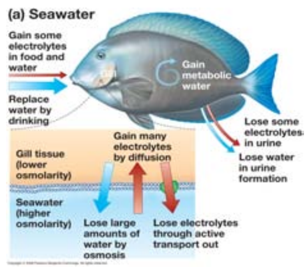
## Life in Saltwater – "Fishes"

- Other marine vertebrates - osmoregulators
  internal osmolarity << SW osmolarity

For example, SW bony fishes

Major problems:
water loss by osmosis and
solute gain by diffusion in gills

Solutions:
drinking seawater (but high ions!),
very concentrated urine,
active transport of Na+, Cl- from gills




F Fig. 42.2

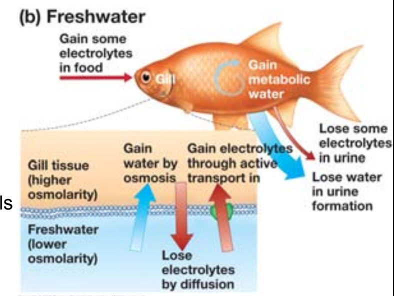
## Life in Freshwater - General

- FW animals - osmoregulators
- internal osmolarity >> FW osmolarity
- For example, FW bony fishes

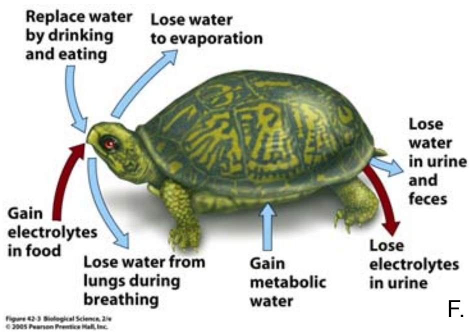
Major problems:
water gain by osmosis,
solute loss by excretion

Solutions:
limited drinking
very dilute urine
active transport of ions into gills

F Fig. 42.2




## Terrestrial animals – related strategies




F. Fig. 42.3

Major problem: water loss via evaporation and excretion
Major sources: drinking, eating, and metabolic water
Much more on excretion in Jeff's lecture on Monday

## Summary

- Define different types of solution tonicity, and then describe the resulting direction of osmotic flow in walled vs. non-walled cells for each solution type.
- Marine animals can avoid problems by ionconforming and osmoconforming
  - Most marine invertebrates ionconform
  - Some marine vertebrates osmoconform, but most do not
- Osmoregulation relies on the same transport mechanisms we've seen elsewhere
- Describe the different environmental challenges, physiological mechanisms, and structural features associated with hydroregulation and/or osmoregulation in aquatic plants, land plants, and marine vs. freshwater vs. land animals

## Challenge #1 – Migrating salmon


F Fig. 42.6

Predict how salmon can adjust to the different tonicities of their freshwater breeding streams and the ocean environments where they spend most of their lives.

## Challenge #2 – Estuarine plants

Predict how Chesapeake Bay grasses adjust to tidal changes in the salinity of bay water.