Introduction Fish 511/

- Who are you?
- My goals? Multiple inputs – Dr. Haukenes, and Dr. Hardy, Dr. Powell
- My approach for learning
- Requirements
  - Read material
  - Learn to critically evaluate information
  - Participate in class discussions
  - Present papers for discussions

Exams and Grading

- Oral roundtable exams – 2 scheduled
- One final take home or oral, depending on constraints and preferences

Respiration in Fish

- Oxygen - O_2
- Carbon Dioxide CO_2
- Ammonia – NH_3

O2 solubility in water is low!

- 1/20 to 1/30th of Air
- Oxygen diffuses more slowly in water
- Water is more dense and viscous than air
- Metabolic cost of gill ventilation is high relative to cost of aerial ventilation

Diffusion Rates

- dV/dt = A * K*dP/D
  - dV/dt = volume of gas diffusing / unit of time
  - A = area available for diffusive exchange
  - K = diffusion constant for gas
  - dP = partial pressure difference
  - D = diffusion distance

Partial pressure and concentration

- P x = partial pressure
- Cx = concentration

- P x * (solubility coefficient) = Cx

Oxygen saturation mg/L in Fresh and Sea Water at sea level

Temp	Fresh	Seawater
0	14.7	11.7
5	12.8	10.4
10	11.3	9.3
15	10.1	8.5
20	9.1	7.8

CO2

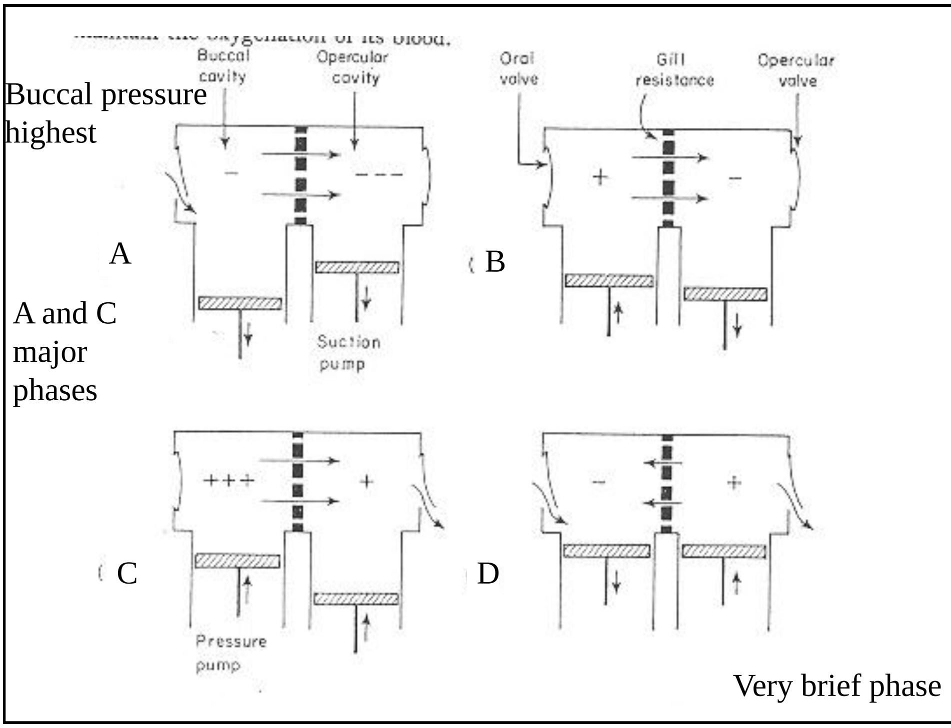
- Enters into incomplete reaction with water to become acid H_2CO_3

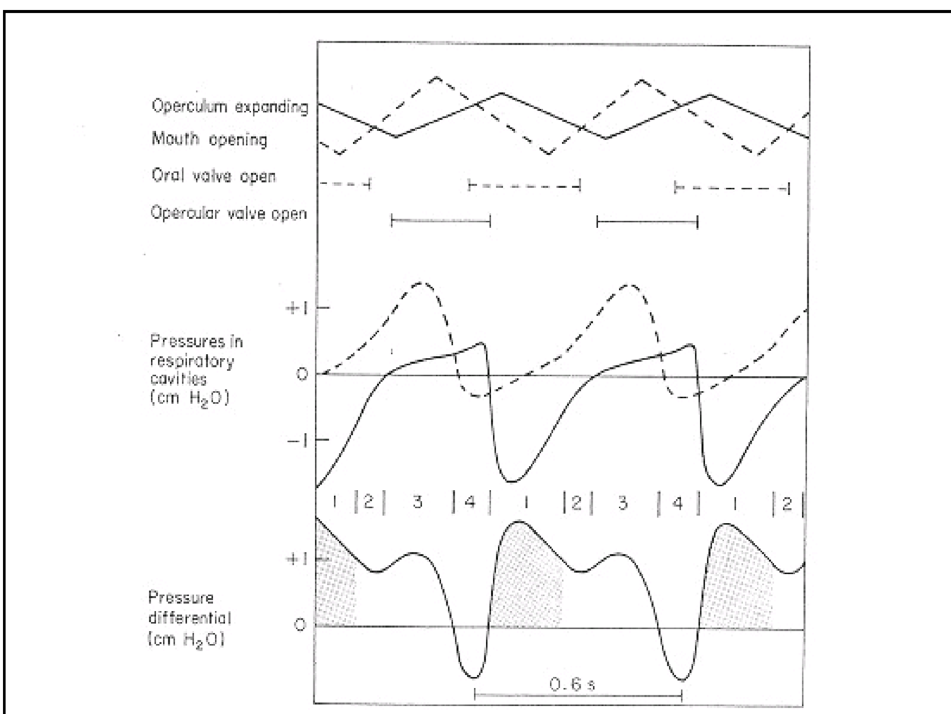
Ammonia NH3

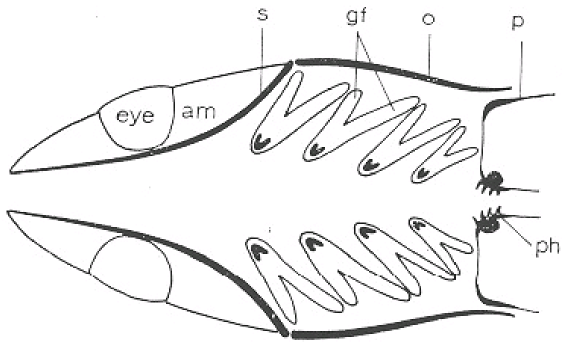
- Toxic compound from metabolic processes that must be rapidly removed.

Branchial Pump in Fish

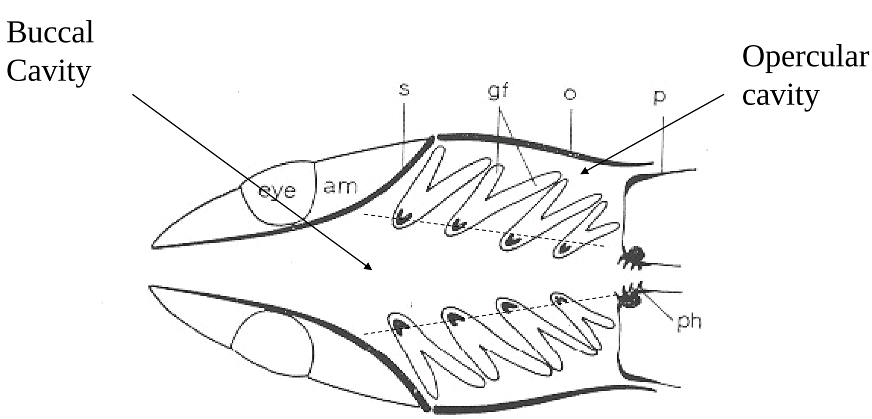
- Drives the gill diffusion system
- Varies in evolution of different fish groups
  - More active in fish that do not swim
  - Powerful and unique system that maximizes diffusion


Buccal pressure highest
Buccal cavity
Opercular cavity
Oral valve
Gill resistance
Opercular valve
A
B
A and C major phases
Suction pump
C
D
Pressure pump
Very brief phase

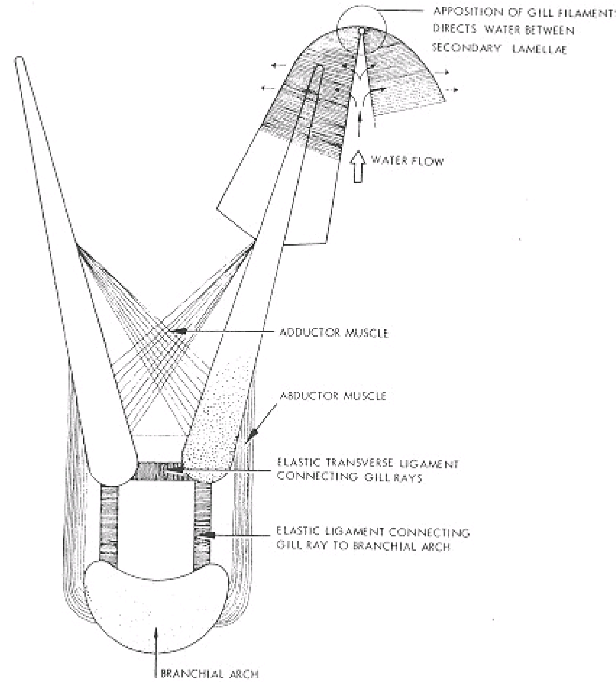

Operculum expanding
Mouth opening
Oral valve open
Opercular valve open
Pressures in respiratory cavities (cm H_2O)
+1
0
−1
Pressure differential (cm H_2O)
0.6 s

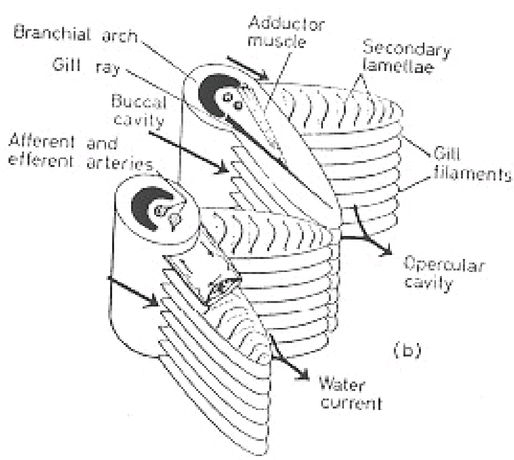


Typical bony fish 4 branchial arches

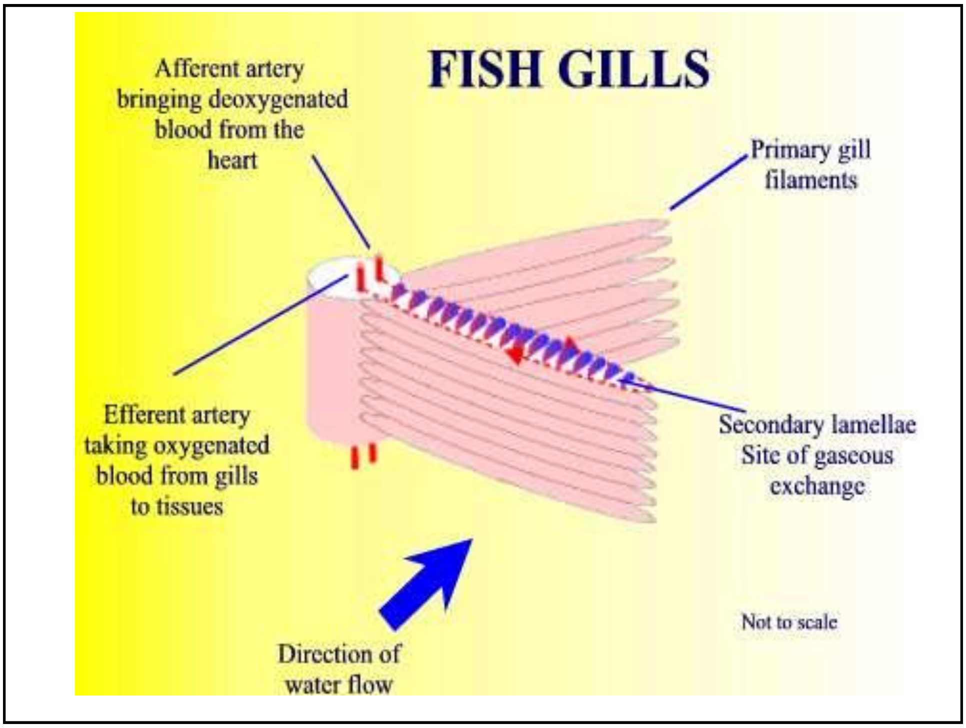


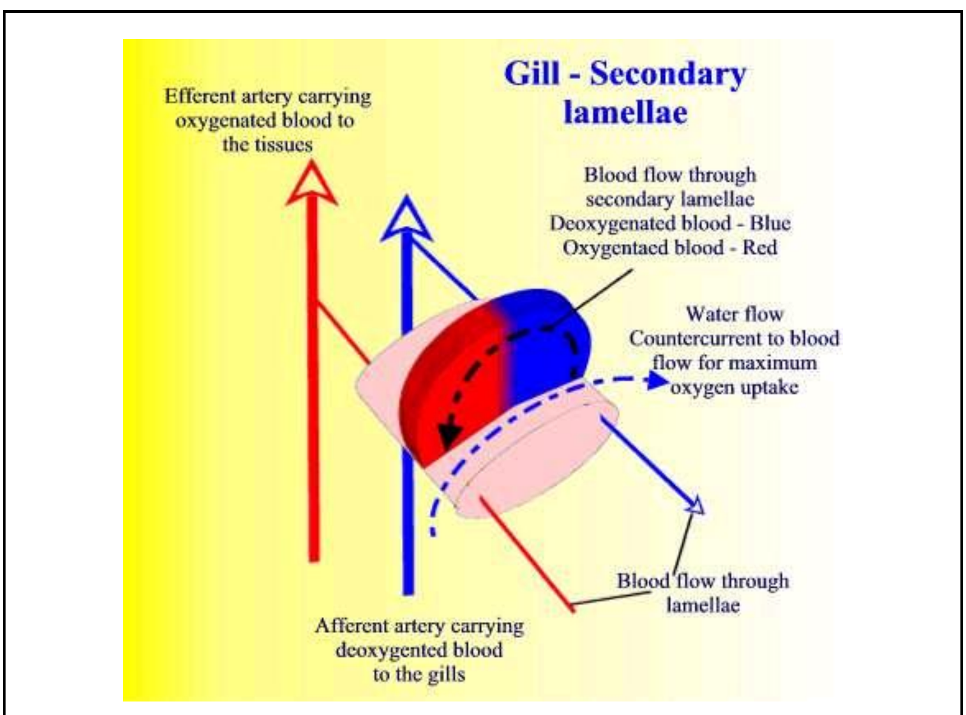
Typical bony fish 4 branchial arches



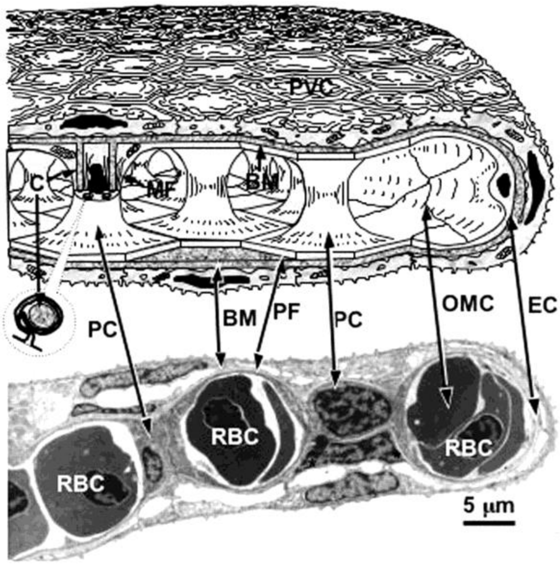


Filaments and associated structures attached to two neighbouring branchial arches.


FISH GILLS
Afferent artery bringing deoxygenated blood from the heart
Primary gill filaments
Efferent artery taking oxygenated blood from gills to tissues
Secondary lamellae Site of gaseous exchange
Not to scale
Direction of water flow


Gill - Secondary lamellae
Efferent artery carrying oxygenated blood to the tissues
Blood flow through secondary lamellae
Deoxygenated blood - Blue
Oxygentaed blood - Red
Water flow
Countercurrent to blood flow for maximum oxygen uptake
Blood flow through lamellae
Afferent artery carrying deoxygented blood to the gills

Schematic and transmission electron micrograph of a cross section through an outer port a teleost (rainbow trout) lamella.



cytoplasmic flanges
(PF

Physiological Reviews

Evans D H et al. Physiol Rev 2005;85:97-177

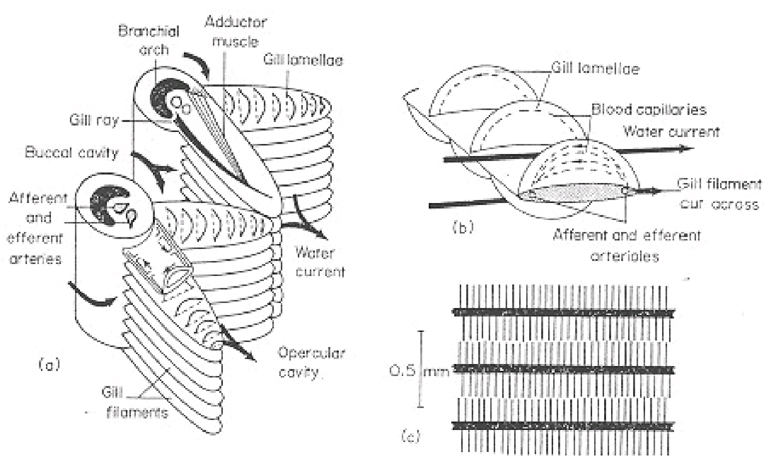
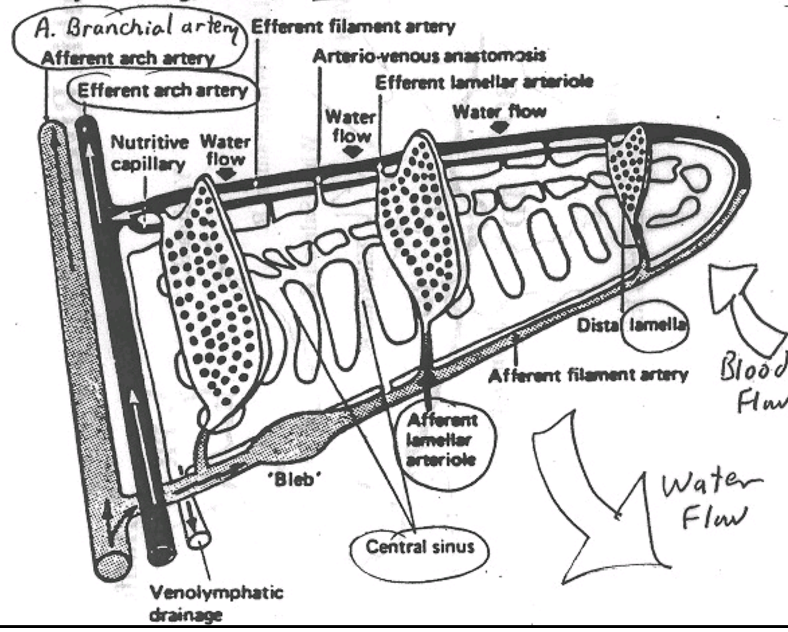
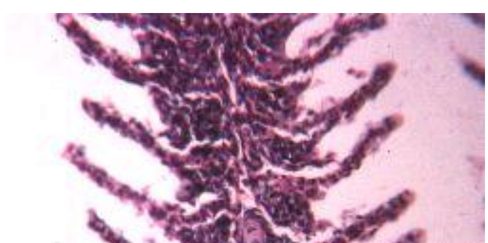


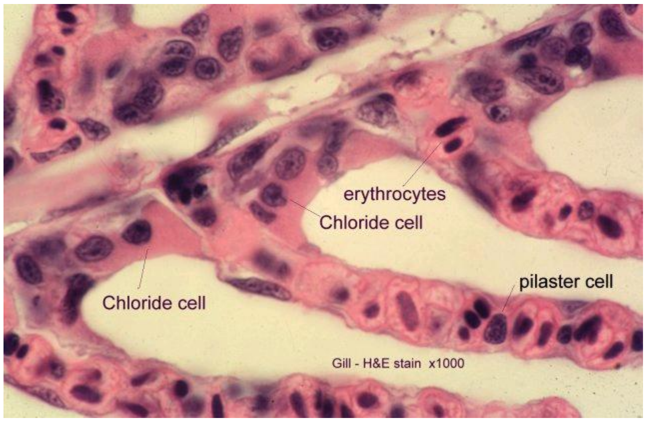
Fig. 7.4 The structure of the teleost gill and counter-current flow of blood and water. (a) Portions of two adjacent gill arches bearing double rows of filaments, which interlock at the tips—a passive posture due to the elasticity of the gill rays. Each filament bears rows of alternating lamellae on upper and lower faces in which the capillary blood flow runs counter to the flow of the waterstream between the lamellae. (b) At higher magnification, part of a single filament with three lamellae above and below. (c) Diagrammatic representation of part of the seive-like arrangement provided by the filaments (3) and lamellae in the trench; the water flow is at right-angles to the page. (Hughes[88])

Fig. 1. The circulation in ~~the~~ one gill filament of a typical teleost. (From Randall, Perry & Heming, 1981*b*.)





http://www.fishdoc.net/disease/gilldisease.htm



http://training.fws.gov/ec/fish/histo1.html

TABLE II

ESTIMATES OF THE RESPIRATORY AREA OF THE GILLS [a]

Habitat	Gill lamellae per Millimeter of Filament	Gill Area per Gram of Body Weight (sq. mm.)
MARINE TELEOSTS		
Scomber scombrus	31	1158
Poronotus triacanthus	31	598
Brevoortia tyrannus	29	1773
Mugil cephalus	27	954
Cynoscion regalis	27	373
Coryphaena hippurus	26	710
Stenotomus chrysops	26	506
Palinurichthys perciformis	24	506
Centropristis striatus	21	458
Prionotus carolinus	20	483
Roccus lineatus	19	302
Archosargus probatocephalus	19	328
Anguilla rostrata	19	302
Paralichthys dentatus	19	242
Tautoga onitus	18	392
Spheroides maculatus	16	470
Opsanus tau	11	197
INDIAN FISHES		
Water-breathing	..	152
Air-breathing	..	ca. 77
TEMPERATE FRESHWATER		
Micropterus dolomieu		
0.3 g.	28	740
837 g.	19	225

[a] Data from the following sources: temperate marine teleosts (Gray, 1954); Indian fishes, (Dubale, 1951); *Micropterus* (Price, 1931).

Diffusion Rates for Respiratory Gas

Fick's law of simple diffusion (diffusion constant, surface area, membrane thickness, partial pressure gradient)

- dV/dt = A * K*dP/D
  - dV/dt = volume of gas diffusing / unit of time
  - A = area available for diffusive exchange
  - K = diffusion constant for gas (cm/sec)
  - dP = partial pressure difference (**to be determined or estimated)**
  - D = diffusion distance

Atmospheric Gas Concentrations

- The pressure exerted by gas in a mixture is the partial pressure of that gas.
- The major components of dry air are nitrogen (approximately 78.98%) and oxygen (approximately 20.98%). ….CO2 is ~ 0.04%
- The partial pressure from nitrogen is ~0.79 times 760 mm Hg,= 600.2 mm Hg or torr.
- Oxygen, ~ 21% of 760 mm Hg, equals 159.5 mm Hg or torr.

Partial pressures – Air vs Water

- In Air – easy to determine PP since with temperature changes PP changes are minor
  - E.g. 10C° to 30°C changes 7% in air
  -
- Water – PP highly affected by temperature
  - 10 to 30 °C = 33% change water

Henry's Law

- Concentration of Dissolved gas = Partial pressure of gas x Solubility coefficient
- The solubility coefficient is a measure of how easily the gas dissolves in the liquid. In water the solubility coefficient (Henry's coefficient) for oxygen is 0.024, and for carbon dioxide it is 0.57. Thus carbon dioxide is approximately 24 times as soluble in water as oxygen.

Partial Pressure Gradient

- Water and blood are driving force for diffusion
- Mean partial pressure between blood and water can be estimated
- ½ (P*i* gas + P*e* gas) – ½ (P*a* gas + P*v* gas)
- Where *i* is inside, *e* is external; *a* is arterial and *v* is venous gas tension.

Partial pressure difference or gradient

- Concentration = solubility coefficient x P O2, therefore

  PO2 = concentration / solubility

- Solubility of O2 in blood versus water
- Water = 0.066 mL/L per mm Hg
- Blood = 1.5 mL/L per mm Hg (= 23X water)

Comparisons Oxygen Conc.

Blood	Water
• $O2$ = 30 mL/L	$O2$ = 10 mL/L

- Which way will this diffuse?

Answers

- Concentration/solubility

Answer? and WHY?

- Blood: PO2 = 30 / 1.5 = 20 mm Hg

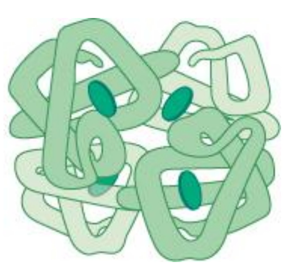
versus

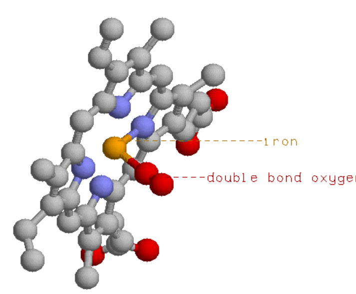
- Water: P O2 = 10 / 0.066 = 150 mm Hg

Therefore O2 will diffuse down the partial pressure gradient from water to blood, despite the fact that concentration gradient is in the opposite direction

Hemoglobin, the Magic Molecule

- Tetrameric molecule in most fish
- Two alpha two beta chains





Four disks = where the oxygen molecules bind
four sausage shapes represent polypeptide chains

$Hb + 4O_2 = Hb.4O_2$

- O_2 binds to the four heme groups
- H^+ and CO_2 bind to specific amino acid residues in globin chain

Preparation for Thursday

Readings, prepare questions