Lecture 4, 25 Jan 2008

Vertebrate Physiology
ECOL 437 (MCB/VetSci 437)
Univ. of Arizona, spring 2008
Kevin Bonine & Kevin Oh

1. Enzymes etc. (Ch 2)
2. Water, Solutes, Osmosis (Ch 3)

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

Housekeeping, 25 January 2008

Upcoming Readings

today: Ch 3
LAB Wed 30 Jan: Bisbal & Specker, plus two optional papers
(see website for links to papers, or get via email)
Mon 28 Jan: Ch 3&10
Wed 30 Jan: Ch 10&11

Lab discussion leaders: 30 Jan
1pm – Josh, Seth
3pm – Aaron, Adam

Lab discussion leaders: 06 Feb
1pm – Rittner, Whitney
3pm – Roxanne, Maria
Enzymes, Kinetics, Pathways...
(Hill et al. Ch 2, con’t)

- Rates of Rxn (V)
- MM constant (Km)
- Michaelis-Menten equation

\[ V_0 = \frac{V_{max}[S]}{K_m + [S]} \]
Figure 2.14 The approach to saturation depends on enzyme-substrate affinity

(b) Determination of $K_m$ for two of the enzymes from (a)

Enzymes
- Lineweaver-Burk Plot

\[
\text{Inverse of M-M equation} \quad \frac{1}{V_0} = \frac{K_m}{V_{max}[S]} + \frac{1}{V_{max}}
\]
Figure 2.12 Reaction velocity as a function of substrate concentration

Enzyme Kinetics
- hyperbolic
- sigmoidal

Natural Selection on Enzyme Function

Lactate dehydrogenase
2 alleles

Hill et al. 2004

Hill et al. 2004
(a) Ligand-gated channel

(b) G protein–coupled receptor and associated G protein system
(c) Enzyme/enzyme-linked receptor

Extracellular fluid

Ligand

Activated active site

Cytoplasm

GTP

Cyclic GMP

Hill et al 2004

(d) Intracellular receptor

Extracellular fluid

Ligand

Cytoplasm

Nuclear envelope

Intracellular receptor

Nucleus

DNA

Hill et al 2004
2nd Messengers

1. Cyclic AMP
2. Cyclic GMP
3. NO
4. DAG
5. IP$_3$
6. Calcium

Amplification

Hill et al. 2004
Chapter 3

Movement of Solutes and Water

What are the different ways to get substances across membranes?
Movement Across Membranes

1. Passive Diffusion (= simple diffusion)
2. Passive Transport (= facilitated diffusion)
3. Active Transport

Transport (pore or carrier) may be highly selective

How does a channel act selectively?
Ion Channels
- Ion selectivity
- Leaky channels (e.g., K+)
- Voltage-gated channels (e.g., Na+, K+, Ca+)
- Ligand-gated channels etc.

Movement Across Membranes
1. Passive Diffusion (= simple diffusion)
- nonpolar/nonelectrolyte
- lipid soluble (steroid hormones)
- few H bonds
- ~smaller size

-rate depends on [ ] gradient
-No saturation
Diffusion

Fick Equation:

\[ J = D \frac{C_1 - C_2}{X} \]

\( J \) = net rate of diffusion
\( D \) = diffusion coefficient (depends on permeability and Temp)
\( C_1 - C_2 \) = [gradient]
\( X \) = distance separating C1 from C2

### TABLE 3.1 The time required for diffusion through water to halve a concentration difference

<table>
<thead>
<tr>
<th>Time required to halve a concentration difference by diffusion</th>
<th>Distance between solutions</th>
<th>A biological dimension that exemplifies the distance specified</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 nanoseconds</td>
<td>10 nanometers</td>
<td>Thickness of a cell membrane</td>
</tr>
<tr>
<td>100 milliseconds</td>
<td>10 micrometers</td>
<td>Radius of a small mammalian cell</td>
</tr>
<tr>
<td>17 minutes</td>
<td>1 millimeter</td>
<td>Half-thickness of a frog sartorius muscle</td>
</tr>
<tr>
<td>1.1 hours</td>
<td>2 millimeters</td>
<td>Half-thickness of a human eye lens</td>
</tr>
<tr>
<td>4.6 days</td>
<td>2 centimeters</td>
<td>Thickness of the human heart muscle</td>
</tr>
<tr>
<td>32 years</td>
<td>1 meter</td>
<td>Length of a long human nerve cell</td>
</tr>
</tbody>
</table>

Source: After Weiss 1996.
Movement Across Membranes

1. Passive Diffusion (= simple diffusion)
2. Passive Transport (= facilitated diffusion)

- pores show some saturation, but not as much as carriers

Movement Across Membranes

1. Passive Diffusion (= simple diffusion)
2. Passive Transport (= facilitated diffusion)
3. Active Transport ($1^o$, $2^o$)
Fernandina
Galapagos Marine Iguana (Iguanidae)

El Nino → lack of food

Starvation

Animals may lose 15% body length
- bone absorption

Only adult vertebrate known to regularly shrink
(astronauts?)

Largest animals die
- natural selection vs.
- sexual selection

(Most efficient
salt glands
known in reptiles)

*Amblyrhynchus cristatus*
In Freshwater

(See Tipsmark et al 2002)
Membrane Selectivity (Channels)
Charge, ease of dehydration, size

Diffusion
- nonpolar nonelectrolyte
- lipophilic
- few H bonds
- smaller size

Transport

-rates depend on
1. electrochemical gradient
2. # carriers/pores

Movement Across Membranes

How is this related to the early test for diabetes??
How would you describe this movement across membrane?
Movement Across Membranes

How does glucose cross membranes?

**Most tissues:**
- Passive transport down [ ] gradient via carrier proteins

**In gut:**
- 2° active to move Glu against [ ] gradient into blood from “food”
(c) Na⁺−glucose cotransporter in apical membrane

**KEY TRANSPORTERS**
- ATPase
- Cotransporter

**SOLUTE MOVEMENT**
- Transport against the electrochemical gradient
- Transport in the direction of the electrochemical gradient

Leinhard et al. 1992
Osmotic Properties of Cells and Relative Ion Concentrations

Permeabilities

\[ \text{K}^+ \gg \text{Na}^+ ; \text{Cl}^- \]

\( [\text{A}^-] = \text{molar equivalent of negative charges carried by other molecules and ions.} \)

Electrogenic vs. Electroneutral

Hill et al 2004
Ion Gradients as an Energy Source

**CET example:**
- Metabolism
- Electron Transport Chain
- ATP creation
  energy currency

1. Move molecules
2. Electrical Signalling
3. Chemiosmotic Energy Transduction

Just add water...

How does water move across membranes?

aquaporins
Movement Across Membranes

Iso    Hypo    Hyper

In specific tissues and cells:
Iso    Hypo    Hyper

Osmotic Properties of Cells and Relative Ion Concentrations

K+    Na+    Ca+    Cl-

[M] = molar equivalent of negative charges carried by other molecules and ions.
Colligative Properties

- Osmotic Pressure
- Freezing Point
- Water Vapor Pressure (boiling point; evaporation)

Hill et al. 2004
Osmolarity

1 osmolar solution (Osm)
has 1 Avogadro’s number of dissolved particles/liter solvent

1 milliosmolar solution (mOsm)
has 0.001 Avogadro’s number of dissolved particles/liter solvent

What osmolarity do you get if you add $6 \times 10^{23}$ molecules of glucose to a liter of water?

What osmolarity do you get if you add $6 \times 10^{23}$ molecules of table salt to a liter of water?

NaCl (strong electrolyte)
Osmotic Pressure Vs. Hydrostatic Pressure

(a) A piston device for direct measurement of osmotic pressure

(b) The consequence if the piston is free to move

(c) The consequence if the solution is placed under pressure that exactly opposes osmosis

Rate of Osmosis = \( K \frac{\Pi_1 - \Pi_2}{X} \)

- Difference in osmotic potential
- Proportionality Coefficient (~ permeability and temp)
- Distance between solutions

Hill et al. 2004
Movement Across Membranes

Electrochemical Gradient

Electrical gradient

Concentration gradient

Electrochemical equilibrium

Equilibrium potential ($E_x$ in mV)

when $[X]$ gradient = electrical gradient
Equilibrium potential ($E_x$ in mV)

“Every ion’s goal in life is to make the membrane potential equal its own equilibrium potential ($E_x$ in mV)”