Vertebrate Physiology 437

1. Membranes (CH4)
2. Nervous System Building Blocks (CH5)
Movement Across Membranes

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

Transport (pore or carrier) may be highly selective
Movement Across Membranes

1. Passive Diffusion (= simple diffusion)

- nonpolar/nonelectrolyte
- lipid soluble
- few H bonds
- ~smaller size

-rate depends on [ ] gradient

-No saturation

4-17 Randall et al. 2002
Movement Across Membranes

1. Passive Diffusion (= simple diffusion)

2. Passive Transport (= facilitated diffusion)

   Down Electrochemical gradient

   A. pore
   B. carrier mediated

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

4-17 Randall et al. 2002
Movement Across Membranes

1. Passive Diffusion (= simple diffusion)
2. Passive Transport (= facilitated diffusion)
3. Active Transport \((1^o, 2^o)\)

**Na+/K+ ATPase Pump**

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**Passive diffusion**
- Passive transport down electrochemical gradient
- Carrier-mediated passive transport

**Passive transport**
- Primary active transport against electrochemical gradient
- Secondary active transport against electrochemical gradient, driven by ion movement down its gradient

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4-17 Randall et al. 2002
4-24 Randall et al. 2002
Movement Across Membranes

(a) Passive diffusion through membrane
(b) Passive transport through channels
(c) Carrier-mediated transport (passive or active)

(Aquaporins)
Movement Across Membranes

- **Extracellular fluid**
- **Cytosol**

**Uniporter**

**Symporter**

**Antiporter**

**Facilitated transport**

**Coupled transport**

4-22 Randall et al. 2002
Movement Across Membranes

Na⁺ gradient  →  Substrate gradient

?? (e.g., glucose)

$2^\circ$ active

Cotransport with Na⁺ renders substrate transport against its concentration gradient energetically favorable.
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

4-27 Randall et al. 2002

3-42 Randall 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

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4-29 Randall et al. 2002

4-17 Randall et al. 2002
Macromolecule Movement

Endo and Exocytosis

- Membrane recycling

e.g., Neurotransmitter release \((Ca^{2+} \text{ influx})\)
Junctions between cells

1. Gap
   ~linked

2. Tight
   ~impermeable barriers

4-32 Randall et al. 2002
Junctions between cells and solute movement

1. Transcellular path

2. Paracellular path

Exterior (mucosal side)  Interior (serosal side)

Acellular basement membrane

4-35 Randall et al. 2002
Solute movement and variability of membrane properties

Exterior (mucosal side)

- Na⁺
  - Passive

K⁺

Epithelial cell of frog skin

Interior (serosal side)

- Na⁺/K⁺ pump

K⁺

Passive

Frog skin between two compartments

4-36 Randall et al. 2002
Solute movement and subsequent water movement

**Osmosis**

Exterior (mucosal side)
- Tight junction
- Active salt transport
- Water flows osmotically

Intercellular clefts

Interior (serosal side)
- Interstitium
- Basolateral membrane

4-39 Randall et al. 2002
Chapter 5

NEURONS
- Anatomy
- Action Potentials (APs)
- Ionic Basis
- Membrane Potential

5-2 Randall et al. 2002
Nervous System

Comprises
- Neurons / Nerve Cells
- Glial Cells (support)

- Signalling via combination of Electrical and Chemical

- Integrate information
  **AFFERENT**

- Coordinate Response
  **EFFERENT**
Nervous System

Synapse
- Presynaptic
- Postsynaptic

1 Sensory Neurons
receive stimuli

2 Interneurons
entirely in CNS

3 Motor Neurons
effector organs
incl. muscle, gland

- Presynaptic
- Postsynaptic

5-2 Randall et al. 2002
Action Potential

All-or-None from spike-initiating zone
- Changes in ion permeability...
- Changes in membrane potential

- Voltage-gated ion channels
- \( \text{Na}^+, \text{K}^+, (\text{Ca}^{2+}) \)
- Feed Forward
  Why not infinite response?

5-2 Randall et al. 2002
At Rest

Membrane Potential
($V_m$ in volts or mV)

- outside is zero by convention

- $V_{rest}$ $K^+$, $Na^+$ about -60 mV

5-7 Randall et al. 2002
Action Potential

Terms:

-Hyperpolarization
  1 and 2

-Depolarization
  3 and 4

-Threshold Potential
  see 4

-Repolarization
  3 and 4

5-9 Randall et al. 2002
Ion Channels

- Ion selectivity
- Leaky channels (e.g., K+)
- Voltage-gated channels (e.g., Na+, K+, Ca+)
- Ligand-gated channels etc.

- charge
- ease of dehydration
- size
To change $V_m$,
A **Small Number of Ions** Actually Move
Relative to the Number Present both
Inside and Outside the cell

The concentration gradients are not abolished
When the channels for an ion species open

Gradients allow for ‘*work*’ to be done,
e.g., action potential sends signal along axon
Membrane Potential

- **Gradient** established by pumps (ATP)
- Gradients allow for ‘work’ to be done, e.g., action potential to send signals along axon
- Mechanism is the rapid movement of a small # ions across the membrane causing change in membrane potential
Membrane Potential

- Driven by ions that are permeable to the membrane (and have different [ ]\text{in} as compared to [ ]\text{out} a.k.a. concentration gradient created with ATP)

  - K+ for example

- Equilibrium Potential ($E_x$ in mV):

  ~The equilibrium potentials of all the permeable ions (a function of their established gradients) will determine the membrane potential of a cell

  - $\text{emf}$ determines which direction a given ion (X) will move when the membrane potential is known

  $\text{emf}_x = V_m - E_x$
Membrane Potential

- **Resting Membrane Potential** driven by **K+ efflux** and, to a lesser extent, **Na+ influx**

- **Na+/K+ ATPase pump** generates gradients that, for these permeable ions, determine membrane potential
Osmotic Properties of Cells and Relative Ion Concentrations

Permeabilities

\[ K^+ \gg Na^+ ; Cl^- \]

Muscle cell interior

<table>
<thead>
<tr>
<th>Ion</th>
<th>Interior Concentration</th>
<th>Exterior Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Na^+</td>
<td>10 mM</td>
<td>120 mM</td>
</tr>
<tr>
<td>K^+</td>
<td>140</td>
<td>2.5</td>
</tr>
<tr>
<td>Ca^{2+}</td>
<td>&lt; 10^{-3}</td>
<td>2.0</td>
</tr>
<tr>
<td>Cl^-</td>
<td>3 – 4</td>
<td>120</td>
</tr>
<tr>
<td>A^-</td>
<td>140</td>
<td></td>
</tr>
</tbody>
</table>

[A^-] = molar equivalent of negative charges carried by other molecules and ions.

A^- (includes proteins, phosphate groups, etc.)

Randall et al. 2002
**Equilibrium Potential**

- Calculate for a given type of ion using the simplified Nernst Equation:

\[ E_x = \frac{0.058}{z} \log \frac{[X]_{out}}{[X]_{in}} \]

\[ E_{Na} = \frac{0.058}{1} \log \frac{[Na^+]_{out}}{[Na^+]_{in}} \]

\[ E_{Na} = \frac{0.058}{1} \log \frac{120 \text{ mM}}{10 \text{ mM}} = 63 \text{ mV} \]

Remember **Equilibrium potential** \( (E_x \text{ in mV}) \)
when \([X] \text{ gradient} = \text{electrical gradient}\)
Membrane Potentials and Electricity

conductance = reciprocal of resistance

vs.

capacitance

5-10 Randall et al. 2002
Membrane Potential

- Nernst for single ion
  \[ V_m = E_x \] if only one ion ‘driving’

- Goldman equation for multiple ions

5-14 Randall et al. 2002
Mid-Lecture MiniQuestion (MLMQ)

Calculate $E_K$ if
\[
[K^+]_{\text{inside}} = 140 \text{ mM} \\
[K^+]_{\text{outside}} = 2.5 \text{ mM}
\]

If the resting membrane potential is $-60 \text{ mV}$, which way will $K^+$ ‘want’ to move (in or out of the cell)?

Which way will $Na^+$ want to move?

Which way will $K^+$ want to move if membrane potential is $-110 \text{ mV}$? $30 \text{ mV}$?