Membrane Dynamics

The body is mostly water

<table>
<thead>
<tr>
<th>Age</th>
<th>Male</th>
<th>Female</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infant</td>
<td>65%</td>
<td>65%</td>
</tr>
<tr>
<td>1–9</td>
<td>62%</td>
<td>62%</td>
</tr>
<tr>
<td>10–16</td>
<td>59%</td>
<td>57%</td>
</tr>
<tr>
<td>17–39</td>
<td>61%</td>
<td>51%</td>
</tr>
<tr>
<td>40–69</td>
<td>55%</td>
<td>47%</td>
</tr>
<tr>
<td>60+</td>
<td>52%</td>
<td>46%</td>
</tr>
</tbody>
</table>

Osmotic Equilibrium

➢ Water moves freely between the ECF and the ICF

➢ The fluid concentrations are equal on the 2 sides of the cell membrane

Chemical Disequilibrium

• The distribution of major solutes among the body fluid compartments is uneven

Chemical Disequilibrium

• Solutes might leak across the cell membrane
  - energy is required to return them
  • Na~ - K+ - ATPase (pump)

• Thus, maintaining the chemical disequilibrium requires a continual output of energy
Electrical Disequilibrium

- The body is electrically neutral
  - For every cation, there is a matching anion

- Ions are not distributed evenly between the ECF and the ICF
  - A few extra anions are in the ICF, giving it a net negative charge
  - Matching cations are in the ECF, giving it a net positive charge

Electrical Disequilibrium

- The uneven distribution of ions between the ICF and ECF → electrical disequilibrium

- Changes in this disequilibrium create electrical signals

  > More on this later!

Homeostasis Does Not Mean Equilibrium

- Homeostasis attempts to maintain the dynamic steady states of the body’s compartments
  - Osmotic equilibrium
  - Chemical disequilibrium
  - Electrical disequilibrium
Homeostasis Does Not Mean Equilibrium

- Transport mechanisms and selective permeability of the cell membrane are important to maintaining these dynamic states.

- The distribution of solutes depends on whether a substance can cross cell membranes.

Osmotic Equilibrium

In most cells:
- Water moves freely by
  - Crossing water-filled ion channels
  - Moving through aquaporins, special protein channels
- The movement of water across a membrane is in response to a solute concentration gradient and is called Osmosis.
Osmosis

- Water moves to dilute the more concentrated solution
- Once the concentrations are equal, net movement stops

How is Osmosis measured?

Osmotic Pressure

- The units are *atmospheres (atm)* or *millimeters of mercury (mm Hg)*
  - mm Hg = pressure exerted on a 1-cm² area by column of mercury 1mm high.
**Osmosis – other terminology**

- Osmolarity – **Number of particles** in solution
  - Isosmotic, hyperosmotic, and hyposmotic

- Tonicity - **Change in volume of a cell held in that solution**
  - Isotonic, hypertonic, and hypotonic

**Molarity vs Osmolarity**

- **Molarity**: #moles/L

- **Osmolarity**: #particles in solution
  - Ions dissociate in solution
  - Glucose vs NaCl

- Water moves by osmosis in response to the total concentration of all particles in the solution.
Osmolarity

• # of osmotically active particles per liter of solution
  - osmoles/L or milliosmoles/L

• Conversion:
  \[ \text{Molarity} \times \text{particles/molecule} = \text{osmolarity} \]
  \[ \text{(mol/L)} \times (\text{osmol/mol}) = (\text{osmol/L}) \]

Osmolarity vs Osmolality

Osmolarity = osmol/L

Osmolality = osmol/kg H₂O
  Used clinically to assess hydration status for fluid replacement therapy

Tonicity

• Penetrating versus nonpenetrating solutes

• Tonicity depends on the concentration of nonpenetrating solutes

\[ \text{TABLE 5.2 Comparing Osmolarities} \]

<table>
<thead>
<tr>
<th>Solution A = 1 OsM Glucose</th>
<th>Solution B = 2 OsM Glucose</th>
<th>Solution C = 1 OsM NaCl</th>
</tr>
</thead>
<tbody>
<tr>
<td>A is hyposmotic to B</td>
<td>B is hyperosmotic to A</td>
<td>C is isosmotic to A</td>
</tr>
<tr>
<td>A is isosmotic to C</td>
<td>B is hyperosmotic to C</td>
<td>C is hyposmotic to B</td>
</tr>
</tbody>
</table>

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Tonicity

- Penetrating versus nonpenetrating solutes
- Tonicity depends on the concentration of nonpenetrating solutes
- Rules for osmolarity and tonicity
- Clinical importance of osmolarity and tonicity

<table>
<thead>
<tr>
<th>Solution</th>
<th>Cell Behavior When Placed in the Solution</th>
<th>Description of the Solution Relative to the Cell</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Cell swells</td>
<td>Solution A is hypotonic</td>
</tr>
<tr>
<td>B</td>
<td>Cell doesn't change size</td>
<td>Solution B is isotonic</td>
</tr>
<tr>
<td>C</td>
<td>Cell shrinks</td>
<td>Solution C is hypertonic</td>
</tr>
</tbody>
</table>

Figure 5.3 The relationship between osmolarity and tonicity

<table>
<thead>
<tr>
<th>TONICITY</th>
<th>OSOMLARITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hypotonic</td>
<td>√</td>
</tr>
<tr>
<td>Isotonic</td>
<td>√</td>
</tr>
<tr>
<td>Hypertonic</td>
<td>√</td>
</tr>
</tbody>
</table>

Figure 5.3c Body Fluid Compartments
TABLE 5.4  Rules for Osmolarity and Tonicity
1. Assume that all intracellular solutes are nonpenetrating.
2. Compare osmolarities before the cell is exposed to the solution. (At equilibrium, the cell and solution are always isosmotic.)
3. Tonicity of a solution describes the volume change of a cell at equilibrium (Tbl. 5.3).
4. Determine tonicity by comparing nonpenetrating solute concentrations in the cell and the solution. Net water movement is into the compartment with the higher concentration of nonpenetrating solutes.
5. Hypotonic solutions are always hypotonic.

Clinical importance of osmolarity and tonicity

Transport Processes
- Bulk flow
  - Gases and liquids are fluids
  - Pressure gradients
- Cell membranes are selectively permeable
  - Permeable versus impermeable
  - Passive transport versus active transport
  - Concentration gradients

Table 5.5 Intravenous Solutions

<table>
<thead>
<tr>
<th>Solution</th>
<th>Also Known as</th>
<th>Osmolarity</th>
<th>Tonicity</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.9% saline</td>
<td>Normal saline</td>
<td>Isotonic</td>
<td>Isotonic</td>
</tr>
<tr>
<td>5% dextrose in 0.9% saline</td>
<td>D5W</td>
<td>Hypertonic</td>
<td>Hypertonic</td>
</tr>
<tr>
<td>0.45% saline</td>
<td>Half-normal saline</td>
<td>Hypertonic</td>
<td>Hypertonic</td>
</tr>
<tr>
<td>5% dextrose in 0.45% saline</td>
<td>D5W-normal saline</td>
<td>Hypertonic</td>
<td>Hypertonic</td>
</tr>
</tbody>
</table>

Figure 5.5 Transport across membranes

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Diffusion: Properties

1. Passive process
2. High concentration to low concentration
   • Chemical gradient
3. Net movement until concentration is equal
   • Equilibrium
4. Rapid over short distances
5. Directly related to temperature
6. Inversely related to molecular weight and size
7. In open system or across a partition
   • Ions move according to an electrochemical gradient

Rules for Diffusion of Uncharged Molecules:

General Properties
1. Diffusion uses kinetic NRG of molecular movement
2. Molecules diffuse from area of [higher] to [lower]
3. Diffusion continues until concentrations are equal; however, molecular movement continues after equilibrium is reached
4. Diffusion is faster:
   - along higher [gradient]
   - over shorter distances
   - at higher $T$
   - for smaller molecules
5. Diffusion can take place in an open system or across a partition that separates 2 systems

Simple Diffusion Across A Membrane

6. The rate of diffusion through a membrane is faster if:
   - the membrane's surface area is larger
   - the membrane is thinner
   - the concentration gradient is larger
   - the membrane is more permeable to the molecule
7. Membrane permeability to a molecule depends on
   - the molecule's lipid solubility
   - the molecule's size
   - the lipid composition of the membrane
Lipophilic Molecules Move by Simple Diffusion Across Lipids

- Additional properties to simple diffusion
  - Rate dependent on solubility in lipids
  - Proportional to surface area of membrane
  - Fick’s law of diffusion

Figure 5.7 Fick’s law of diffusion

Functions of Membrane Proteins

- Structural proteins
- Enzymes
- Membrane receptor proteins
- Transporters
  - Channel proteins
  - Carrier proteins

Figure 5.8 Map of membrane proteins

Channels
- Water channels
- Ion channels
- Open channels
- Gated channels
  - Chemically gated channels
  - Voltage-gated channels
  - Mechanically gated channels

Figure 5.10a Membrane Transporters
(a) Channel proteins create a water-distr pass.

MEMBRANE TRANSPORTERS

Figure 5.11 The structure of channel proteins
One protein subunit of channel.
Channel through center of membrane protein.
Channel through center of membrane protein (viewed from above).