**Ions and Membrane Potentials**

Ions are the basis of electrical properties of cells.

A. Diffusion of Ions
- through ion channels
- down an **electrochemical gradient**: chemical gradient: concentration difference
  electrical gradient: **electrical potential** difference across the membrane
  exerts electrical force on an ion, depending on the charge of the ion

B. Membrane Potential
- electrical potential difference between ICF and ECF
- measured in millivolts (mV)

**Resting Membrane Potential (RMP) = −70 mV** (negative inside)
- in a resting (unstimulated) nerve cell or muscle cell
- results from the unequal concentrations of ions (mostly K⁺ and Na⁺) between the ICF and ECF, and movements of these ions across the membrane

**Formation of the Resting Membrane Potential**

1. The Na⁺/K⁺ pump actively transports Na⁺ out and K⁺ in, forming **concentration gradients** of Na⁺ and K⁺ ions:
   - The ICF has high [K⁺] and low [Na⁺]
   - The ECF has low [K⁺] and high [Na⁺]

2. The resting cell membrane is **permeable to K⁺** due to the presence of K⁺ **leak channels** in the membrane.

3. K⁺ diffuses out of the cell down its **concentration gradient**.

4. Movement of K⁺ out of the cell makes the ICF more negative. The resulting negative electrical potential inside the cell creates an **electrical gradient** that acts in the opposite direction as the concentration gradient.

5. At some point, the concentration gradient and electrical gradient for K⁺ will be exactly balanced (equal and opposite). This point is the **equilibrium potential** for K⁺ (Eₖ ≈ −90 mV).

6. Diffusion of K⁺ outward moves the membrane potential toward Eₖ.
   - Since the membrane is most permeable to K⁺, the RMP is close to Eₖ.

7. The membrane is slightly permeable to Na⁺, so some Na⁺ diffuses inward.
   - This makes the RMP slightly less negative than Eₖ. (RMP ≈ −70 mV)

The **equilibrium potential** of an ion is the potential difference at which the electrical force exactly balances the chemical force (concentration gradient) on the ion.

The **Nernst equation** is used to calculate the equilibrium potential of an ion. In simplified form:

\[ E_{\text{ion}} = \frac{61 \times \log(C_{\text{out}}/C_{\text{in}})}{z} \]

where:
- \( E_{\text{ion}} \) is the equilibrium potential of the ion in millivolts (mV)
- \( z \) is the charge on the ion (+1 for K⁺ and Na⁺)
- \( C_{\text{out}} \) and \( C_{\text{in}} \) are concentrations of the ion in the ECF and ICF
- \( \log \) is the base 10 logarithm (of the number)

Using the Nernst equation, you can calculate the equilibrium potentials:
- for K⁺, \( (E_k) \approx −90 \text{ mV} \)
- for Na⁺, \( (E_{Na}) \approx +60 \text{ mV} \)
The membrane potential is determined by:

1) The **concentration gradients of permeable ions**, mostly K\(^+\) and Na\(^+\)
   - Na\(^+\)/K\(^+\) pump maintains normal concentrations of K\(^+\) and Na\(^+\) in the ICF
     kidneys maintain normal ionic concentrations of the ECF

2) The **relative permeability of the membrane to these ions (K\(^+\) versus Na\(^+\))**
   - due to specific ion channels

   - In the resting cell, **K\(^+\) leak channels** are dominant, so K\(^+\) has the strongest effect on RMP
     RMP is close to \(E_K\), but is slightly less negative because of some Na\(^+\) leakage in

   - RMP is very sensitive to changes in [K\(^+\)] in the ECF or ICF
     RMP is not very sensitive to [Na\(^+\)] because the resting membrane has low permeability to Na\(^+\).

\[
\begin{array}{c}
E_{Na} = +60 \\
mV \\
E_K = -90 \\
\end{array}
\]

When ions diffuse across the membrane, they tend to move the membrane potential toward their equilibrium potential.

Membrane potential changes **very quickly** when ionic permeability of the membrane changes. Changes in permeability result from opening or closing of specific ion channels.

**Thought Questions:**

1. What would be the effect on the RMP of a large increase in [K\(^+\)] of the ECF?
   (Hint: see the Nernst equation, and recall that RMP closely follows \(E_K\))

2. What would be the effect on the RMP of a large increase in [Na\(^+\)] of the ECF?

3. What would be the effect on membrane potential of a large increase in Na\(^+\) permeability?

4. What would be the effect on membrane potential of a large increase in K\(^+\) permeability?