**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
- electrical potential (measured in *millivolts*) is electrical force on an ion

B. Membrane Potential
- electrical potential difference between ICF and ECF, due to imbalance of + and – charges across the membrane.

**Resting Membrane Potential (RMP)** ≈ –70 mV (negative inside)
- potential difference across the membrane of an unstimulated nerve or muscle cell
- results from the unequal distribution of permeable ions (K+ and Na+) between the ICF and ECF, and resulting 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 exactly counterbalance each other. This point is the **equilibrium potential** for K⁺ (E_K ≈ –90 mV).

6. Diffusion of K⁺ outward tends to move the membrane potential toward E_K. Since the resting membrane is most permeable to K⁺, the **RMP is close to E_K**.

7. The resting membrane is slightly permeable to Na⁺, so some Na⁺ diffuses inward. This makes the RMP slightly less negative than E_K.

**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 equilibrium potential of an ion can be calculated using the Nernst equation. In simplified form:

\[
E_{\text{ion}} = \frac{60}{z} \cdot \log \left( \frac{C_{\text{out}}}{C_{\text{in}}} \right)
\]

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 in parentheses)

Using the Nernst equation, you can calculate the equilibrium potentials:

- for K⁺, \((E_K) ≈ –90 \text{ mV}\)
- for Na⁺, \((E_{Na}) ≈ +60 \text{ mV}\)
Two main factors determine the membrane potential:

1) The concentration gradients of permeable ions, primarily K⁺ and Na⁺
   – formed by the Na⁺/K⁺ pump
2) The relative permeability of the membrane to these ions (K⁺ versus Na⁺)
   – due to specific ion channels
   • K⁺ has the greatest influence on RMP because the resting membrane is most permeable to K⁺. K⁺ tends to move out of the cell, which creates a negative potential inside the cell.
   - RMP is close to E_K, but is slightly less negative because of some inward Na⁺ leakage
   - RMP is very sensitive to changes in [K⁺] in the ICF or ECF (as predicted by the Nernst equation)
   - RMP is only slightly affected by [Na⁺] because the resting membrane is not very permeable to Na⁺.

Key points

1. The membrane potential results from the unequal distribution of permeable ions (K⁺ and Na⁺) between the ICF and ECF, and the resulting movements of these ions across the membrane.
2. The Na⁺/K⁺ pump forms concentration gradients of K⁺ and Na⁺ between the ICF and ECF. Once these gradients are in place, the membrane potential depends on the relative permeability of the membrane to K⁺ and Na⁺, which is determined by specific ion channels.
3. Ions that are permeable will diffuse across the membrane down their electrochemical gradients, which moves the membrane potential toward the equilibrium potential of the most permeable ion(s).
   • In the resting cell, K⁺ leak channels are dominant, so RMP is close to E_K.
4. The membrane potential can change very rapidly in response to changes in permeability of the membrane to Na⁺, K⁺, or other ions. Changes in permeability to these ions result from opening or closing of different 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. How would membrane potential be affected by a large increase in Na⁺ permeability of the membrane?
4. How would membrane potential be affected by a large increase in K⁺ permeability?

→ Try using the Membrane Potential Calculator spreadsheet to help you answer these questions!