I. Ion Concentrations
In general, the following concentrations (in mM/L) exist in most mammalian cells:

<table>
<thead>
<tr>
<th>Ion</th>
<th>Intracellular</th>
<th>Extracellular</th>
<th>gradient strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>Na⁺</td>
<td>12</td>
<td>140</td>
<td>11.7 : 1 inward</td>
</tr>
<tr>
<td>K⁺</td>
<td>150</td>
<td>5</td>
<td>30 : 1 outward</td>
</tr>
<tr>
<td>Cl⁻</td>
<td>7</td>
<td>100</td>
<td>14.3 : 1 inward</td>
</tr>
<tr>
<td>Ca²⁺</td>
<td>10⁻⁴</td>
<td>1</td>
<td>10,000 : 1 inward</td>
</tr>
</tbody>
</table>

Where do these gradients come from?

II. Equilibrium Potentials
The following are approximate Equilibrium Potentials (Eᵢ):

- \( E_{Na⁺} = +65 \text{ mV} \)
- \( E_{K⁺} = -85 \text{ mV} \)
- \( E_{Cl⁻} = -85 \text{ mV} \)
- \( E_{Ca²⁺} = +120 \text{ mV} \)

Describe equilibrium potentials in your own words.

What is the benefit of knowing the equilibrium potentials?

What is the main deficiency of equilibrium potentials on their own?

III. Resting Membrane Potential
Describe resting membrane potential in your own words.

What would the resting membrane potential be if permeability to sodium and potassium were equal?
IV. Changes in Membrane Potential

Resting membrane potential is the starting point for neurons. In reality, the membranes of most neurons are rarely “at rest”. They are usually receiving constant communication from other sources.

This communication can be observed in two forms:

1) Depolarization

2) Hyperpolarization

Question: What mechanisms will lead to depolarization or hyperpolarization of a neuron’s membrane?

V. Graded Potentials
VI. Summation of Graded Potentials

a) spatial summation

b) temporal summation

VII. Membrane Threshold
VIII. Action Potentials

When summation of enough depolarizing graded potentials push the membrane potential above the membrane threshold an action potential occurs.

Unlike graded potentials, action potentials are the result of voltage-gated ion channels. The probability of voltage-gated Na⁺ and K⁺ channels opening can be seen in the following graph:

This demonstrates that when threshold is reached, voltage-gated Na⁺ channels open and increase the permeability of the membrane to Na⁺.

★ During the rising phase of the action potential, the membrane is 20 times more permeable to Na⁺ than K⁺.

As the membrane potential increases, the threshold for voltage-gated K⁺ channels is reached and the permeability to K⁺ increases to again become the dominant ion.

The time course for this change in permeability can be seen in the following graph:
IX. Refractory periods

Due to the different behaviors of the voltage-gated sodium and potassium ion channels. Two specific time periods can be identified during which it is either impossible or difficult for a neuron to generate another action potential.

1) absolute refractory period

2) relative refractory period

X. Summary of Graded vs. Action potentials

<table>
<thead>
<tr>
<th>Differences between Graded Potentials and Action Potentials</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>GRADED POTENTIAL</strong></td>
</tr>
<tr>
<td>Amplitude varies with size of the initiating event.</td>
</tr>
<tr>
<td>Can be summed.</td>
</tr>
<tr>
<td>Has no threshold.</td>
</tr>
<tr>
<td>Has no refractory period.</td>
</tr>
<tr>
<td>Is conducted decrementally; that is, amplitude decreases with distance.</td>
</tr>
<tr>
<td>Duration varies with initiating conditions.</td>
</tr>
<tr>
<td>Can be a depolarization or a hyperpolarization.</td>
</tr>
<tr>
<td>Initiated by environmental stimulus (receptor), by neurotransmitter (synapse), or spontaneously.</td>
</tr>
<tr>
<td>Mechanism depends on ligand-gated channels or other chemical or physical changes.</td>
</tr>
</tbody>
</table>
XI. Action Potential Propagation
Transmission of the action potential along an unmyelinated axon relies on the sequential activation of voltage-gated channels along the entire length of the axon membrane.

Transmission of the AP along a myelinated axon allows the use of the cable properties of electrical transmission. The myelin sheath acts as an insulator and prevents the degradation of the potential change that occurs in graded potentials. This is called saltatory conduction and leads to a significant increase in conduction velocity.

Additionally, larger axons have less intracellular resistance to current flow, and thus have faster action potential propagation. Therefore, the fastest action potential transmission is seen in large diameter myelinated axons.
XII. Divergence vs. Convergence

What are some examples of divergence?

What are some examples of convergence?