Action Potentials

• Brief, rapid, large (100mV) changes in membrane potential during which potential actually reverses
  – Initiates at axon hillock
  – Involves only a small portion of the total excitable cell membrane
  – Do not decrease in magnitude away from site of origin
  – Requires activation of voltage regulated gates

Action Potentials

• Membrane at axon hillock reaches threshold potential
  – Voltage-gated Na+ channels in the membrane undergo conformational changes
  – Flow of sodium ions into the ICF reverses the membrane potential from -70 mV to +30 mV (towards equilibrium potential (+60mv) in 1-2 msec (depolarization)
  – Flow of potassium ions into the ECF restores the membrane potential to the resting state (repolarization)
Action Potentials

- **Additional characteristics**
  - Sodium channels open during depolarization by positive feedback
  - When the sodium channels become inactive, the channels for potassium open. This repolarizes the membrane
  - As the action potential develops at one point in the plasma membrane, it regenerates an identical action potential at the next point in the membrane
  - Therefore, it travels along the plasma membrane undiminished
VOLTAGE-GATED SODIUM CHANNEL

(a) Closed but capable of opening
(b) Open (activated)
(c) Closed and not capable of opening (inactivated)

VOLTAGE-GATED POTASSIUM CHANNEL

(d) Closed
(e) Open

Passive spread of current from adjacent site already depolarized

+ Attainment of threshold potential - (decrease in membrane potential)

Influx of Na+ (which further decreases membrane potential)

Opening of voltage-gated Na+ channels

Positive-feedback cycle

Fig. 4-5, p. 76
Fig. 4-6, p. 76
Na⁺ channel closes and is inactivated (activation gate still open; inactivation gate closes).

Na⁺ channel opens and is activated (activation gate opens; inactivation gate already open).

K⁺ channel opens (activation gate opens).

K⁺ voltage-gated channel closed (activation gate closed).

Na⁺ voltage-gated channel closed (activation gate closed; inactivation gate open).

K⁺ channel closes (activation gate closes).

Na⁺ channel reset to closed but capable of opening (activation gate closes; inactivation gate opens).

K⁺ out → falling phase

Na⁺ in → rising phase

Fig. 4-7a, p. 77

Membrane potential (mV)

Time (msec)

Depolarizing triggering event

Resting potential

Threshold potential

ICF

ECF

1 2 3 4

Na⁺ permeability

K⁺ permeability

Action potential

Fig. 4-11, p. 82
Direction of propagation of action potential

Graded potential > threshold
Local current flow that depolarizes adjacent inactive area from resting potential to threshold potential

Active area at peak of action potential
Adjacent inactive area into which depolarization is spreading; will soon reach threshold
Remainder of axon still at resting potential

Adjacent inactive area
Local current flow that depolarizes adjacent inactive area from resting potential to threshold potential
Direction of propagation of action potential

Remainder of axon still at resting potential
New adjacent inactive area into which depolarization is spreading; will soon reach threshold
Previous active area returned to resting potential; no longer active; in refractory period
Adjacent area that was brought to threshold by local current flow; now active at peak of action potential

Active area at peak of action potential
Adjacent inactive area into which depolarization is spreading; will soon reach threshold
Remainder of axon still at resting potential
**Action Potentials**

- **The All or None Law**
  - Action potentials occur in all or none fashion depending on the strength of the stimulus
- **The Refractory Period**
  - Is responsible for setting up limit on the frequency of action potentials
### Action Potentials

- **Two types of propagation**
  - Contiguous conduction
    - Conduction in unmyelinated fibers
    - Action potential spreads along every portion of the membrane
  - Saltatory conduction
    - Rapid conduction in myelinated fibers
    - Impulse jumps over sections of the fiber covered with insulating myelin

### Action Potential: Saltatory Conduction

- Propagates action potential faster than contiguous conduction because action potential doesn’t have to be regenerated at myelinated section
- Myelinated fibers conduct impulses about 50 times faster than unmyelinated fibers of comparable size
Action Potential: Saltatory Conduction

- Myelin
  - Primarily composed of lipids
  - Formed by oligodendrocytes in CNS
  - Formed by Schwann cells in PNS

Action Potential: Saltatory Conduction

- Regeneration of nerve fibers depends on its location
- Schwann cells in PNS guide the regeneration of cut axons
- Fibers in CNS myelinated by oligodendrocytes do not have regenerative ability
  - Oligodendrocytes inhibit regeneration of cut central axons
(a) Myelinated fiber

- Axon of neuron
- Nodes of Ranvier
- Myelin sheath
- Myelin sheath
- Plasma membrane

(b) Schwann cells in peripheral nervous system

- Axon
- Cytoplasm
- Nucleus
- Schwann cell
- Node of Ranvier
(c) Oligodendrocytes in central nervous system

Fig. 4-12c, p. 84

Node of Ranvier
Axon
Voltage-gated Na+ and K+ channels
Myelin sheath

Node of Ranvier
Axon

Fig. 4-12d, p. 84
## Table 4-1 Comparison of Graded Potentials and Action Potentials

<table>
<thead>
<tr>
<th>Property</th>
<th>Graded Potentials</th>
<th>Action Potentials</th>
</tr>
</thead>
<tbody>
<tr>
<td>Triggering events</td>
<td>Stimulus, combination of neurotransmitter with receptor, or inherent shifts in channel permeability</td>
<td>Depolarization to threshold, usually through passive spread of depolarization from an adjacent area undergoing a graded potential or an action potential</td>
</tr>
<tr>
<td>Ion movement producing a change in potential</td>
<td>Net movement of Na⁺, K⁺, Cl⁻, or Ca²⁺ across the plasma membrane by various means</td>
<td>Sequential movement of Na⁺ into and K⁺ out of the cell through voltage-gated channels</td>
</tr>
<tr>
<td>Coding of the magnitude of the triggering event</td>
<td>Graded potential change; magnitude varies with the magnitude of the triggering event</td>
<td>All-or-none membrane response; magnitude of the triggering event is coded in the frequency rather than the amplitude of action potentials</td>
</tr>
<tr>
<td>Duration</td>
<td>Varies with the duration of the triggering event</td>
<td>Constant</td>
</tr>
<tr>
<td>Magnitude of the potential change with distance from the initial location</td>
<td>Decremental conduction; magnitude diminishes with distance from the initial site</td>
<td>Propagated throughout the membrane in an undiminishing fashion; self-regenerated in neighboring inactive areas of the membrane</td>
</tr>
<tr>
<td>Refractory period</td>
<td>None</td>
<td>Relative, absolute</td>
</tr>
<tr>
<td>Summation</td>
<td>Temporal, spatial</td>
<td>None</td>
</tr>
<tr>
<td>Direction of potential change</td>
<td>Depolarization or hyperpolarization</td>
<td>Always depolarization and reversal of charges</td>
</tr>
<tr>
<td>Location</td>
<td>Specialized regions of the membrane designed to respond to the triggering event</td>
<td>Regions of the membrane with an abundance of voltage-gated channels</td>
</tr>
</tbody>
</table>

Table 4-1, p. 81