Neurophysiology

Chapters 10-12

Control and Integration

• Nervous system
  – composed of nervous tissue
  – cells designed to conduct electrical impulses
  – rapid communication to specific cells or groups of cells

• Endocrine system
  – composed of various tissue types
  – cell communication solely through chemical messengers
  – slow speed of action, broadcast

Nervous System Organization:
Radial Symmetric Animals

• Neural Net
  – Cnidarians and ctenophorans
  – Echinoderms
  – no specific CNS

Nervous System Organization:
Bilateral Symmetric Animals

• Nerve Cords
  – Longitudinally oriented tracts of neurons, with lateral commissures

• Evolutionary Trends
  – Reduction of nerve cord numbers
  – Cephalization – anterior concentration of nerve tissue (brain)

Nervous System Organization:
Bilateral Symmetric Animals

• Central Nervous System
  – Brain + Spinal Cord
  – control center (integration)

• Peripheral Nervous System
  – cranial nerves and spinal nerves
  – connects CNS to sensory receptors, muscles and glands

Neurons

• Cell Body
  – nucleus and organelles

• Dendrites
  – receive information

• Axon
  – conduct electrical signals (action potentials)
  – axon hillock - site where AP’s originate
  – axon terminals - where chemical signals are released
Membrane Potentials

• All cell membranes are electrically polarized
  – Unequal distribution of charges
  – Membrane potential (mV) = difference in charge across the membrane
  – Due to unequal ion concentrations across cell membrane (fixed anions)

Ion Movements

• K⁺
  – [K⁺] higher inside cell than outside
  – Attracted to fixed anions inside cell
  – High membrane permeability
  – Flows slowly out of cell

• Na⁺
  – [Na⁺] higher outside cell than inside
  – Attracted to fixed anions inside cell
  – Low membrane permeability
  – Flows slowly into cell

Equilibrium Potential

• Equilibrium (no net movement) will be reached when a particular electrical potential is reached
• Equilibrium potential = theoretical electrical potential at which the net flow of ions across the membrane is 0
  – balance between EG and CG is achieved

Equilibrium Potential

• Equilibrium potential is calculated for a particular ion using the Nernst Equation
  \[ E_x = \frac{RT}{zF} \ln\left(\frac{[X_o]}{[X_i]}\right) \]
  • \( E_x \) = equilibrium potential (mV)
  • \( R \) = gas constant (8.31 J/(K*mol))
  • \( T \) = temperature (K)
  • \( z \) = charge of the ion
  • \( F \) = Faraday’s constant (96500 coulombs/mole)
  • \([X_o]\) and \([X_i]\) = concentrations of ion “X” inside and outside the cell

Equilibrium Potential

• For equilibrium potentials of Na⁺ and K⁺ in eutherian mammals (\( T_b = 310 \) K)
  \[ E_x = 61 \log \left(\frac{[X_o]}{[X_i]}\right) \]
  • Equilibrium potential for K⁺ (\( E_K \)) = -90 mV
  • Equilibrium potential for Na⁺ (\( E_Na \)) = +60 mV

Distribution of Inorganic Ions

• Different ions unevenly distributed across cell membrane
• Each has own specific equilibrium potential and membrane permeability

Table 11.1
**Resting Potentials**

- **Resting potential**
  - Typical membrane potential for cells
  - Depends on concentration gradients and membrane permeabilities for different ions involved
  - **Goldman Equation**
    $$ V_m = \frac{RT}{F} \ln \frac{P_K [K^+]_o + P_Na [Na^+]_o + P_Cl [Cl^-]_o}{P_K [K^+]_i + P_Na [Na^+]_i + P_Cl [Cl^-]_i} $$
  - -65 to -85 mV (unequal to $E_K$ or $E_{Na^+}$)
  - $[Na^+]$ and $[K^+]$ inside the cell are maintained using Na+/K+ pumps

**Electrical Activity of Neurons: Electrical Signals**

- **Electrical signals**
  - due to changes in membrane permeability and altering flow of charged particles
  - changes in permeability are due to changing the number of open membrane channels

**Membrane Proteins Involved in Electrical Signals**

- **Non-gated ion channels** (leak channels)
  - always open
  - specific for a particular ion
- **Gated Ion channels**
  - open only under particular conditions (stimulus)
  - voltage-gated, ligand-gated, stress-gated
- **Ion pumps**
  - active (require ATP)
  - maintain ion gradients

**Types of Electric Signals: Graded Potentials**

- occure in dendrites / cell body
- small, localized change in membrane potential
  - change of only a few mV
  - opening of chemically-gated or physically-gated ion channels
  - travels only a short distance (few mm)
- a triggered event
  - requires stimulus
  - e.g. light, touch, chemical messengers
- graded
  - ↑ stimulus intensity → ↑ change in membrane potential

**Types of Electric Signals: Action Potentials**

- begins at the axon hillock, travels down axon
- brief, rapid reversal of membrane potential
  - Large change (~70-100 mV)
  - Opening of voltage-gated Na⁺ and K⁺ channels
  - self-propagating - strength of signal maintained
- triggered
  - membrane depolarization (depolarizing graded potential)
- "All or none"
  - axon hillock must be depolarized a minimum amount (threshold potential)
  - if depolarized to threshold, AP will occur at maximum strength
  - if threshold not reached, no AP will occur
Action Potential: Depolarization

- Triggering event (graded potential) causes membrane to depolarize
- Slow increase until threshold is reached
- Voltage-gated Na⁺ channels open
  - Na⁺ enters cell → further depolarization → more channels open → further depolarization
- Membrane reverses polarity

Figs 11.12, 11.13

Action Potential: Repolarization

- Na⁺ channels close
- Delayed opening of voltage-gated K⁺ channels
  - K⁺ rushes out of the cell
  - Membrane potential restored
- K⁺ channels close
  - [Na⁺] and [K⁺] restored by the Na⁺-K⁺ pump

Fig 11.12

Action Potential Propagation

- Na⁺ moving into one segment of the neuron quickly moves laterally inside the cell
- Depolarizes adjacent segment to threshold

Fig 11.23

Conduction Velocity

- Conduction velocity
  - Speed at which the action potential travels down the length of an axon
  - Dictates speed of response
- Velocity directly related to axon diameter
  - Increased diameter lowers internal resistance to ion flow
  - $V \propto \sqrt{D}$ in unmyelinated axons
  - $V \propto D$ in myelinated axons

Fig 11.24

Action Potential Propagation: Myelinated Axons

- Myelin - lipid insulator
  - Membranes of certain glial cells
- Nodes of Ranvier contain lots of Na⁺ channels
- Saltatory conduction
  - Signals "jump" from one node to the next
  - AP conduction speed 50-100x
- Vertebrates tend to have more myelinated axons than invertebrates

Fig 11.25

Chemical Synapses

- Presynaptic neuron
  - Synaptic terminal bouton
  - Contains synaptic vesicles filled with neurotransmitter
- Synaptic cleft
  - Space in-between cells
- Postsynaptic neuron
  - Subsynaptic membrane
  - Contains receptors that bind neurotransmitter

Fig 11.1
Chemical Synapses

- Many voltage-gated Ca\(^{2+}\) channels in the terminal bouton
  - AP in knob opens Ca\(^{2+}\) channels
  - Ca\(^{2+}\) rushes in.
- Ca\(^{2+}\) induced exocytosis of synaptic vesicles
- Transmitter diffuses across synaptic cleft and binds to receptors on subsynaptic membrane

Types of Postsynaptic Potentials

- **excitatory postsynaptic potentials (EPSPs)**
  - Transmitter binding opens Na\(^{+}\) channels in the postsynaptic membrane
  - Small depolarization of postsynaptic neuron
    - More positive inside the cell
    - Closer to threshold

- **inhibitory postsynaptic potentials (IPSPs)**
  - Transmitter binding opens K\(^{+}\) or Cl\(^{-}\) ion channels
  - K\(^{+}\) flows out or Cl\(^{-}\) flows in down gradients
  - Small hyperpolarization of postsynaptic neuron
    - More negative inside cell
    - Further from threshold

Summation

- **spatial summation**
  - Numerous presynaptic fibers may converge on a single postsynaptic neuron
  - Additive effects of numerous neurons inducing EPSPs and IPSPs on the postsyn. neuron
- **temporal summation**
  - Additive effects of EPSPs and IPSPs occurring in rapid succession
  - Next synaptic event occurs before membrane recovers from previous event