Neurons are nerve cells that transfer information within the body. Occurs if gated Na$^+$ channels open and Na$^+$ diffuses out, making the inside of the cell more positive than the outside. In a resting neuron, the currents of K$^+$ ions flow outward, moving the membrane potential toward the equilibrium potential for K$^+$(−90 mV). Inhibitory postsynaptic potentials (IPSPs) are hyperpolarizations that move the membrane potential farther from threshold.

If a depolarization shifts the membrane potential sufficiently, it results in a massive influx of Na$^+$ into the cell. Negative charge (Cl$^-$) is also lost during this event, making the inside of the cell less negative. Integration center.

Changes in membrane potential occur because neurons contain gated ion channels. In a mammalian neuron at resting potential, the concentration of K$^+$ is higher inside the cell (140 mM) than outside (5 mM). The concentration of Na$^+$ is higher outside (150 mM) than inside (10 mM). The presynaptic neuron synthesizes and packages the neurotransmitter in synaptic vesicles that are released when an action potential arrives at the presynaptic neuron. Interneurons integrate the information.

Motor neurons trigger muscle or gland activity. A single neurotransmitter may have more than a dozen different receptors. In some synapses, a neurotransmitter binds to a receptor that is metabotropic, which alters a transduction pathway in the postsynaptic cell involving a second messenger and metabolic steps. Inactivated Na$^+$ channels and fewer open Na$^+$ channels and chloride (Cl$^-$) channels close. At equilibrium, both the electrical and chemical gradients are balanced.

A Closer Look

Action potentials in motor neurons carry information into and out of the CNS. Sodium-potassium pumps use the energy of ATP to maintain these K$^+$ and Na$^+$ concentration gradients. The equilibrium potential ($E_{equ}$) of a sodium or potassium channel is determined by the concentration of the ion in the inner and outer compartments. The membrane potential of a neuron not sending signals is called the resting potential.

Resting potential: $E_{rest} = \frac{RT}{F} \ln \left( \frac{[K^+]}{[K^+]_{ext}} \times \frac{[Na^+]}{[Na^+]_{ext}} \right)$, where $R$ is the gas constant, $T$ is the temperature, $F$ is Faraday's constant, and $[K^+]_{ext}$ and $[Na^+]_{ext}$ are the concentrations of K$^+$ and Na$^+$ outside the cell, respectively.

The speed of an action potential increases with the axon's diameter. Action potentials are formed only at nodes of Ranvier, gaps in the myelin sheath. Through summation, an IPSP can counter the effect of an EPSP. Integration center.

Gamma-aminobutyric acid (GABA) is inhibitory; acetylcholine (ACh) is excitatory. A single EPSP is usually too small to trigger an action potential in a postsynaptic neuron. Motor neurons trigger muscle or gland activity. A single neurotransmitter may have more than a dozen different receptors. In some synapses, a neurotransmitter binds to a receptor that is metabotropic, which alters a transduction pathway in the postsynaptic cell involving a second messenger and metabolic steps. Inactivated Na$^+$ channels and fewer open Na$^+$ channels and chloride (Cl$^-$) channels close. At equilibrium, both the electrical and chemical gradients are balanced.

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Gradients across the plasma membrane
- These concentration gradients represent chemical potential energy

- The opening of ion channels in the plasma membrane converts chemical potential to electrical potential
- A neuron at resting potential contains many open K⁺ channels and fewer open Na⁺ channels; K⁺ diffuses out of the cell
- The resulting buildup of negative charge within the neuron is the major source of membrane potential

Table 48.1

Modeling the Resting Potential
- Resting potential can be modeled by an artificial membrane that separates two chambers
  - The concentration of KCl is higher in the inner chamber and lower in the outer chamber
  - K⁺ diffuses down its gradient to the outer chamber
  - Negative charge (Cl⁻) builds up in the inner chamber
- At equilibrium, both the electrical and chemical gradients are balanced

Figure 48.8

Action potentials are the signals conducted by axons
- Changes in membrane potential occur because neurons contain gated ion channels that open or close in response to stimuli

Hyperpolarization
- When gated K⁺ channels open, K⁺ diffuses out, making the inside of the cell more negative
- Increase in magnitude of the membrane potential

Depolarization
- Opening other types of ion channels triggers a depolarization, a reduction in the magnitude of the membrane potential
- Occurs if gated Na⁺ channels open and Na⁺ diffuses into the cell

Graded Potentials and Action Potentials
- Graded potentials are changes in polarization where the magnitude of the change varies with the strength of the stimulus
- These are not the nerve signals that travel along axons, but they do have an effect on the generation of nerve signals
- If a depolarization shifts the membrane potential sufficiently, it results in a massive change in membrane voltage called an action potential
- Action potentials have a constant magnitude, are all-or-none, and transmit signals over long distances
- They arise because some ion channels are voltage-gated, opening or closing when the membrane potential passes a certain level
Neurons are nerve cells that transfer information within the body. Most motor neurons are sensory neurons that detect external stimuli and internal conditions. Peripheral nervous system (PNS) neurons carry information into and out of the CNS. A single neurotransmitter may have more than a dozen different receptors. The speed of an action potential increases with the axon's diameter. The concentration of KCl is higher in the inner chamber and lower in the outer chamber. The action potential causes the release of the neurotransmitter. At electrical synapses, the electrical current flows from one neuron to another. Action potentials are formed only at nodes of Ranvier, gaps in the myelin sheath where voltage-gated Na⁺ channels are found. Action potentials in myelinated axons jump between the nodes of Ranvier in a process called saltatory conduction. Neurons communicate with other cells at synapses. At electrical synapses, the electrical current flows from one neuron to another. At chemical synapses, a chemical neurotransmitter carries information across the gap junction. Most synapses are chemical synapses. The presynaptic neuron synthesizes and packages the neurotransmitter in synaptic vesicles located in the synaptic terminal.

**Figure 48.10c**

**Generation of Action Potentials: A Closer Look**

- An action potential can be considered as a series of stages

**Figure 48.11-1**

**Figure 48.11-2**

**Figure 48.11-3**

**Figure 48.11-4**

**Figure 48.11-5**

- During the refractory period after an action potential, a second action potential cannot be initiated
- The refractory period is a result of a temporary inactivation of the Na⁺ channels

**Conduction of Action Potentials**

- At the site where the action potential is generated, usually the axon hillock, an electrical current depolarizes the neighboring region of the axon membrane
- Action potentials travel in only one direction: toward the synaptic terminals
- Inactivated Na⁺ channels behind the zone of depolarization prevent the action potential from traveling backwards

**Evolutionary Adaptation of Axon Structure**

- The speed of an action potential increases with the axon's diameter
- In vertebrates, axons are insulated by a myelin sheath, which causes an action potential's speed to increase
- Myelin sheaths are made by glia—oligodendrocytes in the CNS and Schwann cells in the PNS

**Figure 48.12-3**

**Figure 48.13**

- Action potentials are formed only at nodes of Ranvier, gaps in the myelin sheath where voltage-gated Na⁺ channels are found
- Action potentials in myelinated axons jump between the nodes of Ranvier in a process called saltatory conduction

**Neurons communicate with other cells at synapses**

- At electrical synapses, the electrical current flows from one neuron to another
- At chemical synapses, a chemical neurotransmitter carries information across the gap junction
- Most synapses are chemical synapses
- The presynaptic neuron synthesizes and packages the neurotransmitter in synaptic vesicles located in the synaptic terminal
• The action potential causes the release of the neurotransmitter
• The neurotransmitter diffuses across the synaptic cleft and is received by the postsynaptic cell

35 Figure 48.15

36 Generation of Postsynaptic Potentials

• Direct synaptic transmission involves binding of neurotransmitters to ligand-gated ion channels in the postsynaptic cell
• Neurotransmitter binding causes ion channels to open, generating a postsynaptic potential

38 • Postsynaptic potentials fall into two categories
  • Excitatory postsynaptic potentials (EPSPs) are depolarizations that bring the membrane potential toward threshold
  • Inhibitory postsynaptic potentials (IPSPs) are hyperpolarizations that move the membrane potential farther from threshold

39 • After release, the neurotransmitter
  • May diffuse out of the synaptic cleft
  • May be taken up by surrounding cells
  • May be degraded by enzymes

40 Summation of Postsynaptic Potentials

• Most neurons have many synapses on their dendrites and cell body
• A single EPSP is usually too small to trigger an action potential in a postsynaptic neuron

41 Figure 48.17

42 • Through summation, an IPSP can counter the effect of an EPSP
• The summed effect of EPSPs and IPSPs determines whether an axon hillock will reach threshold and generate an action potential

43 Modulated Signaling at Synapses

• In some synapses, a neurotransmitter binds to a receptor that is metabotropic
• In this case, movement of ions through a channel depends on one or more metabolic steps
• Binding of a neurotransmitter to a metabotropic receptor activates a signal transduction pathway in the postsynaptic cell involving a second messenger
• Compared to ligand-gated channels, the effects of second-messenger systems have a slower onset but last longer

44 Neurotransmitters
Neurons are nerve cells that transfer information within the body. They may be degraded by enzymes. These are not the nerve signals that travel along axons, but they do have an effect that diffuses out of the cell. Channels open, and Na\(^+\) enters. Acetylcholine is a common neurotransmitter in vertebrates and invertebrates. Motor neurons are active in the CNS and PNS. At chemical synapses, a chemical neurotransmitter carries information across the synapse in the form of electrical signals.

Interneurons integrate the information. They are active in the CNS and PNS. Vertebrates have two major classes of acetylcholine receptor, one that is ligand gated and one that is metabotropic.

A single neurotransmitter may have more than a dozen different receptors. Neurons use two types of signals to communicate: electrical signals (long conduction velocity for moving action potentials) and chemical signals (short distance). The synaptic terminal of one axon passes information across the synapse in the form of neurotransmitters. Carries information into and out of the CNS. Motor neurons are active in the PNS. Sensory neurons are active in the CNS and Schwann cells in the PNS. There are more than 100 neurotransmitters, belonging to five groups: acetylcholine, biogenic amines, amino acids, neuropeptides, and gases. A single neurotransmitter may have more than a dozen different receptors.

Table 48.2

**Acetylcholine**

- Acetylcholine is a common neurotransmitter in vertebrates and invertebrates
- It is involved in muscle stimulation, memory formation, and learning
- Vertebrates have two major classes of acetylcholine receptor, one that is ligand gated and one that is metabotropic

**Amino Acids**

- Amino acid neurotransmitters are active in the CNS and PNS
- Known to function in the CNS are
  - Glutamate (most common NT)
  - Long term memory
  - Gamma-aminobutyric acid (GABA)
  - Glycine
- They are active in the CNS and PNS

**Biogenic Amines**

- Biogenic amines include
  - Epinephrine
  - Norepinephrine
  - Dopamine
  - Serotonin
- They are active in the CNS and PNS

**Neuropeptides**

- Several neuropeptides, relatively short chains of amino acids, also function as neurotransmitters
- Neuropeptides include substance P and endorphins, which both affect our perception of pain
- Opiates bind to the same receptors as endorphins and can be used as painkillers

**Gases**

- Gases such as nitric oxide and carbon monoxide are local regulators in the PNS

**Choose the correct pathway of information flow through neurons while taking a test, starting with reading a question and ending with marking an answer.**

A. interneurons → motor neurons → sensory neurons → effectors
B. effectors → sensory neurons → interneurons → motor neurons
C. sensory neurons → interneurons → motor neurons → effectors
D. interneurons → sensory neurons → motor neurons → effectors

**At step four in the graph, it is likely that**

A. most Cl\(^-\) channels closed.
B. most Na\(^+\) channels opened.
C. most K\(^+\) channels closed.
D. most K⁺ channels opened.
E. Na/K pumps were inactivated.

54 Of the following choices, the slowest conduction velocity for moving action potentials is likely seen in
A. a large-diameter, nonmyelinated axon.
B. a small-diameter, nonmyelinated axon.
C. A myelinated axon.
D. any of the above, as all neurons conduct action potentials at the same speed.

55 • The equilibrium potential \( E_{\text{ion}} \) is the membrane voltage for a particular ion at equilibrium and can be calculated using the Nernst equation

\[
E_{\text{ion}} = 62 \text{ mV} \left( \log [\text{ion}]_{\text{outside}}/[\text{ion}]_{\text{inside}} \right)
\]

• The equilibrium potential of K⁺ \( (E_K) \) is negative, while the equilibrium potential of Na⁺ \( (E_{Na}) \) is positive

• In a resting neuron, the currents of K⁺ and Na⁺ are equal and opposite, and the resting potential across the membrane remains steady