

Chapter 48: Neurons, Synapses, Signaling

1. What is a neuron?

Neurons are the nerve cells that transfer information within the body. Communication by neurons consists of long-distance electrical signals and short-distance chemical signals.

2. Neurons can be placed into three groups based on their location and function.

<i>type of neuron</i>	<i>function</i>
sensory neurons	transmit information from a sense receptor to the brain or spinal cord
interneurons	integrate information within brain or spinal cord; connect sensory and motor neurons; located entirely within CNS
motor neurons	transmit information from the brain or spinal cord to a muscle or gland; cause muscle contraction or gland secretion

3. Which division of the nervous system includes the brain and spinal cord?

The central nervous system (CNS) includes the brain and a longitudinal nerve cord. The neurons that carry information into and out of the CNS constitute the peripheral nervous system (PNS).

7. What are glial cells?

The neurons of vertebrates and most invertebrates require supporting cells called glial cells, or glia, which nourish neurons, insulate the axons of neurons, and regulate the extracellular fluid surrounding neurons.

8. All cells have a membrane potential across their plasma membrane. What is the typical resting potential of a neuron?

Because the attraction of opposite charges across the plasma membrane is a source of potential energy, this charge difference, or voltage, is called the membrane potential. The membrane potential of a resting neuron – one that is not sending a signal – is its resting potential and is typically between -60 and -80 mV.

10. How are the concentration gradients of Na^+ and K^+ maintained?

Concentration gradients of sodium and potassium are maintained by sodium-potassium pumps in the plasma membrane. These ion pumps use the energy of ATP hydrolysis to actively transport Na^+ out of the cell and K^+ into the cell.

11. What is the increase in the magnitude of membrane potential called?

When gated potassium channels that are closed in a resting neuron are stimulated to open, the membrane's permeability to K^+ is increased. Net diffusion of K^+ out of the neuron increases, shifting the membrane potential toward E_{K} (equilibrium potential for potassium). This increase in the magnitude of the membrane potential, called hyperpolarization, makes the inside of the membrane more negative. In a resting neuron, hyperpolarization results from any stimulus that increases the outflow of positive ions or the inflow of negative ions. Although opening potassium channels in a resting neuron causes hyperpolarization, opening some other types of ion channels has an opposite effect, making the inside of the membrane less negative. A reduction in the magnitude of the membrane potential is called a depolarization. Depolarization often involves gated sodium channels. If a stimulus causes the gated sodium channels in a resting neuron to open, the membrane's permeability to Na^+ increases. Na^+ diffuses into the cell along its concentration gradient, causing a depolarization as the membrane potential shifts toward E_{Na} .

12. A wave of depolarization will follow if depolarization causes the membrane potential to drop to which critical value?

Sometimes, the response to hyperpolarization or depolarization is simply a shift in the membrane potential. This shift, called a graded potential, has a magnitude that varies with the strength of the stimulus, with a large stimulus causing a greater change in the membrane potential. Graded potentials decay with distance from their source. If depolarization shifts the membrane potential sufficiently, the result is a massive change in membrane voltage called an action potential.

Unlike graded potentials, action potentials have a constant magnitude and can regenerate in adjacent regions of the membrane. Action potentials occur whenever a depolarization increases the membrane to a particular value, called the threshold.

13. *What is the wave of depolarization called?*

Action potentials arise because some of the ion channels in neurons are voltage-gated ion channels, opening or closing when the membrane potential passes a particular level. If a depolarization opens voltage-gated sodium channels, the resulting flow of Na^+ into the neuron results in further depolarization. Because the sodium channels are voltage gated, an increased depolarization causes more sodium channels to open, leading to an even greater flow of current. The result is a process of positive feedback that triggers a very rapid opening of all voltage-gated sodium channels and the marked change in membrane potential that defines an action potential.

14. *What is the response of neurons to stimulus called?*

Once initiated, the action potential has a magnitude that is independent of the strength of the triggering stimulus. Because action potentials occur fully or not at all, they represent an all-or-none response to stimuli.

15. *What triggers depolarization? How is the charge on the membrane reestablished in repolarization?* 

First, the gated Na^+ and K^+ channels are closed. Ungated channels maintain the resting potential. Second, a stimulus opens some sodium channels. Na^+ inflow through those channels depolarizes the membrane. If the depolarization reaches the threshold, it triggers action potential. Third, depolarization opens most sodium channels, while the potassium channels remain closed. Na^+ influx makes the inside of the membrane positive with respect to the outside. Fourth, most sodium channels become inactivated, blocking Na^+ inflow. Most potassium channels open, permitting K^+ outflow, which makes the inside of the cell negative again. Fifth, the sodium channels close, but some potassium channels are still open. As these potassium channels close and the sodium channels become unblocked (though still closed), the membrane returns to its resting state.

16. *Explain how the action potential is conducted.* 

First, an action potential is generated as Na^+ flows inward across the membrane at one location. Second, the depolarization of the action potential spreads to the neighboring region of the membrane, reinitiating the action potential there. To the left of this region, the membrane is repolarizing as K^+ flows outward. Third, the depolarization-repolarization process is repeated in the next region of the membrane. In this way, local currents of ions across the plasma membrane cause the action potential to be propagated along the length of the axon.

17. *What are the two types of glial cells that produce myelin sheaths?*

The electrical insulation that surrounds vertebrate axons is called a myelin sheath. Myelin sheaths are produced by two types of glia: oligodendrocytes in the CNS and Schwann cells in the PNS.

18. *How does a myelin sheath speed impulse transmission?*

In myelinated axons, voltage-gated sodium channels are restricted to gaps in the myelin sheath called nodes of Ranvier. The extracellular fluid is in contact with the axon membrane only at the nodes. As a result, action potentials are not generated in the regions between the nodes. Rather, the inward current produced during the rising phase of the action potential at a node travels all the way to the next node, where it depolarizes the membrane and regenerates the action potential. Thus, the time-consuming process of opening and closing of ion channels occurs at only a limited number of positions along the axon. This mechanism for action potential propagation is called salutatory conduction because the action potential appears to jump along the axon from node to node. A major selective advantage of myelination is its space efficiency.

19. *In the disease multiple sclerosis, the myelin sheaths harden and deteriorate. What is the effect on nervous system function?*

The hardening and deterioration of myelin sheaths lead to muscle paralysis through a disruption in neuron function.

20. *What occurs to the synaptic vesicles as the Ca^{2+} level increases?*

The majority of synapses are chemical synapses, which involve the release of a chemical neurotransmitter by the presynaptic neuron. At each terminal, the presynaptic neuron synthesizes the neurotransmitter and packages it in multiple membrane-bound compartments called synaptic vesicles. The arrival of an action potential at a synaptic terminal depolarizes the plasma membrane, opening voltage-gated channels that allow Ca^{2+} to diffuse into the terminal. The

resulting rise in Ca^{2+} concentration in the terminal causes some of the synaptic vesicles to fuse with the terminal membrane, releasing the neurotransmitter.

21. *What is contained within the synaptic vesicles?*

Neurotransmitters are contained in the synaptic vesicles.

23. *Explain how an action potential is transmitted from one cell to another across a synapse in four steps.* ✍

First, an action potential arrives, depolarizing the presynaptic membrane. Next, the depolarization opens voltage-gated channels, triggering an influx of Ca^{2+} . Third, the elevated Ca^{2+} concentration causes synaptic vesicles to fuse with the presynaptic membrane, releasing neurotransmitter into the synaptic cleft. Finally, the neurotransmitter binds to ligand-gated ion channels in the postsynaptic membrane. In this example, binding triggers opening, allowing Na^+ and K^+ to diffuse through.

24. *Are neurotransmitters that hyperpolarize the postsynaptic membrane excitatory or inhibitory neurotransmitters?*

At some synapses, the ligand-gated ion channel is permeable to both K^+ and Na^+ . When this channel opens, the membrane potential depolarizes toward a value roughly midway between E_{K} and E_{Na} . Because such a depolarization brings the membrane potential toward threshold, it is called an excitatory postsynaptic potential (EPSP). At other synapses, the ligand-gated ion channel is selectively permeable for only K^+ or Cl^- . When such a channel opens, the postsynaptic membrane hyperpolarizes. A hyperpolarization produced in this manner is an inhibitory postsynaptic potential (IPSP) because it moves the membrane potential further from the threshold.

25. *Define and explain summation.*

On some occasions, two EPSPs occur at a single synapse in such rapid succession that the postsynaptic neuron's membrane potential has not returned to the resting potential before the arrival of the second EPSP. When that happens, the EPSPs add together, an effect called temporal summation. Moreover, EPSPs produced nearly simultaneously by different synapses on the same postsynaptic neuron can also add together, an effect called spatial summation. Through spatial and temporal summation, several EPSPs can combine to depolarize the membrane at the axon hillock to the threshold, causing the postsynaptic neuron to produce an action potential. Summation applies as well to IPSPs: Two or more IPSPs occurring nearly simultaneously at synapses in the same region or in rapid succession at the same synapse have a larger hyperpolarizing effect than a single IPSP. Through summation, an IPSP can counter the effect of an EPSP.

26. *What will determine whether an action potential is generated in the postsynaptic neuron?*

Through spatial and temporal summation, several EPSPs can combine to depolarize the membrane at the axon hillock to the threshold, causing the postsynaptic neuron to produce an action potential.

27. *List several of the major neurotransmitters.*

Researchers have identified more than 100 neurotransmitters belonging to five groups: acetylcholine, amino acids, biogenic amines, neuropeptides, and gases. Major neurotransmitters include acetylcholine, epinephrine, norepinephrine, dopamine, serotonin, GABA, glutamate, glycine, substance P, endorphins, and nitric oxide.

28. *What is the most common neurotransmitter in both vertebrates and invertebrates?*

Acetylcholine is the most common neurotransmitter in both invertebrates and vertebrates.