Overview: Lines of Communication

- The cone snail kills prey with venom that disables neurons
- **Neurons** are nerve cells that transfer information within the body
- Neurons use two types of signals to communicate: electrical signals (long-distance) and chemical signals (short-distance)

Concept 48.1: Neuron organization and structure reflect function in information transfer

- Nervous systems process information in three stages:
  - sensory input
  - Integration
  - and motor output

Fig 48-3

- Many animals have a complex nervous system which consists of:
  - A **central nervous system (CNS)** where integration takes place; this includes the brain and a nerve cord
  - A **peripheral nervous system (PNS)**, which brings information into and out of the CNS
Nerve tissues are made of neurons and glia

Most neurons are nourished or insulated by cells called glia

Neuron Structure and Function

Most of a neuron’s organelles are in the cell body

Most neurons have dendrites, highly branched extensions that receive signals from other neurons

The axon is typically a much longer extension that transmits signals to other cells at synapses

An axon joins the cell body at the axon hillock

Sensory Neurons

Sensors detect external stimuli and internal conditions and transmit information along sensory neurons

Integration Neurons

Sensory information is sent to the brain or ganglia, where interneurons integrate the information

Motor Neurons

Motor output leaves the brain or ganglia via motor neurons, which trigger muscle or gland activity

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A synapse is a junction between an axon and another cell

The synaptic terminal of one axon passes information across the synapse in the form of chemical messengers called neurotransmitters
Information is transmitted from a **presynaptic cell** (a neuron) to a **postsynaptic cell** (a neuron, muscle, or gland cell)

### Concept 48.2: Ion pumps and ion channels maintain the resting potential of a neuron

- Every cell has a voltage (difference in electrical charge) across its plasma membrane called a **membrane potential**
- Messages are transmitted as changes in membrane potential
- The **resting potential** is the membrane potential of a neuron not sending signals

### Formation of the Resting Potential

- In a mammalian neuron at resting potential, the concentration of K⁺ is greater inside the cell, while the concentration of Na⁺ is greater outside the cell
- Sodium-potassium pumps use the energy of ATP to maintain these K⁺ and Na⁺ 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
- Anions trapped inside the cell contribute to the negative charge within the neuron

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**K⁺**

**Na⁺**

**Cl⁻**

**Outward Chloride**

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**K⁺**

**Na⁺**

**Cl⁻**

**Outward Chloride**
Modeling of 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 builds up in the inner chamber
- At equilibrium, both the electrical and chemical gradients are balanced

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

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

- 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.
Concept 48.3: Action potentials are the signals conducted by axons

- Neurons contain \textit{gated ion channels} that open or close in response to stimuli
- Membrane potential changes in response to opening or closing of these channels
- \textbf{Graded potentials} are changes in polarization where the magnitude of the change varies with the strength of the stimulus

- When gated K\textsuperscript{+} channels open, K\textsuperscript{+} diffuses out, making the inside of the cell more negative
- This is \textbf{hyperpolarization}, an increase in magnitude of the membrane potential

- Other stimuli trigger a \textbf{depolarization}, a reduction in the magnitude of the membrane potential
- For example, depolarization occurs if gated Na\textsuperscript{+} channels open and Na\textsuperscript{+} diffuses into the cell

- An action potential occurs if a stimulus causes the membrane voltage to cross a particular \textbf{threshold}
- An action potential is a brief all-or-none depolarization of a neuron's plasma membrane
- Action potentials are signals that carry information along axons
**Generation of Action Potentials: A Closer Look**

- A neuron can produce hundreds of action potentials per second.
- The frequency of action potentials can reflect the strength of a stimulus.
- An action potential can be broken down into a series of stages.

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**Fig. 48-10-1**

1. Most voltage-gated Na⁺ and K⁺ channels are closed, but some K⁺ channels (not voltage-gated) are open.

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**Fig. 48-10-2**

2. Depolarization
   - Voltage-gated Na⁺ channels open first and Na⁺ flows into the cell.

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**Fig. 48-10-3**

3. During the rising phase or the threshold is crossed, and the membrane potential increases.

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**Fig. 48-10-4**

4. During the falling phase, voltage-gated Na⁺ channels become inactivated; voltage-gated K⁺ channels open, and K⁺ flows out of the cell.
5. During the **undershoot**, membrane permeability to K⁺ is at first higher than at rest, then voltage-gated K⁺ channels close; resting potential is restored

- 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

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**Conduction of Action Potentials**

- An action potential can travel long distances by regeneration itself along the axon
- At the site where the action potential is generated, usually the axon hillock, an electrical current depolarizes the neighboring region of the axon membrane

- Inactivated Na⁺ channels behind the zone of depolarization prevent the action potential from traveling backwards
- Action potentials travel in only one direction: toward the synaptic terminals

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![Fig 48-11a](image1.png)

![Fig 48-11b](image2.png)
**Conduction Speed**

- 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

**Concept 48.4: Neurons communicate with other cells at synapses**

- At electrical synapses, the electrical current flows from one neuron to another across the gap junction
- At chemical synapses, a chemical neurotransmitter carries information. 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.

### 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.

### Postsynaptic Potentials

- 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.

### Summation of Postsynaptic Potentials

- After release, the neurotransmitter:
  - May diffuse out of the synaptic cleft.
  - May be taken up by surrounding cells.
  - May be degraded by enzymes.

- Unlike action potentials, postsynaptic potentials are graded and do not regenerate.
- 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.
- If two EPSPs are produced in rapid succession, an effect called **temporal summation** occurs.
Modulated Synaptic Transmission

- In indirect synaptic transmission, a neurotransmitter binds to a receptor that is not part of an ion channel.
- This binding activates a signal transduction pathway involving a second messenger in the postsynaptic cell.
- Effects of indirect synaptic transmission have a slower onset but last longer.

Neurotransmitters

- The same neurotransmitter can produce different effects in different types of cells.
- There are five major classes of neurotransmitters: acetylcholine, biogenic amines, amino acids, neuropeptides, and gases.
### Table 48.1a: Major Neurotransmitters

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<th>Structure</th>
<th>Functional Class</th>
<th>Secretion Sites</th>
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#### Anatomical Amines

- GABA (γ-aminobutyric acid)
- Dopamine
- Norepinephrine
- Serotonin

#### Neuropeptides (a very large group; only two of which are shown)

- Substance P
- Met-enkephalin

### Table 48.1b: Major Neurotransmitters

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