Chapter 48

Neurons, Synapses, and Signaling

PowerPoint® Lecture Presentations for

Biology

Eighth Edition

Neil Campbell and Jane Reece

Lectures by Chris Romero, updated by Erin Barley with contributions from Joan Sharp

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Key concepts

1. Excitable membrane of neuronal cells makes signaling possible.
2. Synapse is the fundamental unit of information processing in the nervous system.

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Fig. 48-1

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Overview: Lines of Communication

- **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)

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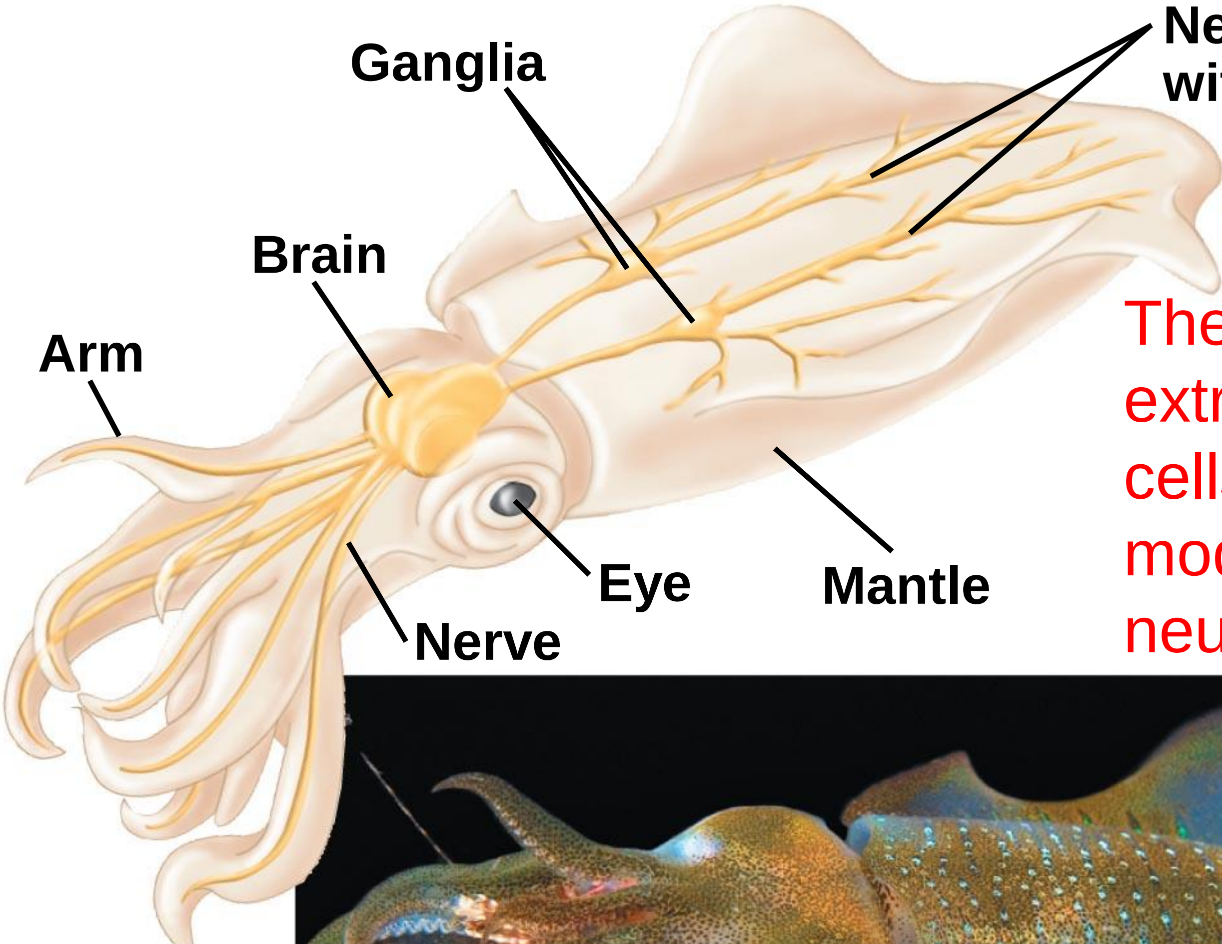
Fig. 48-2



The squid possesses extremely large nerve cells and is a good model for studying neuron function

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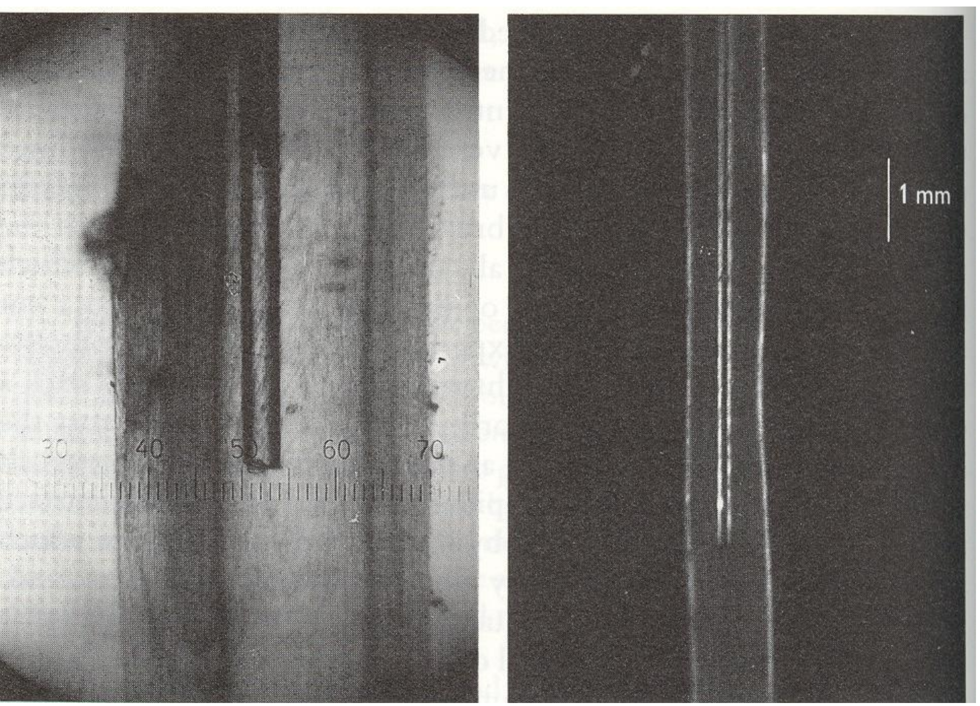
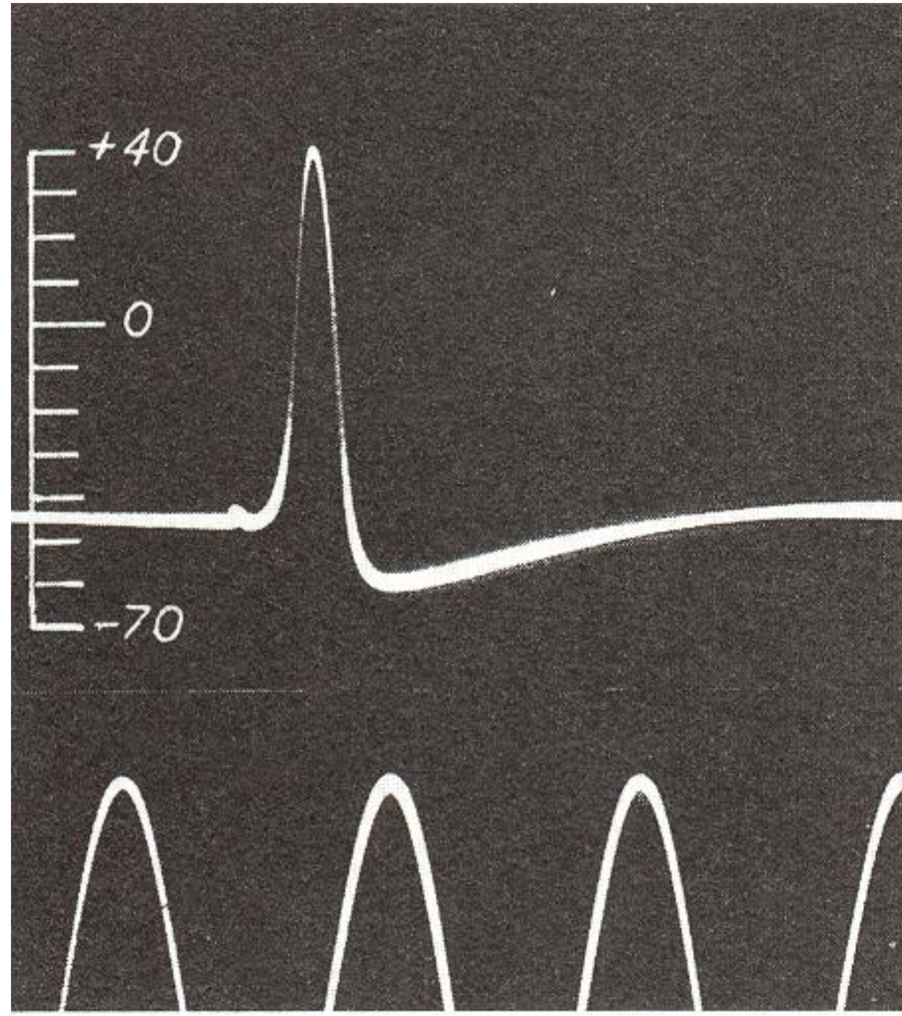
Hodgkin, Huxley and Ionic Basis of Action Potential

Alan Hodgkin

Andrew Huxley



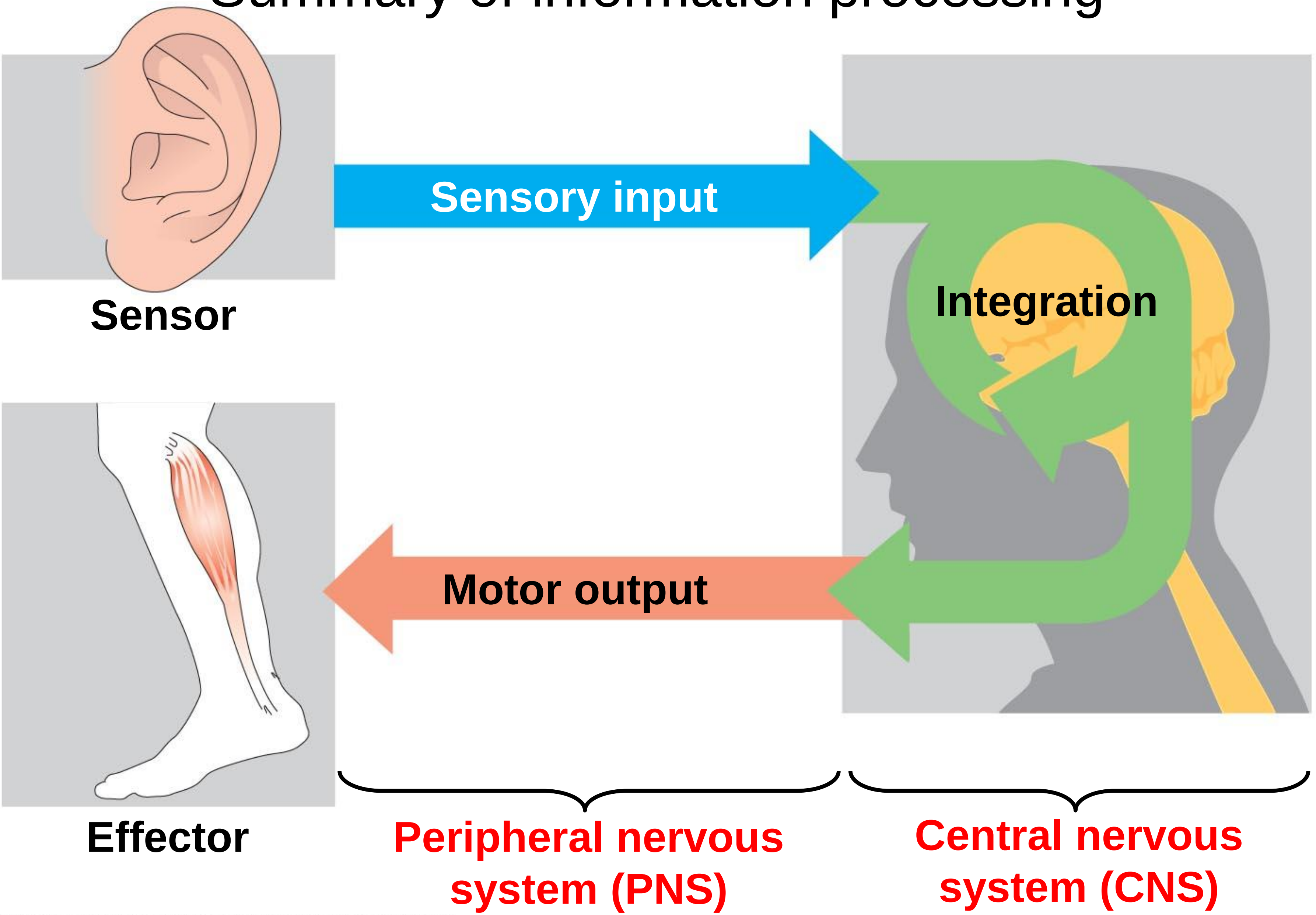
Recording electrode inside squid giant axon



Resting potential and action potential recorded between inside and outside of the axon with capillary filled with sea water (1939)

Fig. 48-3

Summary of information processing



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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**

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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**

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- Information is transmitted from a **presynaptic cell** (a neuron) to a **postsynaptic cell** (a neuron, muscle, or gland cell)

- Most neurons are nourished or insulated by cells called **glia**

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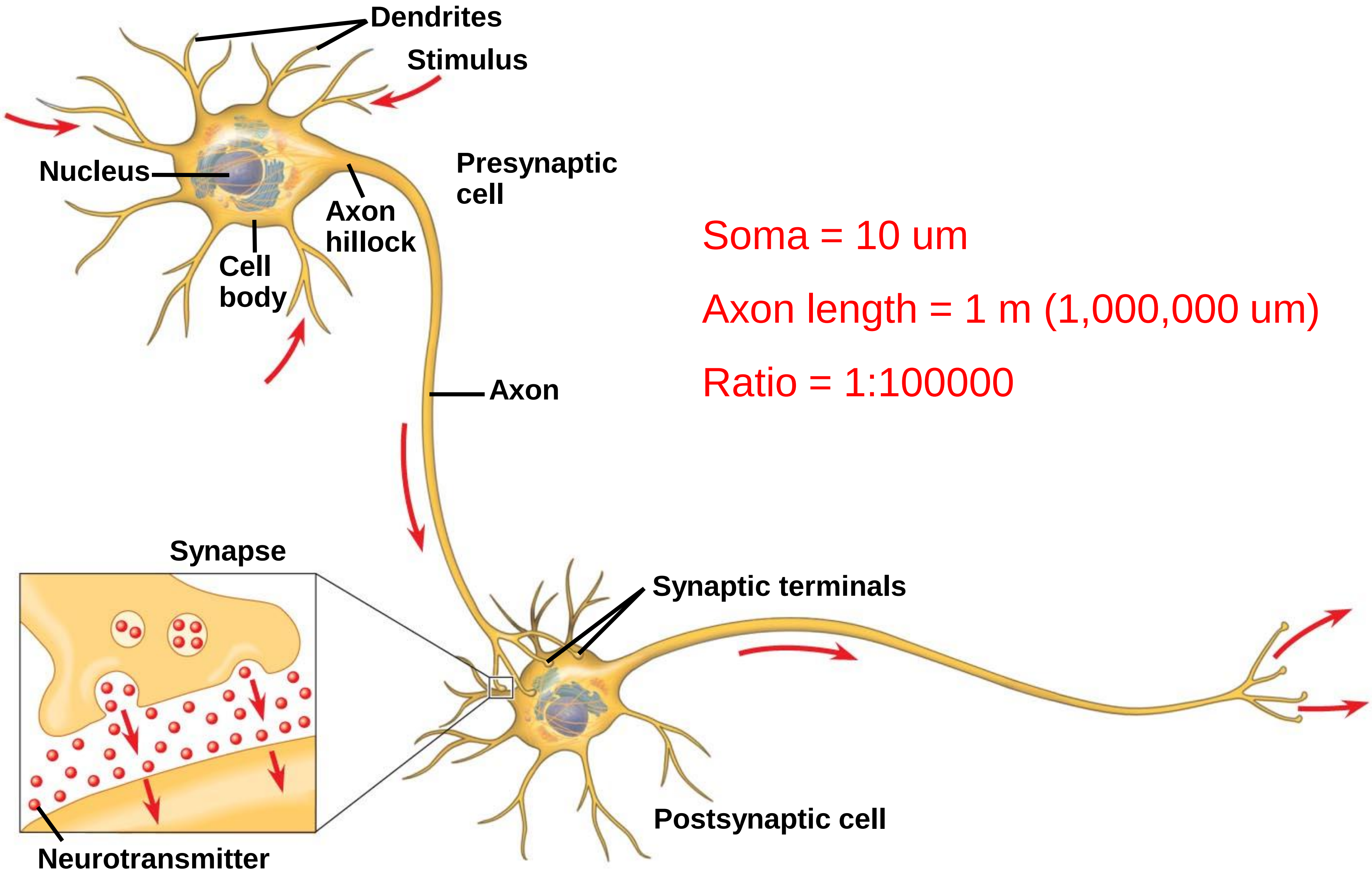
Fig. 48-4

Neuron structure and organization



Soma = 10 um

Axon length = 1 m (1,000,000 um)

Ratio = 1:100000

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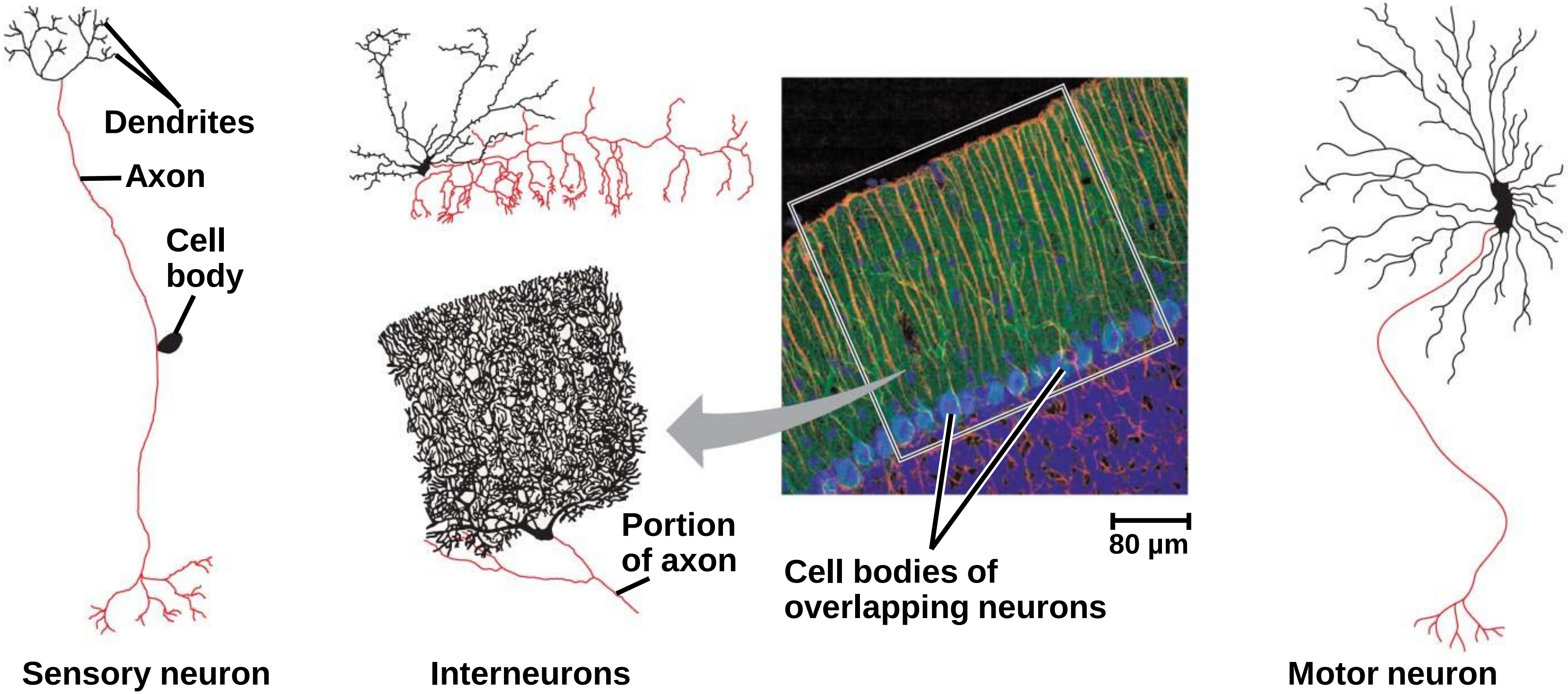
Fig. 48-5

Structural diversity of neurons



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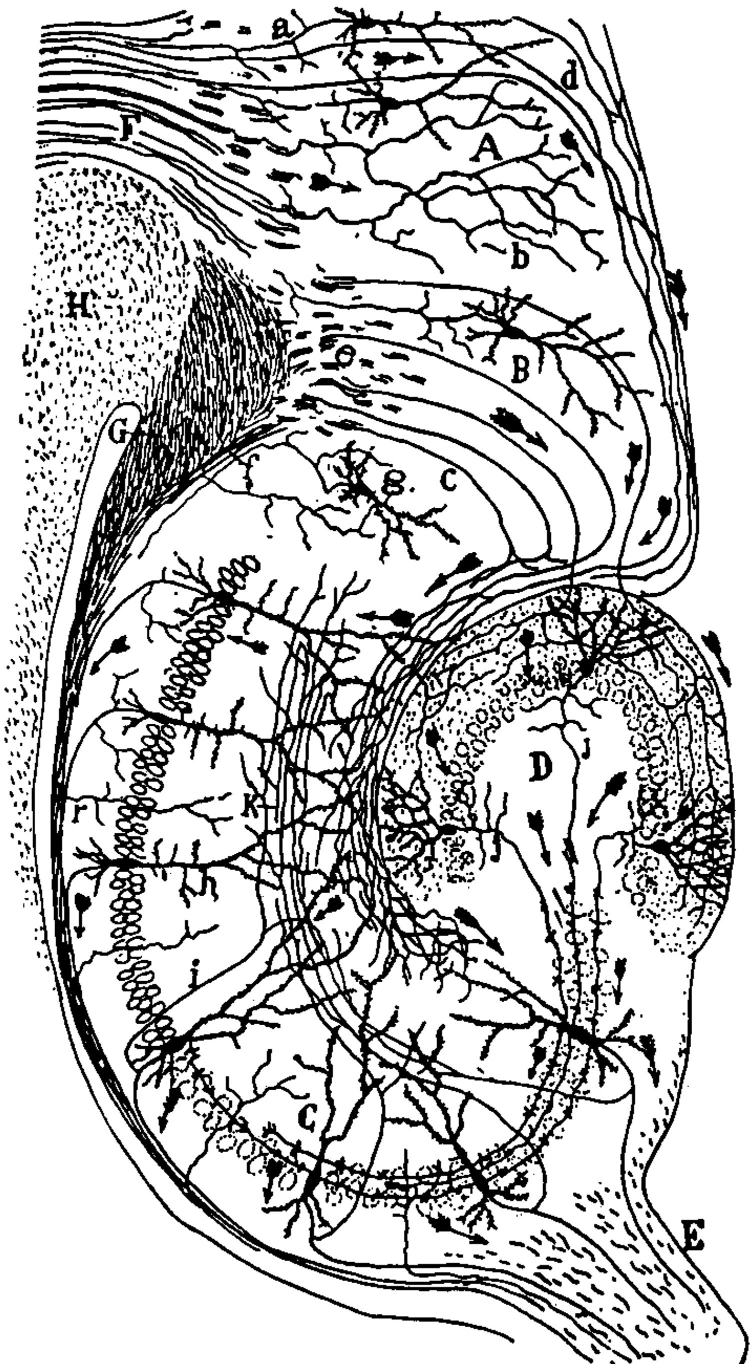

Ramon y Cajal’s illustration of the circuits in the hippocampus

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 ("**excitable**")

- The **resting potential** is the membrane potential of a neuron not sending signals

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Fig. 48-6

The basis of the membrane potential

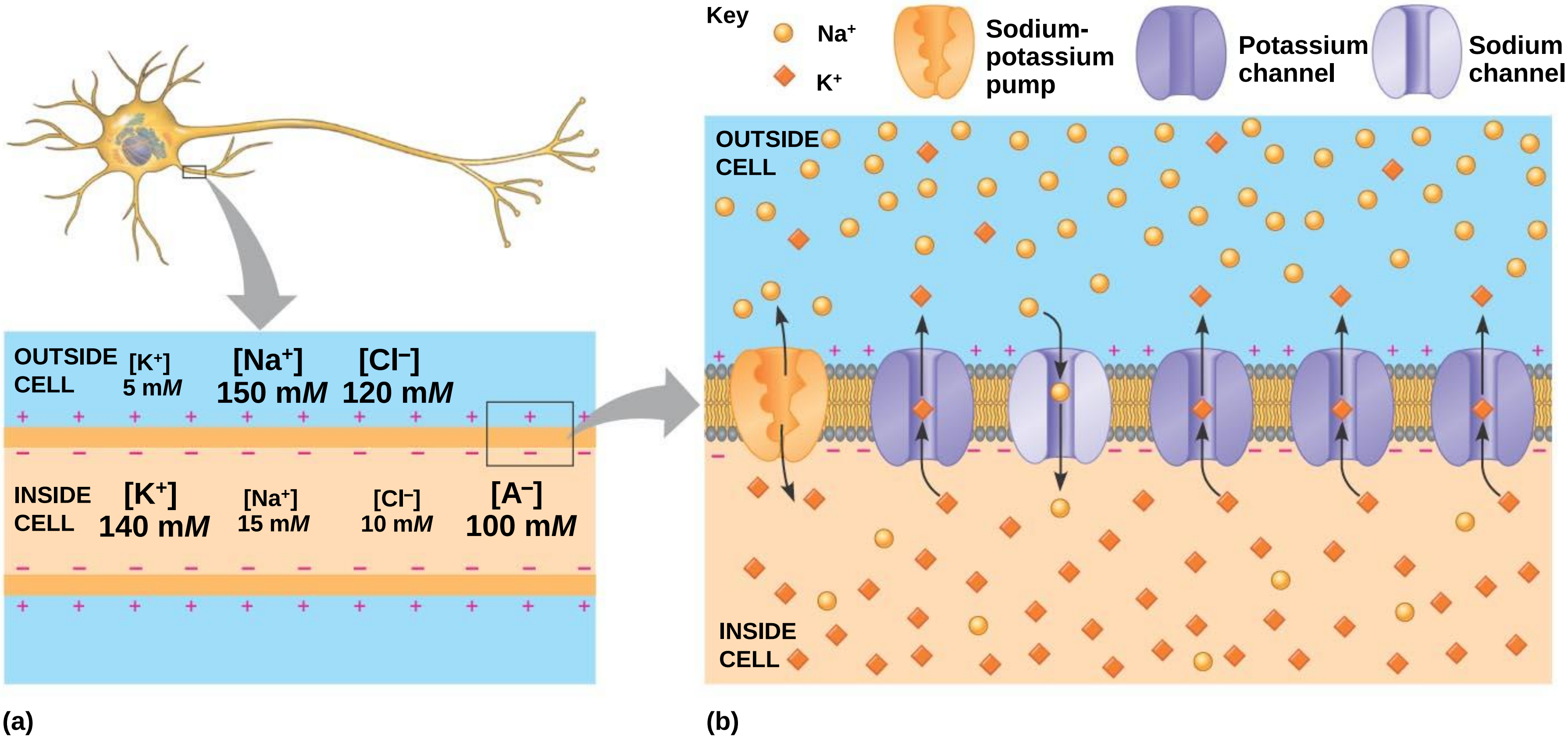

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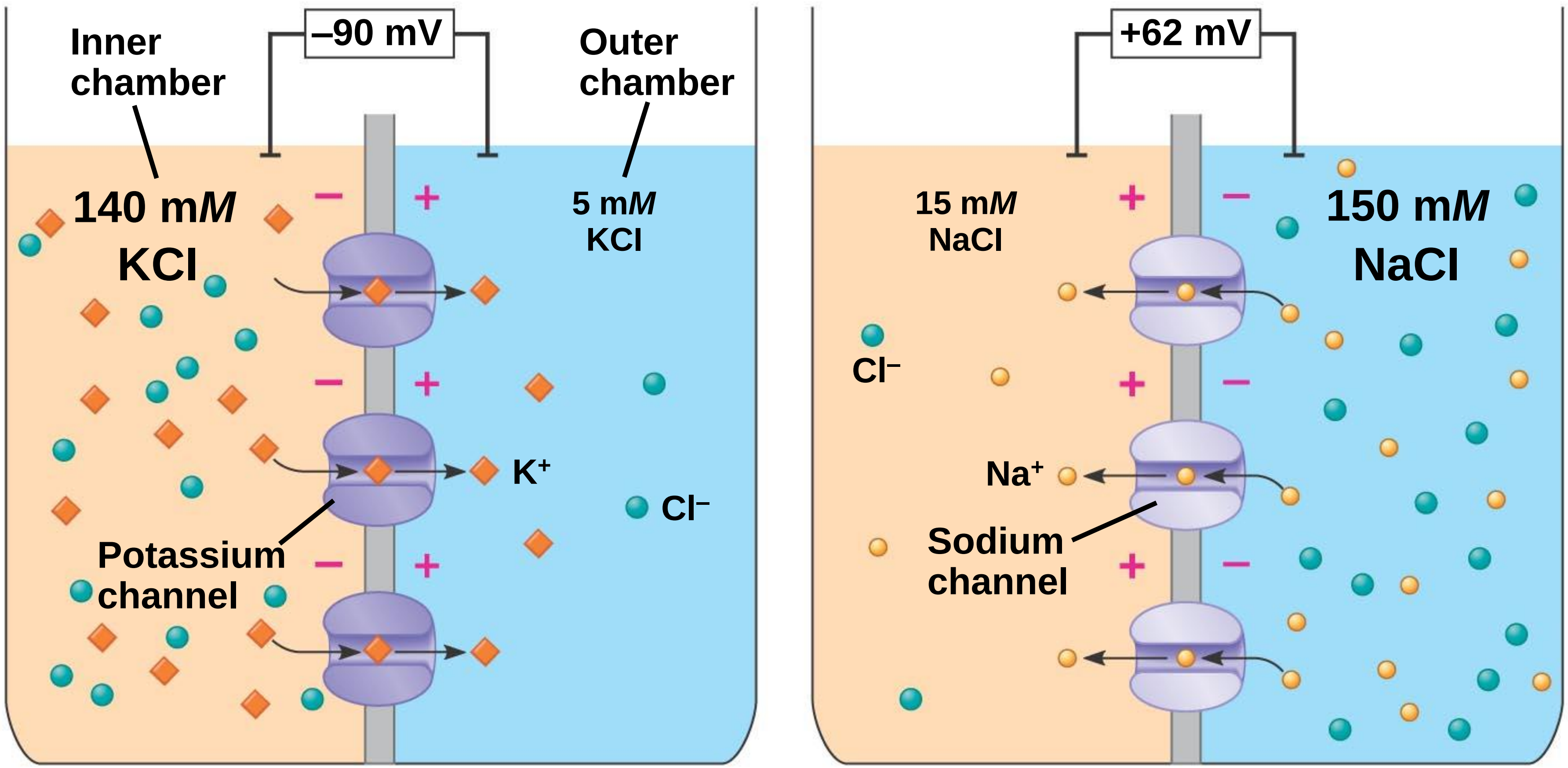
Fig. 48-7

Modeling a mammalian neuron



(a) Membrane selectively permeable to K^+

(b) Membrane selectively permeable to Na^+

$$E_K = 62\text{ mV}\left(\log\frac{5\text{ m}M}{140\text{ m}M}\right) = -90\text{ mV}$$

$$E_{Na} = 62\text{ mV}\left(\log\frac{150\text{ m}M}{15\text{ m}M}\right) = +62\text{ mV}$$

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Fig. 48-8

Intracellular recording

TECHNIQUE

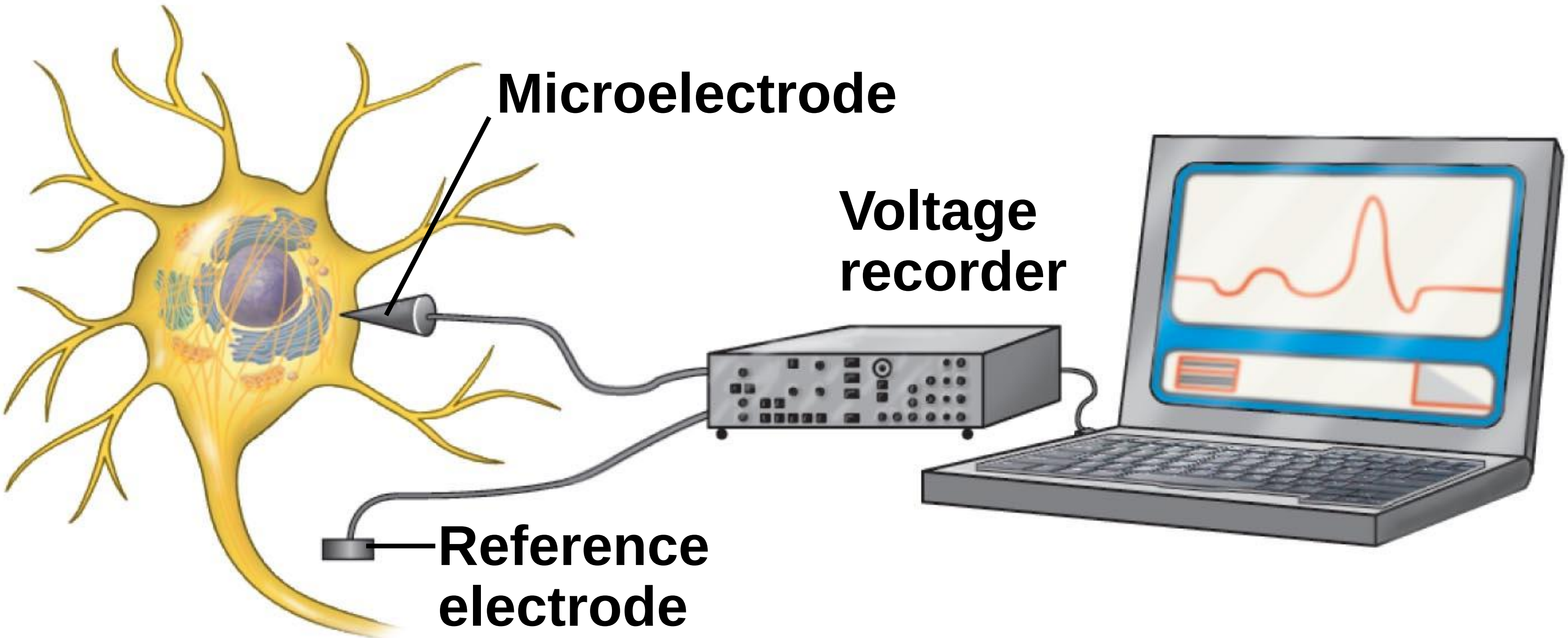

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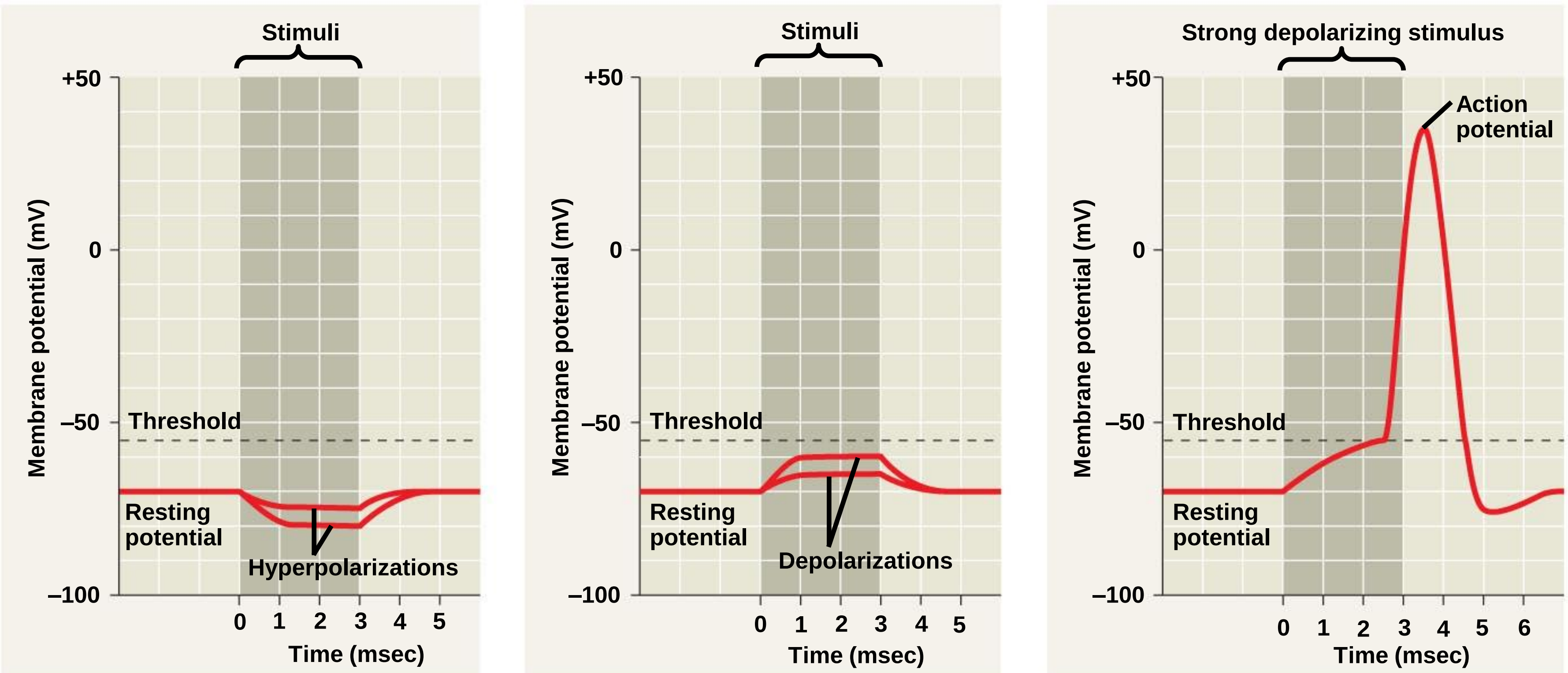
Fig. 48-9

Graded potentials and an action potential in a neuron



(a) Graded hyperpolarizations **(b) Graded depolarizations** **(c) Action potential**

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- An action potential occurs if a stimulus causes the membrane voltage to cross a particular **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 (“**firing frequency**”)

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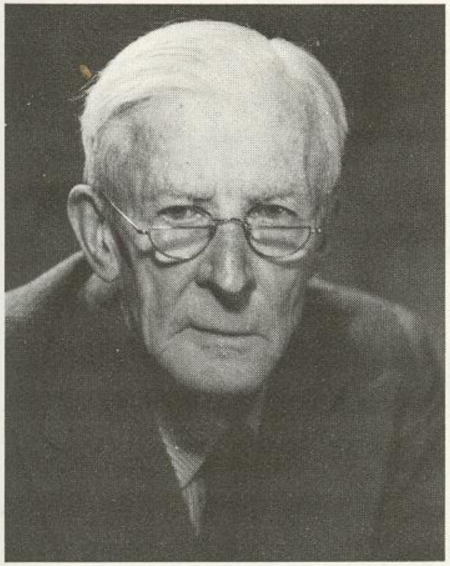
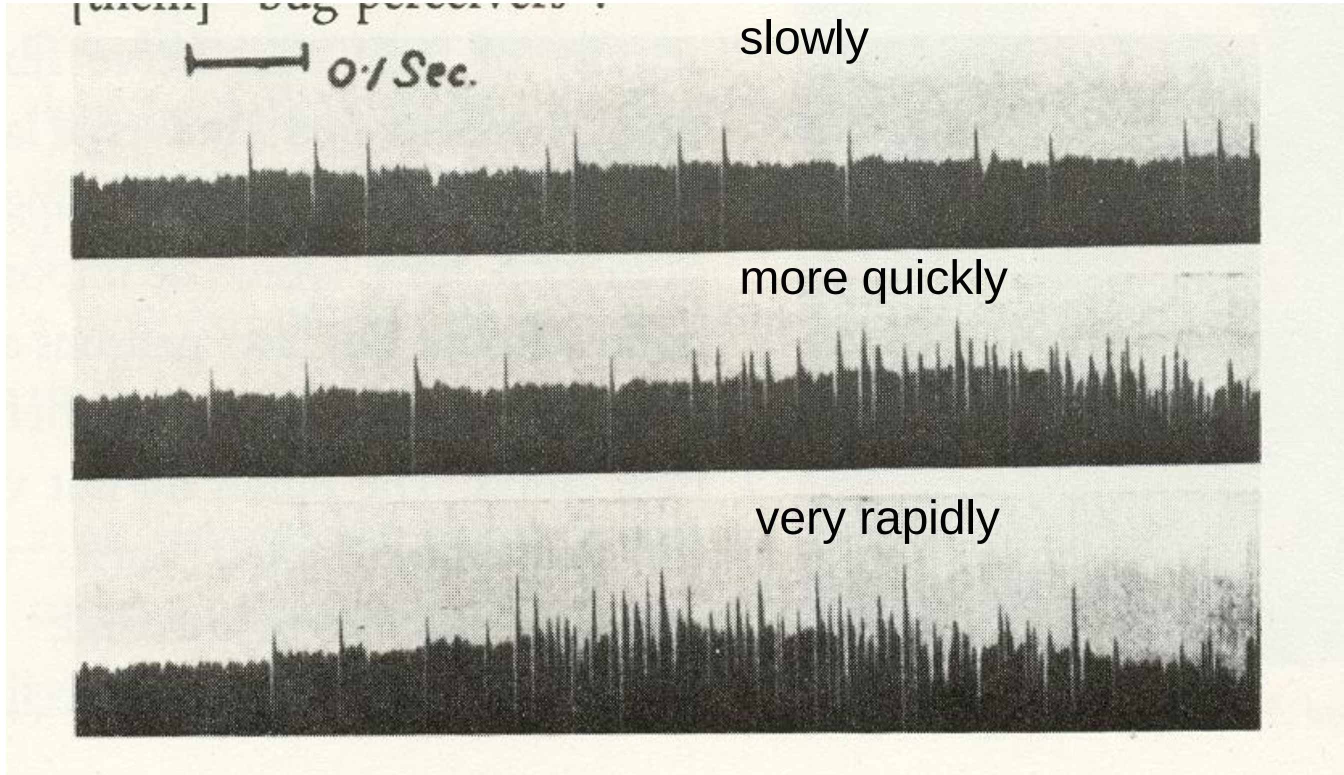


Lord Adrian of Cambridge.

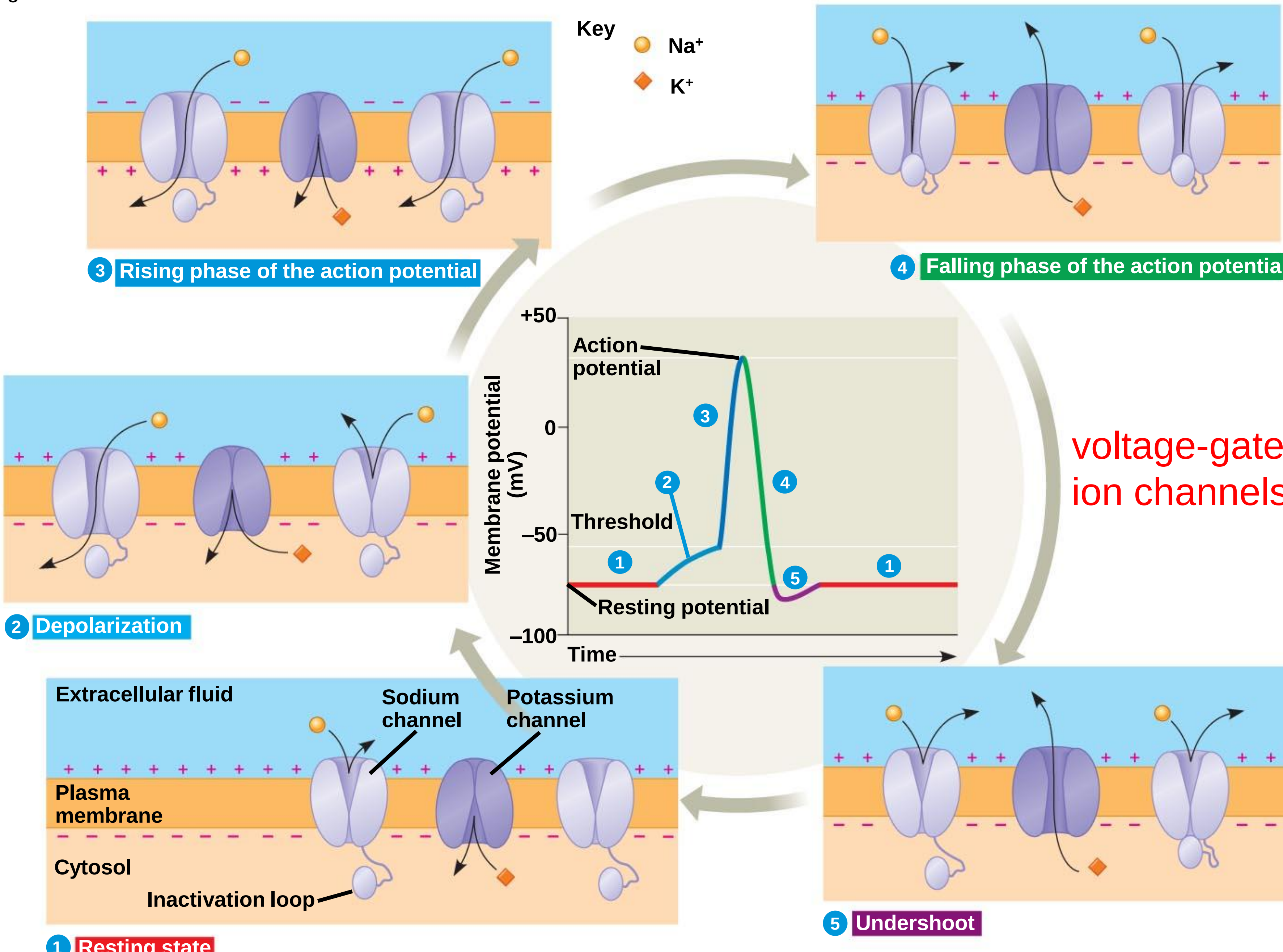


Some of Adrian's first recordings from a very small number of nerve fibers in the sensory nerves of cat's toe (1926).

Adrian's Laws: 1. The nerve impulse (action potential) is "all-or-none"

2. The strength of stimulus is coded by the firing frequency

Fig. 48-10-5



voltage-gated ion channels

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- 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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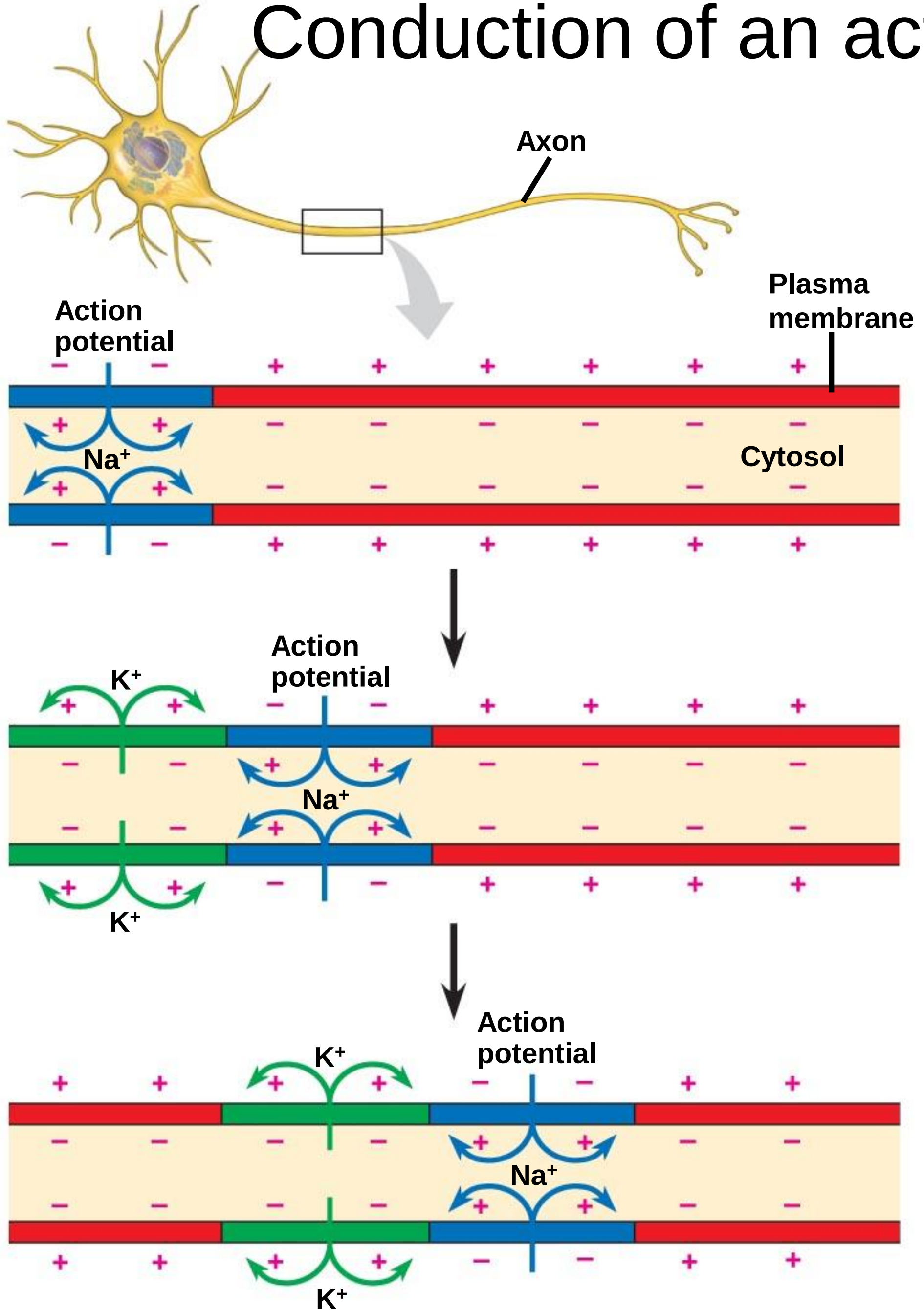
Fig. 48-11-3

Conduction of an action potential



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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

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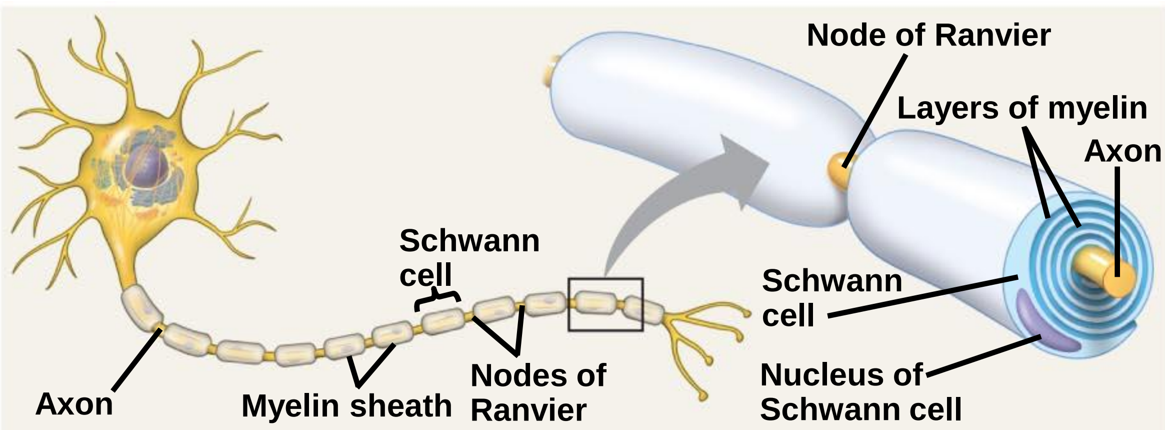
Fig. 48-12

Schwann cells and the myelin sheath



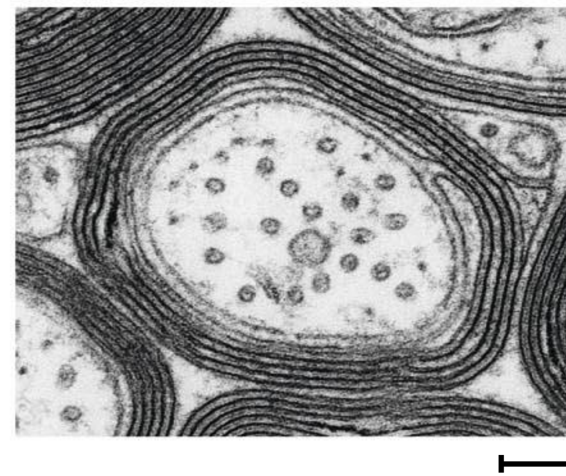


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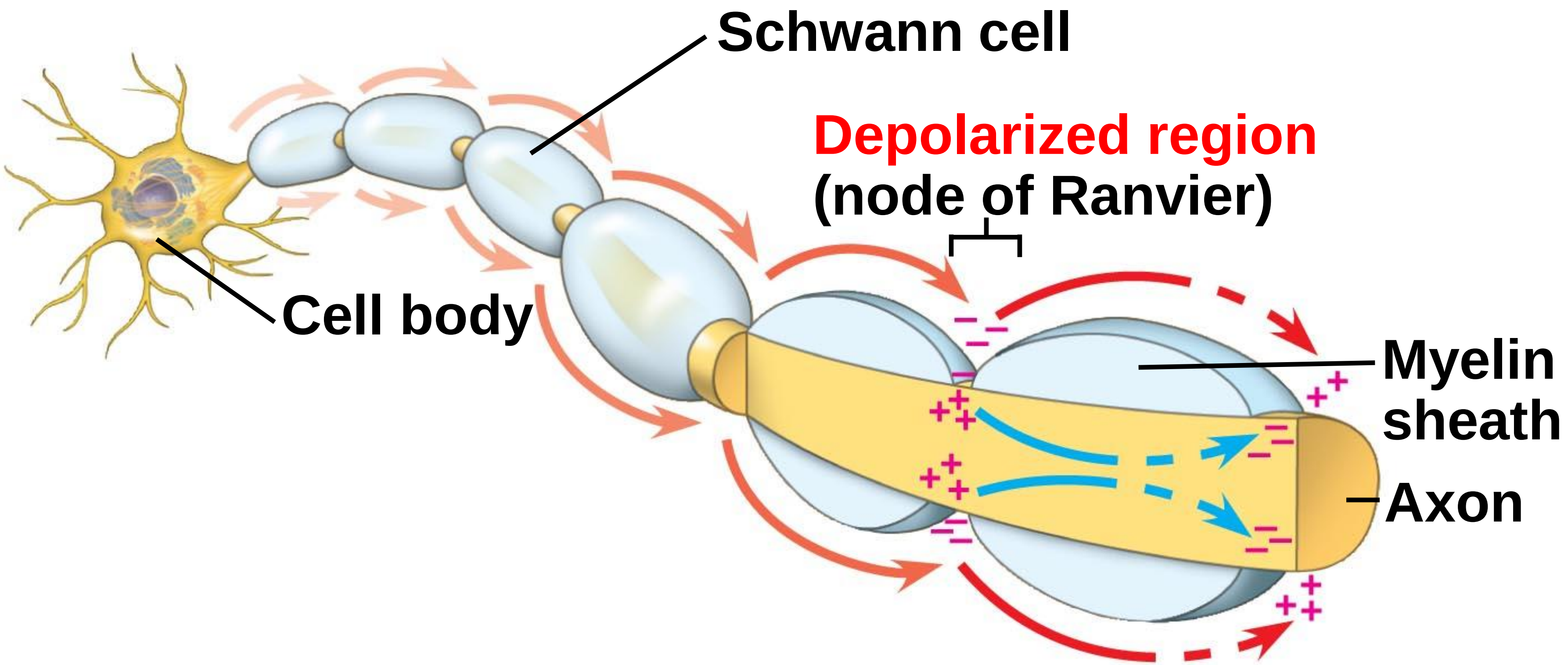
Fig. 48-13

Saltatory conduction



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Concept 48.4: Neurons communicate with other cells at synapses

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

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Fig. 48-14

Synaptic terminals on the cell body of a postsynaptic neuron

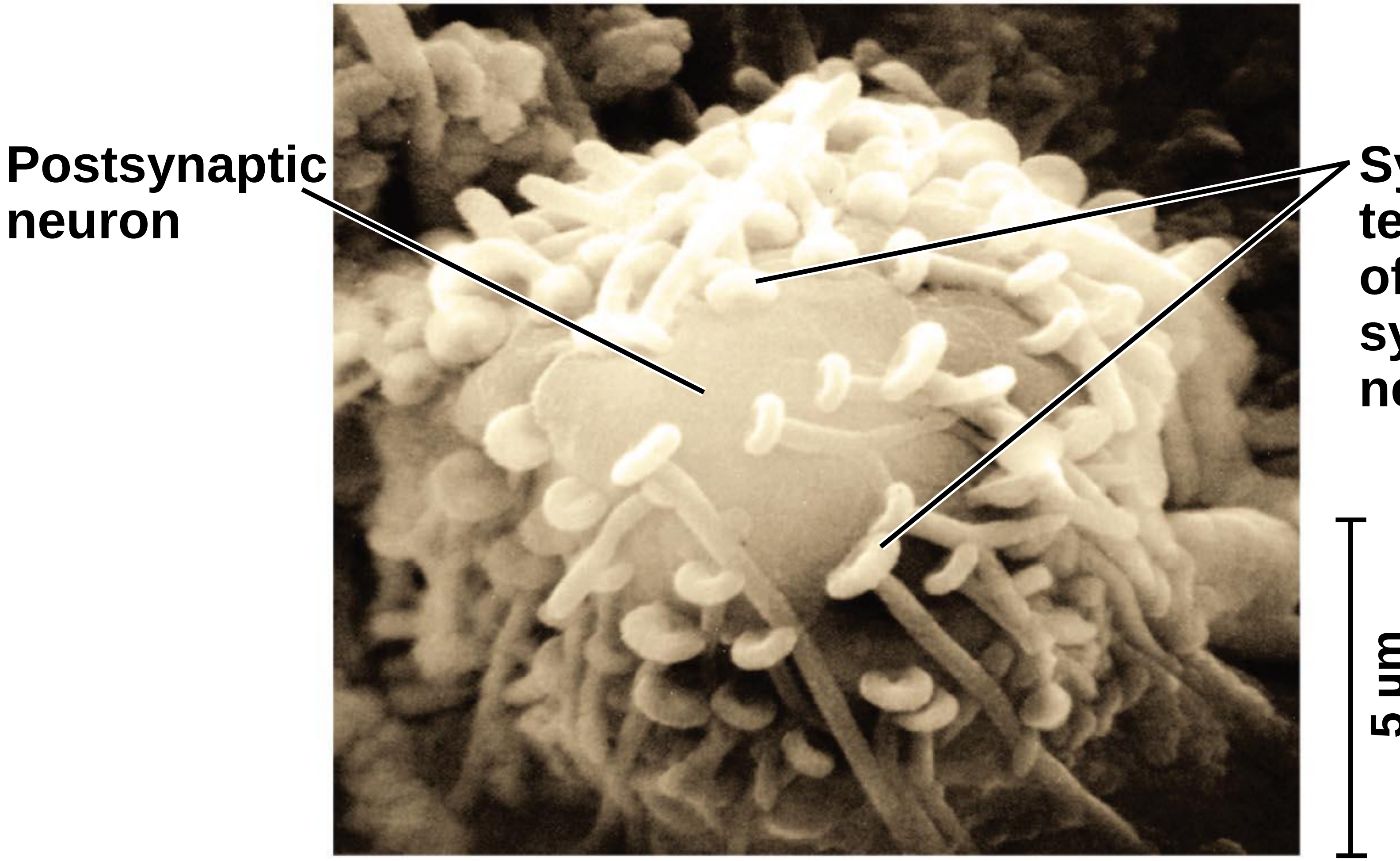

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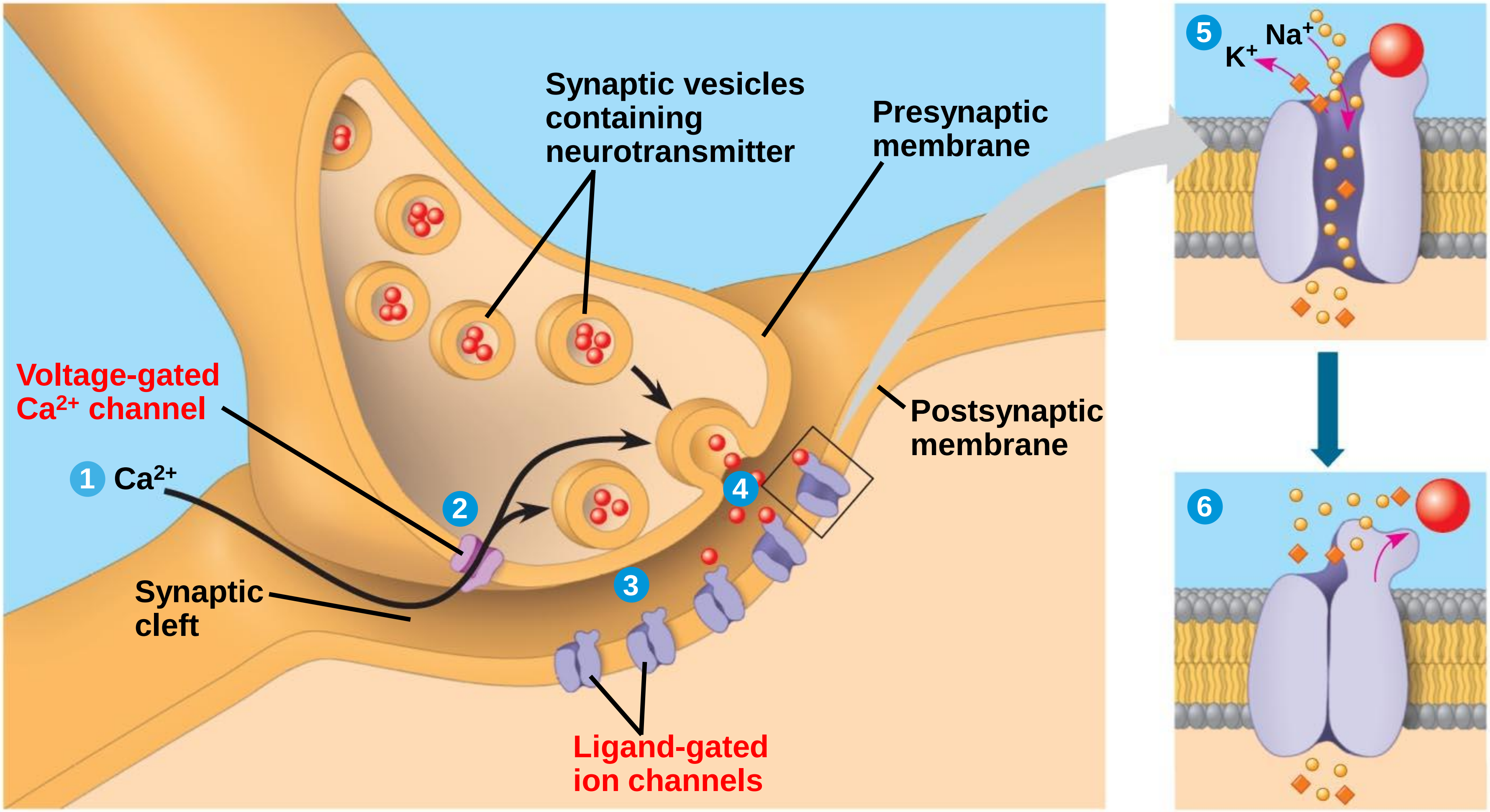
Fig. 48-15

A chemical synapse



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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*

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- 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

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

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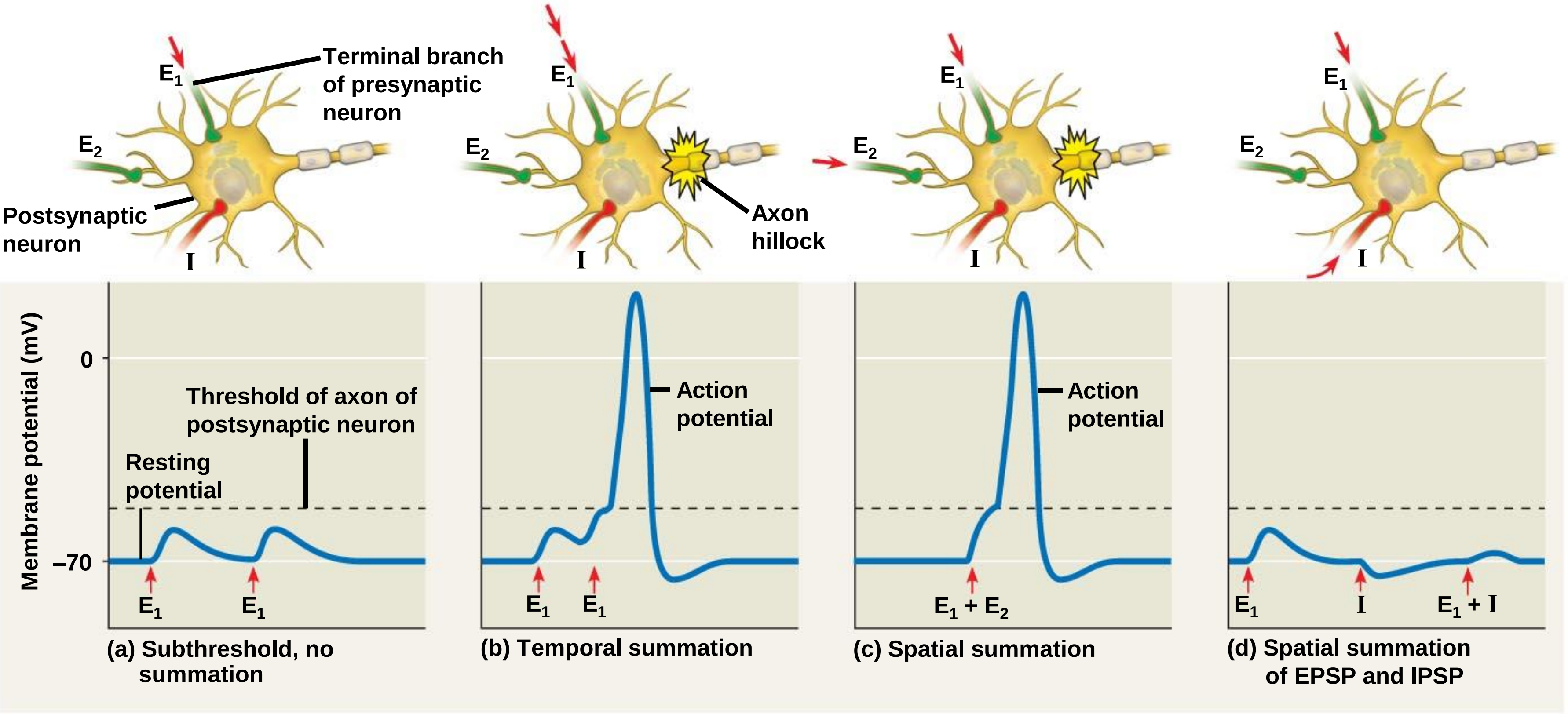
Fig. 48-16

Summation of postsynaptic potentials



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Neurotransmitters

- There are five major classes of neurotransmitters: acetylcholine, biogenic amines, amino acids, neuropeptides, and gases

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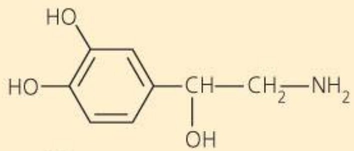
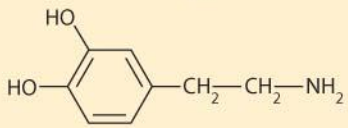
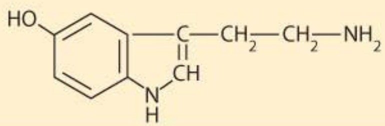
Table 48-1

Table 48.1 Major Neurotransmitters

Neurotransmitter	Structure	Functional Class	Secretion Sites
Acetylcholine	$H_3C-C(=O)-O-CH_2-CH_2-N^+-[CH_3]_3$	Excitatory to vertebrate skeletal muscles; excitatory or inhibitory at other sites	CNS; PNS; vertebrate neuromuscular junction
Biogenic Amines			
Norepinephrine		Excitatory or inhibitory	CNS; PNS
Dopamine		Generally excitatory; may be inhibitory at some sites	CNS; PNS
Serotonin		Generally inhibitory	CNS
Amino Acids			
GABA (gamma-aminobutyric acid)	$H_2N-CH_2-CH_2-CH_2-COOH$	Inhibitory	CNS; invertebrate neuromuscular junction
Glutamate	$H_2N-CH(COOH)-CH_2-CH_2-COOH$	Excitatory	CNS; invertebrate neuromuscular junction
Glycine	H_2N-CH_2-COOH	Inhibitory	CNS
Neuropeptides (a very diverse group, only two of which are shown)			
Substance P	Arg—Pro—Lys—Pro—Gln—Gln—Phe—Phe—Gly—Leu—Met	Excitatory	CNS; PNS
Met-enkephalin (an endorphin)	Tyr—Gly—Gly—Phe—Met	Generally inhibitory	CNS
Gases			
Nitric oxide	N=O	Excitatory or inhibitory	PNS

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Neuropeptides

- 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

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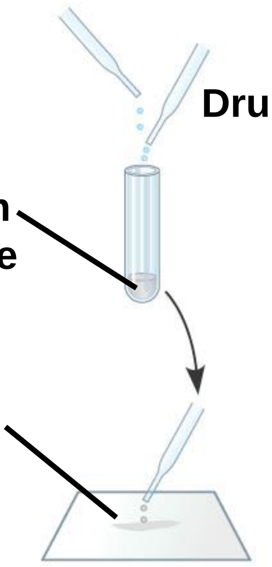
Fig. 48-17

Does the brain have a specific receptor for opiates?

EXPERIMENT



RESULTS

Drug	Opiate	Concentration That Blocked Naloxone Binding
Morphine	Yes	6×10^{-9} *M*
Methadone	Yes	2×10^{-8} *M*
Levorphanol	Yes	2×10^{-9} *M*
Phenobarbital	No	No effect at 10^{-4} *M*
Atropine	No	No effect at 10^{-4} *M*
Serotonin	No	No effect at 10^{-4} *M*

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You should now be able to:

1. Distinguish among the following sets of terms: sensory neurons, interneurons, and motor neurons; membrane potential and resting potential; ungated and gated ion channels; electrical synapse and chemical synapse; EPSP and IPSP; temporal and spatial summation
2. Explain the role of the sodium-potassium pump in maintaining the resting potential

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3. Describe the stages of an action potential; explain the role of voltage-gated ion channels in this process

4. Explain why the action potential cannot travel back toward the cell body

5. Describe saltatory conduction

6. Describe the events that lead to the release of neurotransmitters into the synaptic cleft

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7. Explain the statement: “Unlike action potentials, which are all-or-none events, postsynaptic potentials are graded”

8. Name and describe five categories of neurotransmitters

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