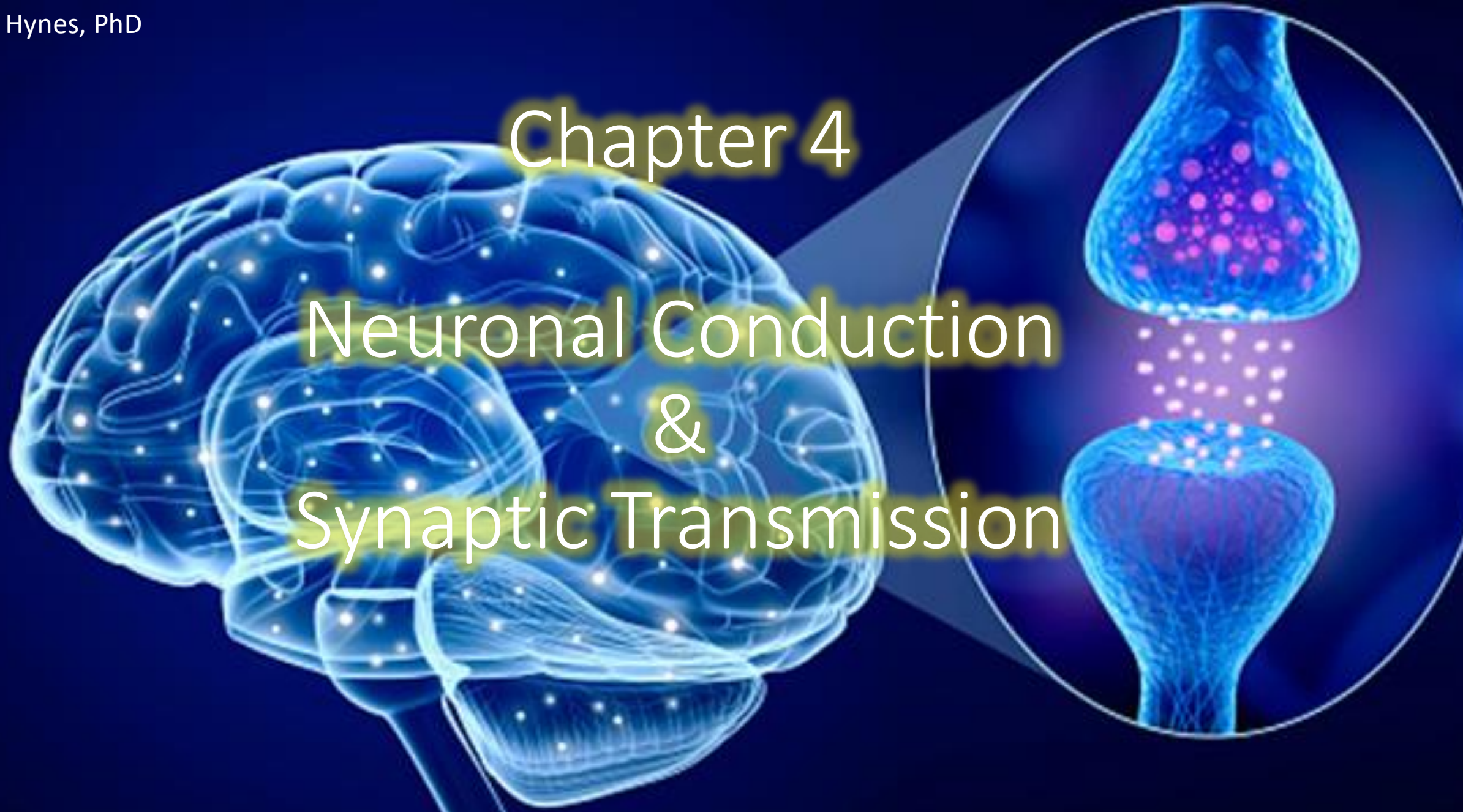
Tristan Hynes, PhD

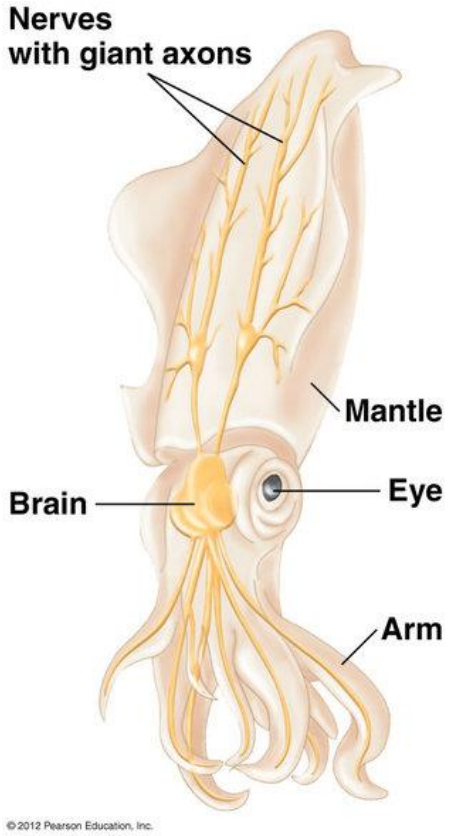


Chapter 4

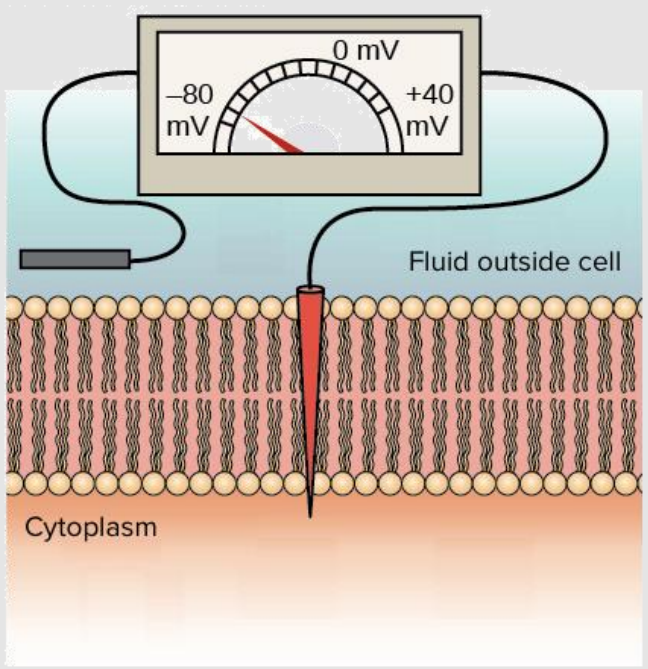
Neuronal Conduction & Synaptic Transmission

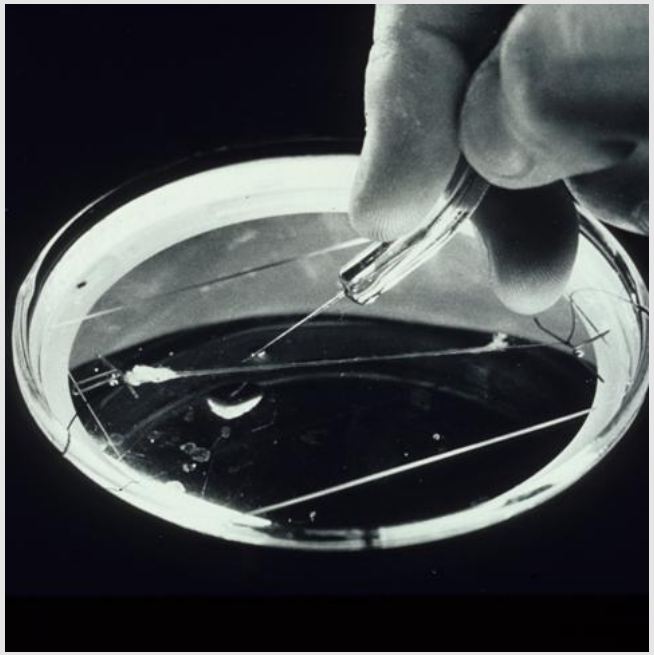
How are signals conveyed within and between neurons?

The Membrane Potential (Hodgins & Huxley)



Recording the Membrane Potential

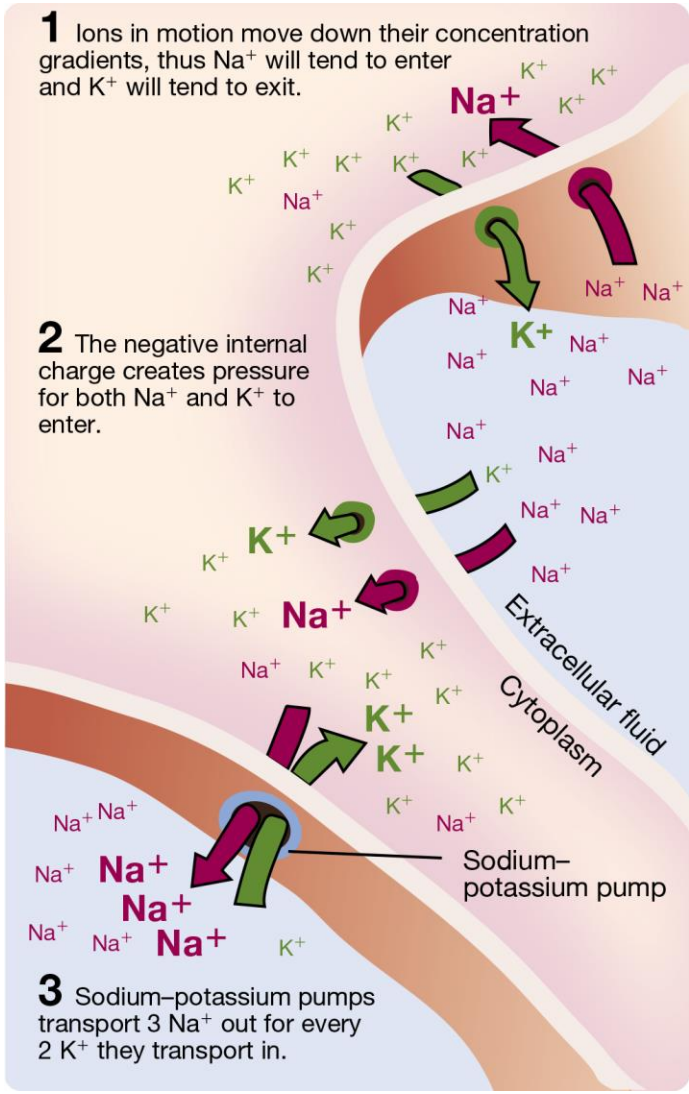




- Resting membrane potential
  - What is the membrane potential?
  - How is it measured?
  - Why is it important?

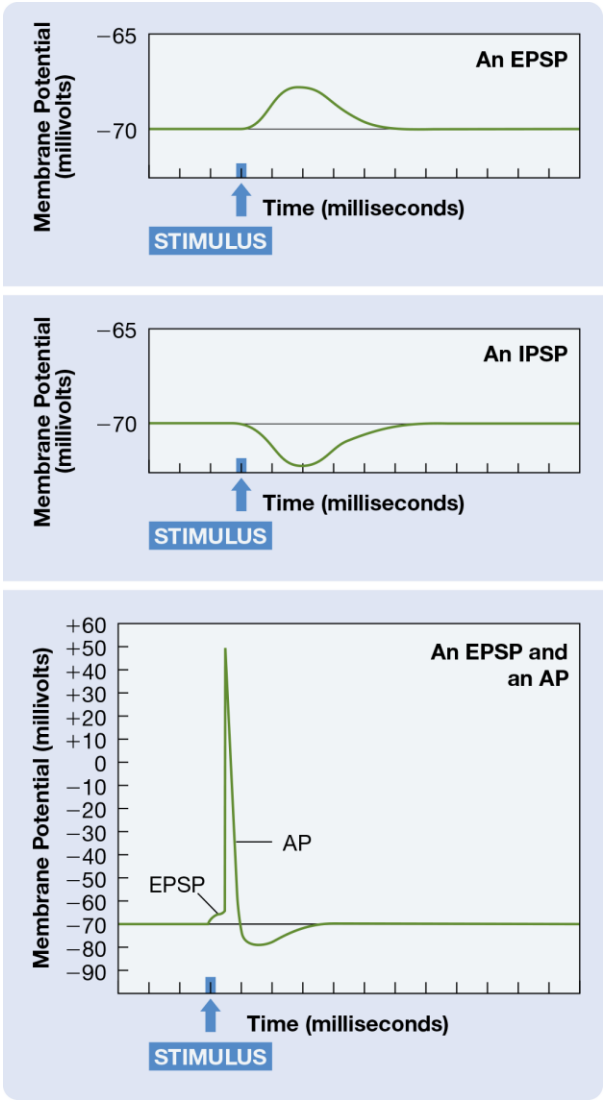
Ionic Basis of the Resting Potential

- Concentrations of Ions
  - Na^+
  - K^+
- Diffusion pressure
- Electrostatic pressure
- Ion channels
- Sodium-potassium pump

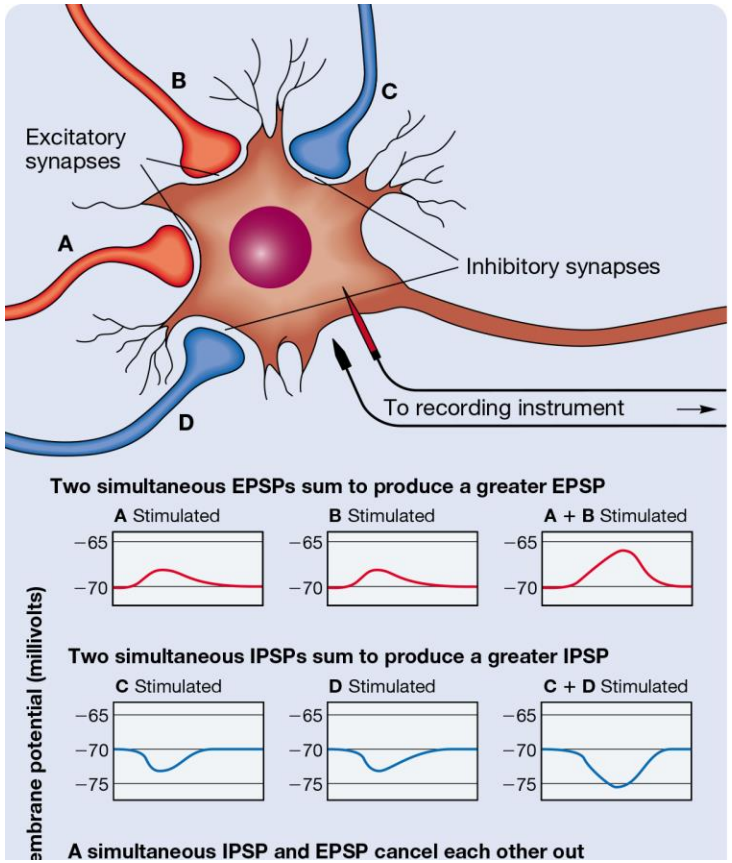


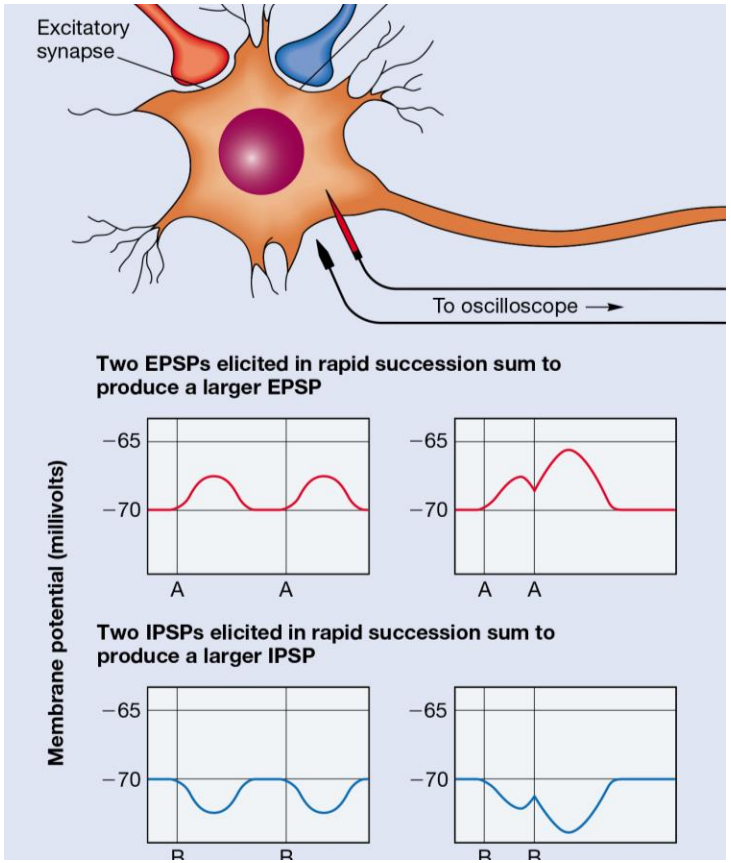
Generation and Conduction of Postsynaptic Potentials

- Postsynaptic potentials
  - Role of neurotransmitter and presynaptic neuron
- Excitatory postsynaptic potentials (EPSPs)
- Inhibitory postsynaptic potentials (IPSPs)
- Three important properties
  - Graded
  - Decremental
  - Transmission is rapid



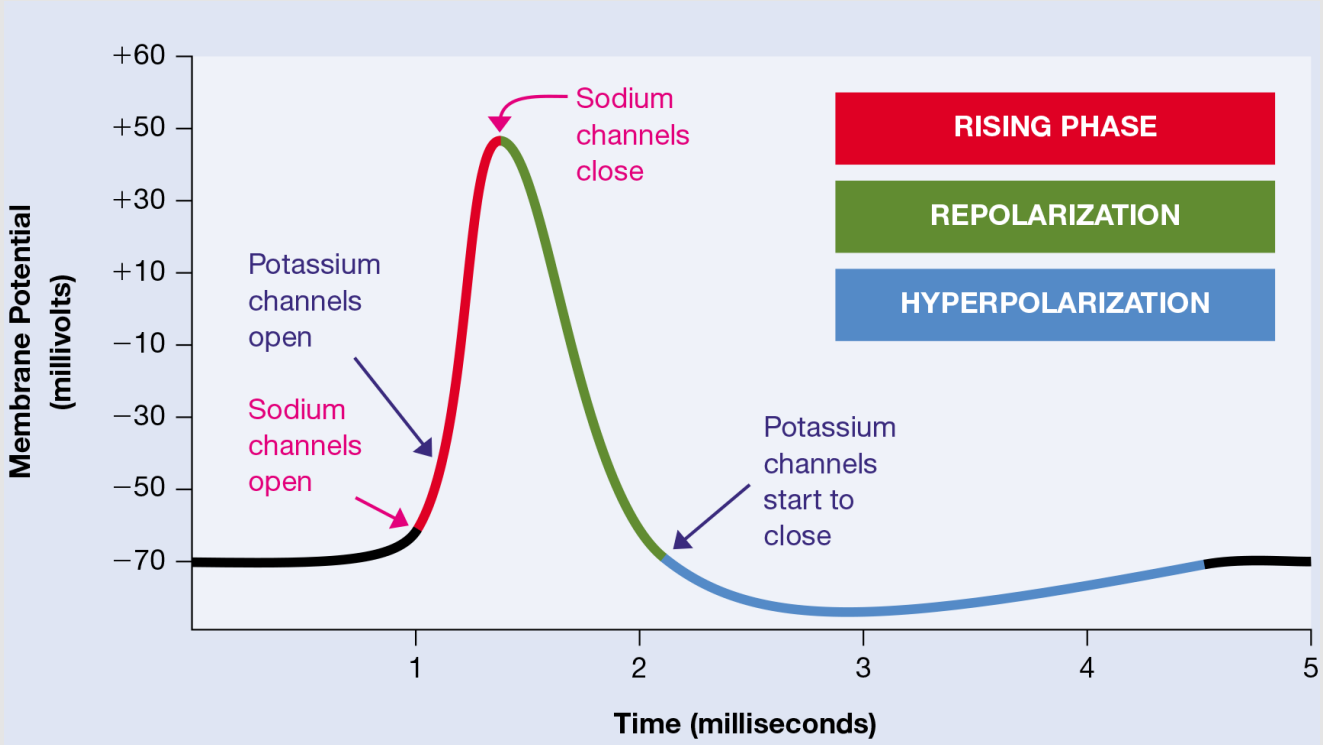
Integration of Postsynaptic Potentials and Generation of Action Potentials





- Action potentials
  - Begin at axon hillock
  - All-or-none
- Neural integration of multiple signals
  - Spatial summation
  - Temporal summation

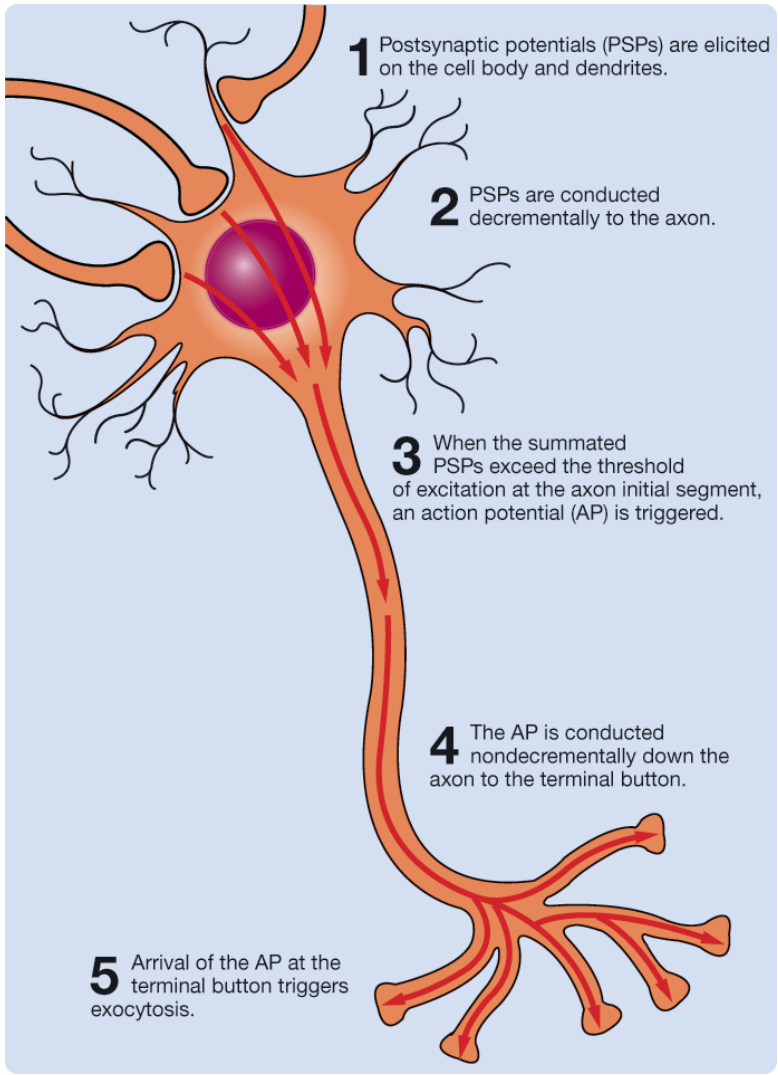
Ionic Basis of Action Potentials



- Threshold is reached (EPSPs)
  - Voltage-gated Na^+ channels open
  - Na^+ rushes in
  - Voltage-gated K^+ channels slowly open
  - K^+ leaves cell
  - Cell becomes hyperpolarized
- Refractory periods
  - Absolute
  - Relative

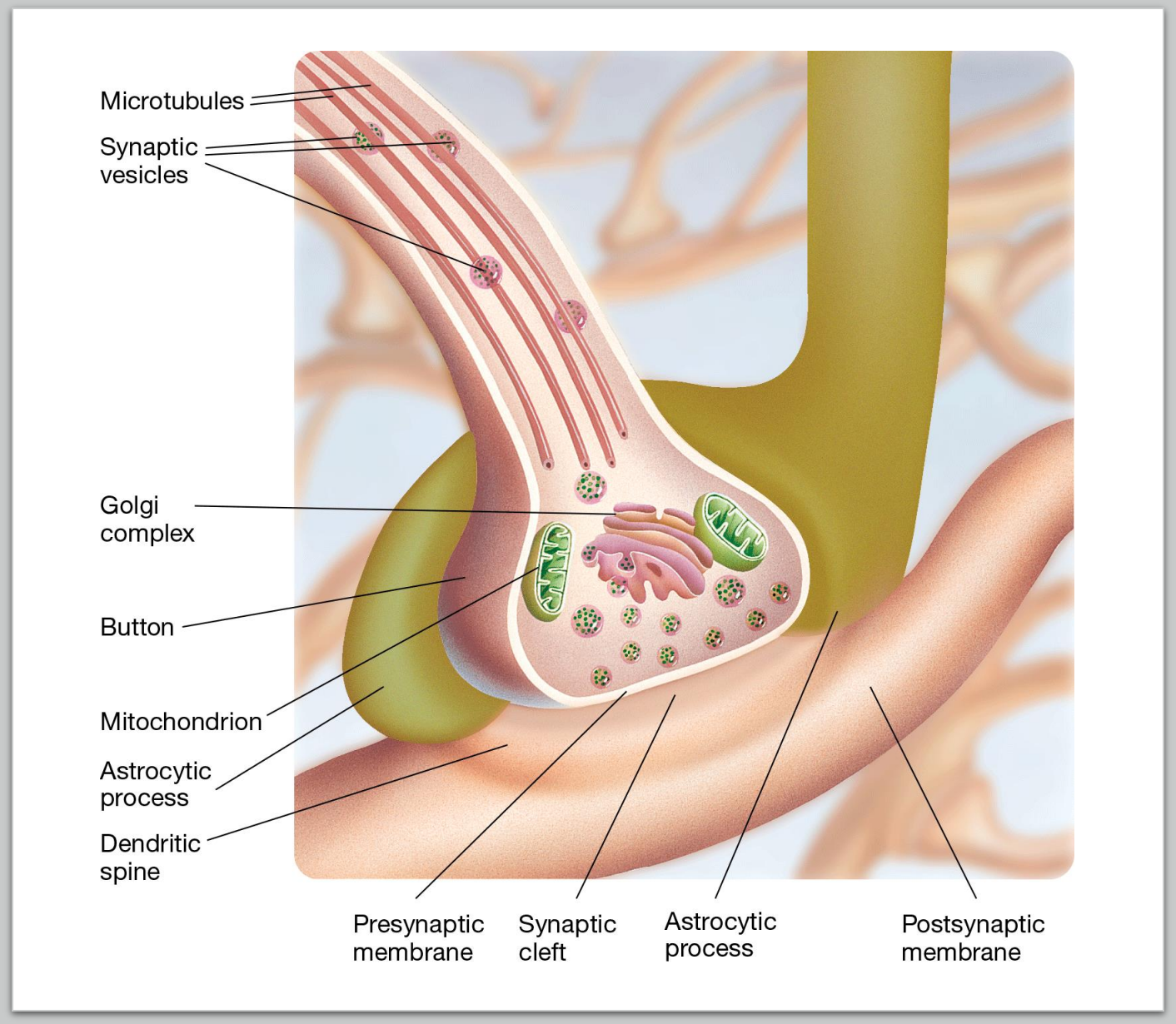
Axonal Conduction of Action Potentials

- Conduction of action potentials
  - Active, slower, non-decremental
- Diffusion of Na^+ triggers next action potential
- Na^+ channels tightly packed creating waves of depolarization
- Direction of transmission
  - Orthodromic conduction
  - Antidromic conduction
- Conduction in myelinated axons
  - Nodes of Ranvier
  - Saltatory conduction
  - Faster transmission
  - Requires less energy
- Velocity of axonal conduction
  - Larger/myelinated are fastest
- Conduction in neurons without axons
  - Transmission is decremental



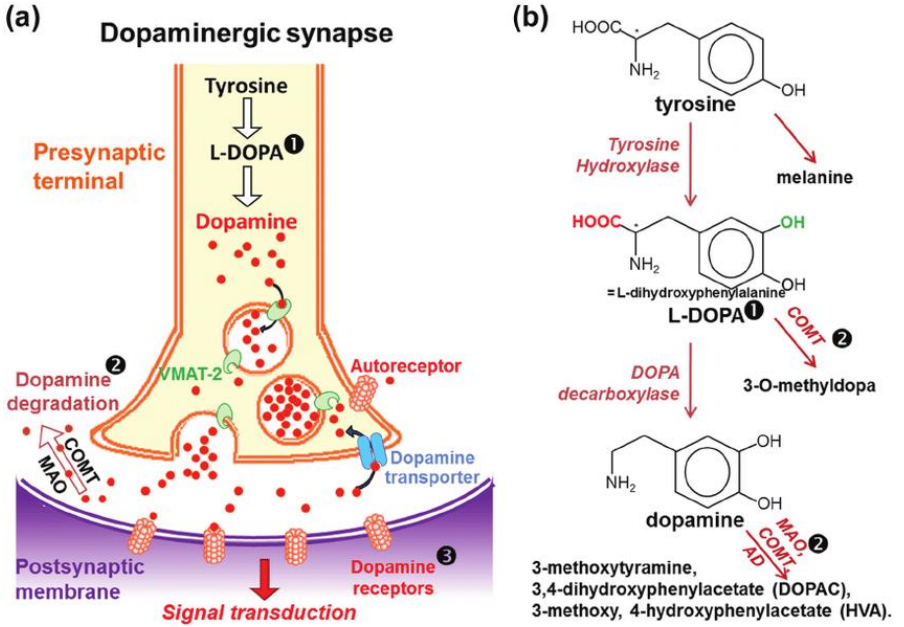
Structure of The Synapse

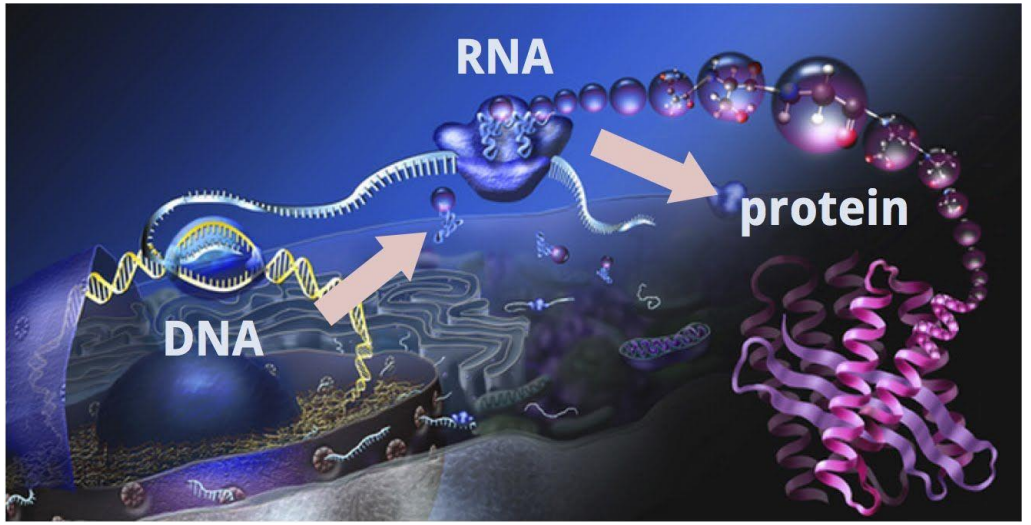
- Dendritic spines
- Types
  - Axosomatic
  - Axodendritic
  - Axoaxonic
  - Dendrodendritic
  - Dendroaxonic
  - Synapses between main shafts
  - Nondirected synapses
- Presynaptic Inhibition
- Postsynaptic Inhibition
- Directed and non-directed synapses



Synthesis, Packaging, and Transport of Neurotransmitters

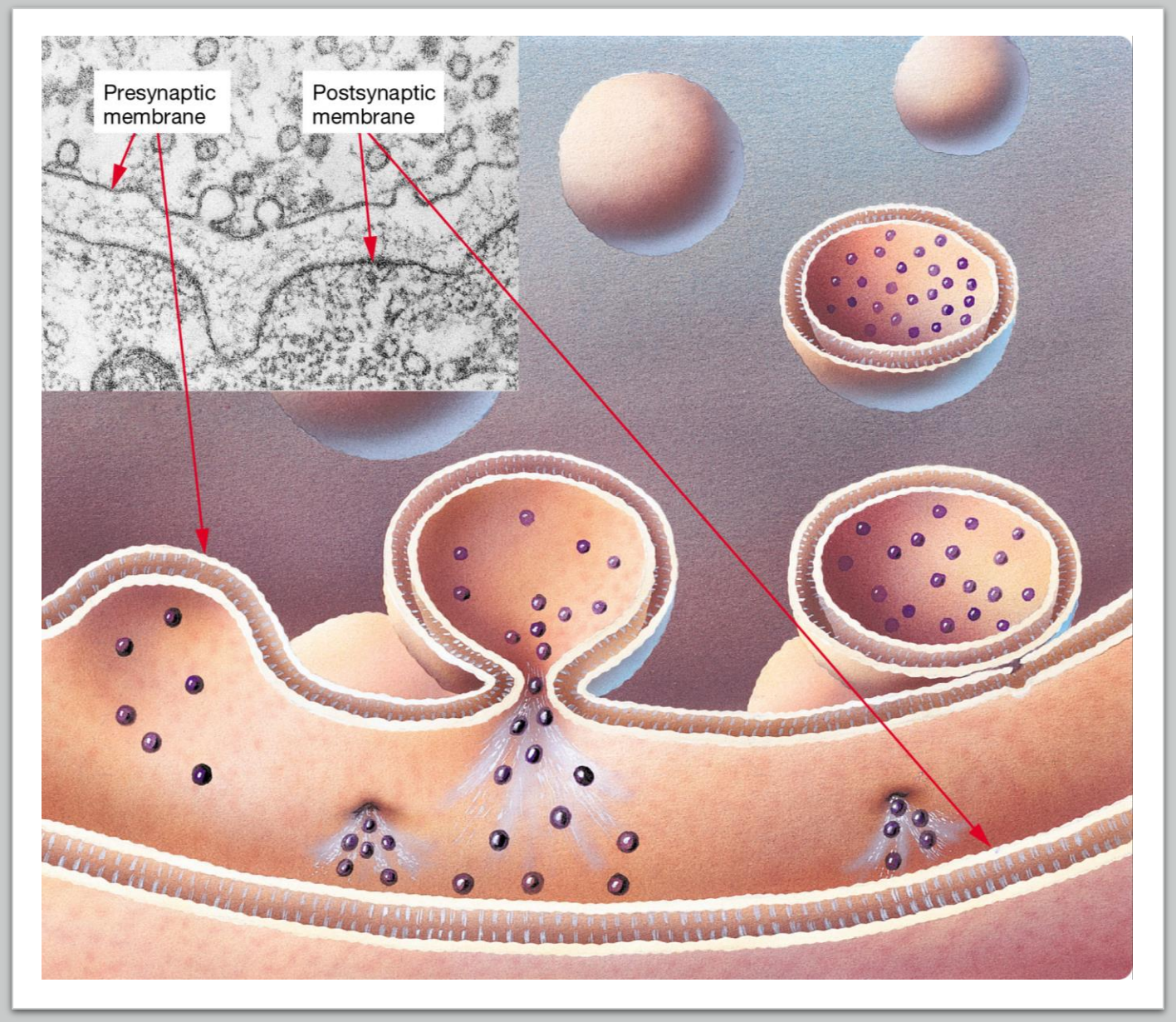
- Small-molecule neurotransmitters
  - Synthesized in cytoplasm
  - Packaged by Golgi
- Large-molecule neurotransmitters
  - Synthesized in soma by ribosomes
  - Carried down microtubules
- Coexistence





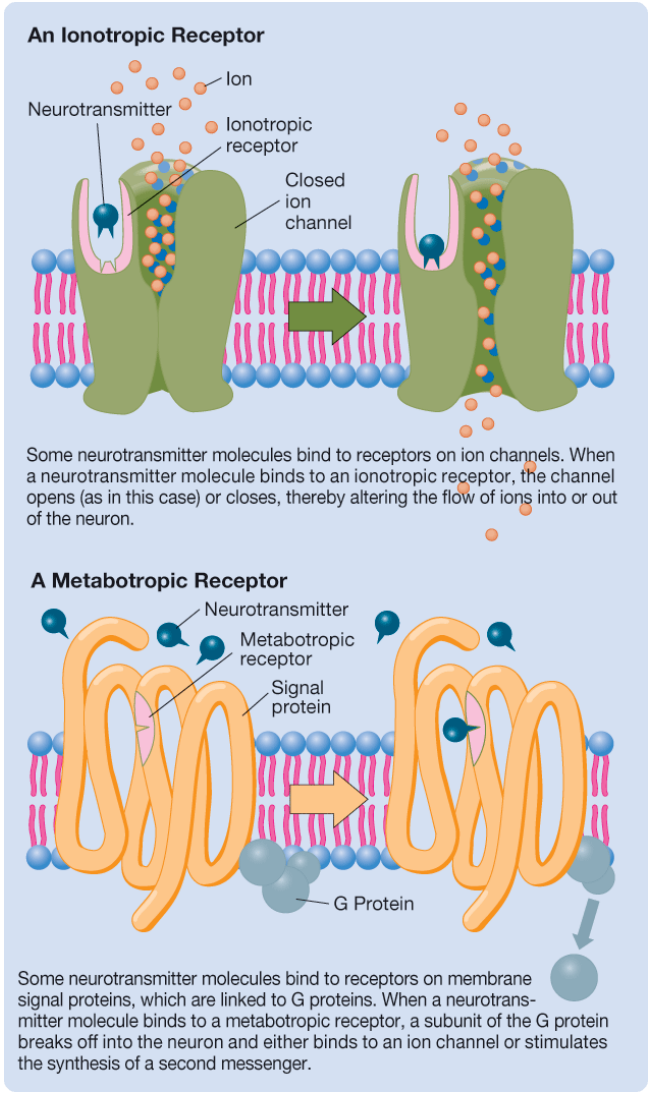
Release of Neurotransmitters

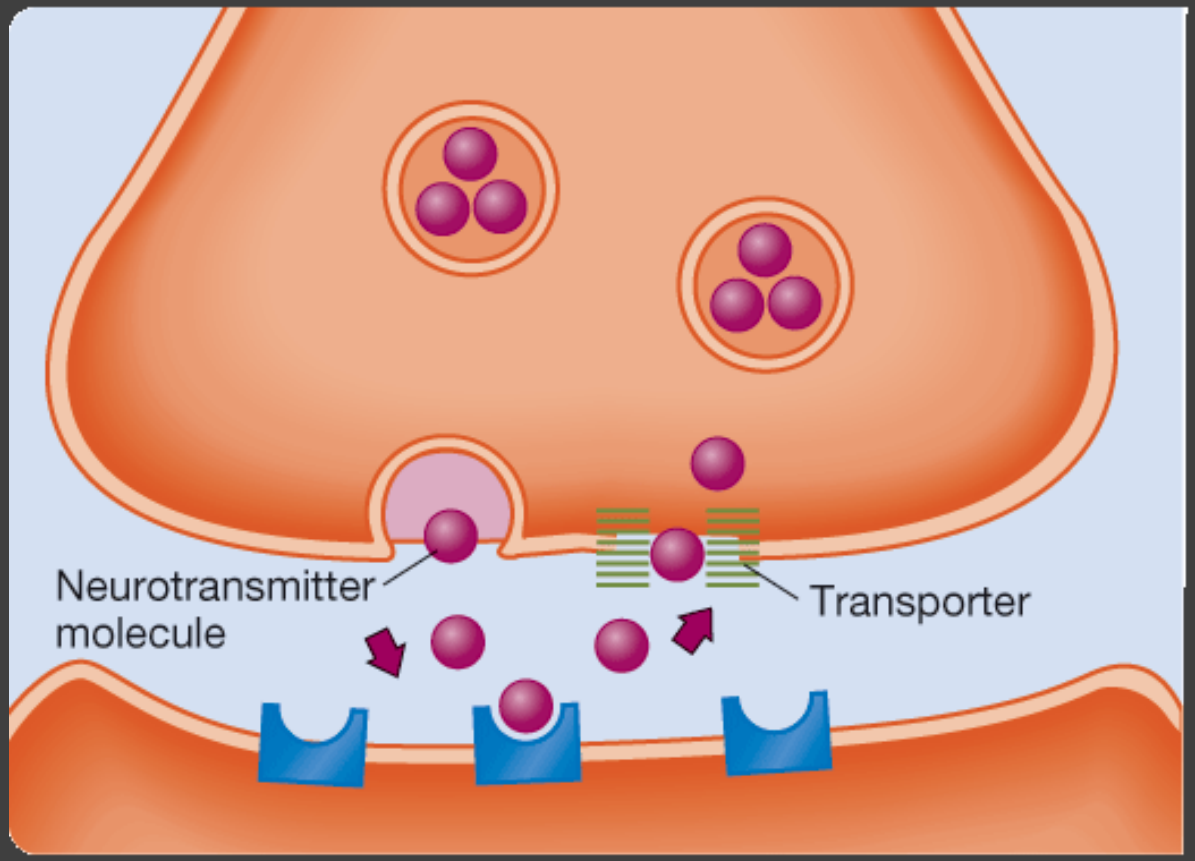
- AP arrives at terminal buttons
- Voltage-gated calcium channels open
- Ca^{2+} enters
- Synaptic vesicles fuse and empty contents (exocytosis)
- Coexistence (neurotransmitter/neuropeptide)

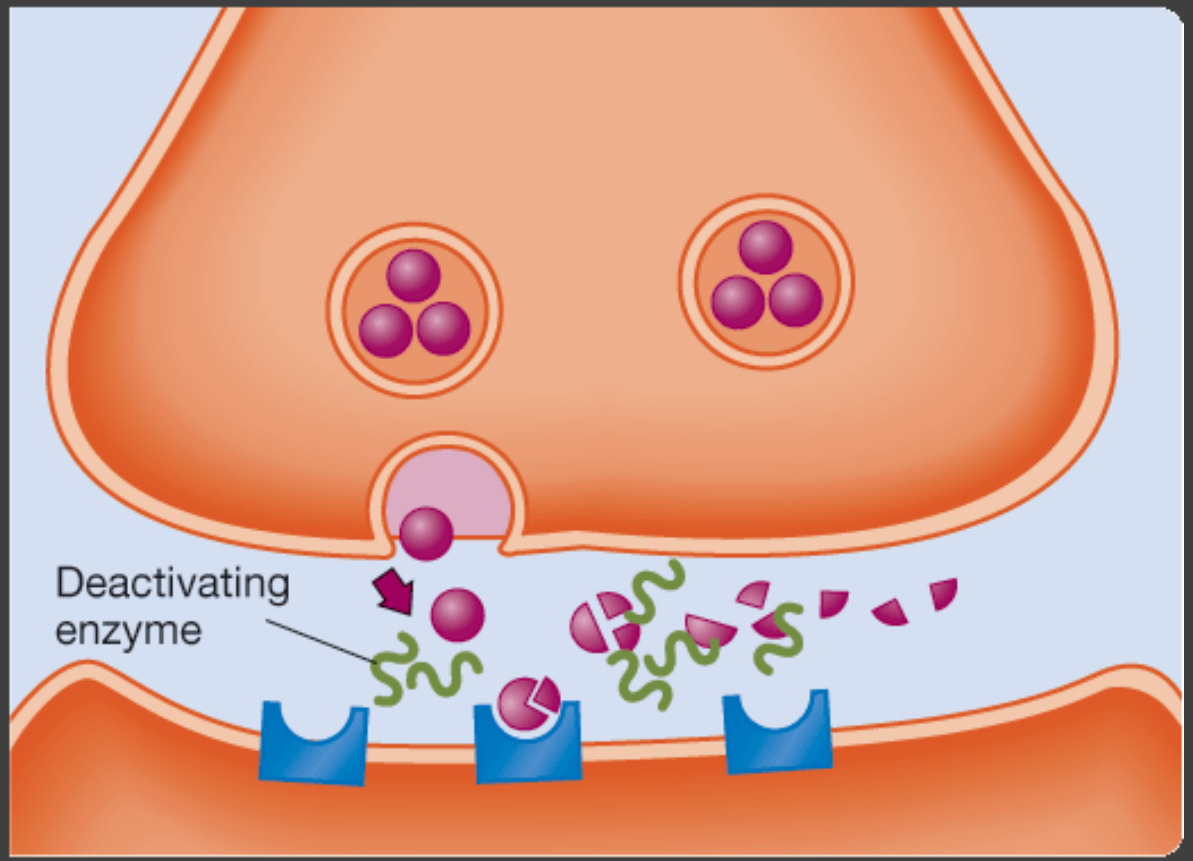


Activation of Receptors by Neurotransmitters

- Diffusion of neurotransmitter
- Binding to receptors
  - Ionotropic – brief EPSPs or IPSPs
  - Metabotropic – activate second messengers
- Autoreceptors





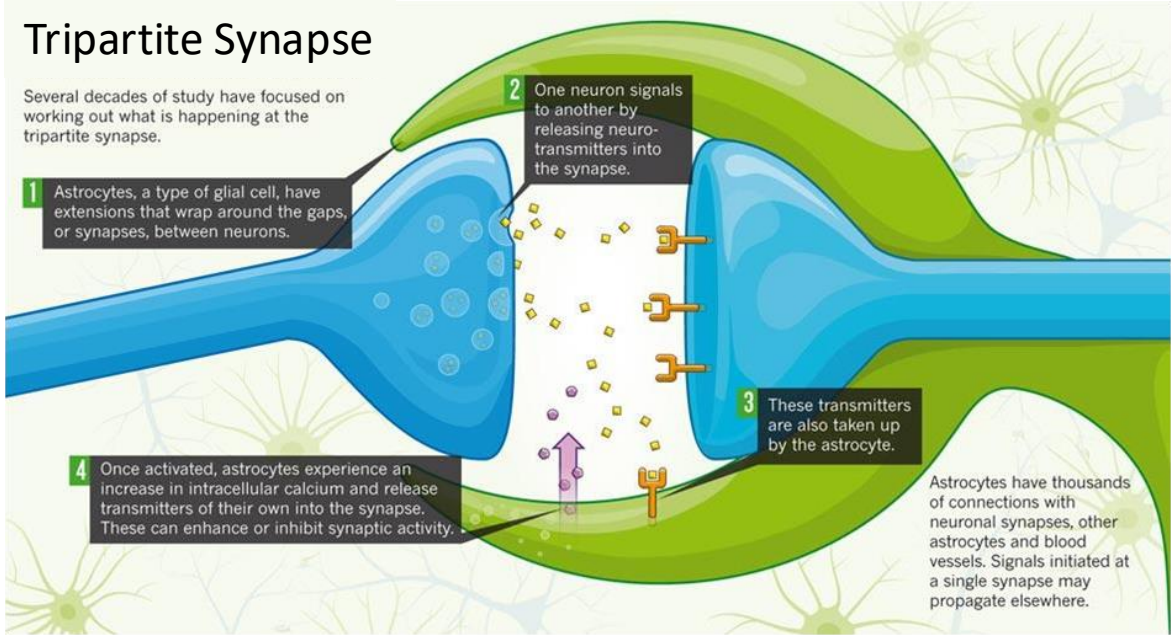


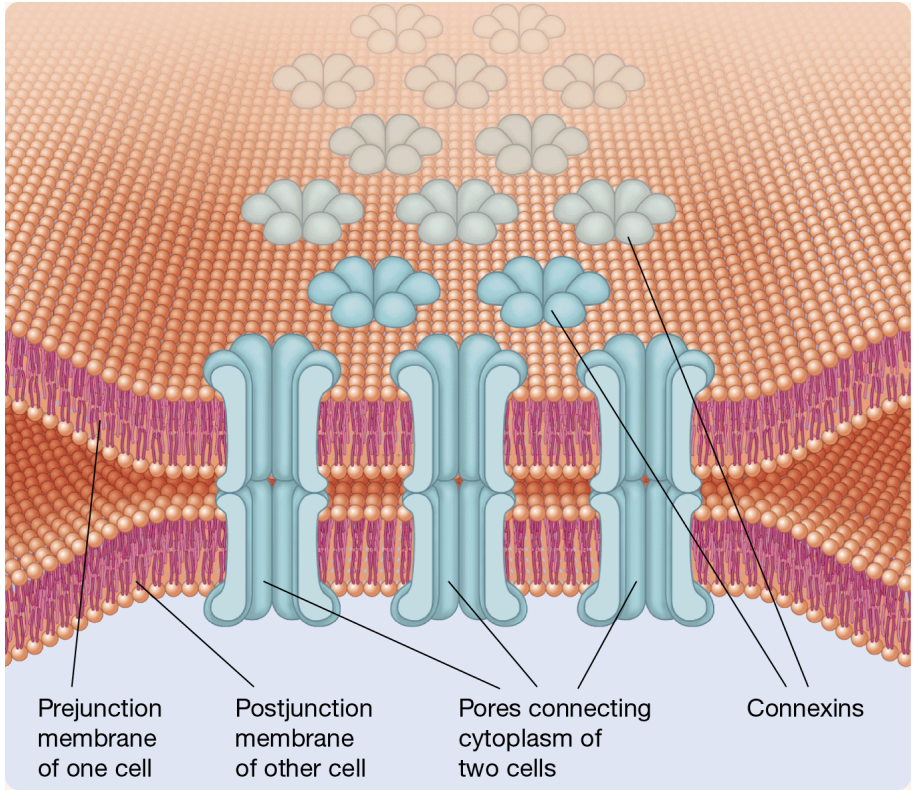
Reuptake, Enzymatic Degradation, and Recycling

- Two message-terminating mechanisms
  - Enzymatic degradation
  - Reuptake by transporters

Glia, Gap Junctions, and Synaptic Transmission

- Gap junctions
- Electrical synapses
- Local inhibitory circuits
- Glial and neuronal gap junctions





Overview of the Neurotransmitter Classes

Small-Molecule Neurotransmitters

Amino acids		Glutamate Aspartate Glycine GABA
Monoamines	Catecholamines	Dopamine Epinephrine Norepinephrine
	Indolamines	Serotonin
Acetylcholine		Acetylcholine
Unconventional neurotransmitters	Soluble gases	Nitric oxide Carbon monoxide
	Endocannabinoids	Anandamide

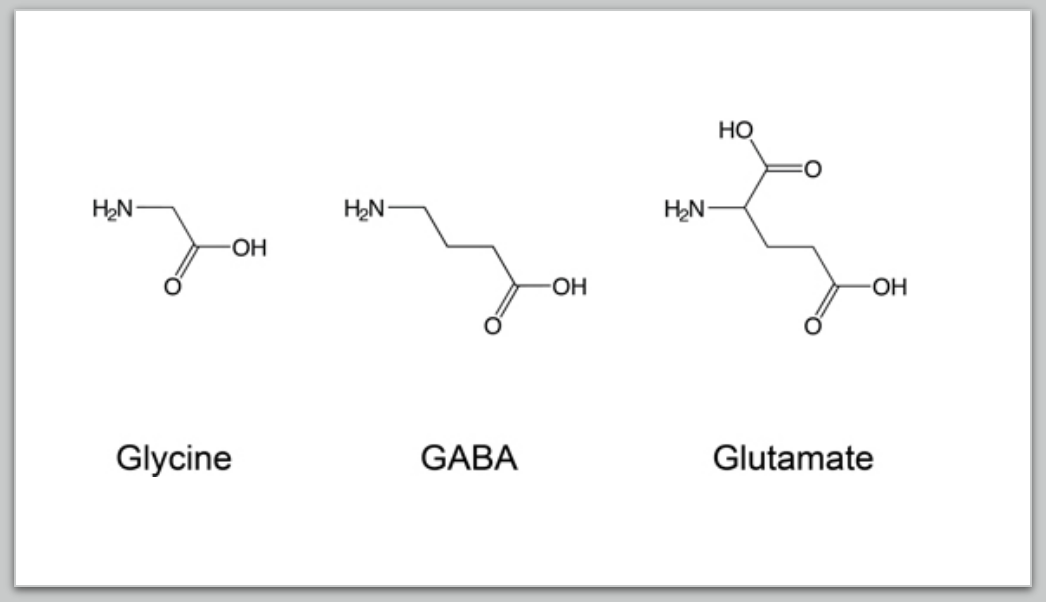
Large-Molecule Neurotransmitters

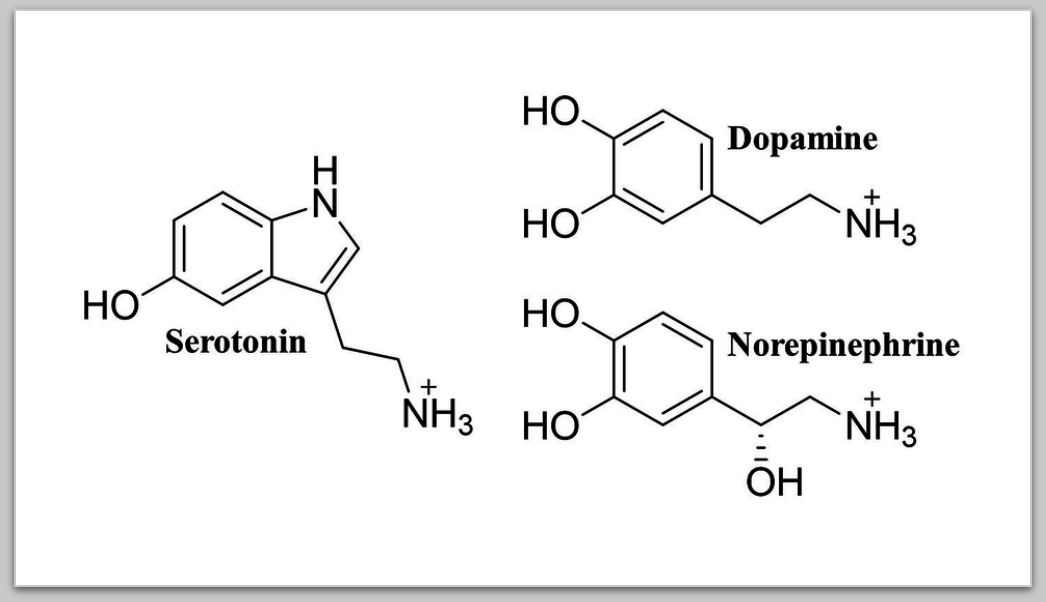
Neuropeptides	Pituitary peptides Hypothalamic peptides Brain–gut peptides Opioid peptides Miscellaneous peptides

The Roles and Functions of Neurotransmitters (1 of 3)

- Amino acid neurotransmitters
  - Fast-acting/point-to-point synapses
  - GABA, glutamate, aspartate, glycine

- Monoamine neurotransmitters
  - Slow, lingering and diffuse effects
  - Arise from brainstem
  - Catecholamines/Indolamines

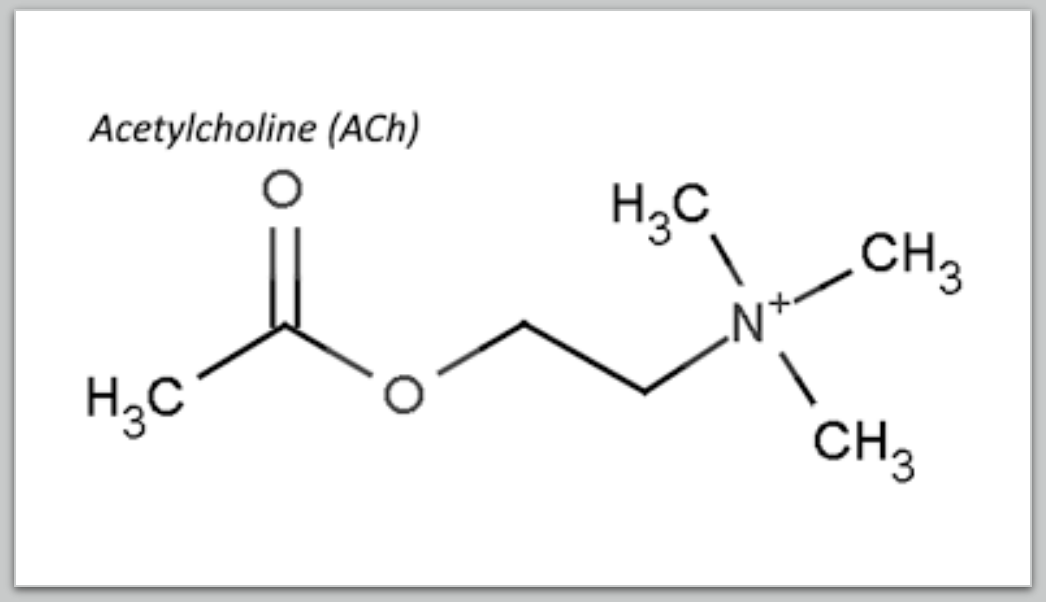


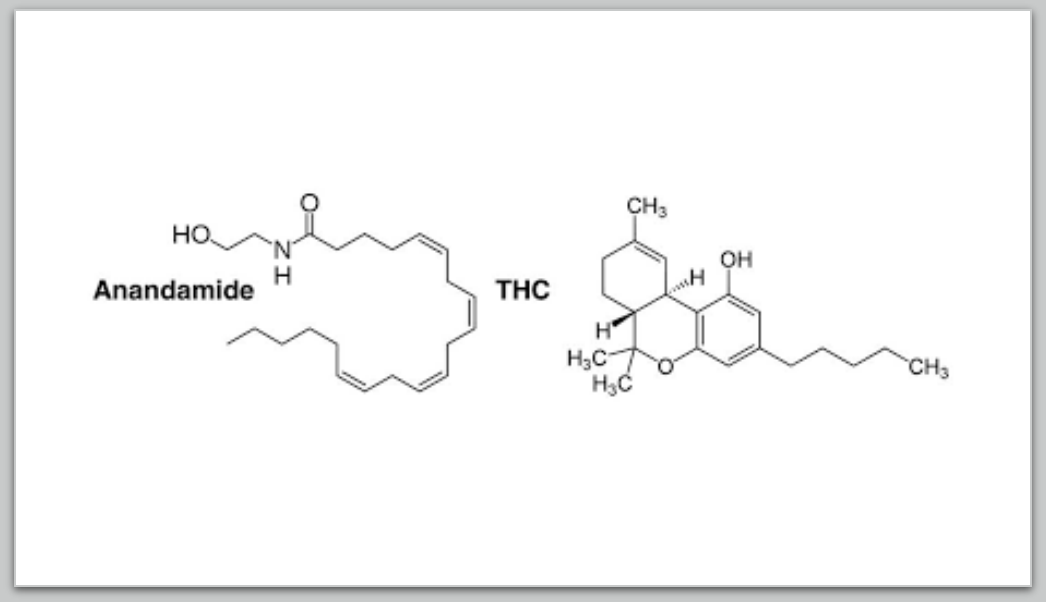


The Roles and Functions of Neurotransmitters (2 of 3)

- Acetylcholine
  - Neuromuscular junctions
  - Autonomic nervous system
  - Central nervous system
  - Deactivated by enzymes in synapse

- Unconventional neurotransmitters
  - Soluble gases (nitric oxide/carbon monoxide)
  - Produced in neural cytoplasm
  - Short-acting
  - Anandamide

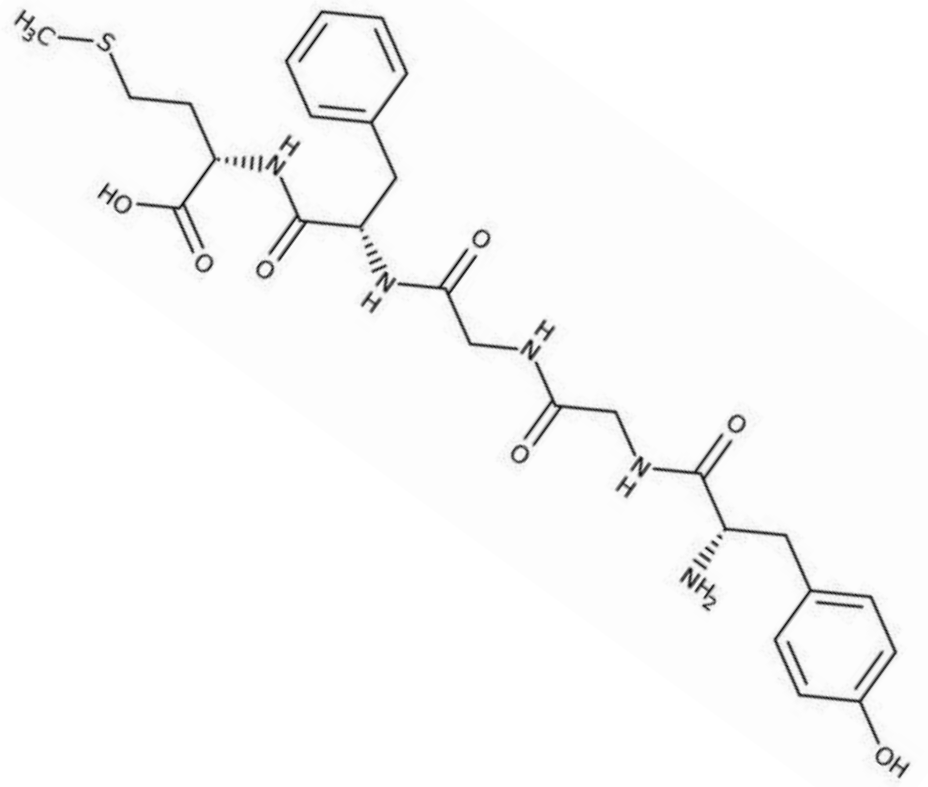




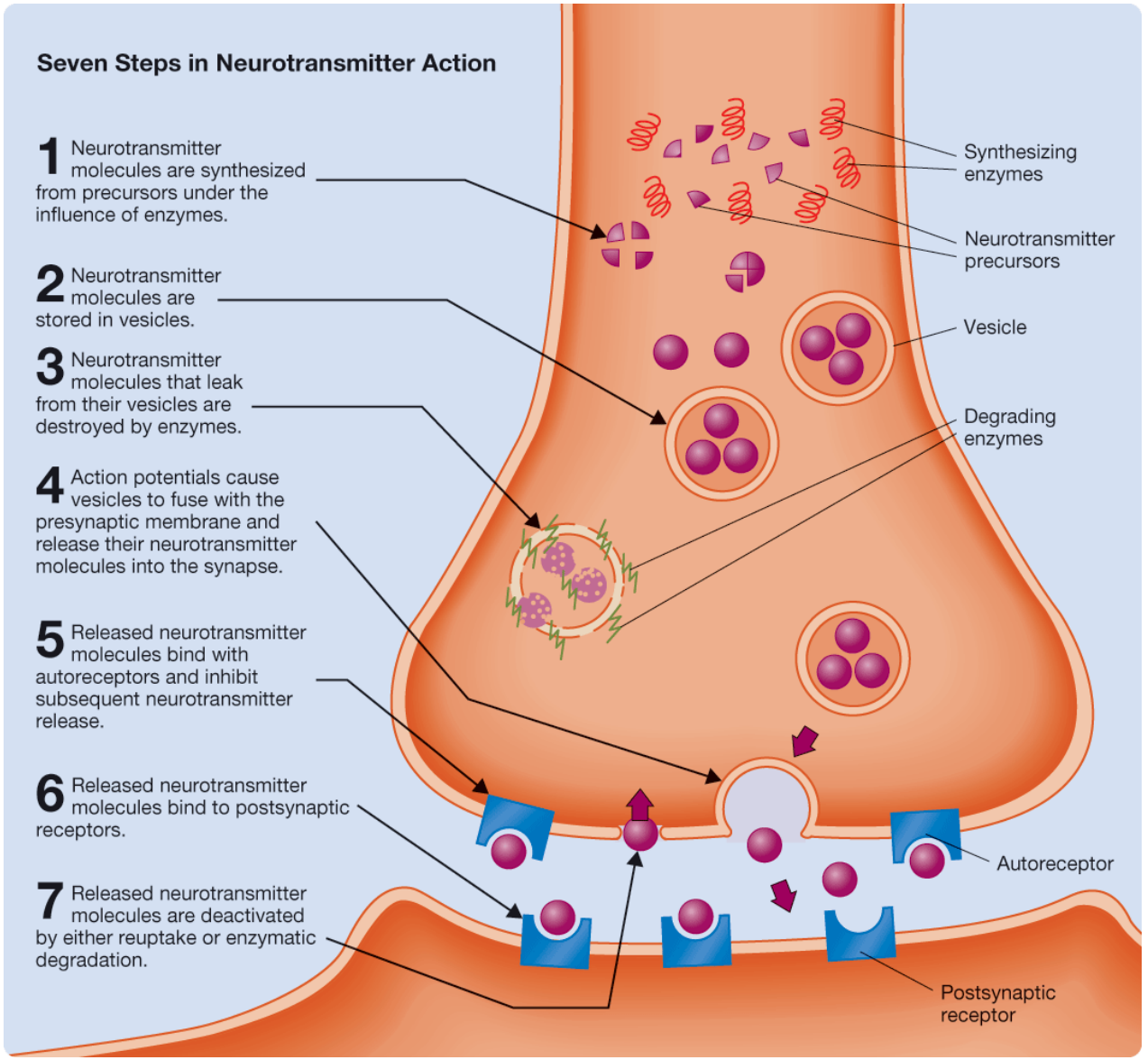
The Roles and Functions of Neurotransmitters (3 of 3)

- Neuropeptides
  - Short chains of amino acids
  - Five categories of neuropeptides
  - Endorphins as an example
    - Analgesia/reward systems

Neuropeptides	Pituitary peptides Hypothalamic peptides Brain–gut peptides Opioid peptides Miscellaneous peptides

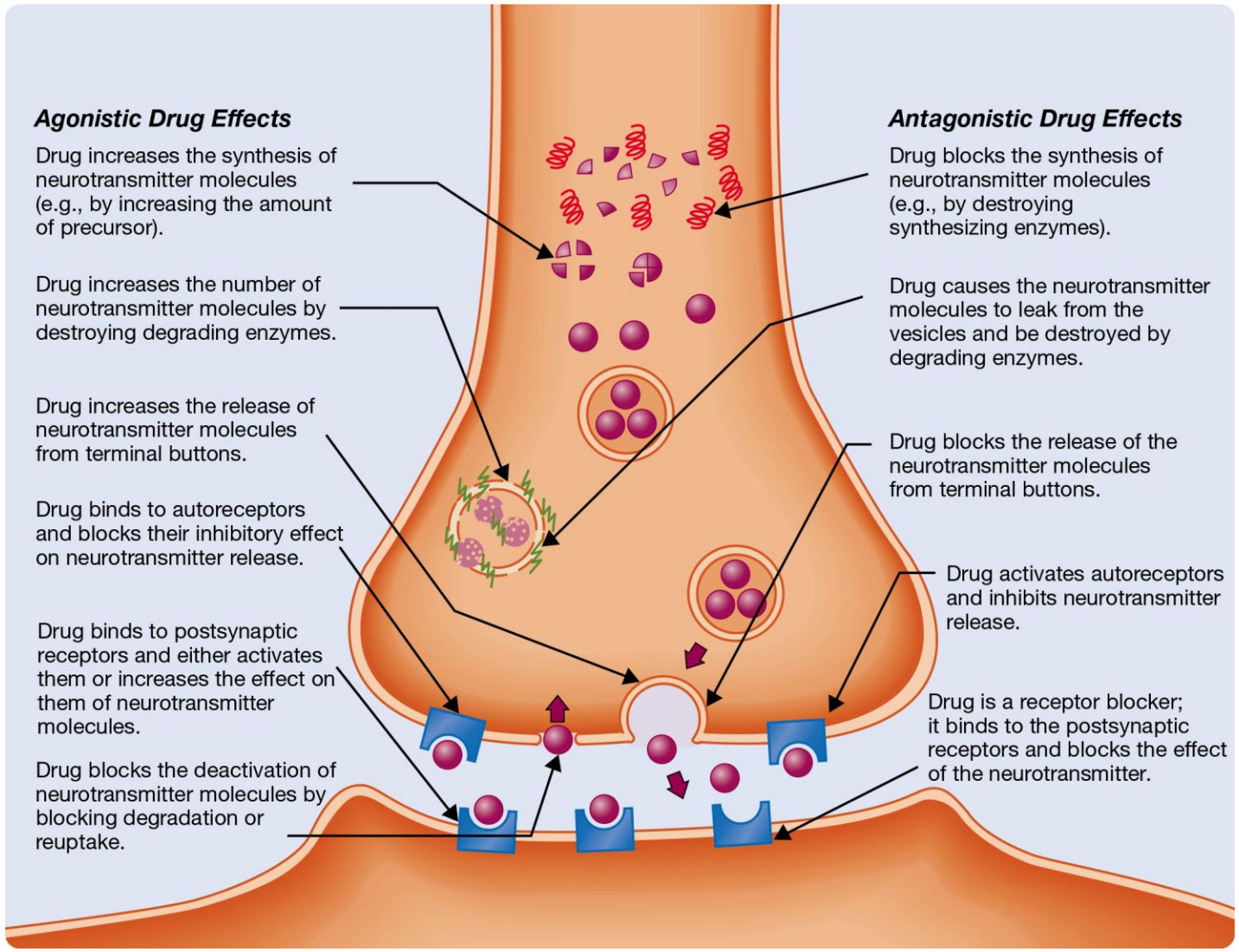


Seven Steps in Neurotransmitter Action

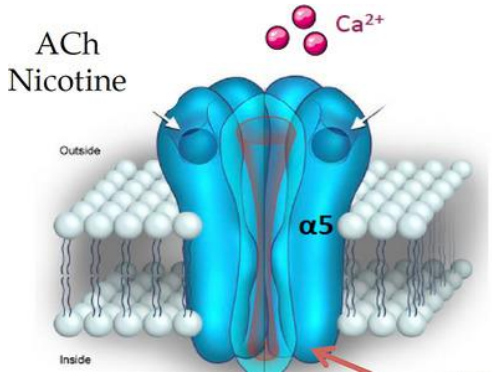


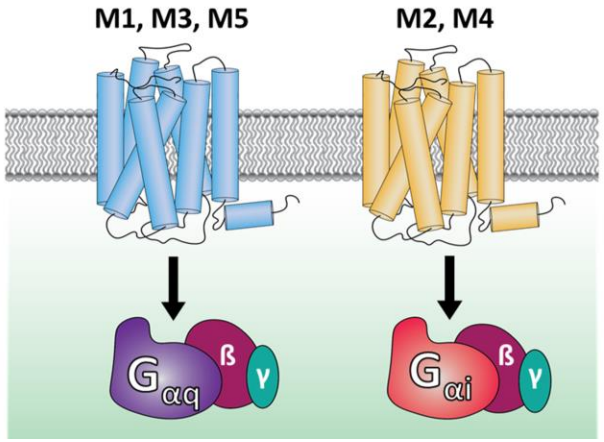
Mechanisms of Drug Action

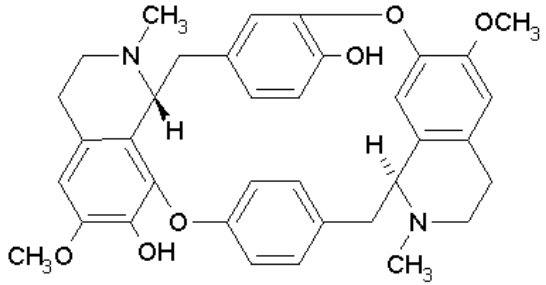
AGONIST **VS.** **ANTAGONIST**



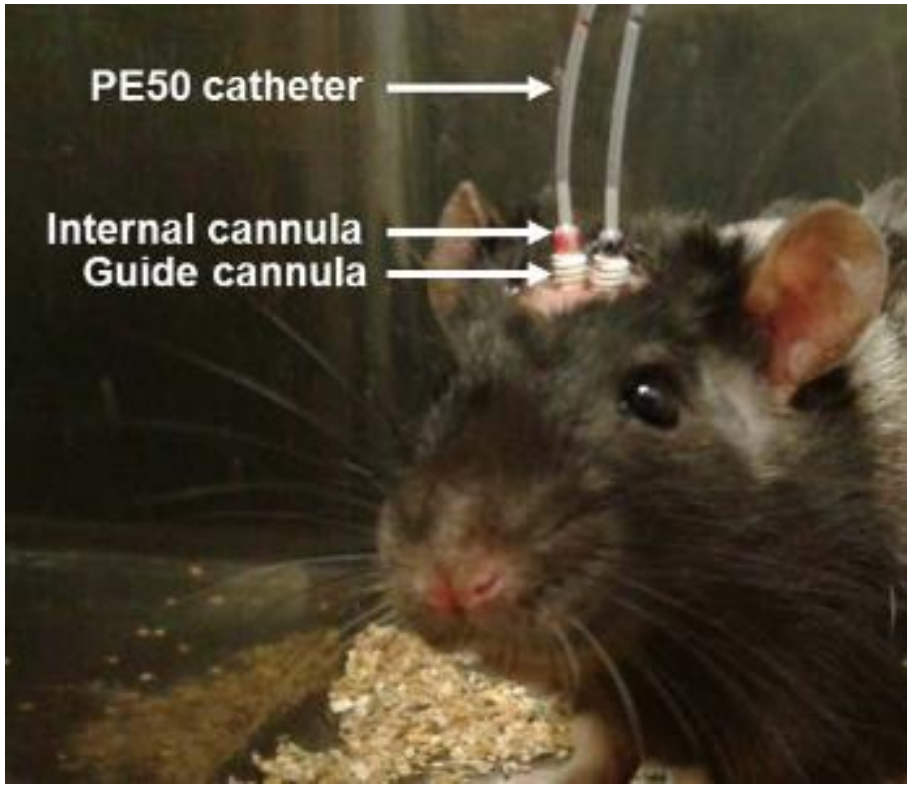
Behavioral Pharmacology: Discovery of Receptor Subtypes







Behavioral Pharmacology: Discovery of Endogenous Opioids



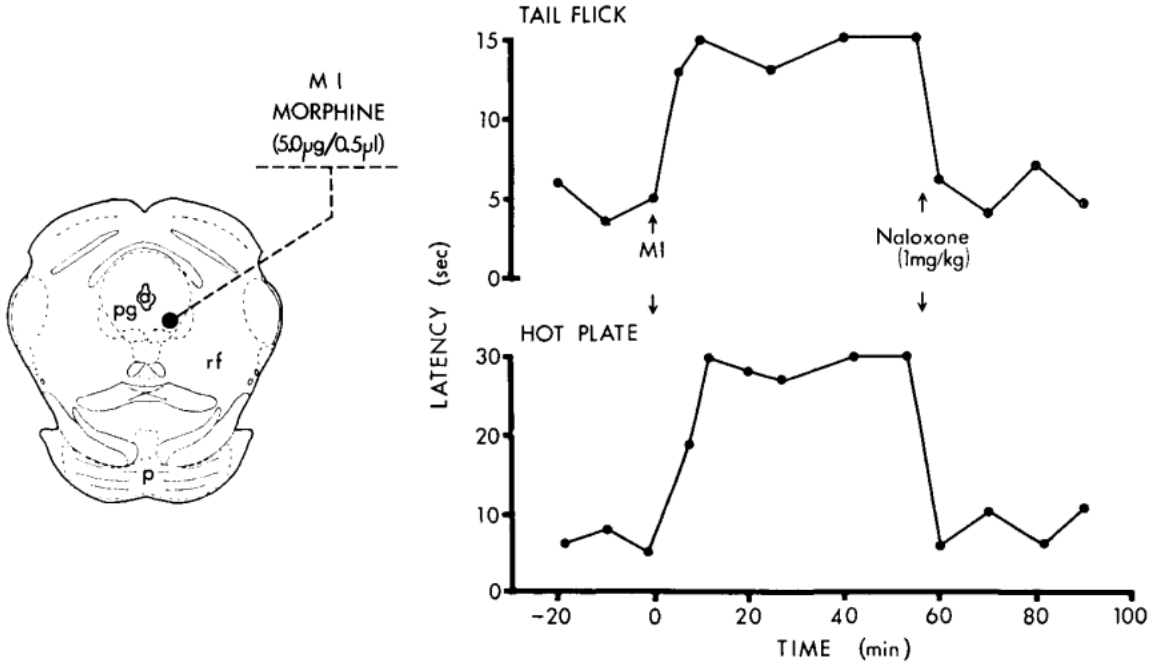
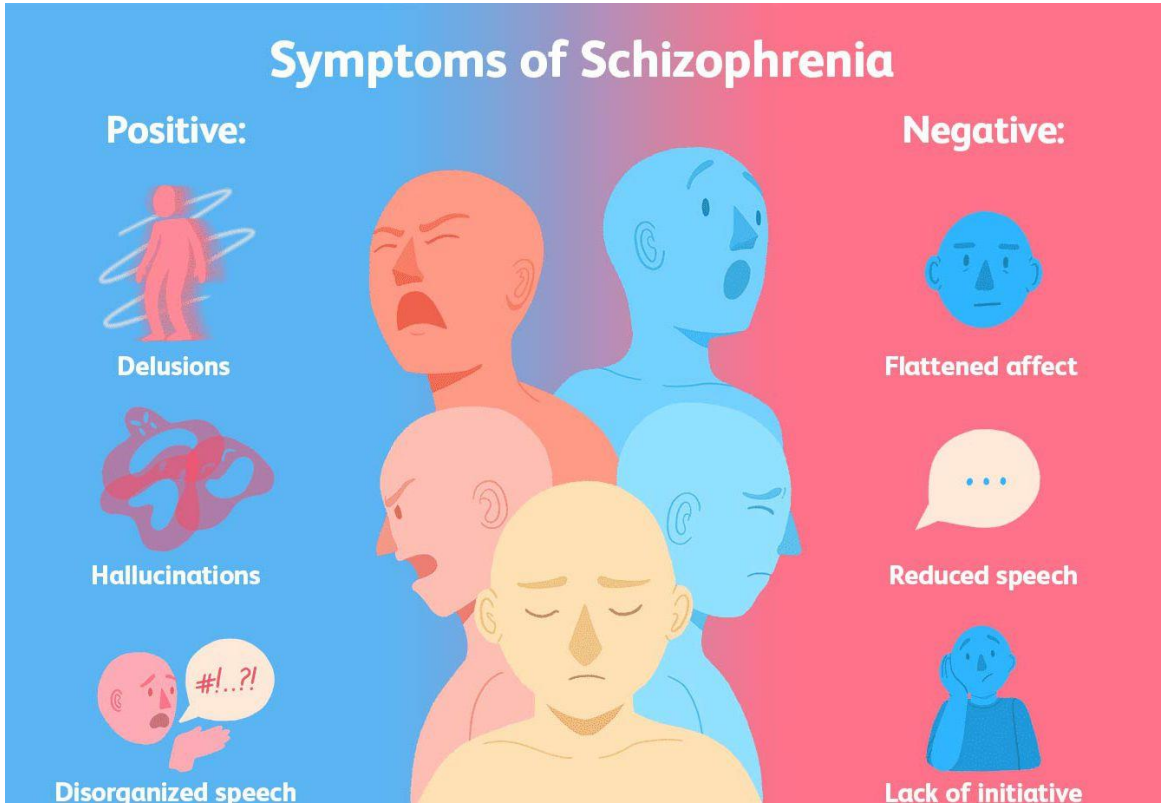


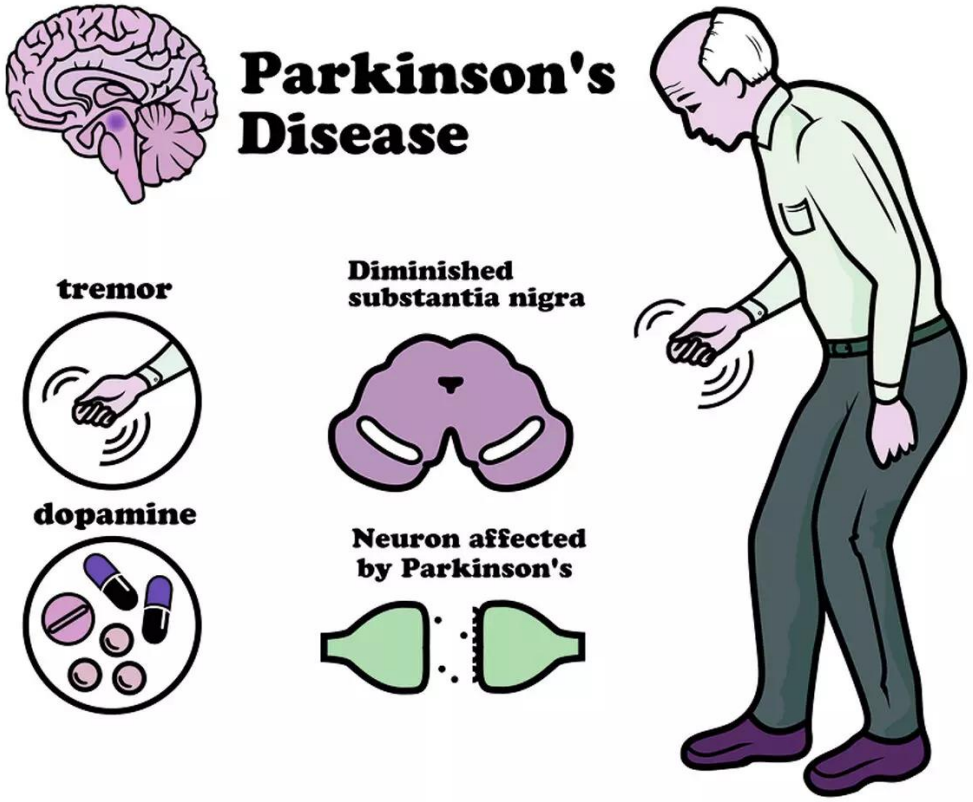
Fig. 1. The effect of an intracerebral injection of morphine sulfate (5 μg/0.5 μl) at the first arrow (MI) into the site indicated in the adjacent coronal section on the tail flick (top) and hot plate (bottom) is shown. Naloxone hydrochloride (1 mg/kg, i.p.) was given at the second arrow. Abbreviations: a, aqueduct; p, pons; pg, periaqueductal gray; rf, reticular formation.

(Yaksh et al., 1979)

Behavioral Pharmacology: Discovery of Antipsychotic Drugs



Haloperidol (D2 Antagonist)



Ropinirole (D2 Agonist)