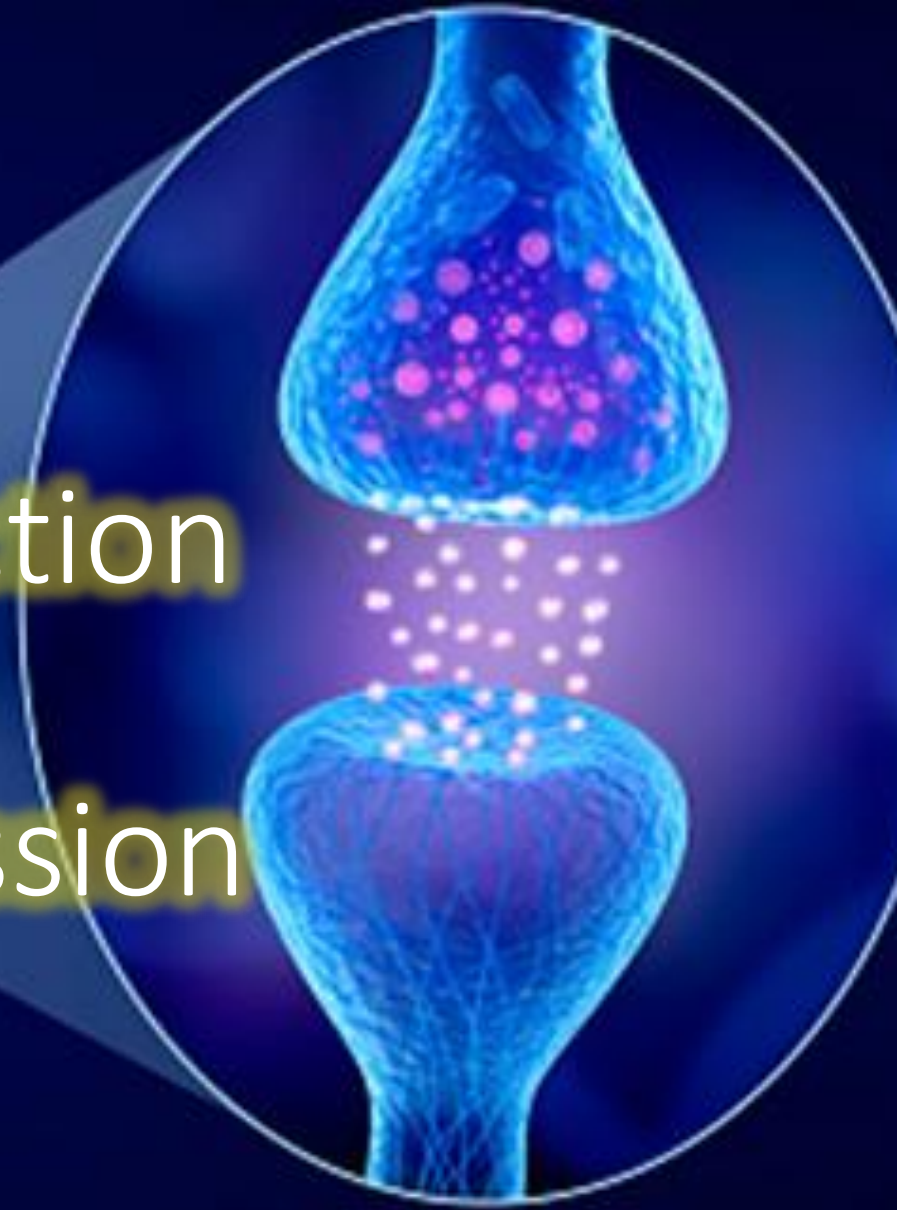


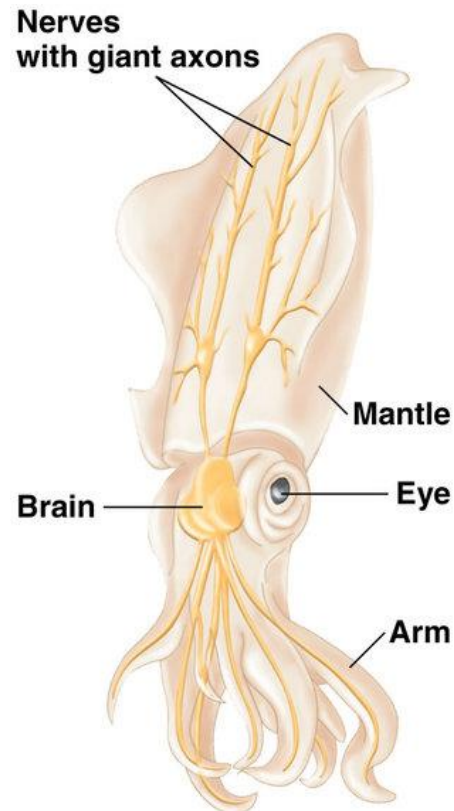
# Chapter 4

## Neuronal Conduction & Synaptic Transmission



**How are signals conveyed within and between neurons?**

# The Membrane Potential (Hodgins & Huxley)



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Rodger Kram  
@RodgerKram

Replying to @sjoerdm

embarrassed to admit, it was only after college that i realized neuroscientists study squid giant axons not giant squid axons. influential boyhood movie I guess.

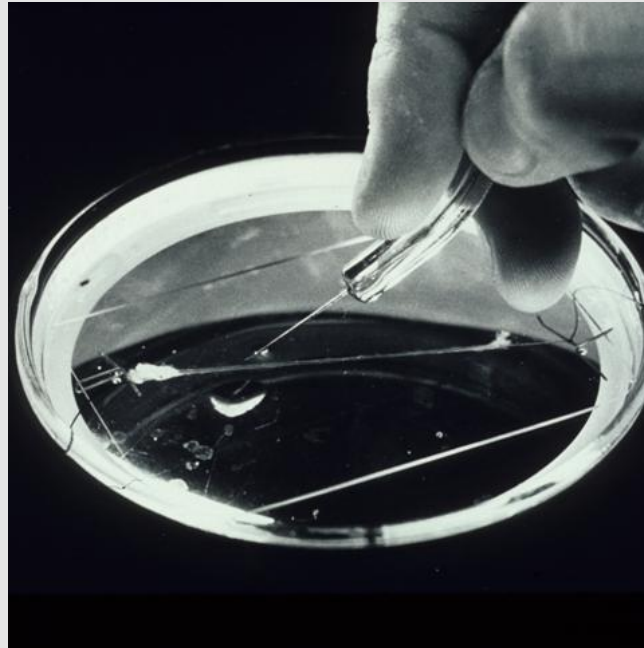
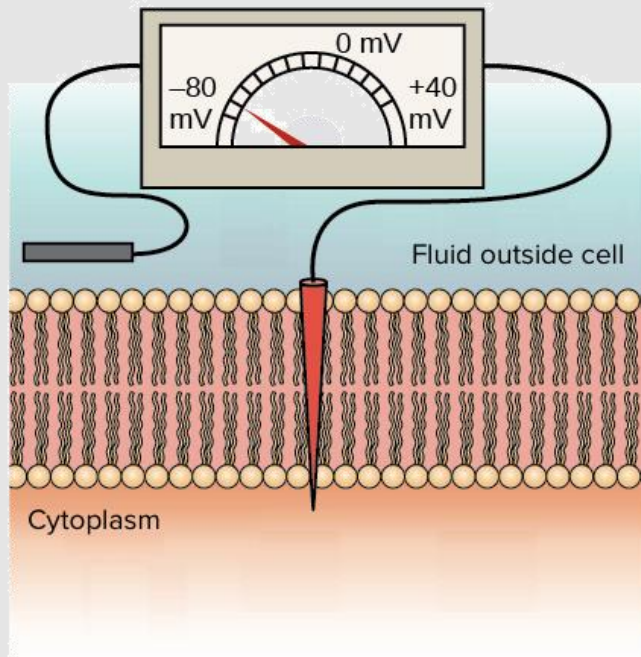


itcamefromblog.com

Behind the Scenes of Disney's '20,000 Leagues Under the Sea'

A look behind the scenes of Disney's 1954 live-action hit based on the Jules Verne classic novel.

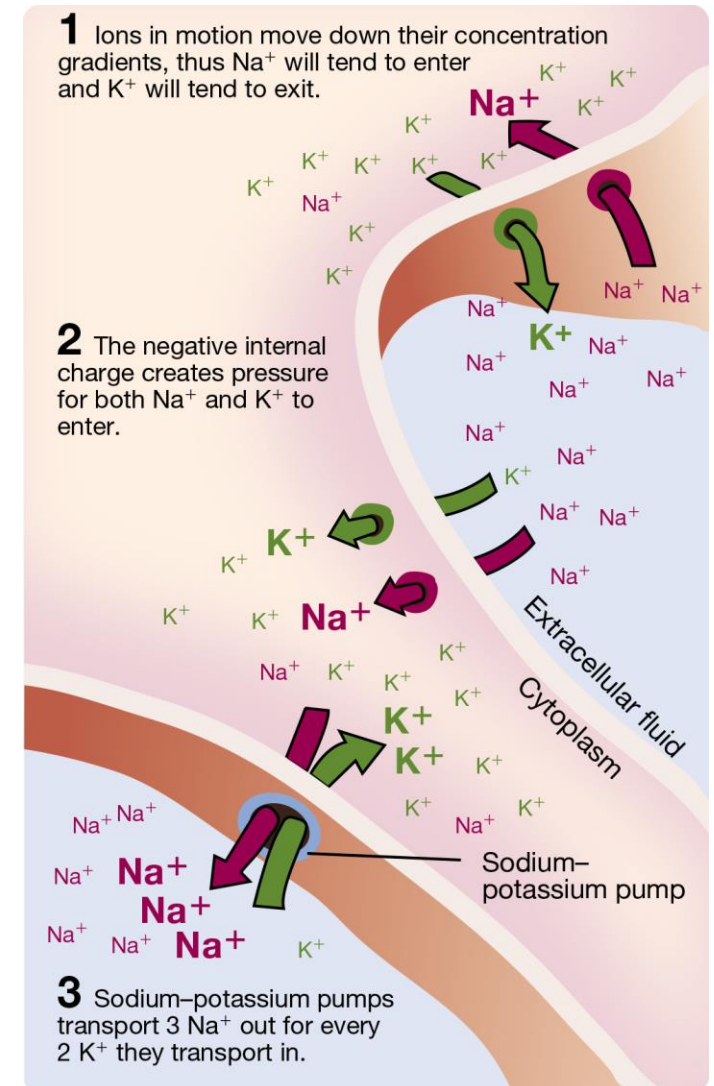
# Recording the Membrane Potential



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

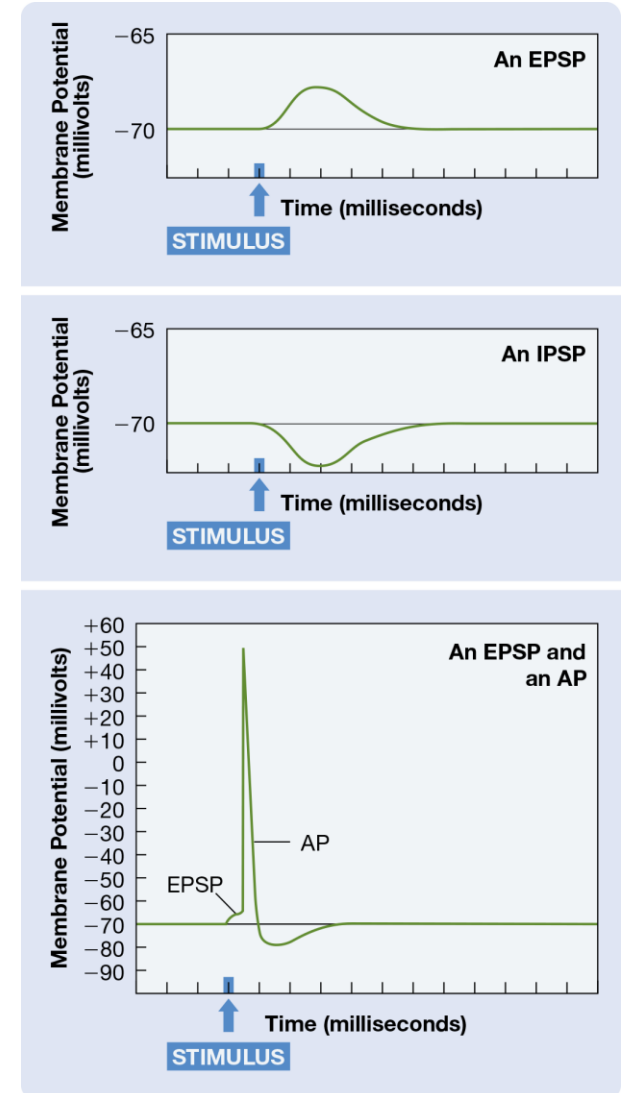
# Ionic Basis of the Resting Potential

- Concentrations of Ions
  - $\text{Na}^+$
  - $\text{K}^+$
- Diffusion pressure
- Electrostatic pressure
- Ion channels
- Sodium-potassium pump

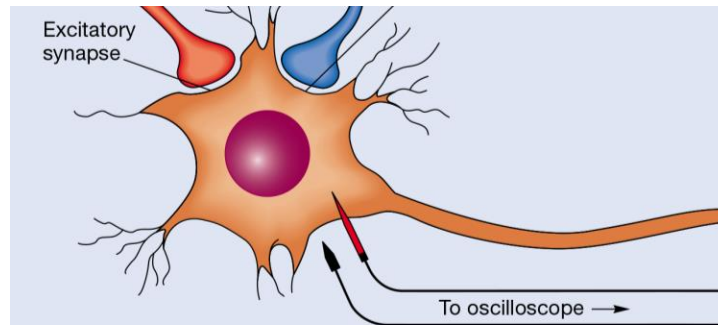
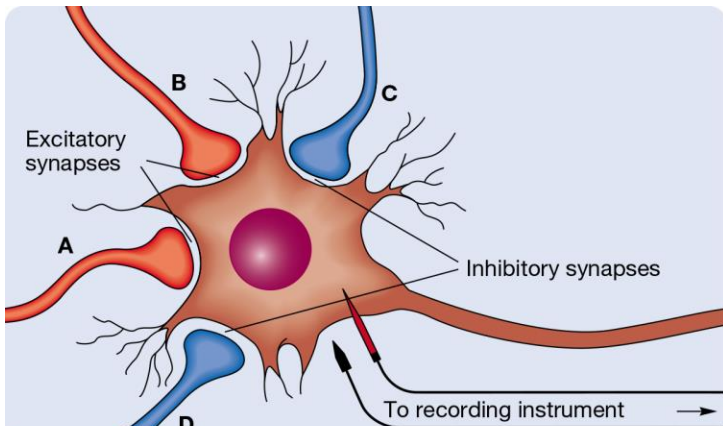


# Generation and Conduction of Postsynaptic Potentials

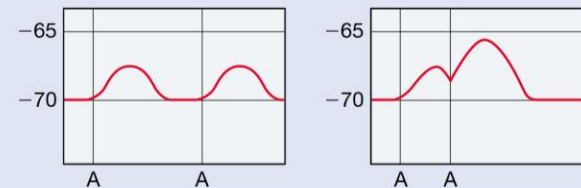
- Postsynaptic potentials
  - Role of neurotransmitter and presynaptic neuron
- Excitatory postsynaptic potentials (EPSPs)
- Inhibitory postsynaptic potentials (IPSPs)
- Three important properties
  - Graded
  - Decremental
  - Transmission is rapid



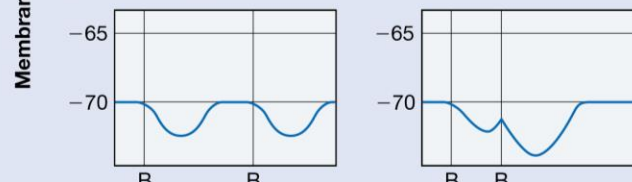
# Integration of Postsynaptic Potentials and Generation of Action Potentials



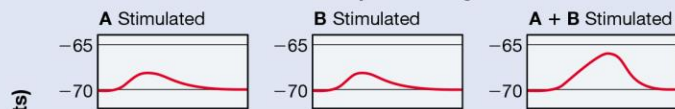
Two EPSPs elicited in rapid succession sum to produce a larger EPSP



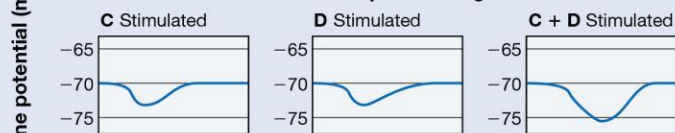
Two IPSPs elicited in rapid succession sum to produce a larger IPSP



Two simultaneous EPSPs sum to produce a greater EPSP



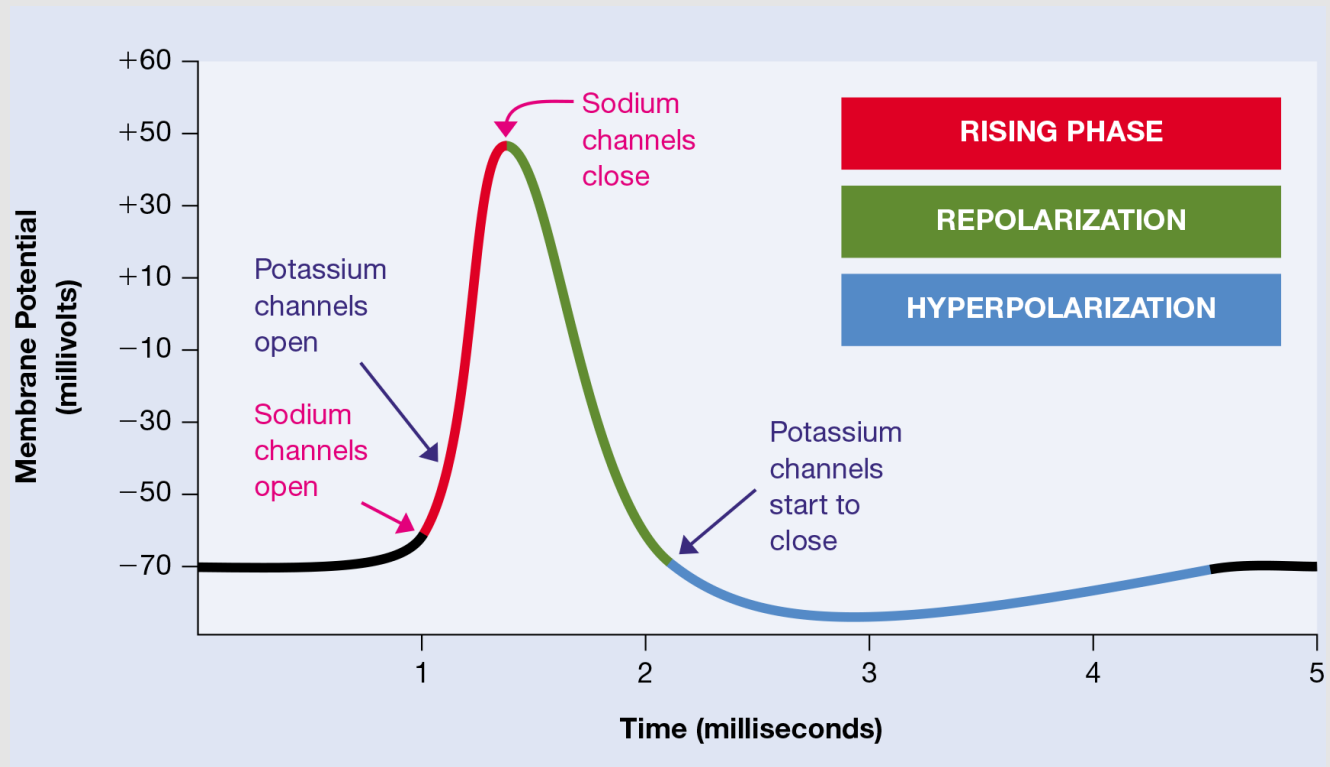
Two simultaneous IPSPs sum to produce a greater IPSP



A simultaneous IPSP and EPSP cancel each other out

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

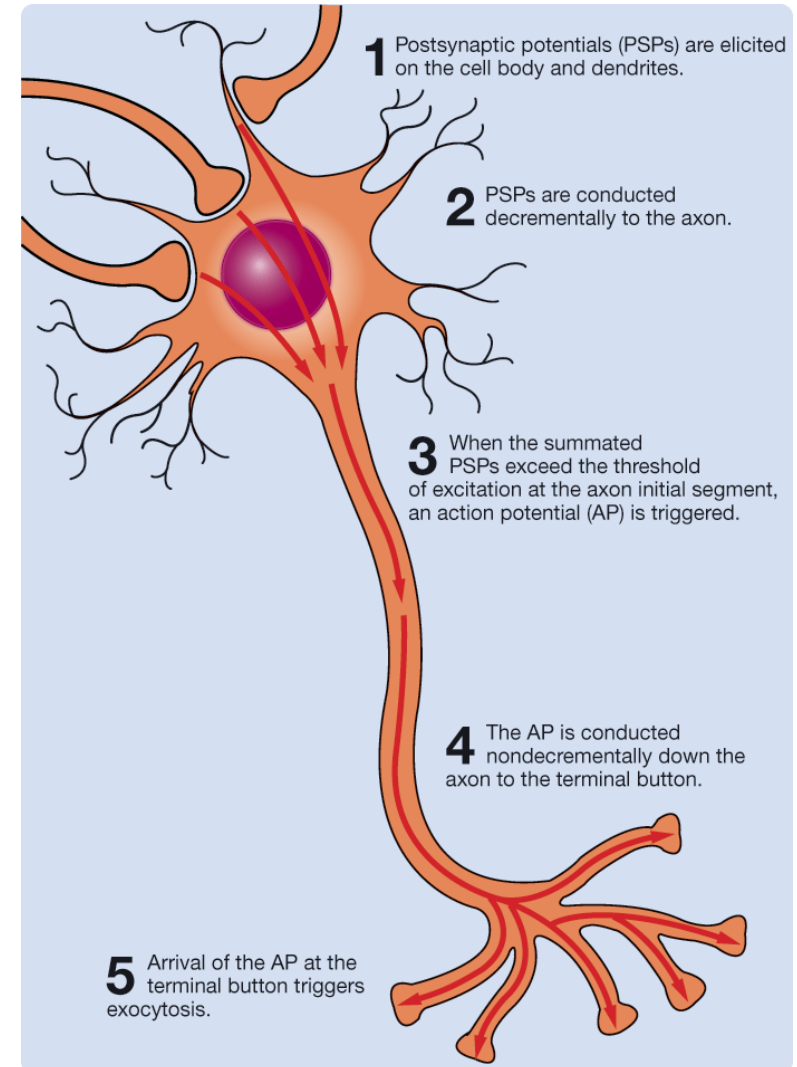
# Ionic Basis of Action Potentials



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

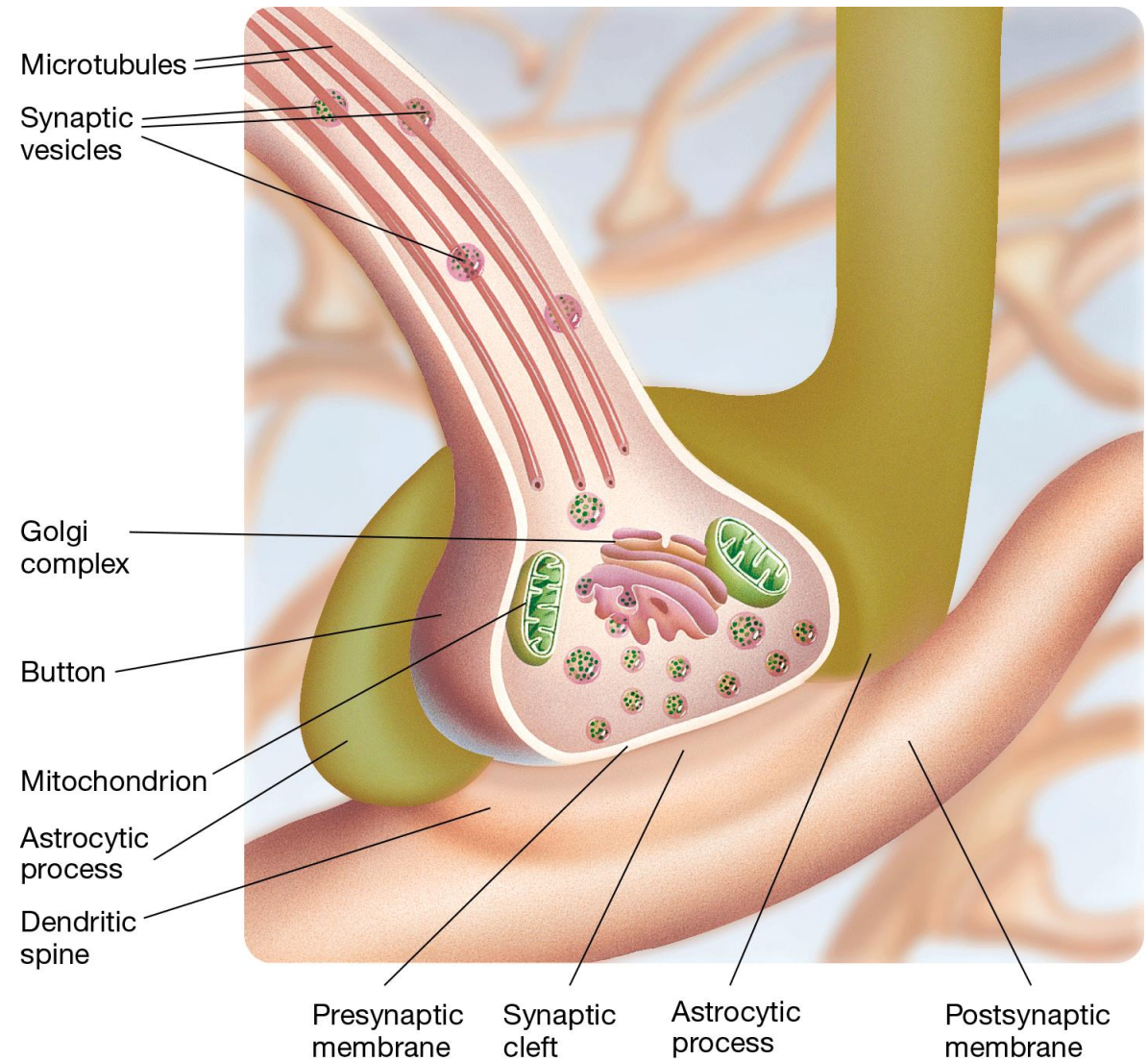
# Axonal Conduction of Action Potentials

- Conduction of action potentials
  - Active, slower, non-decremental
- Diffusion of  $\text{Na}^+$  triggers next action potential
- $\text{Na}^+$  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

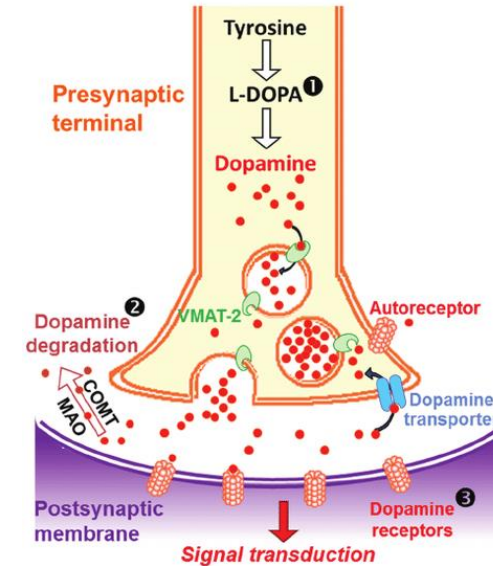
- Dendritic spines
- Types
  - Axosomatic
  - Axodendritic
  - Axoaxonic
  - Dendrodendritic
  - Dendroaxonic
  - Synapses between main shafts
  - Nondirected synapses
- Presynaptic Inhibition
- Postsynaptic Inhibition
- Directed and non-directed synapses



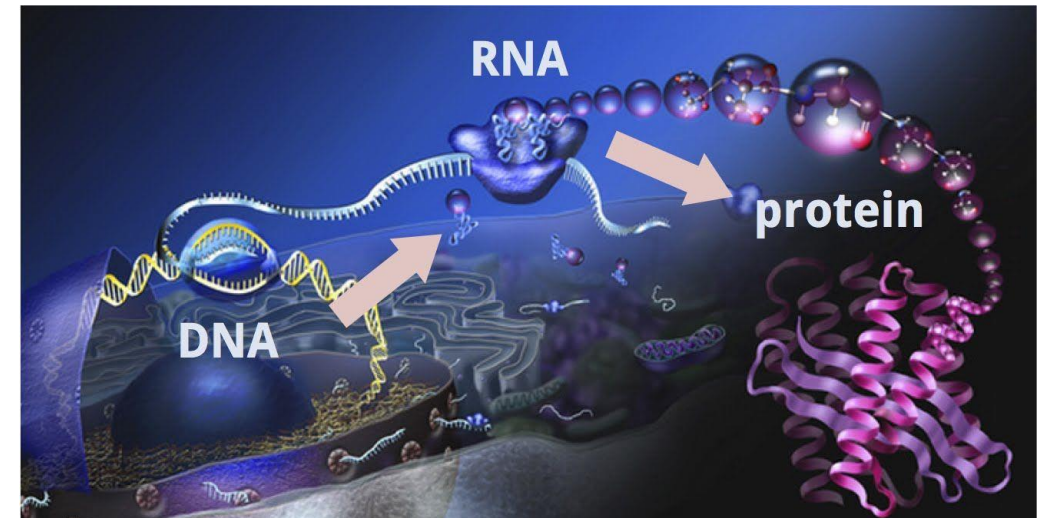
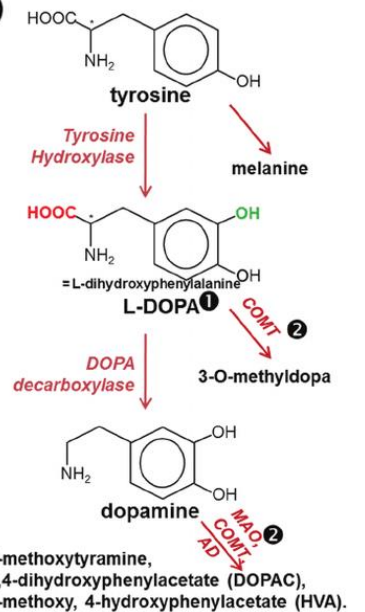
# Synthesis, Packaging, and Transport of Neurotransmitters

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

(a) Dopaminergic synapse

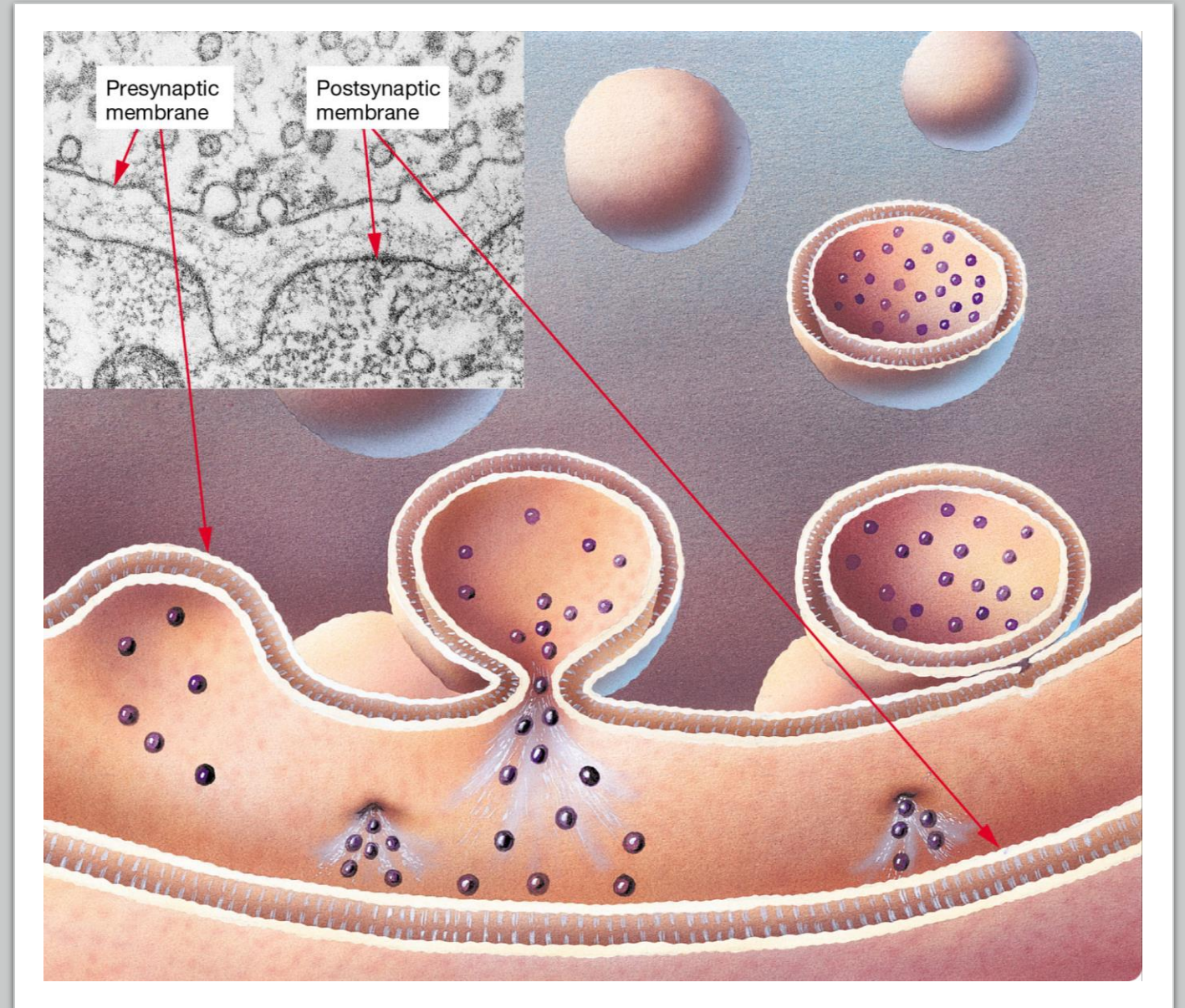


(b)



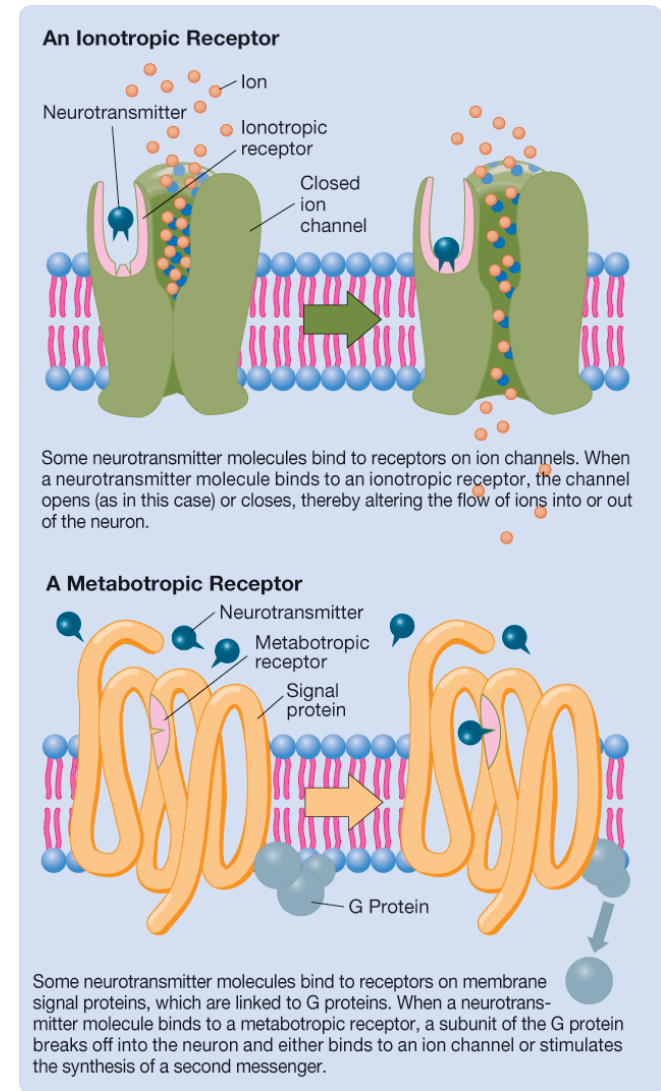
# Release of Neurotransmitters

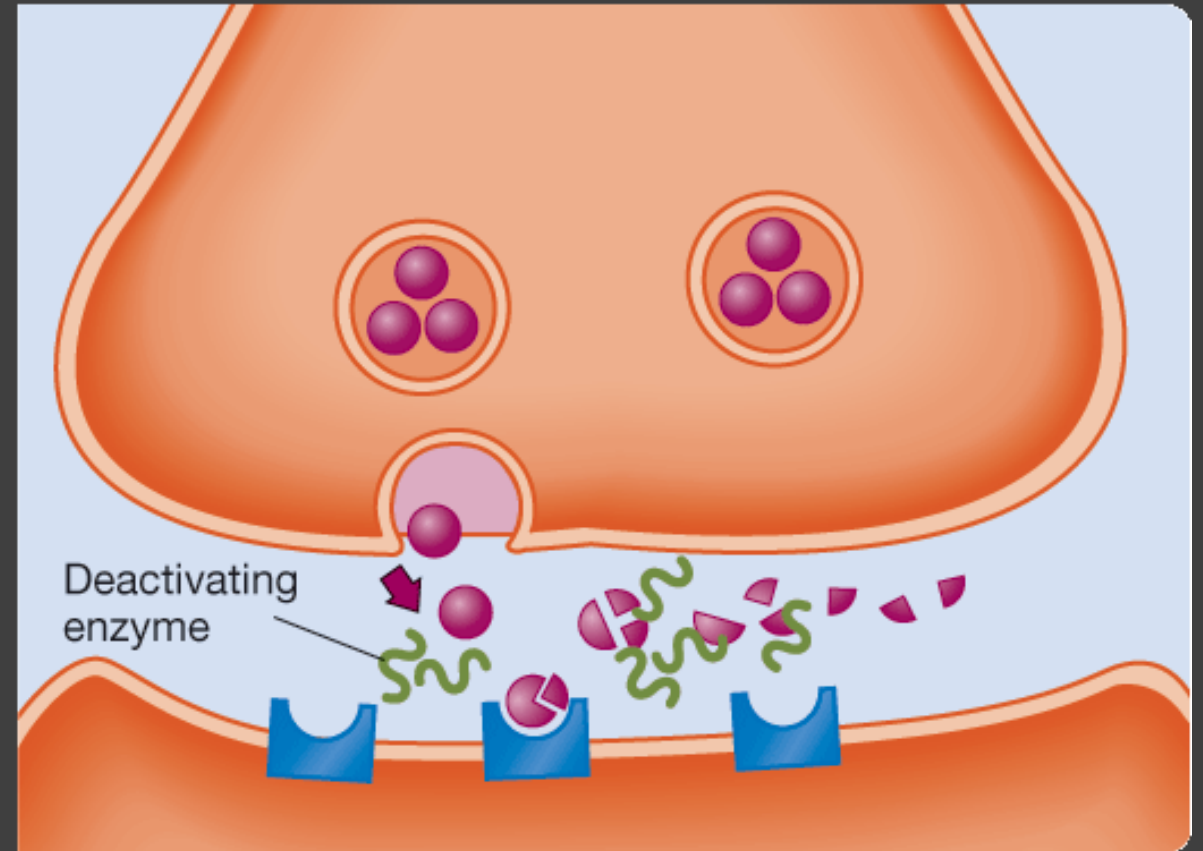
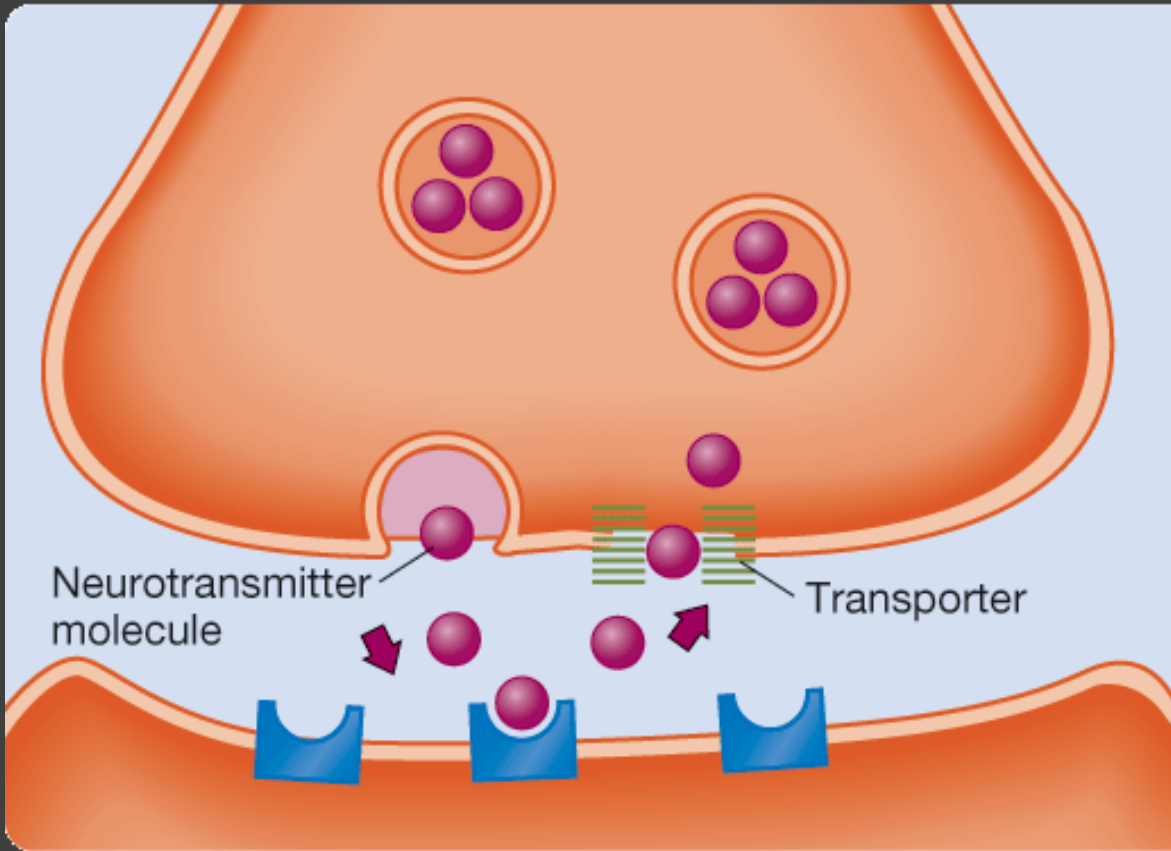
- AP arrives at terminal buttons
- Voltage-gated calcium channels open
- $\text{Ca}^{2+}$  enters
- Synaptic vesicles fuse and empty contents (exocytosis)
- Coexistence (neurotransmitter/neuropeptide)



# 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

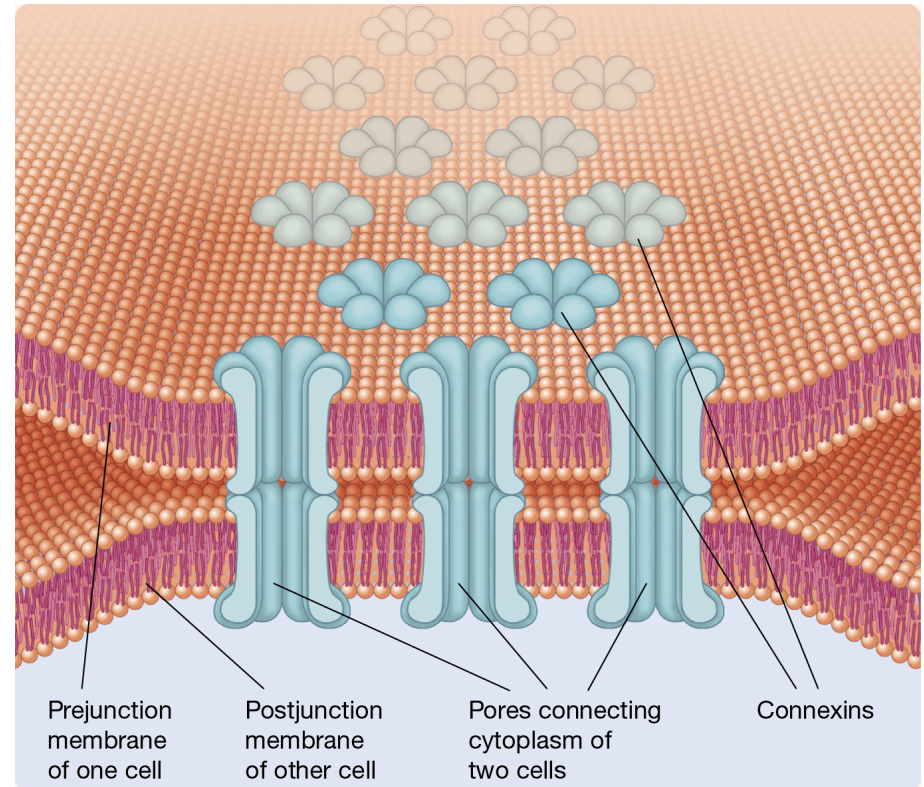
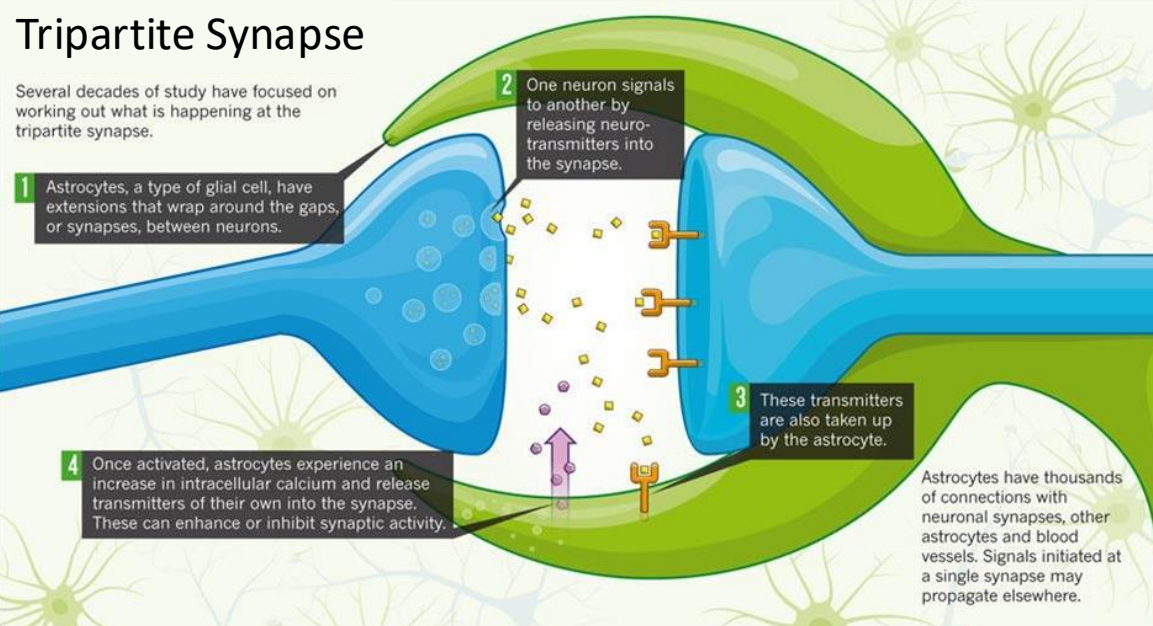
- Two message-terminating mechanisms
  - Enzymatic degradation
  - Reuptake by transporters

# Glia, Gap Junctions, and Synaptic Transmission

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

## Tripartite Synapse

Several decades of study have focused on working out what is happening at the tripartite synapse.



# Overview of the Neurotransmitter Classes

## Small-Molecule Neurotransmitters

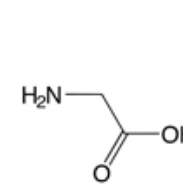
Amino acids		Glutamate Aspartate Glycine GABA
Monoamines	Catecholamines	Dopamine Epinephrine Norepinephrine
	Indolamines	Serotonin
Acetylcholine		Acetylcholine
Unconventional neurotransmitters	Soluble gases	Nitric oxide Carbon monoxide
	Endocannabinoids	Anandamide

## Large-Molecule Neurotransmitters

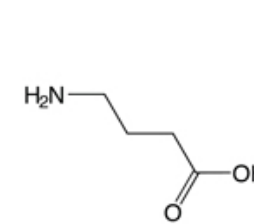
Neuropeptides	Pituitary peptides Hypothalamic peptides Brain-gut peptides Opioid peptides Miscellaneous peptides
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# The Roles and Functions of Neurotransmitters (1 of 3)

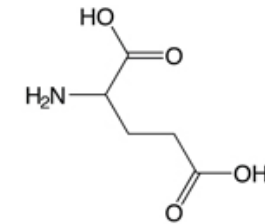
- Amino acid neurotransmitters
  - Fast-acting/point-to-point synapses
  - GABA, glutamate, aspartate, glycine
- Monoamine neurotransmitters
  - Slow, lingering and diffuse effects
  - Arise from brainstem
  - Catecholamines/Indolamines



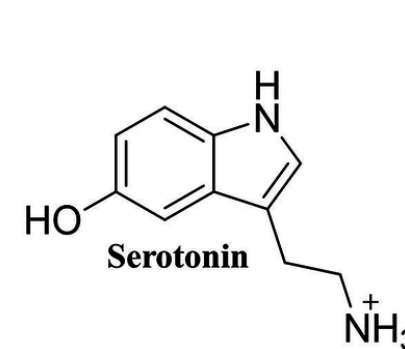
Glycine



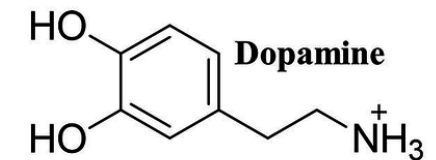
GABA



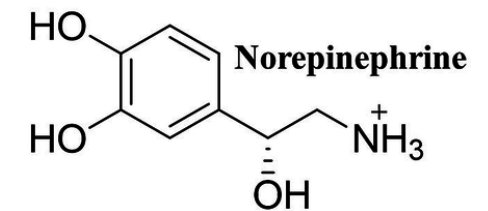
Glutamate



Serotonin



Dopamine

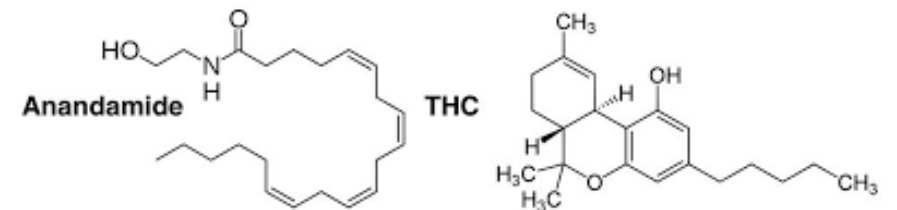
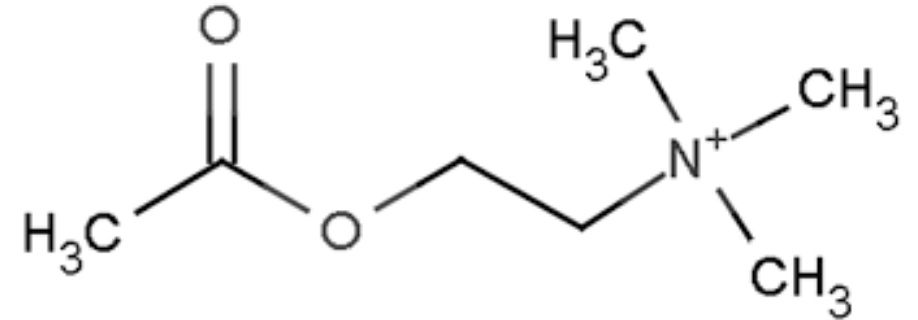


Norepinephrine

# 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

Acetylcholine (ACh)



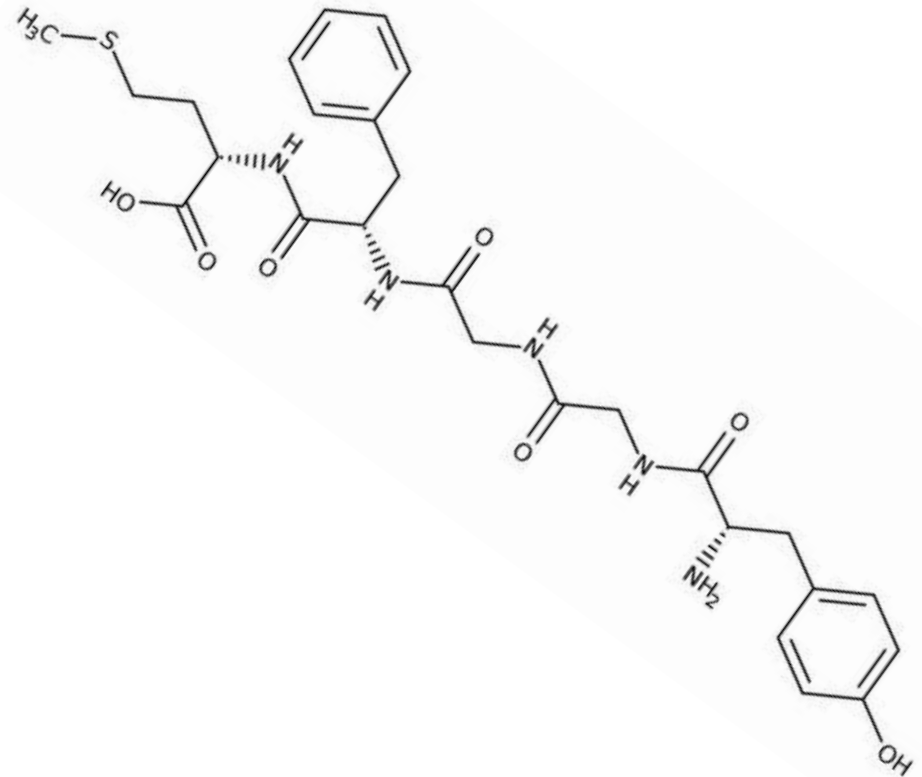
# The Roles and Functions of Neurotransmitters

## (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

## Seven Steps in Neurotransmitter Action

**1** Neurotransmitter molecules are synthesized from precursors under the influence of enzymes.

**2** Neurotransmitter molecules are stored in vesicles.

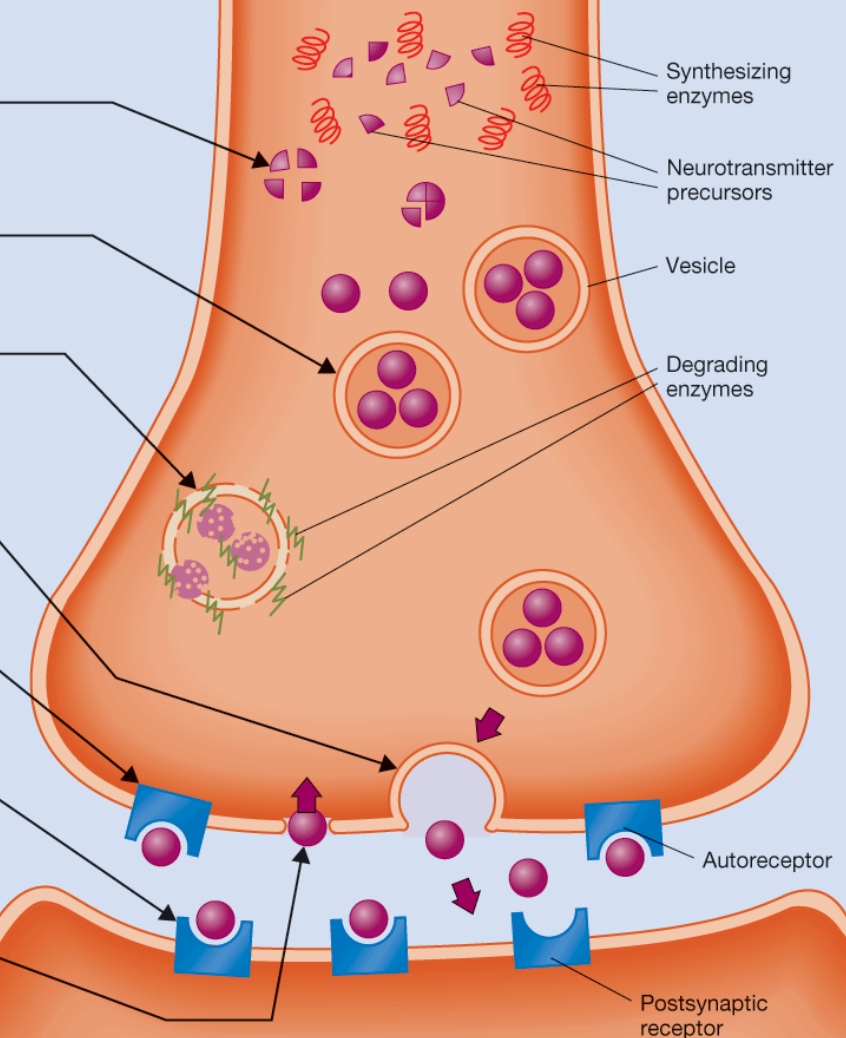
**3** Neurotransmitter molecules that leak from their vesicles are destroyed by enzymes.

**4** Action potentials cause vesicles to fuse with the presynaptic membrane and release their neurotransmitter molecules into the synapse.

**5** Released neurotransmitter molecules bind with autoreceptors and inhibit subsequent neurotransmitter release.

**6** Released neurotransmitter molecules bind to postsynaptic receptors.

**7** Released neurotransmitter molecules are deactivated by either reuptake or enzymatic degradation.

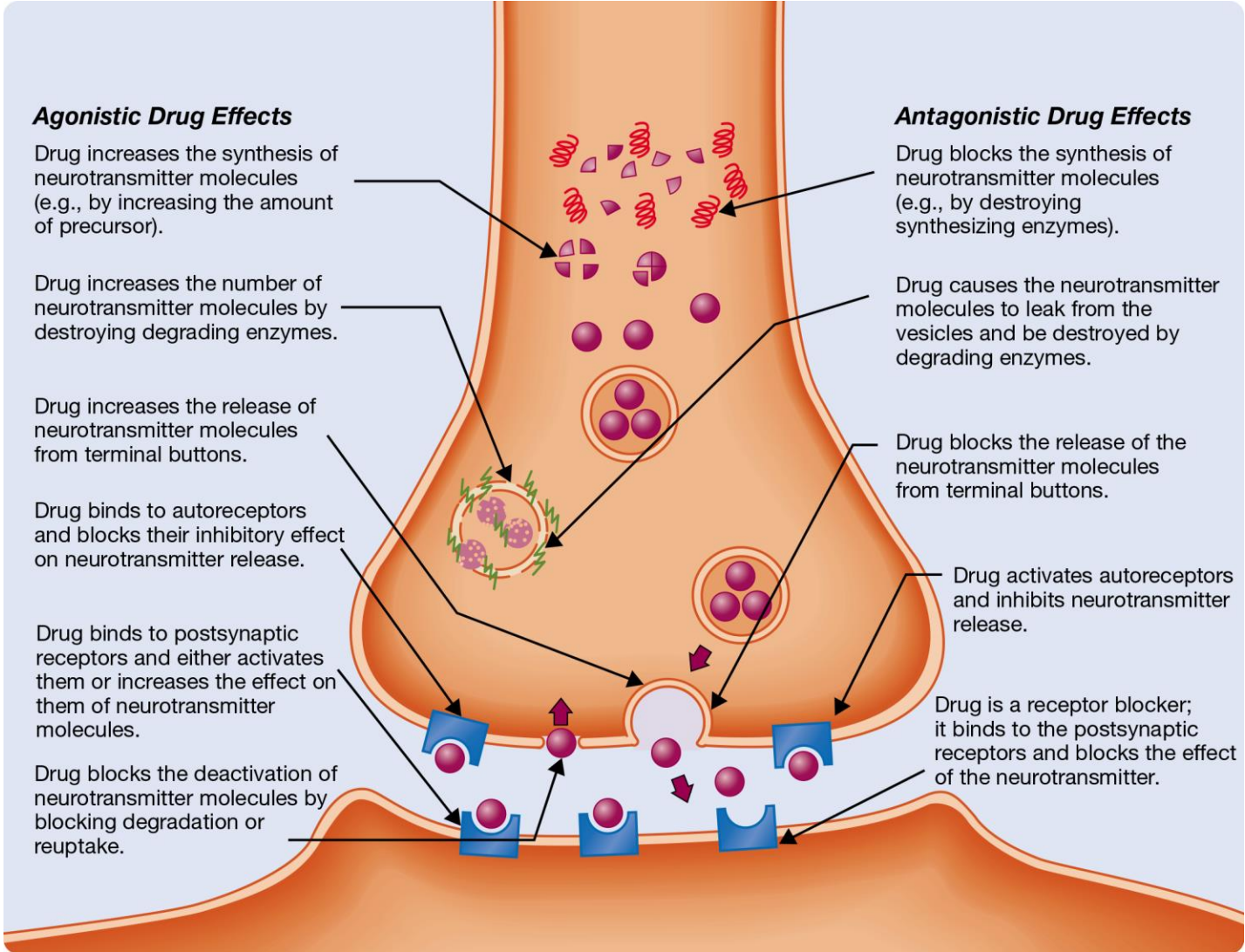


# Mechanisms of Drug Action

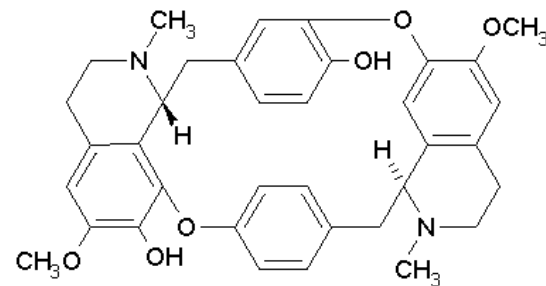
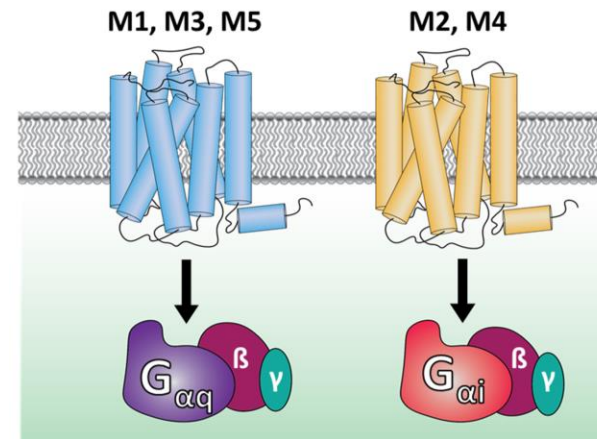
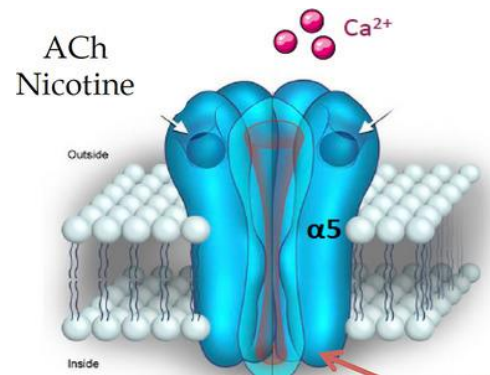
## AGONIST

VS.

## ANTAGONIST



# Behavioral Pharmacology: Discovery of Receptor Subtypes



# Behavioral Pharmacology: Discovery of Endogenous Opioids

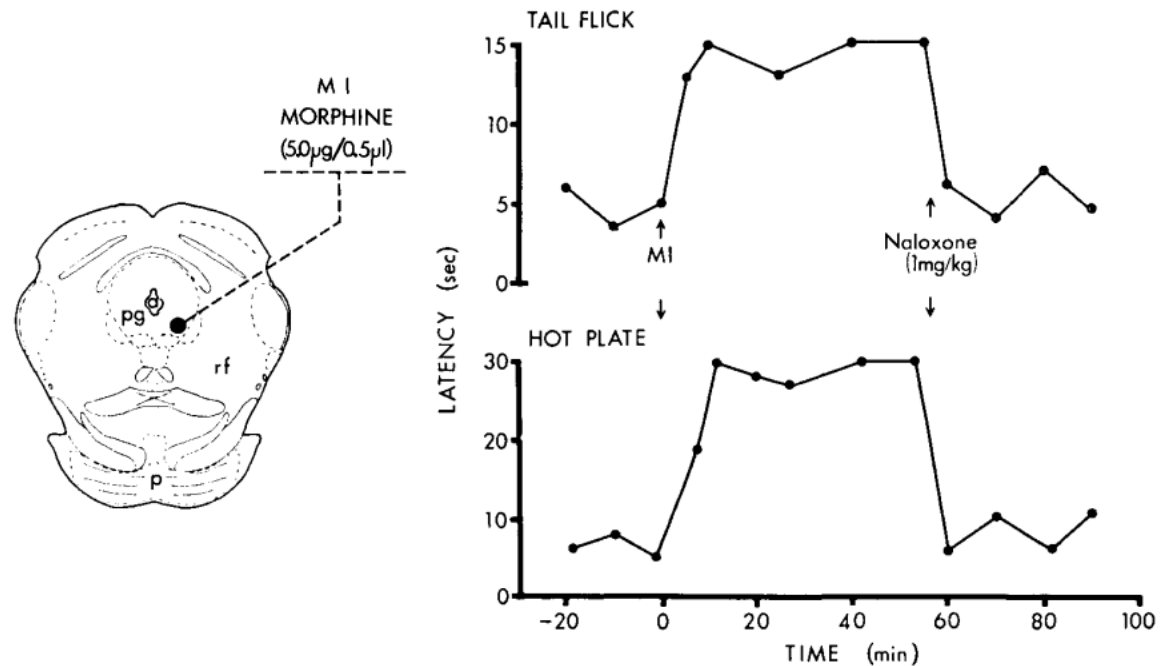
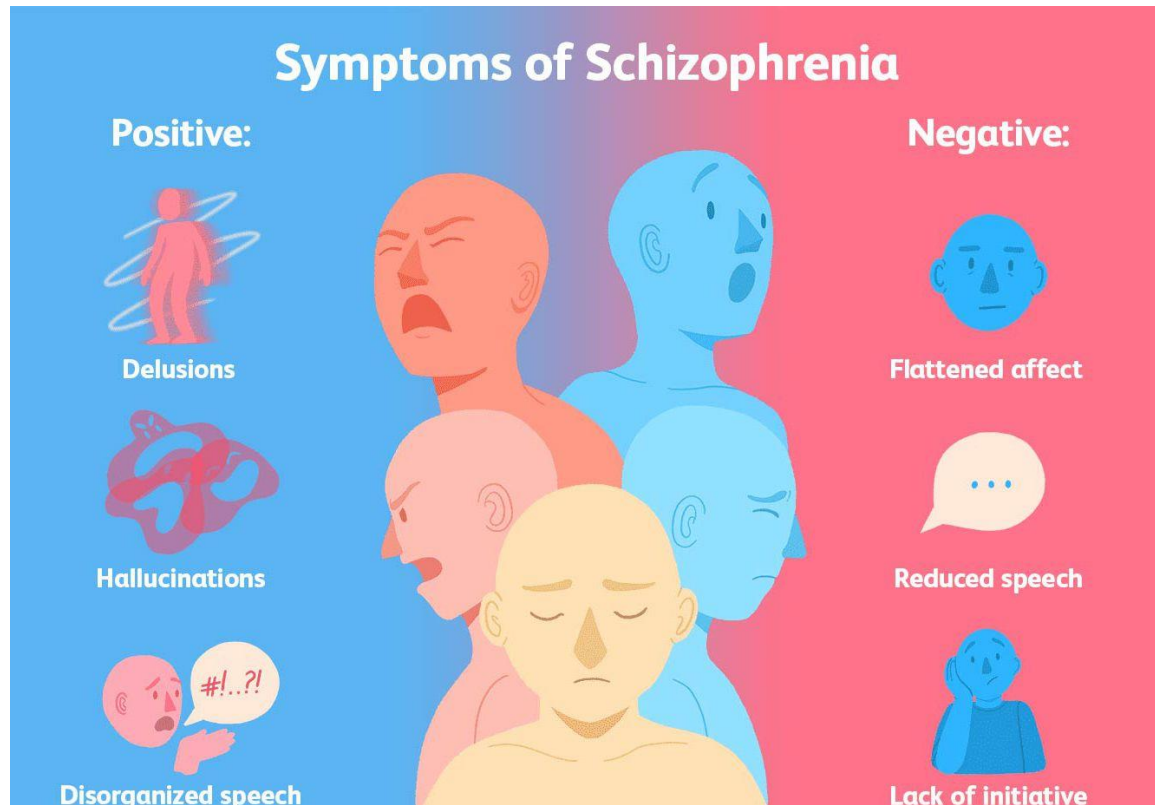


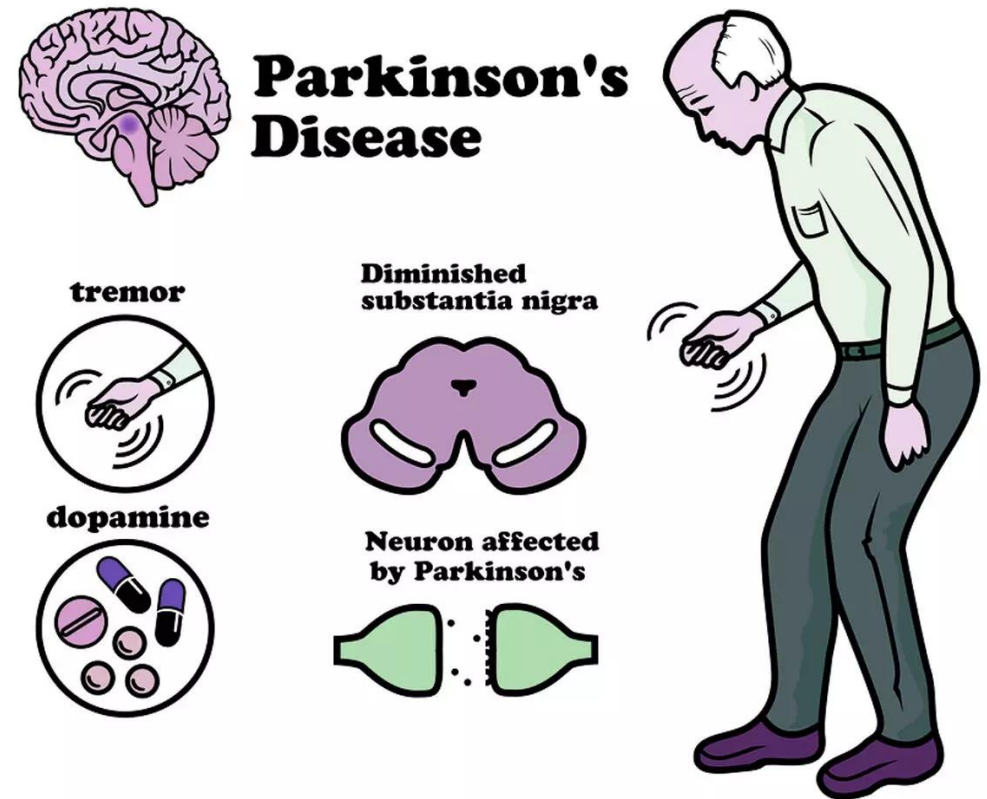
Fig. 1. The effect of an intracerebral injection of morphine sulfate ( $5 \mu\text{g}/0.5 \mu\text{l}$ ) at the first arrow (MI) into the site indicated in the adjacent coronal section on the tail flick (top) and hot plate (bottom) is shown. Naloxone hydrochloride ( $1 \text{ mg/kg}$ , i.p.) was given 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)