

The Brain, Biology and Cognition

Neural Conduction and Synaptic Transmission

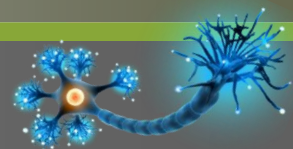
Dr Kate Williams



How are signals made in a neuron?



- Neurons work through Membrane potential:
 - Difference in electrical charge between inside and outside of cell.
- Membrane potential recorded with electrodes (electrical conductors: intra and extra cellular).
- Inside neuron is negative compared to outside
- Resting membrane potential is about -70mV
- Membrane is said to be *polarized*: carries a charge



Ions Contributing to Resting Potential



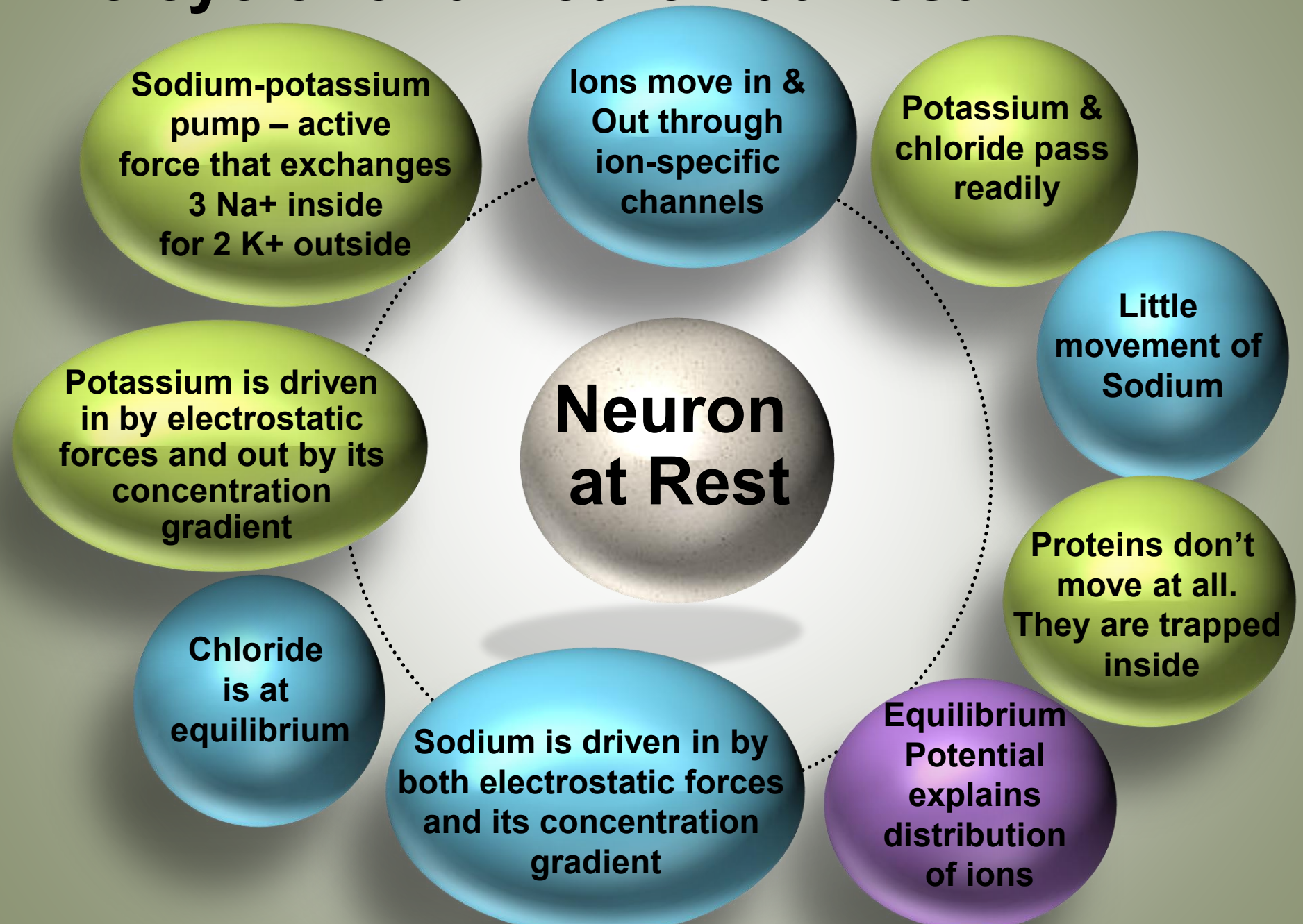
- Neurons are polarized because particles are separated into +ve & -ve charged particles called ions – 4 ions that contribute are:

- 1 Sodium (Na^+)
- 2 Chloride (Cl^-)
- 3 Potassium (K^+)
- 4 Negatively charged proteins (A^-)
Synthesized within the neuron, found primarily within the neuron

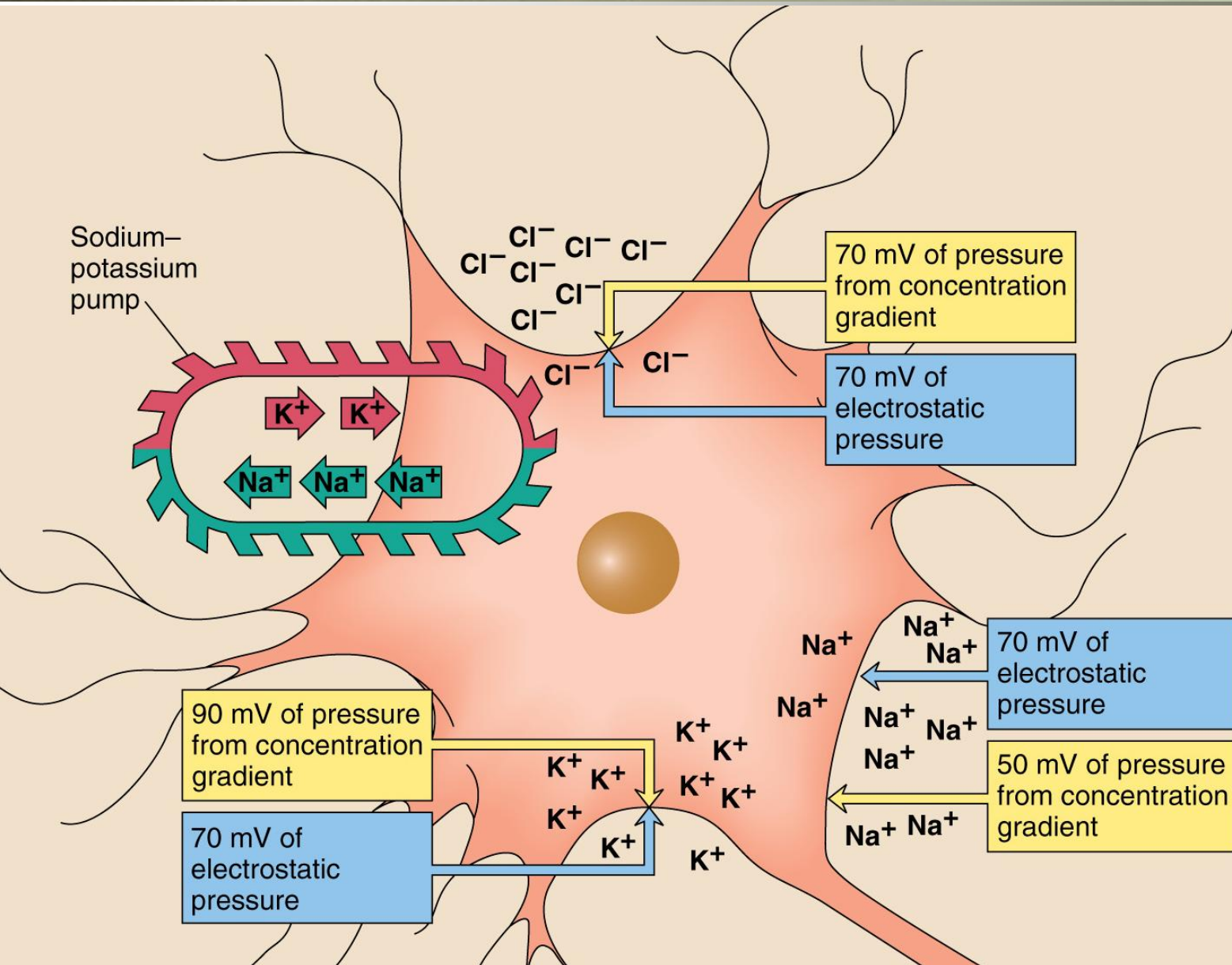
- Unequal balance of charges due to interaction of 4 factors.
 1. Homogenizing (equalizing) factor of random motion.
 2. Electrostatic pressure: + & – charges disperse same charges & attract opposite charges (like magnets).
 3. Differences in permeability of ions (ability to pass membrane).
 4. Equilibrium Potential: active, energy-consuming process involved in maintenance of resting potential.

Hodgkin-Huxley model

The cycle for a Neuron at Rest



The Neural Membrane



The passive and active factors that influence the distribution of Na^+ , K^+ , and Cl^- ions across the neural membrane

Hodgkin-Huxley model

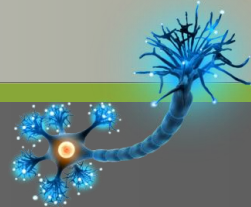
Generation and Conduction of Postsynaptic Potentials (PSPs)



Neurons pass messages through “firing”: releasing neurotransmitter chemicals.

Neurotransmitters bind at postsynaptic receptors and cause electrical changes

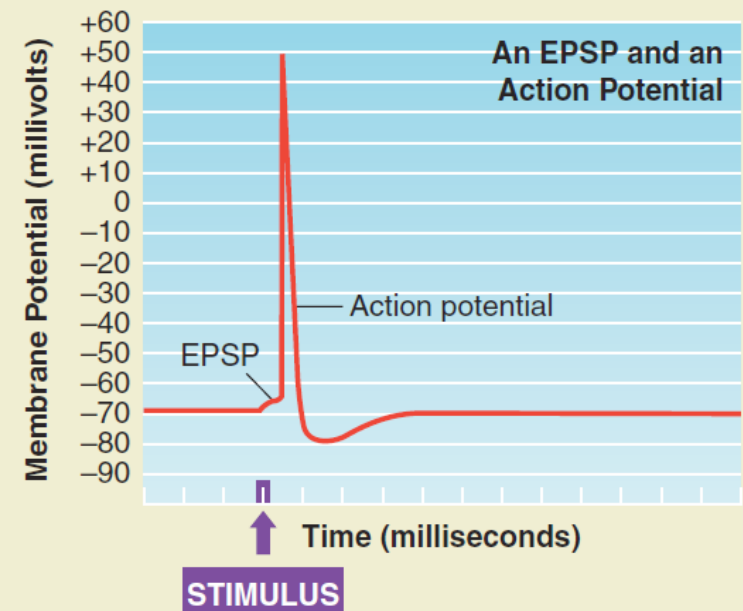
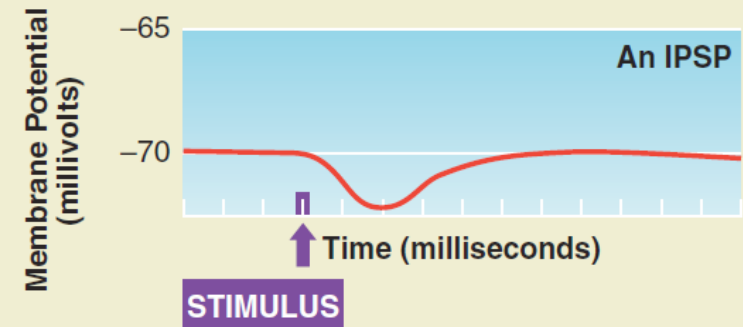
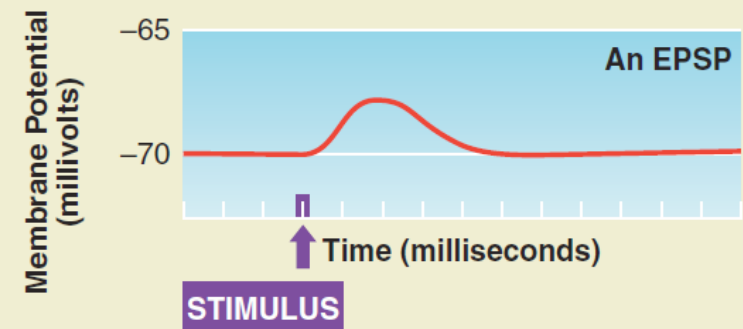
- **Depolarization: make membrane potential less negative – Excitatory (EPSPs: increase neuron fire)**
- **Hyperpolarization: make membrane potential more negative – Inhibitory (IPSPs decrease neuron fire)**
- **Both are graded responses: amplitude is the same as the intensity of the signal that elicits them**
 - **Weak signal = small potential; strong = large.**



Integration of Postsynaptic Potential and Generation of Action Potentials

EPSPs and IPSPs

- Travel passively from site of origination
- Get smaller as they travel (decremental)
- One EPSP not sufficient to cause neuron to “fire” and release neurotransmitter – summation is needed
- To generate an AP (or “fire”), the threshold of activation must be reached near the axon hillock
- Integration of IPSPs and EPSPs must result in a potential of about -65mV in order to generate an AP.

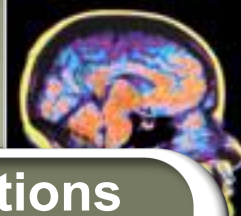


Integration

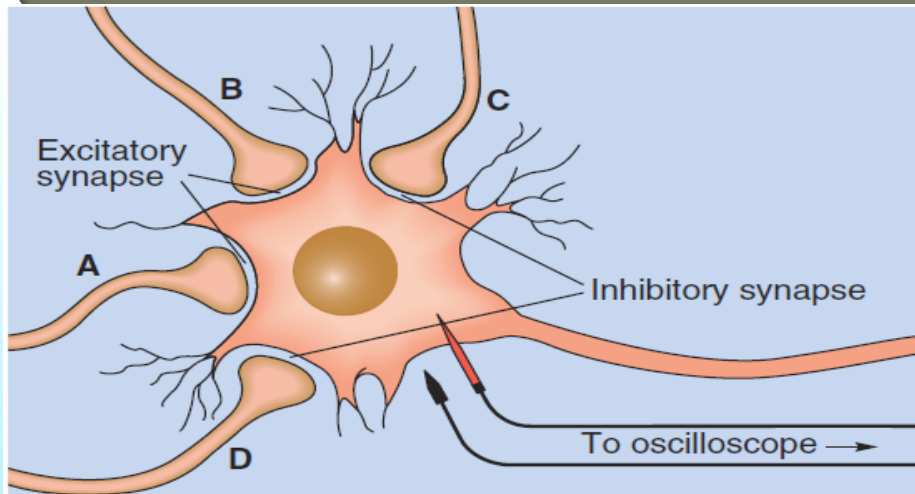


- **Adding or combining several individual signals into one overall signal = integration.**
- **Spatial summation = integration of events happening at different places**
- **Temporal summation = integration of events happening at different times**

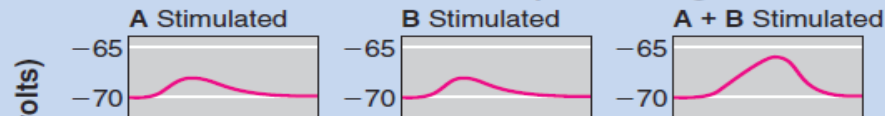
Integration



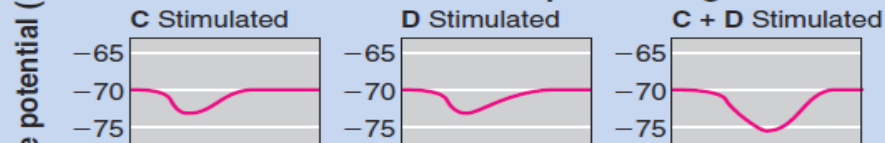
Three possible combinations of spatial summation



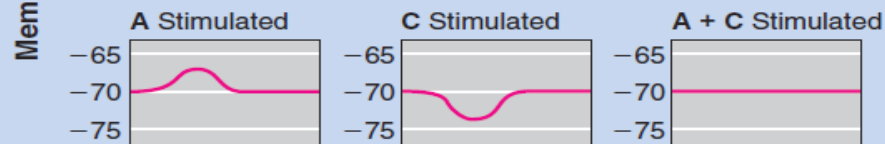
Two simultaneous EPSPs sum to produce a greater EPSP



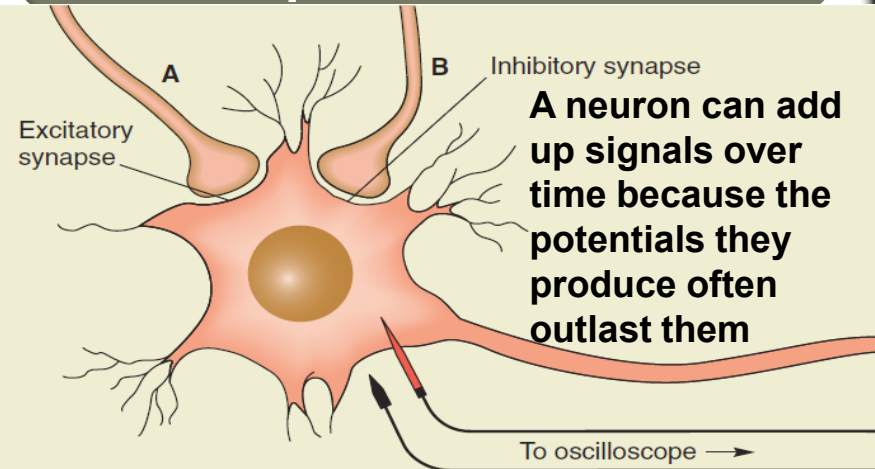
Two simultaneous IPSPs sum to produce a greater IPSP



A simultaneous IPSP and EPSP cancel each other out

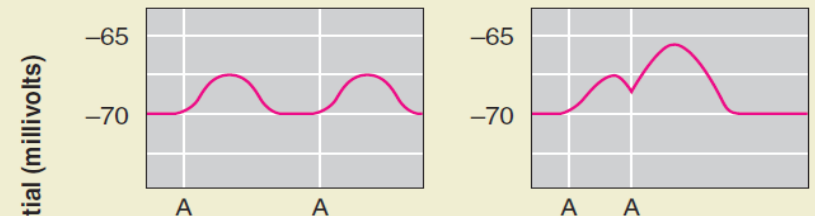


Two possible combinations of temporal summation.

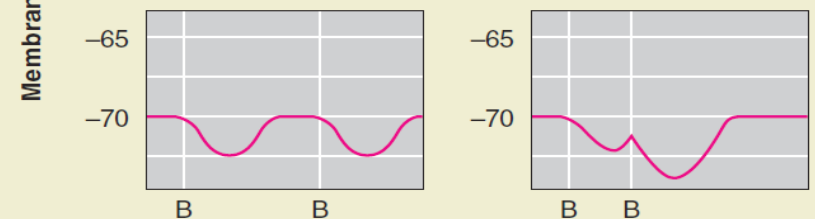


A neuron can add up signals over time because the potentials they produce often outlast them

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



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



Conduction of Action Potentials

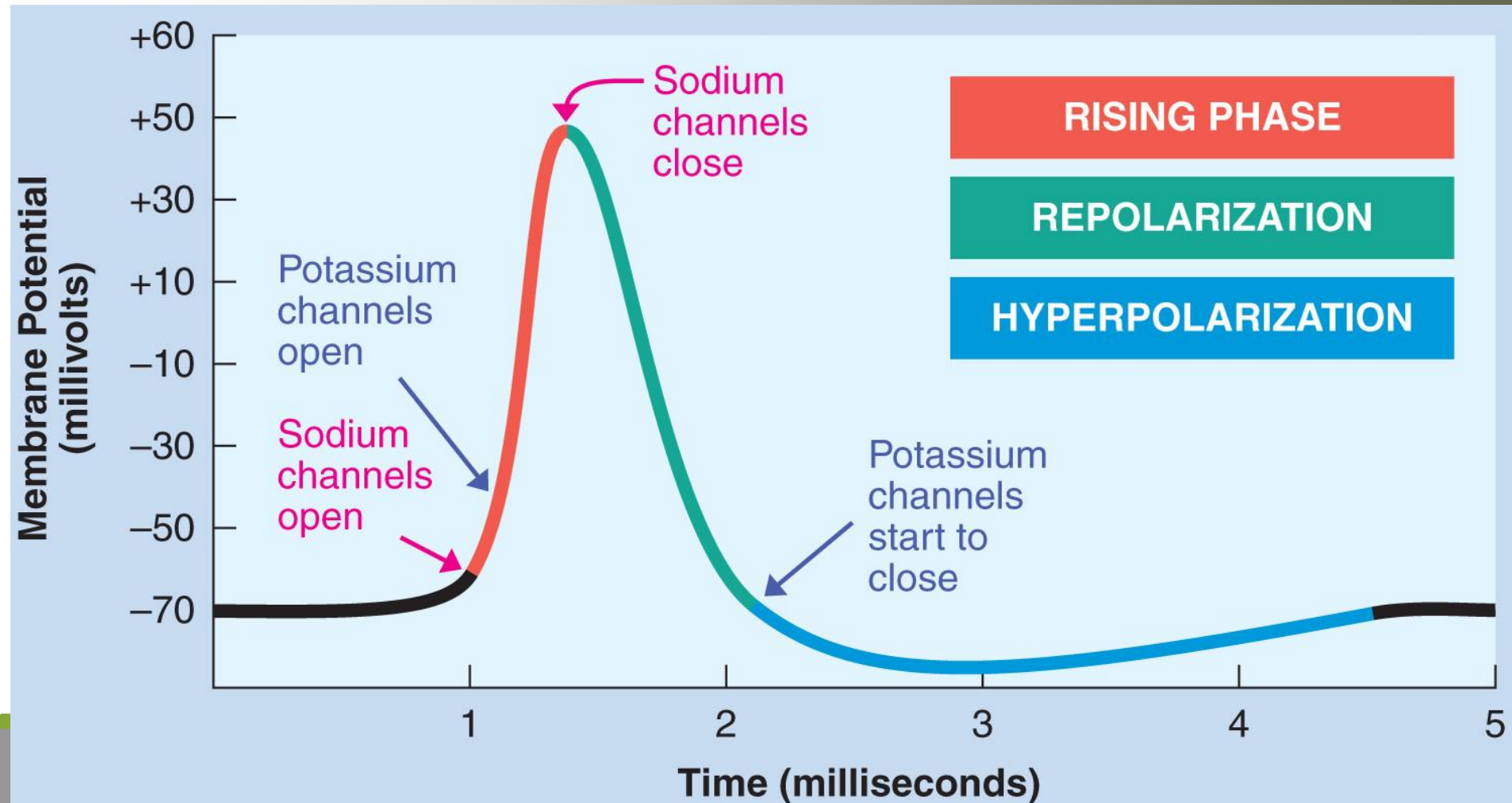


- **When threshold is reached the neuron “fires” and the action potential either occurs or not**
 - **All-or-none effect**
- **When threshold is reached, voltage-activated ion channels are opened**

Sodium and Potassium Channels



The opening and closing of voltage-activated sodium and potassium channels during the three phases of the action potential: rising phase, repolarization, and hyperpolarization.

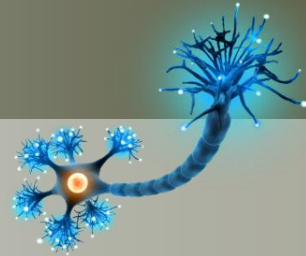


Refractory Periods



After an AP starts, 1 to 2 milliseconds where another cannot be started

The absolute refractory period.



This is followed by relative refractory period:

Time when possible for neuron to fire again but at more difficult rate with above normal levels of stimulation.

Refractory period prevents backwards movement of APs and limits rate of firing.

Post Synaptic Potential vs. Action Potential



PSPs

EPSPs/IPSPs

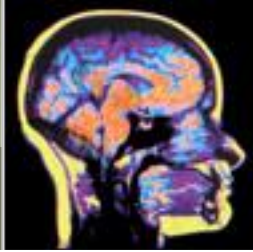
- **Decremental**
- **Fast**
- **Passive (energy is not used)**

APs

Action Potentials

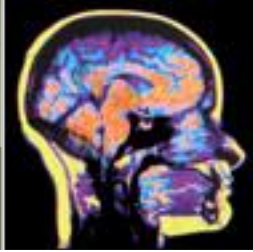
- **Nondecremental**
- **Conducted more slowly than PSPs**
- **Passive and active**

Axonal Conduction of Action Potentials



- **Once AP is generated it travels passively along axonal membrane to the next voltage-activated sodium channel.**
- **Arrival of this signal opens the channel and sodium rushes into the neuron to generate an AP.**
- **The signal is then carried passively to the next sodium channel where another AP is activated.**
- **This keeps happening until a full-blown AP is triggered in all terminal buttons.**
- **A single wave spreading at constant speed along the axon.**

Axonal Conduction of Action Potentials



- Once AP reaches Terminal buttons it triggers exocytosis.
- Axons of some neurons are insulated with myelin
 - Thus, ions can pass through axonal membrane at nodes of Ranvier (gaps between adjacent myelin segments)
- When an AP is generated in a myelinated axon, the signal is conducted passively, its instant and decremented along the first segment of myelin to the next node of Ranvier.
- This signal diminishes as it moves along but is strong enough to open the voltage-activated sodium channels at the next node to generate the next AP.

Velocity and Conduction



Velocity of Axonal Conduction

Maximum velocity of conduction in human motor neurons is about 60 meters per second

Conduction in Neurons without Axons

Conduction in interneurons is typically passive and decremental

The Hodgkin-Huxley Model in Perspective



- **Based on motor neurons of squids**
- **Considered a theory.**
- **Provides simple and effective explanation of how neurons conduct signals.**
- **However, is not representative of variety, complexity, and plasticity of many of the neurons seen in the brains of a mammal.**
 - **E.g., cerebral neurons fire continually without any input, do not have axons and do not display action potentials.**

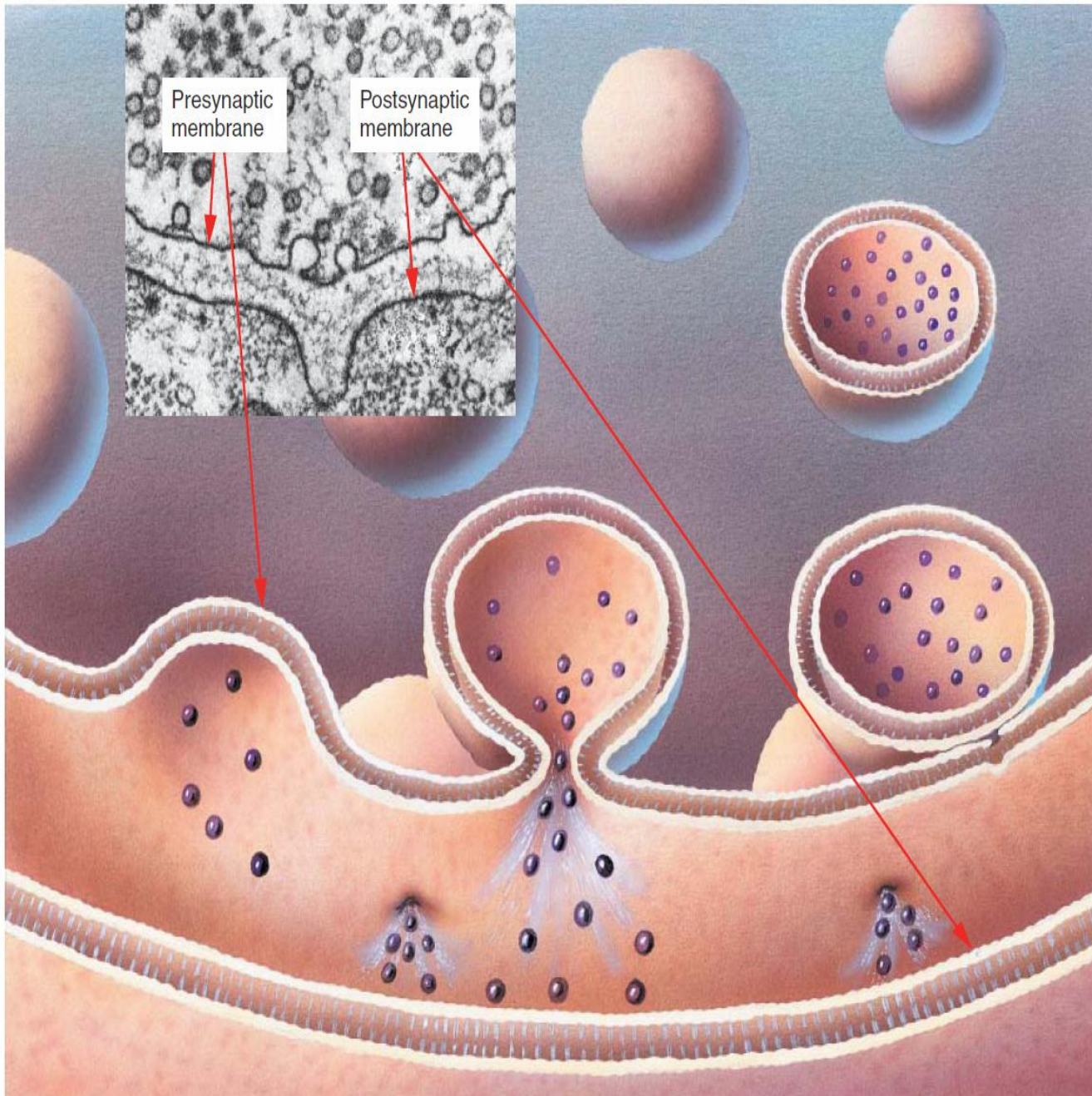
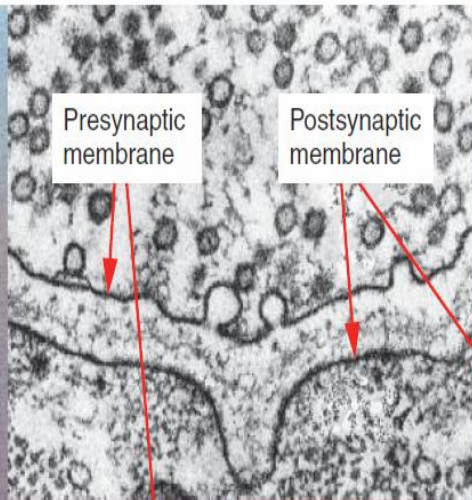
Synthesis, Packaging, and Transport of Neurotransmitter Molecules



Neurotransmitter Molecules are either:

- **Small: synthesized in terminal button & packaged in synaptic vesicles by golgi complex.**
- **Large: assembled in cell body on ribosomes, packaged in vesicles by golgi complex, and transported in microtubules to axon terminal.**
- **Many neurons contain 2 neurotransmitters (coexistence)**

Release of Neurotransmitter (NT) Molecules



Exocytosis – the process of NT release

The arrival of an AP at the terminal opens voltage-activated Ca^{2+} channels

The entry of Ca^{2+} causes vesicles to fuse with the terminal membrane and release their contents

Schematic and photographic illustrations of exocytosis.

Activation of Receptors by NT Molecules



- Released NT molecules produce signals in postsynaptic neurons by binding to receptors
- Each site receiving neurotransmitters is a specialized protein that will only receive one type of NT.
- A NT is a ligand of its receptor
- Ligand = a molecule that binds to another

Receptors



- Most NTs can bind to several types of receptors.
- Advantage: one NT can transmit different messages throughout different parts of the brain.
- Once bound it can influence the postsynaptic neuron in 1 of 2 ways depending on whether the receptor is....
- Ionotropic: associated with ligand-activated ion channels
- Metabotropic: associated with signal proteins and G proteins

See Pinel book for illustration

Reuptake, Enzymatic Degradation, & Recycling

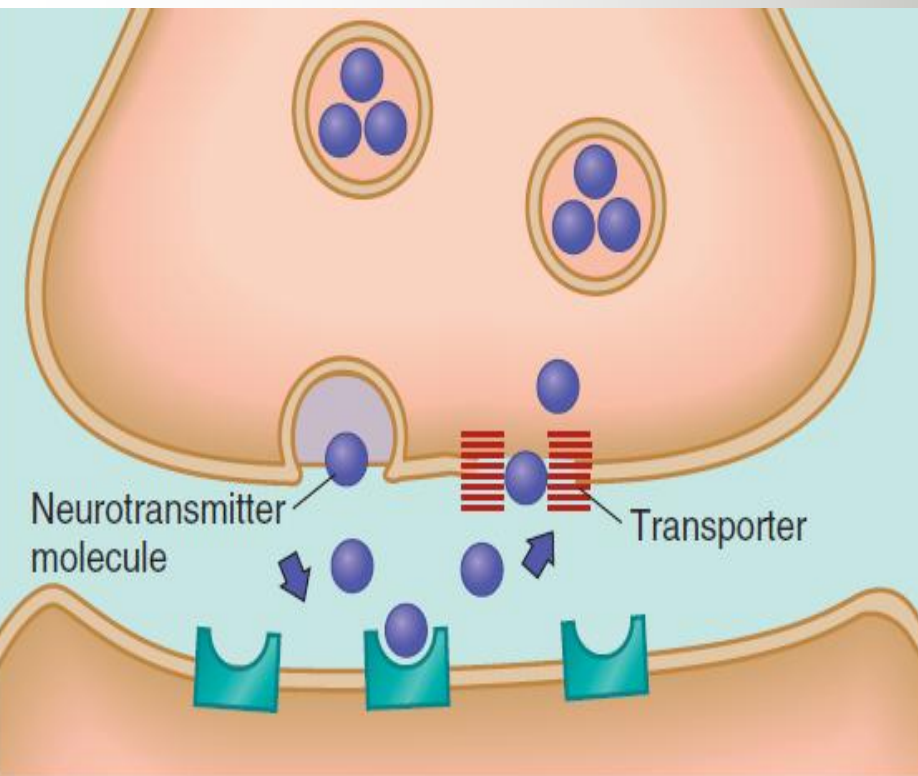


When NT is in the synapse, it is “active”.

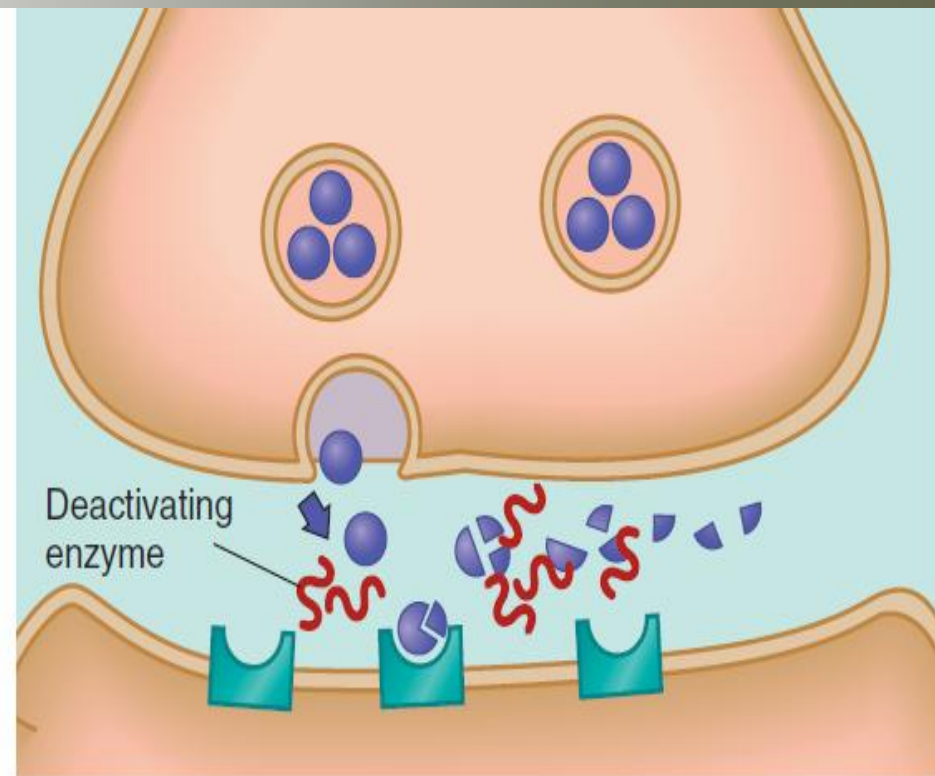
Activity must be turned off to avoid clogging-up channel of communication

Reuptake – scoop up and recycle NT

Enzymatic degradation – a NT is broken down by enzymes

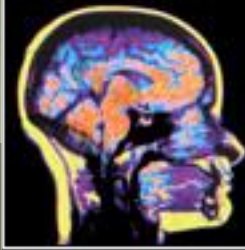


Reuptake



Enzymatic Degradation

Pharmacology of Synaptic Transmission & Behaviour



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.

