

Information Processing in the Nervous System

This is your brain on thought!

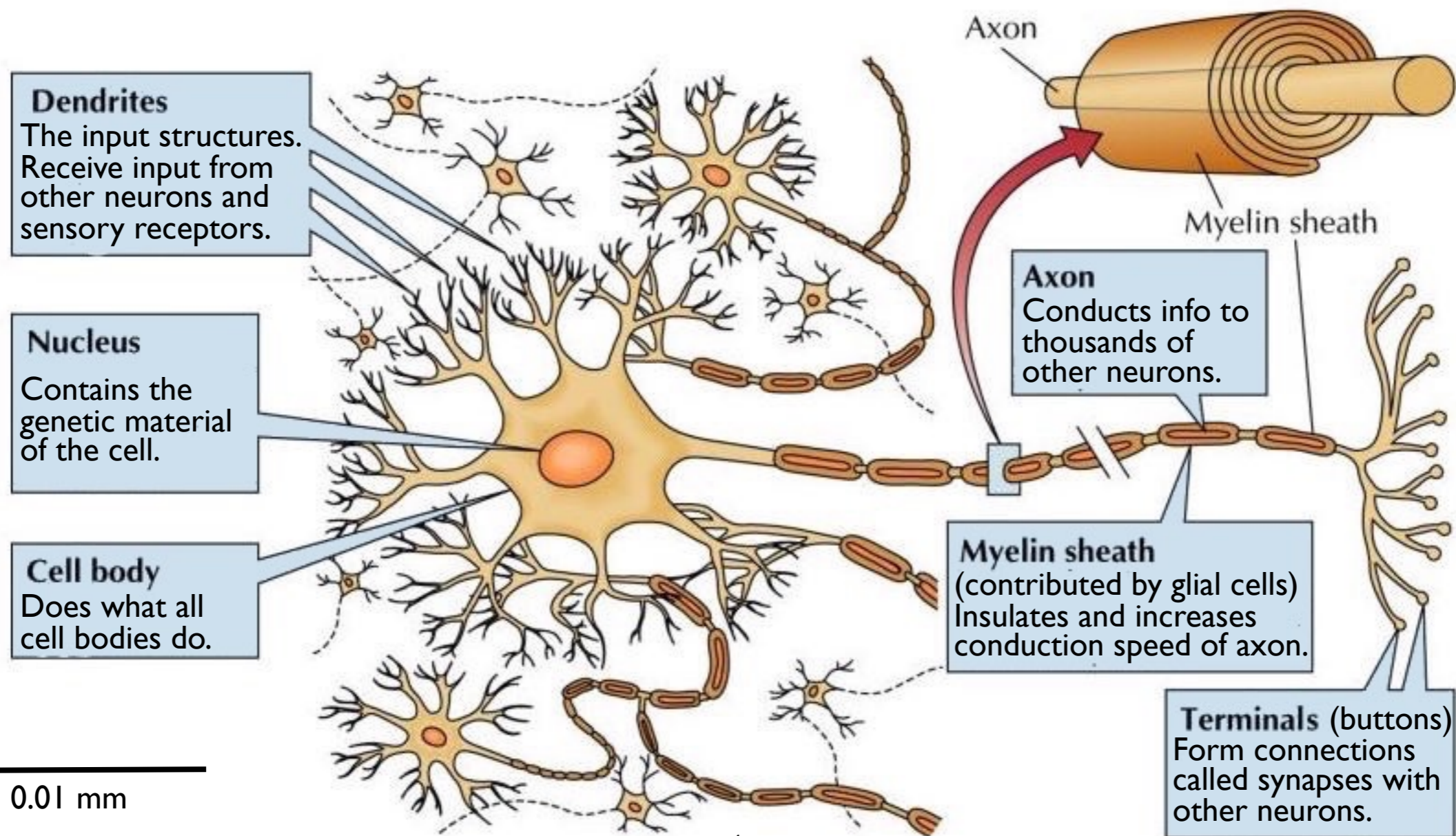
To Be Useful, Your Brain Must...

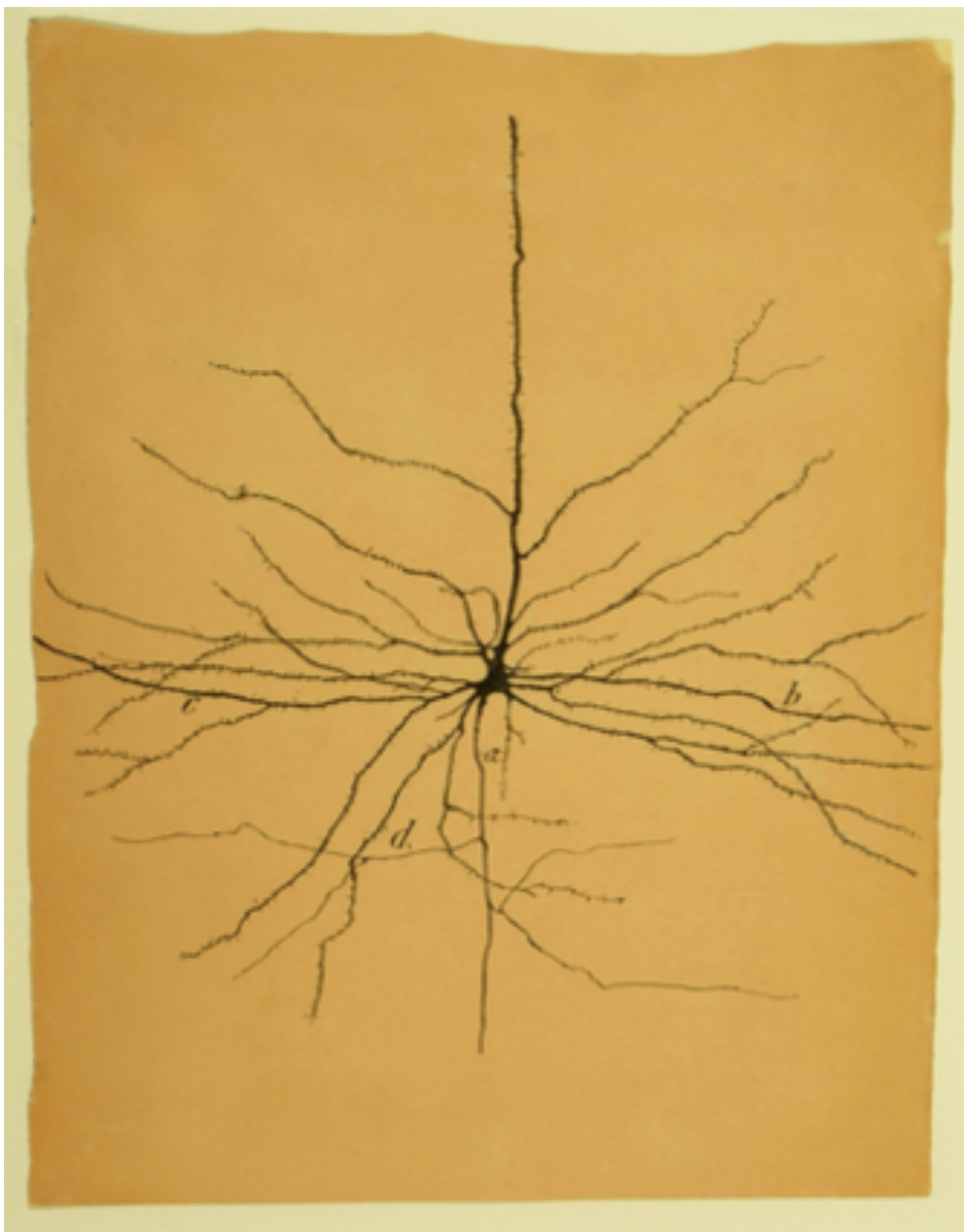
- receive information from the environment - sensation
- process this information - perception
- think about it - cognition
- decide on a course of action - decision making
- send commands out to muscles and glands - create behavior

The Information Processing Cells in the Nervous System are Called Neurons.

- Neurons are little electrical devices.
- They must...
 - receive input from other neurons
 - process that information - decide on output
 - send output to other neurons

A “Typical” (or Multipolar) Neuron Looks Like This.

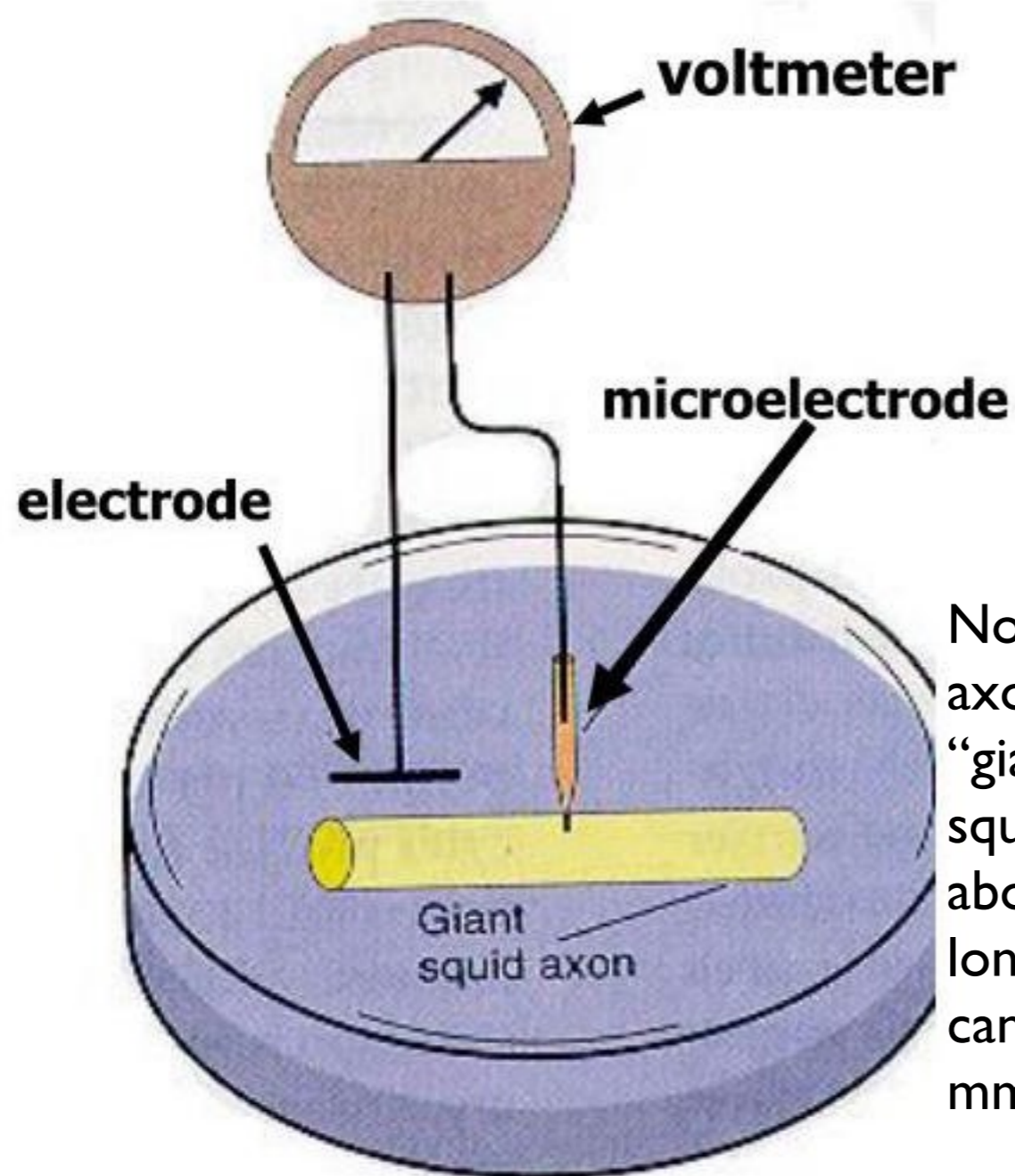




Drawing of a pyramidal neuron in the cerebral cortex by famed neuroanatomist Ramon y Cajal. Almost everything you see sticking off the cell body (center) are dendrites. A little bit of the axon is visible below and right of the cell body

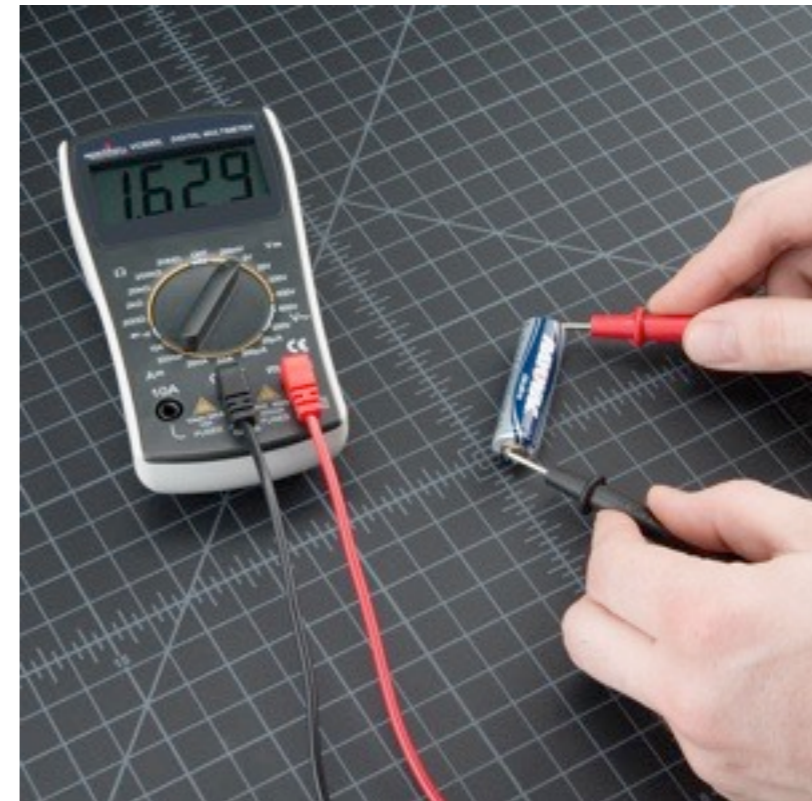
A photograph of pyramidal neurons in the cortex. Pyramidal neurons are very large as neurons go and are the primary output cells of the cerebral cortex. The very large dendrite sticking out the top of each cell extends upward towards the surface of the cortex. The axons are too thin to be visible in this photograph.

Neurons are Electrically Polarized.



Which is to say, you can measure a voltage across the cell membrane. It's just like measuring a voltage across the poles of a flashlight battery, except that the voltage is much smaller, and it occurs for the same reason, a separation of electric charges.

Note: it's the axon that is "giant," not the squid, which is about a foot long. The axon can be up to 1 mm in diameter,



Voltages Measured Across Membranes are Called Membrane Potentials.

- resting potential - when the cell is at rest, the membrane potential is typically about -70 mV, negative inside the cell
- graded potentials - small and variable changes in resting potential, usually of a few mV
- action potentials - large, all-or-none voltage changes of about 100 mV that occur on the axon when it is conducting information

Changes in Potential (Voltage) are Caused by the Movement of Charged Particles.

- In electric circuits (like flashlights), those particles are electrons.
- In neurons, they are ions, usually sodium (Na^+), potassium (K^+), or chloride (Cl^-).

Voltage Changes in Neurons are Either Excitatory or Inhibitory.

- Voltage changes occur when ions move through tiny holes in the cell membrane called ion channels.
- Excitatory changes occur when Na ions move into the cell across the membrane.
- Inhibitory changes occur when K ions move out across the membrane (and sometimes when Cl ions move in).

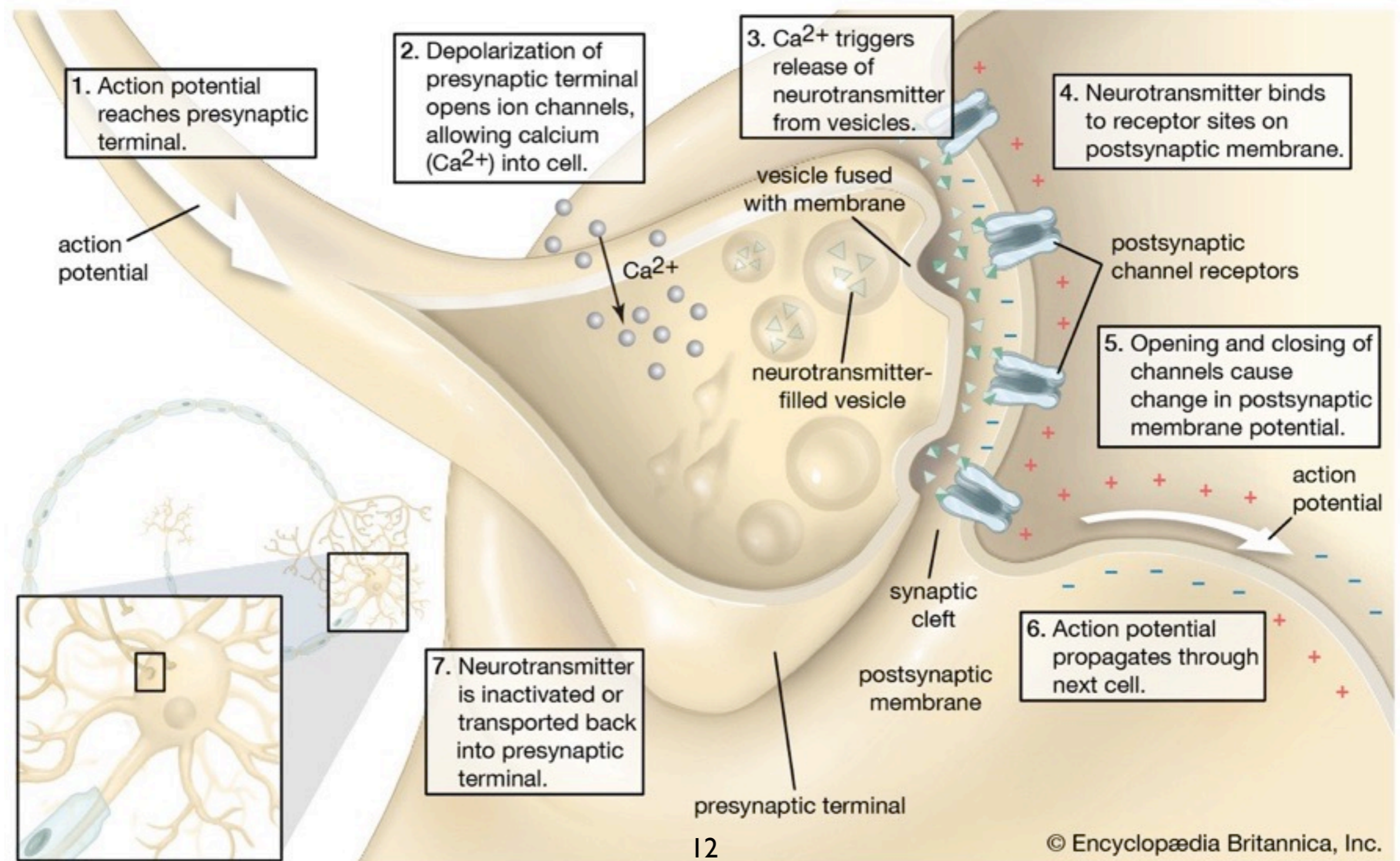
Steps in Neural Transmission

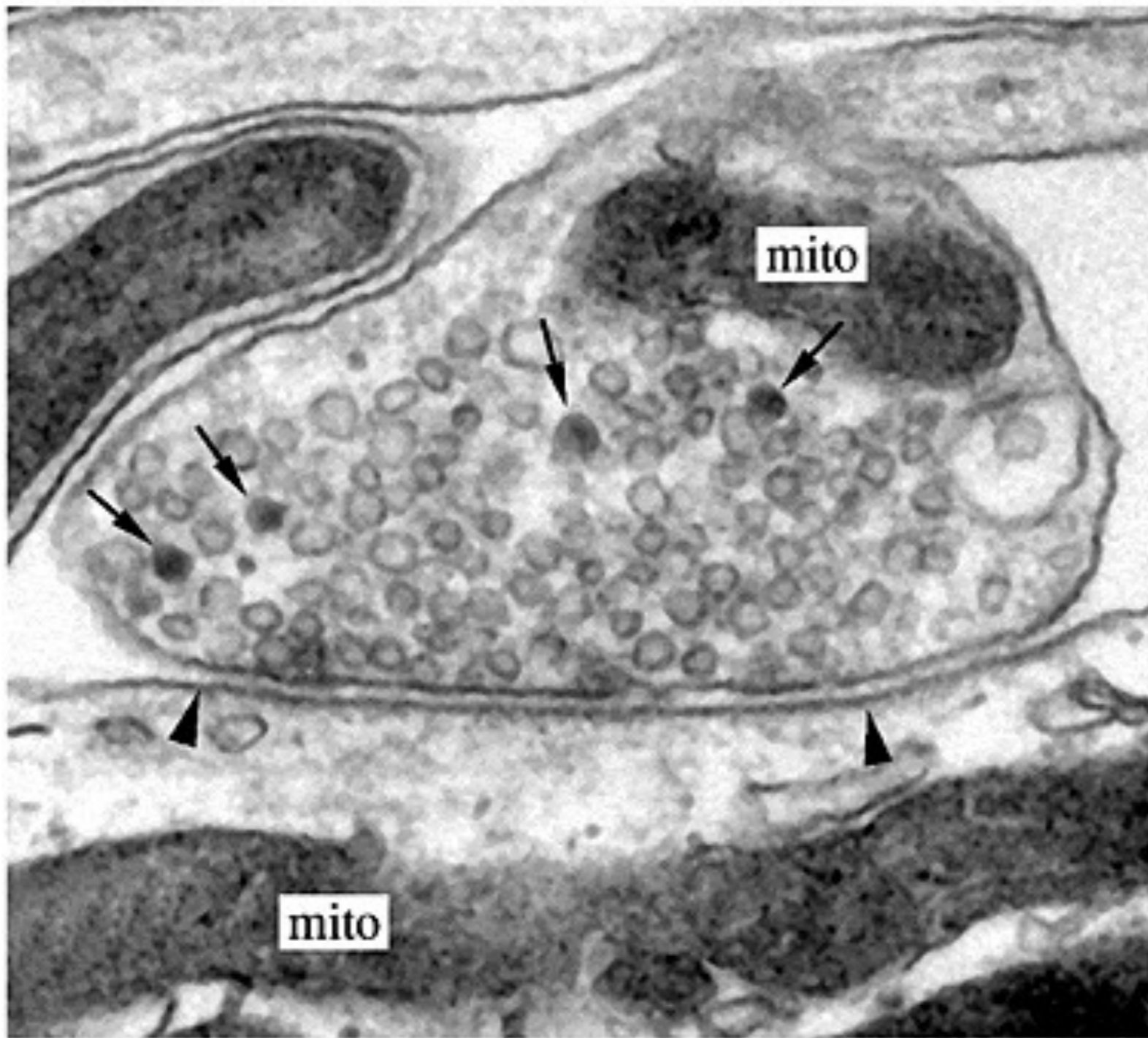
- Activity occurs at synapses on dendrites or the cell body.
- This causes either excitatory or inhibitory changes on the membrane.
- These changes propagate (move) along the dendrites and cell body as graded potentials. Graded potentials die out quickly, however, so can't go far.
- When the graded potentials reach the axon, they either increase or decrease the rate at which the axon is forming (“firing”) action potentials.

Steps in Neural Transmission (cont.)

- Action potentials can propagate along the entire length of the axon, no matter how long it is, without dying out.
- Information is encoded in the rate at which the axon is firing action potentials - the rate law.
- When the action potentials reach the terminal buttons, they excite (depolarize) these buttons.
- That causes the terminal buttons to release neurotransmitter onto the next neurons.

Here's What Happens at Synapses





A photograph of a synapse taken with an electron microscope. The terminal button is in the center of the photo, attached to its axon at the top. The small, bubble-like structures in the terminal button are vesicles, which are filled with the neurotransmitter. The larger black thing labelled "mito" is a mitochondrion, the power plants of the cell. The synaptic cleft is the gap running horizontally just below center. Areas where the cleft appears darker are areas where transmitter is being released. To give you an idea of scale, a typical synaptic cleft is about one millionth of an inch across, from the presynaptic membrane to the postsynaptic membrane. The postsynaptic cell is at the bottom.

Neurotransmitters

- At synapses, information is transferred to the next neuron by a chemical substance, a neurotransmitter, that is released by the terminal button.
- Common neurotransmitters in the brain are:
 - glutamate - the primary excitatory transmitter
 - GABA - the primary inhibitory transmitter
 - modulatory transmitters such as serotonin, norepinephrine, dopamine, and acetylcholine.
- In the peripheral nervous system, acetylcholine is the primary excitatory neurotransmitter.

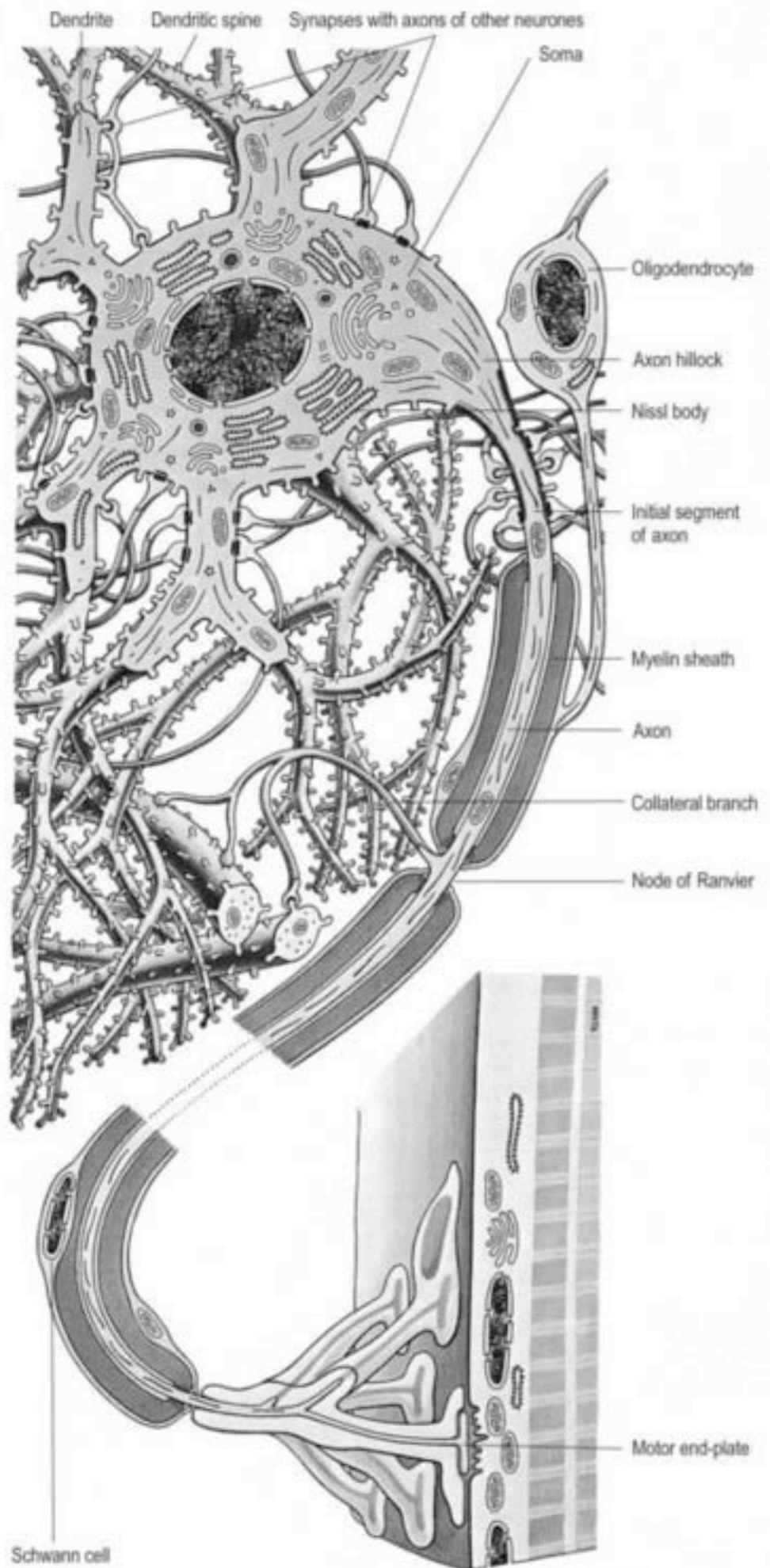
How Drugs Work

- Drugs work in the nervous system by affecting the action of neurotransmitters. For example:
 - Amphetamine stimulates the release of dopamine and norepinephrine.
 - Cocaine prevents the inactivation of dopamine after it is released.
 - Antipsychotic medications such as Thorazine block dopamine receptors.
 - Antidepressant medications such as Prozac prevent the inactivation of serotonin.
 - Tranquilizers such as Valium and Xanax increase the activity of GABA.

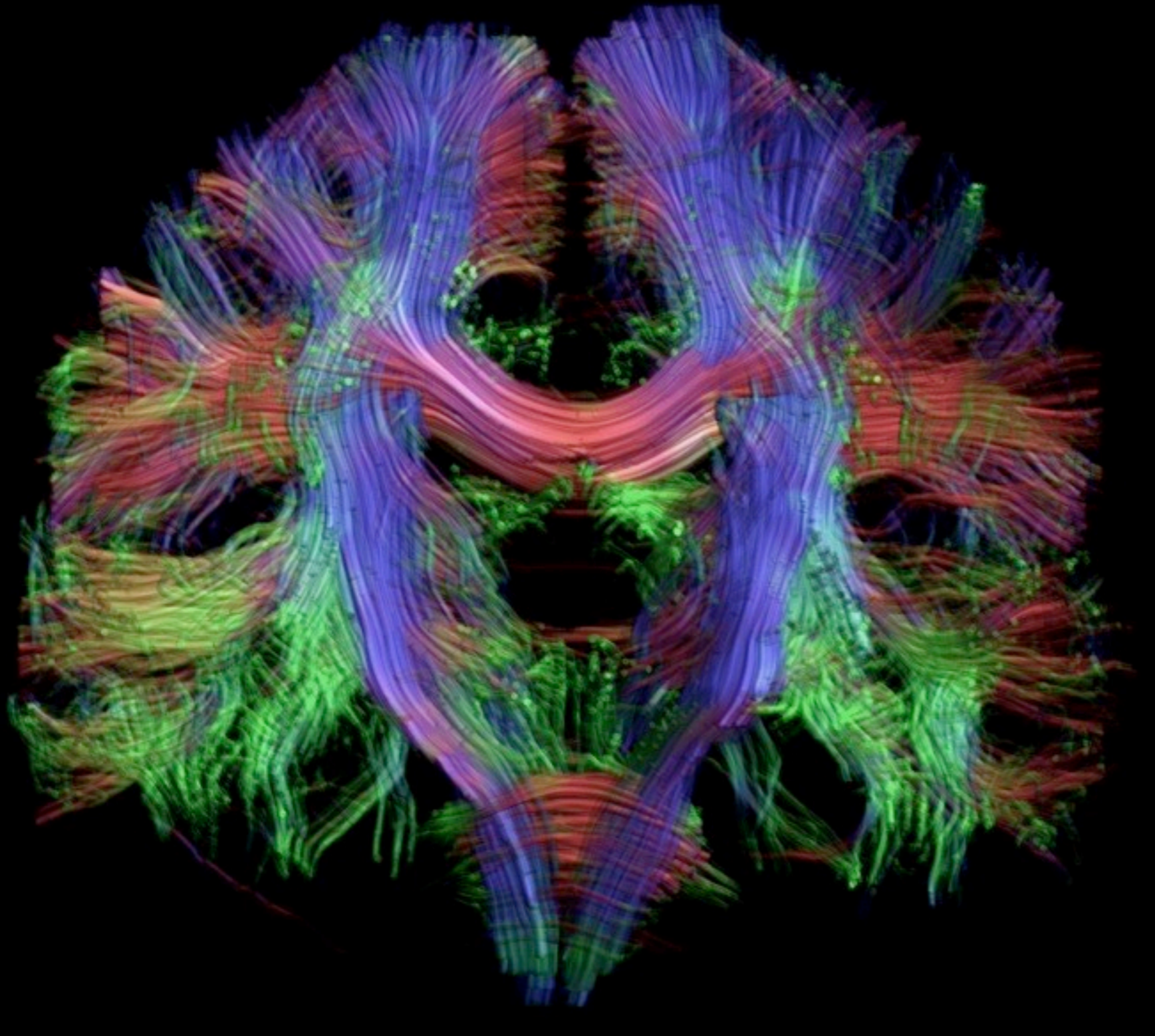
Glial Cells

- There are roughly 100 billion neurons in an adult human brain. (The book says between 100 and 150 billion, which is probably an overestimate, although nobody has actually counted them all. Latest estimates are around 86 billion.)
- There may be 10X as many glial cells, which serve multiple functions, among which are:
 - They contribute the myelin sheath to the axon of neurons.
 - They contribute to the blood-brain barrier, which prevents toxins from entering (and leaving) the brain from the blood.
 - They are key components of the brain's immune defense against invading organisms.
 - They fill in spaces with “scar tissue” after damage to the brain.

Typical Neuron Revisited



This is one motor neuron in the spinal cord, sending its axon out into the peripheral nervous system where it is making synapses on a muscle fiber to create muscle contraction and movement. Each spine (bump) on the dendrites of this neurons receives a synaptic input from another neuron, probably thousands of such synapses altogether. The neuron must integrate all of this incoming information and “make a decision” about how rapidly to fire off action potentials on its axon. This is but one neuron in one segment of a spinal cord that is densely packed with neurons. By studying it, you can get some idea of how complex a nervous system consisting of 100 billion such neurons must be. Each of those neurons receives thousands of synaptic inputs, and its axon may branch extensively and create thousands of synaptic outputs onto other neurons. For some neurons, that number is hundreds of thousands. Is it any wonder that we are only just beginning to understand how such a complex system creates thought and behavior?



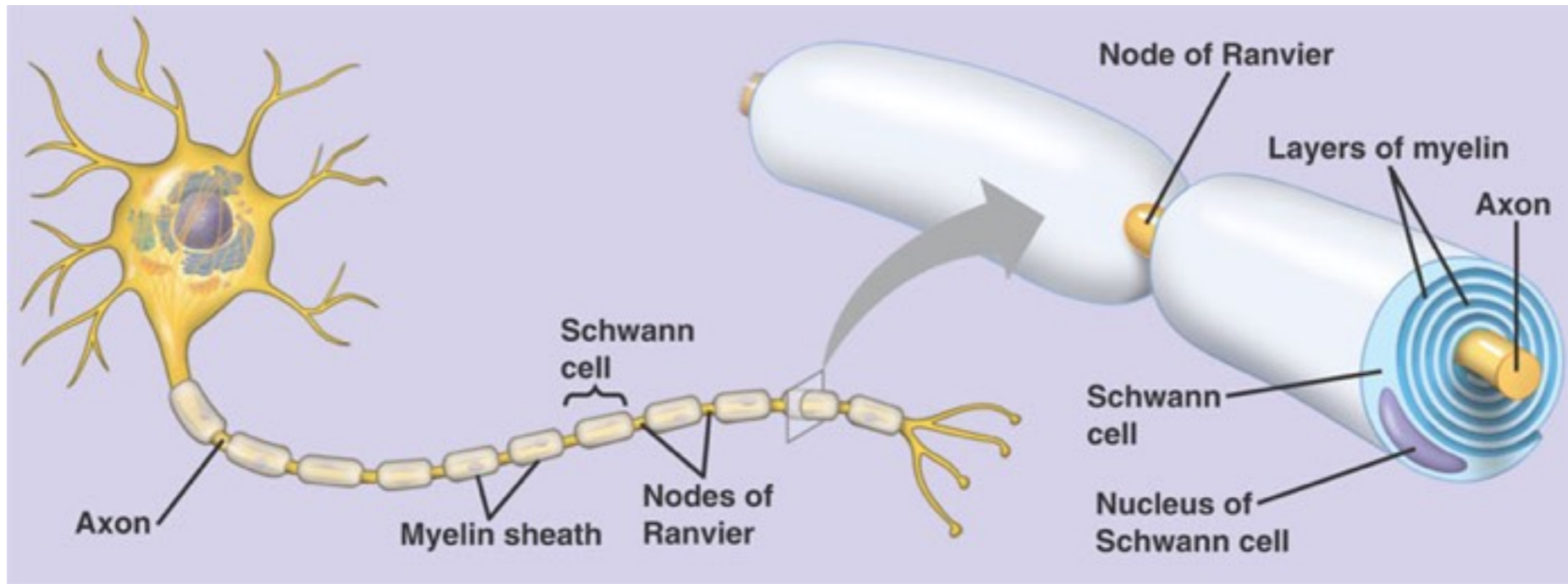
The bad news for those of you contemplating medical school or a career in neuropsychology or neuroscience is that every one of those nuclei and tracts, hundreds of them, has a name! (Relax! We only need to know a few, for now.)

This image is a cross-section of the human brain showing a few of those tracts, color coded to show the direction in which they are conducting action potentials. Blue tracts are ascending/descending, carrying information from the cerebral cortex (for the most part) downward to the brainstem and spinal cord (motor), or in the opposite direction (sensory). Pink, purple, and orange tracts are carrying information from side to side. Some of them even cross the midline from one side of the brain to the other. Green tracts are seen more or less in cross-section, carrying action potentials front to back, or vice versa.

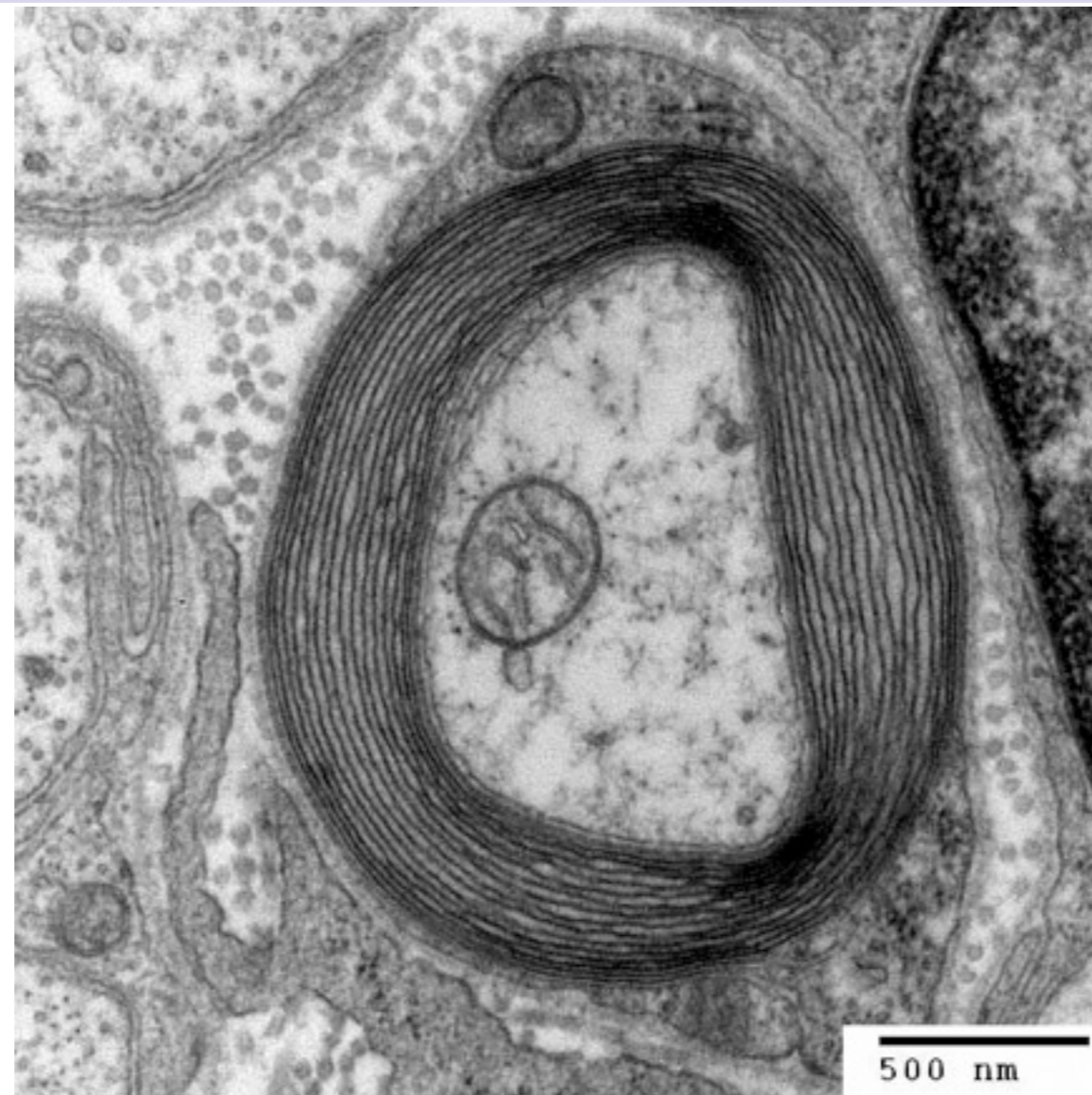
Luckily for us, neurons are not just randomly peppered throughout the brain, their axons forming an incomprehensibly twisted “plate of spaghetti.” In the brain, cell bodies tend to cluster together into balls or bunches, which are called nuclei (singular, nucleus). Axons also tend to “travel in packs” or cords or cables called “tracts”.

What Could Possibly Go Wrong?

Rule: if it's there, it can go wrong!



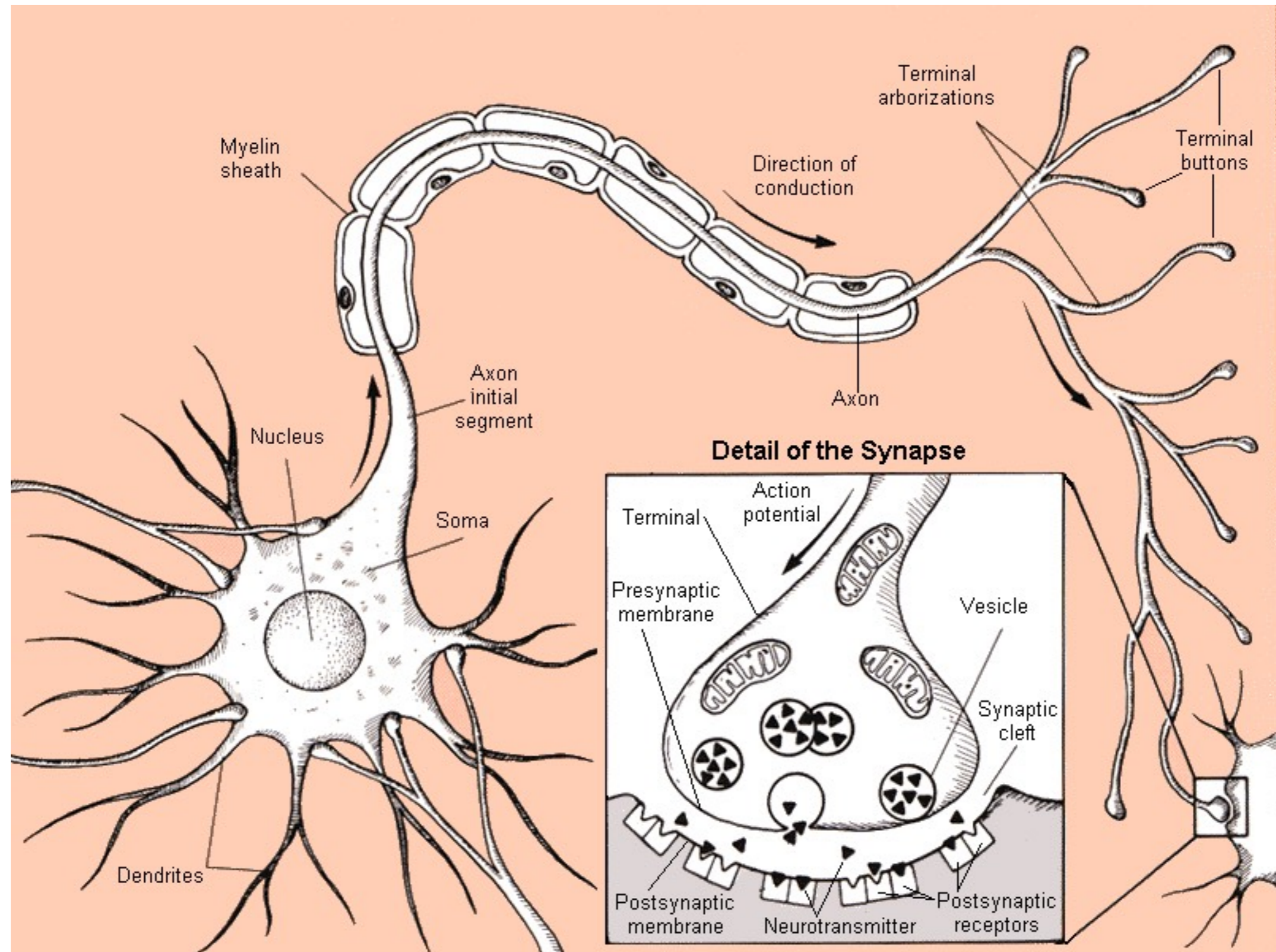
Myelin Sheath



Demyelinating Diseases

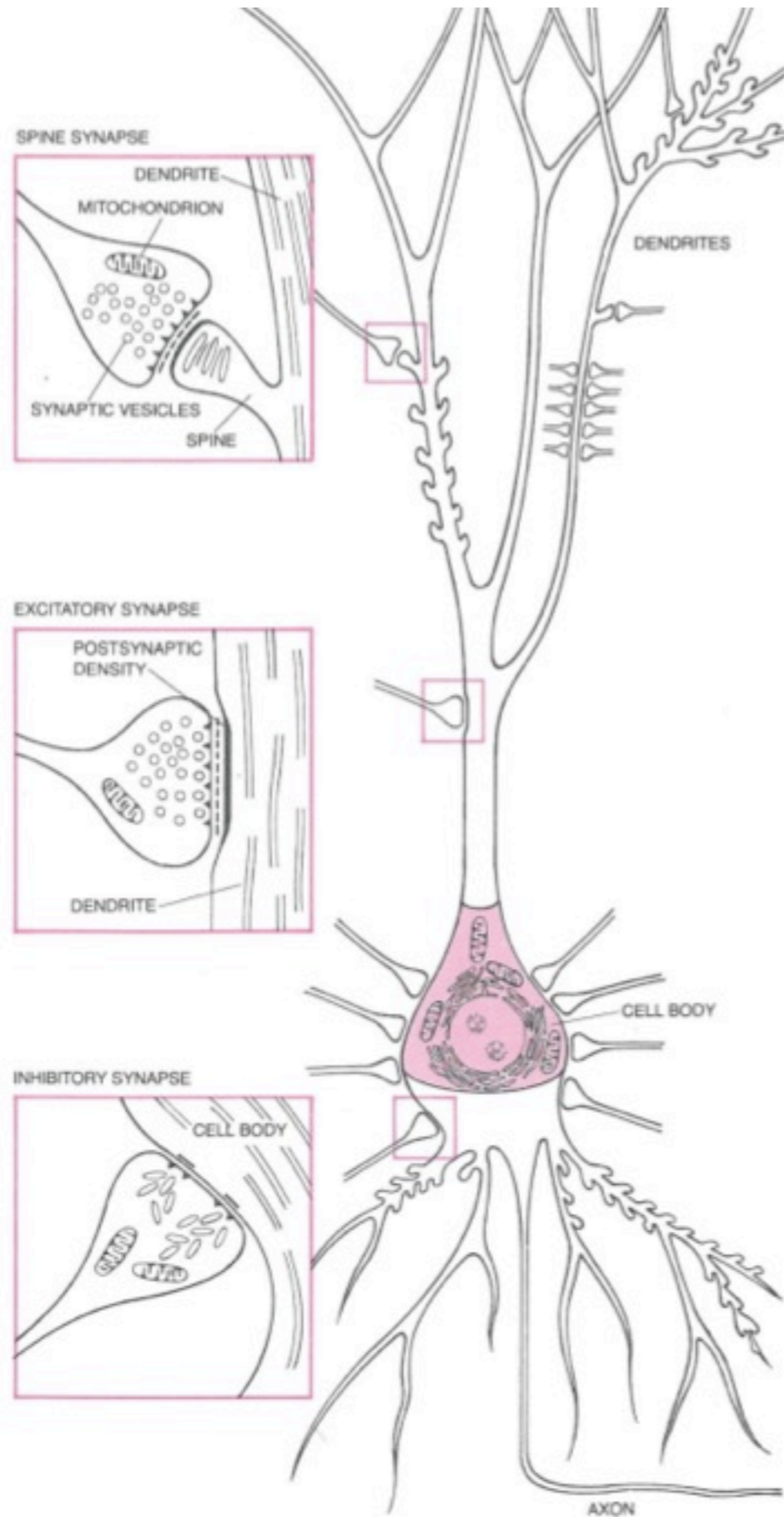
- multiple sclerosis (MS) - demyelination of motor and sensory pathways (usually “idiopathic”)
- vitamin B12 deficiency
- tabes dorsalis - demyelination of the dorsal column sensory paths (touch sense) due to untreated syphilis
- progressive multifocal leucoencephalopathy - a viral inflammation (encephalitis) of white matter of the brain, almost always in people with severe immune deficiencies
- optic neuritis - inflammation and destruction of the myelin sheath of the optic nerve leading to progressive loss of vision, usually the result of multiple sclerosis

Detail of a Synapse

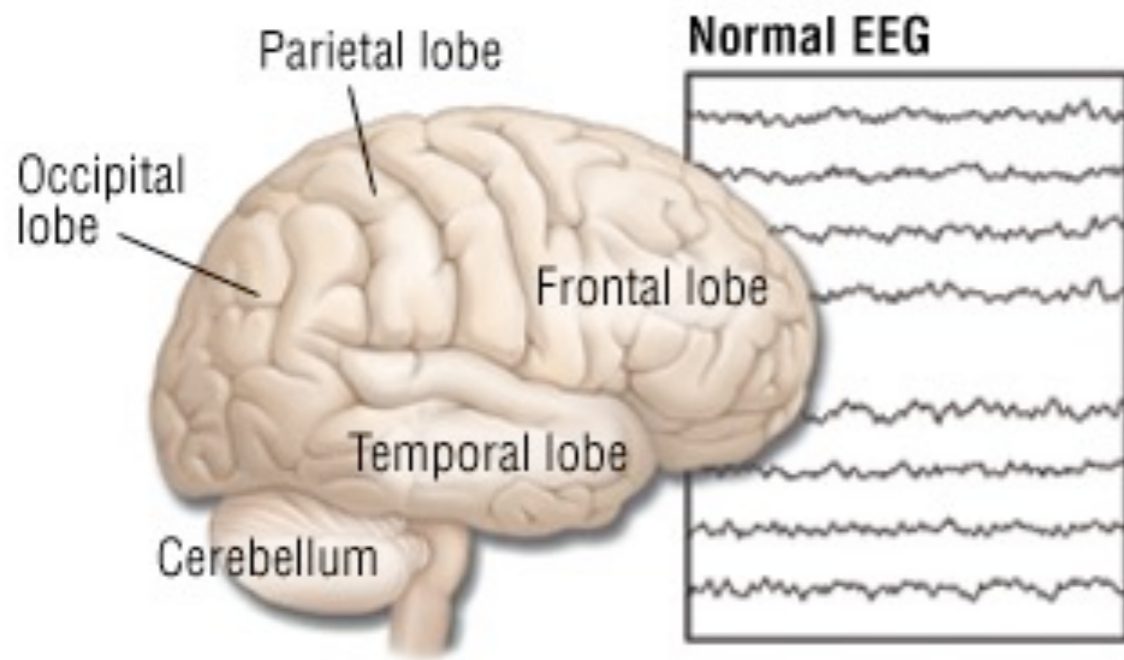


Diseases Involving Neurotransmitter Release or Reception

- myasthenia gravis (“grave weakness of muscles”) - due to an autoimmune disease that attacks acetylcholine receptors (see Prologue, chap 2)
- Parkinson’s disease - due to an as yet unidentified process that causes death and degeneration of dopamine neurons (loss of DA in basal ganglia)
- excitotoxicity - due to excessive or uncontrolled release of glutamate
- epilepsy, depression, schizophrenia, OCD, etc.

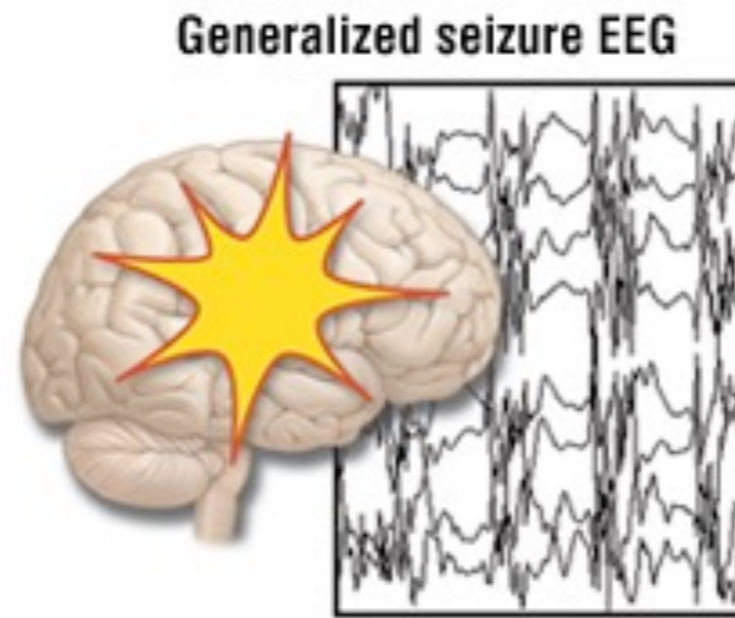
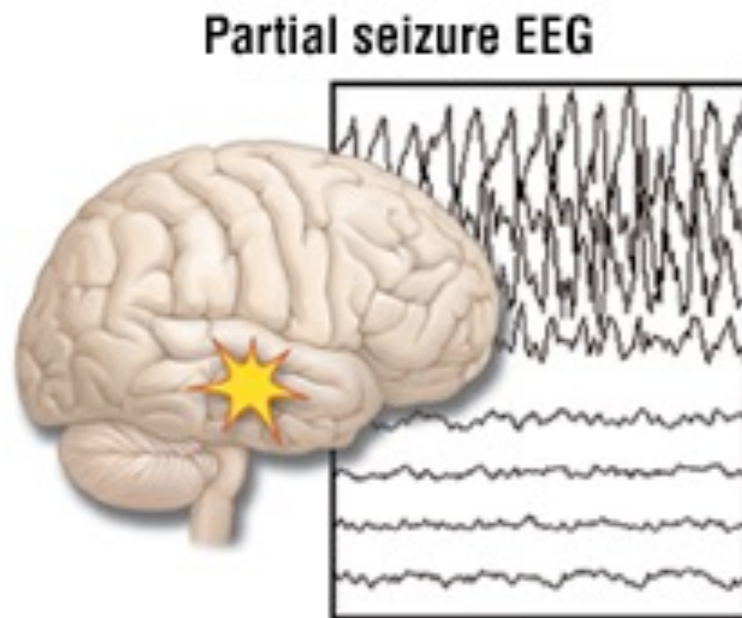


excitatory
and
inhibitory
synapses



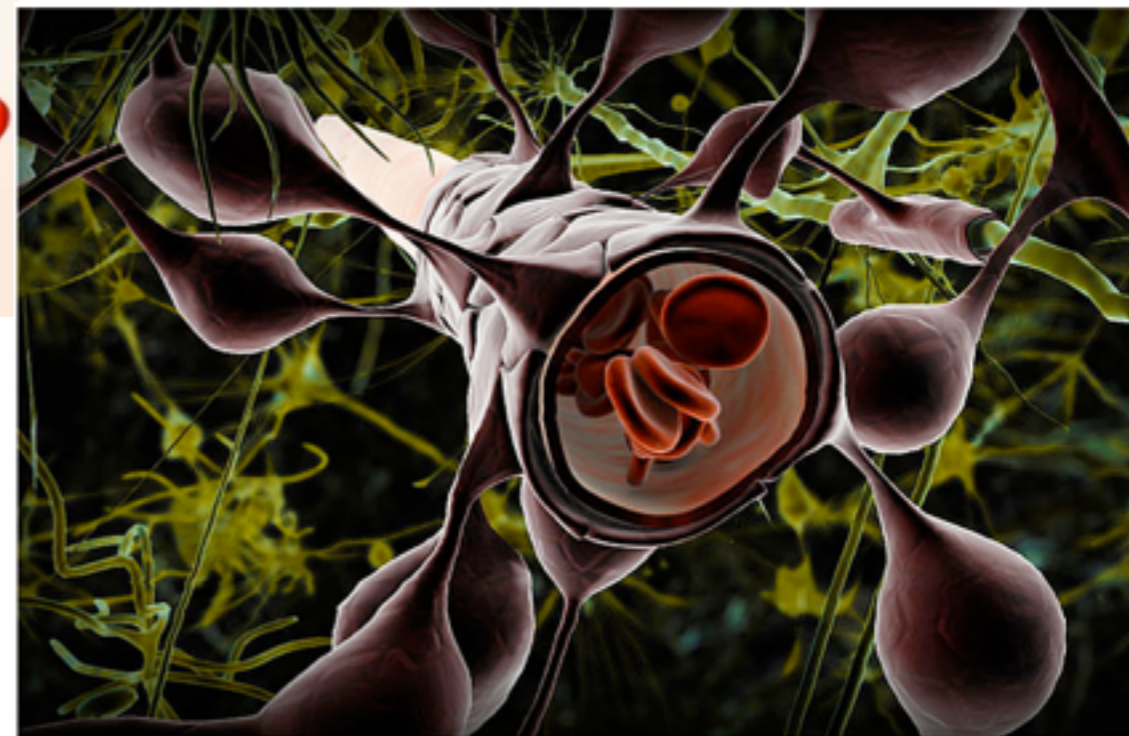
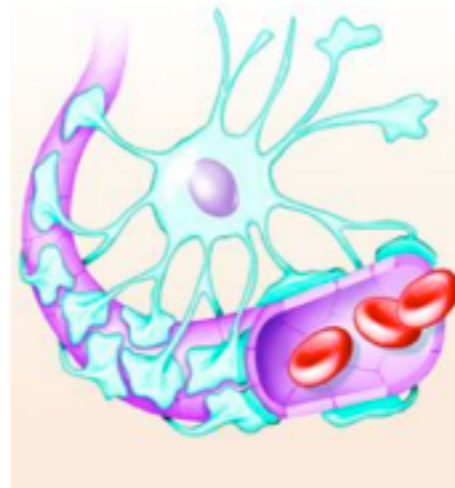
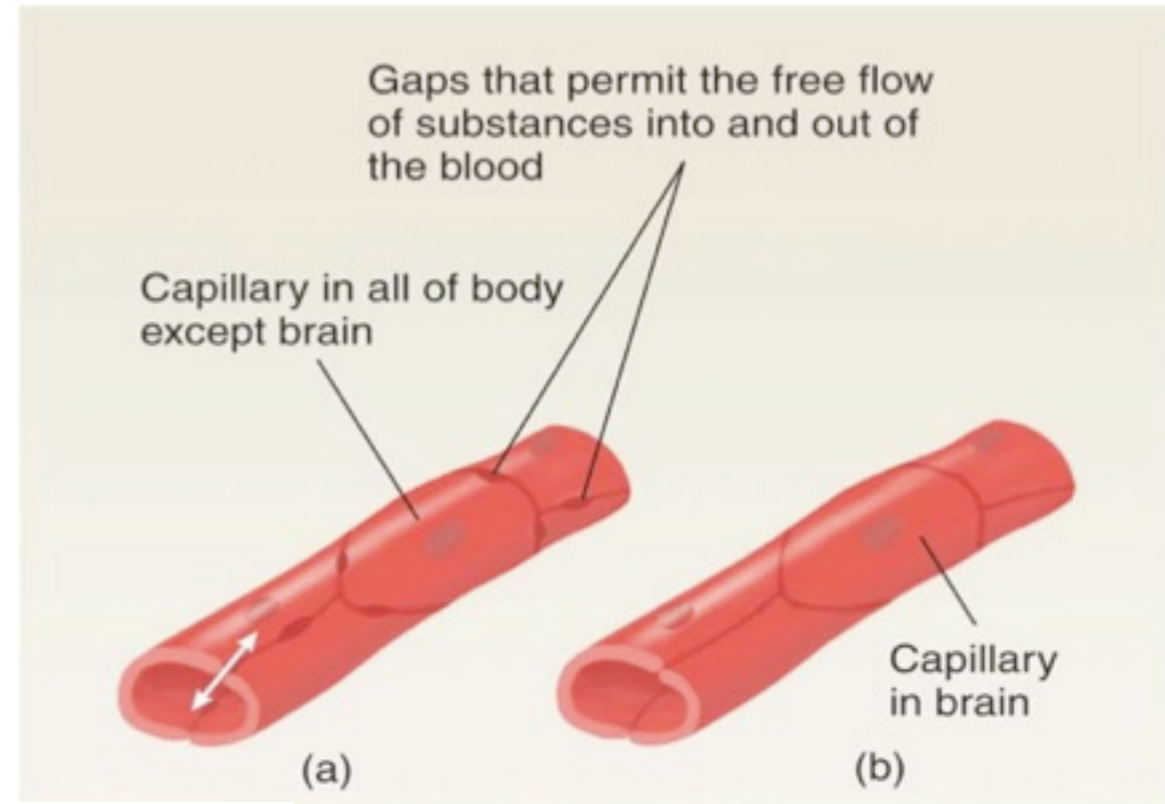
when inhibition
goes wrong

(some people think)



Blood-Brain Barrier

- Blue dye injected into the general circulation will stain every part of the body except the brain and spinal cord.
- In part, this is due to the structure of the capillaries.
- To get into the brain, chemicals have to diffuse through the cell membrane or be taken up by special transporters.
- Astrocytes and the BBB.

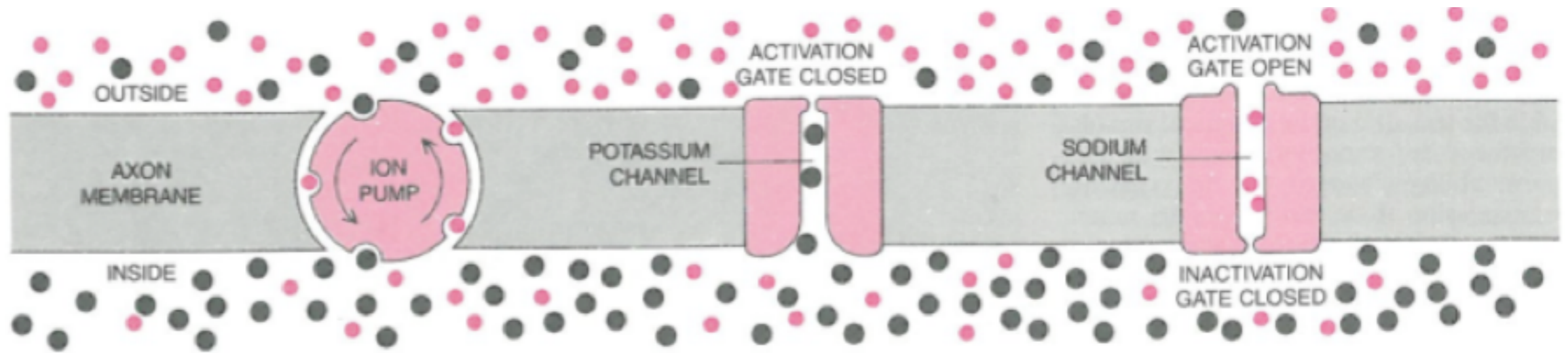


Clinical Significance of the BBB

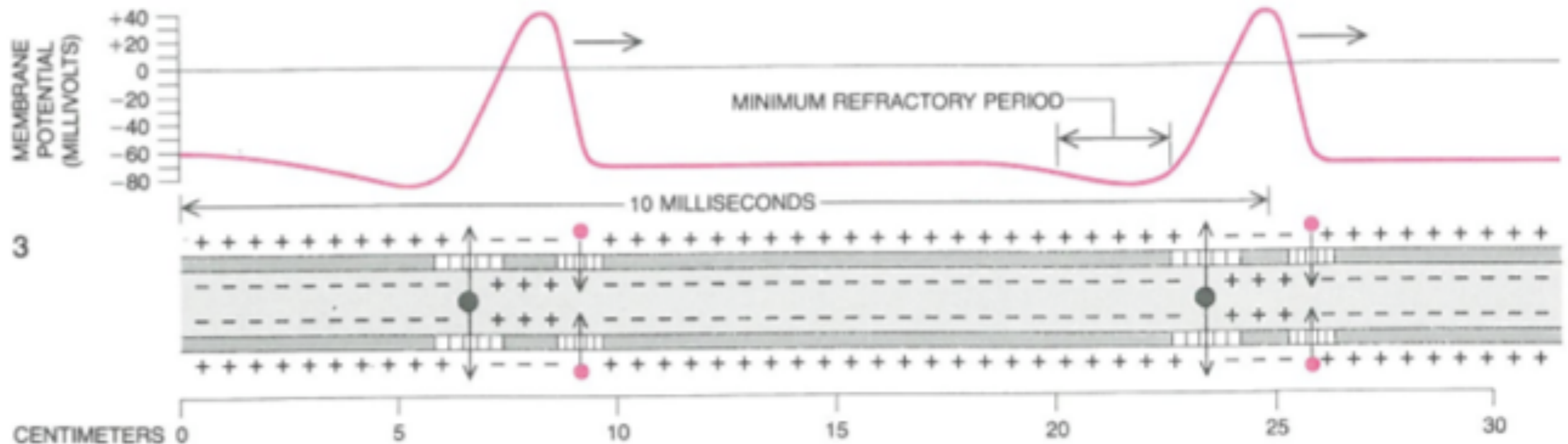
- prevents almost all blood-borne pathogens from entering the brain
- when they do, the infections can be hard to treat because antibodies cannot cross the BBB, and antibiotics and antivirals cross only with difficulty (if at all) - example: rabies
- disruption of the BBB can result in seizures
- autoimmune diseases of the brain such as MS may result when the BBB fails allowing the entry of immune cells such as T lymphocytes
- Alzheimer's disease may be triggered when a failure in the BBB allows amyloid beta proteins to enter the brain from the blood
- De Vivo disease - a developmental disorder in the brain due to the BBB being insufficiently permeable to glucose

Cell Membrane:

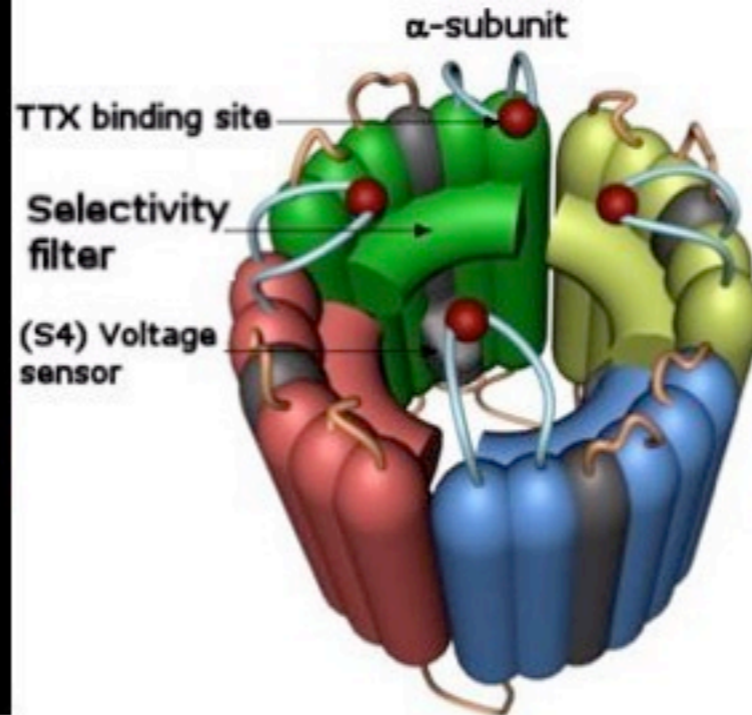
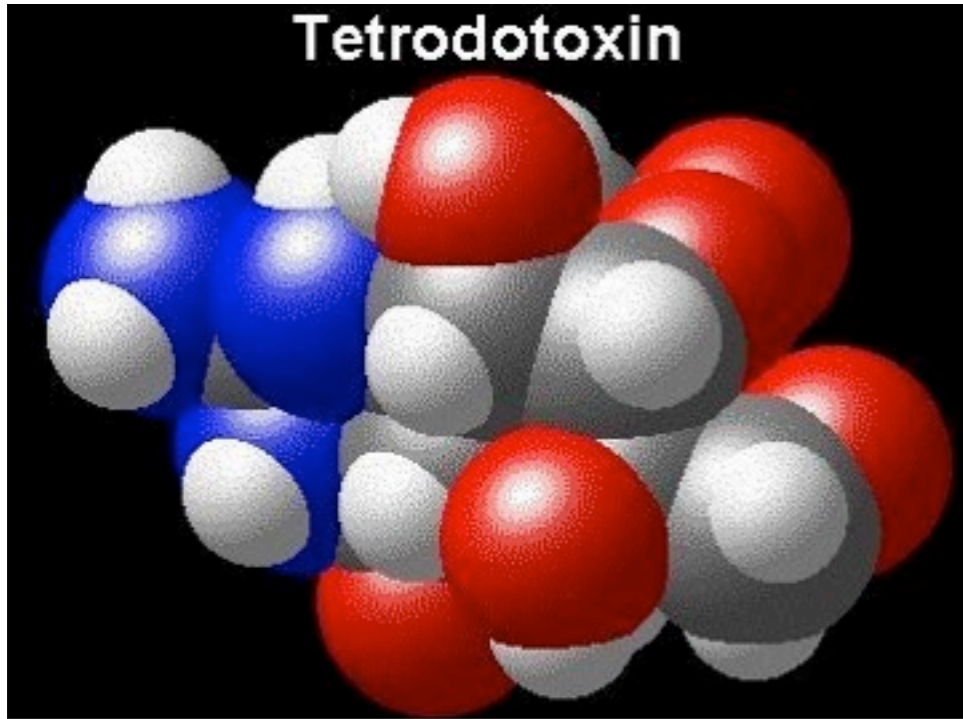
Ions, Channels, and Pumps



Action Potentials

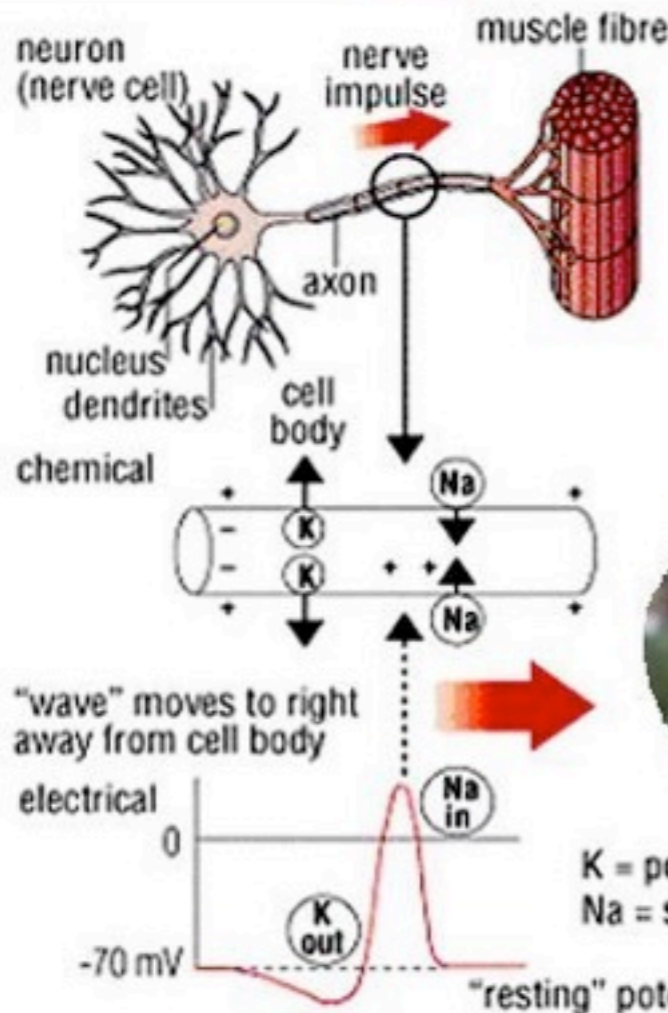


Ion Channel Poisons

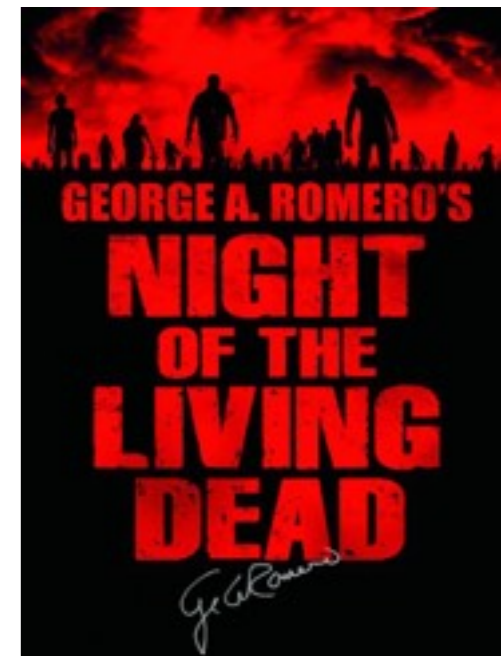


TTX is a substance found in the Japanese puffer fish, as well as other animals, that blocks Na⁺ channels by binding to the channel protein.

Once a molecule of TTX binds to the channel, sodium ions cannot pass through. This prevents the formation of action potentials on axons.



Japanese Puffer Fish



On to Neuroanatomy (next set of slides)

