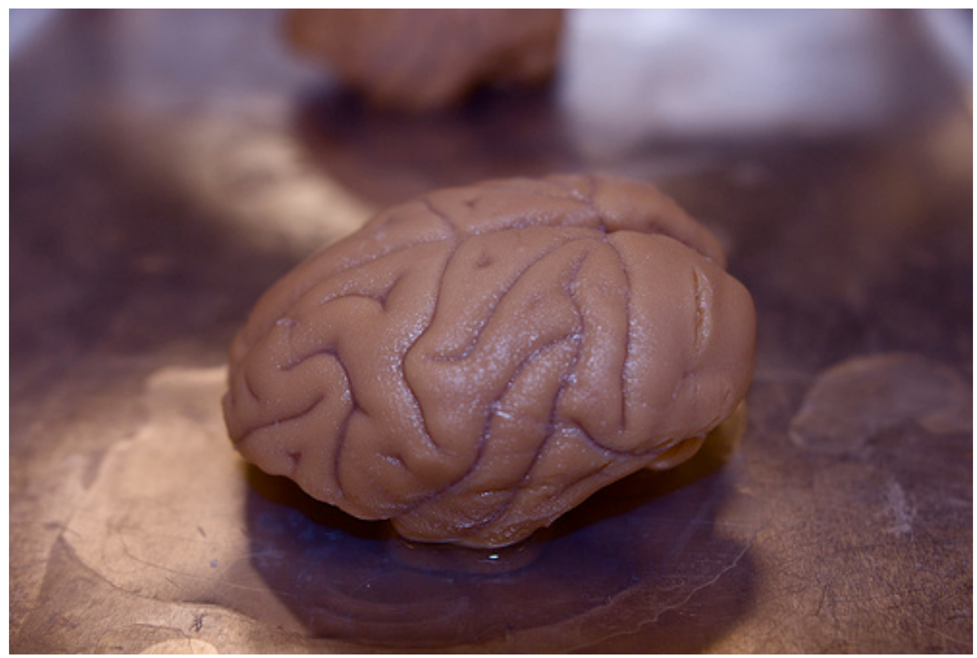
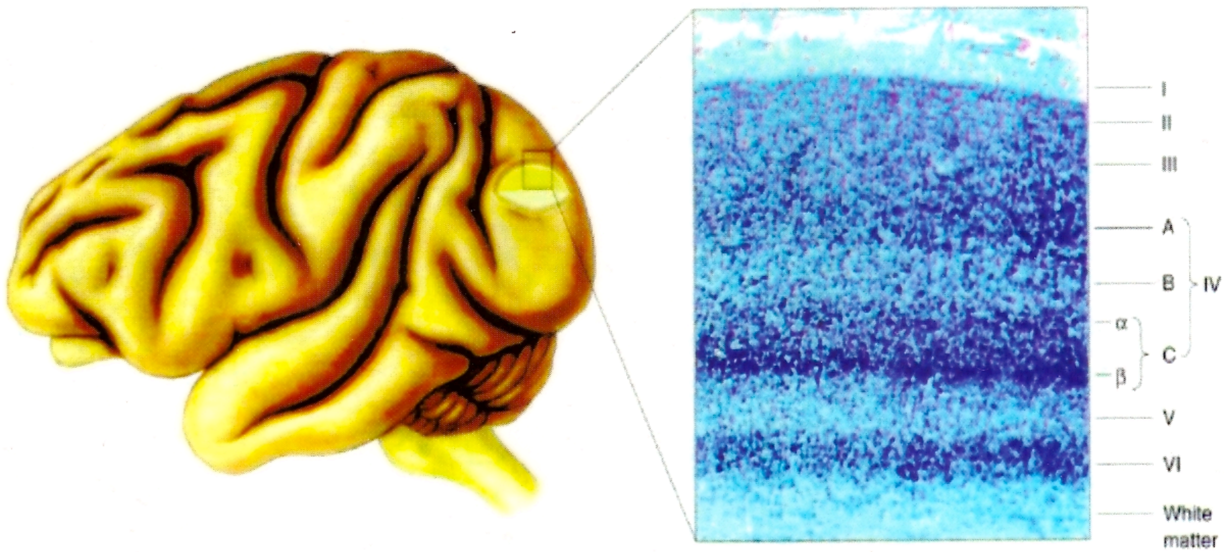
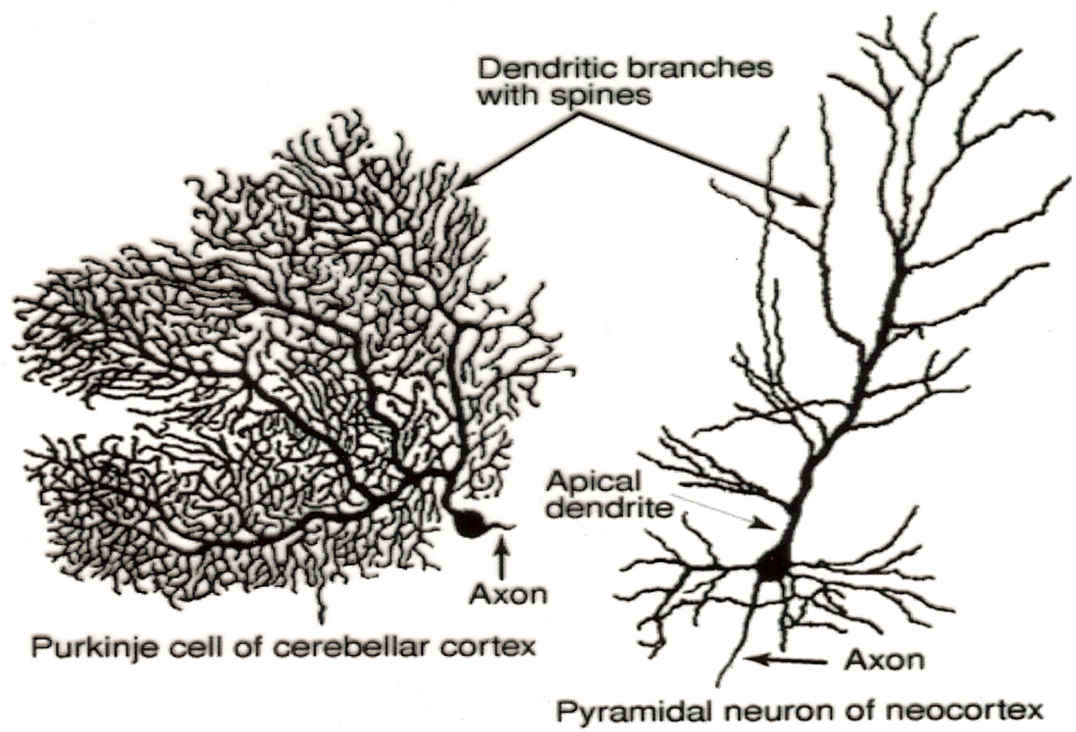
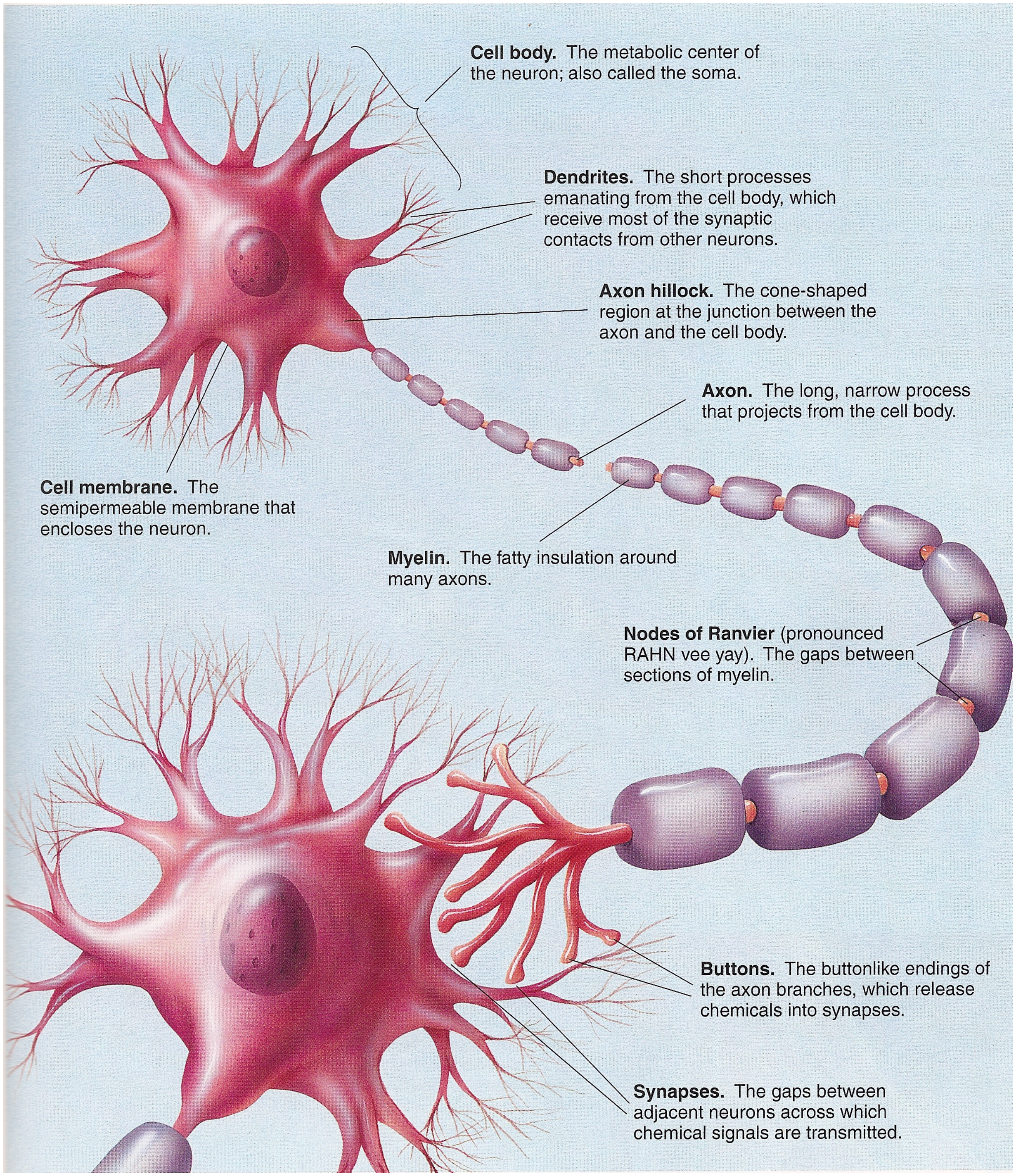
Each of the 10^{11} (one hundred billion) neurons has on average 7,000 synaptic connections to other neurons. It has been estimated that the brain of a three-year-old child has about 10^{15} synapses
(1 quadrillion)

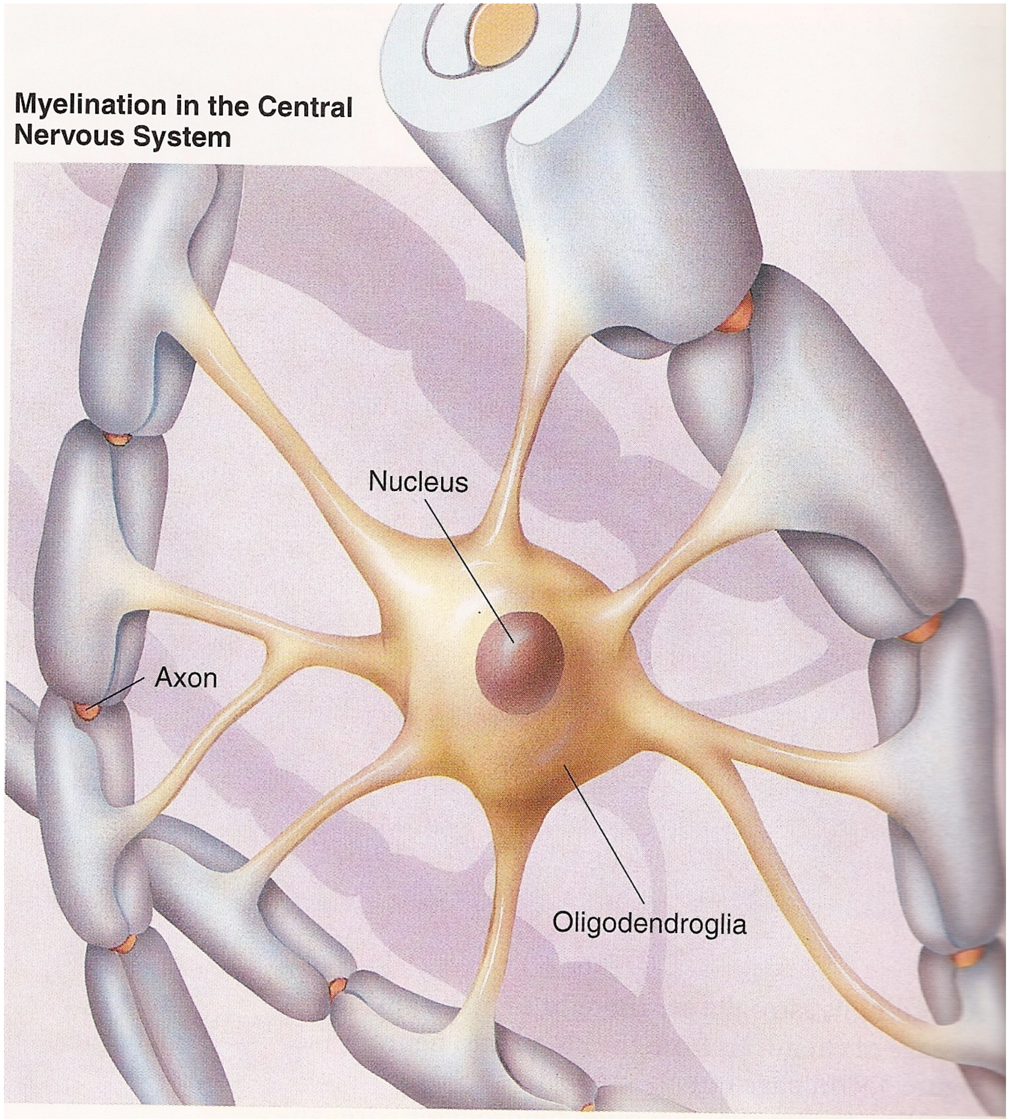



I
II
III
A
B
IV
α
C
β
V
VI
White matter

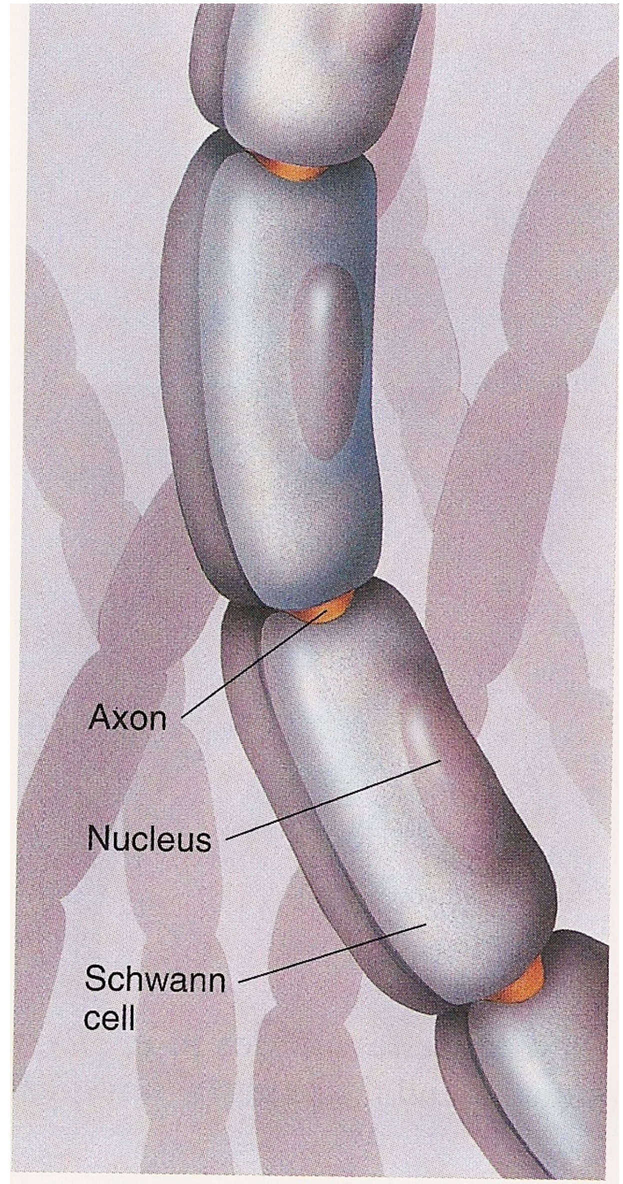

Dendritic branches with spines
Apical dendrite
Axon
Axon
Purkinje cell of cerebellar cortex
Pyramidal neuron of neocortex


Cell body. The metabolic center of the neuron; also called the soma.
Dendrites. The short processes emanating from the cell body, which receive most of the synaptic contacts from other neurons.
Axon hillock. The cone-shaped region at the junction between the axon and the cell body.
Axon. The long, narrow process that projects from the cell body.
Cell membrane. The semipermeable membrane that encloses the neuron.
Myelin. The fatty insulation around many axons.
Nodes of Ranvier (pronounced RAHN vee yay). The gaps between sections of myelin.
Buttons. The buttonlike endings of the axon branches, which release chemicals into synapses.
Synapses. The gaps between adjacent neurons across which chemical signals are transmitted.

CNS


Myelination in the Central Nervous System
Nucleus
Axon
Oligodendroglia

PNS


Axon
Nucleus
Schwann cell

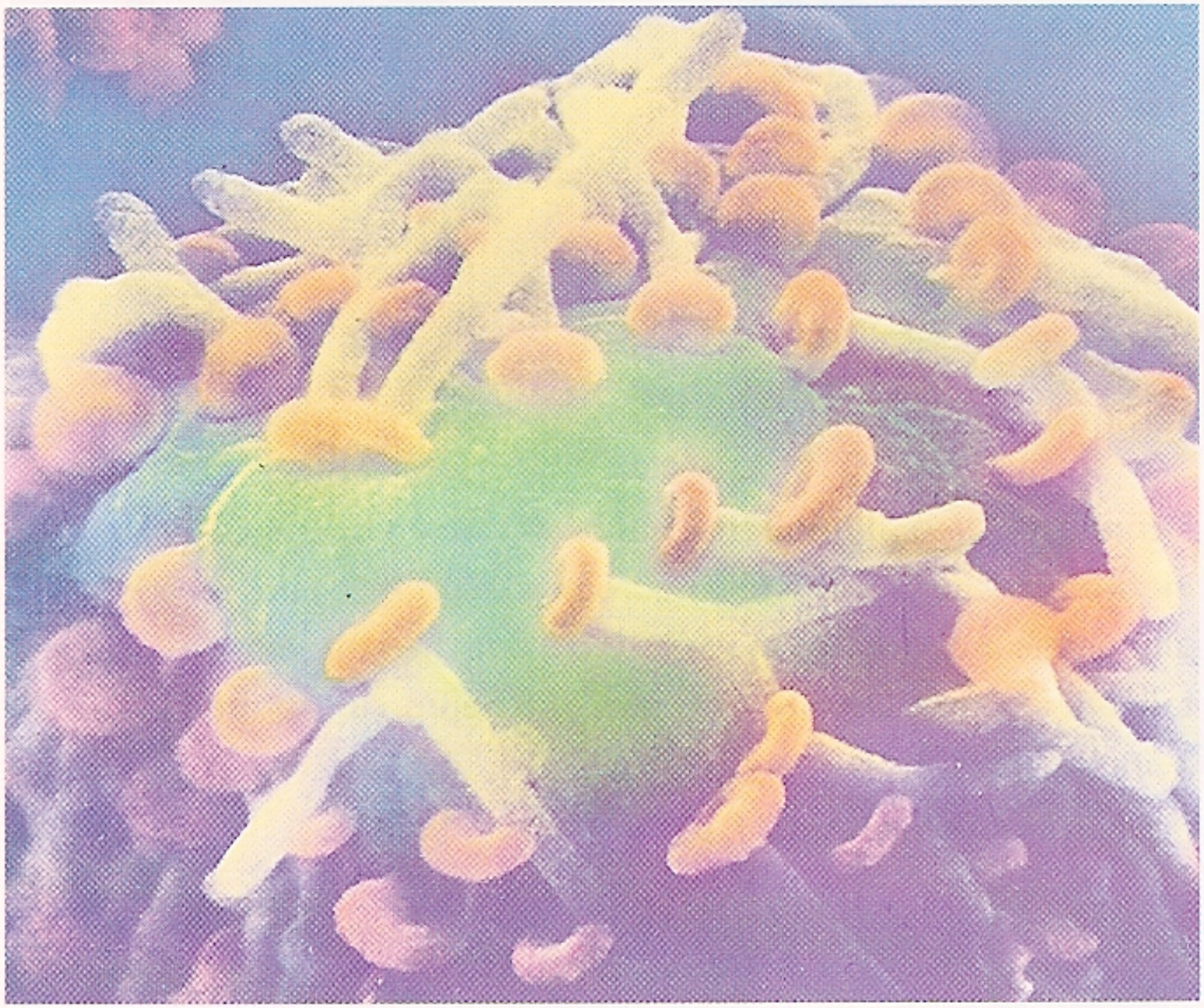
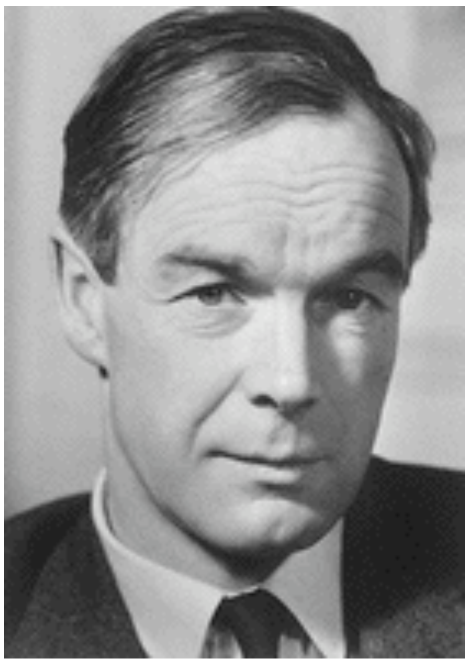
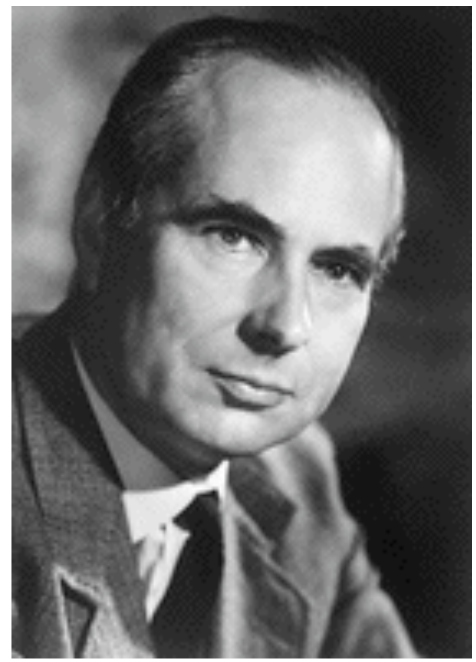


Figure 3.13 A color-enhanced scanning electron micrograph of a neuron cell body (green) studded with terminal buttons (orange). Each neuron receives numerous synaptic contacts.
(Courtesy of Jerold J. M. Chun, M. D., Ph.D.)

Sir Alan Lloyd Hodgkin



Andrew Huxley

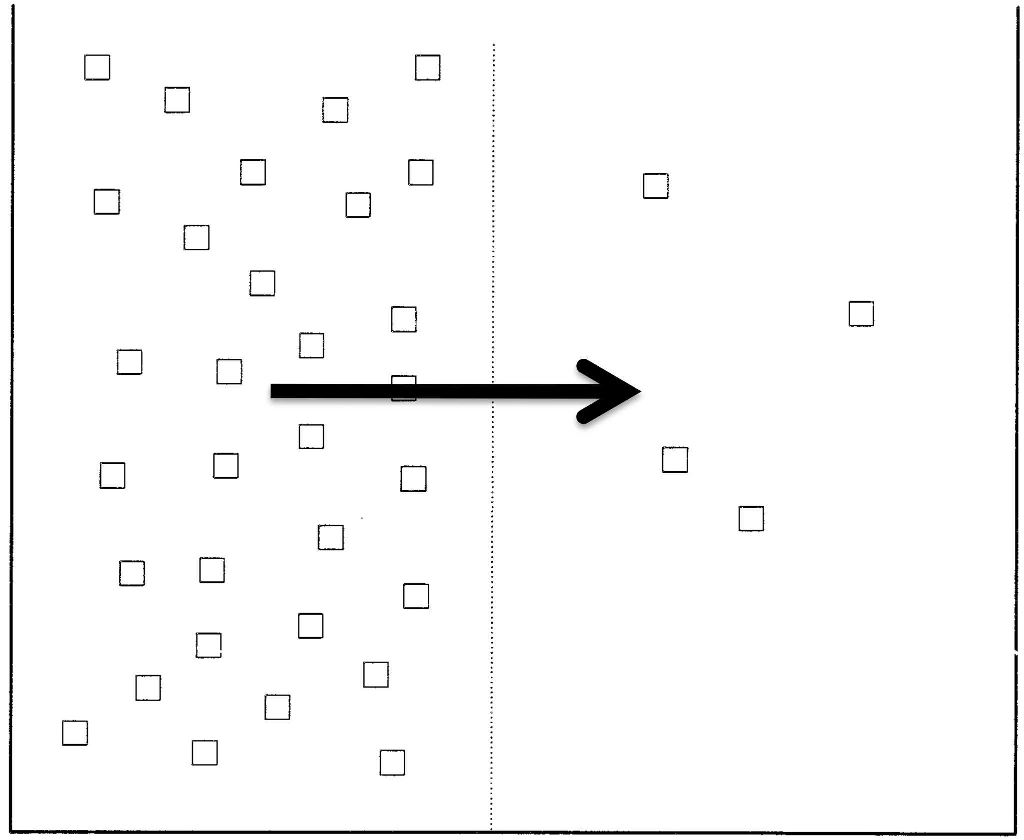


1963 Nobel Prize in Physiology or Medicine

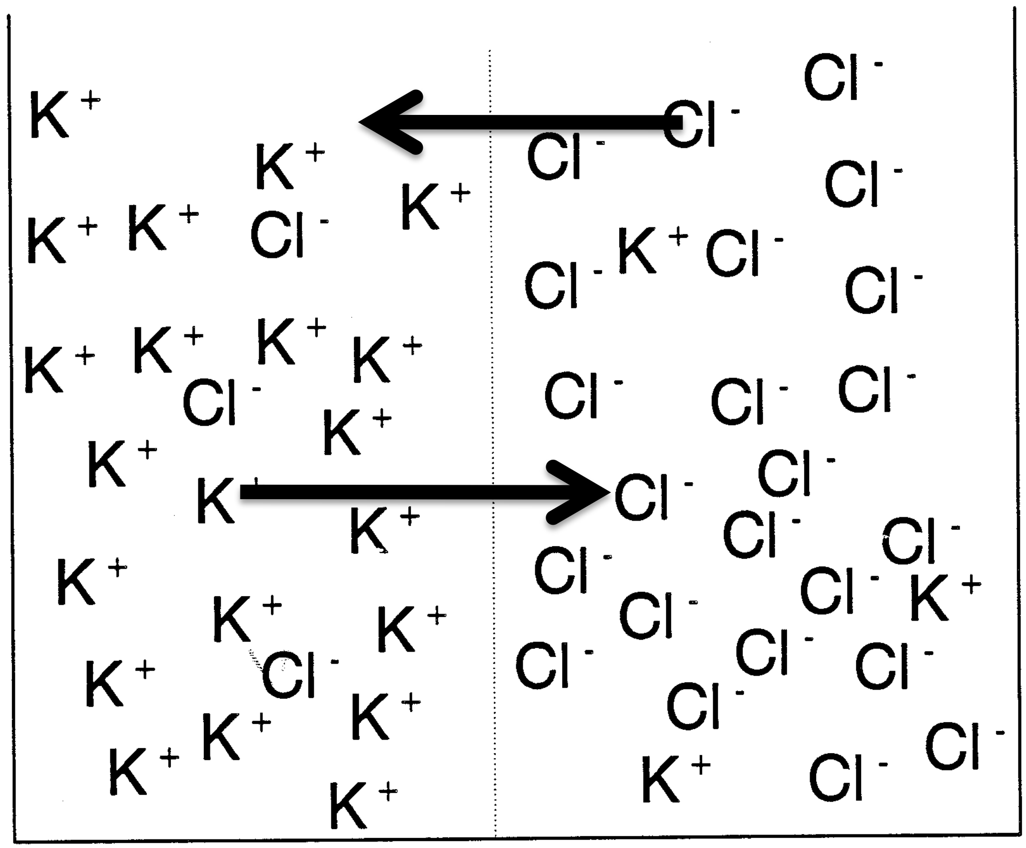
Neuron Membrane Potential

- -semi-permeable membrane separating different quantities of ions
- Force due to concentration gradient
- Force due to electrostatic attraction/repulsion
  - Na+
  - Cl-
  - K+
  - others…

Concentration Gradient



Electrostatic Pressure



Nernst Equation

$$V_{Eq} = \frac{RT}{zF} \ln\left(\frac{[X]_{out}}{[X]_{in}}\right)$$

V = voltage (at equilibrium)
R = ideal gas constant (expresses energy of concentration gradient per Kelvin per mole)
T = temperature (K)
z = valence of the ionic species (eg., +1 for Na+, -1 for Cl-)
F = Faraday constant (electric charge/mole of electrons)
[X] = concentration of ion inside/outside membrane

Two forces at work:
-electrostatic pressure
-concentration gradient

Cl-: negatively charged chloride ions
Na+: positively charged sodium ions
K+: positively charged potassium ions

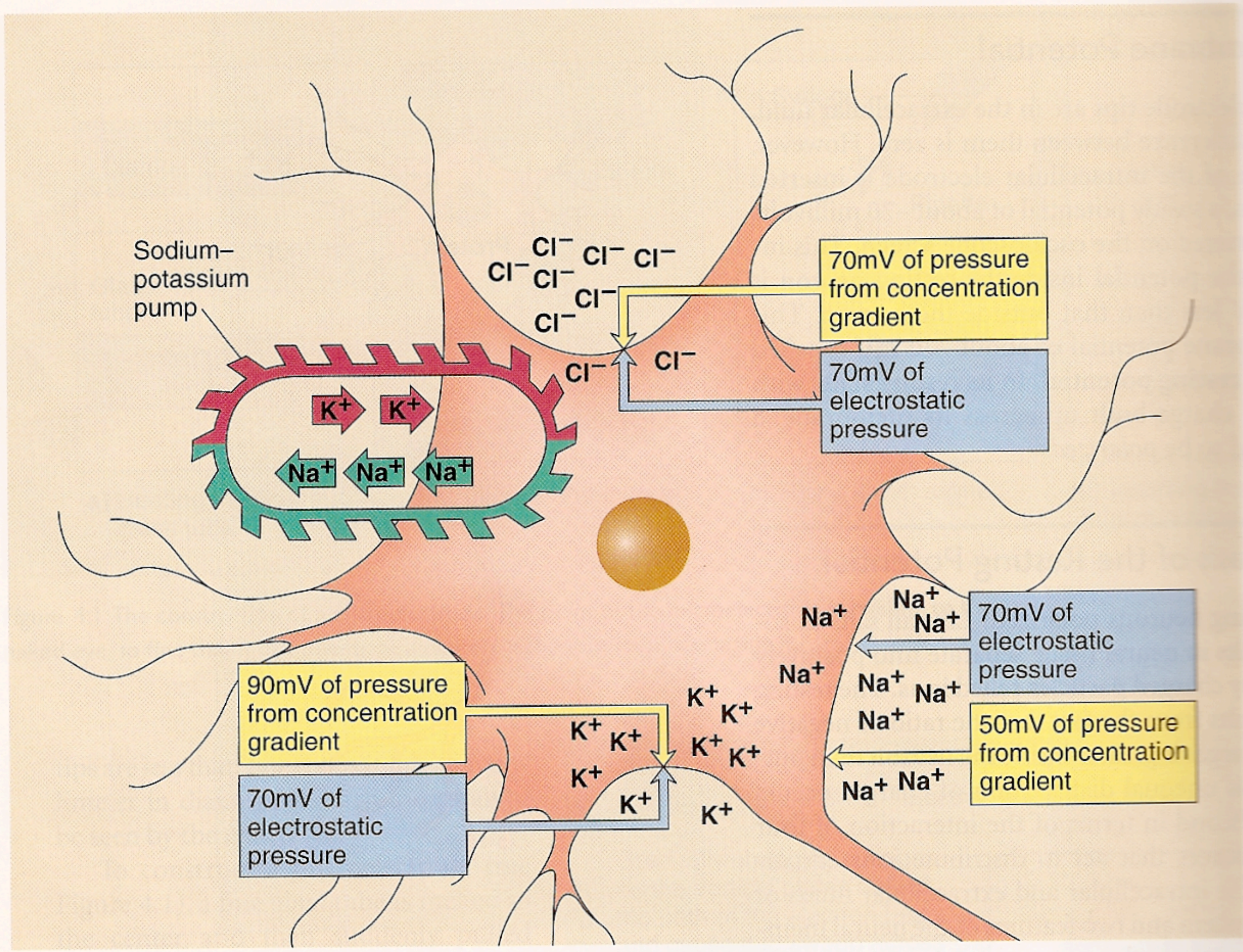
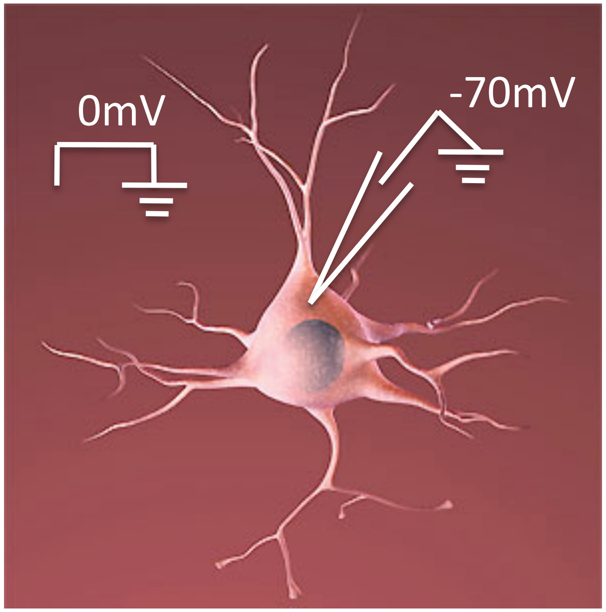


Figure 4.4 The passive and active forces that influence the distribution of Na^+, K^+, and Cl^- ions across the neural membrane. Passive forces continuously drive K^+ ions out of the resting neuron and Na^+ ions in; therefore, K^+ ions must be actively pumped in and Na^+ ions must be actively pumped out to maintain the resting equilibrium.

Membrane Potential

- The interior of the neuron is kept at approximately -70 mV with respect to the exterior



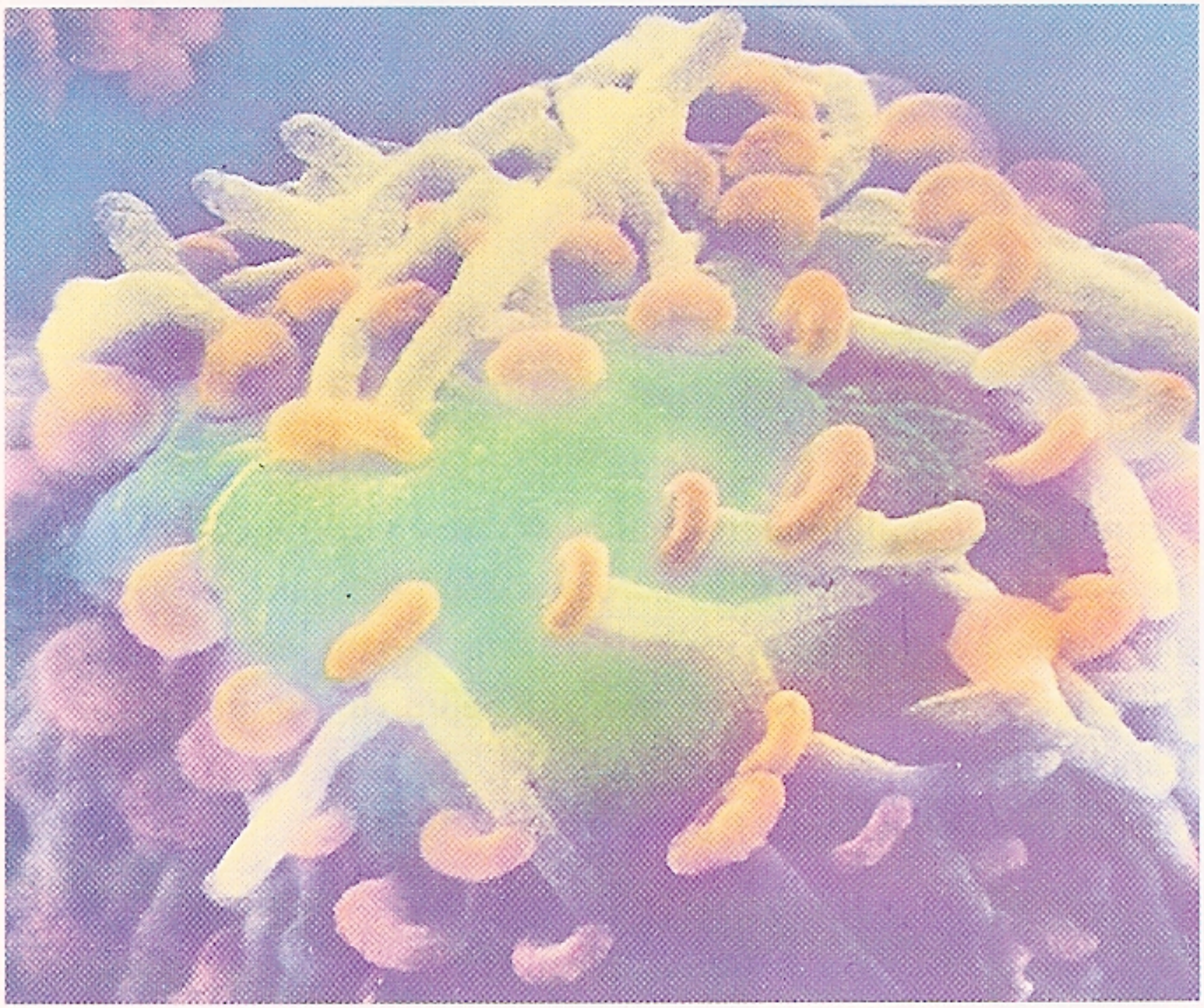
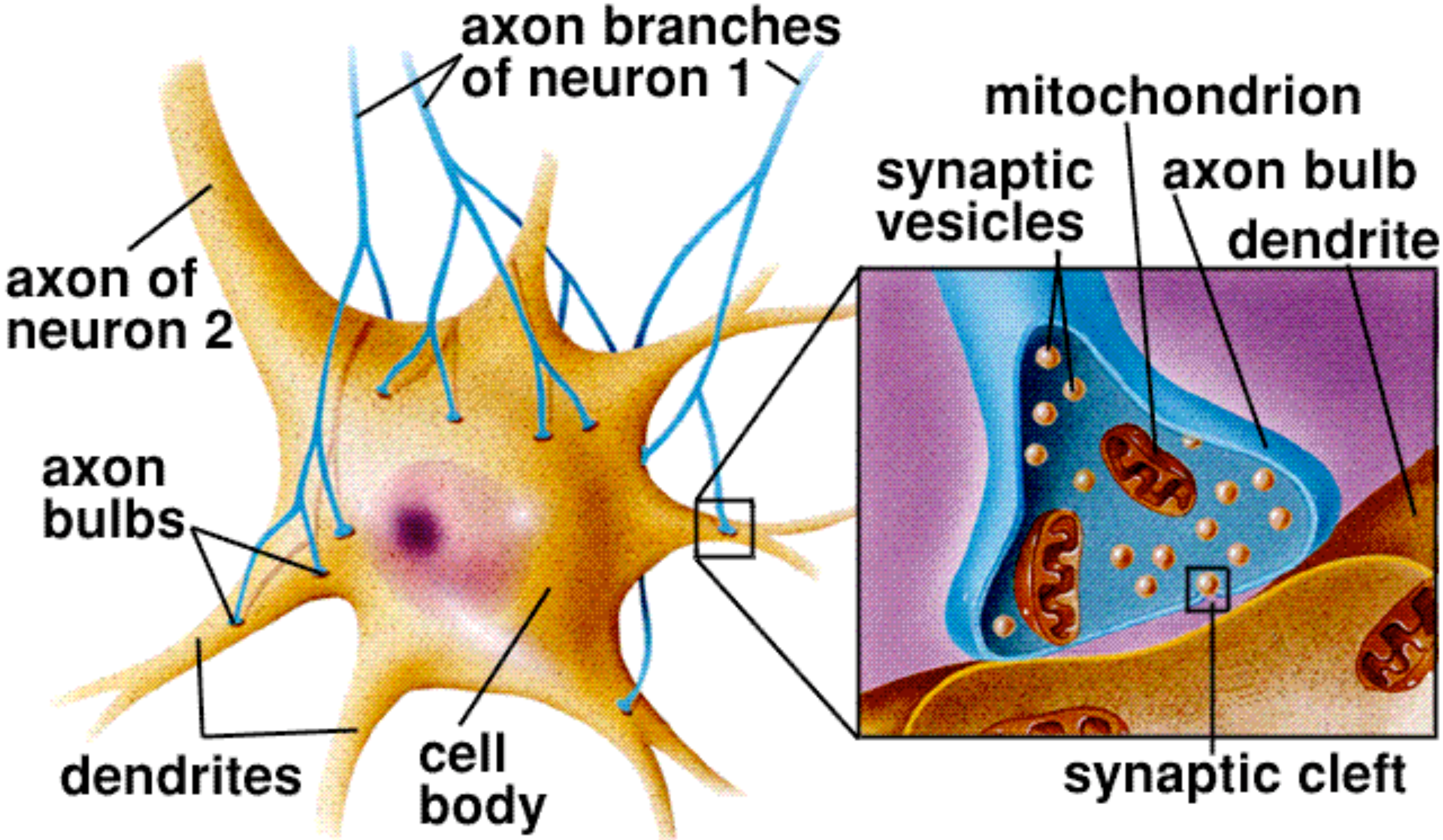
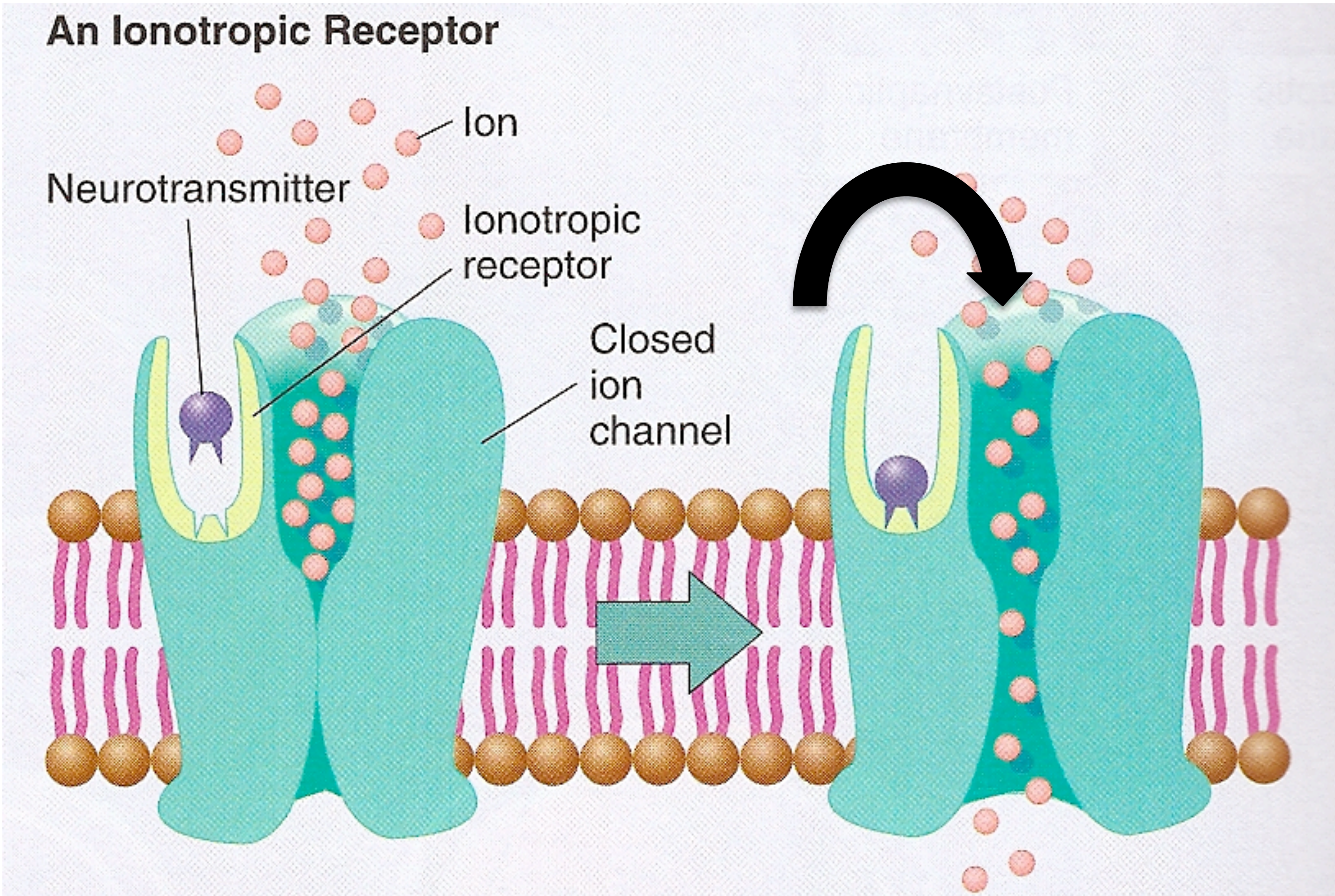


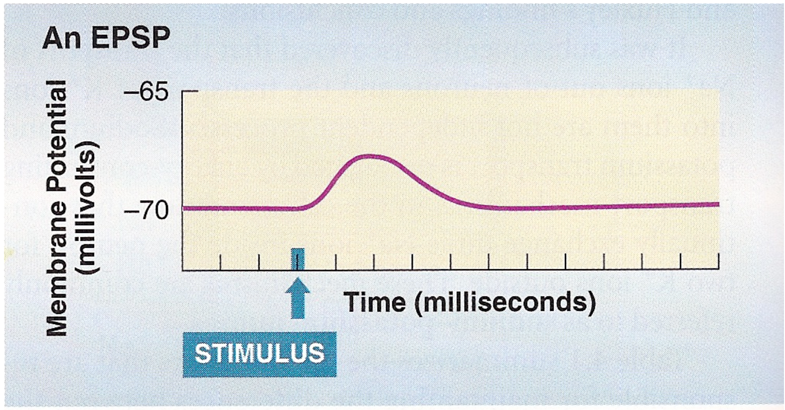
Figure 3.13 A color-enhanced scanning electron micrograph of a neuron cell body (green) studded with terminal buttons (orange). Each neuron receives numerous synaptic contacts.
(Courtesy of Jerold J. M. Chun, M. D., Ph.D.)

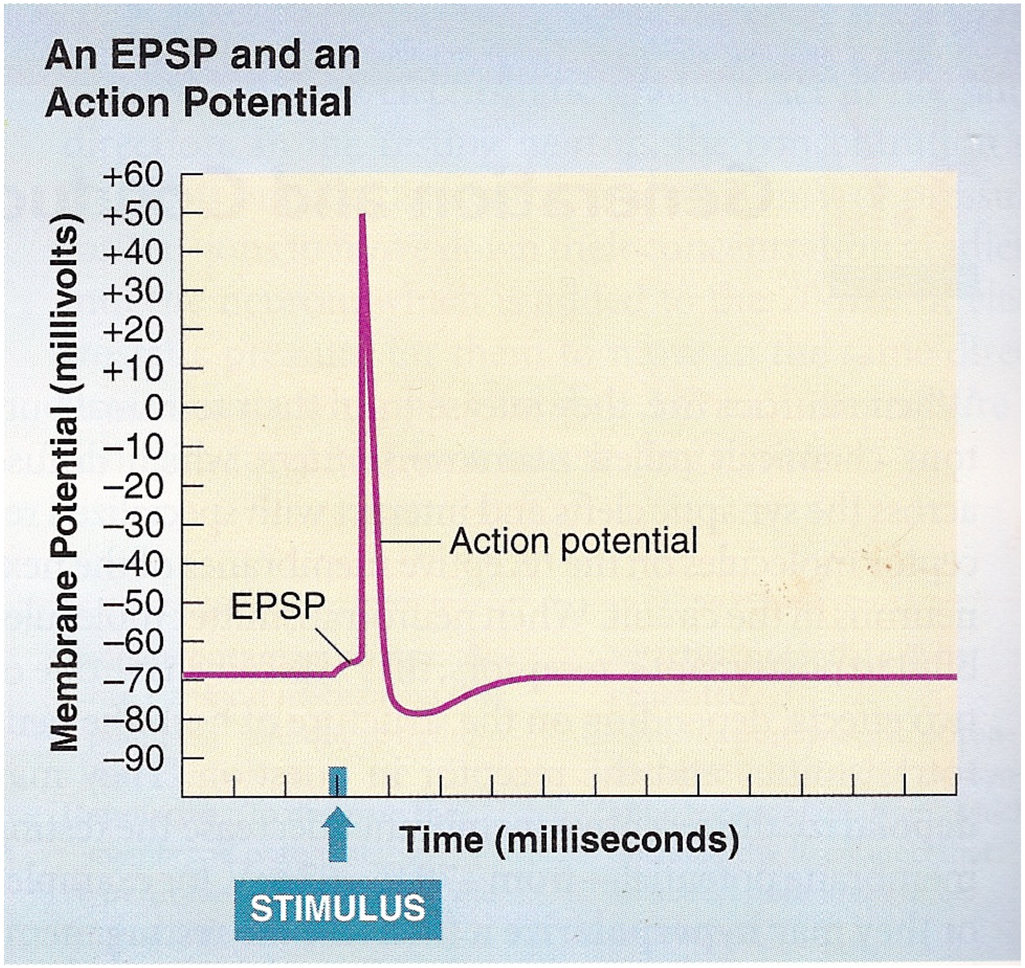
Synapse Location and Anatomy

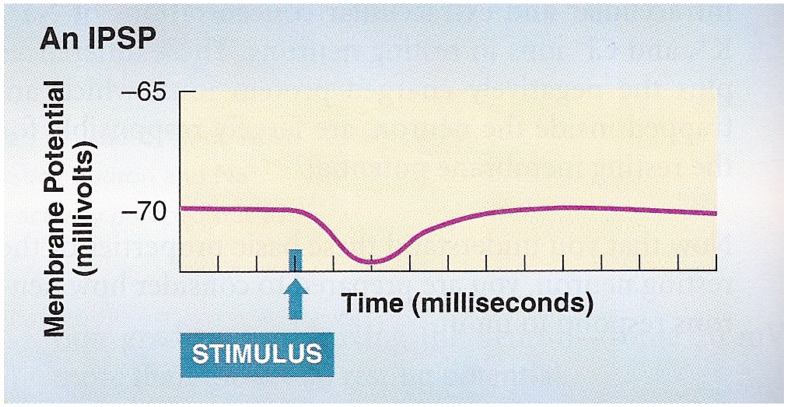


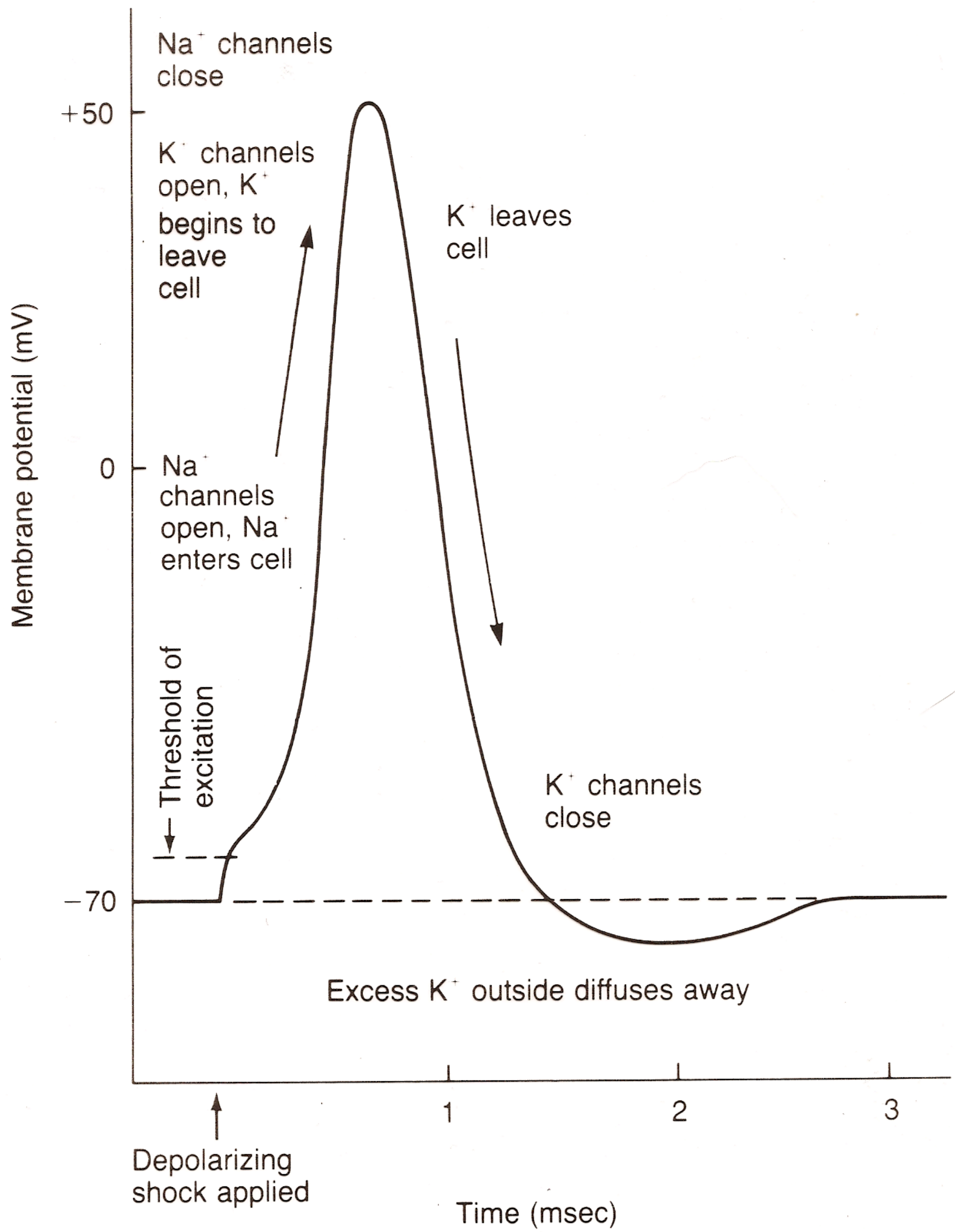


An Ionotropic Receptor
Ion
Neurotransmitter
Ionotropic
receptor
Closed
ion
channel


An EPSP
Membrane Potential (millivolts)
−65
−70
Time (milliseconds)
STIMULUS


An EPSP and an Action Potential
Membrane Potential (millivolts)
+60
+50
+40
+30
+20
+10
0
−10
−20
−30
−40
−50
−60
−70
−80
−90
Action potential
EPSP
Time (milliseconds)
STIMULUS


An IPSP
Membrane Potential (millivolts)
−65
−70
Time (milliseconds)
STIMULUS



Na+ channels close
+50
K+ channels open, K+ begins to leave cell
K+ leaves cell
0
Na+ channels open, Na+ enters cell
Membrane potential (mV)
Threshold of excitation
K+ channels close
−70
Excess K+ outside diffuses away
1
2
3
Depolarizing shock applied
Time (msec)

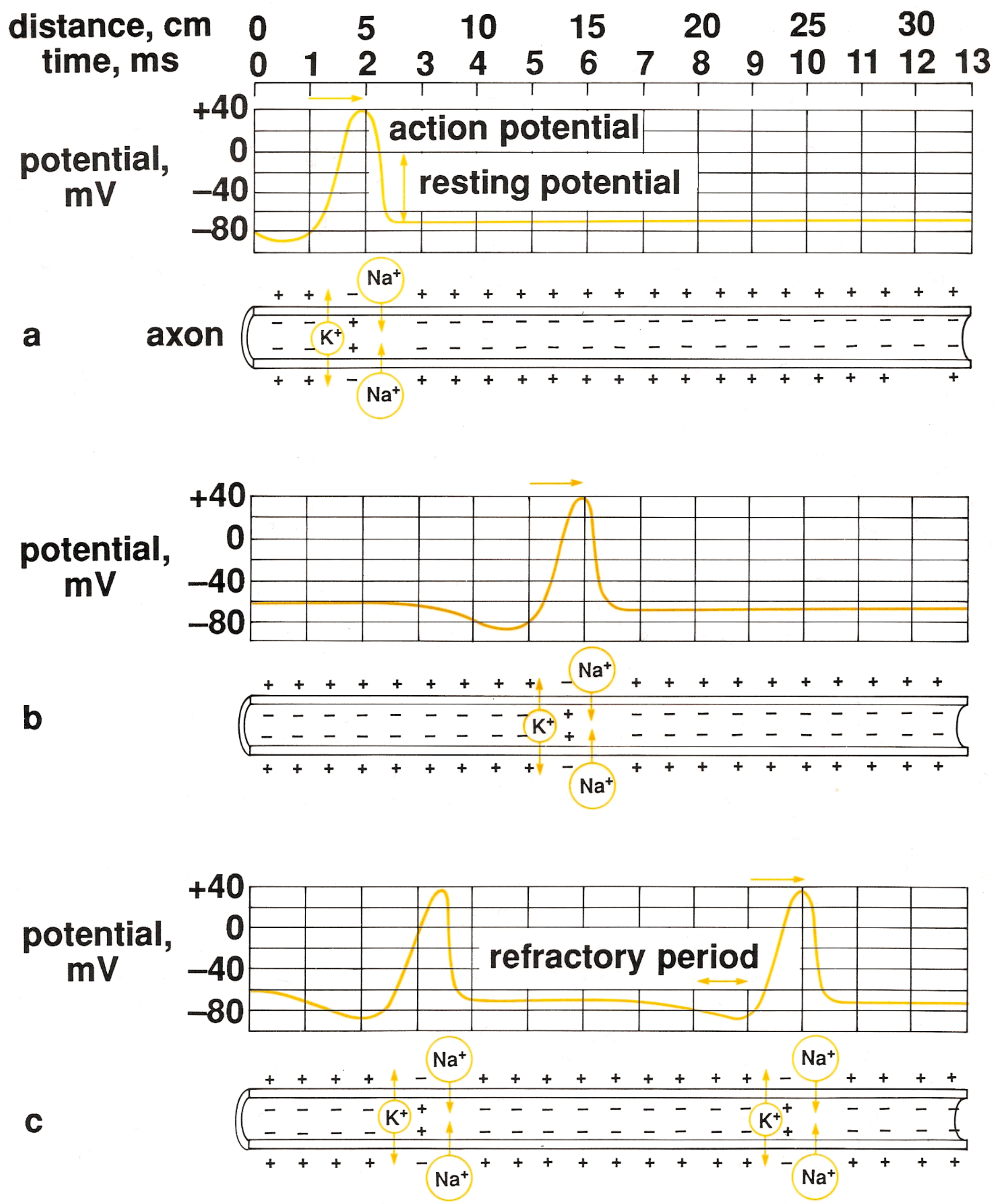
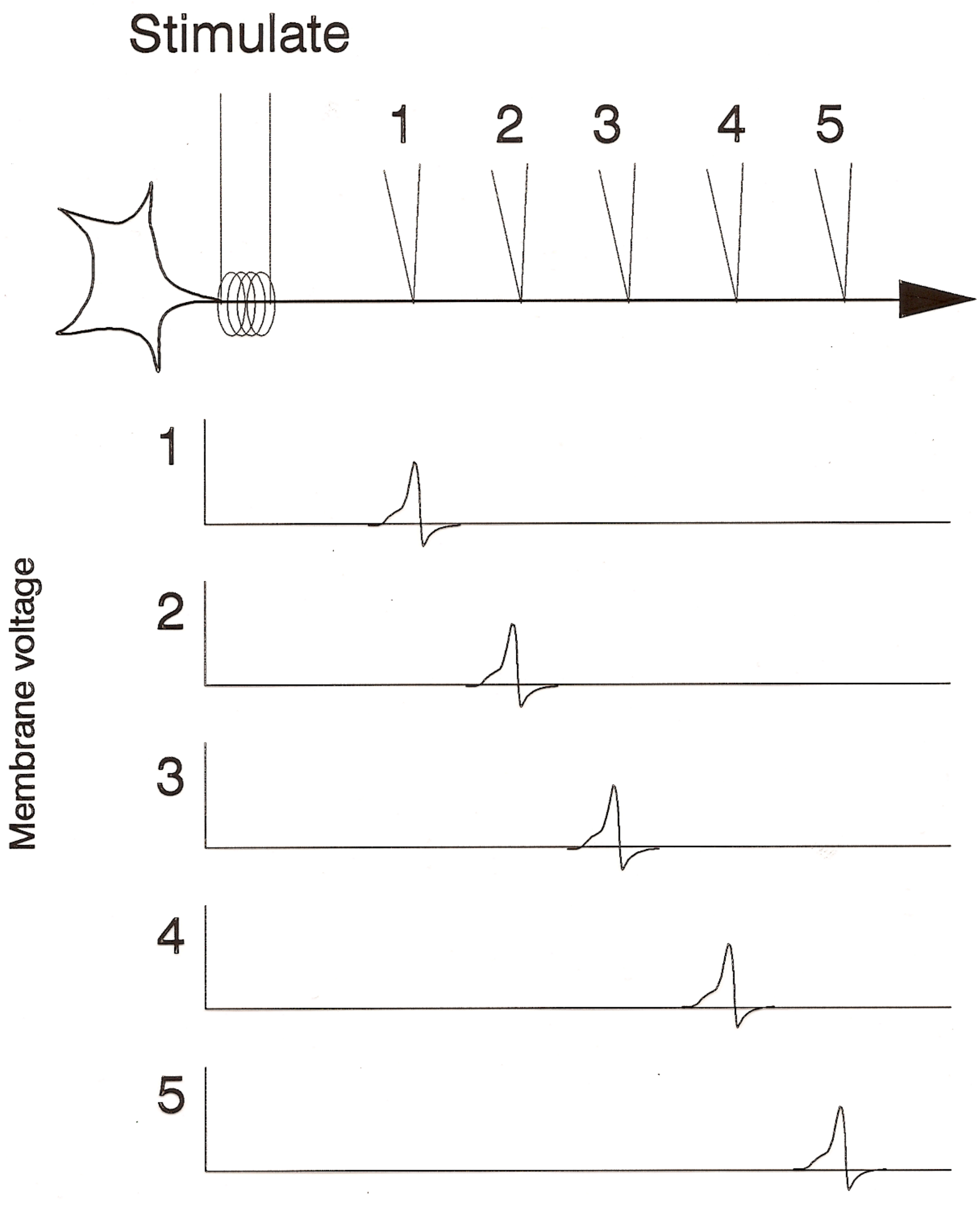
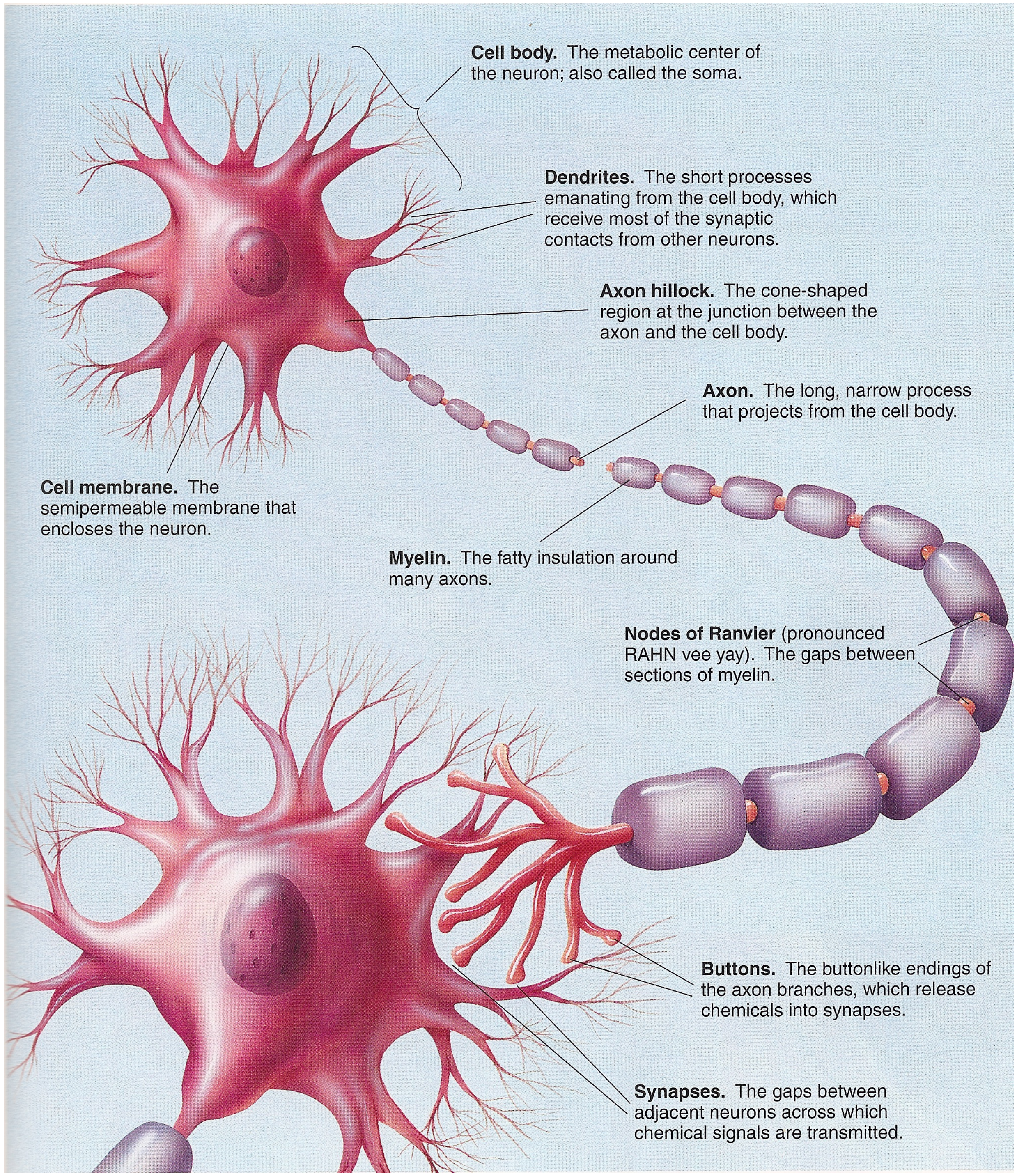
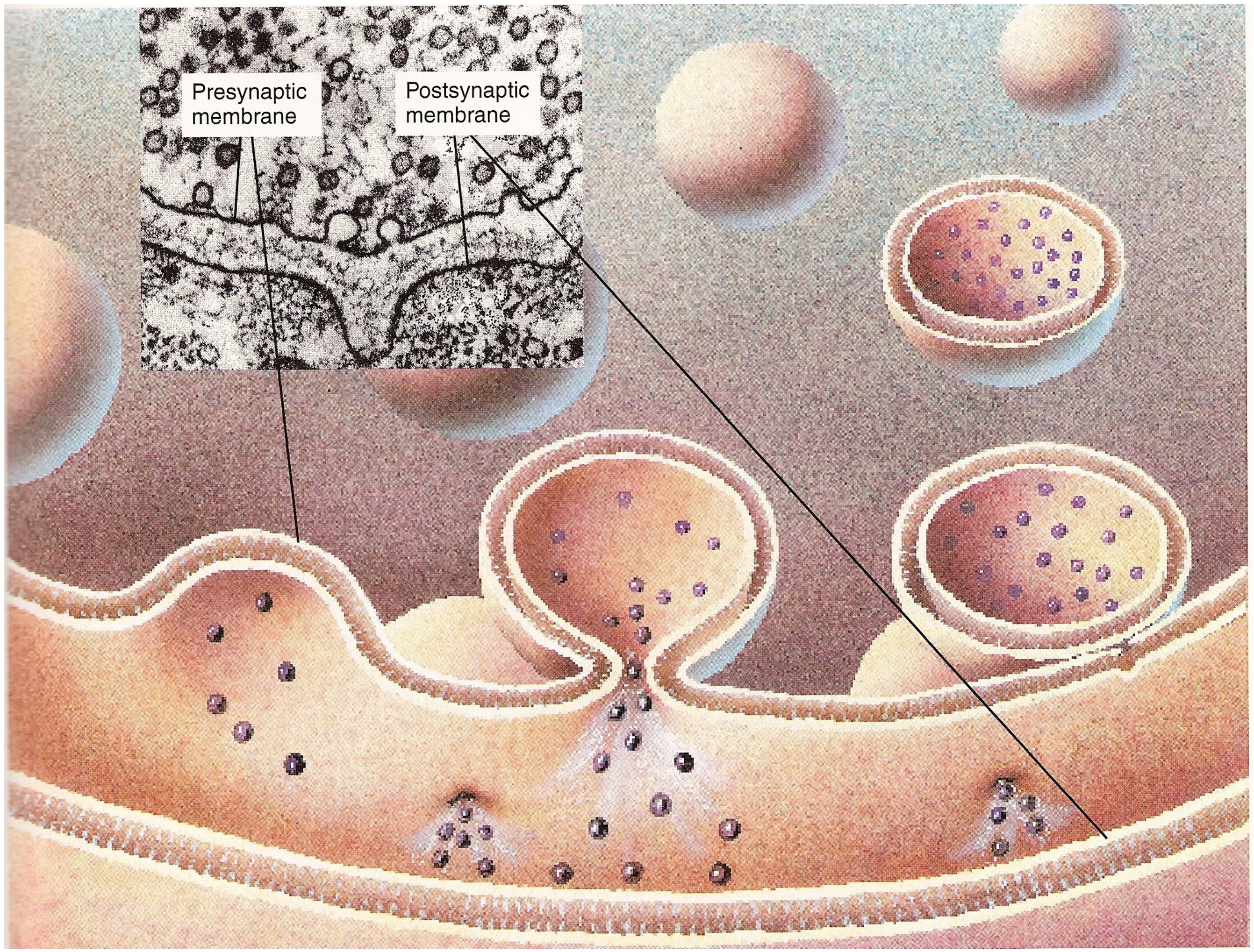


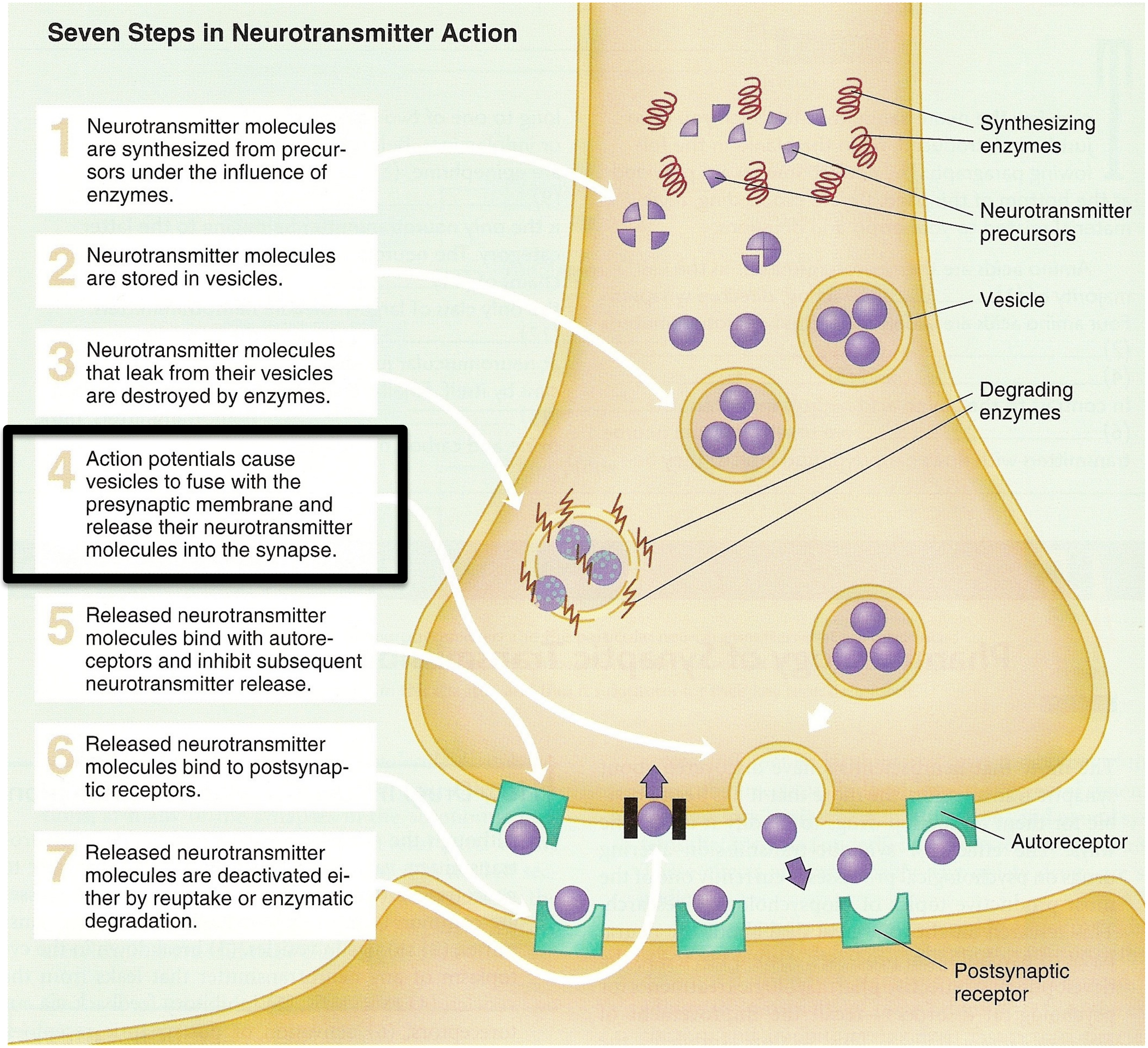
Fig. 4.8 Propagation of the nerve impulse along the axon


Stimulate
1
2
3
4
5
Membrane voltage
1
2
3
4
5

Graded potential
Vs
Saltatory Conduction

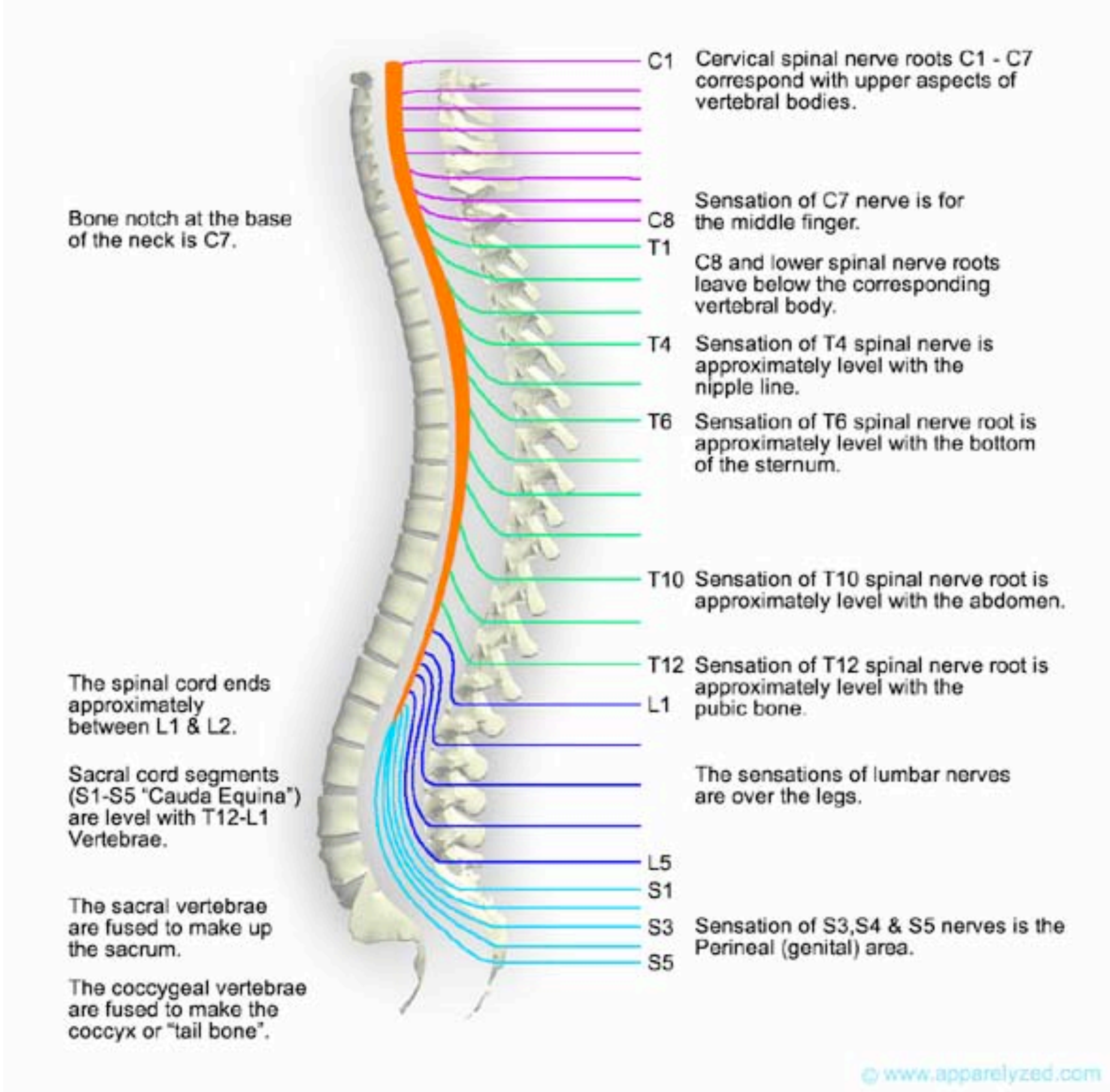


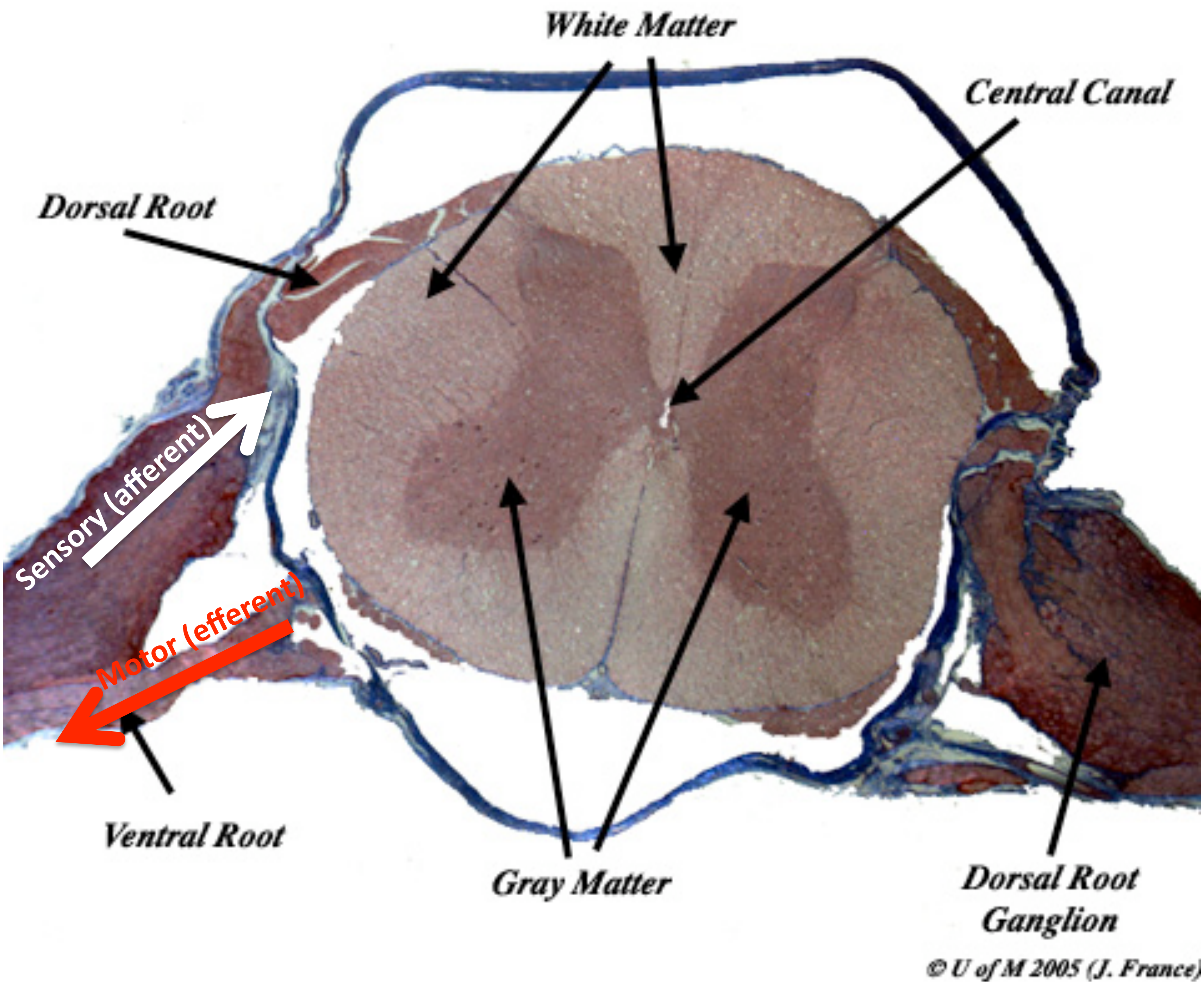

Presynaptic
membrane
Postsynaptic
membrane


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 either by reuptake or enzymatic degradation.
Synthesizing enzymes
Neurotransmitter precursors
Vesicle
Degrading enzymes
Autoreceptor
Postsynaptic receptor

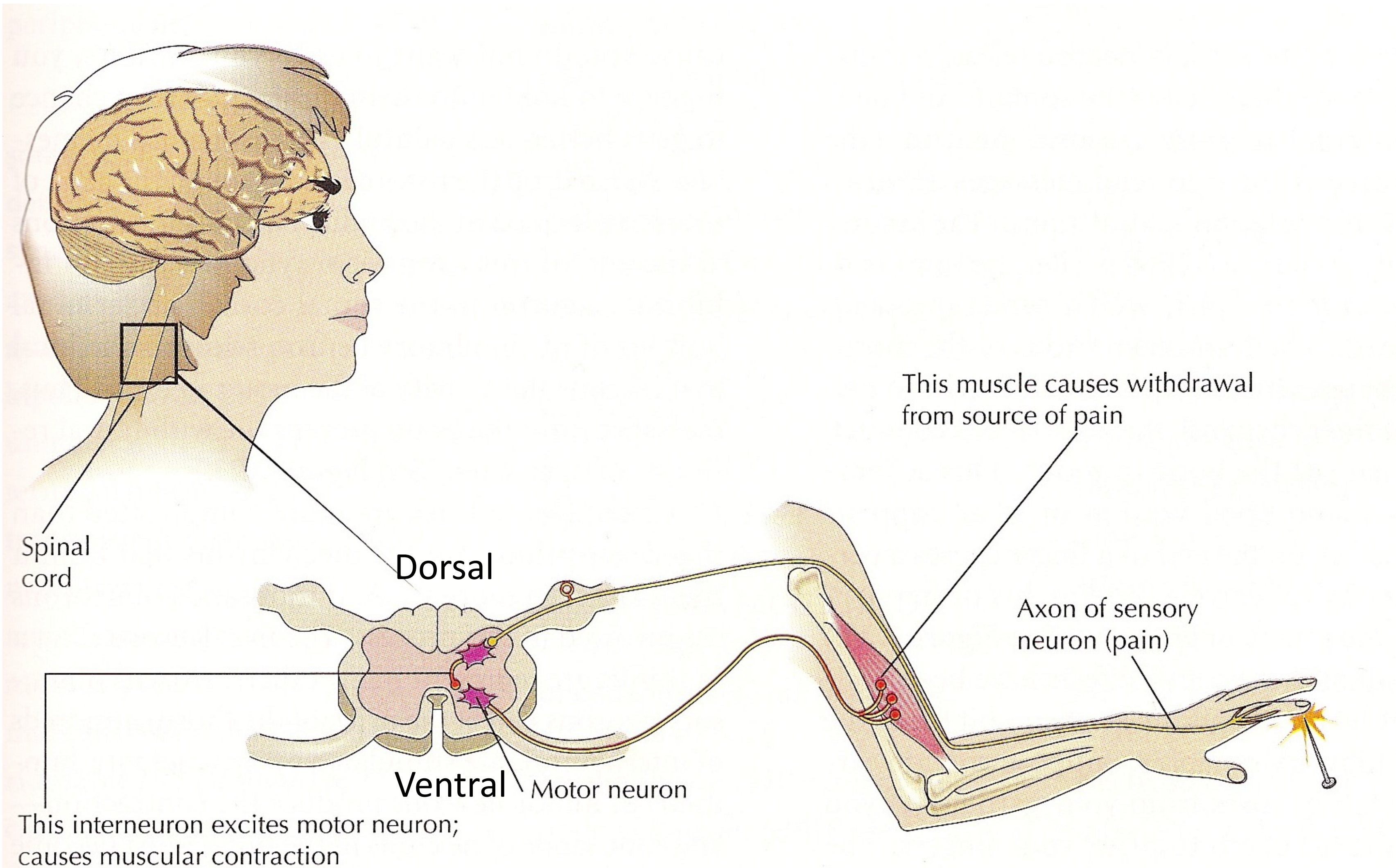
Spinal Cord

- Many cortical neurons synapse with other cortical neurons
- Interaction with the environment (except for the eye) generally through the spinal cord


C1
Cervical spinal nerve roots C1 - C7 correspond with upper aspects of vertebral bodies.
Bone notch at the base of the neck is C7.
C8
Sensation of C7 nerve is for the middle finger.
T1
C8 and lower spinal nerve roots leave below the corresponding vertebral body.
T4
Sensation of T4 spinal nerve is approximately level with the nipple line.
T6
Sensation of T6 spinal nerve root is approximately level with the bottom of the sternum.
T10
Sensation of T10 spinal nerve root is approximately level with the abdomen.
T12
Sensation of T12 spinal nerve root is approximately level with the pubic bone.
L1
The spinal cord ends approximately between L1 & L2.
Sacral cord segments (S1-S5 "Cauda Equina") are level with T12-L1 Vertebrae.
The sensations of lumbar nerves are over the legs.
L5
S1
S3
S5
Sensation of S3,S4 & S5 nerves is the Perineal (genital) area.
The sacral vertebrae are fused to make up the sacrum.
The coccygeal vertebrae are fused to make the coccyx or "tail bone".
© www.apparelyzed.com

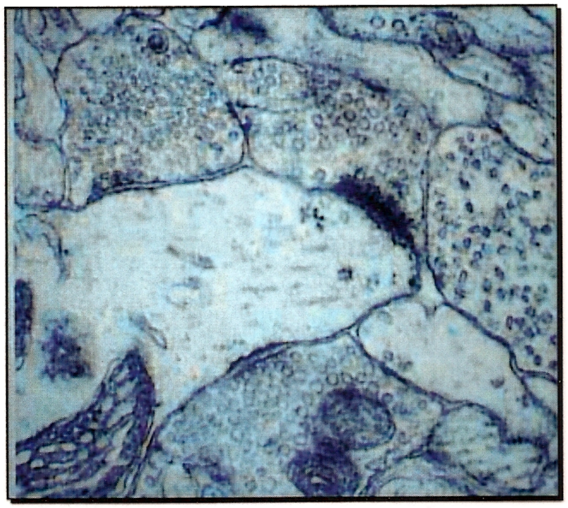

White Matter
Central Canal
Dorsal Root
Sensory (afferent)
Motor (efferent)
Ventral Root
Gray Matter
Dorsal Root
Ganglion
© U of M 2005 (J. France)

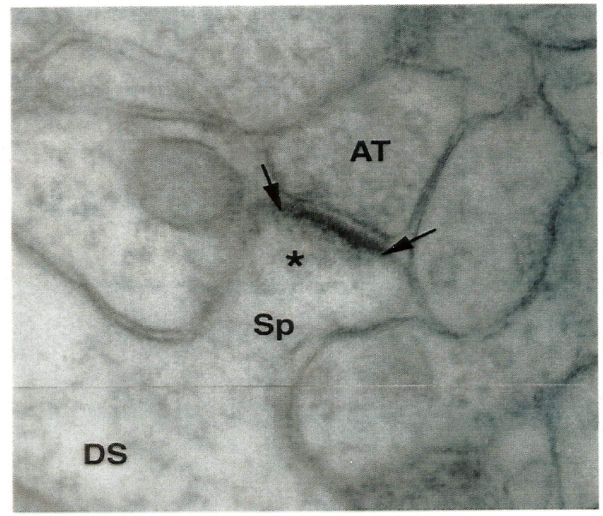
Reflex arc



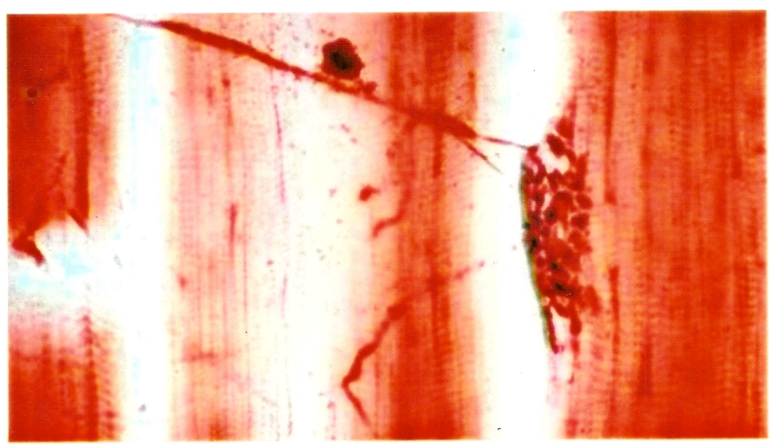
Spinal
cord
Dorsal
This muscle causes withdrawal
from source of pain
Axon of sensory
neuron (pain)
Ventral
Motor neuron
This interneuron excites motor neuron;
causes muscular contraction

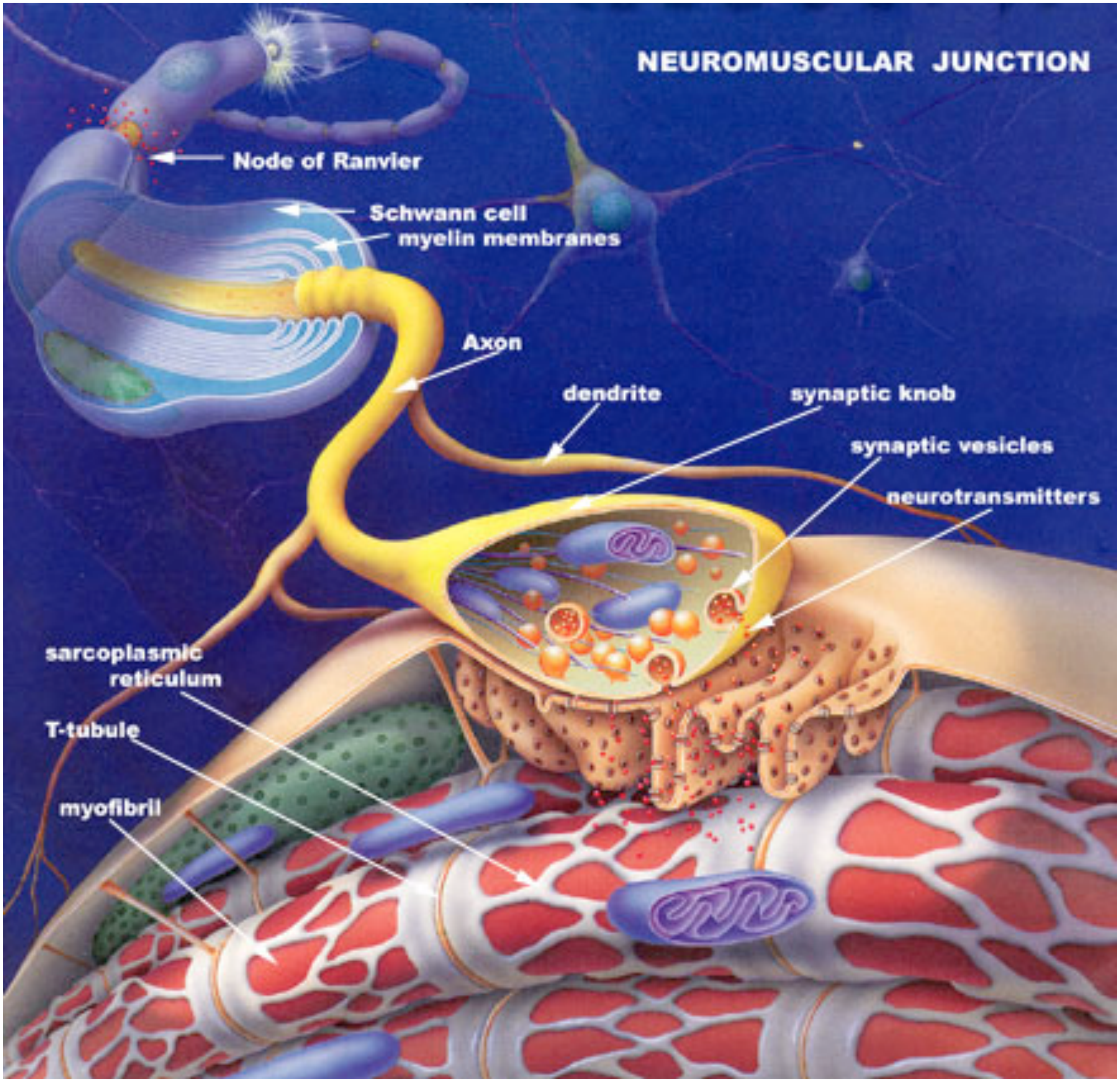
Synapses in the brain



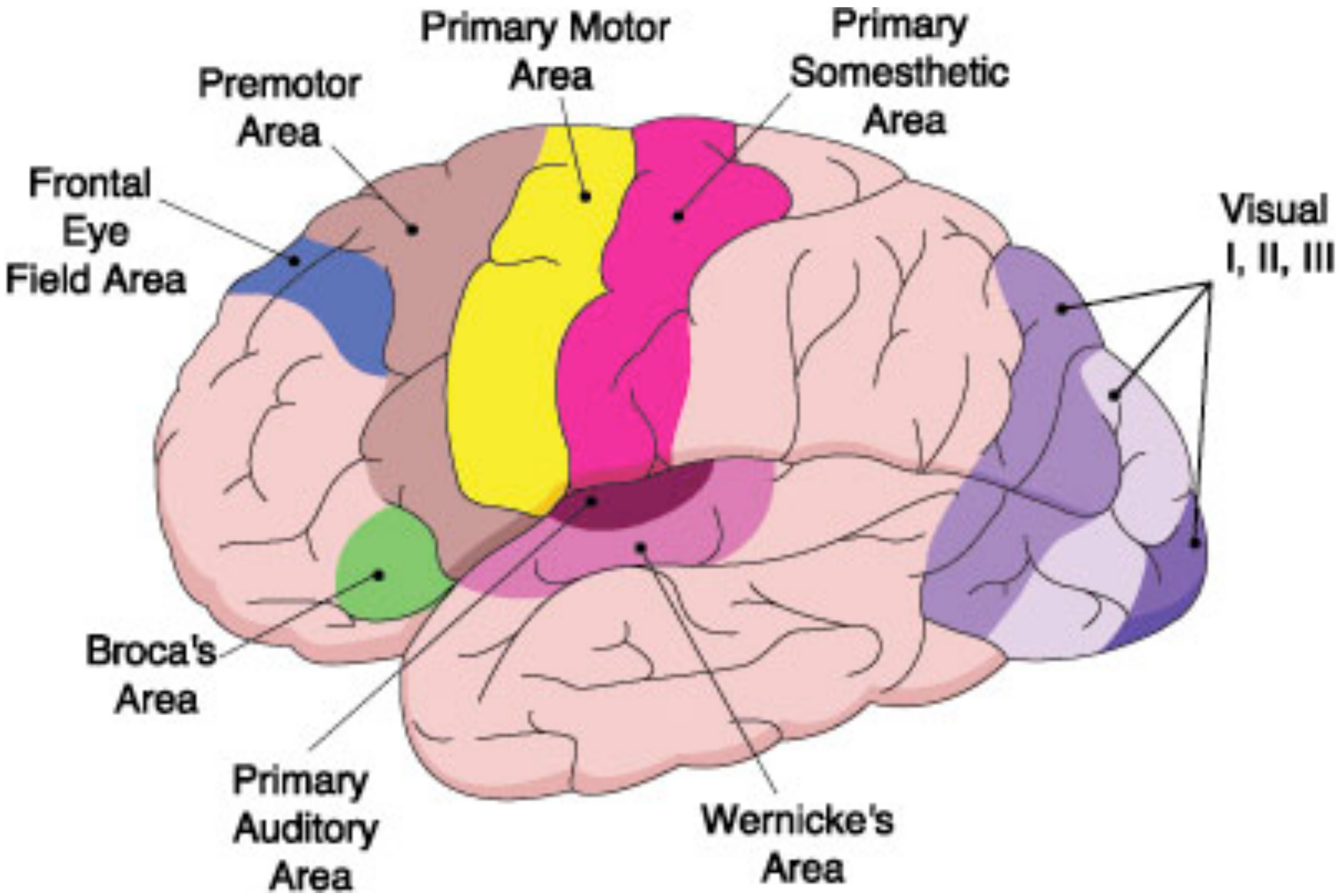


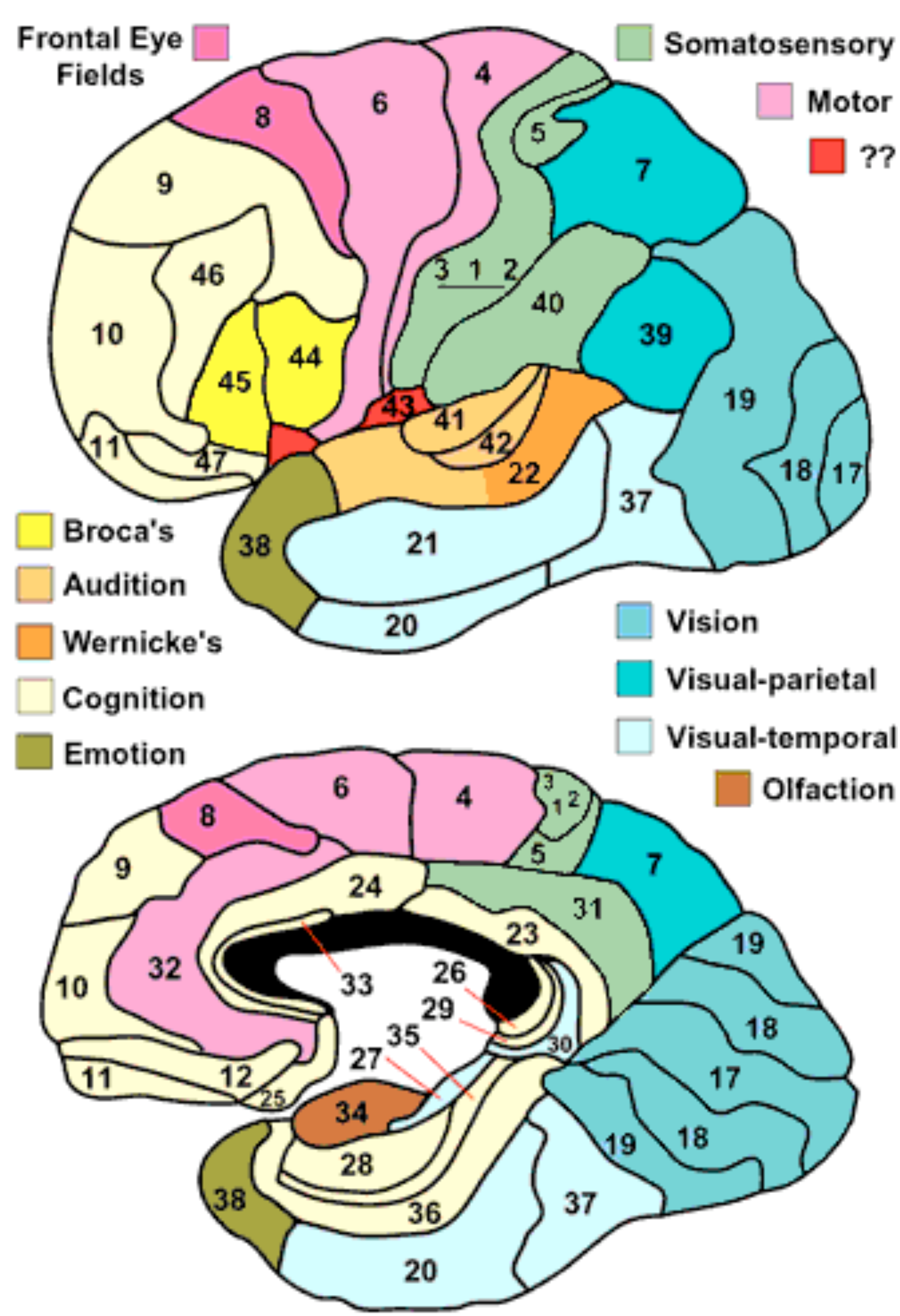
Neuromuscular junction



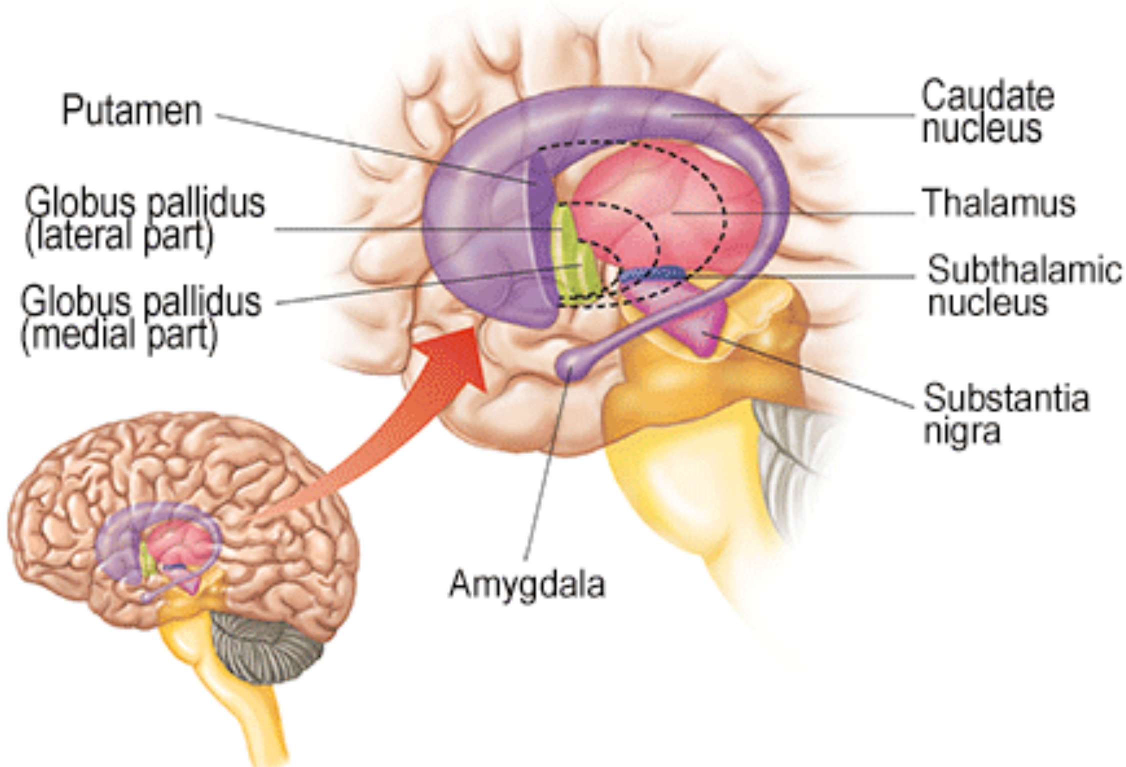

NEUROMUSCULAR JUNCTION
Node of Ranvier
Schwann cell
myelin membranes
Axon
dendrite
synaptic knob
synaptic vesicles
neurotransmitters
sarcoplasmic
reticulum
T-tubule
myofibril

Organization of Cortex



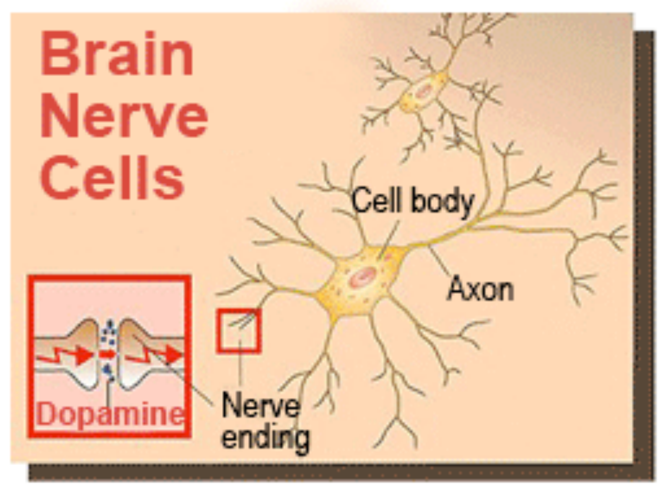

Frontal Eye Fields
Somatosensory
Motor
??
Broca's
Audition
Wernicke's
Cognition
Emotion
Vision
Visual-parietal
Visual-temporal
Olfaction

The Human Basal Ganglia



Near the base of the brain is a small area called the substantia nigra which contains cells that produce dopamine.

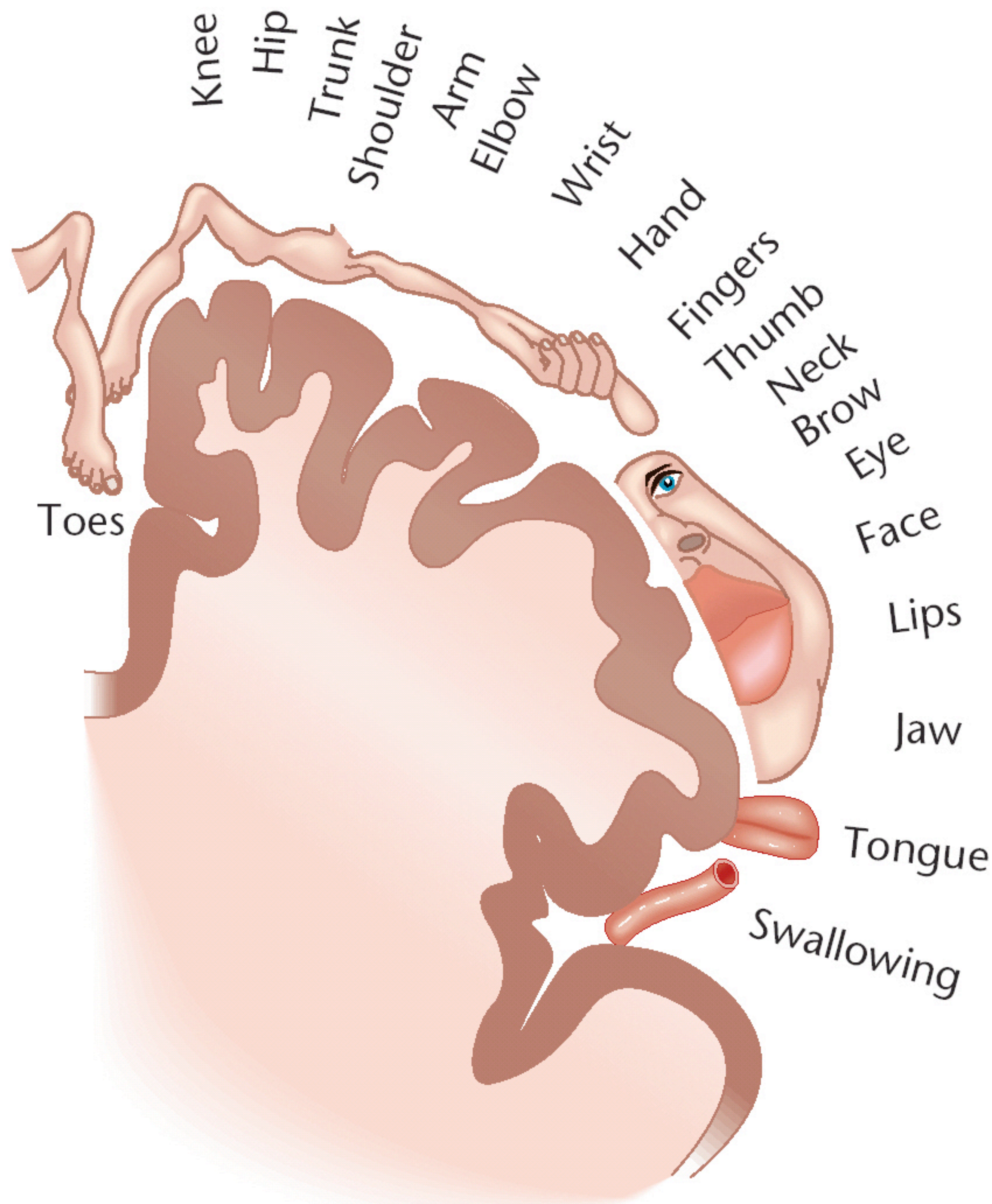
Dopamine acts as a transmitter between the nerve endings.



Parkinson's Disease

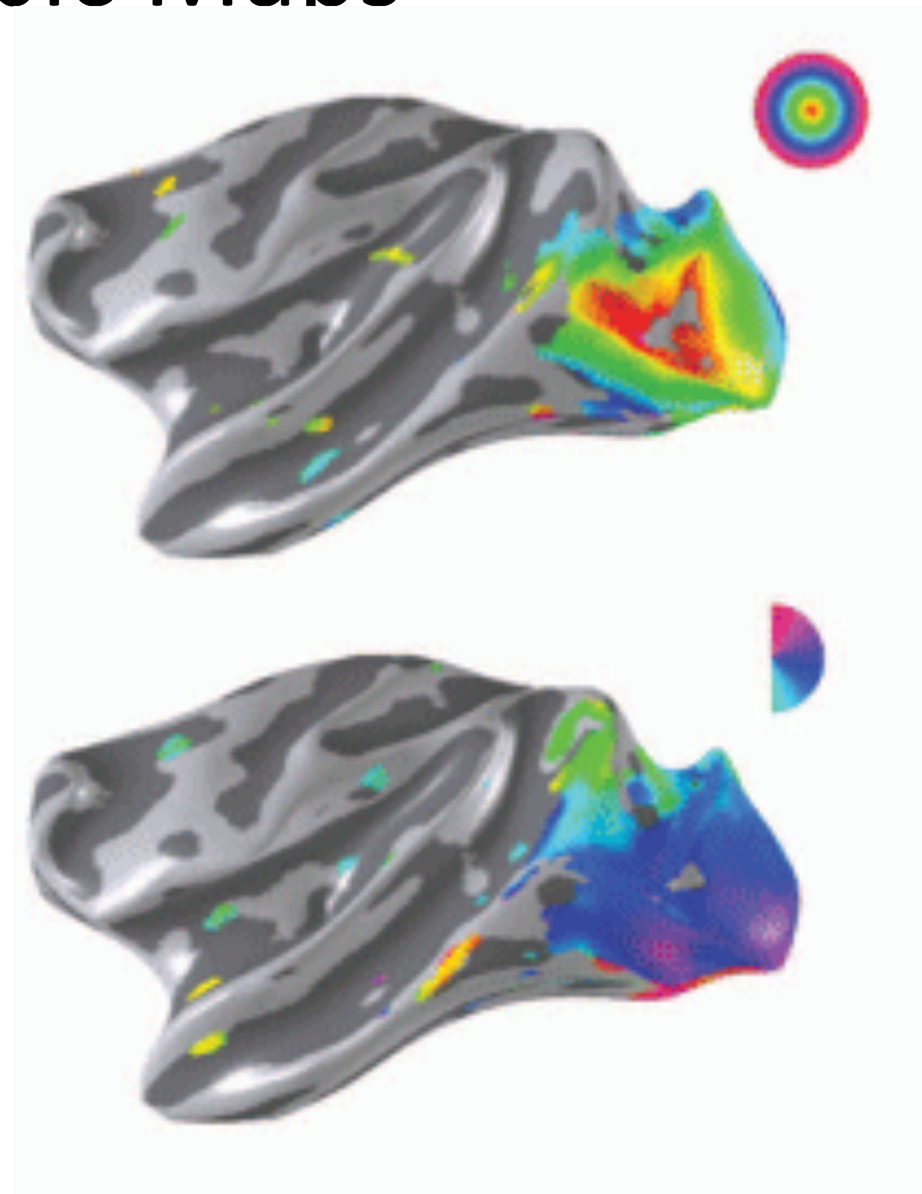
- Degradation of substantia nigra (pars compacta)
  - Loss of dopamine
  - Puts a "break" on input to motor cortex
- muscle rigidity, tremor, a slowing of physical movement (bradykinesia)
- This can be alleviated using
  - Levodopa
  - Deep brain stimulation of the internal segment of the globus pallidus (GPi) or subthalamic nucleus (STN)

Penfield Map

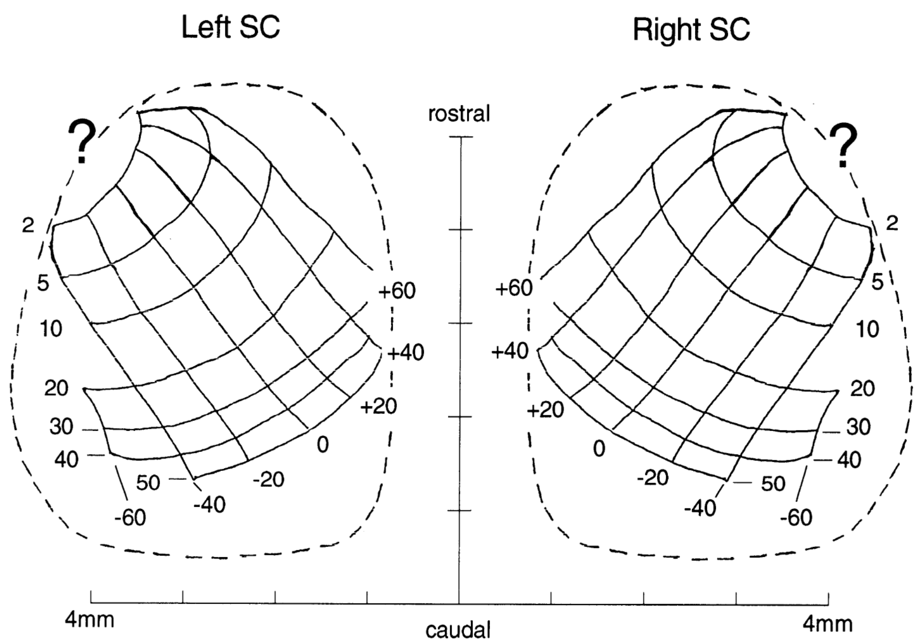


Retinotopic Maps

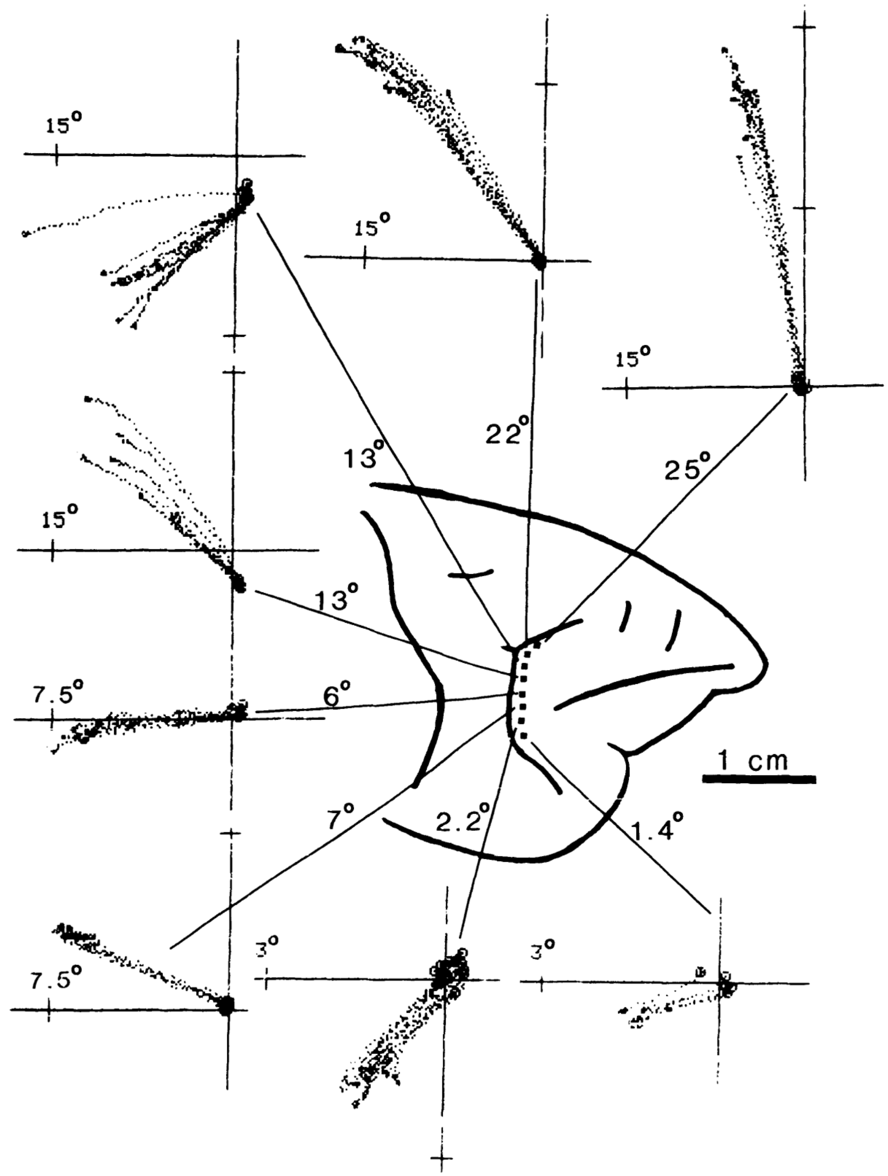
- Much of visual cortex is organized in reference to position on the retina



Saccade Maps – Superior Colliculus



Saccade Maps – Frontal Eye Field



- Many brain regions seem not to have any particular map (e.g., frontal cortex), but this may reflect our incomplete understanding of those areas