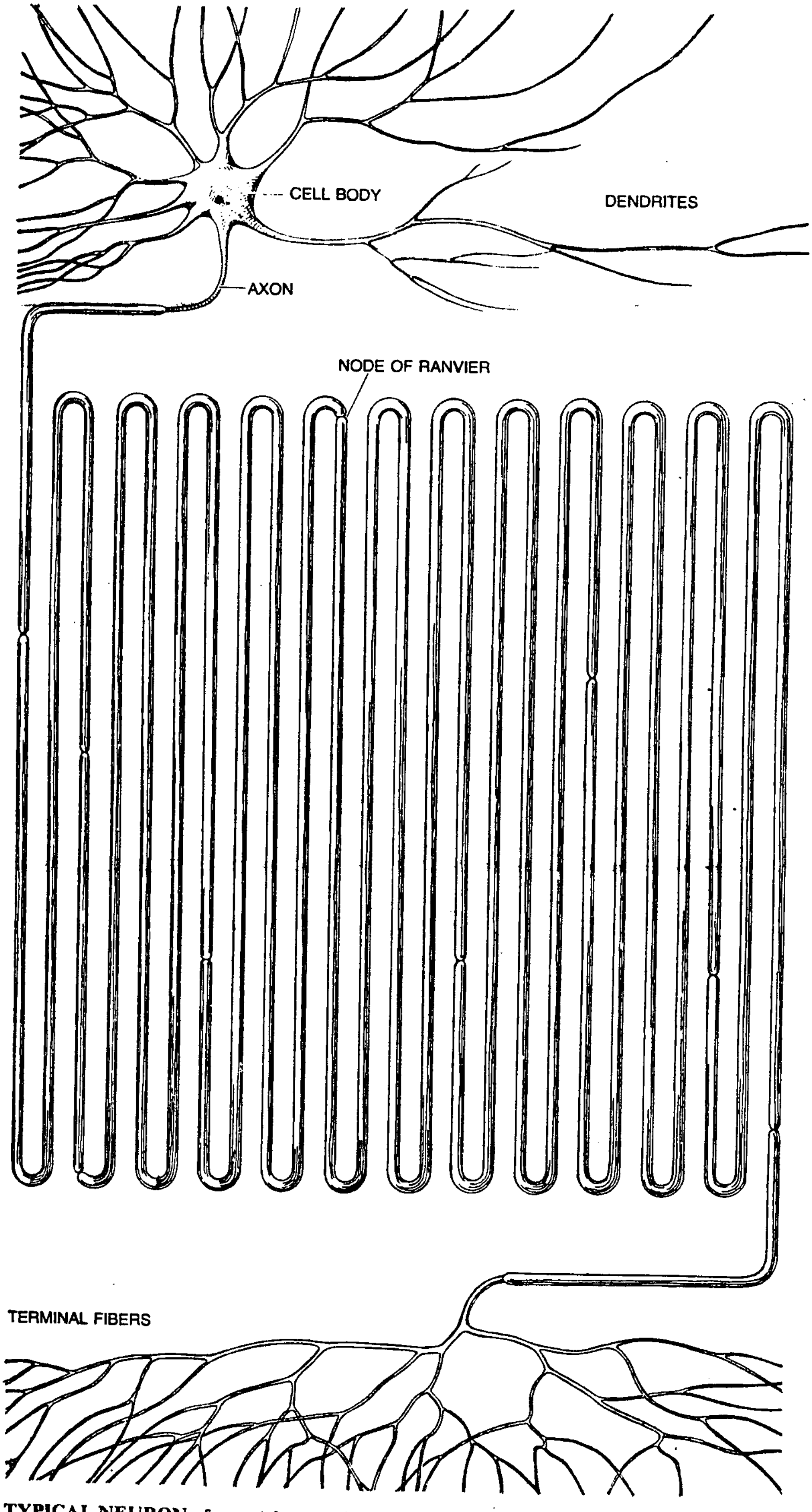
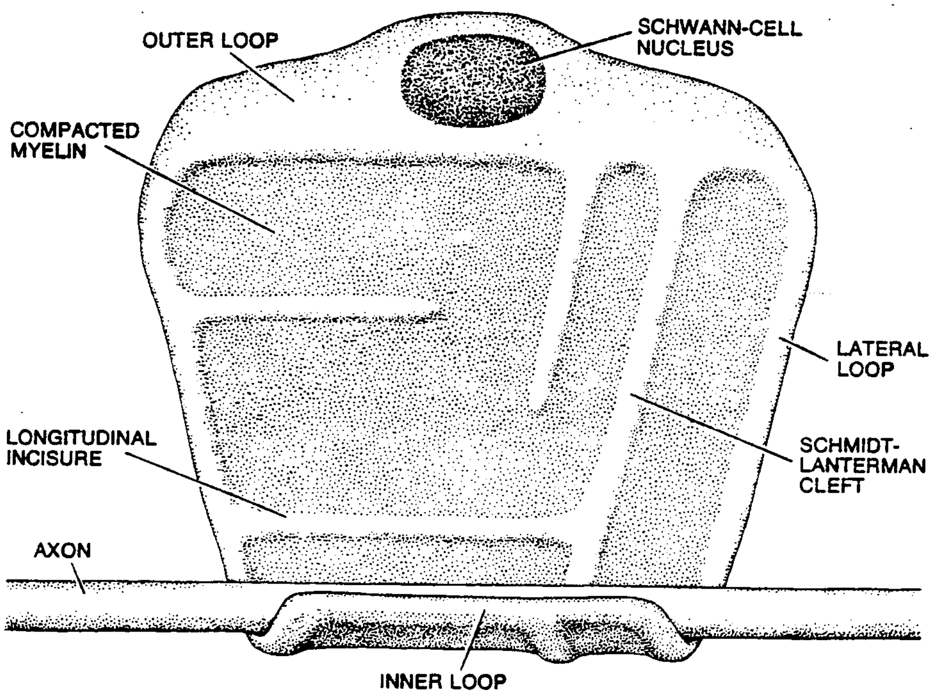
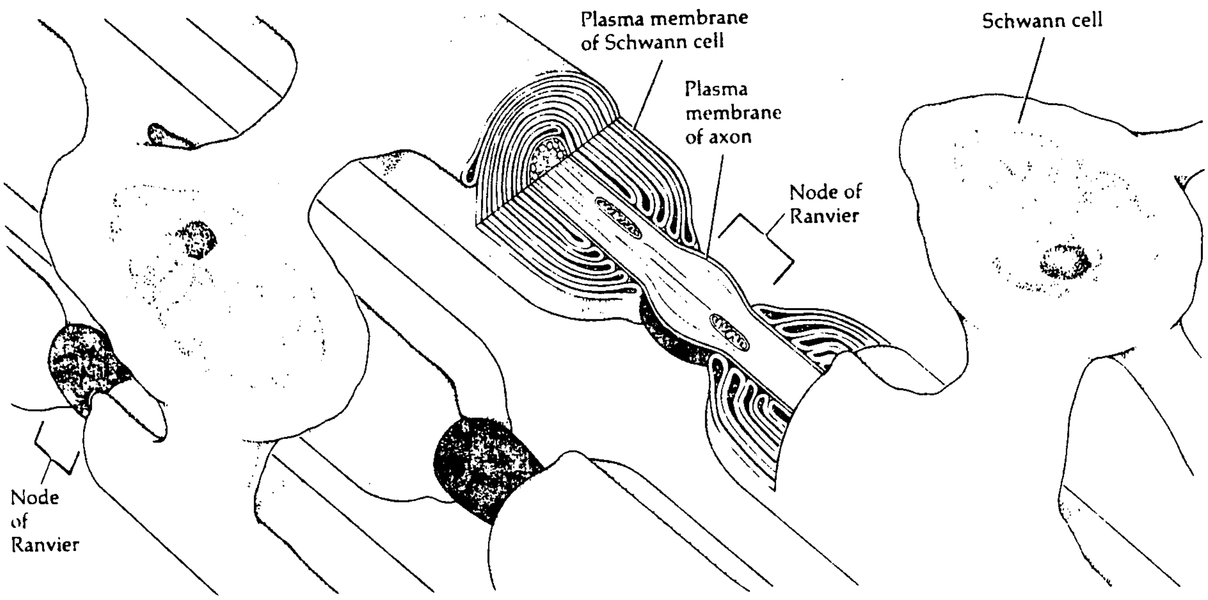
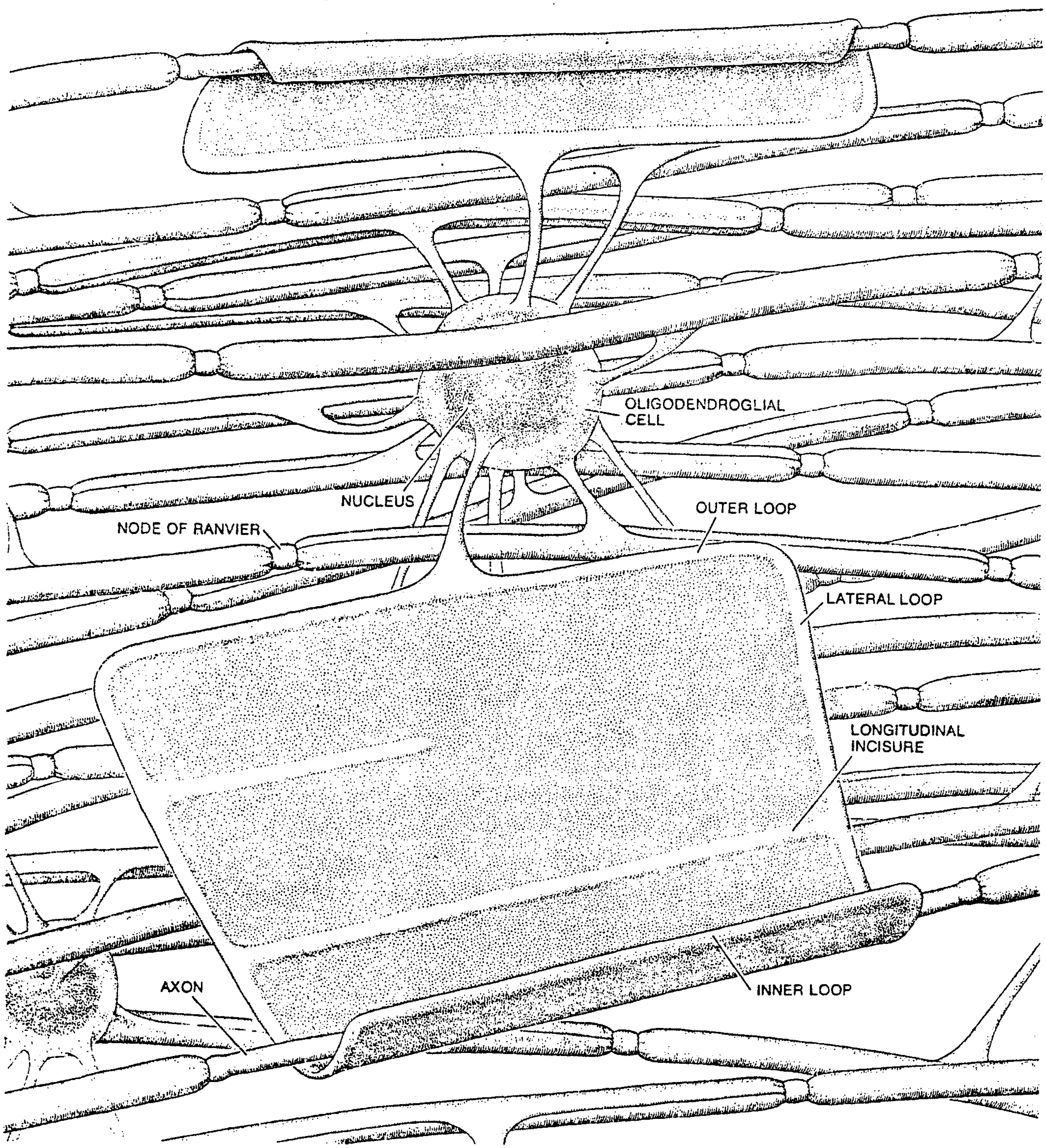


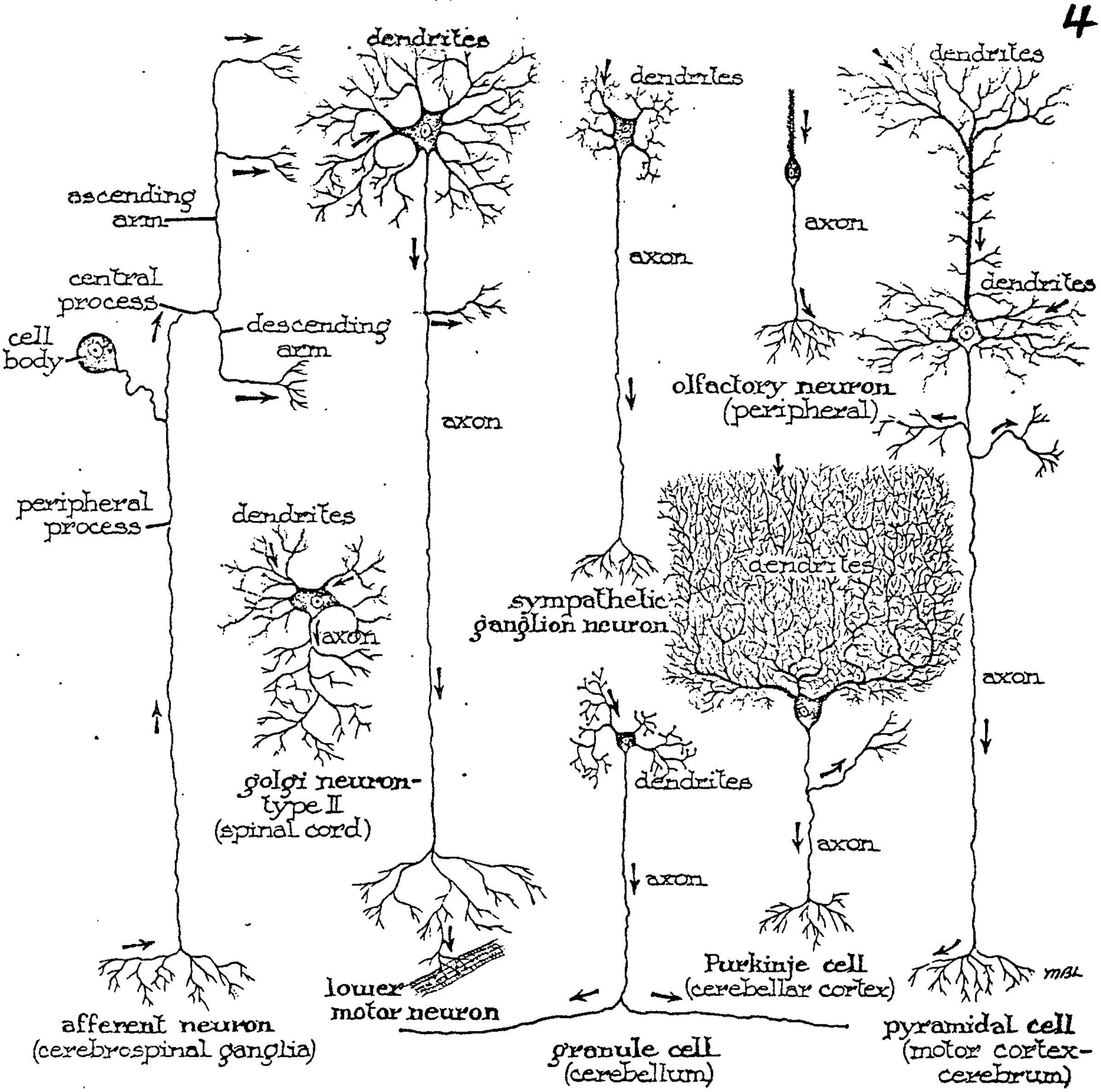
TYPICAL NEURON of a vertebrate animal can carry nerve impulses for a considerable distance. The neuron depicted here, with its various parts drawn to scale, is enlarged 250 times. The nerve impulses originate in the cell body and are propagated along the axon, which may have one or more branches. This axon, which is folded for diagrammatic purposes, would be a centimeter long at actual size. Some axons are more than a meter long. The axon's terminal branches form synapses with as many as 1,000 other neurons. Most synapses join the axon terminals of one neuron with the dendrites forming a "tree" around the cell body of another neuron. Thus the dendrites surrounding the neuron in the diagram might receive incoming signals from tens, hundreds or even thousands of other neurons. Many axons, such as this one, are insulated by a myelin sheath interrupted at intervals by the regions known as nodes of Ranvier.

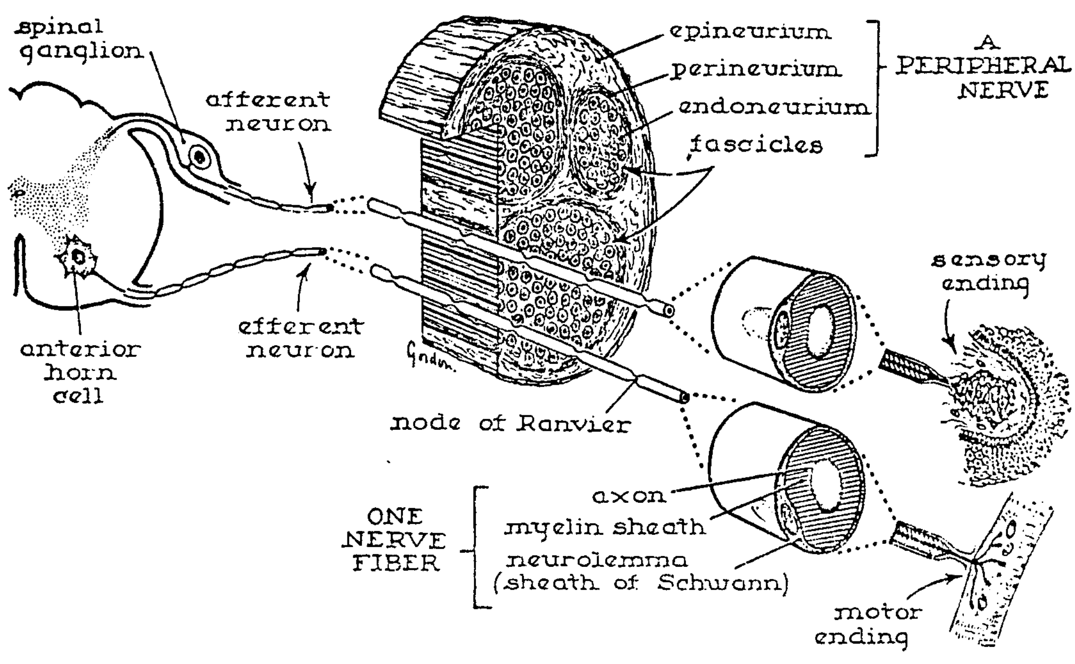


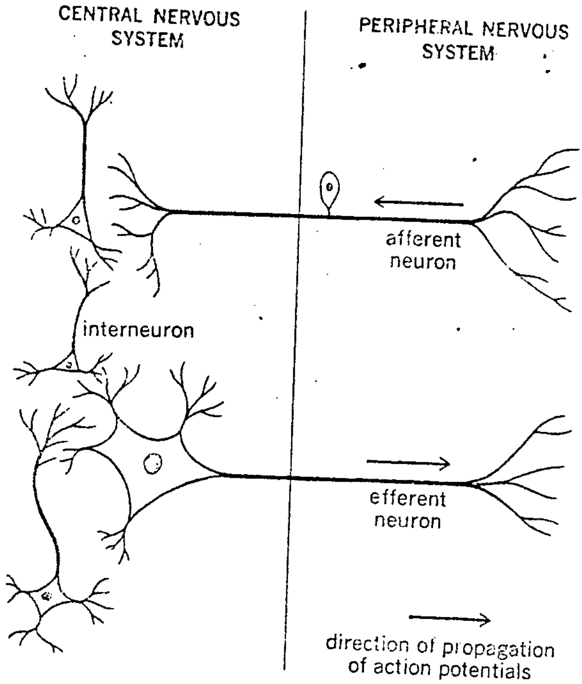
UNROLLED MYELIN SHEATH from an axon in a nerve shows cytoplasmic channels that remain in the sheath where the Schwann cell's membrane does not quite compact on itself. Channels that lead from the sheath back to the cell body of the Schwann cell are Schmidt-Lanterman clefts. These are always present in myelin outside the brain and the spinal cord.



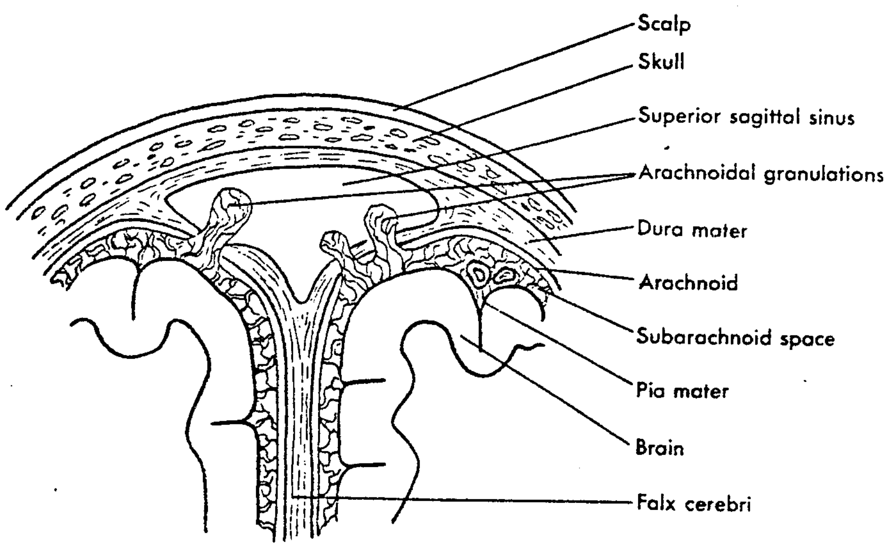

OLIGODENDROGLIAL CELL
NUCLEUS
OUTER LOOP
NODE OF RANVIER
LATERAL LOOP
LONGITUDINAL INCISURE
AXON
INNER LOOP


dendrites
ascending arm
central process
cell body
descending arm
axon
peripheral process
afferent neuron
(cerebrospinal ganglia)
dendrites
axon
golgi neuron-type II
(spinal cord)
lower motor neuron
dendrites
axon
sympathetic ganglion neuron
dendrites
axon
granule cell
(cerebellum)
axon
olfactory neuron
(peripheral)
dendrites
dendrites
axon
Purkinje cell
(cerebellar cortex)
dendrites
dendrites
axon
pyramidal cell
(motor cortex-cerebrum)
MBL

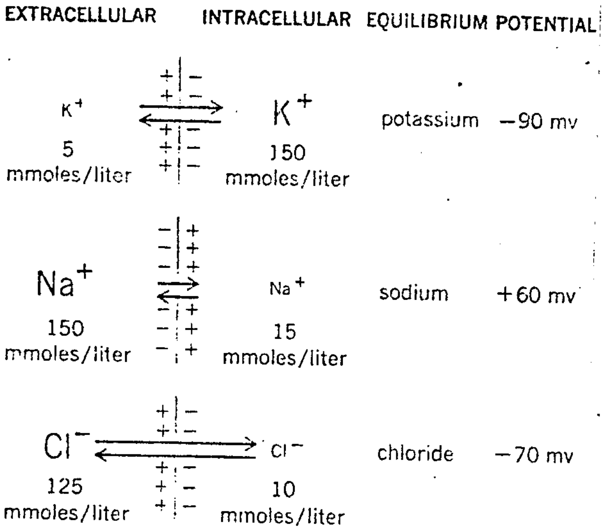

spinal ganglion
afferent neuron
anterior horn cell
efferent neuron
epineurium
perineurium
endoneurium
fascicles
A PERIPHERAL NERVE
node of Ranvier
sensory ending
ONE NERVE FIBER
axon
myelin sheath
neurolemma
(sheath of Schwann)
motor ending

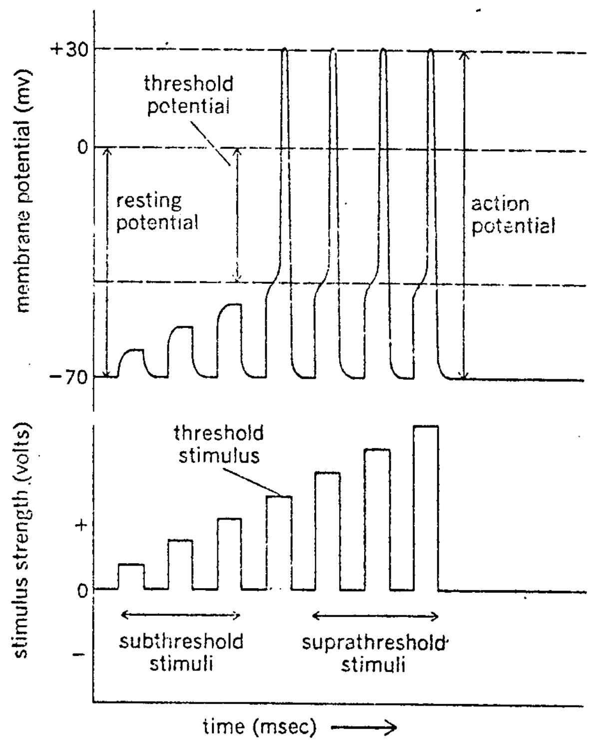


CENTRAL NERVOUS SYSTEM
PERIPHERAL NERVOUS SYSTEM
afferent neuron
interneuron
efferent neuron
direction of propagation of action potentials

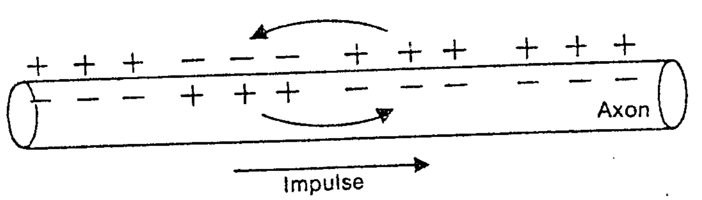


Scalp
Skull
Superior sagittal sinus
Arachnoidal granulations
Dura mater
Arachnoid
Subarachnoid space
Pia mater
Brain
Falx cerebri

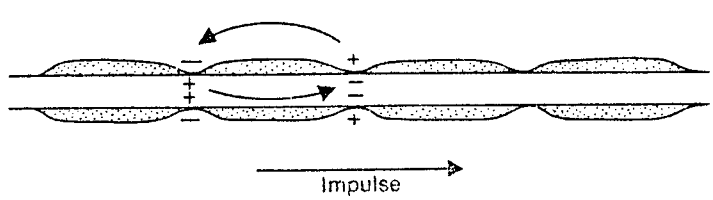


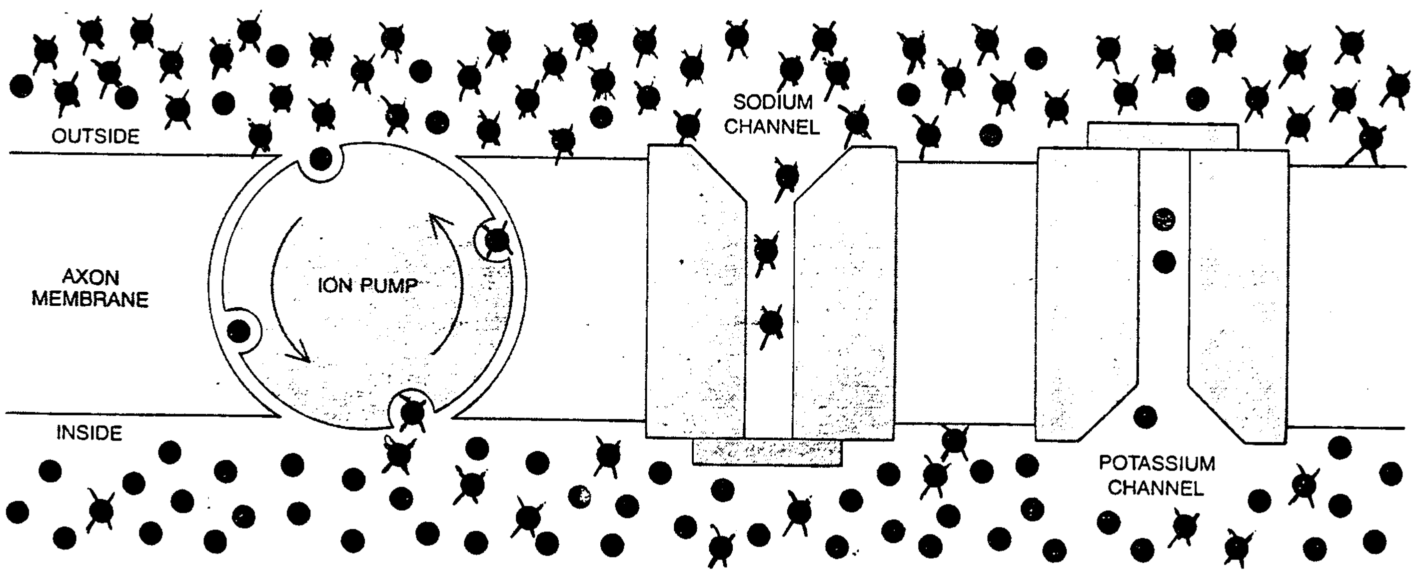


Propagation in unmyelinated axon

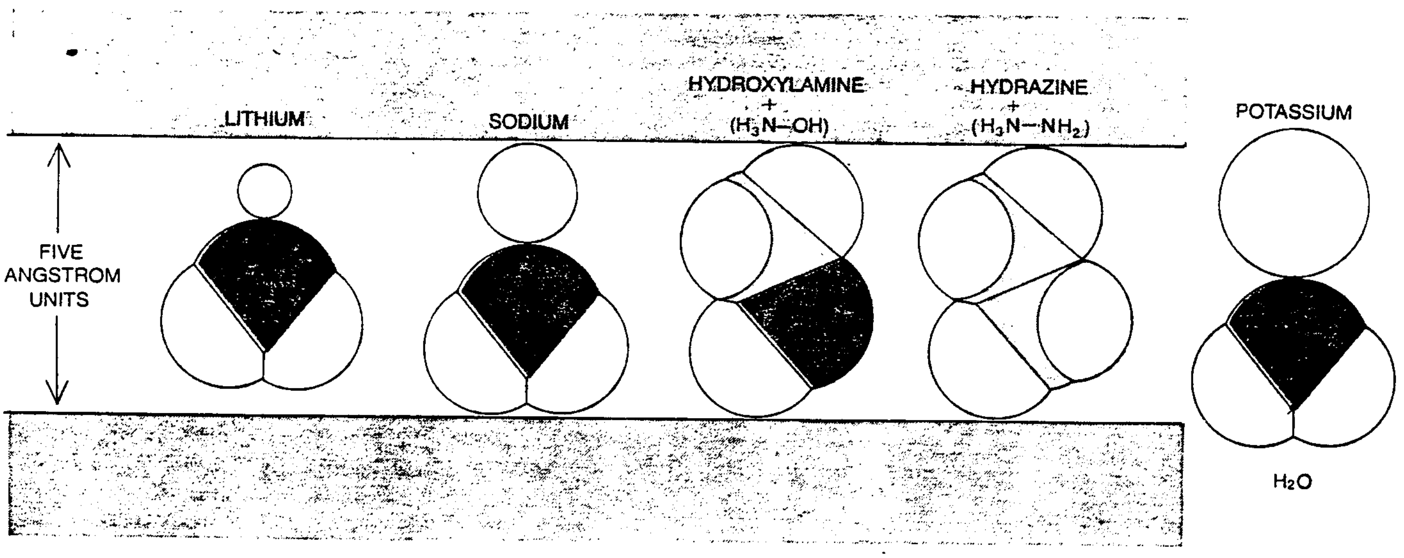


Saltatory propagation in myelinated axon

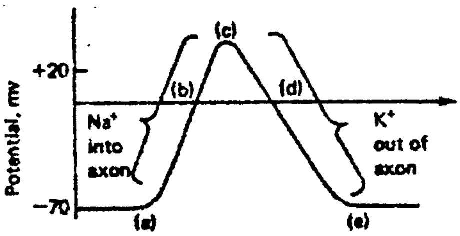




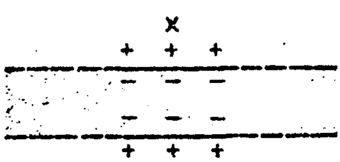
TWO KINDS OF ION CHANNELS traverse the axon membrane. An energy-dependent "pump" driven by the hydrolysis of ATP transports sodium ions (X's) and potassium ions (dots) "uphill" and establishes concentration gradients of these ions across the membrane. The second type of channel enables the ions to flow "downhill" in response to changes in the voltage across the membrane. In this diagram the separate sodium and potassium channels are shown in the resting state, with the charged gates held closed by the membrane potential. When the resting potential is reduced, the channels open (the sodium channels quickly and the potassium channels slowly) and give rise to a pulse of current that propagates down the axon. This article concerns the channels that allow downhill ion movements.



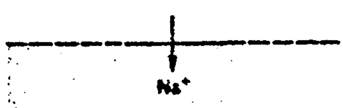
IONIC SELECTIVITY of the sodium channel is achieved through its dimensions and its electrostatic properties. As is shown here, partially hydrated lithium ions or sodium ions and the small positively charged molecules hydroxylamine and hydrazine have the appropriate dimensions to pass through the sodium channel, which appears to have a cross section of three angstrom units by five angstrom units at its narrowest point. A hydrated potassium ion, however, is too big to pass through the channel. These models are of the space-filling type.



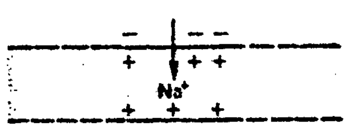
The oscilloscope record of the action potential.



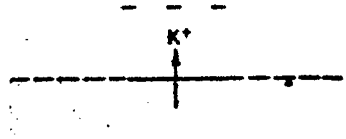
Resting condition at point X.
Potential difference = −70 mv. Point (a) on curve.



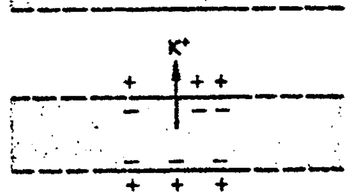
Sodium "gates" open, Na^+ enters fiber and neutralizes negative charge.
Potential difference = 0 mv. Point (b) on curve.



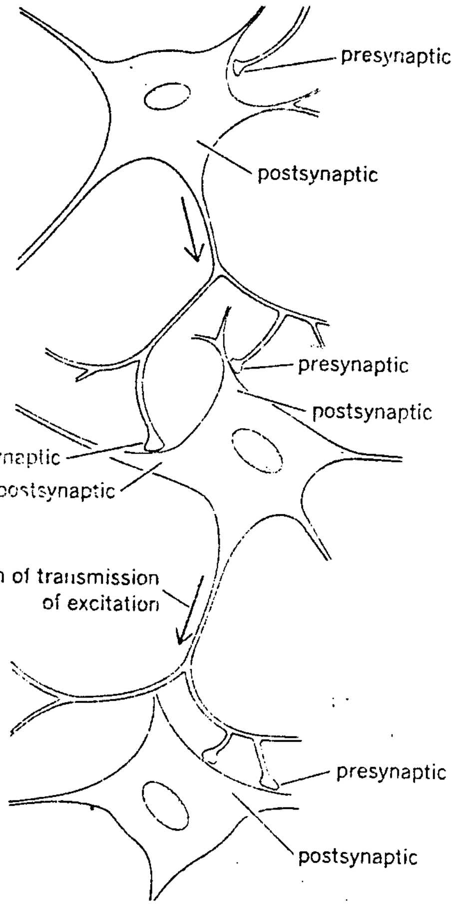
Continued influx of Na^+ leads to positive charge inside fiber. Peak of action potential.
Potential difference = +20 mv. Point (c) on curve.

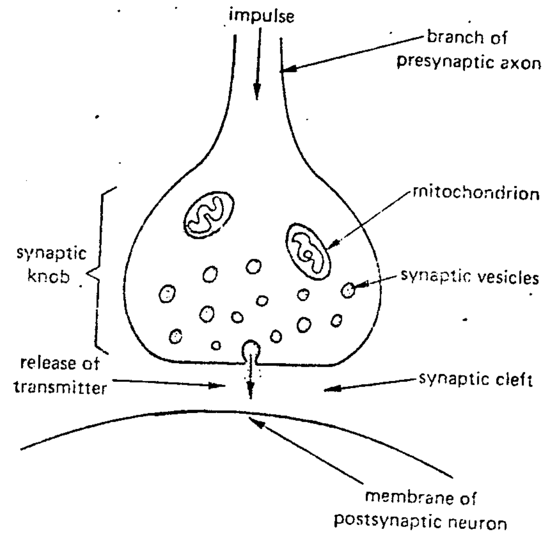


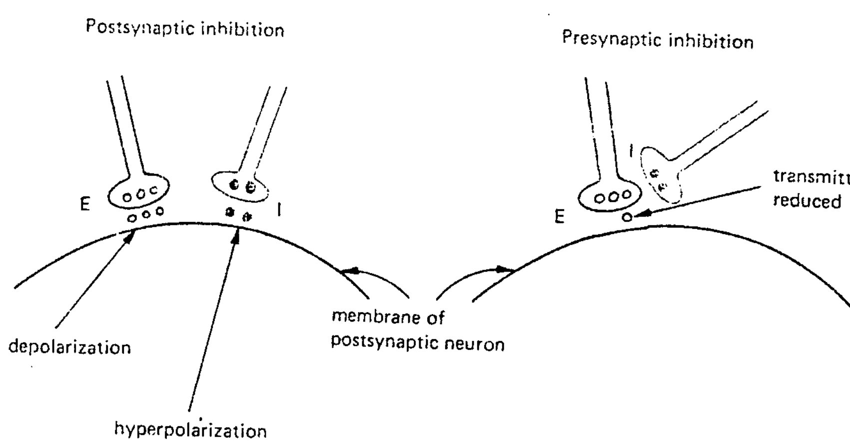
Sodium "gates" closed. K^+ moves out of fiber reducing positive charge inside.
Potential difference = 0 mv. Point (d) on curve.

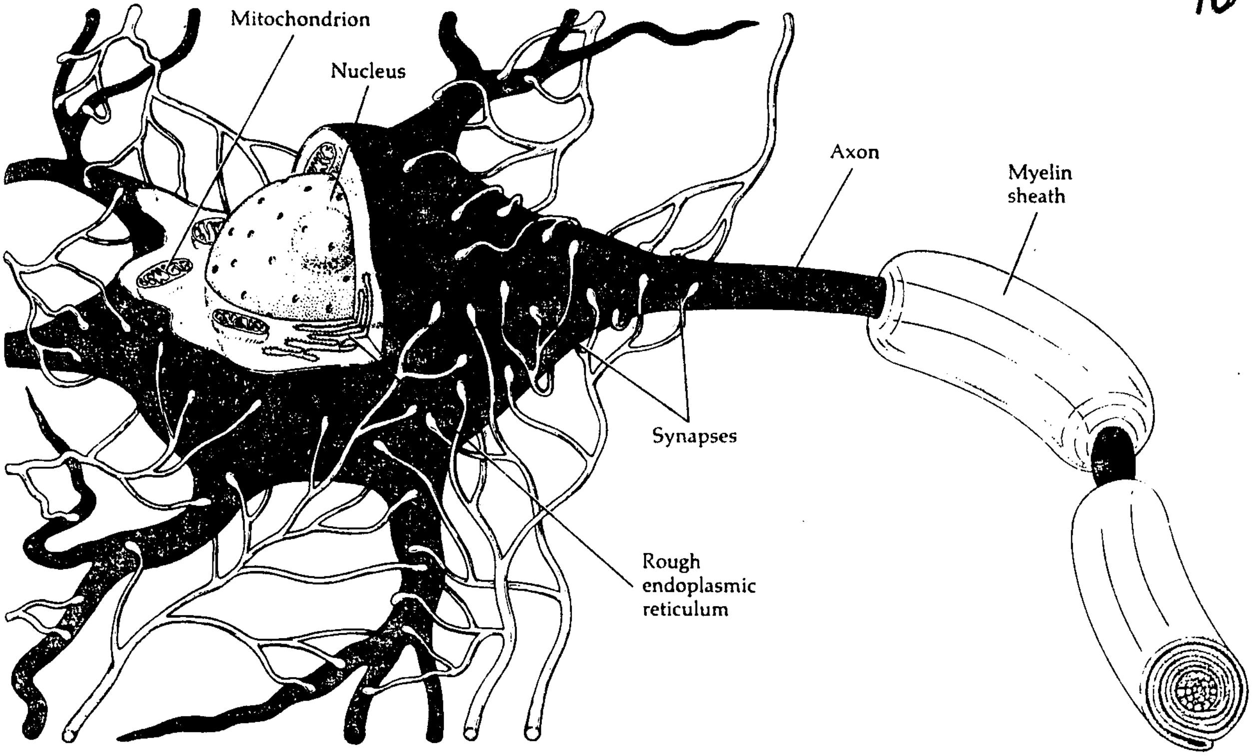


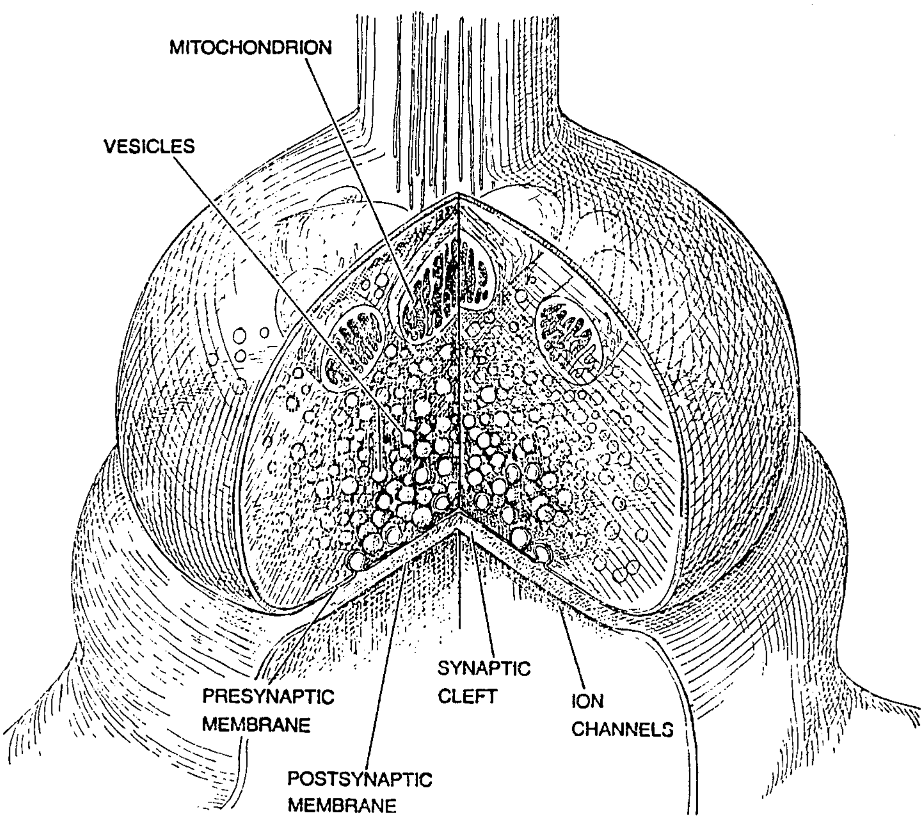
Continued outflow of K^+ restores resting condition.
Potential difference = −70 mv. Point (e) on curve.


presynaptic
postsynaptic
presynaptic
postsynaptic
presynaptic
postsynaptic
direction of transmission of excitation
presynaptic
postsynaptic

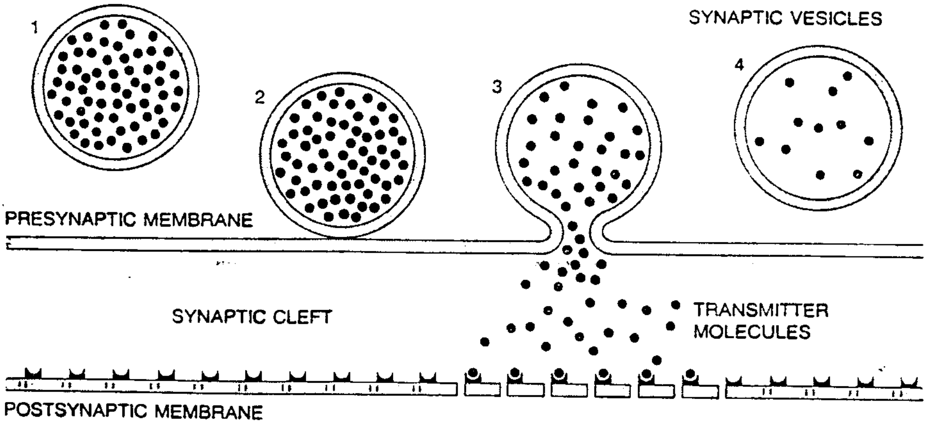

impulse
branch of presynaptic axon
mitochondrion
synaptic knob
synaptic vesicles
release of transmitter
synaptic cleft
membrane of postsynaptic neuron


Postsynaptic inhibition
Presynaptic inhibition
E
I
E
I
transmitter reduced
depolarization
hyperpolarization
membrane of postsynaptic neuron

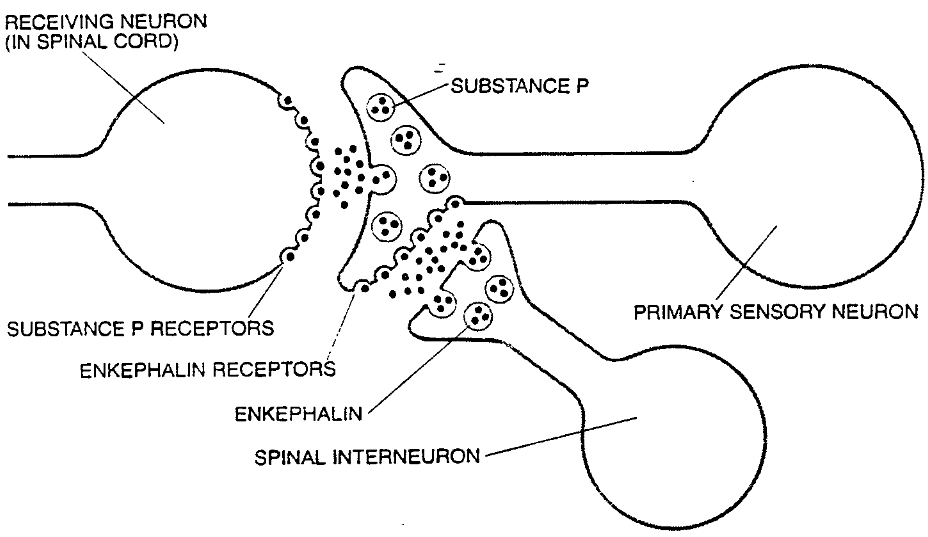




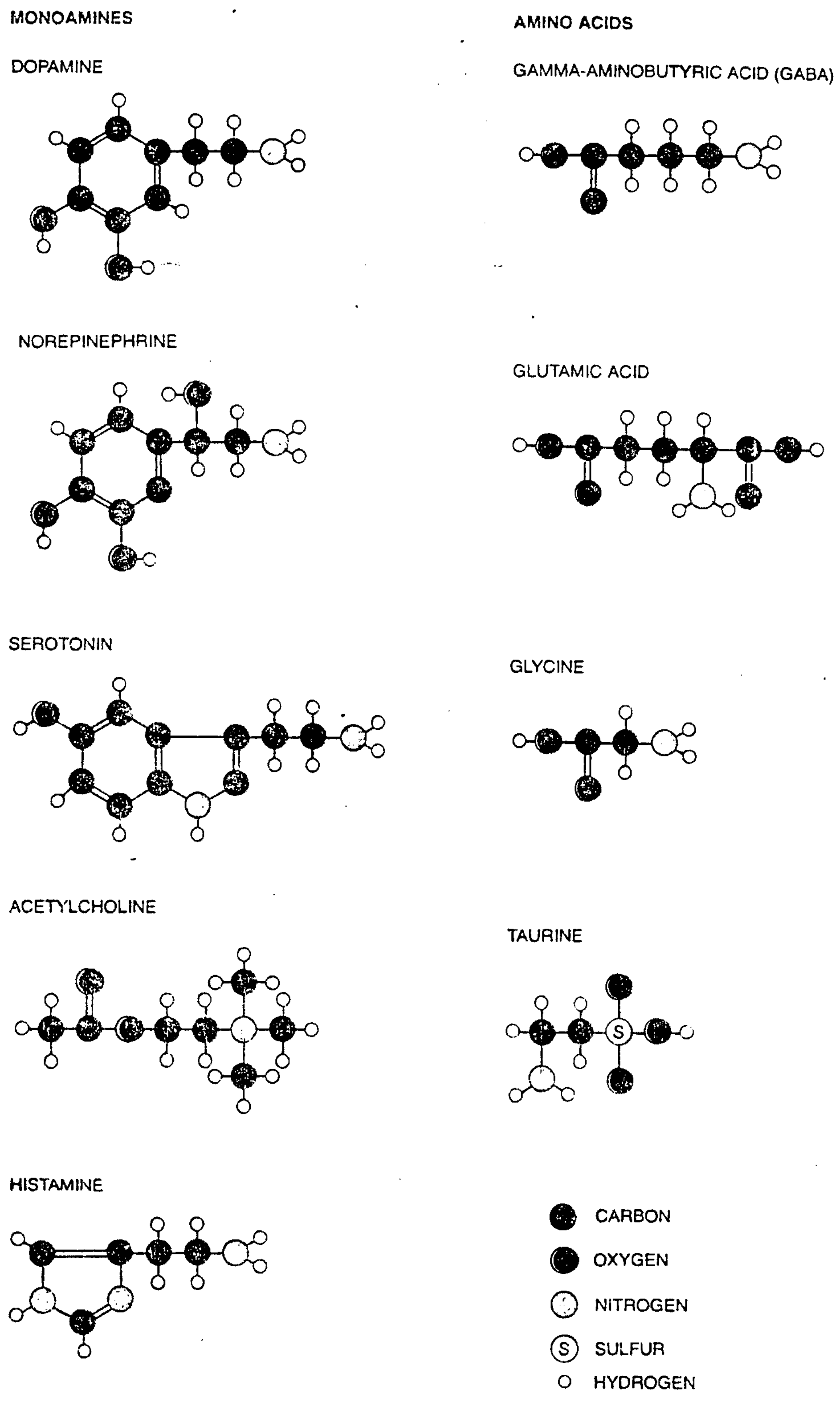
SYNAPSE is the relay point where information is conveyed by chemical transmitters from neuron to neuron. A synapse consists of two parts: the knoblike tip of an axon terminal and the receptor region on the surface of another neuron. The membranes are separated by a synaptic cleft some 200 nanometers across. Molecules of chemical transmitter, stored in vesicles in the axon terminal, are released into the cleft by arriving nerve impulses. Transmitter changes electrical state of the receiving neuron, making it either more likely or less likely to fire an impulse.



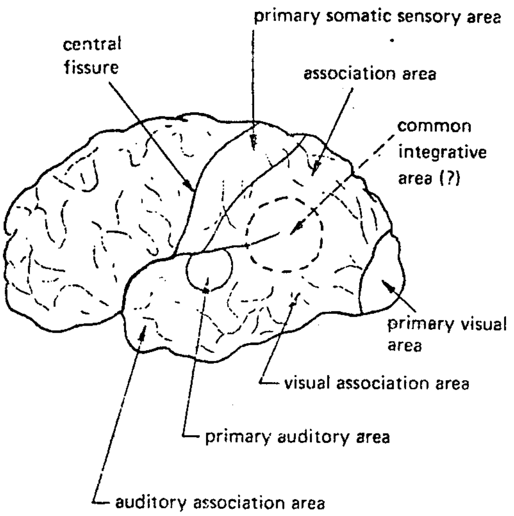
SYNAPTIC VESICLES are clustered near the presynaptic membrane. The diagram shows the probable steps in exocytosis. Filled vesicles move up to synaptic cleft, fuse with the membrane, discharge their contents and are reclaimed, re-formed and refilled with transmitter.

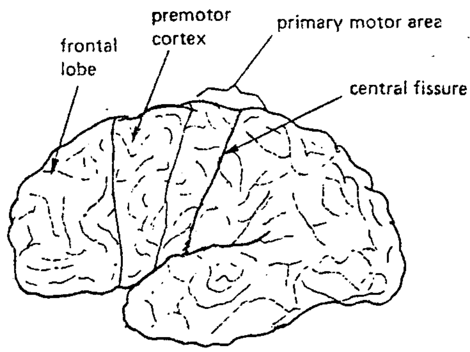


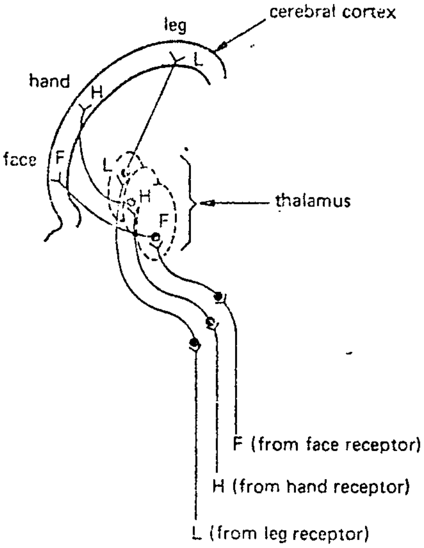
HYPOTHETICAL GATING MECHANISM at the first synaptic relay in the spinal cord may regulate the transmission of pain information from the peripheral pain receptors to the brain. In the dorsal horn of the spinal cord, interneurons containing the peptide transmitter enkephalin make synapses onto the axon terminals of the pain neurons, which utilize substance P as their transmitter. Enkephalin released from the interneurons inhibits the release of substance P, so that the receiving neuron in the spinal cord receives less excitatory stimulation and hence sends fewer pain-related impulses to the brain. Opiate drugs such as morphine appear to bind to unoccupied enkephalin receptors, mimicking the pain-suppressing effects of enkephalin system.



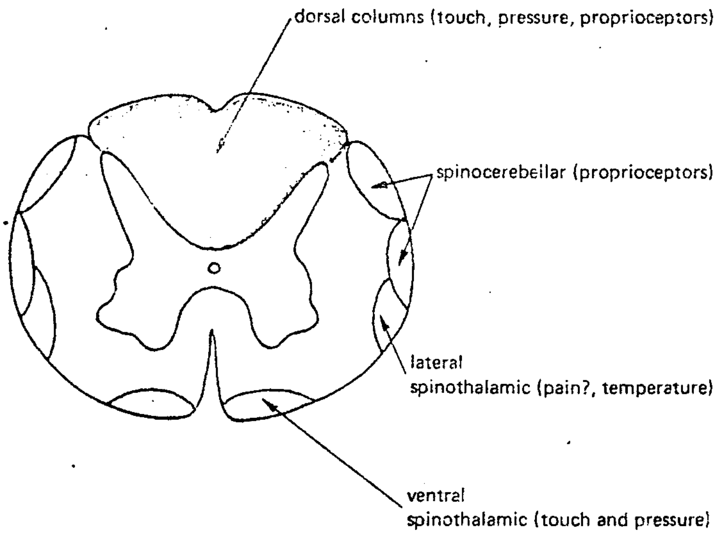
TRANSMITTER CHEMICALS tend to be small molecules that incorporate a positively charged nitrogen atom. Each has a characteristic excitatory or inhibitory effect on neurons, although some transmitters are excitatory in one part of the brain and inhibitory in another. Histamine and taurine are considered putative transmitters because the experimental evidence for them is not yet complete. According to Dale's principle only one transmitter is released from all the terminals of an axon. Exceptions to this principle, however, have been found recently.

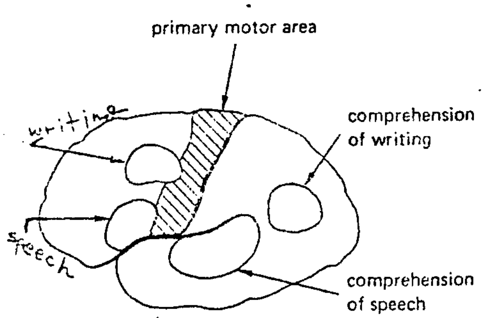




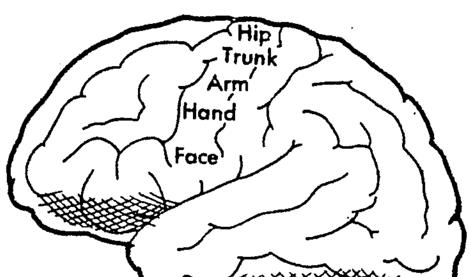


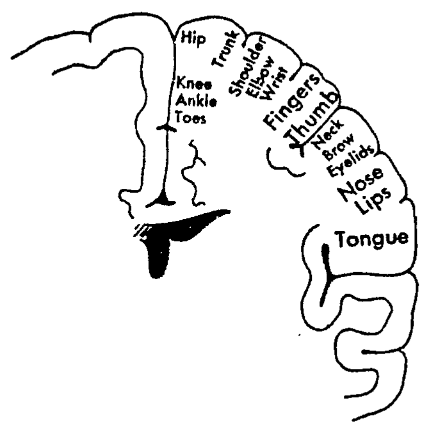
Localization



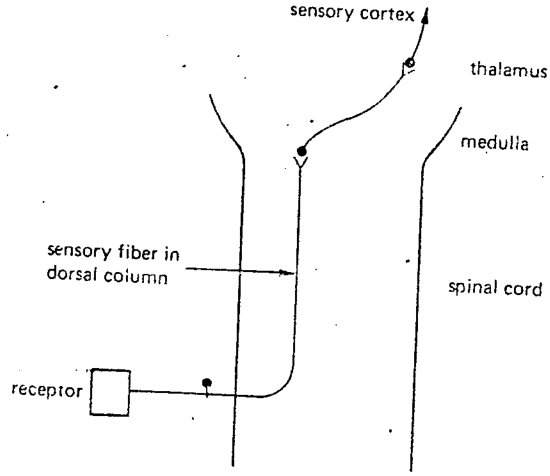


language

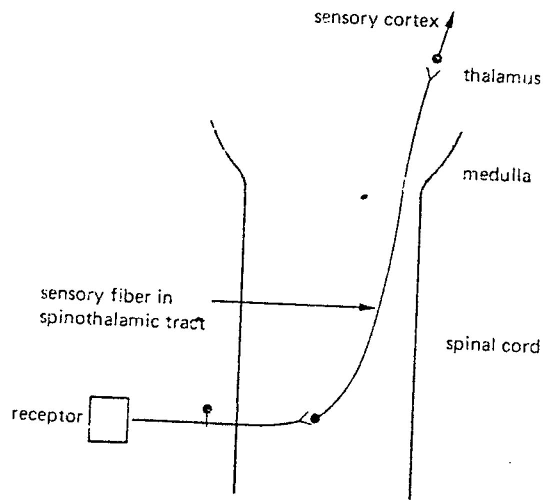




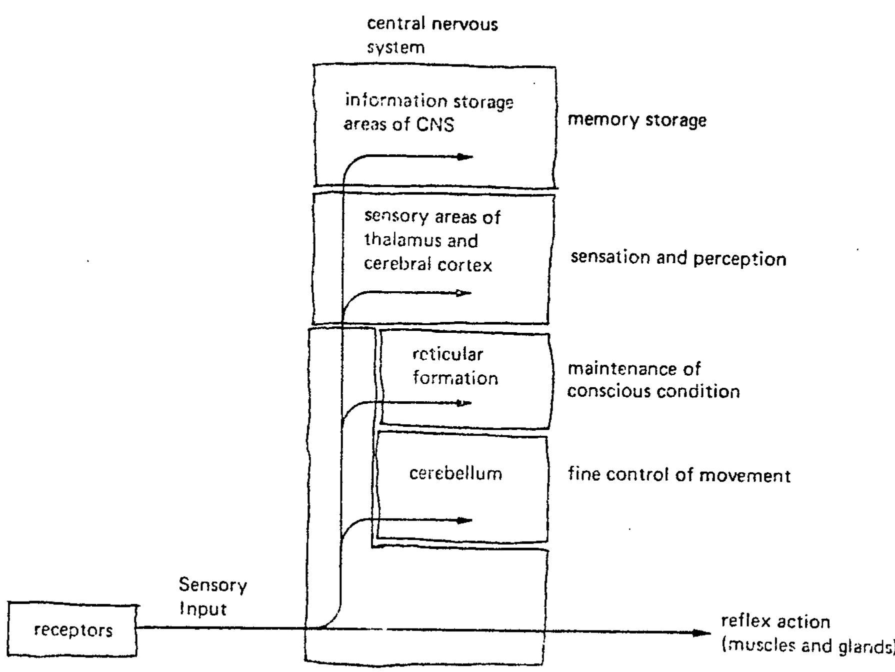
MOTOR CORTEX

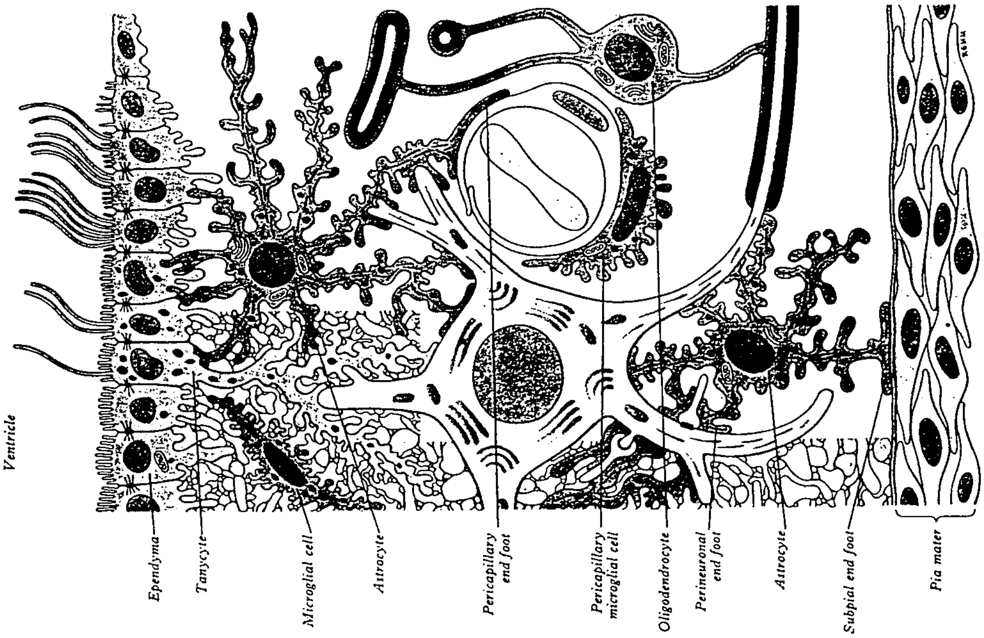


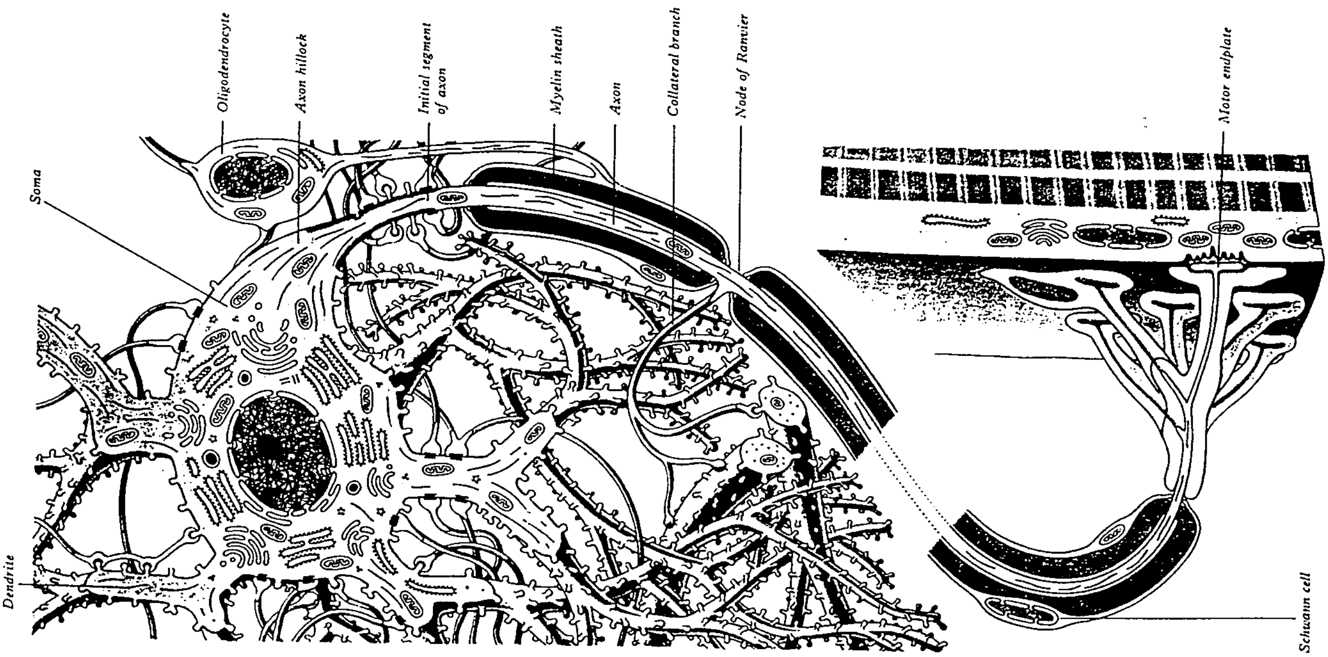
A. Dorsal column pathway

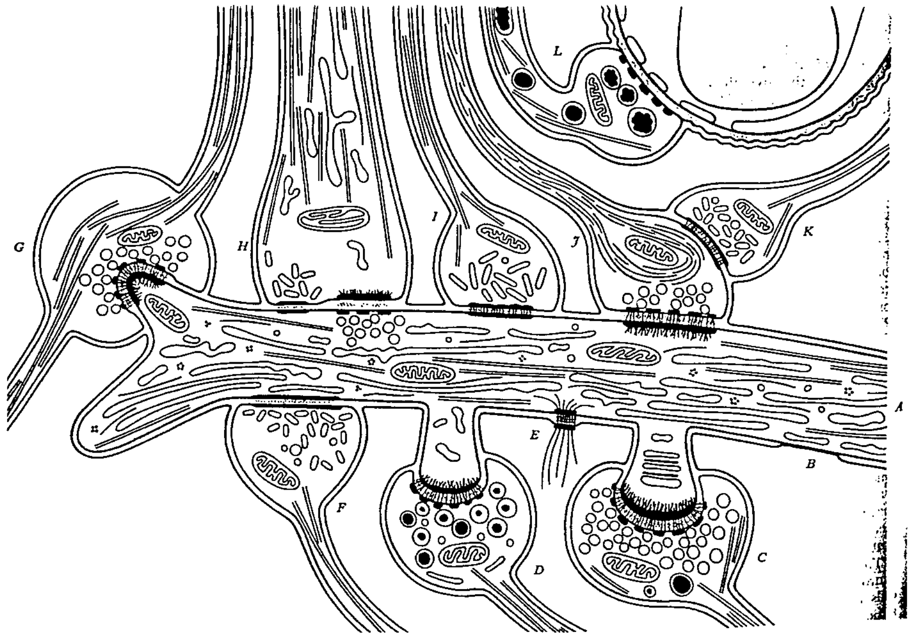


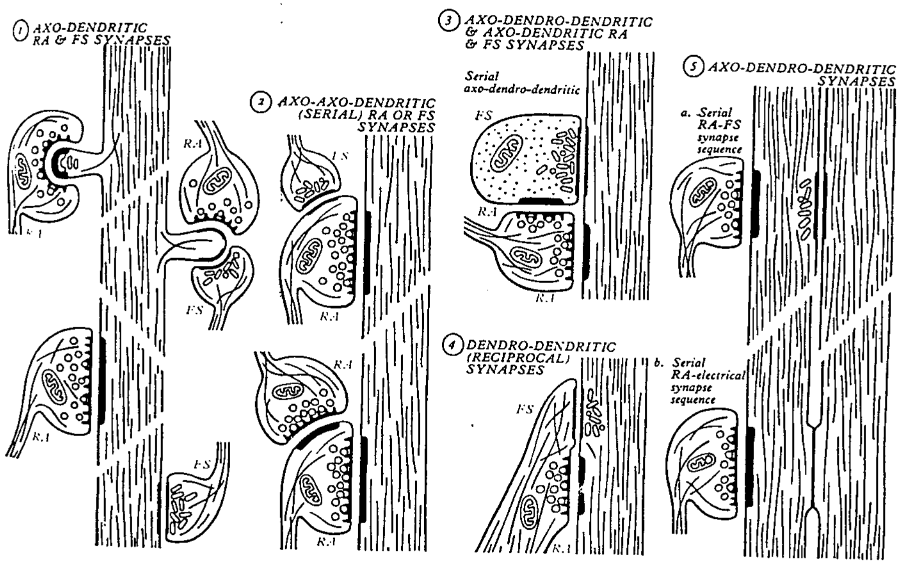
B. Spinothalamic pathway

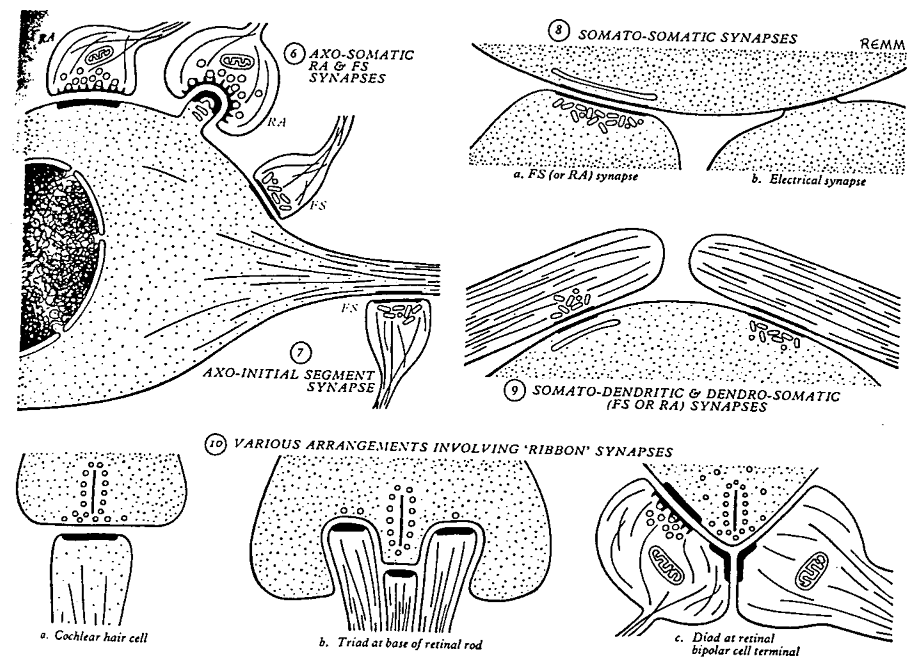



Ventricle
Ependyma
Tanycyte
Microglial cell
Astrocyte
Pericapillary end foot
Pericapillary microglial cell
Oligodendrocyte
Perineuronal end foot
Astrocyte
Subpial end foot
Pia mater


Soma
Dendrite
Oligodendrocyte
Axon hillock
Initial segment of axon
Myelin sheath
Axon
Collateral branch
Node of Ranvier
Motor endplate
Schwann cell


A
B
C
D
E
F
G
H
I
J
K
L


1 AXO-DENDRITIC RA & FS SYNAPSES
RA
FS
2 AXO-AXO-DENDRITIC (SERIAL) RA OR FS SYNAPSES
3 AXO-DENDRO-DENDRITIC & AXO-DENDRITIC RA & FS SYNAPSES
Serial axo-dendro-dendritic
4 DENDRO-DENDRITIC (RECIPROCAL) SYNAPSES
5 AXO-DENDRO-DENDRITIC SYNAPSES
a. Serial RA-FS synapse sequence
b. Serial RA-electrical synapse sequence


6 AXO-SOMATIC RA & FS SYNAPSES
RA
FS
7 AXO-INITIAL SEGMENT SYNAPSE
8 SOMATO-SOMATIC SYNAPSES
REMM
a. FS (or RA) synapse
b. Electrical synapse
9 SOMATO-DENDRITIC & DENDRO-SOMATIC (FS OR RA) SYNAPSES
10 VARIOUS ARRANGEMENTS INVOLVING 'RIBBON' SYNAPSES
a. Cochlear hair cell
b. Triad at base of retinal rod
c. Diad at retinal bipolar cell terminal