Modeling in Neuroscience
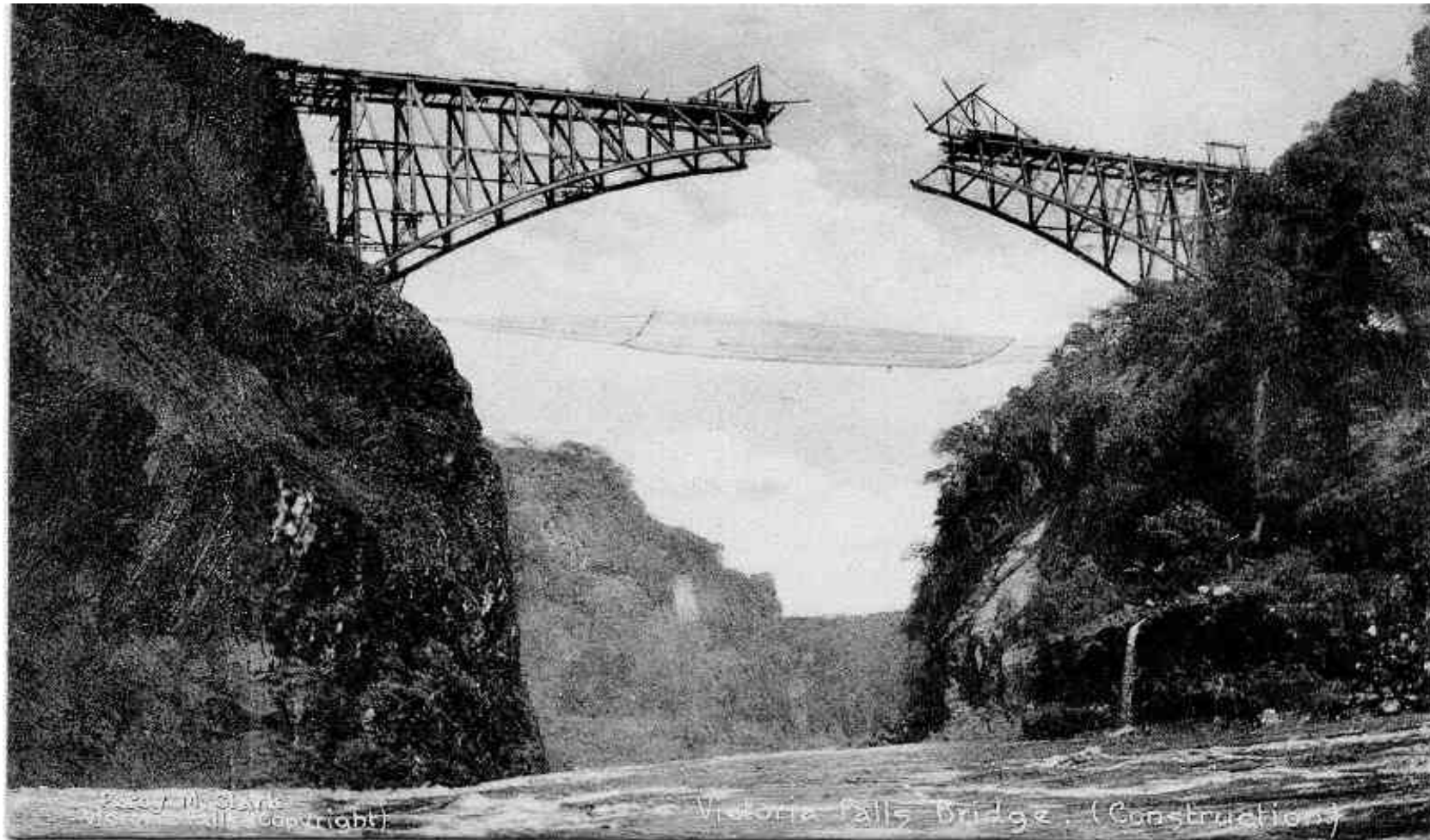# I. Biological bases

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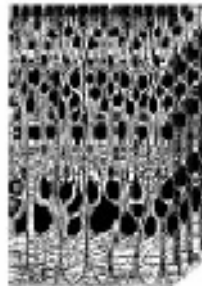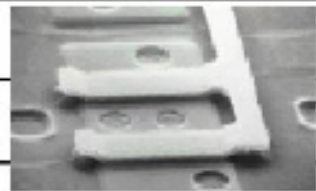Research Group

Supporting materials: http://cneuro.rmki.kfki.hu/education/neuromodel/

Neuromodel 2025

Computational Neuroscience

Structure – Dynamics – Implementation – Algorithm – Computation - Function
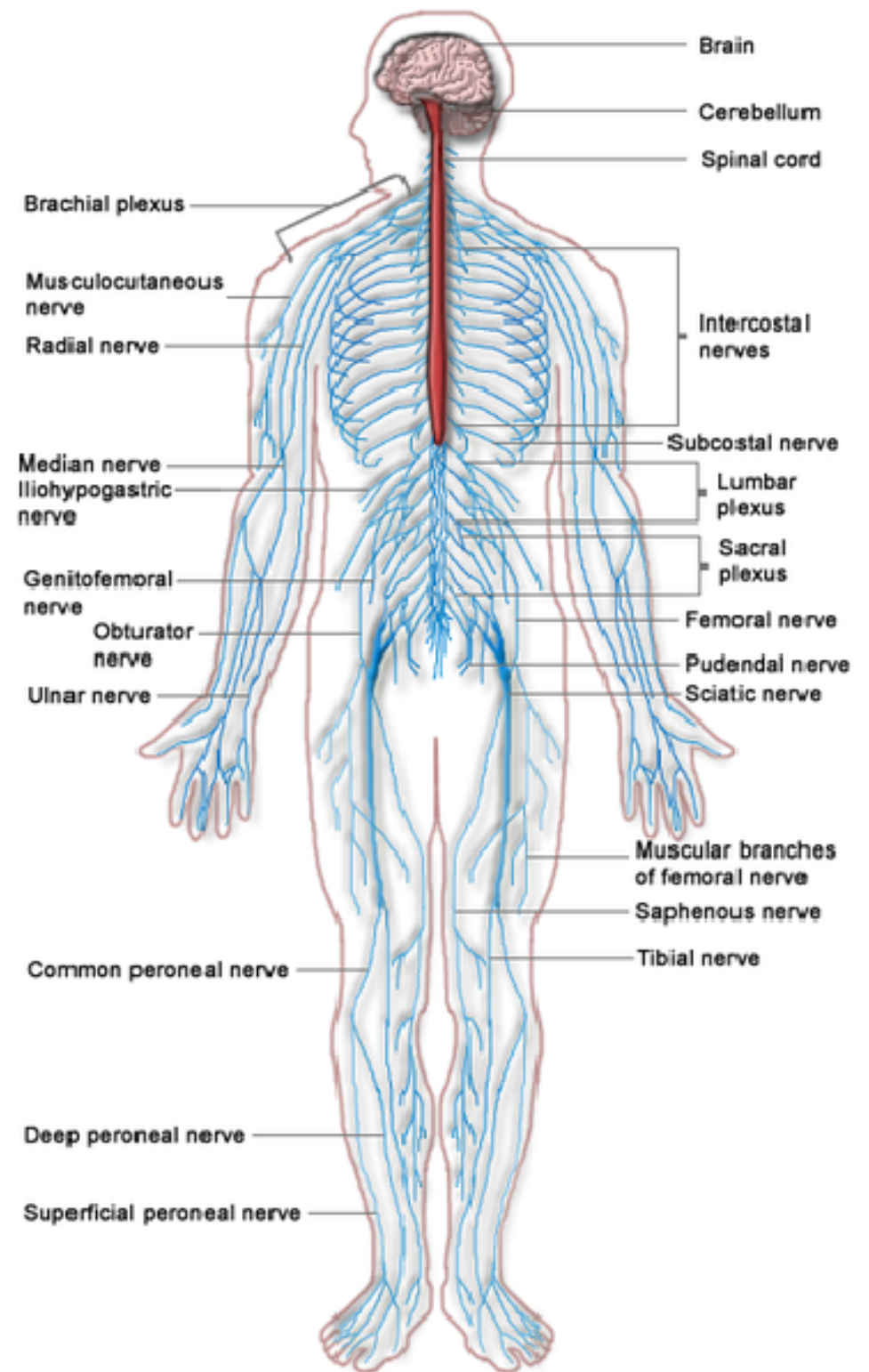
The brain and the computer I.

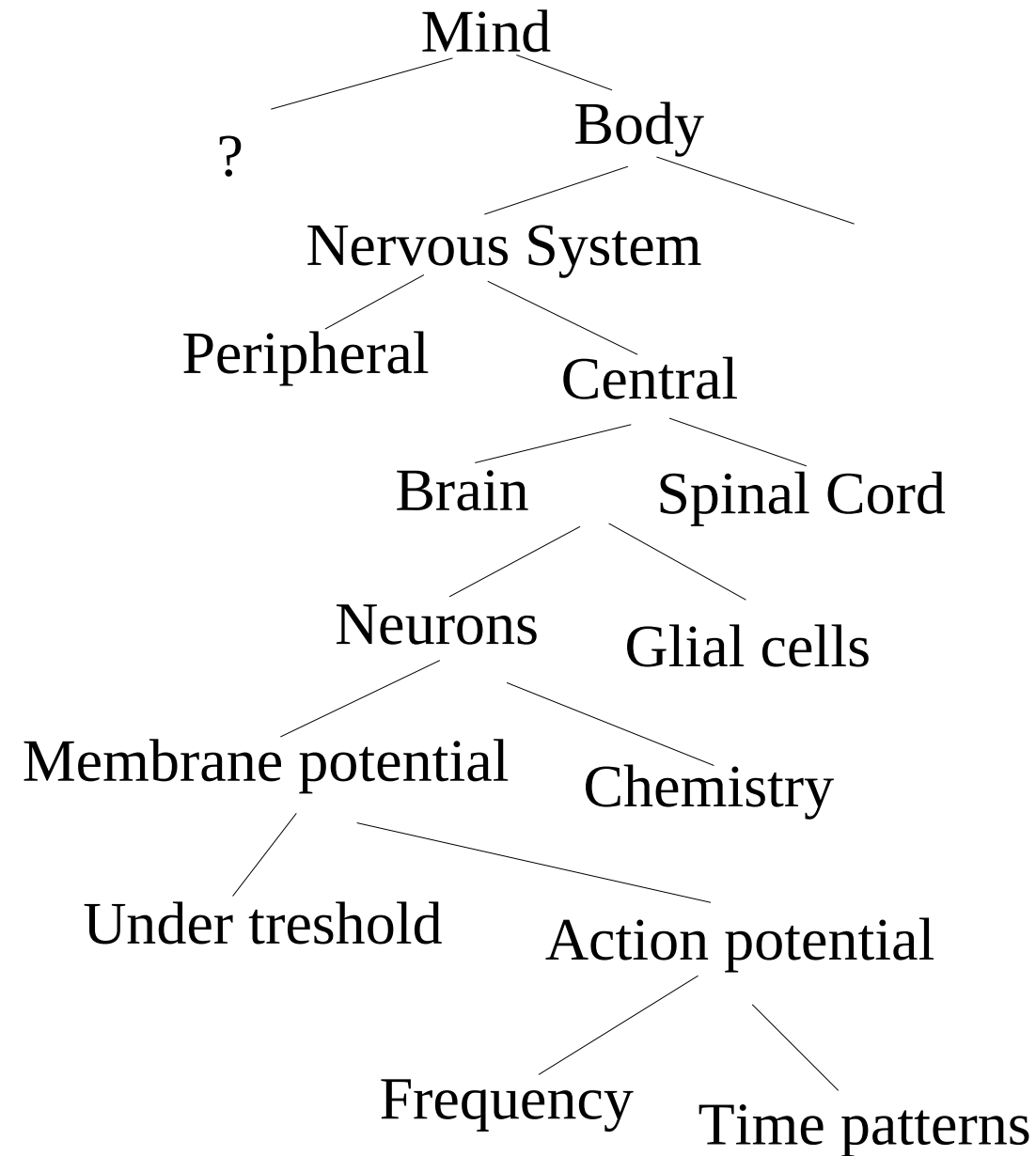|	1 mm³ of cortex		1 mm² of a CPU	
Number of units	50,000 neurons		1 million transistors	
Connections/unit	10,000		2	
Total connections	500 million		2 million	
Wiring	4 km of axons		0.002 km of wire	

	Whole brain		Whole CPU	
Weight	1.3 kg		~0.4kg	
Power	20 W		27 W	
Units	10^{11} neurons		10^8 transistors	
connections	1×10^{15}		2×10^9	
wiring	8 million km of axons		2 km of wire	

The brain and the computer II.

Properties	Brain	Computer
# processing elements	10^{14} synapse, 10^9 neuron	10^8 transistor
Element size	10^{-6} m	10^{-6} m
Energy use	30W	30W
Connections per element	10000	3
Processing speed	100 Hz	10^9 Hz
Computation	parallel, distributed	serial
Fault tolerant	yes	no
Learns	yes	a little
Conscious	usually	Not (yet)

Hierarchy of description

Mind

?   Body

Nervous System

Peripheral   Central

Brain   Spinal Cord

Neurons   Glial cells

Membrane potential   Chemistry

Under treshold   Action potential

Frequency   Time patterns

Brain
Cerebellum
Spinal cord
Brachial plexus
Musculocutaneous nerve
Radial nerve
Intercostal nerves
Median nerve
Iliohypogastric nerve
Subcostal nerve
Lumbar plexus
Genitofemoral nerve
Sacral plexus
Obturator nerve
Femoral nerve
Ulnar nerve
Pudendal nerve
Sciatic nerve
Muscular branches of femoral nerve
Saphenous nerve
Tibial nerve
Common peroneal nerve
Deep peroneal nerve
Superficial peroneal nerve

Brain of vertebrates (mammals)

as visible with naked eye

human

Human brain: Left lateral view

Primary motor area
Primary sensory area
PARIETAL LOBE
Visual cortex
FRONTAL LOBE
OCCIPITAL LOBE
TEMPORAL LOBE
Broca's area; tumor location (?)
Wernicke's area
Cerebellum
Brain stem

6
5
4
2
3
1

rat

Cingulate Gyrus
Thalmus
Septum
Olfactory Bulb
Hippocampus
Amygdala
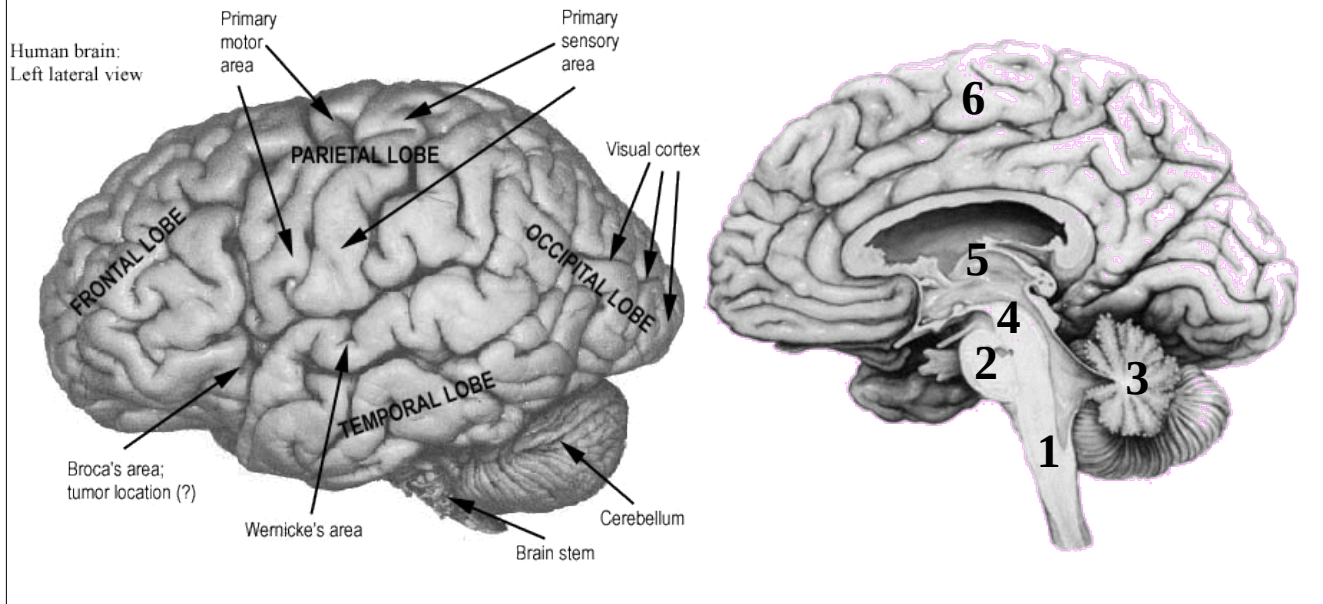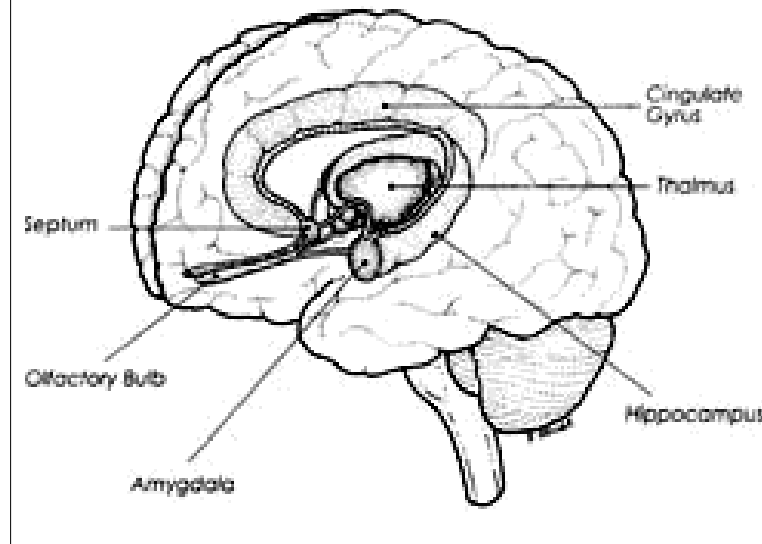
1. *medulla oblongata*
2. *pons*
3. *cerebellum*
4. *mesencephalon*
5. *metencephalon*
   - *thalamus*
   - *hypothalamus*
   - *epithalamus*
6. *telencephalon*
   - *ganglia basalis*
   - *cortex*
     - *paleocortex*
     - *archicortex*
       - *hippocampus, ...*
     - *neocortex*
       - *lobus frontalis*
       - *lobus parietalis*
       - *lobus occipitalis*
       - *lobus temporalis*

paleocortex

archicortex

periarchicortex

isocortex

proisocortex

The archicortex
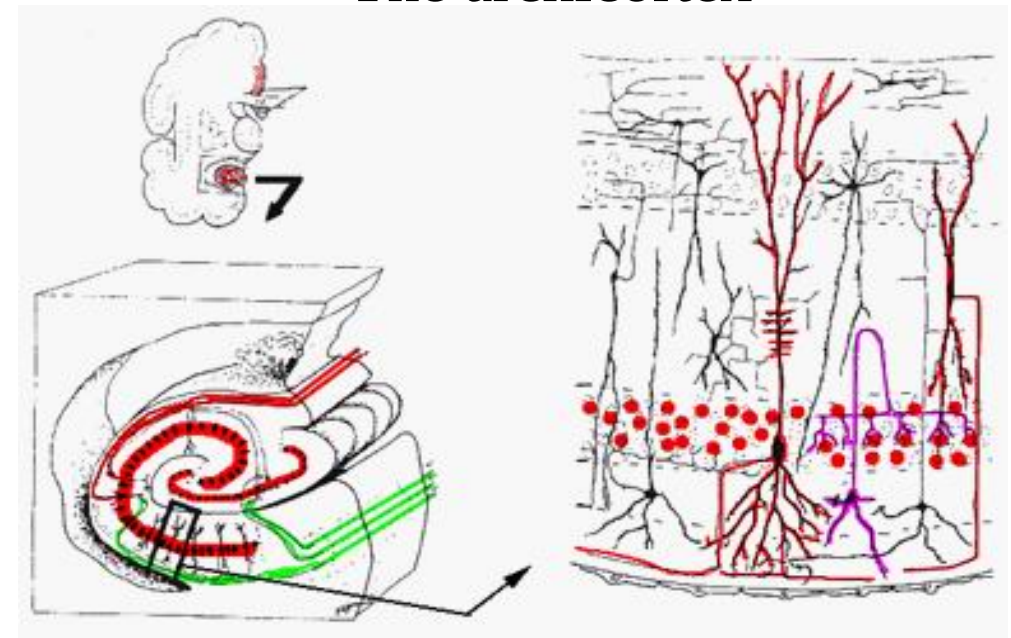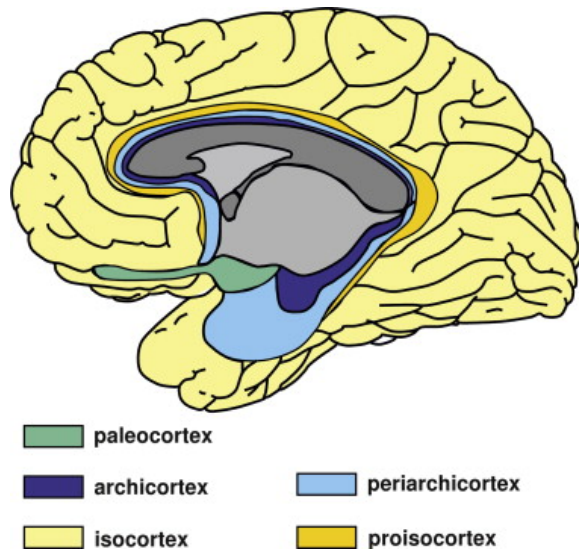
The neocortex
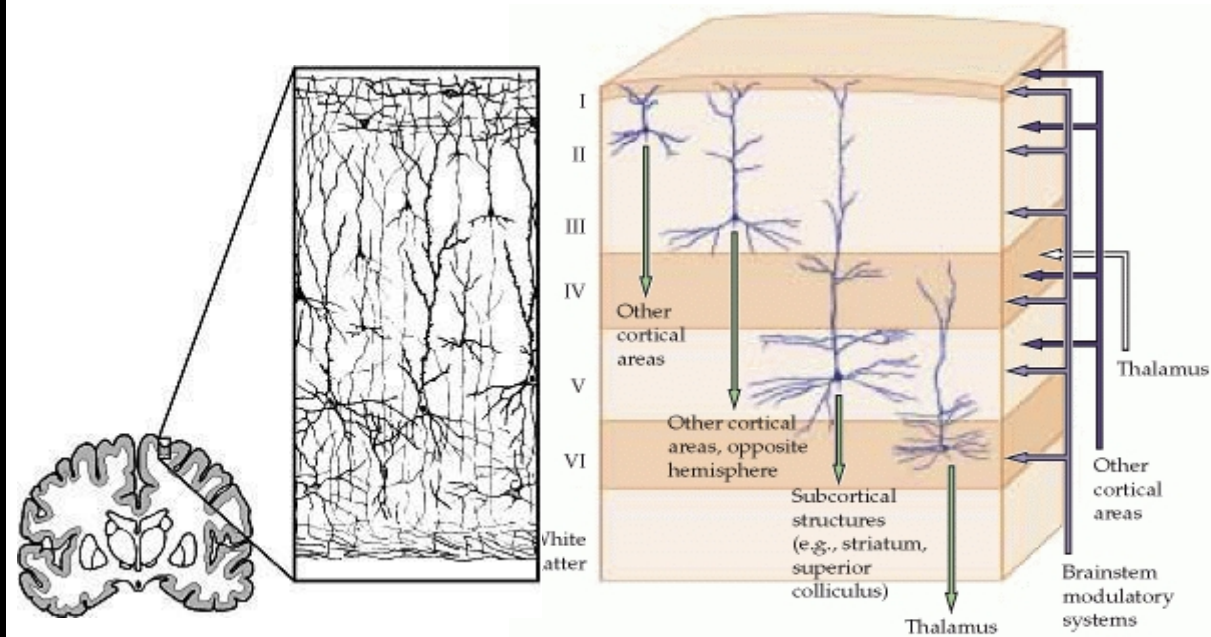
Elementary unit of the nervous system: The neuron

Parts of the neuron:
  dendrite
  soma
    nucleus
  axon
    initial segment
    terminal

synapse

glia
  myelin sheath
    Ranvier-nodes

Function:
  reception
  integration
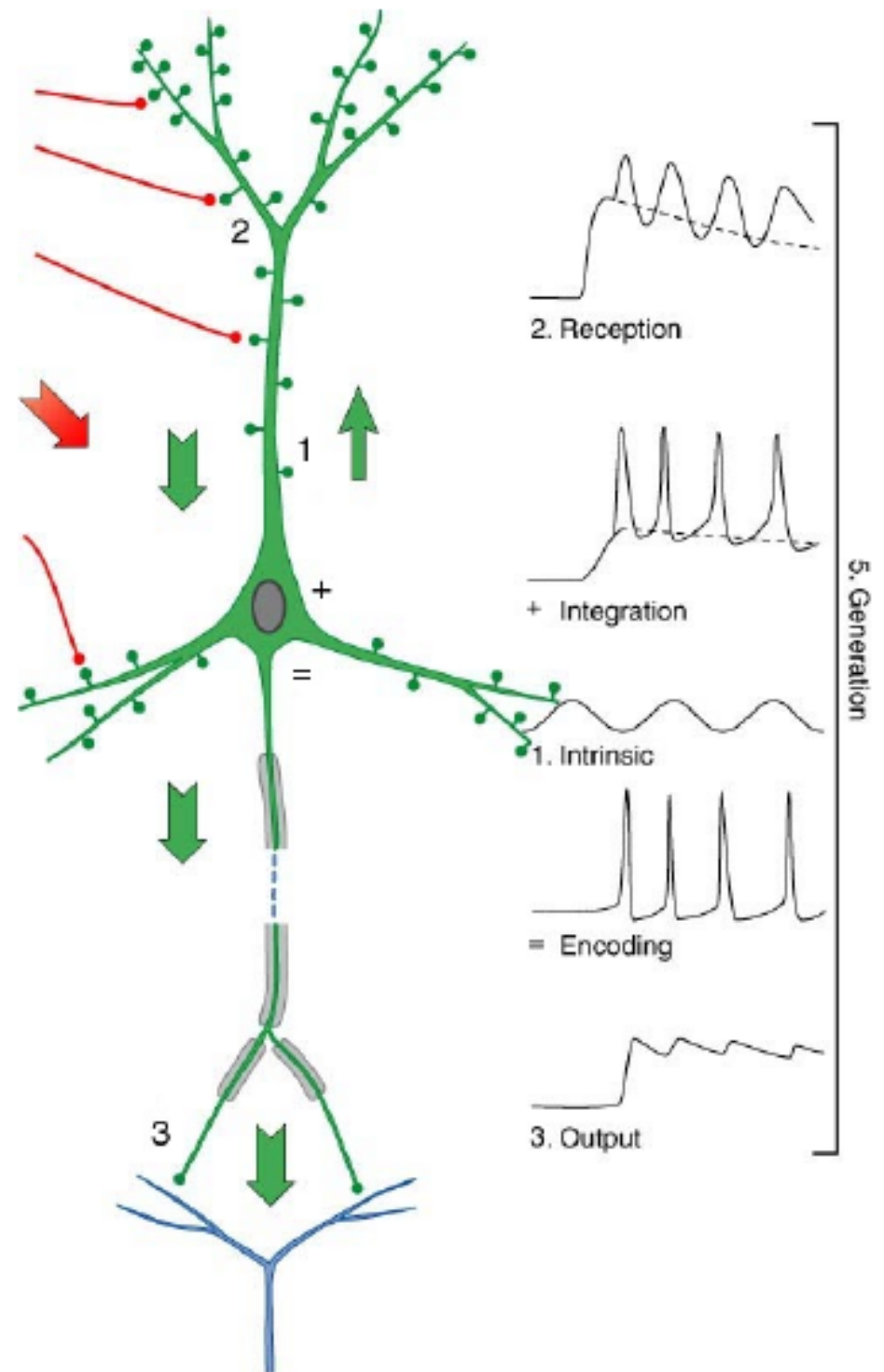   *reproduction*
  transmission
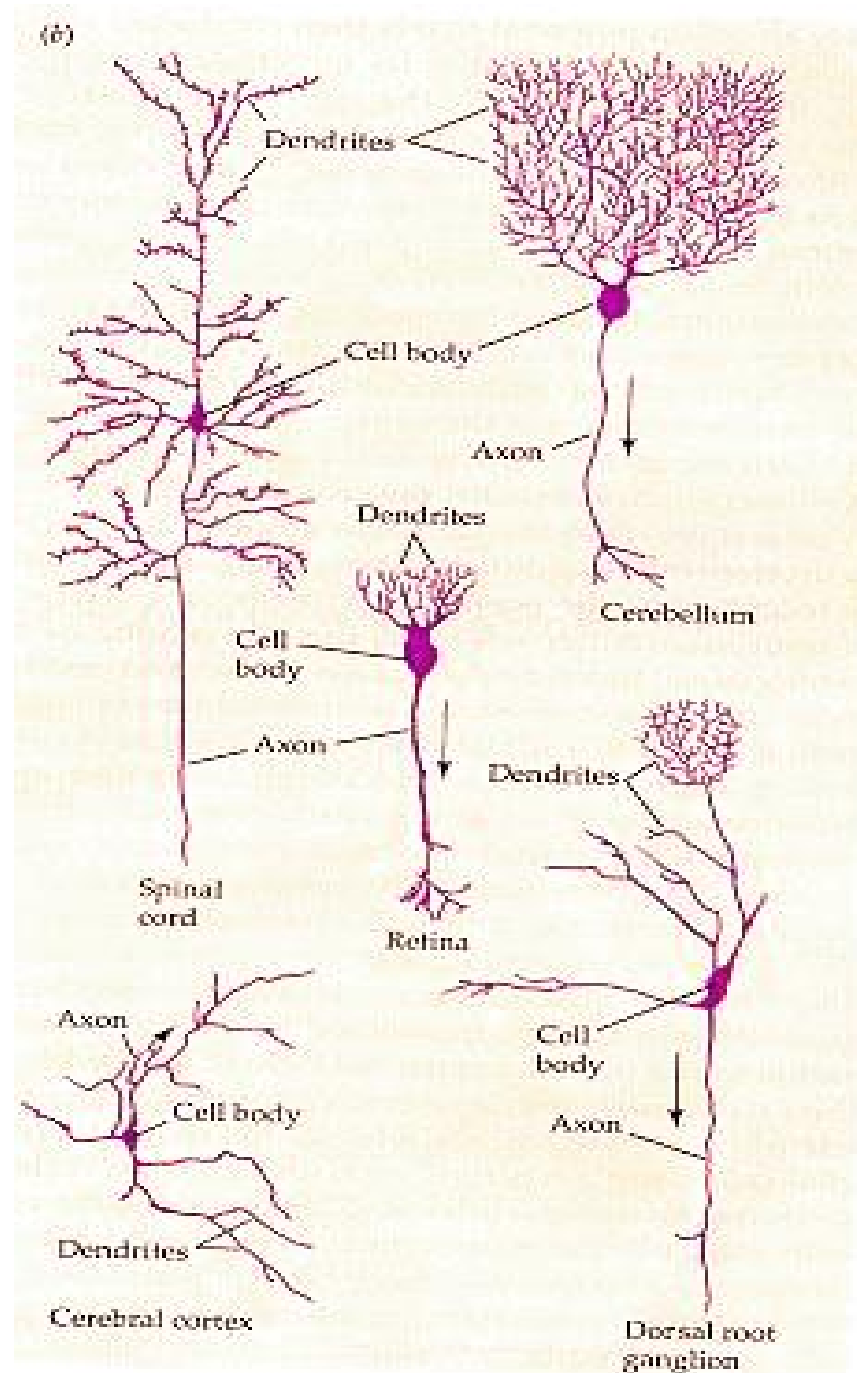   *encoding*
    output

communication

background
  speed up
    amplification

2. Reception

+ Integration

1. Intrinsic

= Encoding

3. Output

5. Generation

Types of neurons

Pyramidal cell in the cerebral cortex

Purkinje cell in the cerebellum

Bipolar cell in the retinal

Mitral cell in the olfactory bulb

Reticular cell in the thalamus

The cell
with electronmicroscope

microtubules

mitochondrion

centriole

vesicle

cytosol

rough endoplasmic reticulum   ribosomes

chromatin
nuclear envelope
nuclear pore   } nucleus
nucleolus

Golgi complex

lysosome

flagellum

plasma membrane

smooth endoplasmic reticulum
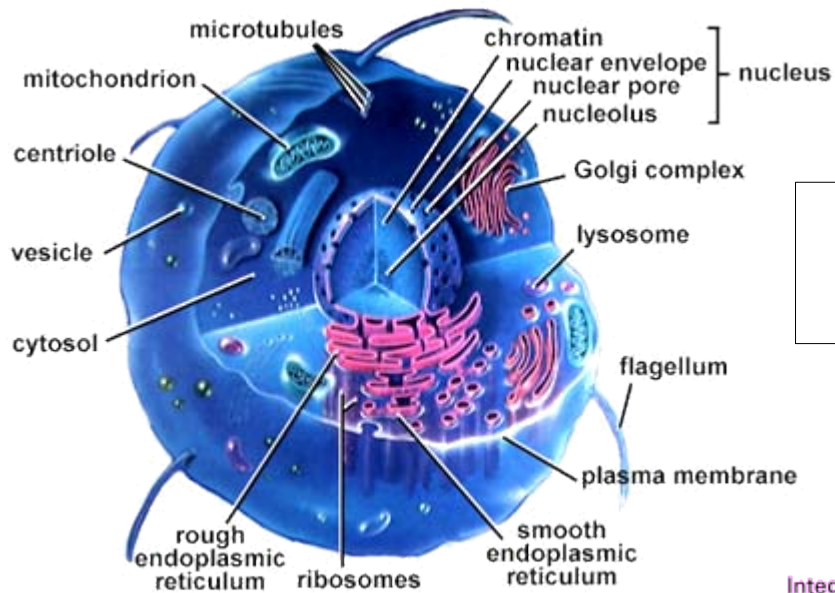
nucleus
cytoplasm
membrane

lipid bilayer
proteins
    integral
    peripheral
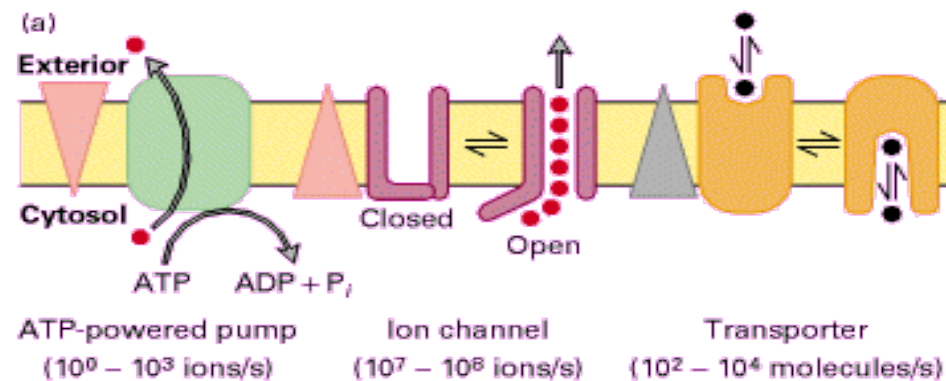
extracellular space (EC)
intracellular space (IC)

Oligosaccharide   Glycoprotein   Glycolipid   Peripheral protein

Integral protein

Exterior

Leaflets

Phospholipid bilayer

Hydrophobic core

Cytosol

Integral protein

Peripheral proteins

Fatty acyl tails

Hydrophilic polar head
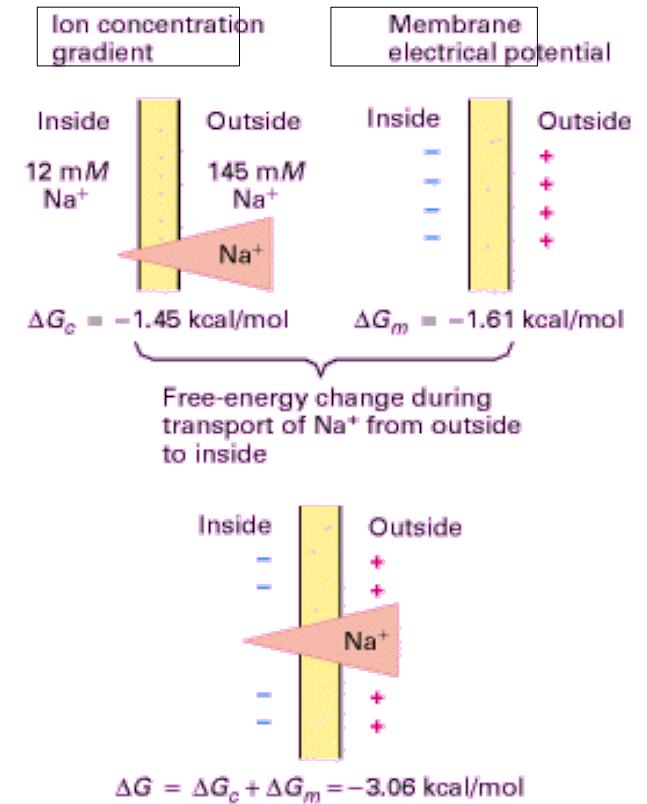
Phospholipid

10
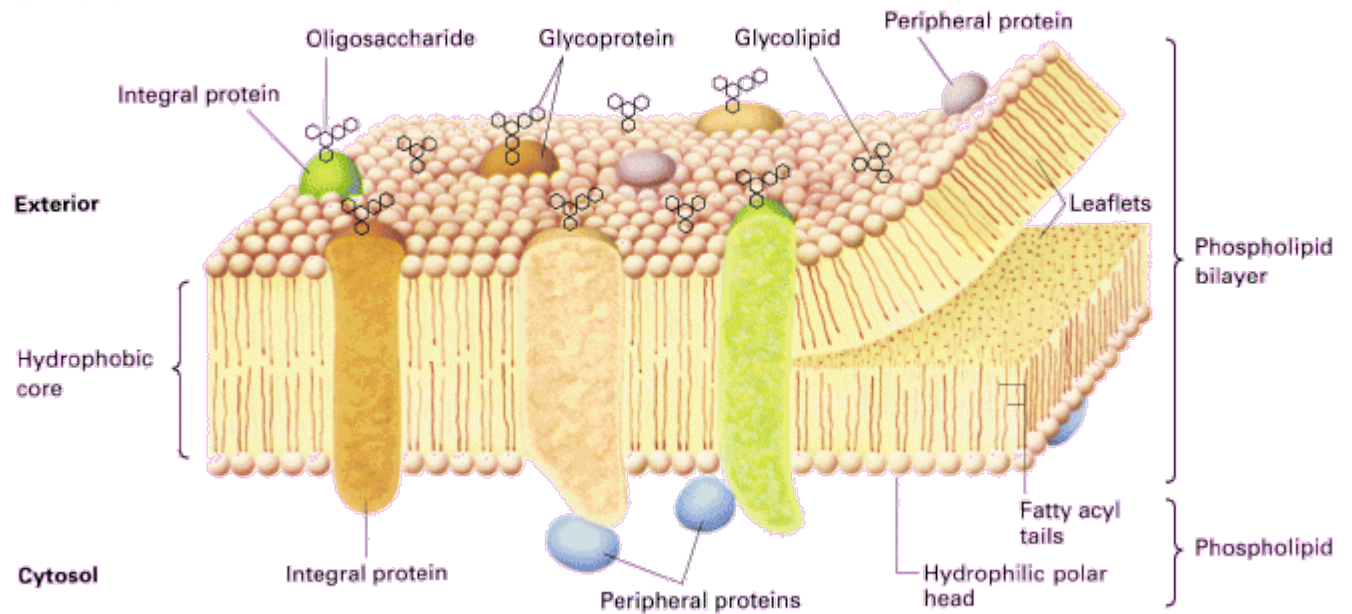
Trough the cell membrane

Different permeability, for different ions and molecules

Membrane transport, trough proteins
• pumps (+energy!)
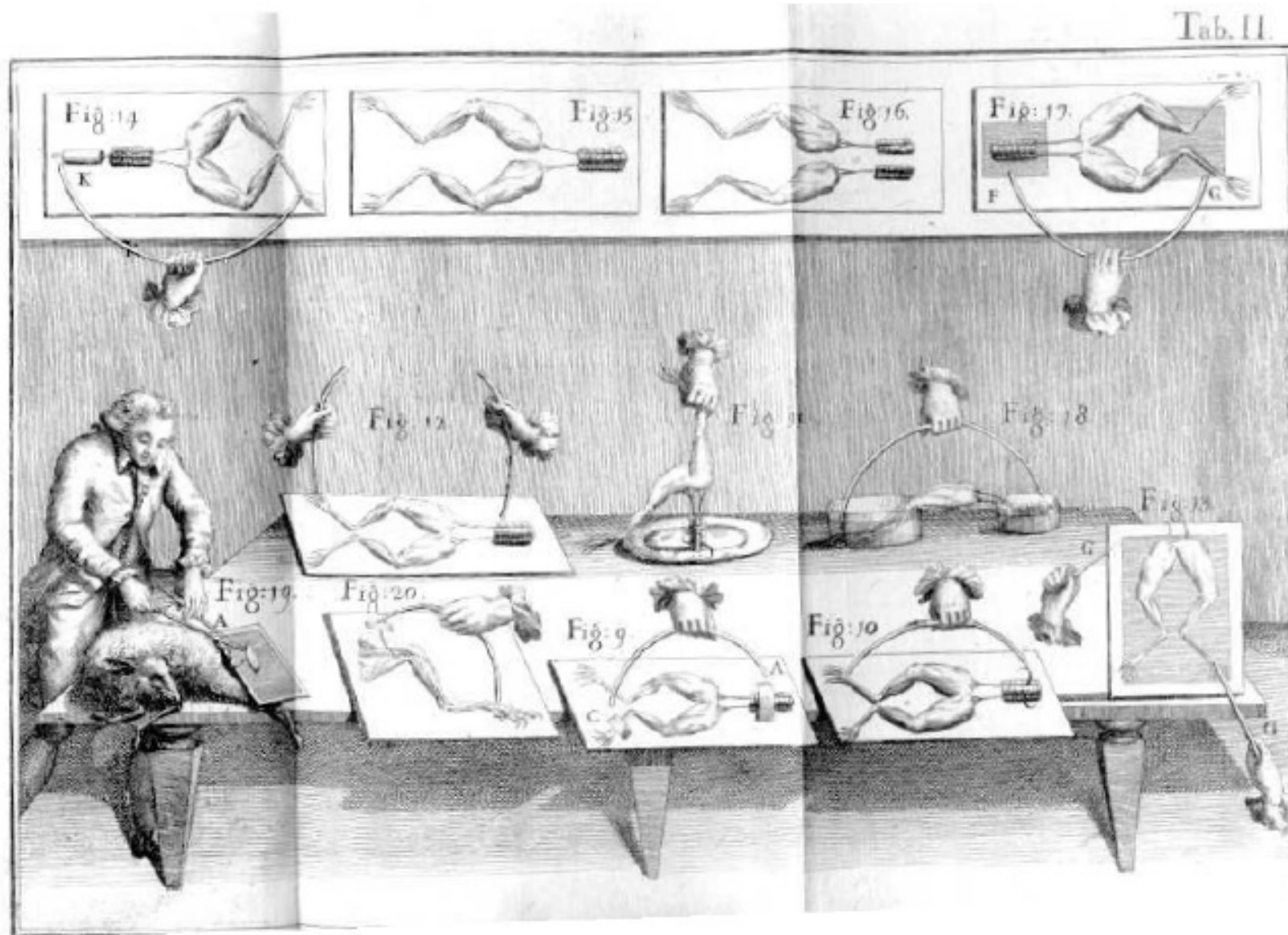• channels
• transporters

Forces of ion transport

Gases — CO_2 N_2 O_2

Small uncharged polar molecules — Ethanol

Water — H_2O
Urea — NH_2-C-NH_2 (O)

Large uncharged polar molecules — Glucose

Ions — K^+, Mg^{2+}, Ca^{2+}, Cl^-, HCO_3^-, HPO_4^{2-}

Charged polar molecules — Amino acids, ATP, Glucose 6-phosphate

(a)

Exterior
Cytosol
ATP   ADP + P_i
ATP-powered pump ($10^0 - 10^3$ ions/s)
Ion channel ($10^7 - 10^8$ ions/s)   Closed   Open
Transporter ($10^2 - 10^4$ molecules/s)

Ion concentration gradient
Inside   Outside
12 mM Na^+ 145 mM Na^+
Na^+
$\Delta G_c = -1.45$ kcal/mol

Membrane electrical potential
Inside   Outside
$\Delta G_m = -1.61$ kcal/mol

Free-energy change during transport of Na^+ from outside to inside

Inside   Outside
Na^+

$\Delta G = \Delta G_c + \Delta G_m = -3.06$ kcal/mol

Discovery of the electricity in animals

Galvani, De Viribus - Electricitatis in Motu Musculari. 1792.

The electric neuron: resting potential
with electrode

The phenomenon:
Potential difference between the two side
EC and IC of the membrane

Microelectrode filled with conducting salt solution

Reference electrode in contact with the solution bathing the axon

Axon

Axonal membrane

Plasma membrane

K+ channel

K+ ⟶ K+

K+ ⟶ K+

140 mM K+ | K+ ⟶ K+ | 4 mM K+

K+ ⟶ K+

K+ ⟶ K+

Primarily K+ channels open

12 mM Na+ | Na+ ⟵ Na+ | 150 mM Na+

Sodium channel

Few Na+ or Cl⁻ channels open

4 mM Cl⁻ | Cl⁻ ⟵ Cl⁻ | 120 mM Cl⁻

Chloride channel

148 mM A⁻ | | 34 mM A⁻

Axonal cytosol | Extracellular fluid

Reason:
on the two different sides of the membrane:
• different concentrations of ions on
• the two side of the membrane
• different permeability for different
• ions

The generation of the resting potential
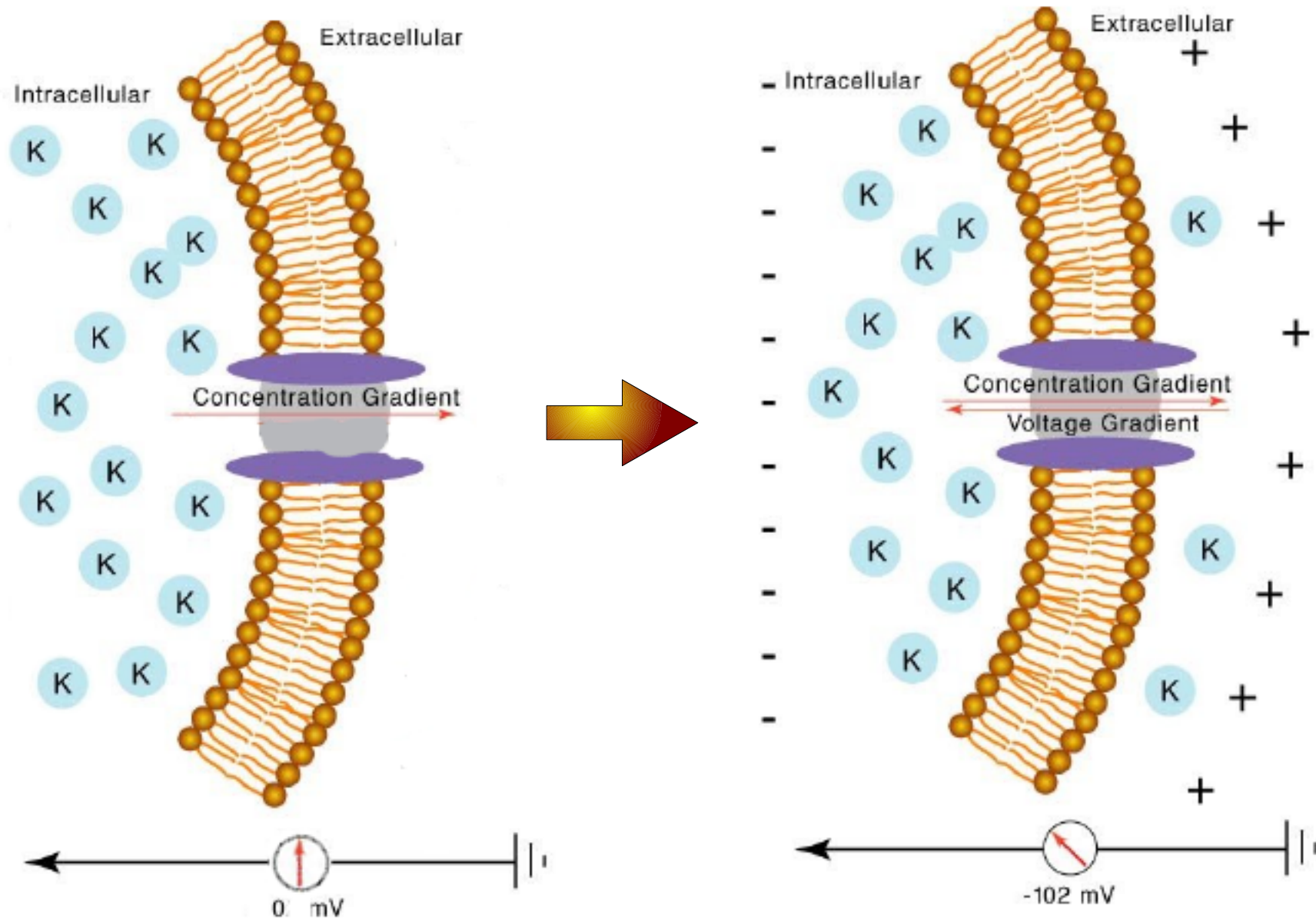
14

The electric neuron: action potential

with electrode

What is the action potential?
A short change in the membrane potential
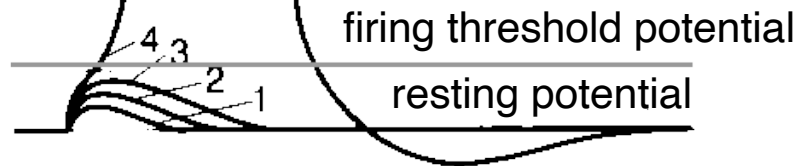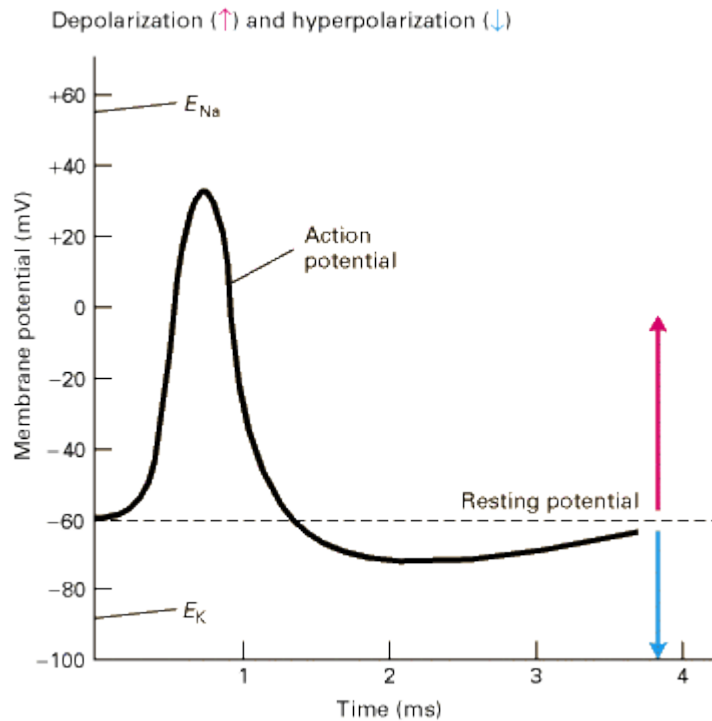
Traveling action potential
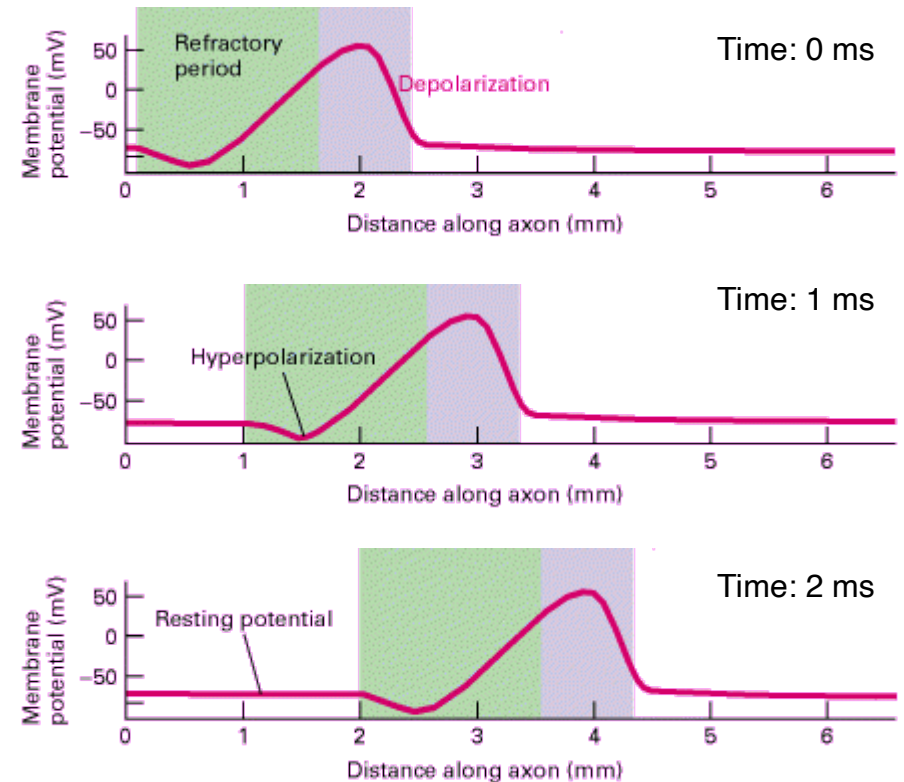
The action potential is an 'all or none' phenomenon
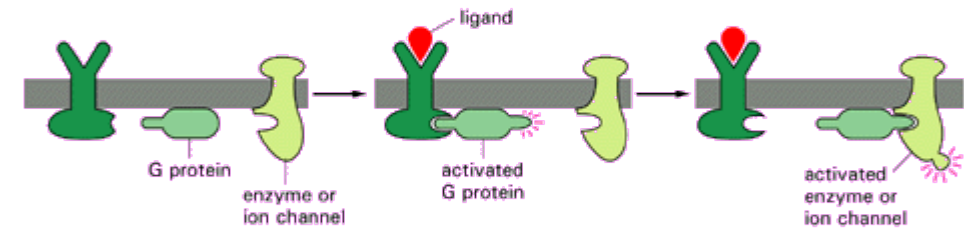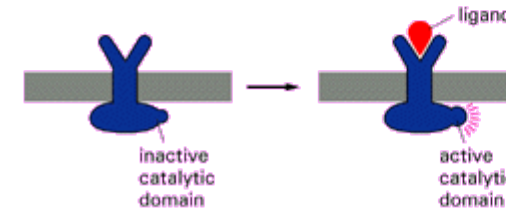
Between two neuron: The synapse

Ionotrophic (A) and metabotrophic (B,C) receptors
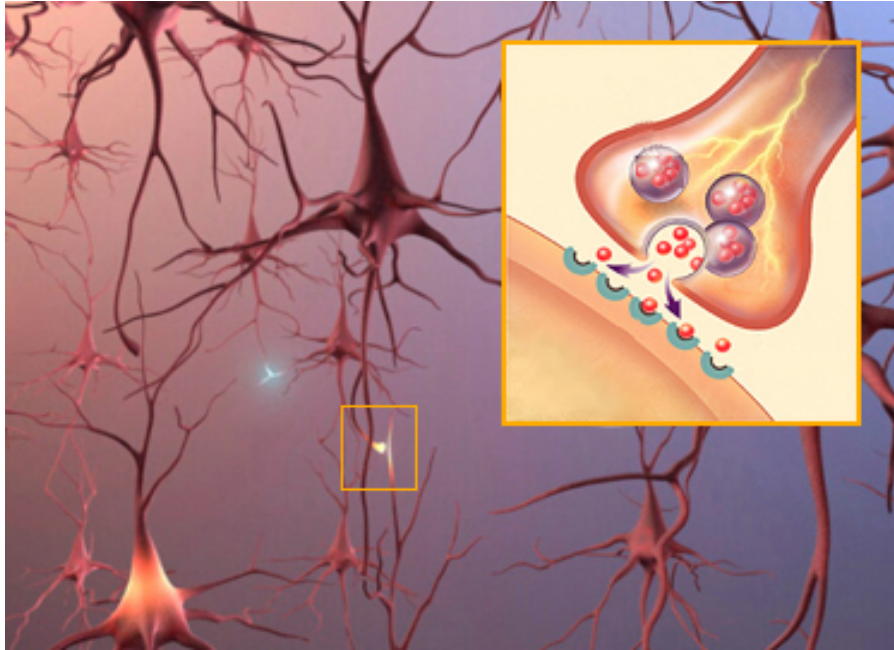
(A) ION-CHANNEL-LINKED RECEPTOR

(B) G-PROTEIN-LINKED RECEPTOR

(C) ENZYME-LINKED RECEPTOR

Excitatory and inhibitory postsynaptic potentials
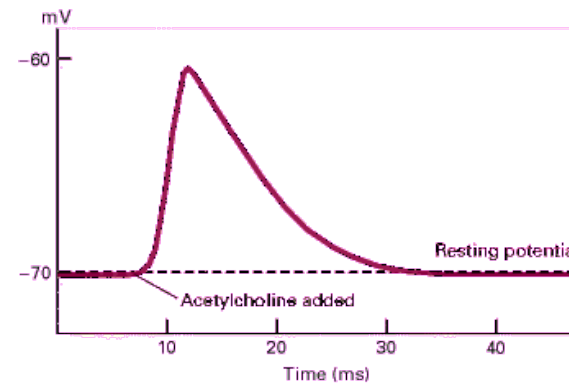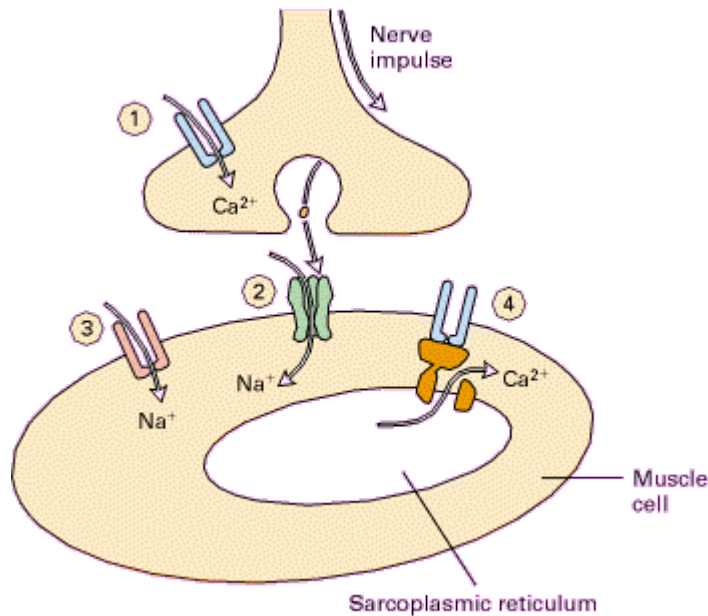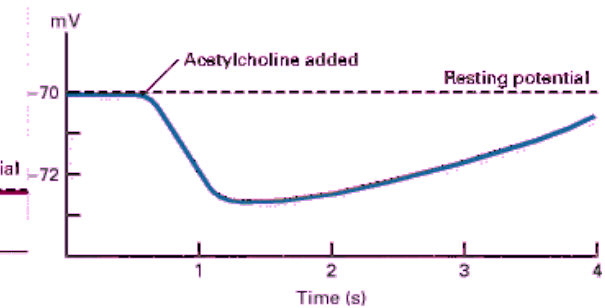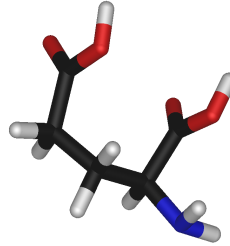
Excitatory and **inhibitory** neurotransmitters
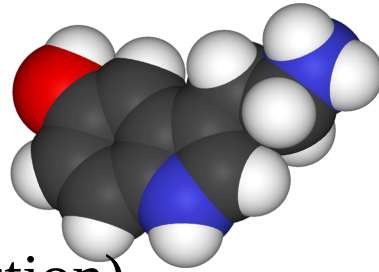
Glutamat
(information transmission)
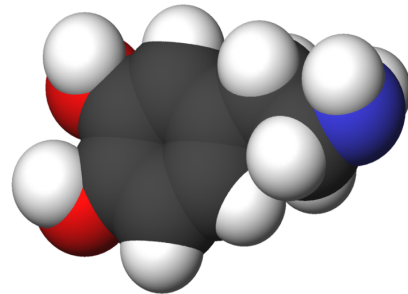
Serotonin
(mood, wake/sleep)

Acetlicholin
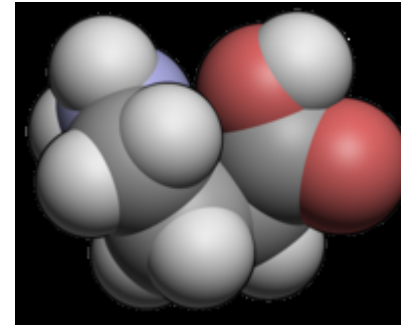(neuromuscular junction)

Noradneraline
(arousal)

Dopamine
(reward system,
Parkinson disease,
schizophrenia)

GABA-gamma aminobutyric acid
(in the central neural system)

Glycine
(in the periphery)