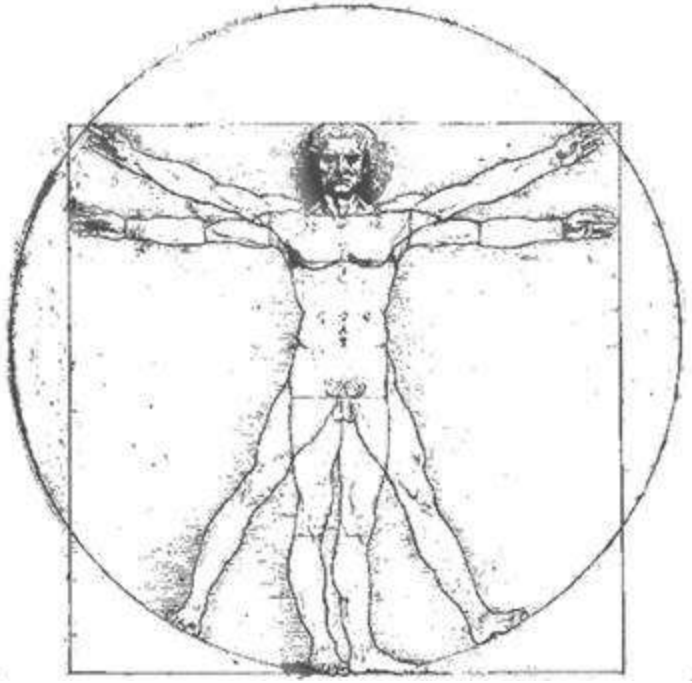


ORGANIZATION OF THE HUMAN BODY

Contents

- Overview of Anatomy & Physiology
- Levels of Structural Organization
- The Language of Anatomy

Overview of Anatomy & Physiology

Overview of Anatomy & Physiology

ANATOMY

- The study of the structure and shape of the body and body parts and their relationship to one another
- Derived from the Greek words: to cut (tomy) apart (ana)

Overview of Anatomy & Physiology

Gross Anatomy

- The study of large, easily observable structures (eg, heart, bones)

Microscopic Anatomy

- A microscope or magnifying instrument is used to see very small structures in the body (eg, cells, tissues)

Overview of Anatomy & Physiology

PHYSIOLOGY

- The study of how the body and its parts work or function
- Derived from the Latin words: nature (physio), the study of (ology)

Overview of Anatomy & Physiology

Subdivisions of Physiology (Examples)

- Neurophysiology: explains the workings of the nervous system
- Cardiac physiology: studies the function of the heart

Levels of Structural Organization

Levels of the Hierarchy

- Atoms: building blocks of matter
- Molecules: groups of atoms (eg, water, sugar, proteins)
- Organelles: basic components of microscopic cells
- Cells: smallest units of all living things

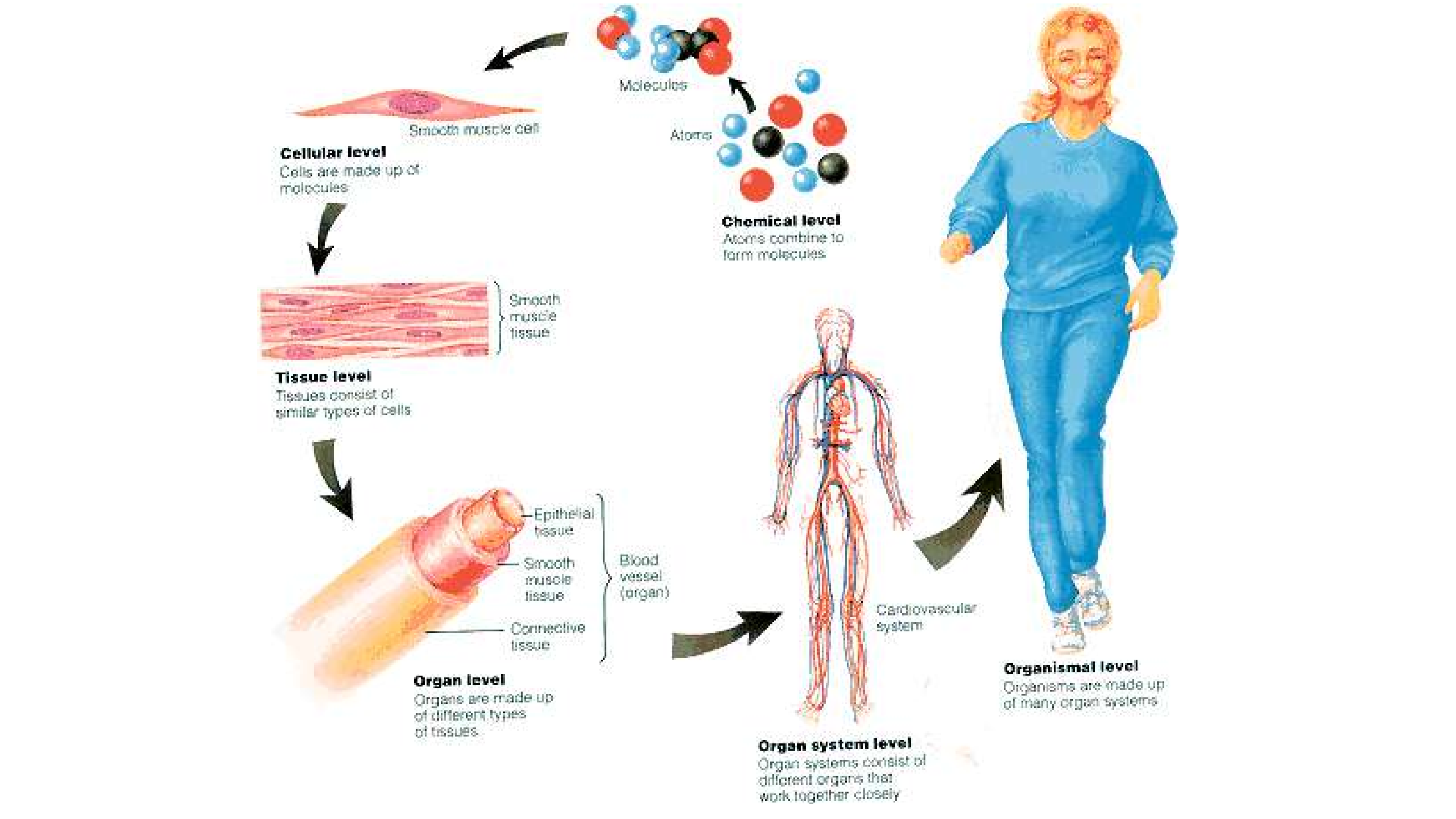
Levels of the Hierarchy

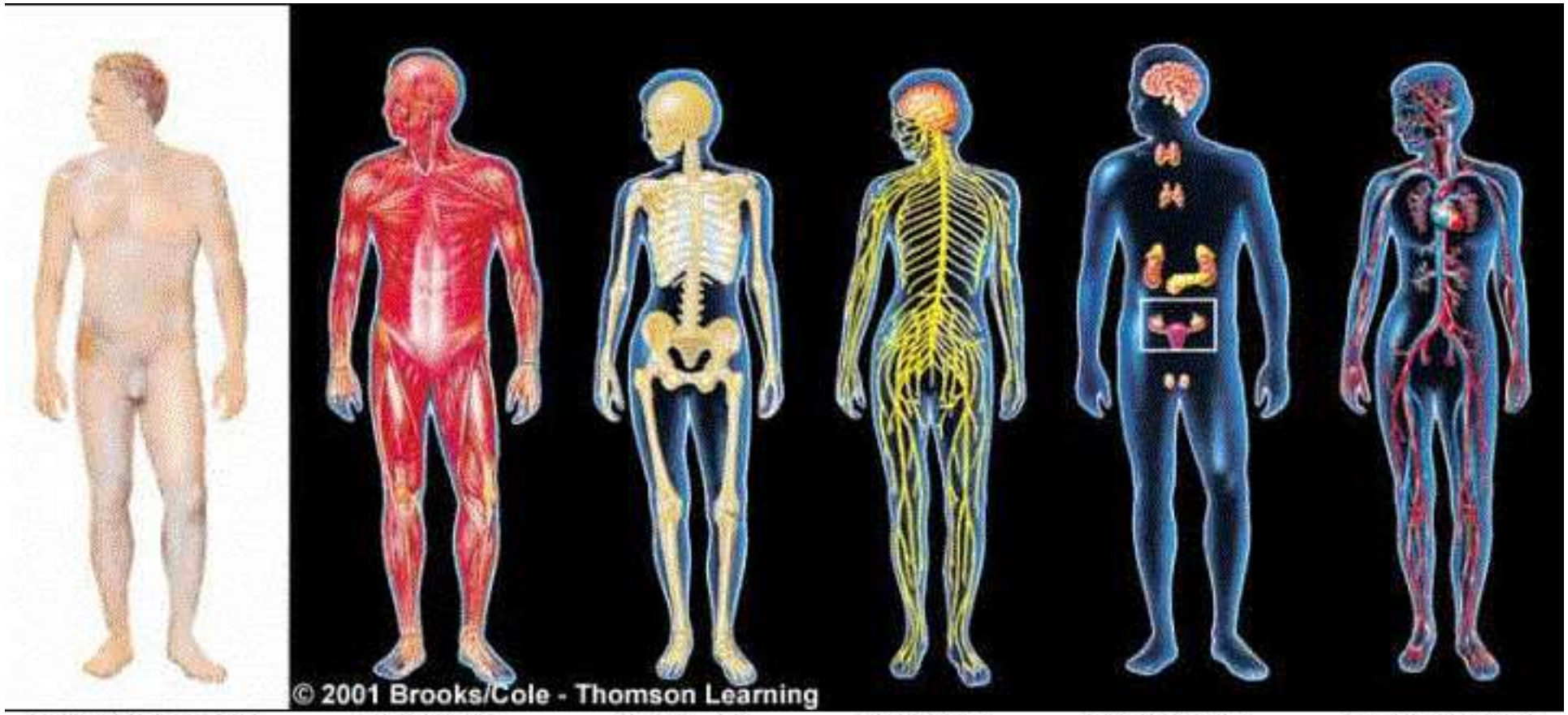
Tissues: groups of similar cells that have a common function

Organ: a structure composed of two or more tissue types that perform a specific function for the body

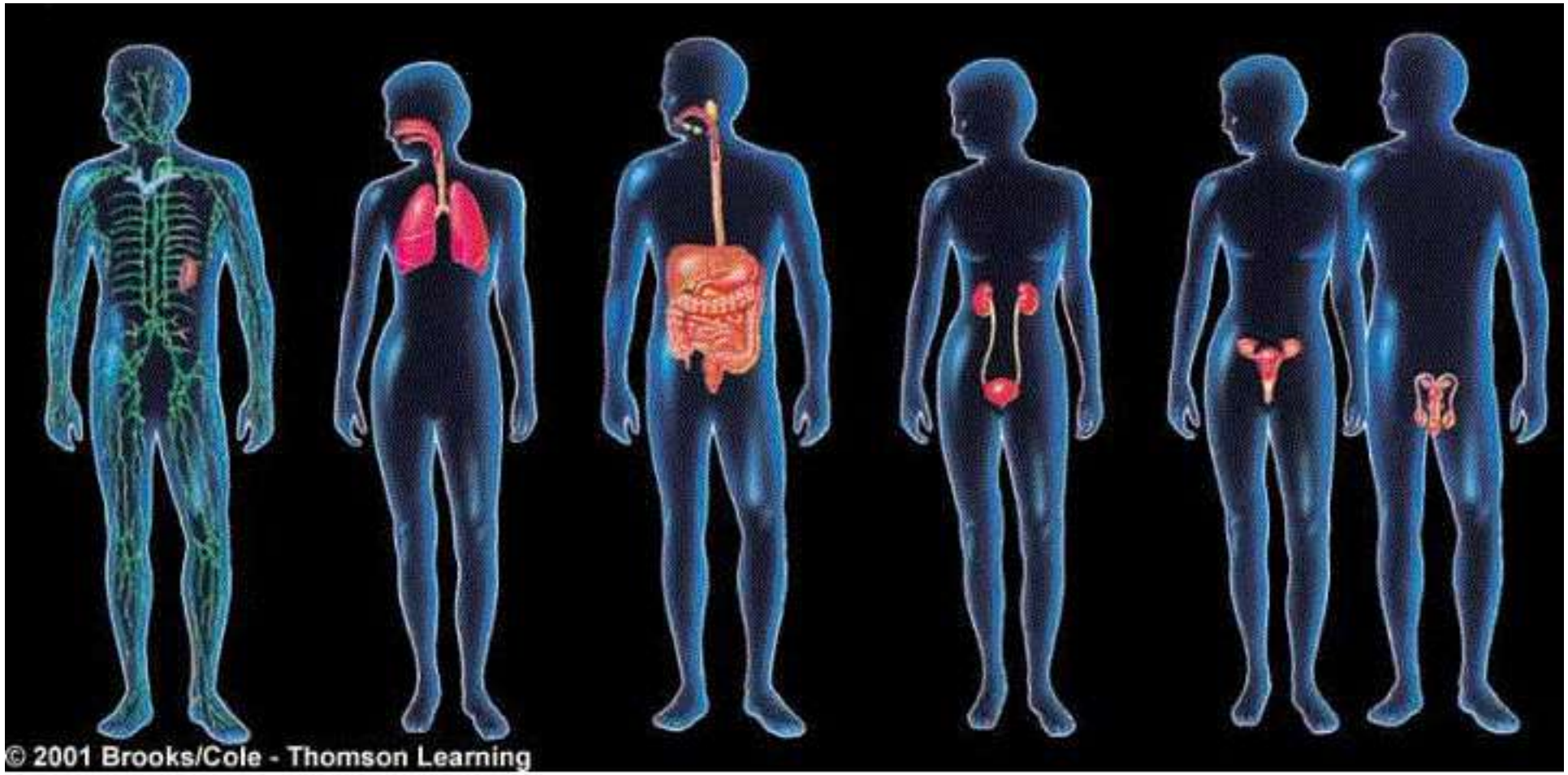
Organ System: a group of organs that cooperate and work closely together to accomplish a common purpose

Organism: the highest level of structural organization


Molecules
Atoms
Smooth muscle cell
Cellular level
Cells are made up of molecules
Chemical level
Atoms combine to form molecules
Smooth muscle tissue
Tissue level
Tissues consist of similar types of cells
Epithelial tissue
Smooth muscle tissue
Connective tissue
Blood vessel (organ)
Organ level
Organs are made up of different types of tissues
Cardiovascular system
Organ system level
Organ systems consist of different organs that work together closely
Organismal level
Organisms are made up of many organ systems



INTEGUMENTARY SYSTEM | MUSCULAR SYSTEM | SKELETAL SYSTEM | NERVOUS SYSTEM | ENDOCRINE SYSTEM | CIRCULATORY SYSTEM



LYMPHATIC SYSTEM | RESPIRATORY SYSTEM | DIGESTIVE SYSTEM | URINARY SYSTEM | REPRODUCTION SYSTEM

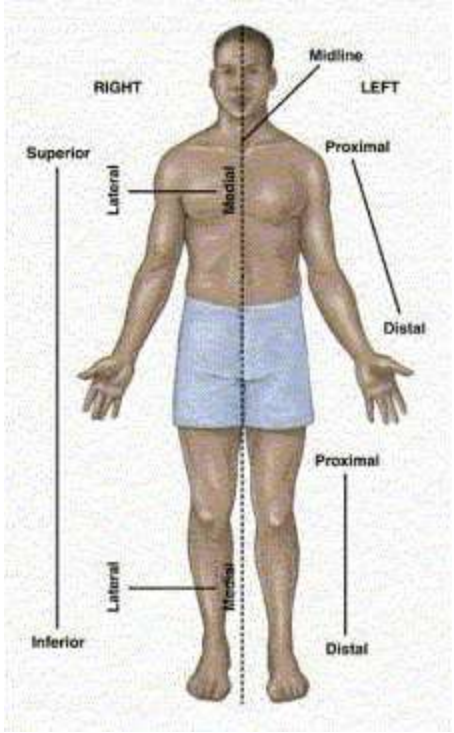
The Language of Anatomy

Gross Anatomy: Introduction

- Anatomical position
- Directional terms
- Regional terms
- Body planes and sections
- Body cavities and membranes
- Abdominopelvic regions and quadrants

Anatomical Position

- The body is erect with the feet parallel and the arms hanging at the sides with the palms facing forward



Directional Terms

Superior (cranial or cephalad)

- Toward the head end or upper part of a structure of the body

Inferior (caudal)

- Away from the head end or toward the lower part of a structure or the body

Anterior (ventral)

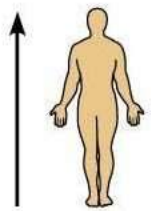
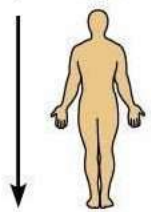
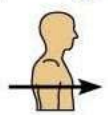
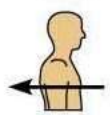
- Toward or at the front of the body

Posterior (dorsal)

- Toward or at the backside of the body

TABLE

1.1 Orientation and Directional Terms

Term	Definition		Example
Superior (cranial)	Toward the head end or upper part of a structure or the body; above		The head is superior to the abdomen.
Inferior (caudal)	Away from the head end or toward the lower part of a structure or the body; below		The navel is inferior to the chin.
Anterior (ventral)*	Toward or at the front of the body; in front of		The breastbone is anterior to the spine.
Posterior (dorsal)*	Toward or at the back of the body; behind		The heart is posterior to the breastbone.

*Whereas the terms *ventral* and *anterior* are synonymous in humans, this is not the case in four-legged animals. *Ventral* specifically refers to the "belly" of a vertebrate animal and thus is the inferior surface of four-legged animals. Likewise, although the dorsal and posterior surfaces are the same in humans, the term *dorsal* specifically refers to an animal's back. Thus, the dorsal surface of four-legged animals is their superior surface.

Directional Terms

Medial
- Toward or at the midline of the body

Lateral
- Away from the midline of the body

Proximal
- Close to the origin of the body part or the point of attachment of a limb to the body trunk

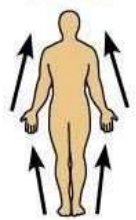
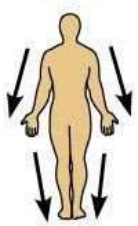
Distal
- Farther away from the origin of a body part or the point of attachment of a limb to the body Trunk

Superficial
- Toward or at the body surface

Deep
- Away from the body surface; more internal elbow

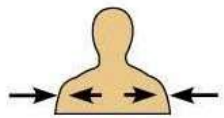
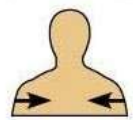
TABLE

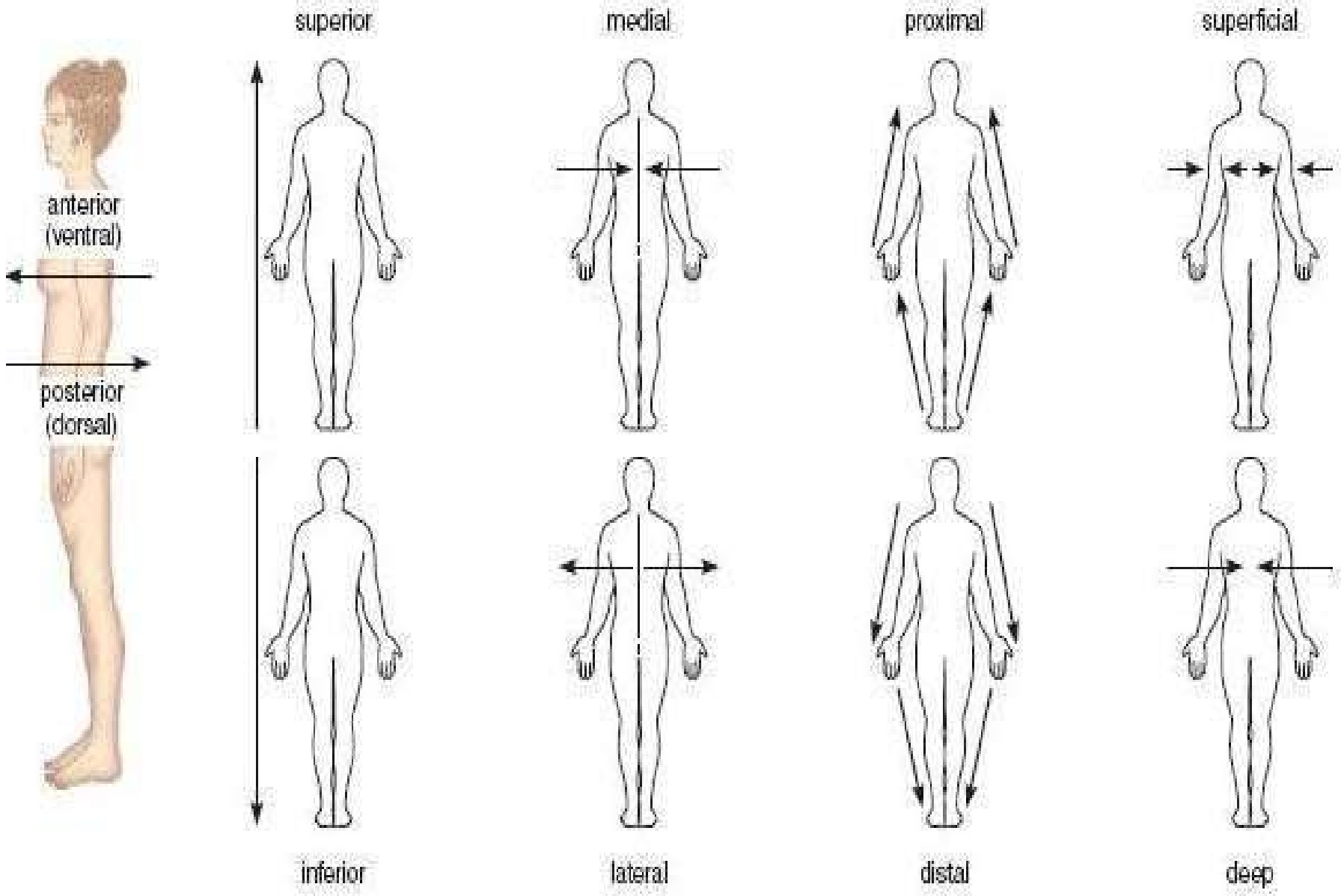
1.1 Orientation and Directional Terms

Term	Definition		Example
Medial	Toward or at the midline of the body; on the inner side of		The heart is medial to the arm.
Lateral	Away from the midline of the body; on the outer side of		The arms are lateral to the chest.
Proximal	Closer to the origin of the body part or the point of attachment of a limb to the body trunk		The elbow is proximal to the wrist.
Distal	Farther from the origin of a body part or the point of attachment of a limb to the body trunk		The knee is distal to the thigh.

TABLE

1.1 Orientation and Directional Terms

Term	Definition		Example
Superficial (external)	Toward or at the body surface		The skin is superficial to the skeletal muscles.
Deep (internal)	Away from the body surface; more internal		The lungs are deep to the skin.
Ipsilateral	On the same side		The right hand and right foot are ipsilateral.
Contralateral	On opposite sides		The right hand and left foot are contralateral.


anterior
(ventral)
posterior
(dorsal)
superior
medial
proximal
superficial
inferior
lateral
distal
deep

Regional Terms

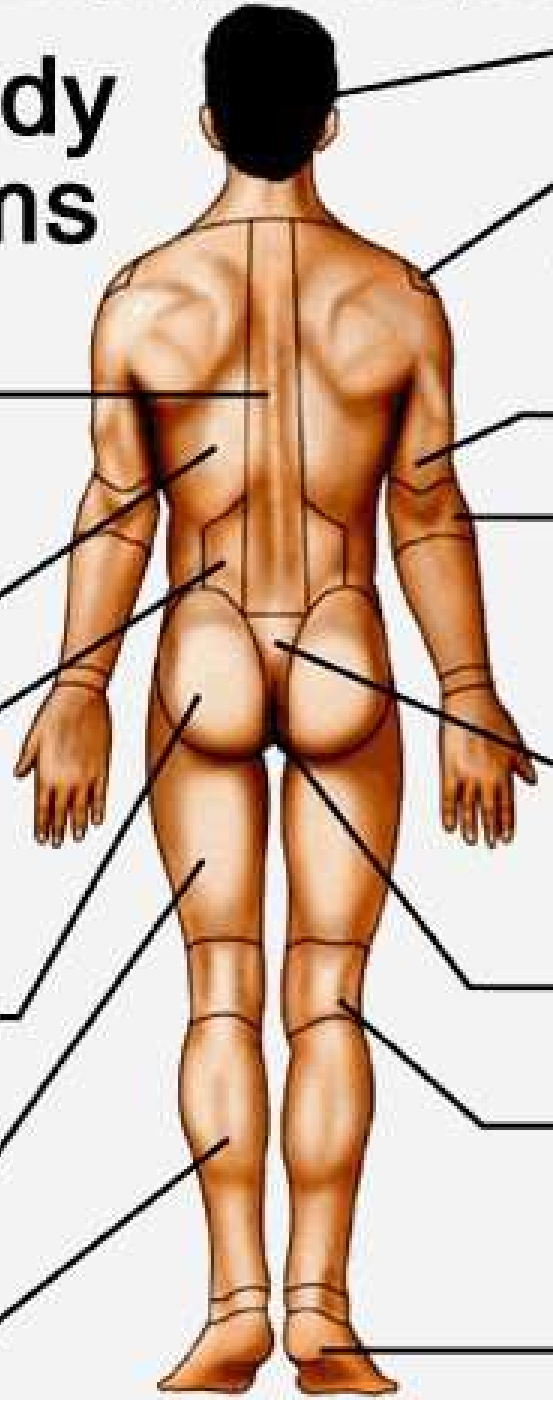
Axial

- makes up the main axis of the body.
- consists of the head, neck, and trunk

Appendicular

- consists of the appendages or limbs

Posterior Body Region Terms



Occipital (back of head)

Acromial (point of shoulder)

Vertebral (spinal column)

Brachial (arm)

Dorsum (back)

Cubital (elbow)

Lumbar (lower back)

Sacral (between hips)

Gluteal (buttocks)

Perineal

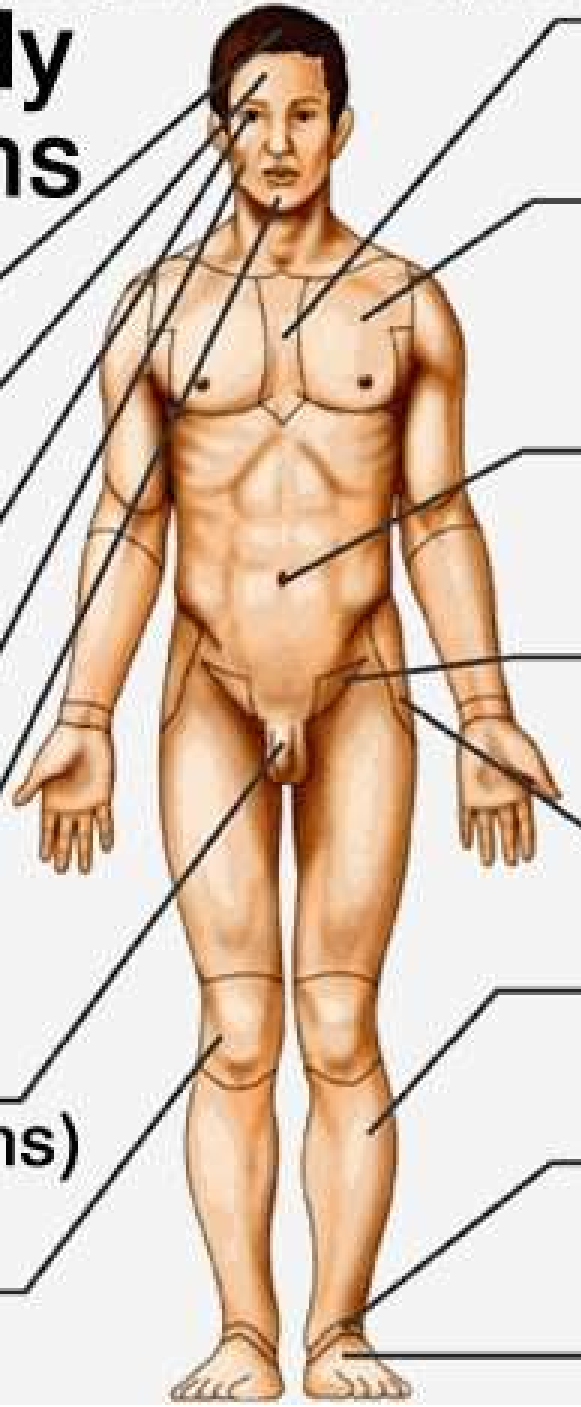
Femoral (thigh)

Popliteal (back of knee)

Crural (leg)

Plantar (sole)

Anterior Body Region Terms (2)



Cephalic (head)

Frontal (forehead)

Orbital (eye cavity)

Buccal (cheek)

Mental (chin)

Genital (reproductive organs)

Petallar (front of knee)

Sternal

Pectoral region (chest)

Umbilical (navel)

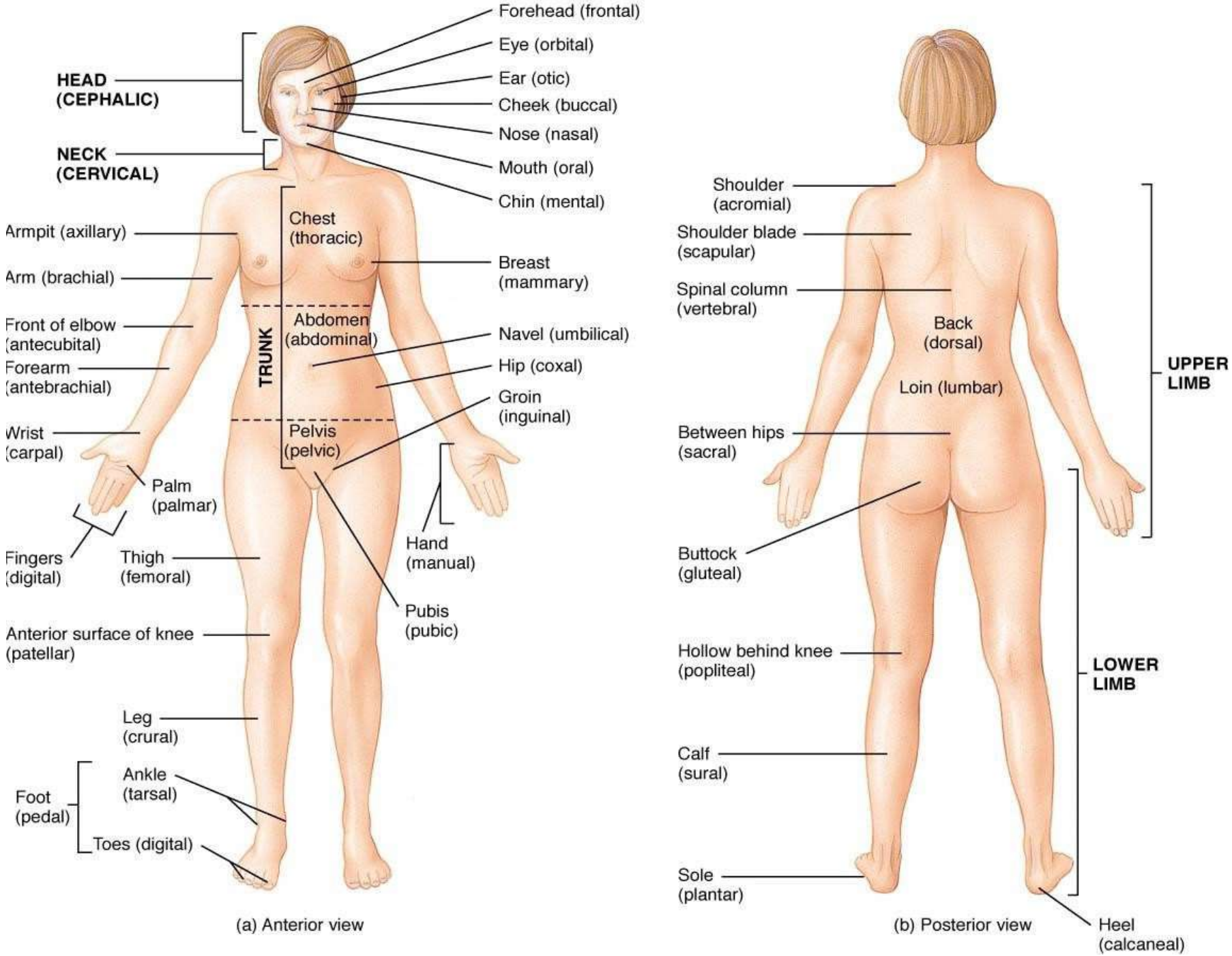
Inguinal (groin)

Coxal (hip)

Crural (leg)

Tarsal (instep)

Pedal (foot)


HEAD (CEPHALIC)
NECK (CERVICAL)
Forehead (frontal)
Eye (orbital)
Ear (otic)
Cheek (buccal)
Nose (nasal)
Mouth (oral)
Chin (mental)
Chest (thoracic)
Armpit (axillary)
Arm (brachial)
Breast (mammary)
Front of elbow (antecubital)
Forearm (antebrachial)
TRUNK
Abdomen (abdominal)
Navel (umbilical)
Hip (coxal)
Groin (inguinal)
Pelvis (pelvic)
Wrist (carpal)
Palm (palmar)
Fingers (digital)
Thigh (femoral)
Hand (manual)
Pubis (pubic)
Anterior surface of knee (patellar)
Leg (crural)
Foot (pedal)
Ankle (tarsal)
Toes (digital)
(a) Anterior view
Shoulder (acromial)
Shoulder blade (scapular)
Spinal column (vertebral)
Back (dorsal)
Loin (lumbar)
UPPER LIMB
Between hips (sacral)
Buttock (gluteal)
Hollow behind knee (popliteal)
LOWER LIMB
Calf (sural)
Sole (plantar)
Heel (calcaneal)
(b) Posterior view

Body Planes & Sections

Sagittal section

- A cut made along the lengthwise or longitudinal plane of the body
- Divides the body into right and left

parts Midsagittal/Median section

- The cut is made down the median plane of the body and the right and left parts are equal in size

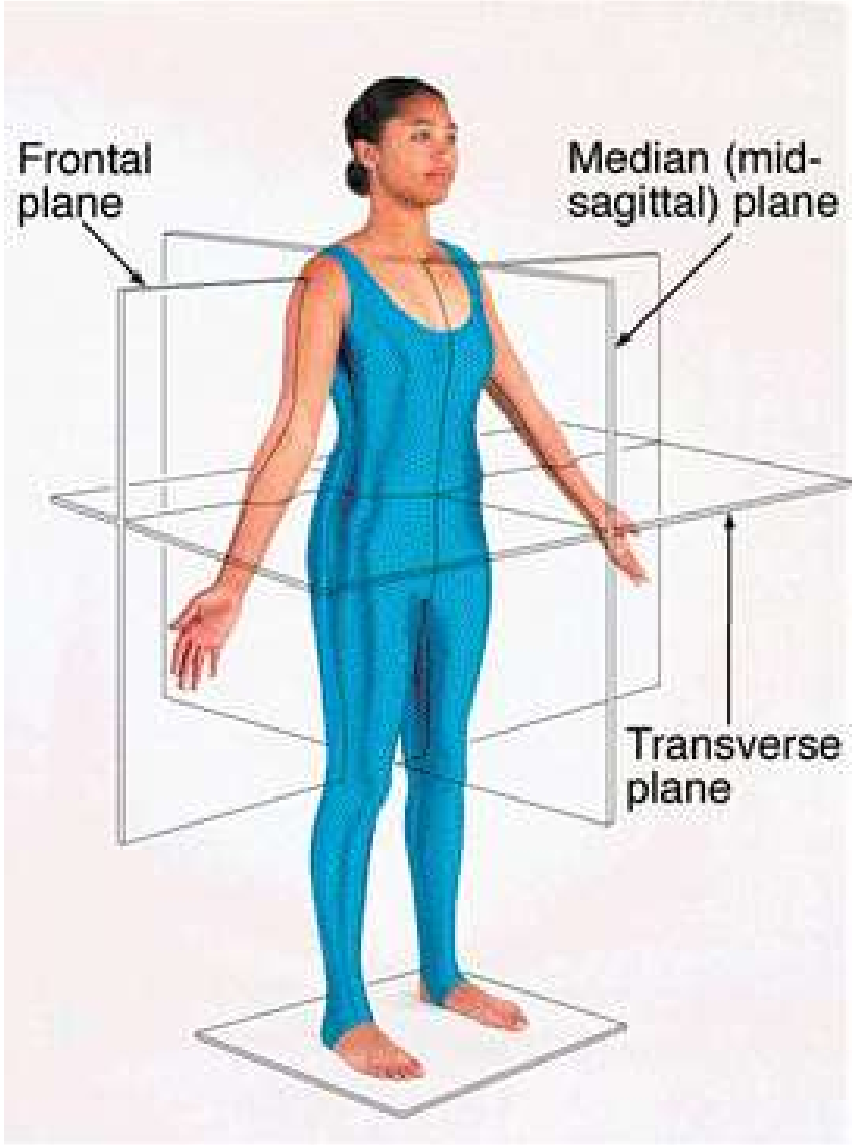
Body Planes & Sections

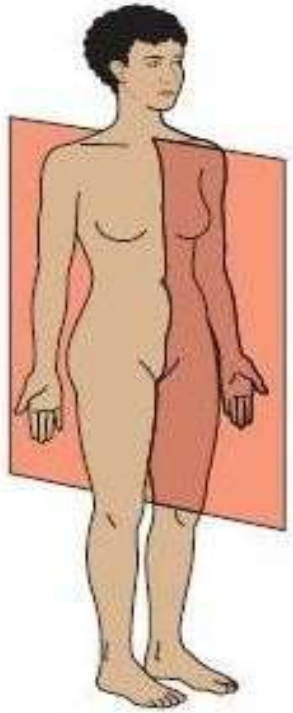
Frontal section

- A cut made along a lengthwise plane that divides the body (or an organ) into anterior and posterior parts
- Also called a coronal section

Transverse section

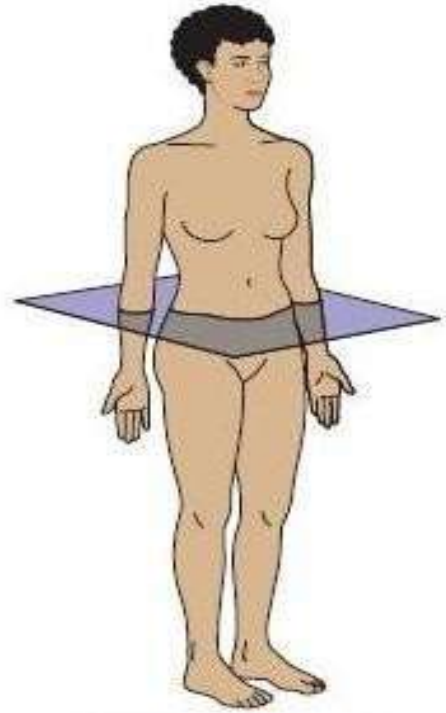
- A cut is made along a horizontal plane, dividing the body or organ into superior and inferior parts
- Also called a cross-section





a. Sagittal (median) plane

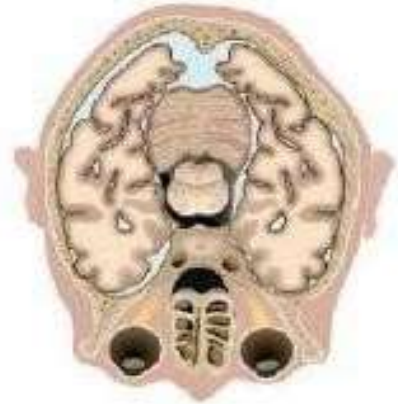
b. Frontal (coronal) plane



c. Transverse (horizontal) plane

d. Sagittal section of pelvic cavity

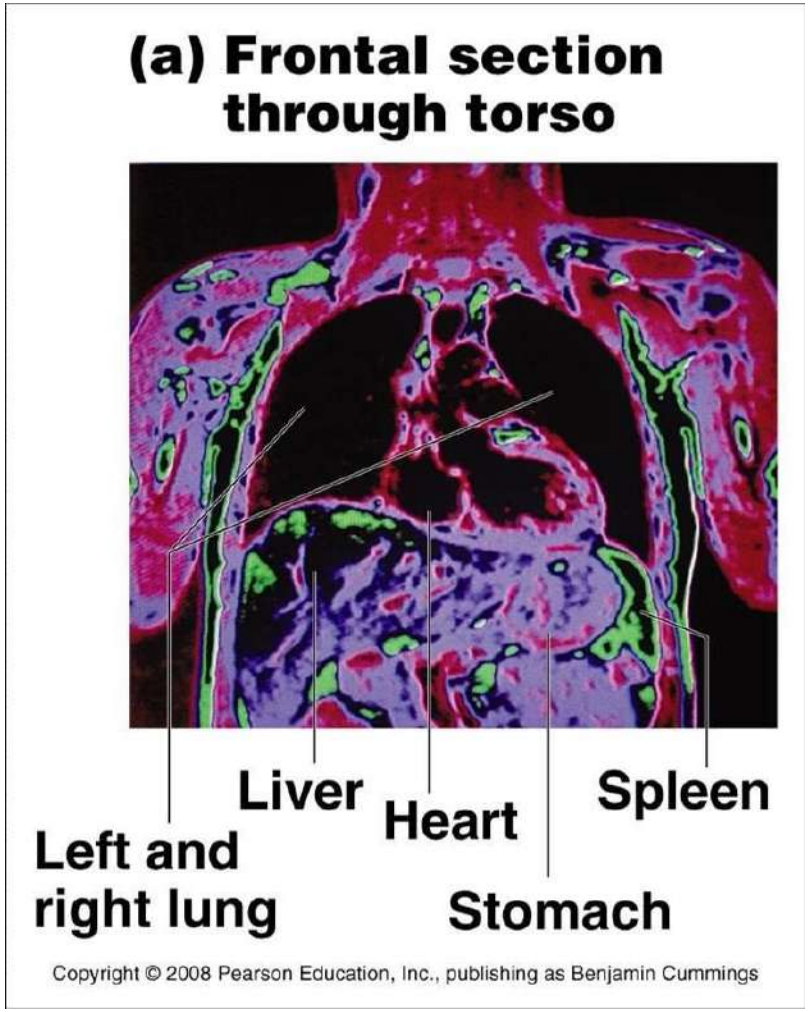
e. Frontal section of thoracic cavity



f. Transverse section of head at eye level

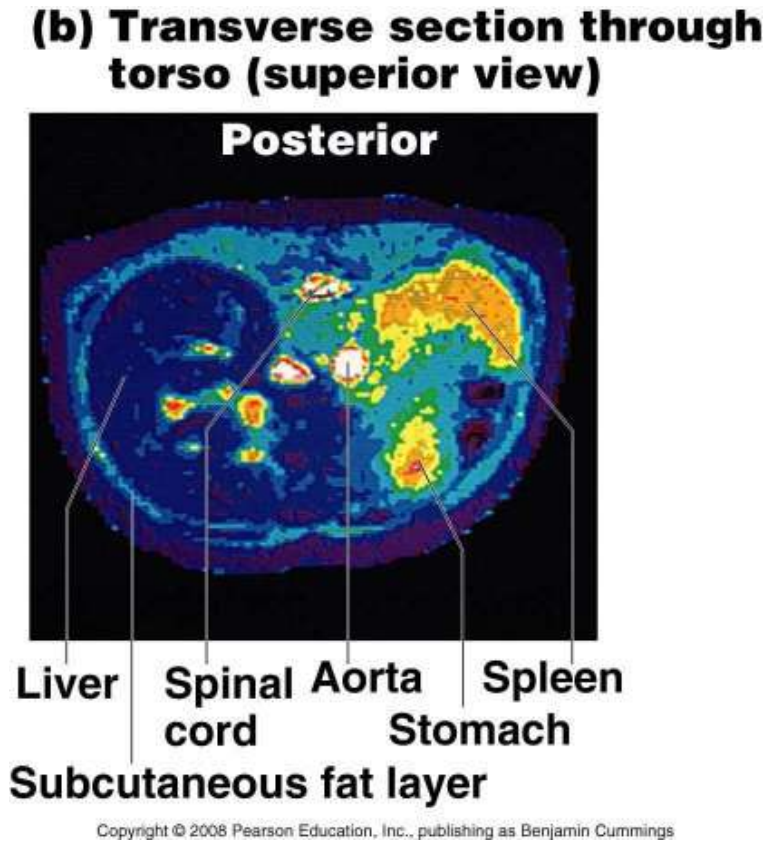
Body Planes and Sections

- In this frontal view a magnetic resonance imaging (MRI) system presents the internal structures of the torso
- Here you can readily see various organs with the torso



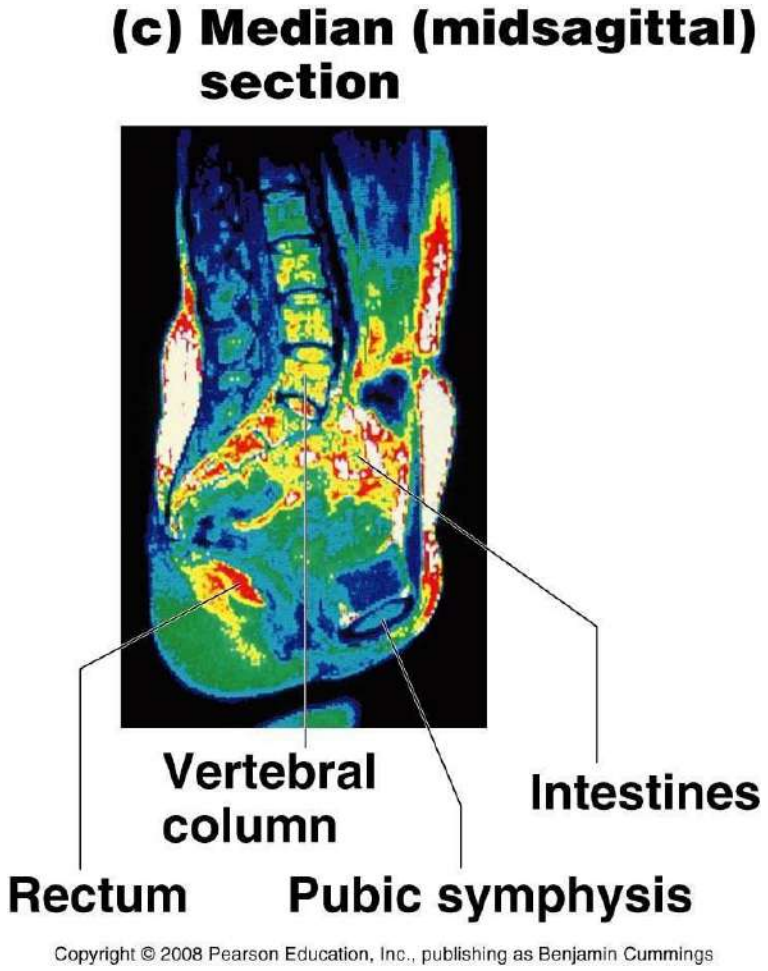
Body Planes and Sections

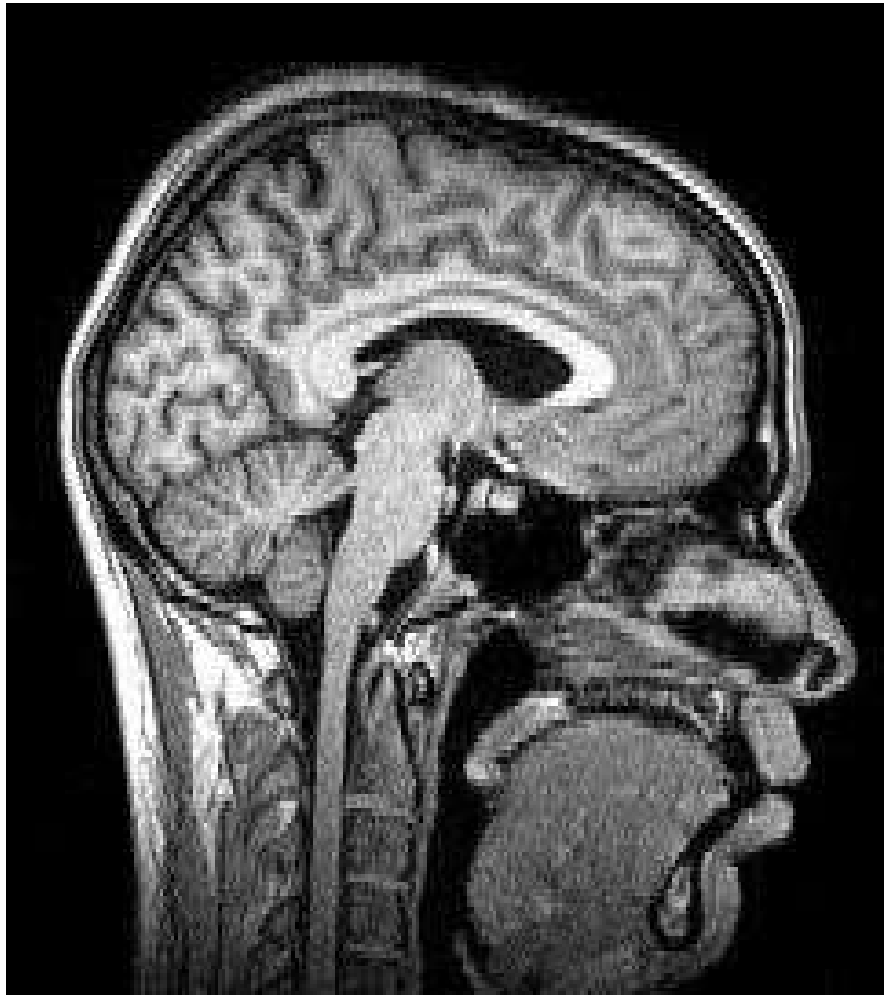
- In this transverse view a (MRI) system presents the internal structures of the torso
- This view is useful in illustrating how organs are distributed within the cavity from anterior/ lateral or medial lateral perspective

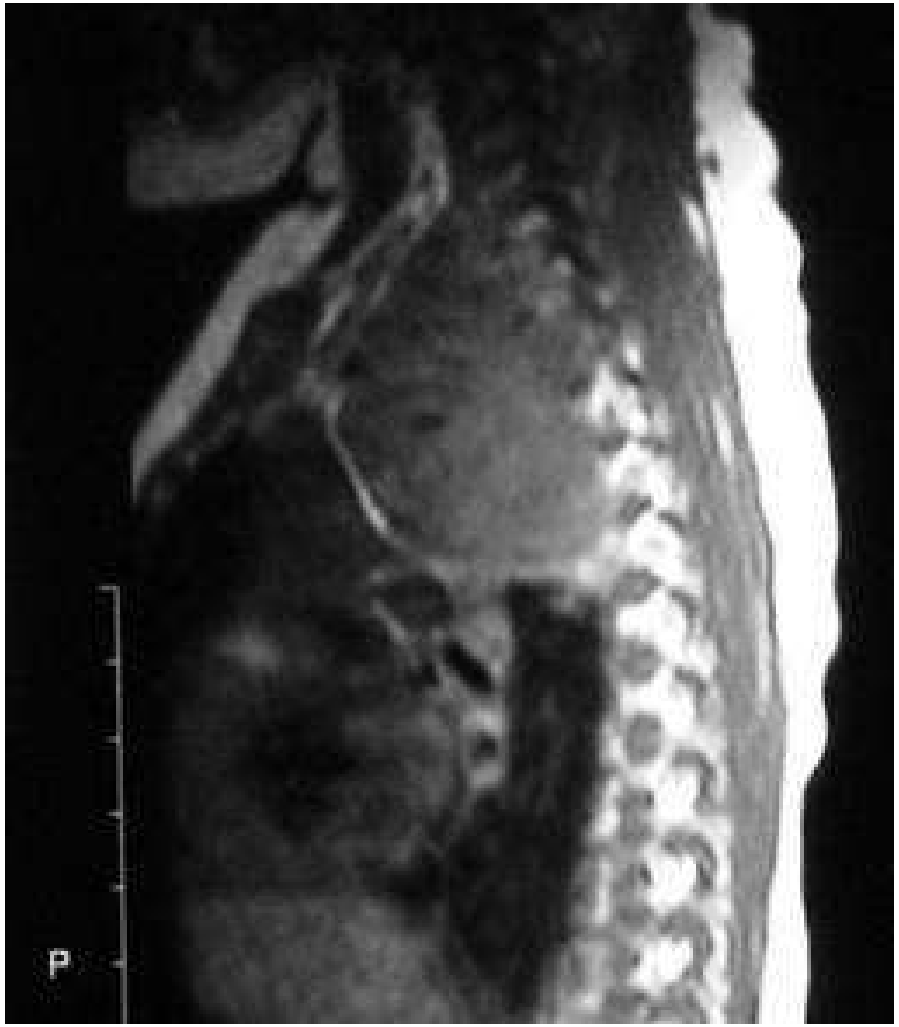


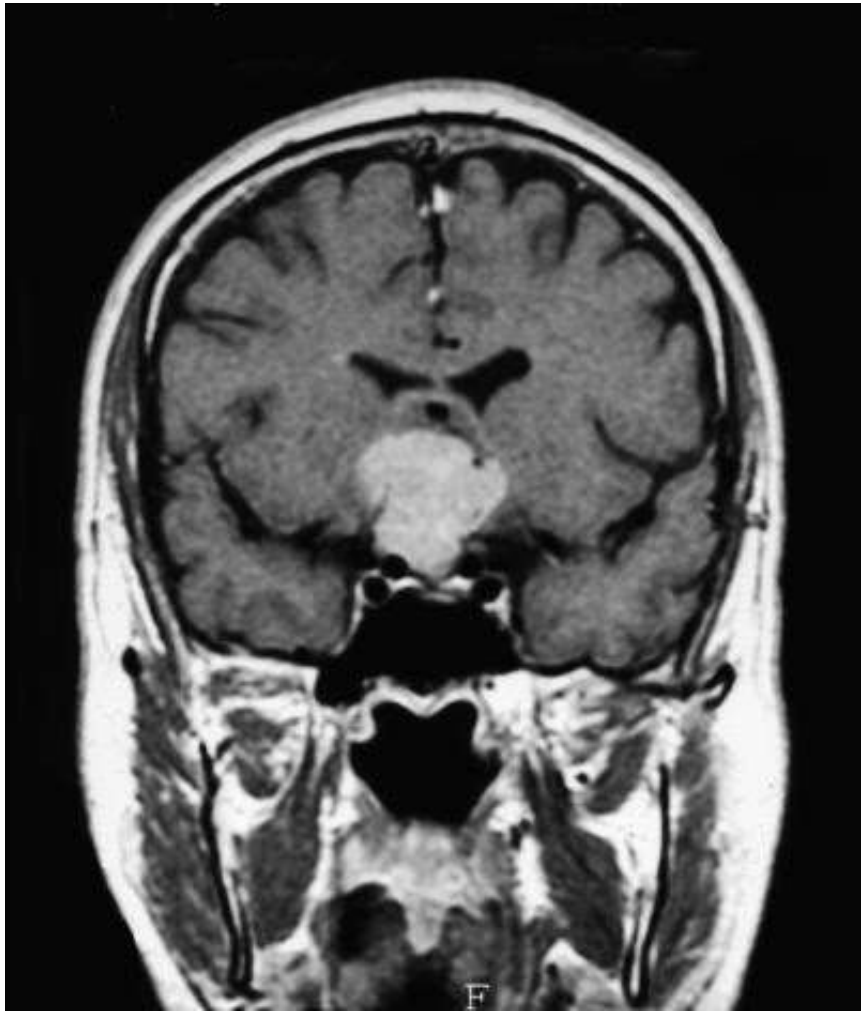
Body Planes and Sections

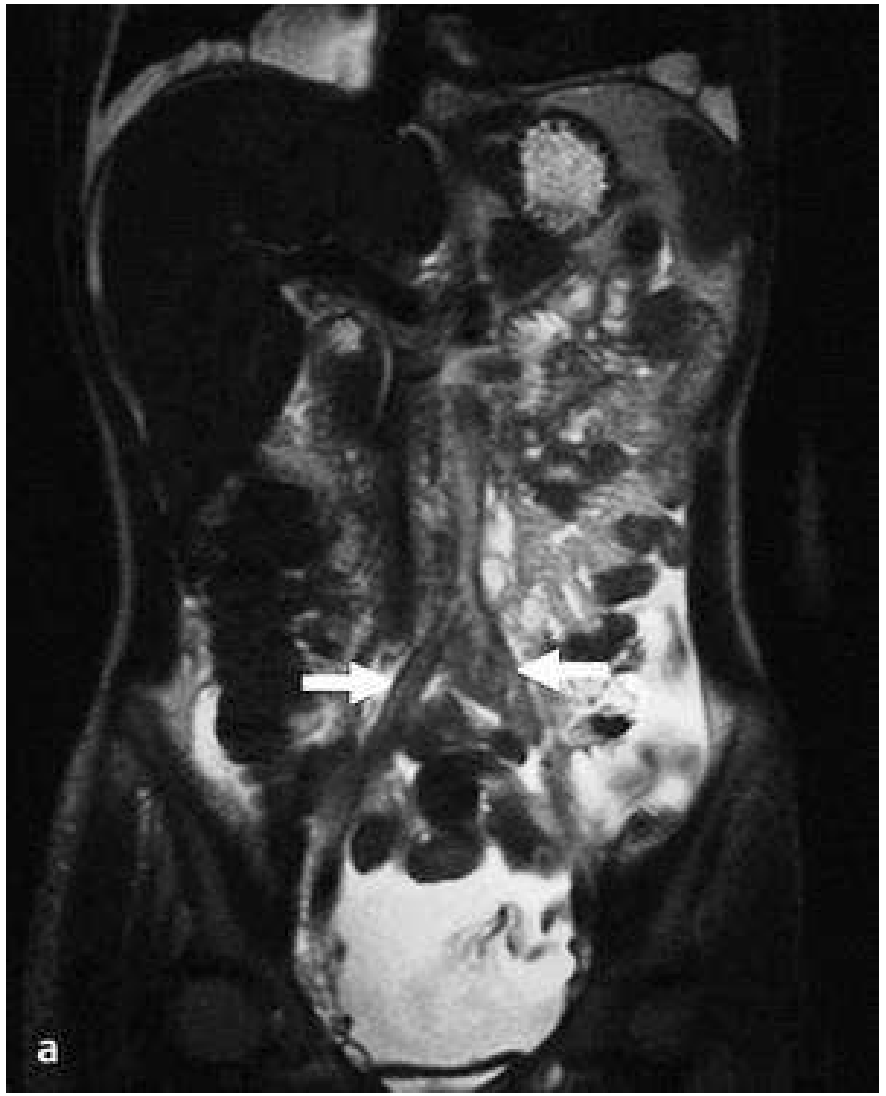
- In this midsagitall view a (MRI) system presents the internal structures of the abdominopelvic cavity
- This view is useful in visualizing structures from a superior / inferior perspective

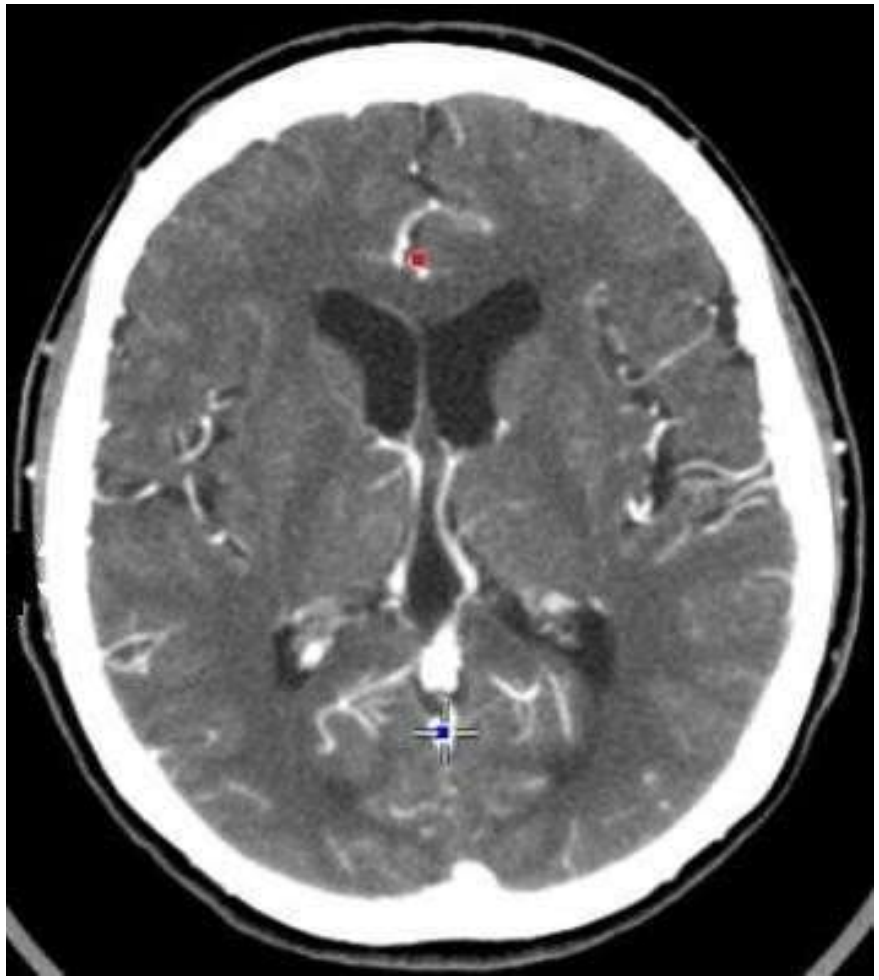


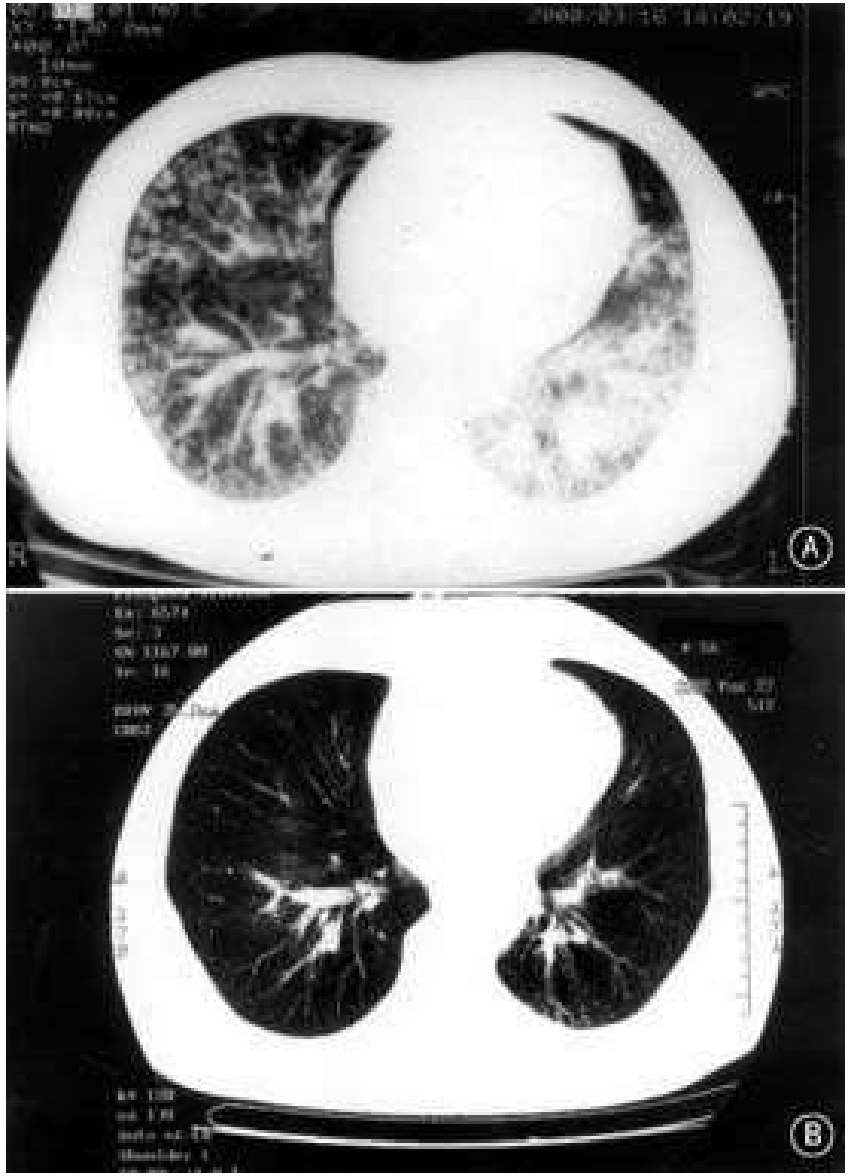



P

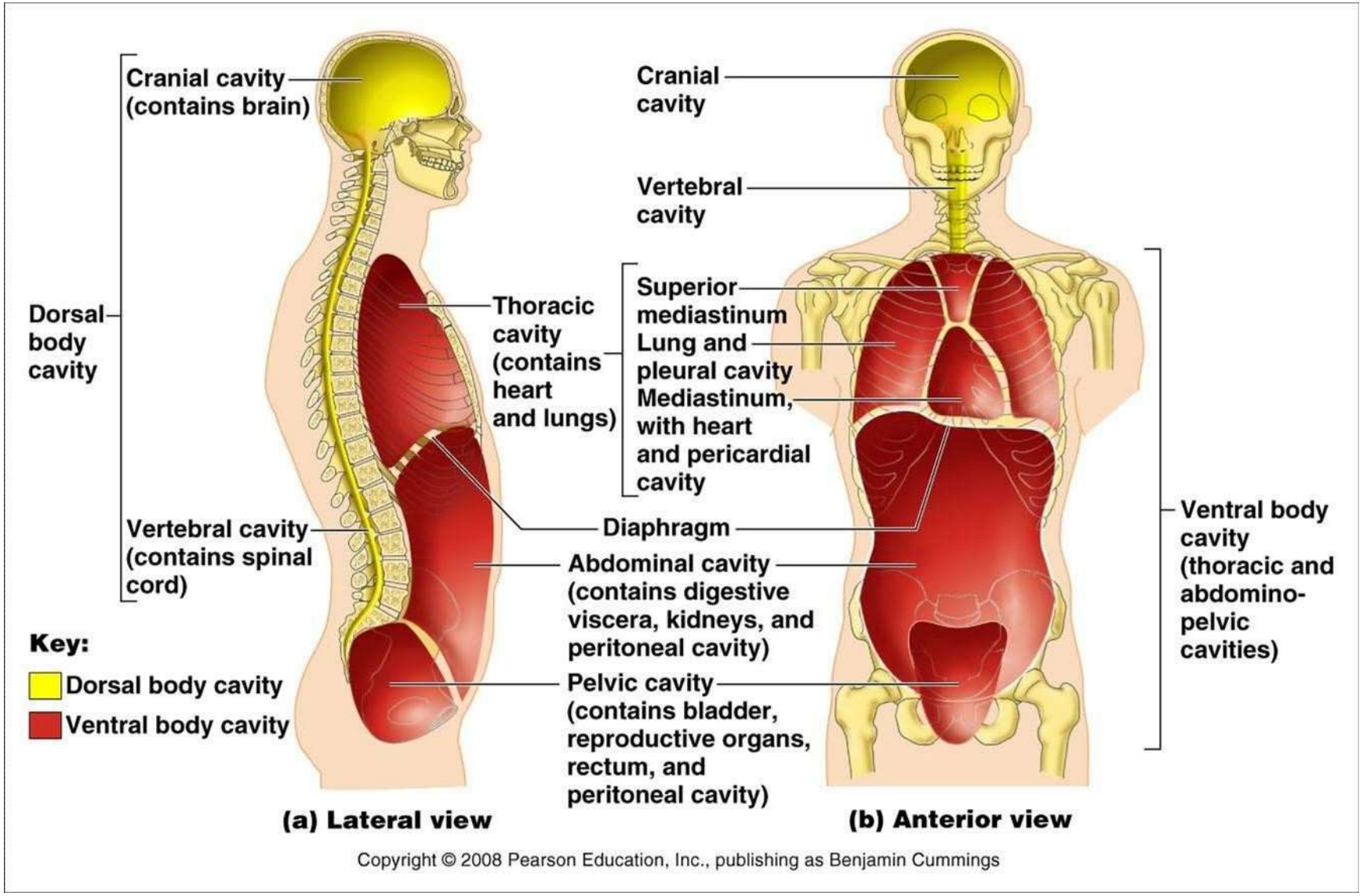



a




A
B

Body Cavities



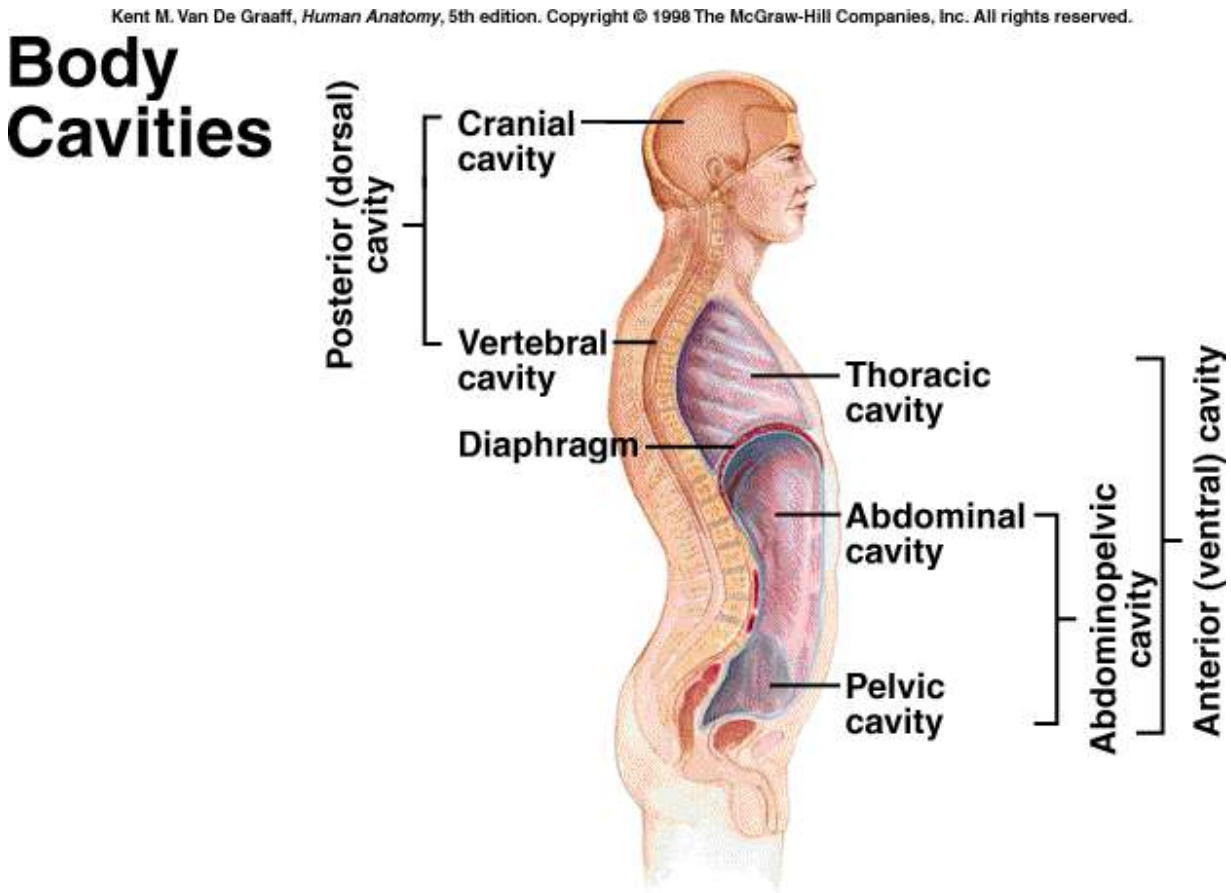
Body Cavities

DORSAL BODY CAVITY

- Has two subdivisions which are continuous with each other
  1. Cranial cavity: the space inside the skull
  2. Spinal cavity: extends from the cranial cavity nearly to the end of the vertebral column

Body cavities

- Dorsal body cavity is divided into a cranial cavity which encases the brain, and the vertebral cavity which encases the spinal cord



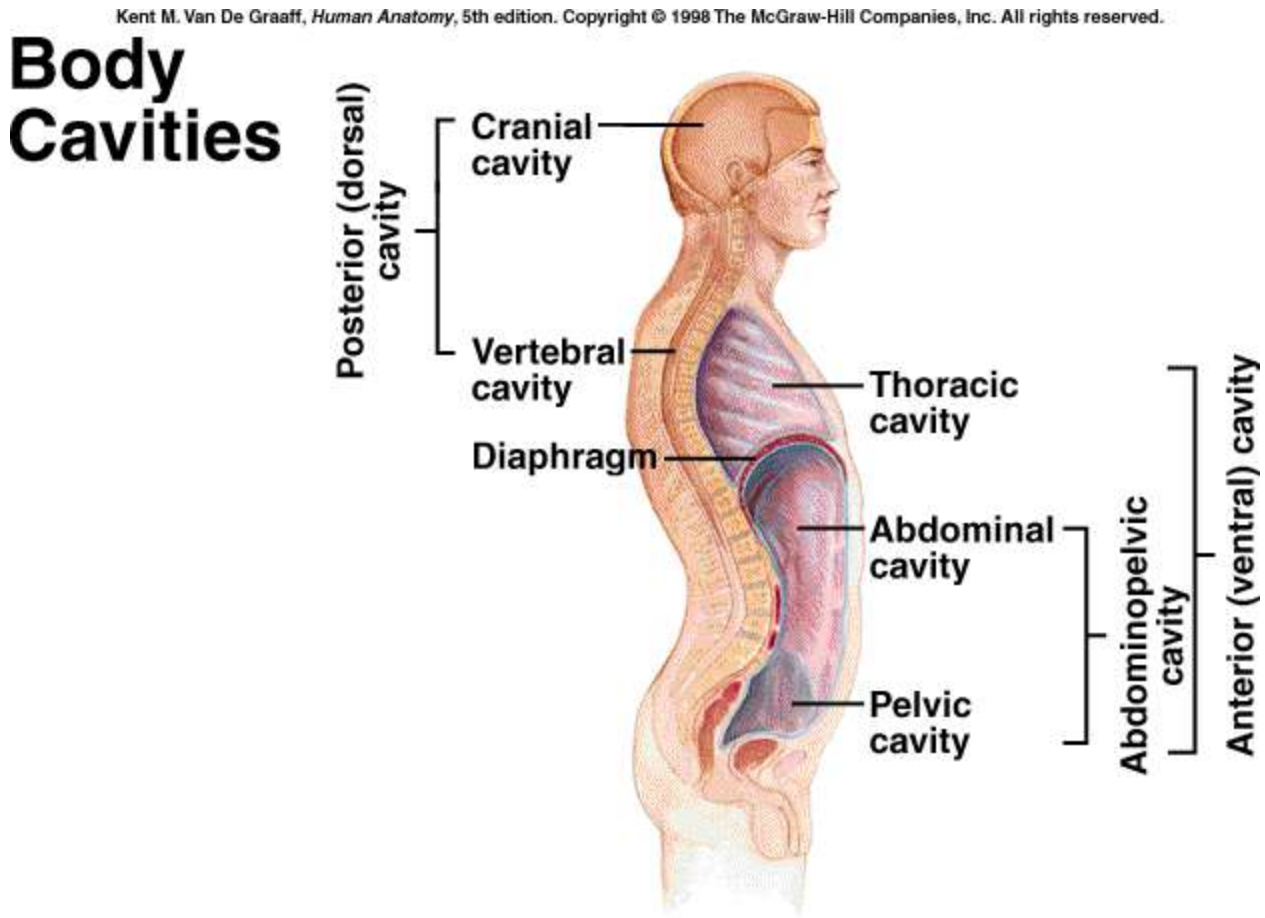
Body Cavities

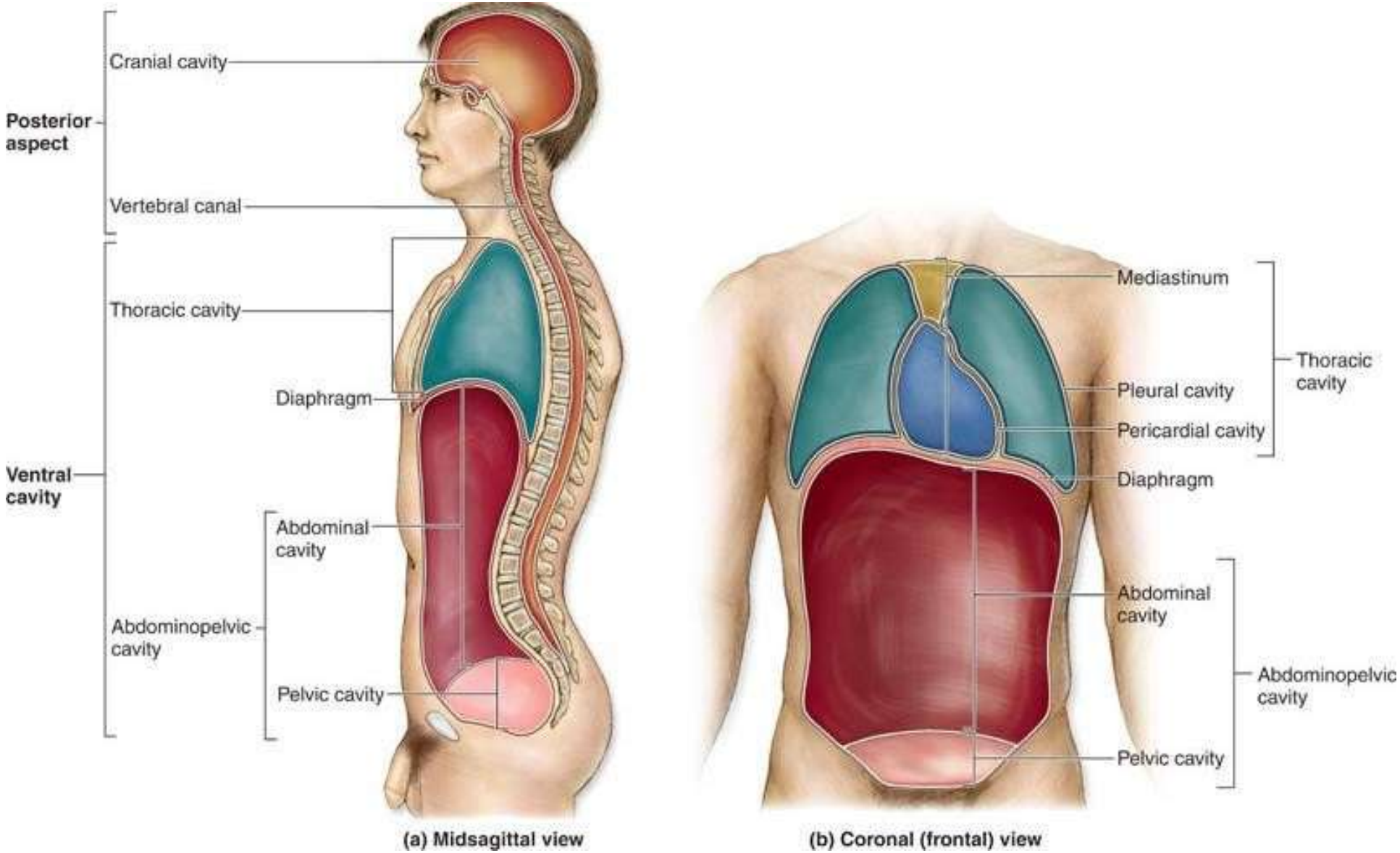
VENTRAL BODY CAVITIES

- Much larger than the dorsal cavity
- Contains all the structures in the chest and abdomen
- Two major subdivisions:
  1. Thoracic cavity: houses the lungs, heart and mediastinal structures
  2. Abdominopelvic cavity: stomach, liver, intestines, spleen, reproductive organs, urinary bladder, etc

Body cavities

- The ventral body cavity houses the visceral organs
- The ventral body cavity is divided into the thoracic, abdominal, and pelvic cavities



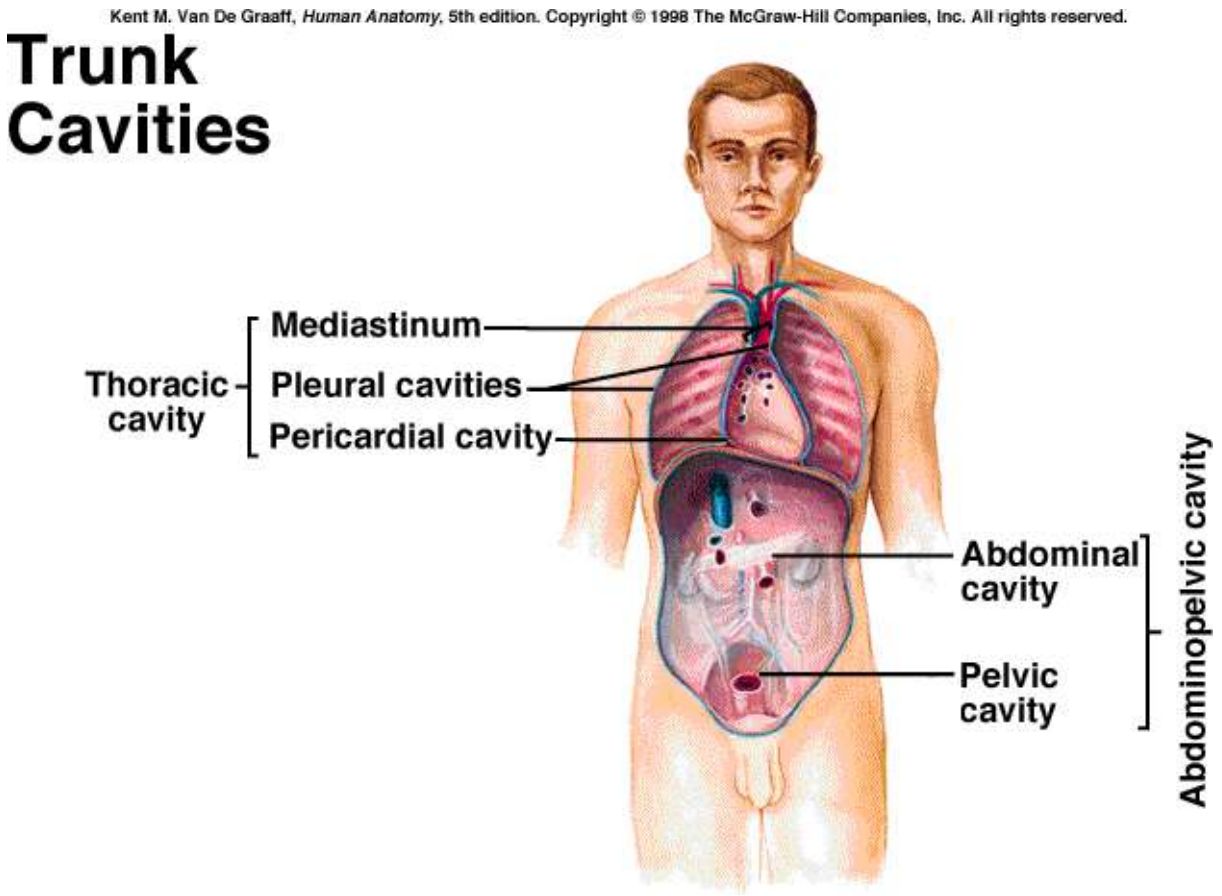


(a) Midsagittal view

(b) Coronal (frontal) view

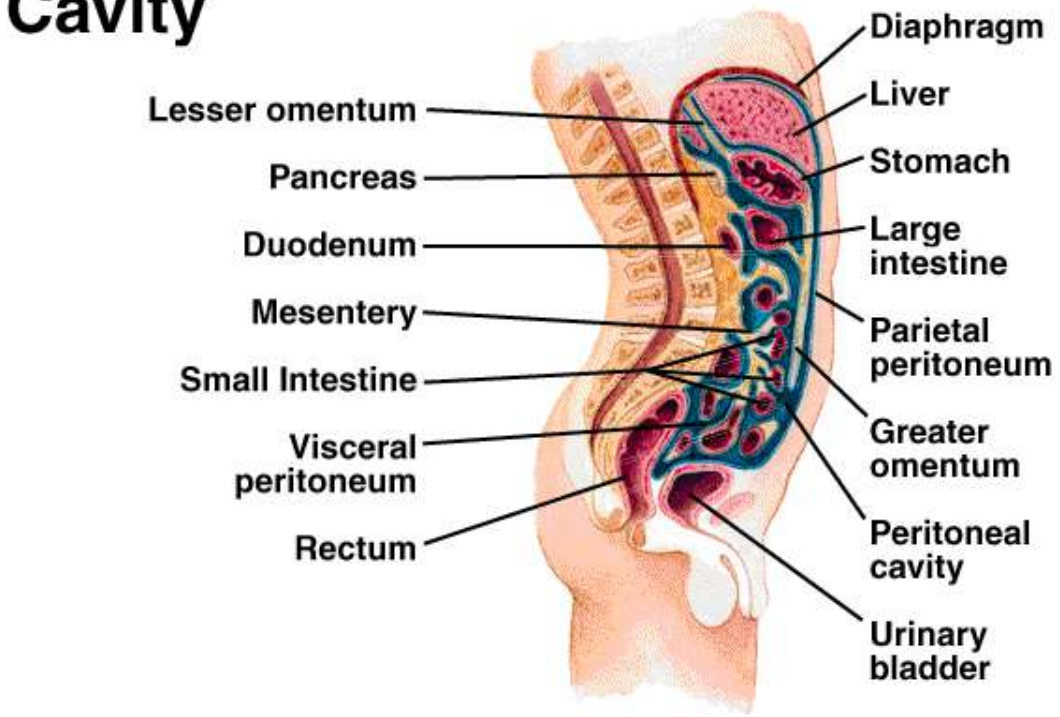
Thoracic Cavity

- The thoracic cavity is surrounded by the ribs and muscles of the chest
- It is further divided into
  - pleural cavities
  - mediastinum
  - pericardial

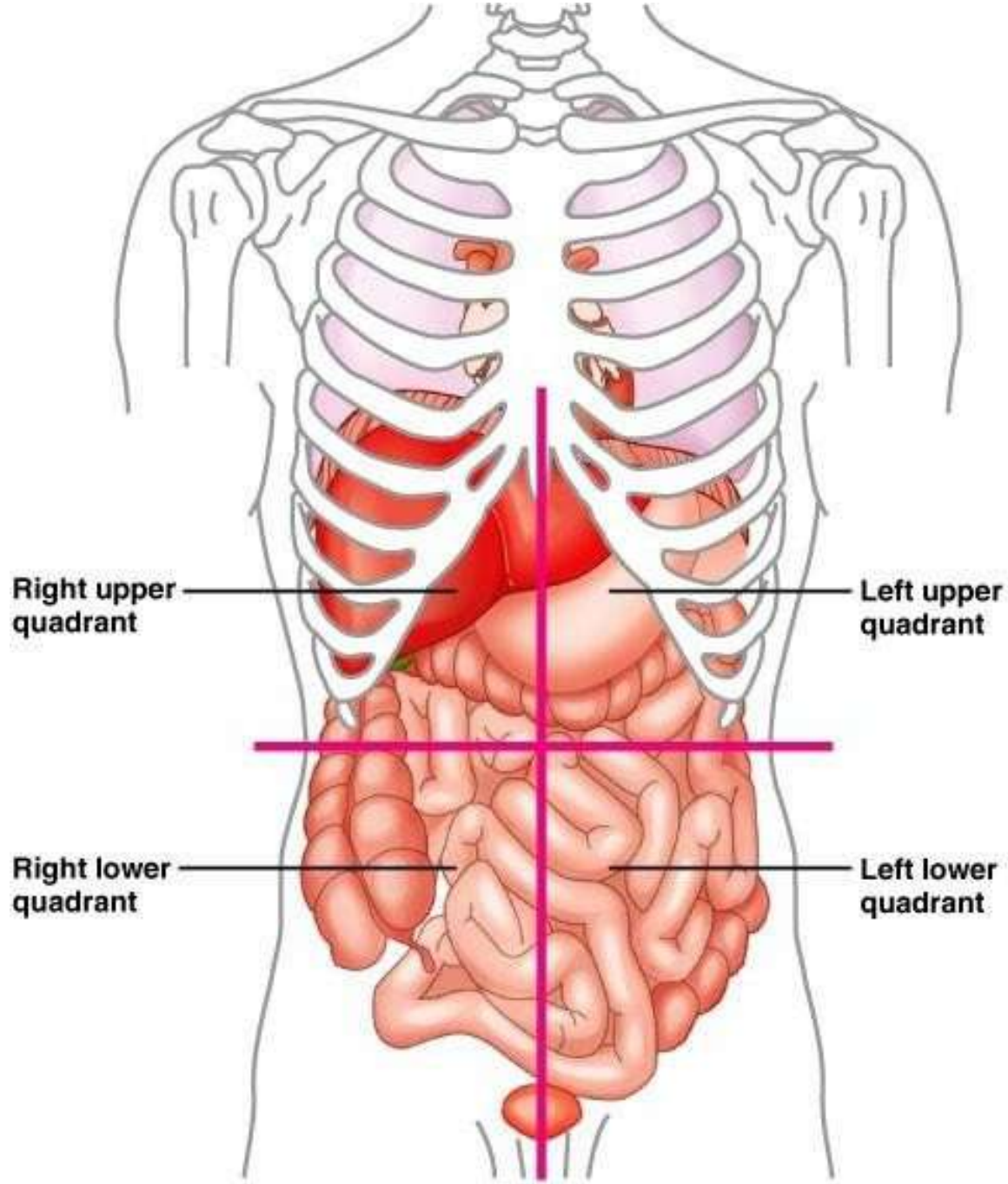


Abdominopelvic Cavity

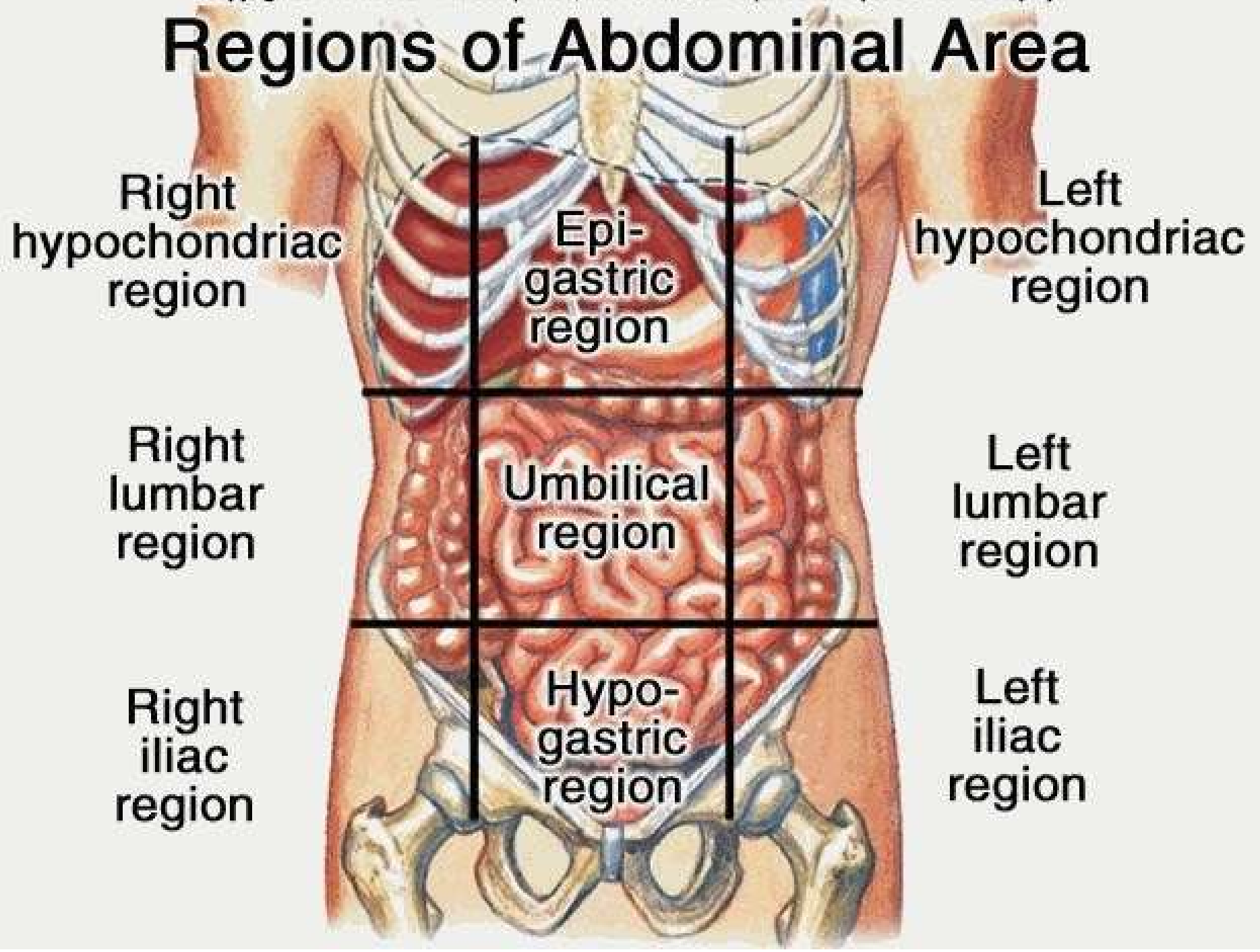
- Abdominopelvic cavity lies below the diaphragm
- It is further divided into . .
  - Abdominal cavity
    - Stomach, intestines, spleen, liver
  - Pelvic cavity
    - Bladder, rectum, and some reproductive organs



Abdominopelvic Quadrants and Regions

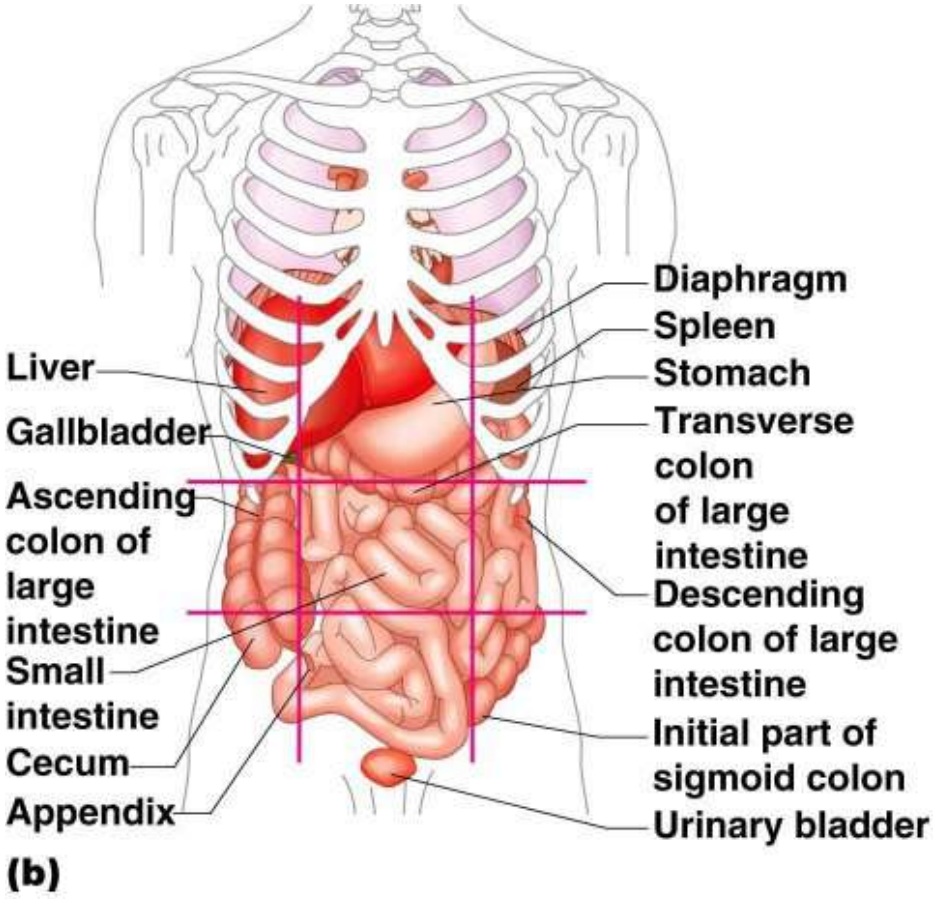


Regions of Abdominal Area



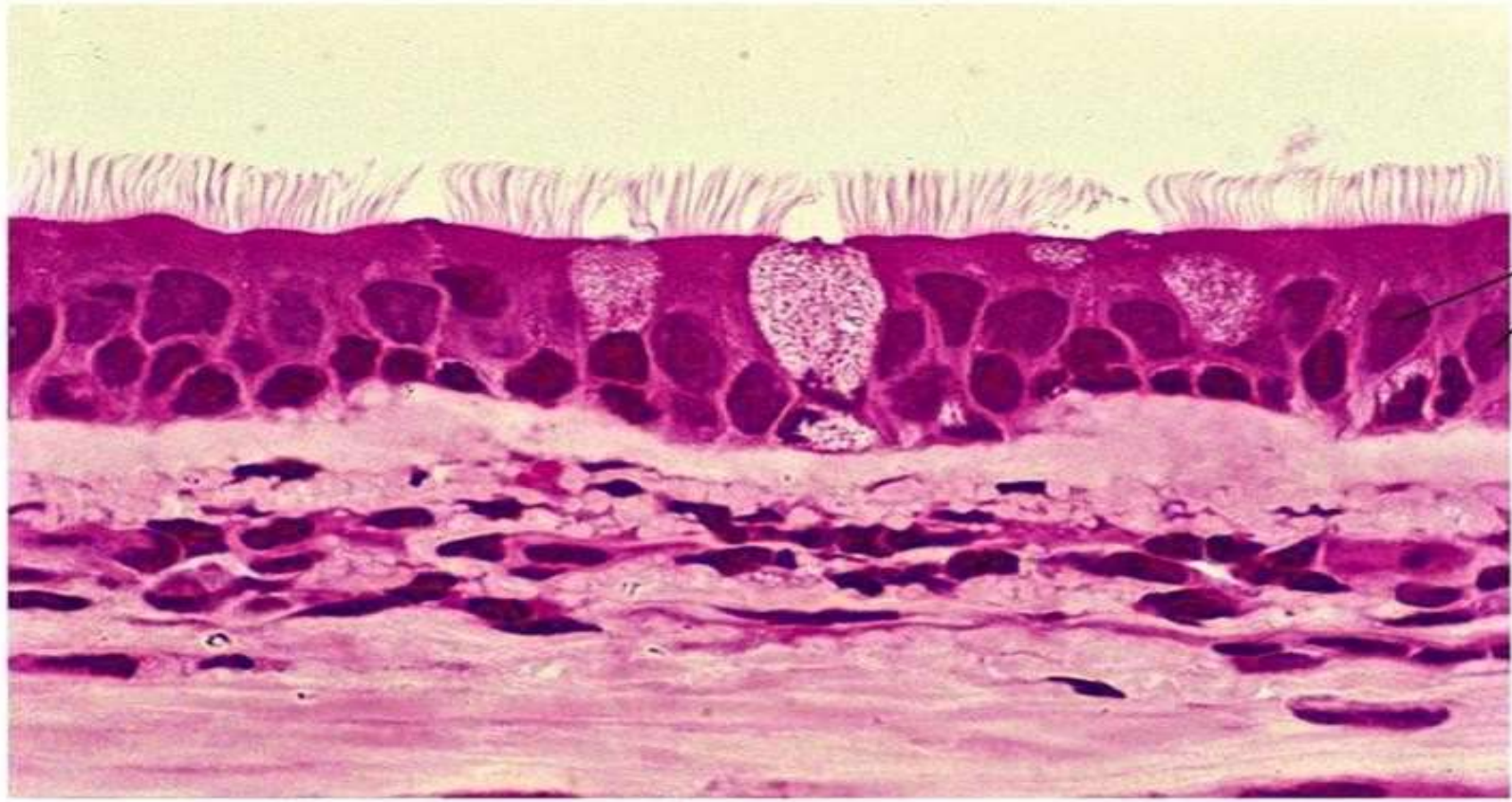
Abdominal Regions & Quadrants

- Using Your text to reference structures found within these regions

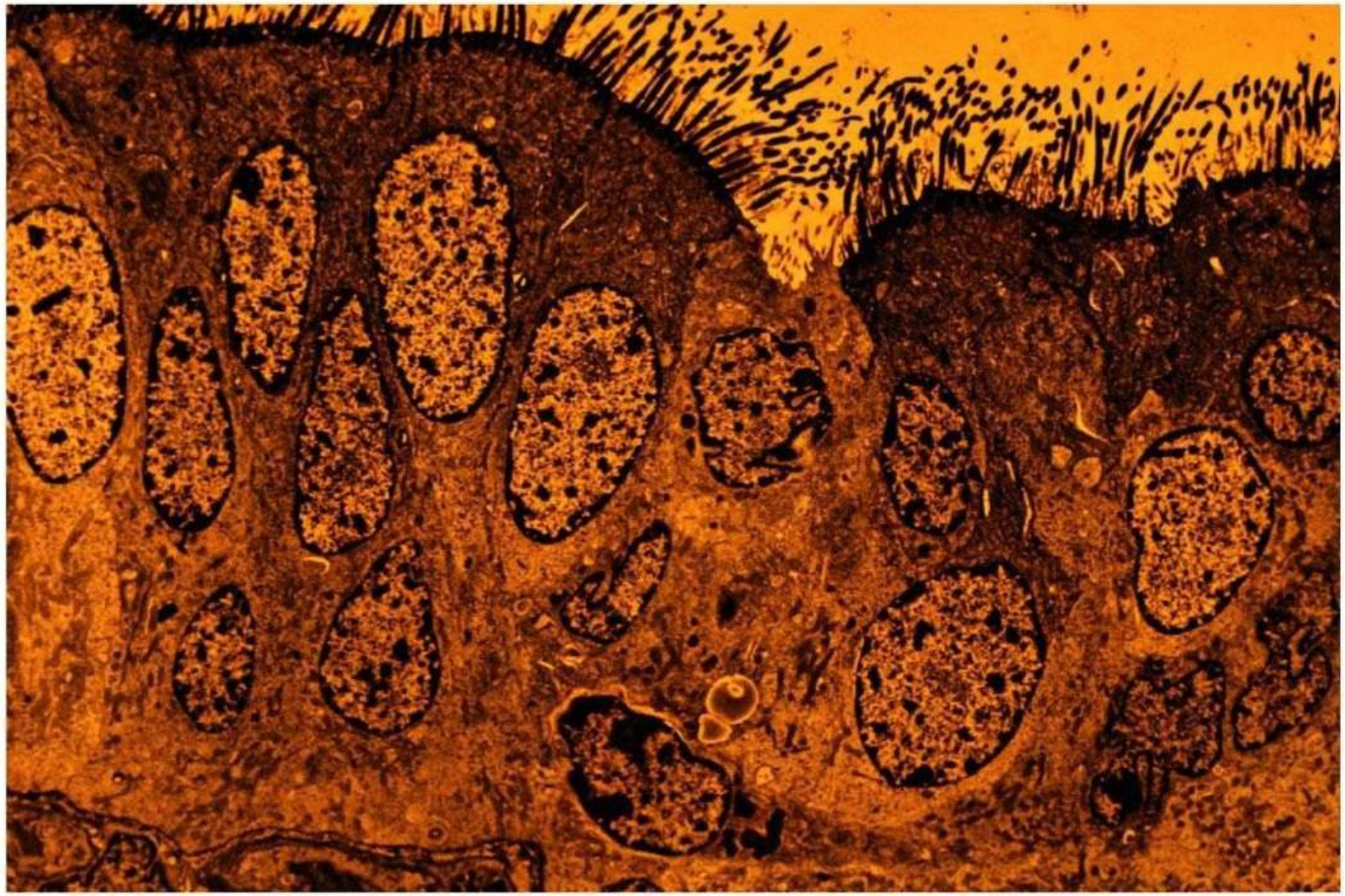


Advanced Imaging Systems

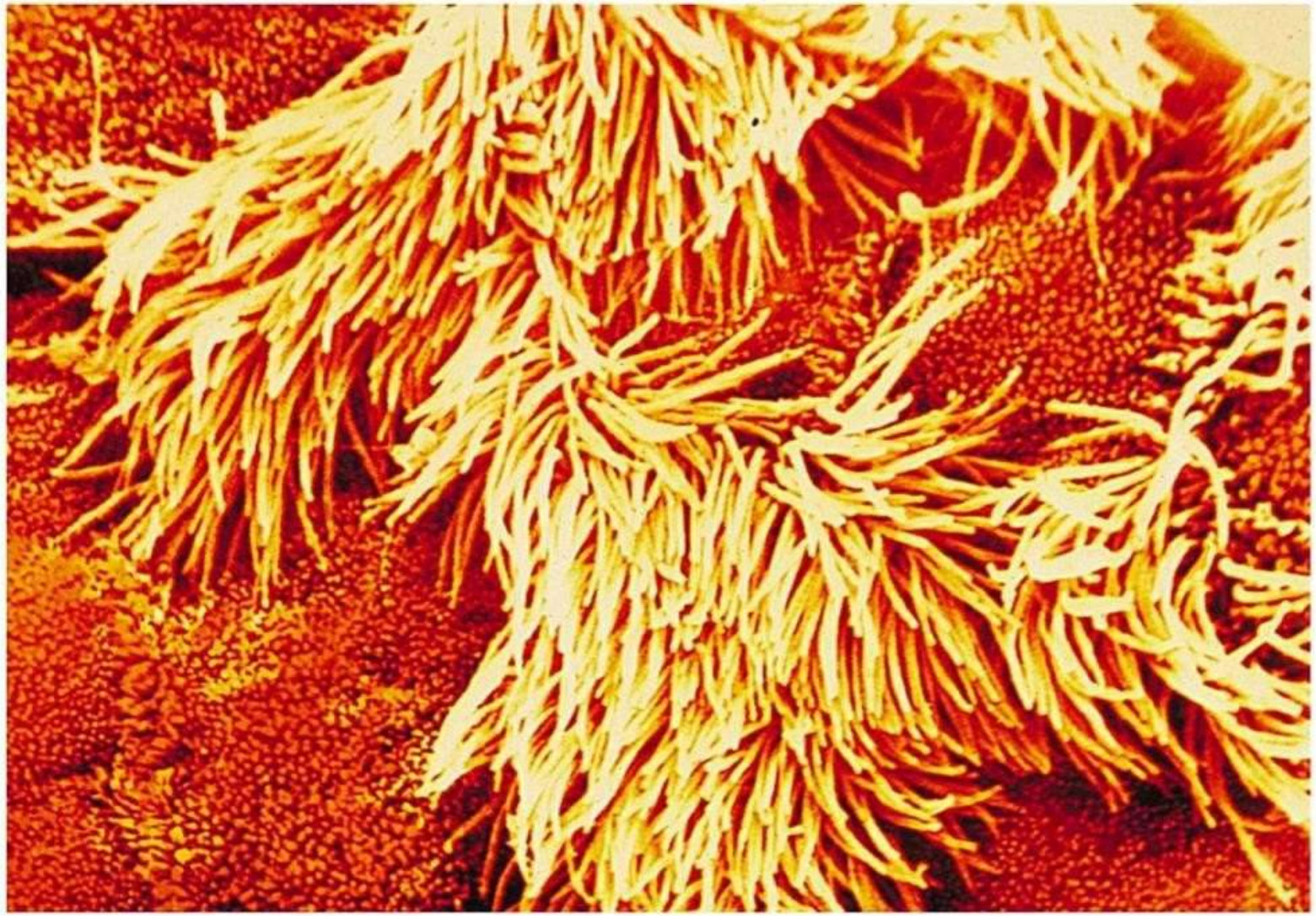
- Medical personnel now employ a variety of advanced imaging systems that allow for study of internal structures without disrupting tissue
- These systems are frequently utilized in clinical applications to examine for evidence of disease



(a) Light micrograph

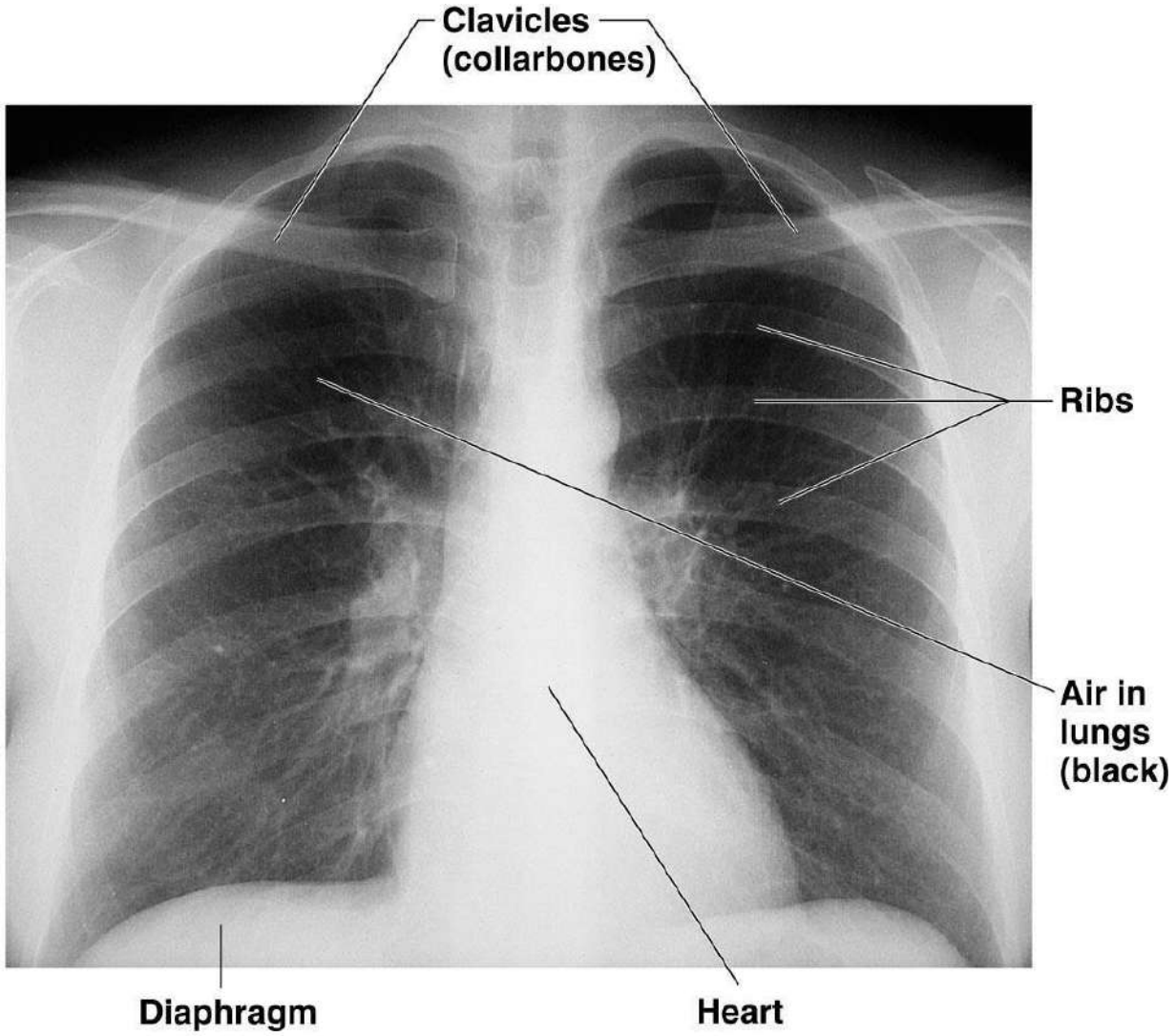


(b) Transmission electron micrograph

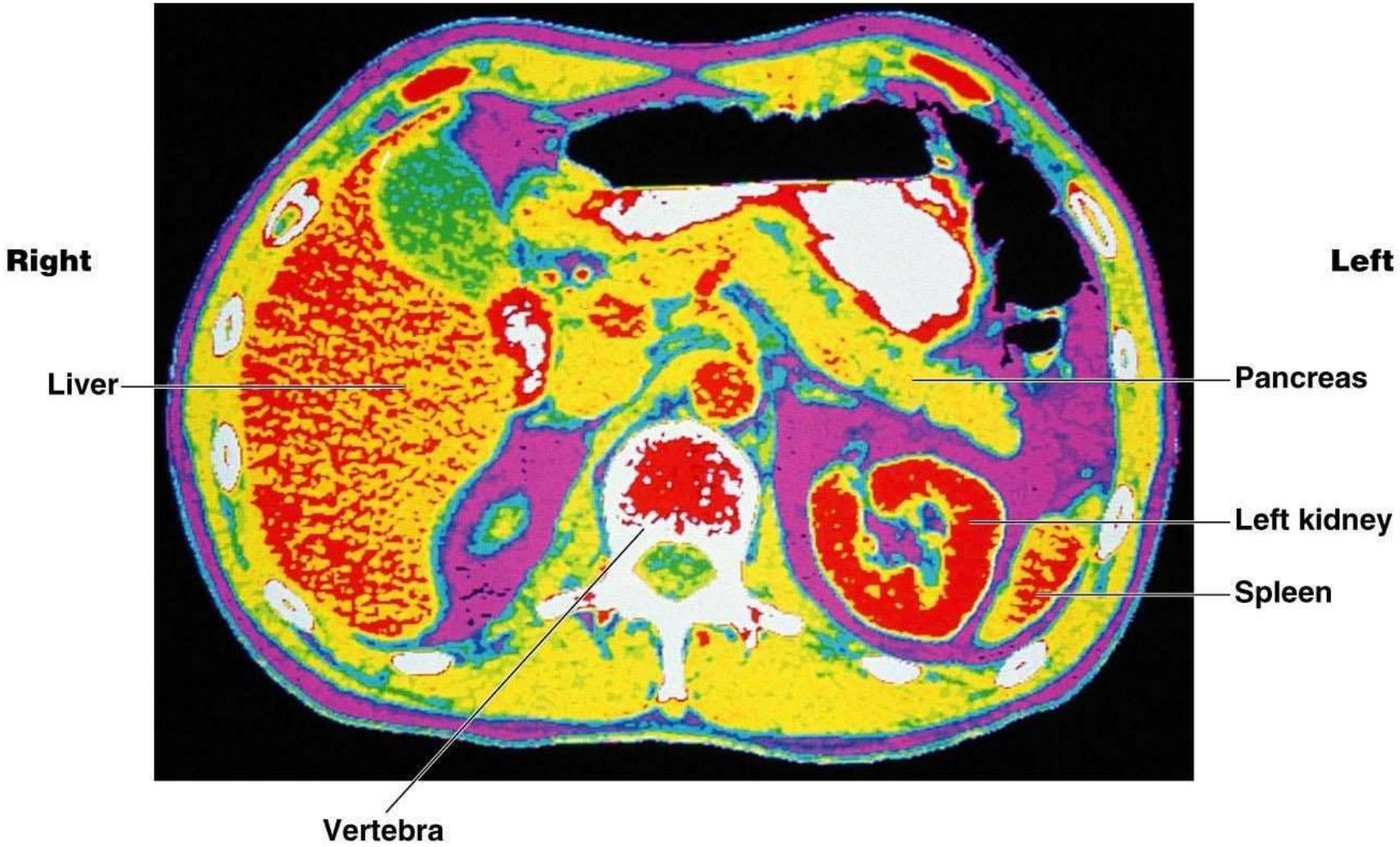


(c) Scanning electron micrograph

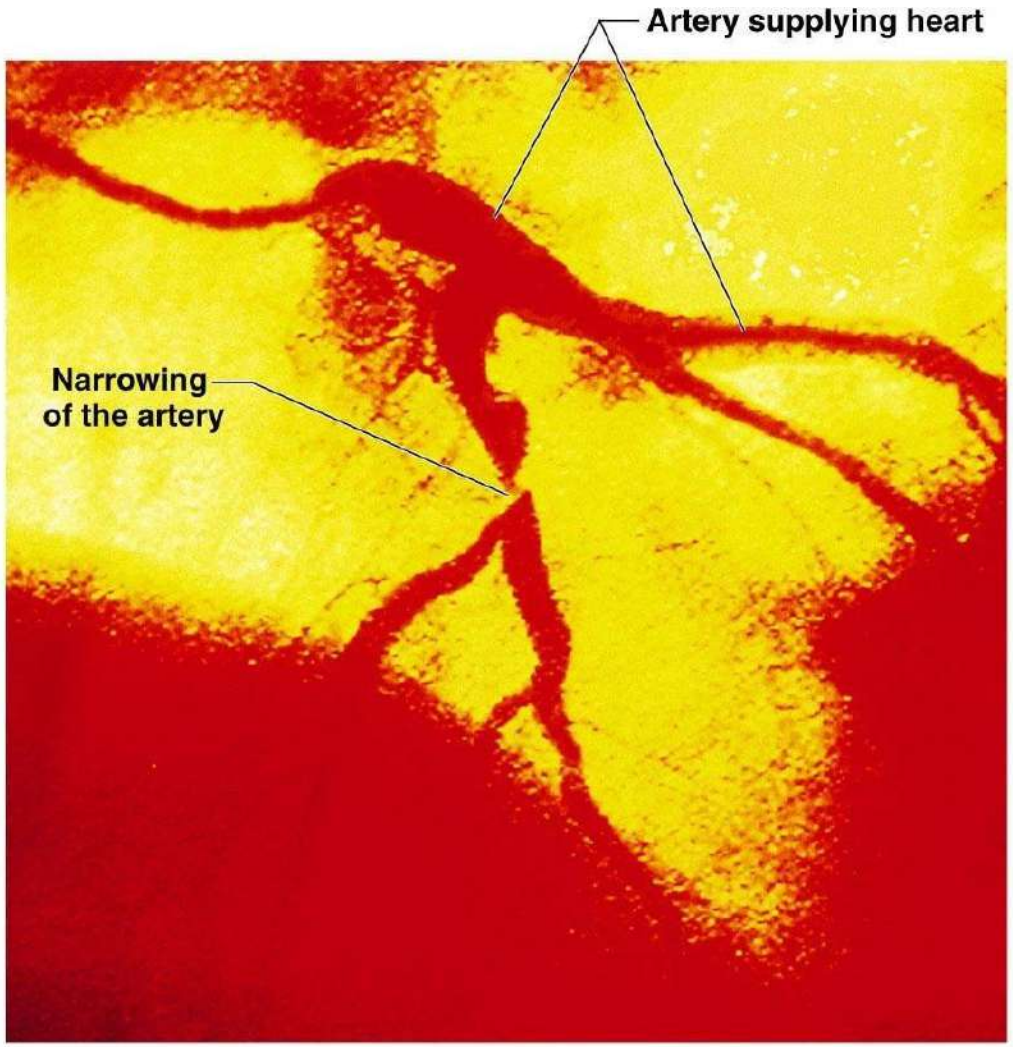
X-ray



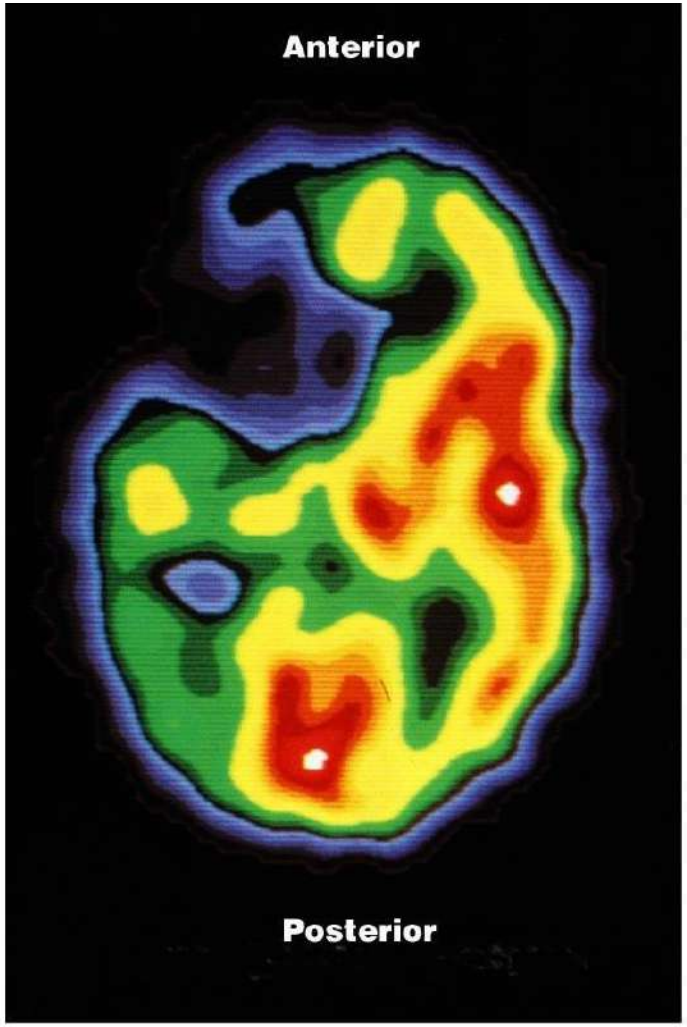
Computerized Tomograph



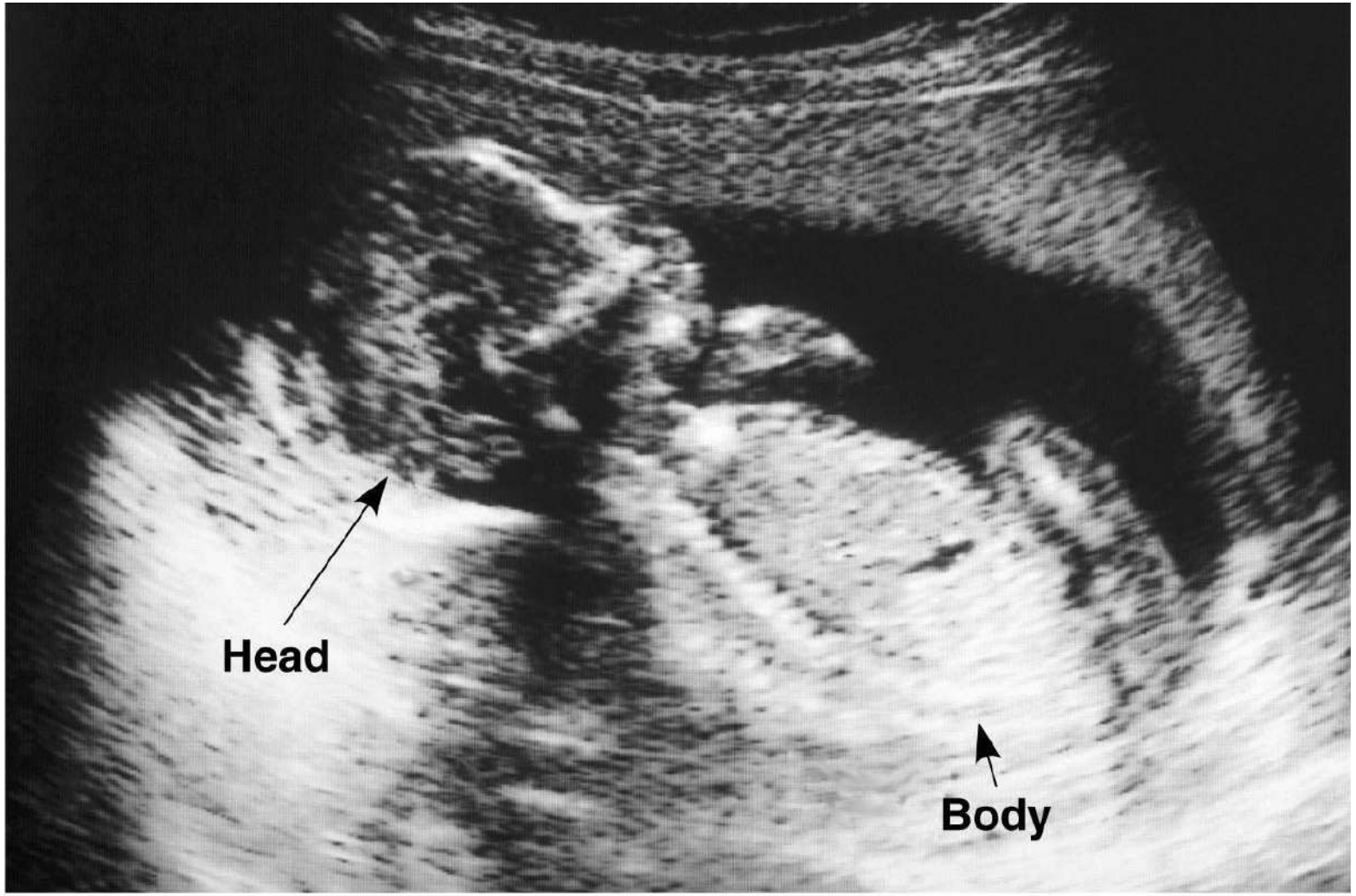
Digital Subtraction Angiography



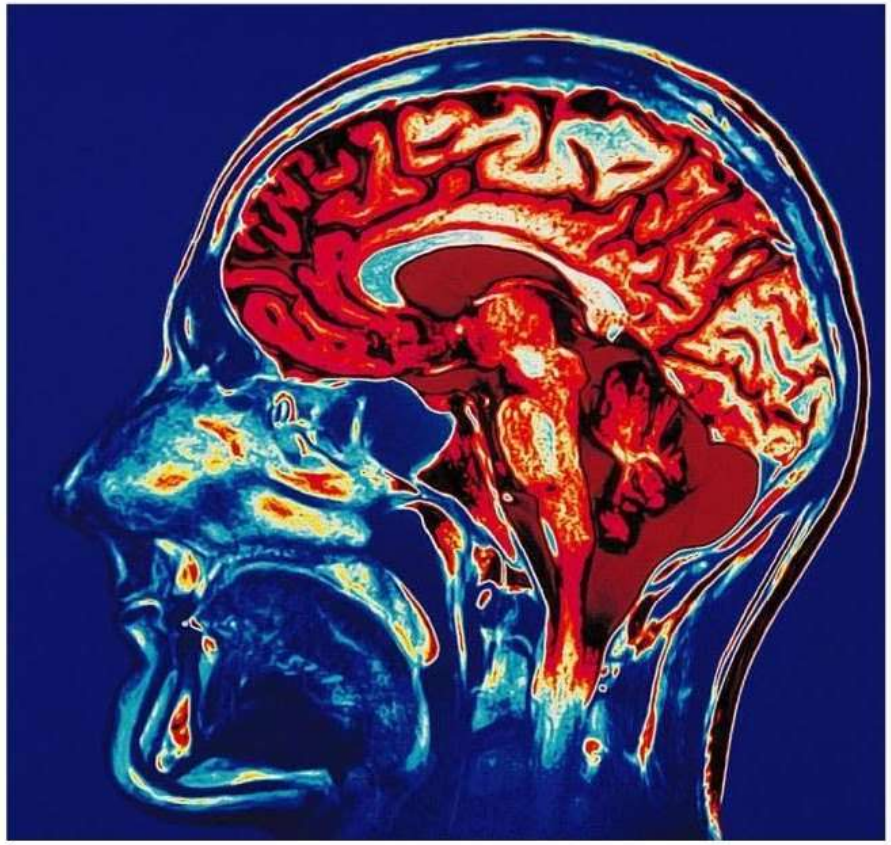
Positron Emission Tomogrphy



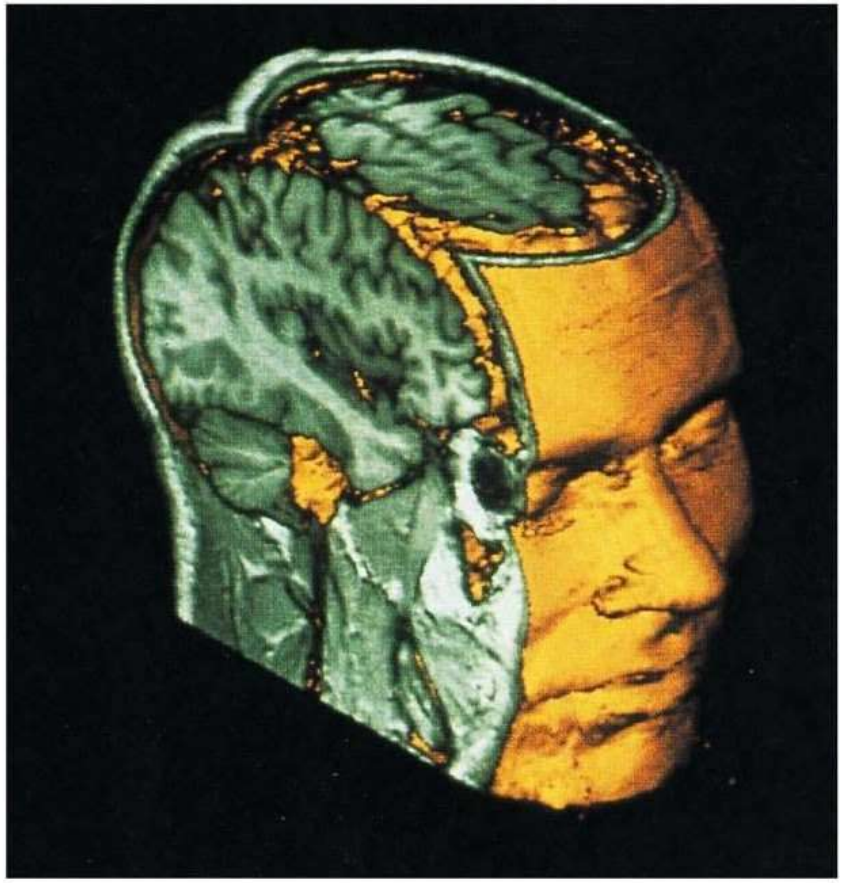
Sonography



MRI

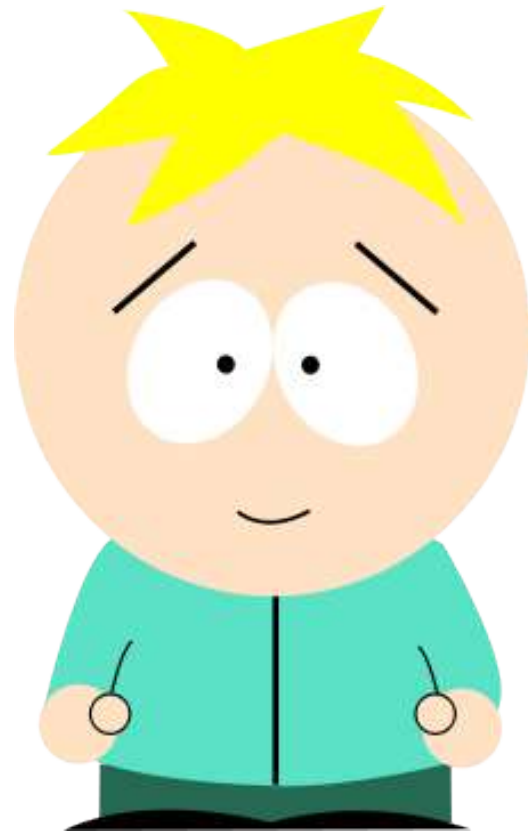


(a)



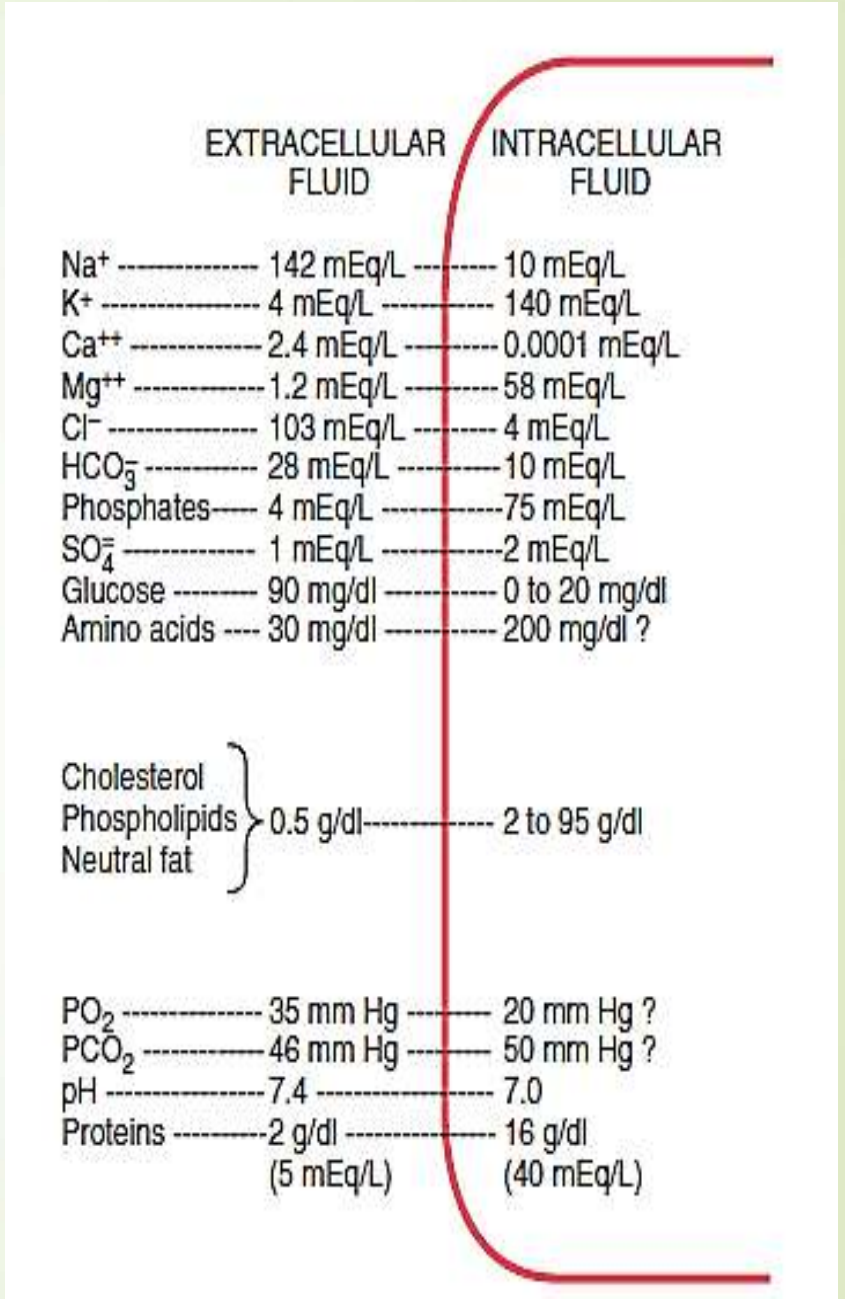
(b)

Thank you



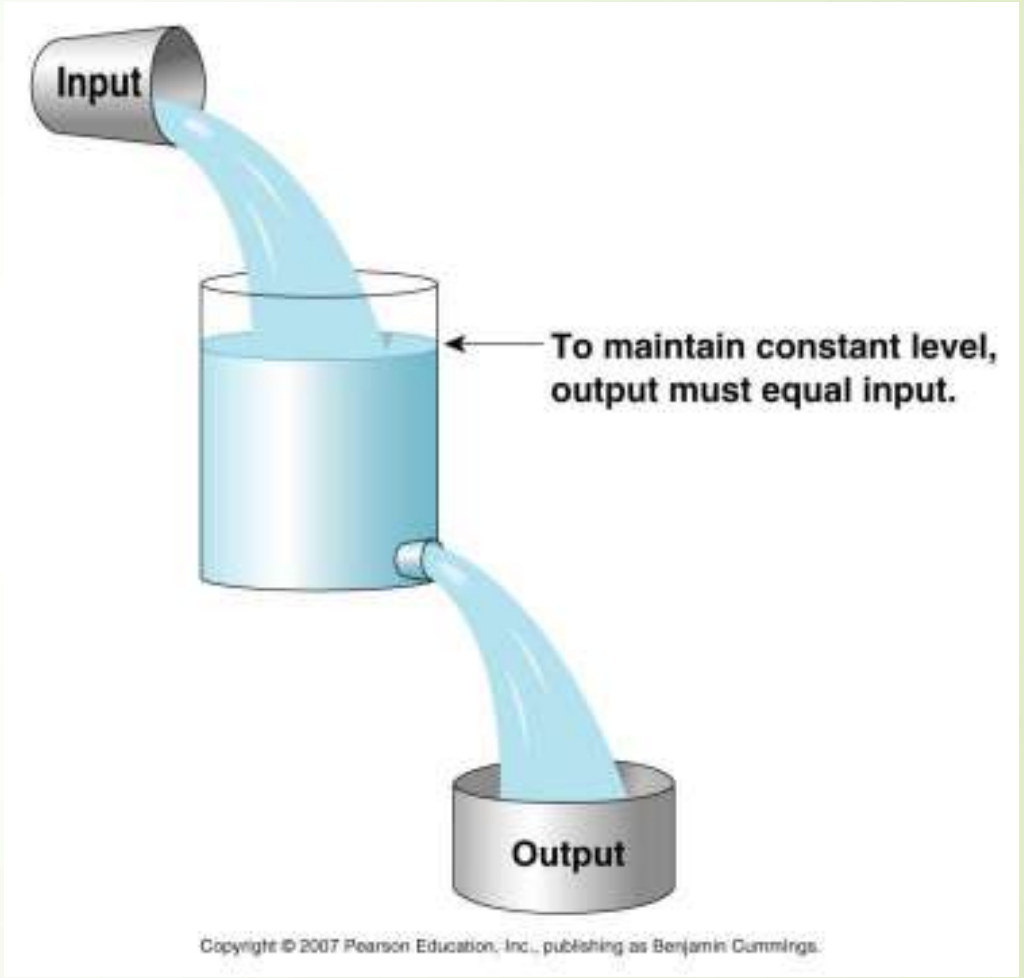
Transport of Substances Through Cell Membranes

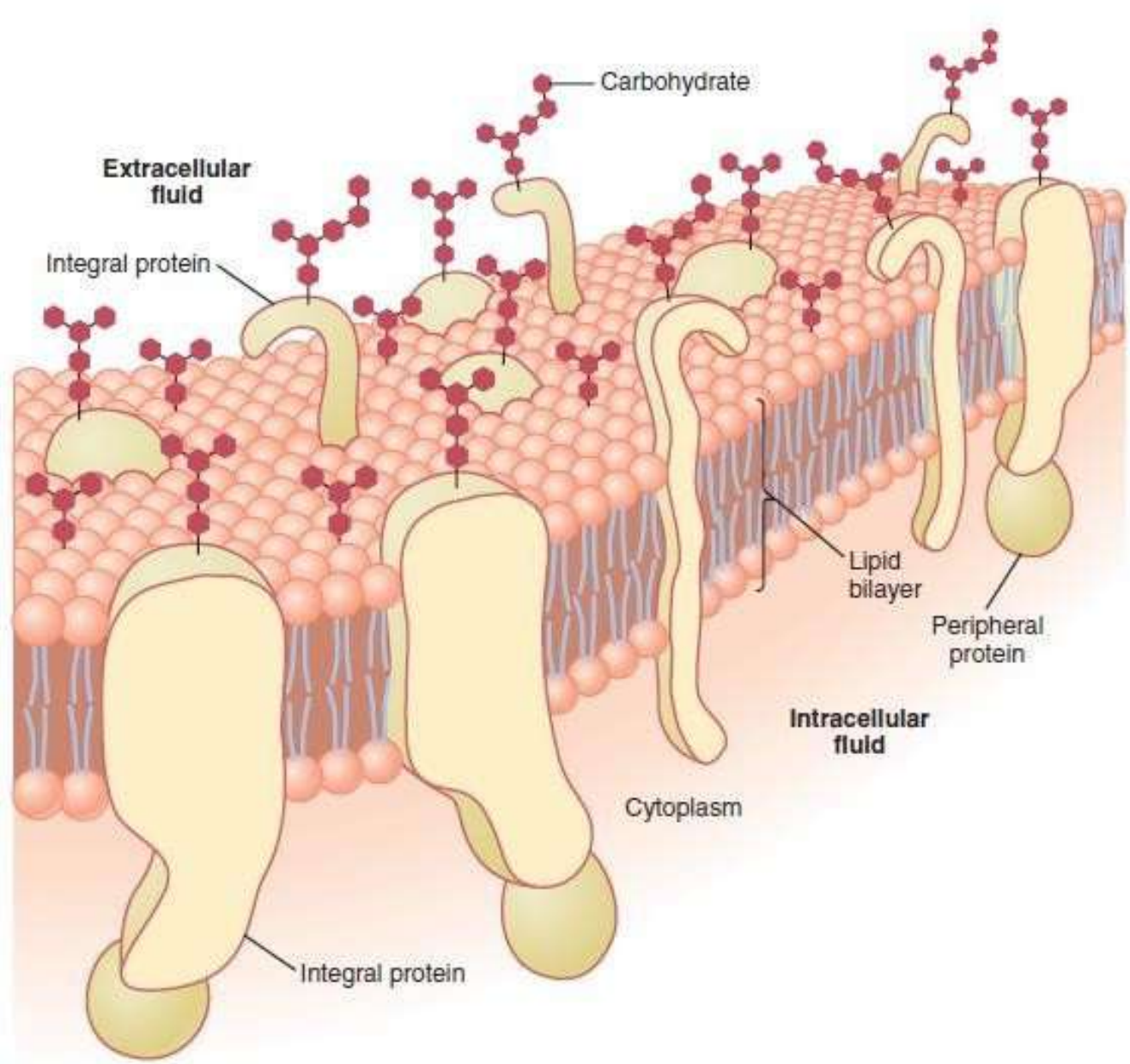
- Figure1. chemical compositions of extracellular and intracellular fluids.
- The question mark indicates that precise values for intracellular fluid are unknown.
- The red line indicates the cell membrane



Law of Mass Balance

- Most simply, ins = outs
- Homeostasis is not the same as equilibrium
  - E.g., membrane potentials





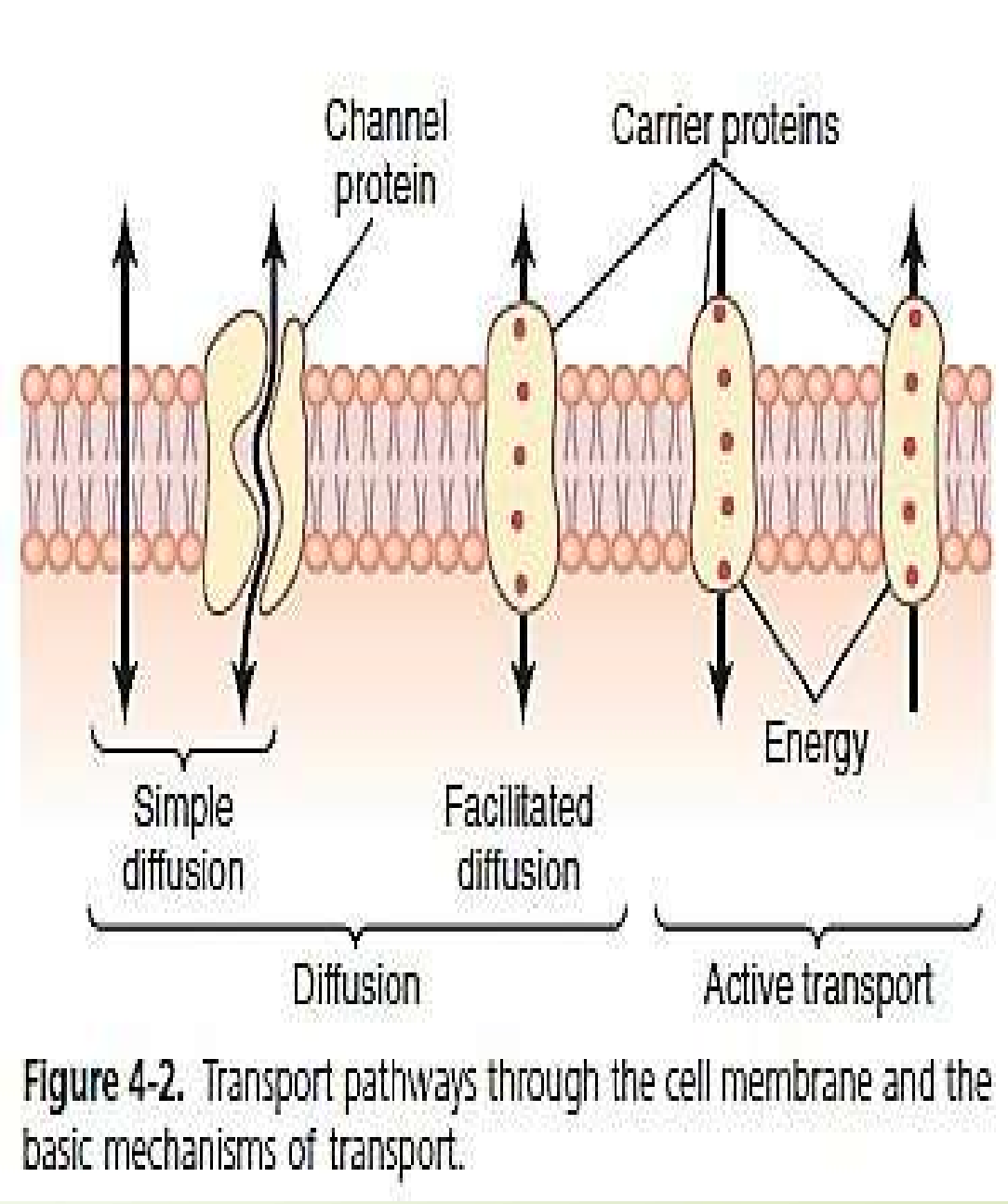


Figure 4-2. Transport pathways through the cell membrane and the basic mechanisms of transport.

Membrane Dynamics

- Cell membrane structures and functions
- Membranes form fluid body compartments
- Membranes as barriers and gatekeepers
- How products move across membranes
- i.e., methods of transport
- Distribution of water and solutes in cells & the body
- Chemical and electrical imbalances
- Membrane permeability and changes

Cell Membrane

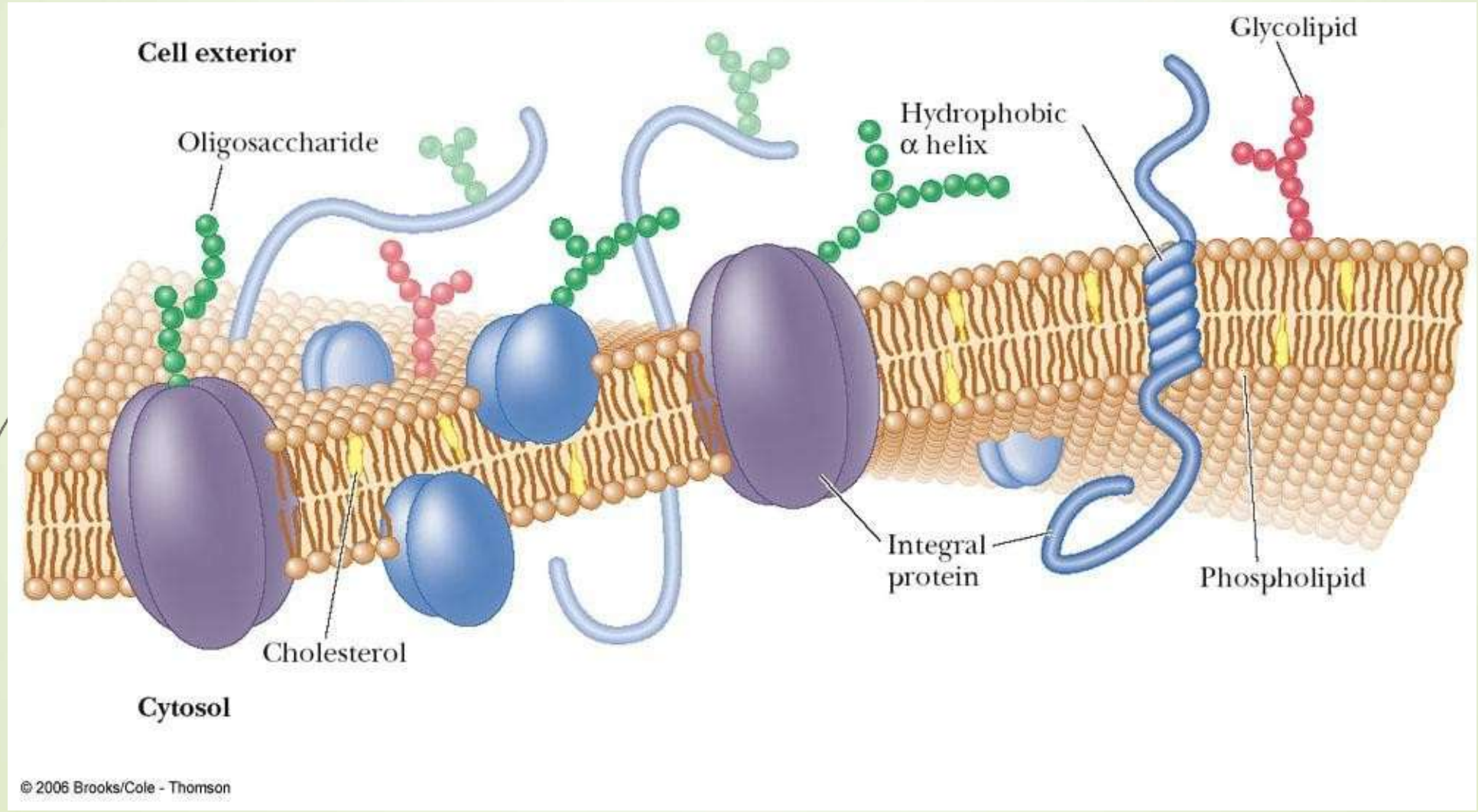
The cell membrane (also called the plasma membrane) envelops the cell and is a thin, pliable, elastic structure only 7.5 to 10 nanometers thick.

It is composed almost entirely of proteins and lipids. The approximate composition is :

1. proteins, 55 percent;
2. phospholipids, 25 percent;
3. cholesterol, 13 percent;
4. other lipids, 4 percent; and
5. carbohydrates, 3 percent.

Biological membranes

Lipids and proteins are associated in biological membranes.



Membrane Structure: Protein to Lipid Ratio varies from cell type to cell type

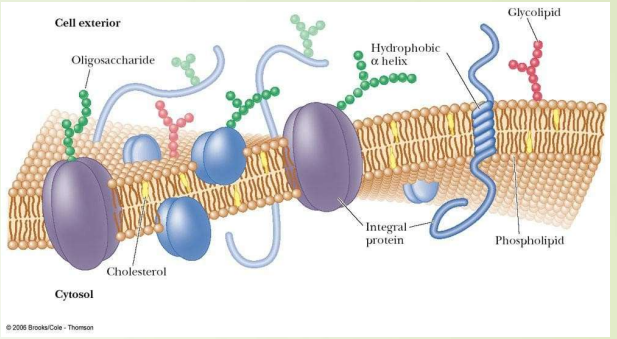
Table 5-1: Composition of Selected Membranes

MEMBRANE	PROTEIN	LIPID	CARBOHYDRATE
Red blood cell membrane	49%	43%	8%
Myelin membrane around nerve cells	18%	79%	3%
Inner mitochondrial membrane	76%	24%	0%

Ratio for cells with high metabolic activity?

Biological membranes

What is the fluid mosaic model of membrane structure?



Fluid mosaic model is the most widely accepted description of biological membranes.

√ The term mosaic implies that the two components exist side by side without forming some other substance of intermediate nature.

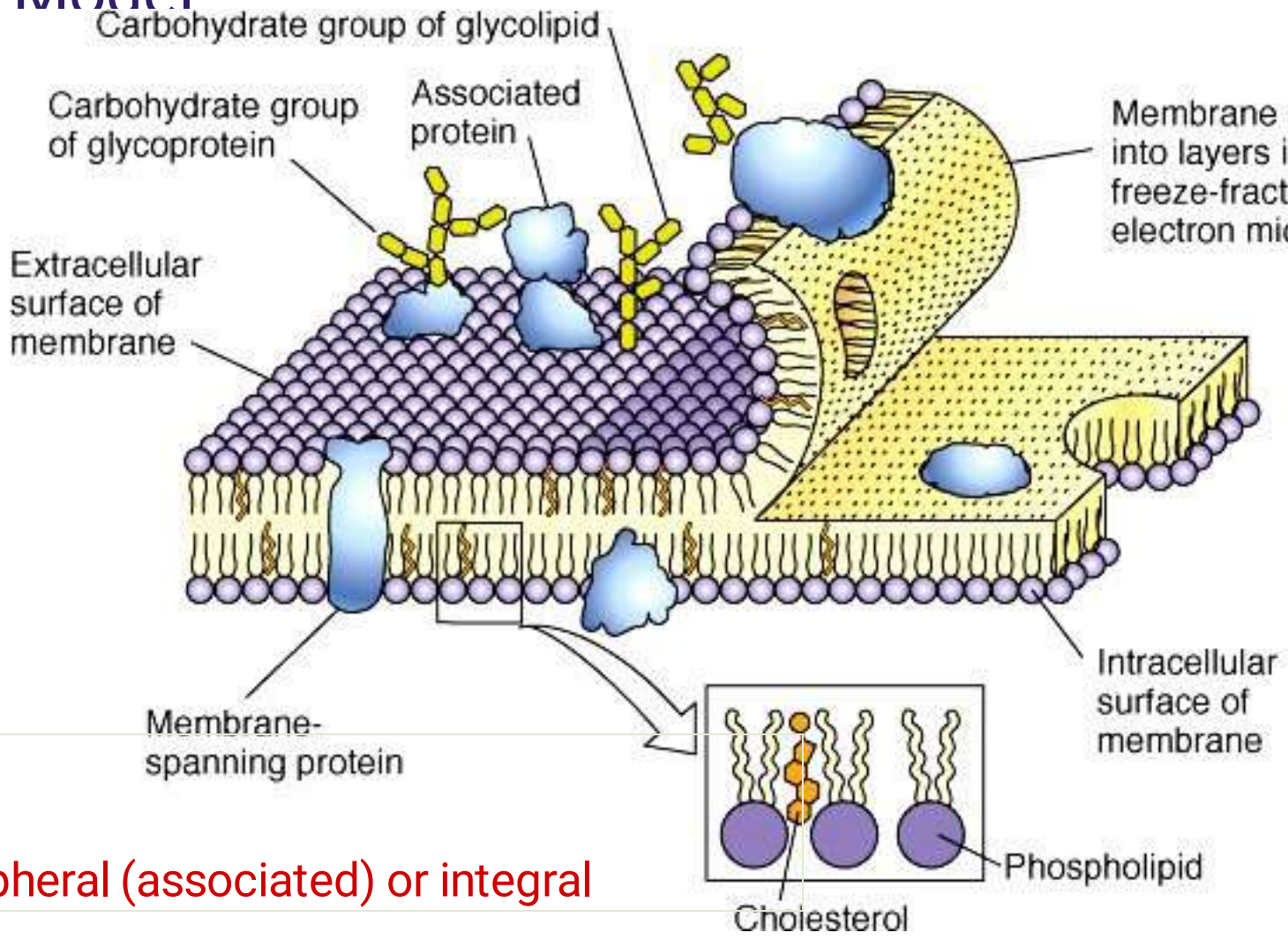
√ The basic structure of biological membranes is that of the lipid bilayers, with the proteins embedded in the bilayer structure.

√ Fluid-mosaic model of membrane structure;

- Membrane proteins can be seen embedded in the lipid bilayer
- proteins float in the lipid bilayer and can move alone the plane of the membrane.

Like iceberg in the sea of lipid

Cell Membrane Structure: Fluid Mosaic Model



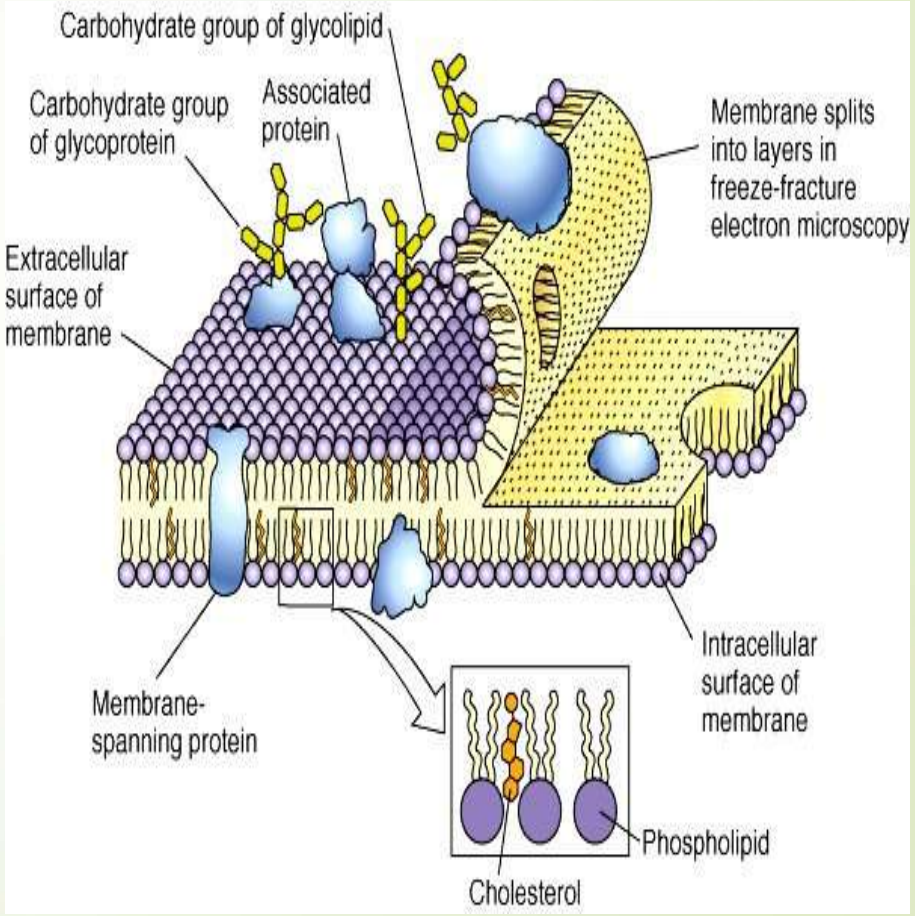
Thickness ~ 8nm

PLs Cholesterol

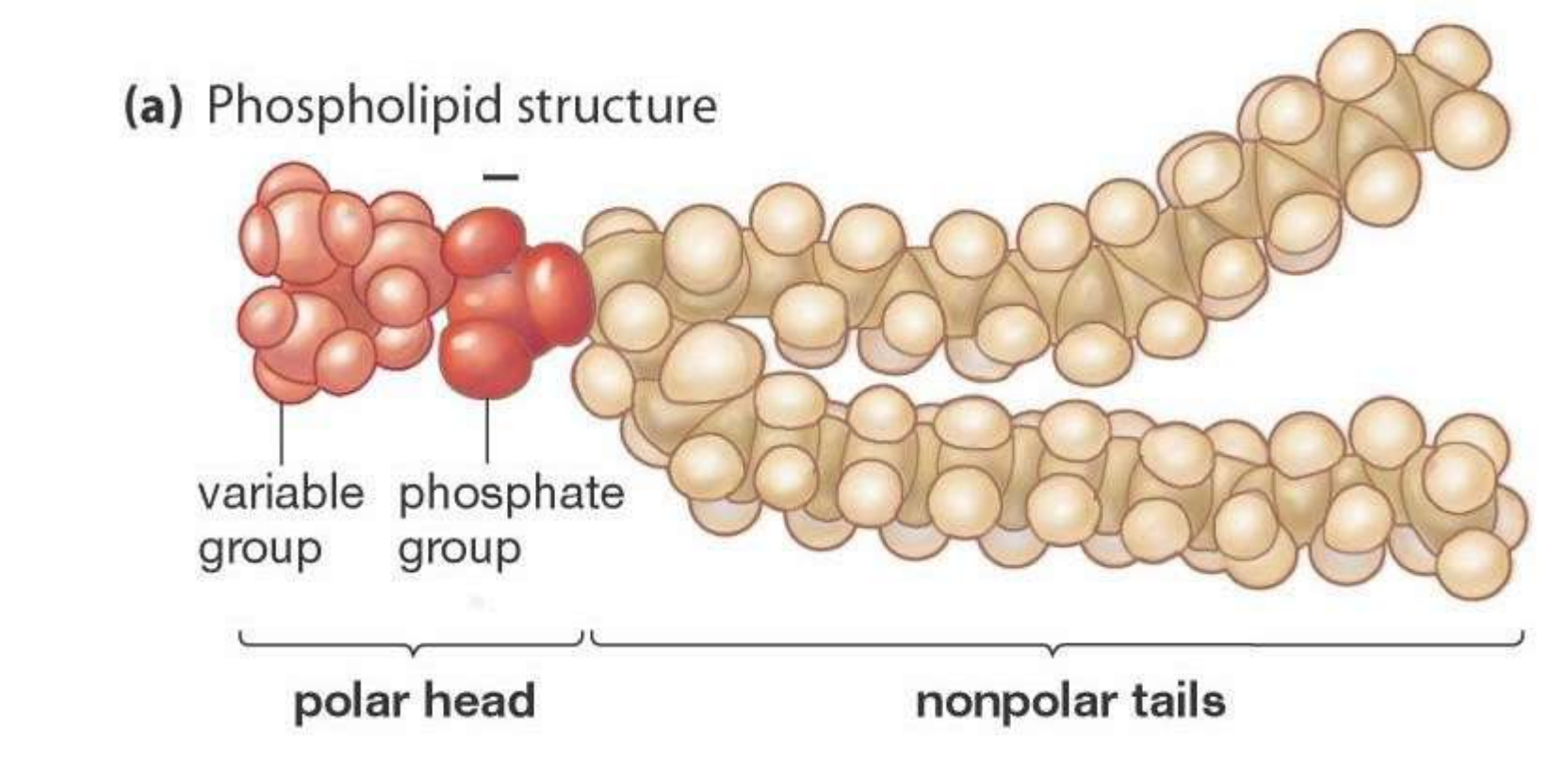
Proteins: peripheral (associated) or integral

The Cell Membrane Lipid Barrier Impedes Penetration by Water-Soluble Substances.

- The basic lipid bilayer is composed of three main types of lipids: phospholipids, sphingolipids, and cholesterol.
- Phospholipids are the most abundant of the cell membrane lipids.
- One end of each phospholipid molecule is soluble in water; that is, it is hydrophilic.
- The other end is soluble only in fats; that is, it is hydrophobic.
- The phosphate end of the phospholipid is hydrophilic, and the fatty acid portion is hydrophobic.



Phospholipids are Building Blocks of Cellular Membranes



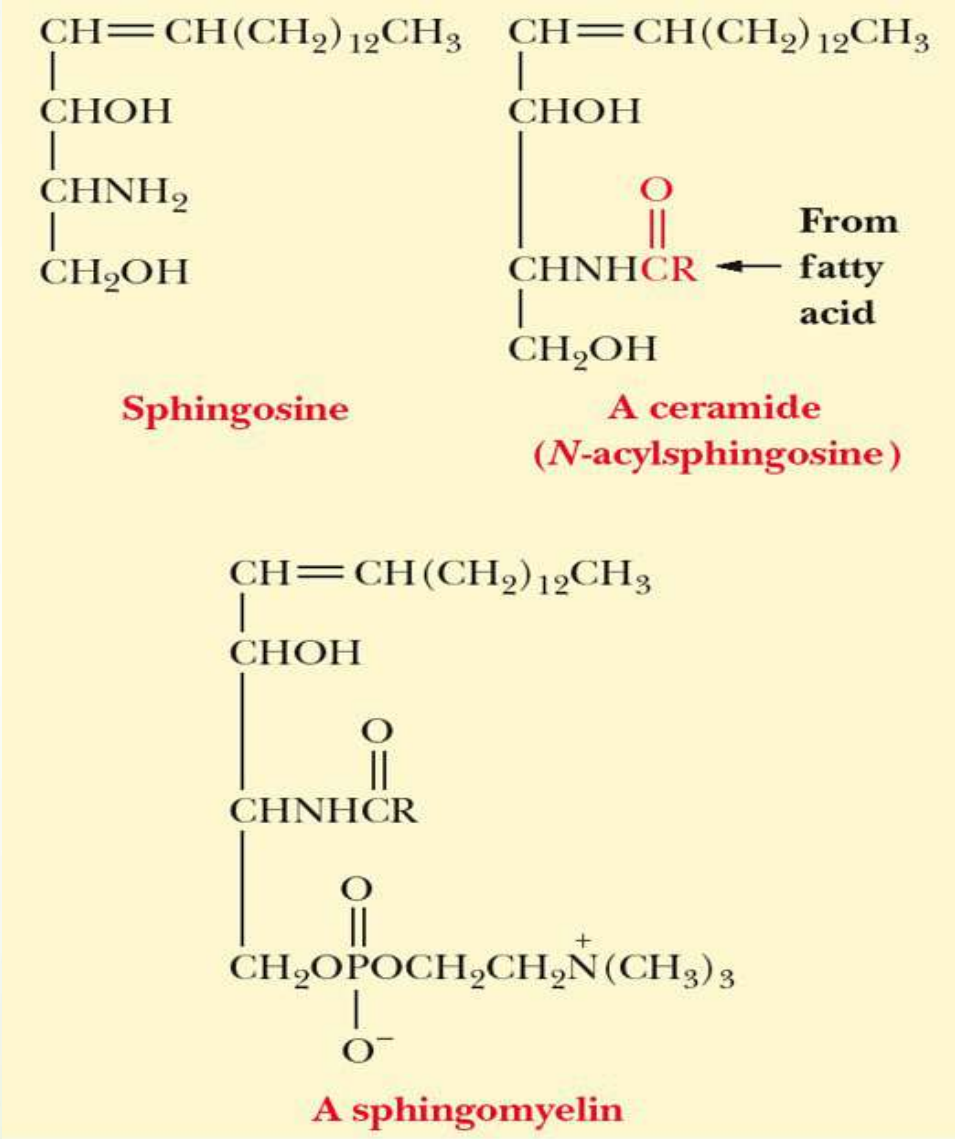
The hydrophilic head group and hydrophobic tails are the keys to phospholipid function.

The Cell Membrane Lipid Barrier Impedes Penetration by Water-Soluble Substances.

- Sphingolipids: Do not contain glycerol, but they contain the long-chain amino alcohol sphingosine.

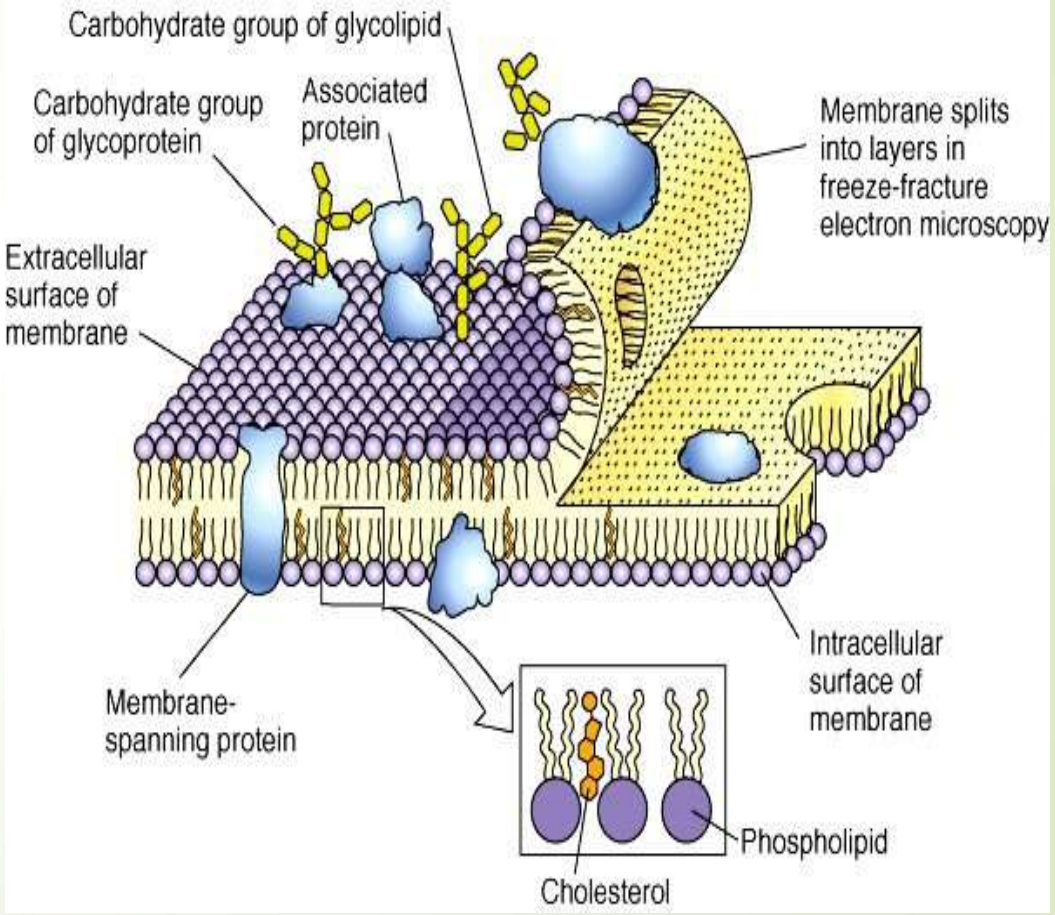
- Found in both animal and plants
- They are particularly abundant in the nervous system.

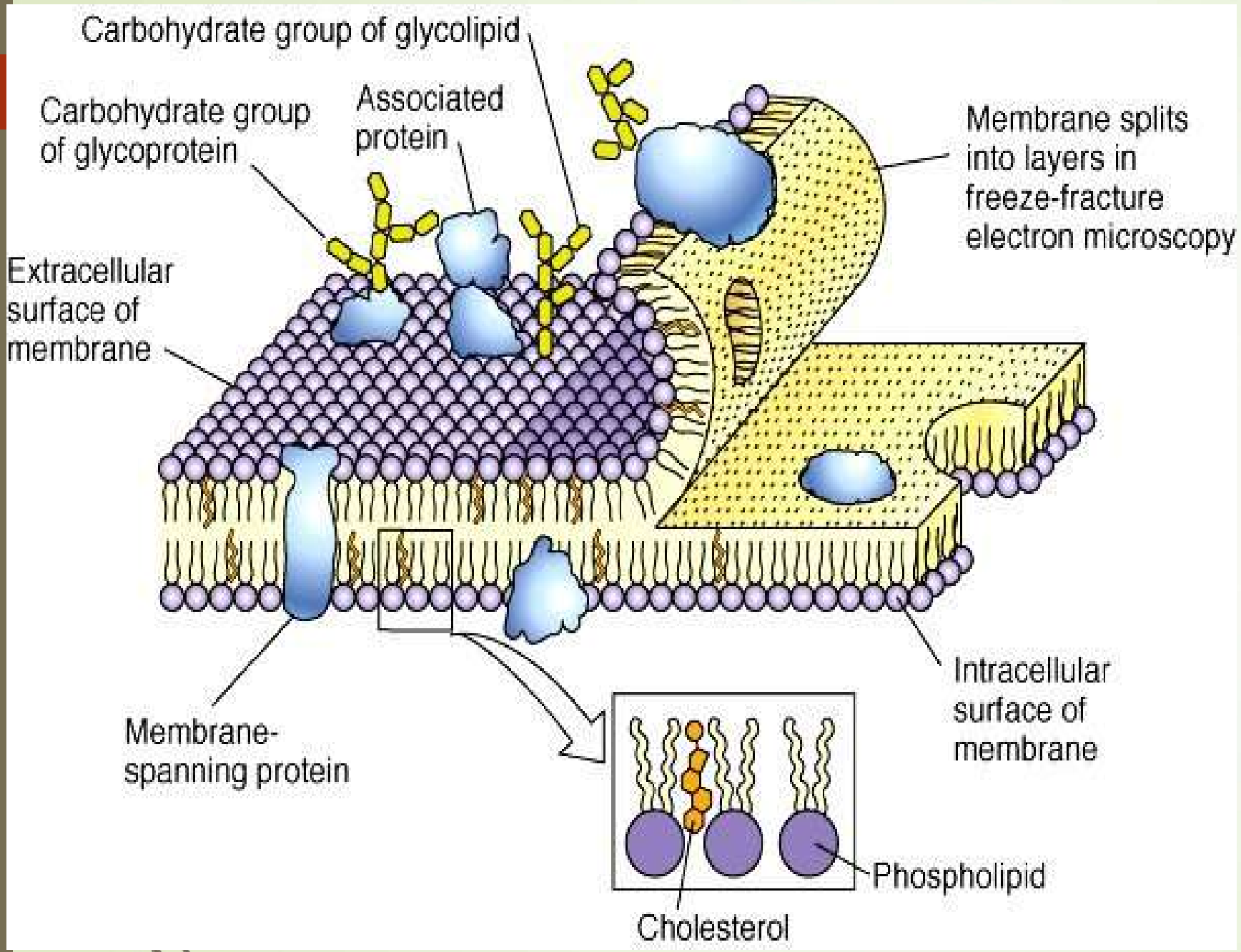
- The simplest compound of this class are ceramides, which consists of one fatty acid linked to the amino group of sphingosine by an amide bond.

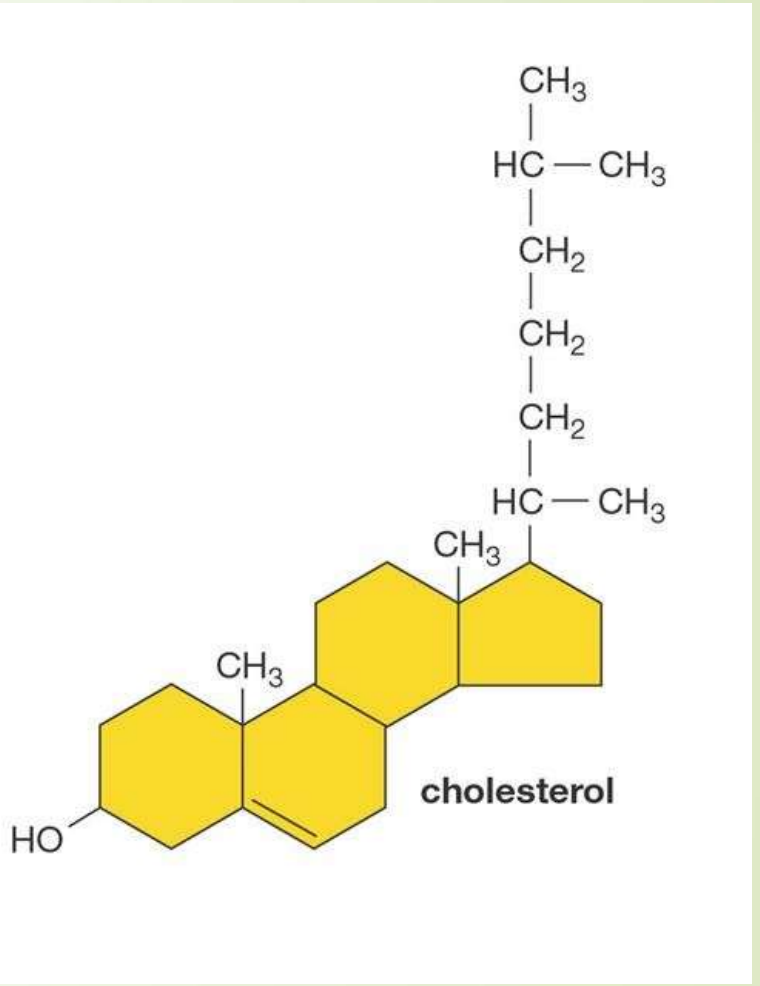


The Cell Membrane Lipid Barrier Impedes Penetration by Water-Soluble Substances.

- The cholesterol molecules in the membrane are also lipids because their steroid nuclei are highly fat soluble.
- These molecules, in a sense, are dissolved in the bilayer of the membrane.
- They mainly help determine the degree of permeability (or impermeability) of the bilayer to water-soluble constituents of body fluids.
- Cholesterol controls much of the fluidity of the membrane as well.

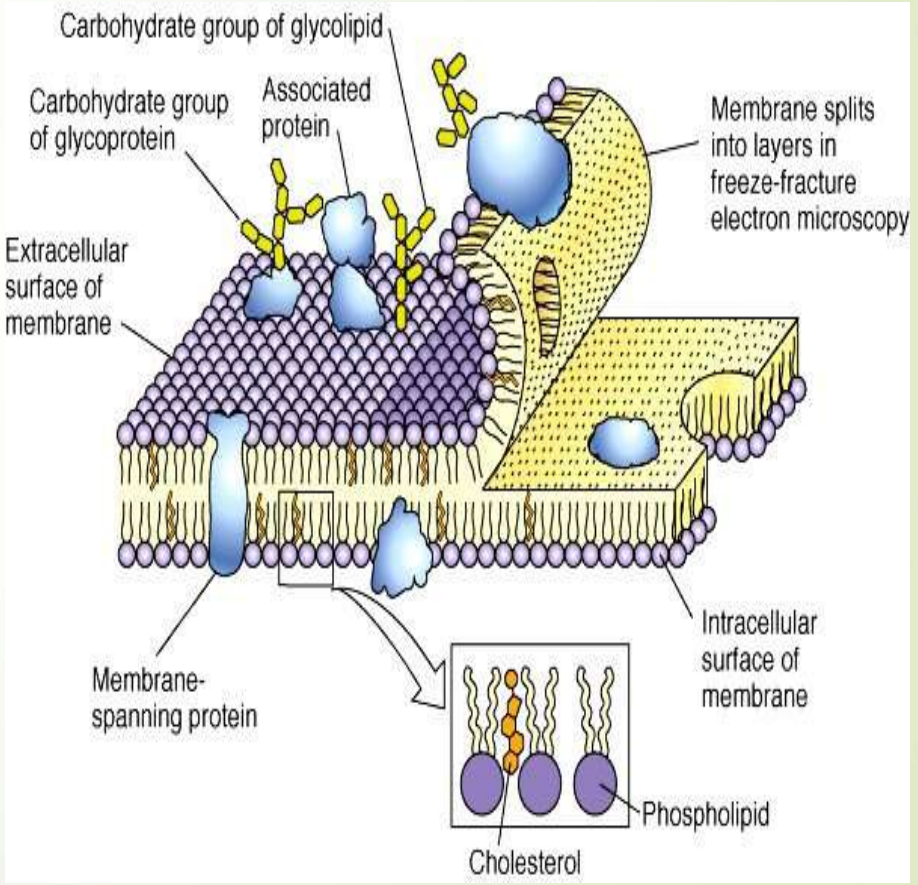



Carbohydrate group of glycolipid
Carbohydrate group of glycoprotein
Associated protein
Membrane splits into layers in freeze-fracture electron microscopy
Extracellular surface of membrane
Membrane-spanning protein
Intracellular surface of membrane
Phospholipid
Cholesterol


CH3
HC — CH3
CH2
CH2
CH2
HC — CH3
CH3
CH3
HO
cholesterol

Membrane Carbohydrates—The Cell "Glycocalyx."

- Membrane carbohydrates occur almost invariably in combination with proteins or lipids in the form of glycoproteins or glycolipids.
- In fact, most of the integral proteins are glycoproteins, and about one tenth of the membrane lipid molecules are glycolipids.
- The "glyco" portions of these molecules almost invariably protrude to the outside of the cell, dangling outward from the cell surface.



Membrane Carbohydrates—The Cell "Glycocalyx."

The carbohydrate moieties attached to the outer surface of the cell have several important functions:

1. Many of them have a negative electrical charge, which gives most cells an overall negative surface charge that repels other negatively charged objects.
2. The glycocalyx of some cells attaches to the glycocalyx of other cells, thus attaching cells to one another.
3. Many of the carbohydrates act as receptor substances for binding hormones, such as insulin; when bound, this combination activates attached internal proteins that, in turn, activate a cascade of intracellular enzymes.
4. Some carbohydrate moieties enter into immune reactions

The Cell Membrane Lipid Barrier Impedes Penetration by Water-Soluble Substances.

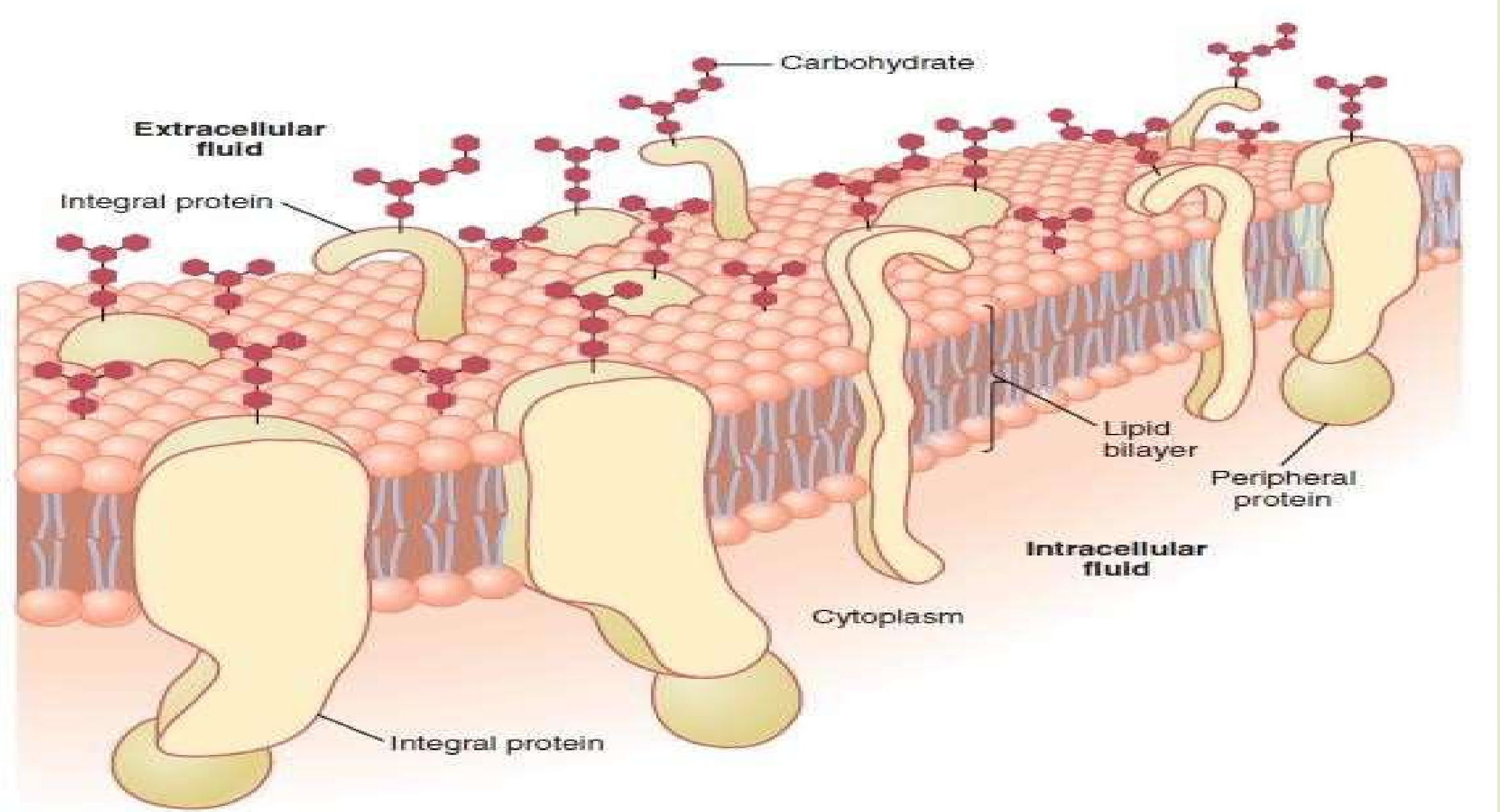
- The lipid layer in the middle of the membrane is impermeable to the usual water-soluble substances, such as
- ions,
- glucose, and
- urea.
- Conversely, fat-soluble substances can penetrate this portion of the membrane with ease, such as
- oxygen,
- carbon dioxide, and
- Alcohol.

Integral and Peripheral Cell Membrane Proteins

- Globular masses floating in the lipid bilayer.
- These membrane proteins are mainly glycoproteins.

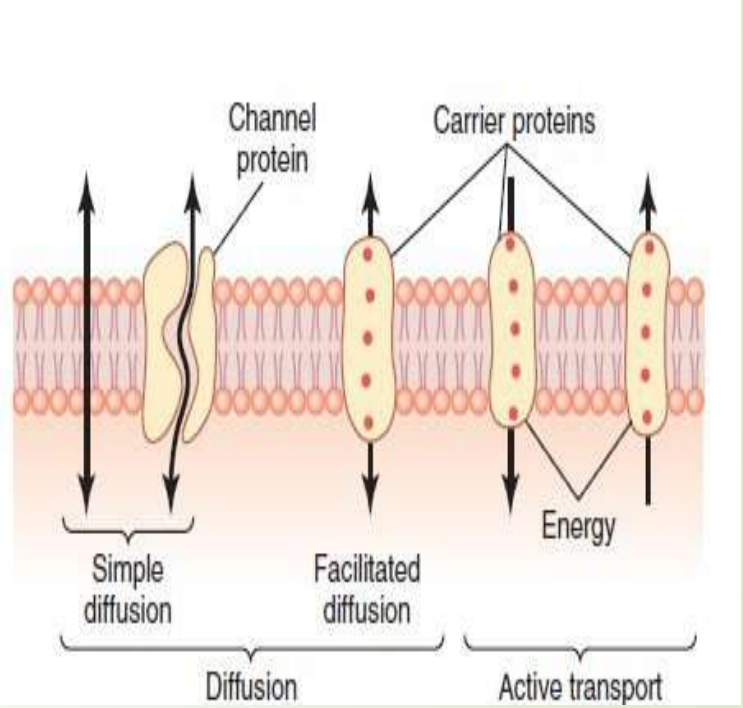
- There are two types of cell membrane proteins:
- Integral proteins that protrude all the way through the membrane

- Peripheral proteins that are attached only to one surface of the membrane and do not penetrate all the way through.


Carbohydrate
Extracellular fluid
Integral protein
Lipid bilayer
Peripheral protein
Intracellular fluid
Cytoplasm
Integral protein

Integral and Peripheral Cell Membrane Proteins

- Many of the integral proteins provide structural channels (or pores) through which water molecules and water soluble substances, especially ions, can diffuse between the extracellular and intracellular fluids.
- These protein channels also have selective properties that allow preferential diffusion of some substances over others.
- Other integral proteins act as carrier proteins for transporting substances that otherwise could not penetrate the lipid bilayer.
- Sometimes these carrier proteins even transport substances in the direction opposite to their electrochemical gradients for diffusion, which is called “active transport.” Still others act as enzymes.



Integral and Peripheral Cell Membrane Proteins

- Integral membrane proteins can also serve as receptors for water-soluble chemicals, such as peptide hormones, that do not easily penetrate the cell membrane.
- Interaction of cell membrane receptors with specific ligands that bind to the receptor causes conformational changes in the receptor protein.
- This process, in turn, enzymatically activates the intracellular part of the protein or induces interactions between the receptor and proteins in the cytoplasm that act as second messengers, relaying the signal from the extracellular part of the receptor to the interior of the cell.

Integral and Peripheral Cell Membrane Proteins

- In this way, integral proteins spanning the cell membrane provide a means of conveying information about the environment to the cell interior.
- Peripheral protein molecules are often attached to the integral proteins.
- These peripheral proteins function almost entirely as enzymes or as controllers of transport of substances through the cell membrane “pores.”

Membrane Proteins

Integral

(Membrane-spanning or intrinsic)

- Can span membrane several times
- Either move around or are kept in place by cytoskeleton proteins

Allows for cell polarity

Associated (peripheral or extrinsic)

- Loosely bound to membrane
- Enzymes and structural proteins

Movement across Membrane

Membrane permeability varies for different molecules & cell types

depends on??

Two movement categories:

- Passive and
- Active

Passive Transport

= Diffusion (Def?) – 3 types:

1. simple diffusion
2. Osmosis
3. Filtration
4. facilitated diffusion (= mediated transport)

Active Transport

Always protein-mediated – 3 types:

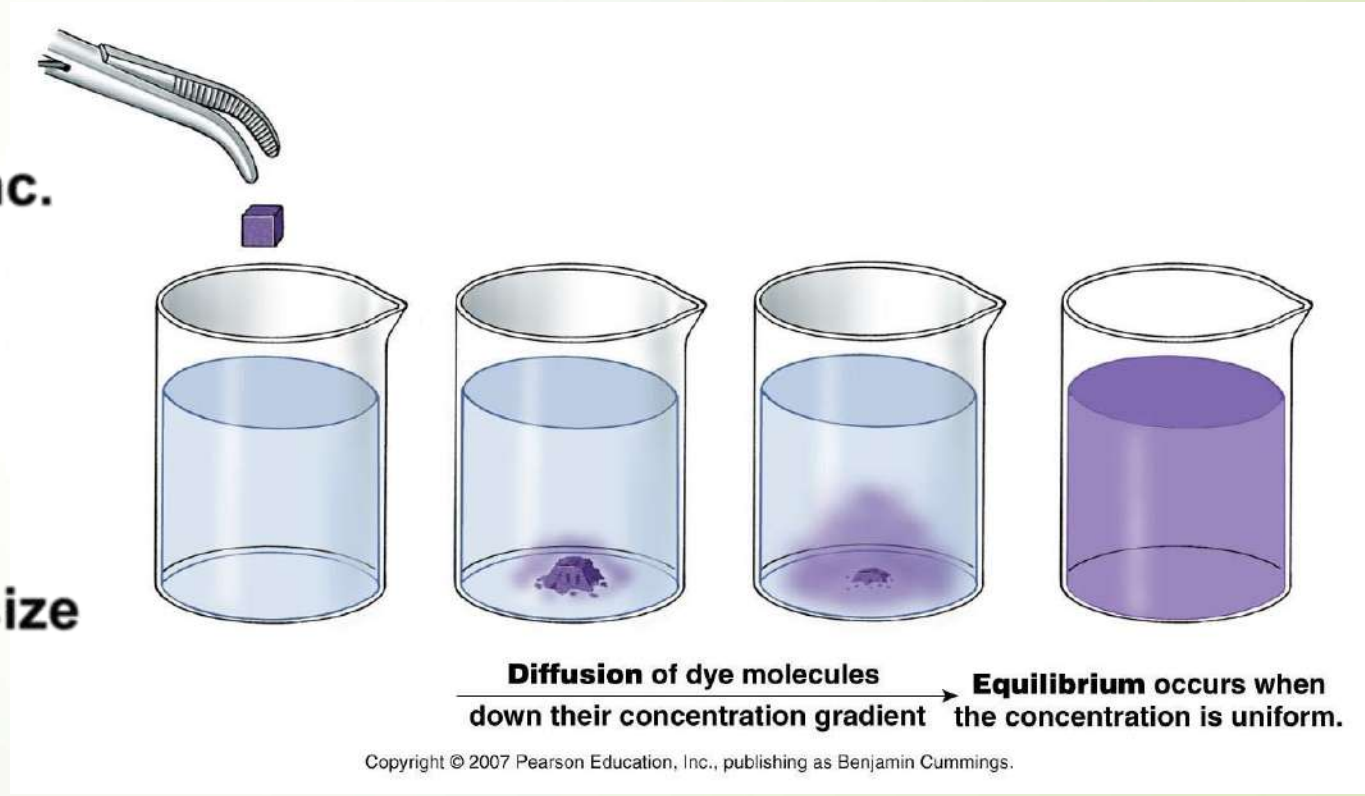
co-transport

vesicular transport

receptor mediated transport

Diffusion Process (Passive)

- **Uses energy of concentration gradient**
- **Net movement until state of equilibrium reached (no more conc. gradient)**
- **Direct correlation to temperature** (why?)
- **Indirect correlation to molecule size**
- **Slower with increasing distance**
- **Lipophilic molecules can diffuse through the phospholipid bilayer**



Distance – Time Relationship

Time for diffusion to progress to given distance ~ to distance squared

diffusion over 100 m takes 5 sec.

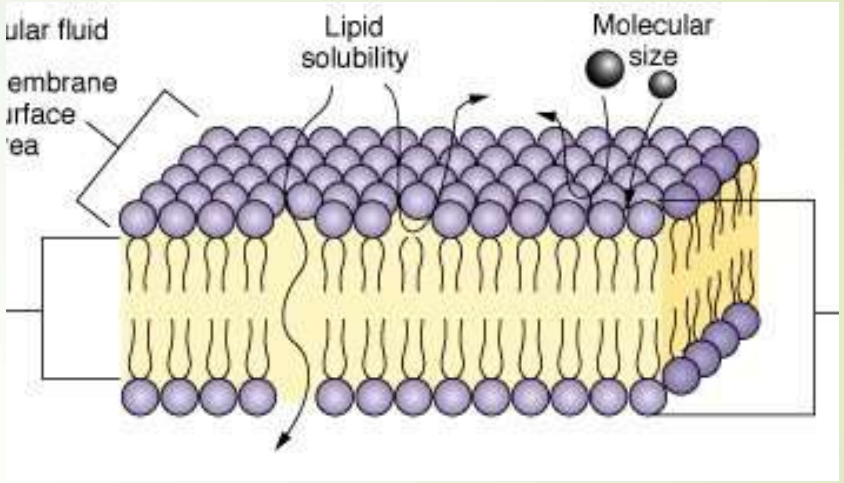
diffusion over 200 m takes ??

diffusion over 400 m takes ??

diffusion over 800 m takes ??

Diffusion effective only over short distances!

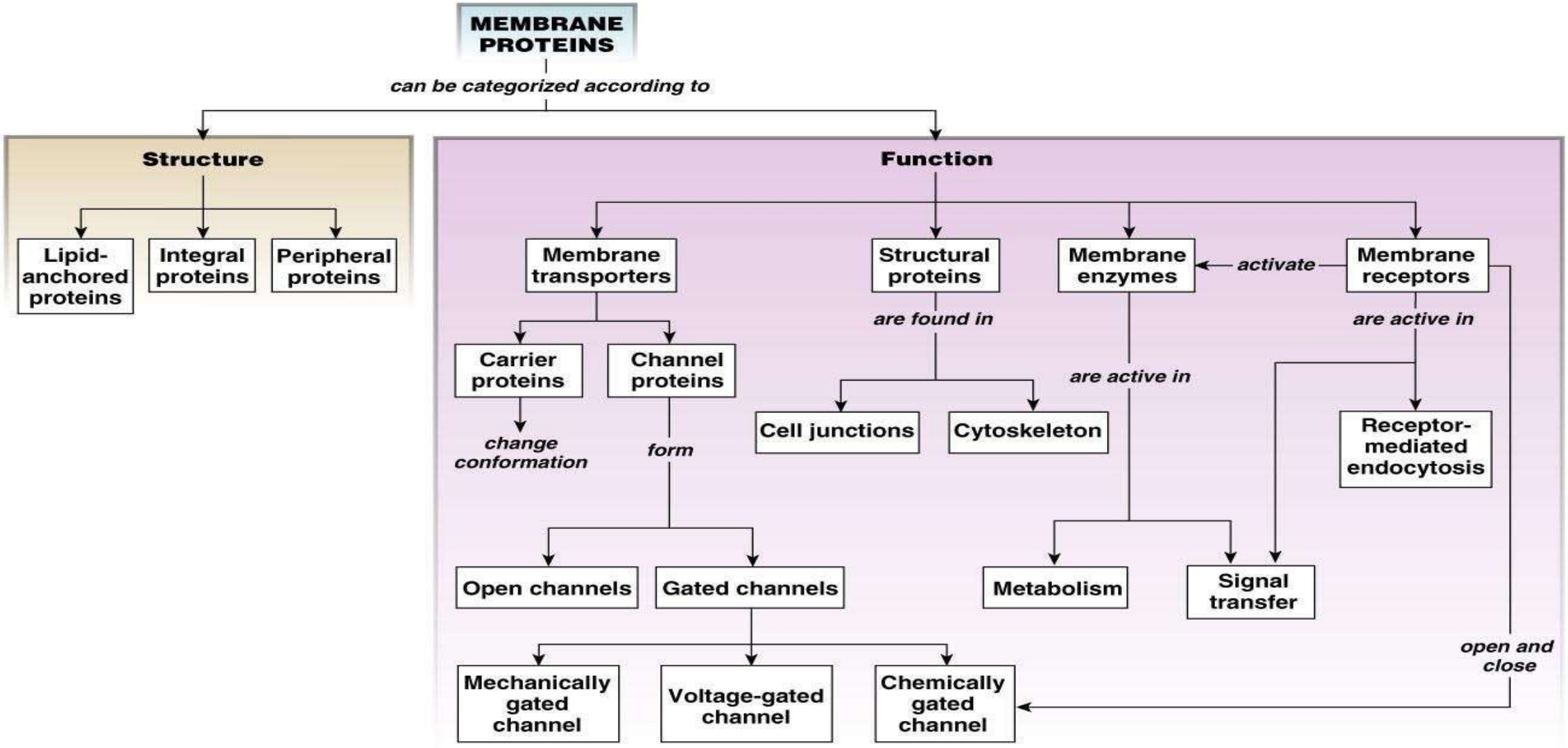
Fick's law of Diffusion



$$\text{rate of diffusion} = \frac{\text{surface area} \times \text{conc. gradient}}{\text{membrane resistance} \times \text{membrane thickness}}$$

depends on size and lipid-solubility of molecule and composition of lipid bilayer

Membrane Proteins



Protein-Mediated Transport

- More selective
- Active or Passive
- Membrane Proteins
  - Structural
  - Enzymes
  - Receptors
  - Transporters (allows Specificity, Competition, Saturation
    - Channel
    - Gated

Transporters

Cell Membrane Regulates Exchange with Environment

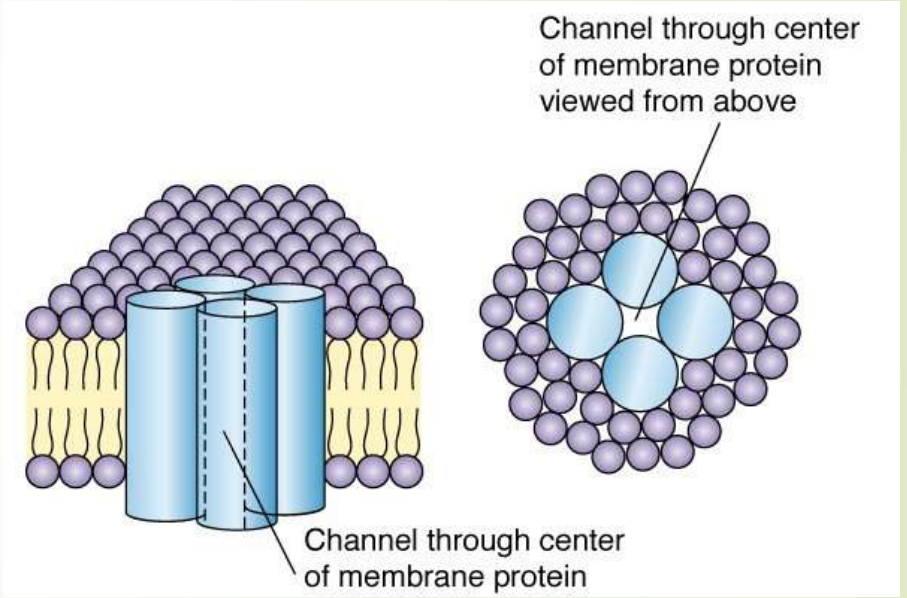
Many molecules use transporters to cross cell membrane. Why? Examples ?

Two categories of transporter proteins

1. Channel proteins (rapid but not as selective – for small molecules only, e.g., water and ions)
2. Carrier proteins (slower but very selective – also works for large molecules)

1. Channel Proteins

- For small molecules such as ??
- Aquaporin; plus > 100 ion channels
- Selectivity based on size & charge of molecule
- All have gate region
  - Open
  - Gated



Open Channels vs. Gated Channels

= pores

Have gates, but gates are open most of the time.

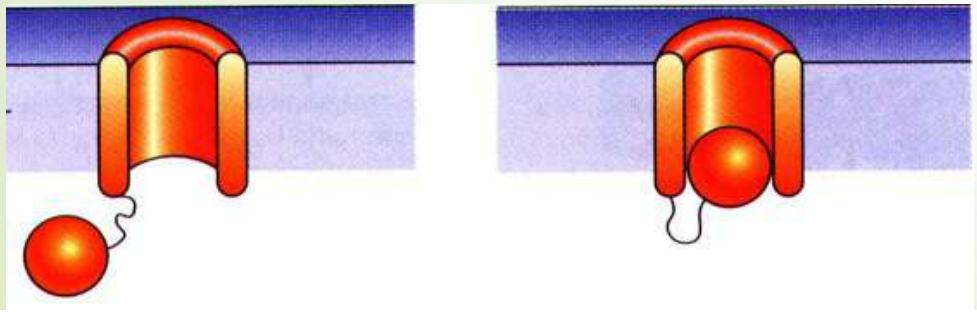
Also referred to as “leak channels”.

Gates closed most of the time

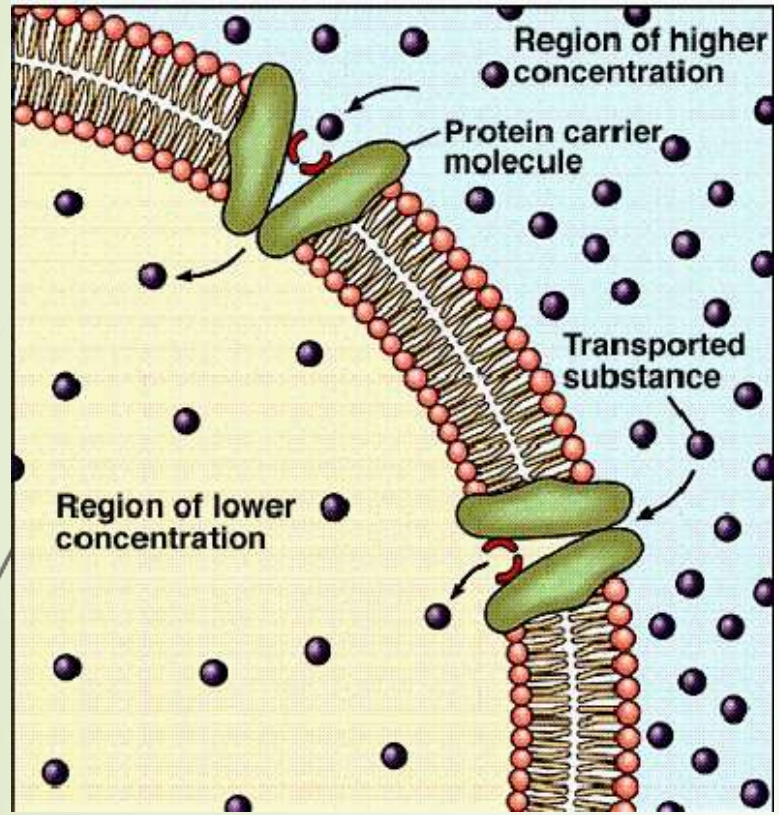
Chemically gated channels (controlled by messenger molecule or ligand)

Voltage gated channels (controlled by electrical state of cell)

Mechanically gated channels (controlled by physical state of cell: temp.; stretching of cell membrane etc.)



2. Carrier Proteins



- Never form direct connection between ECF and ICF – 2 gates!
- Bind molecules and change conformation
- Used for small organic molecules (such as?)
- Ions may use channels or carriers
- Rel. slow (1,000 to 1 Mio / sec)

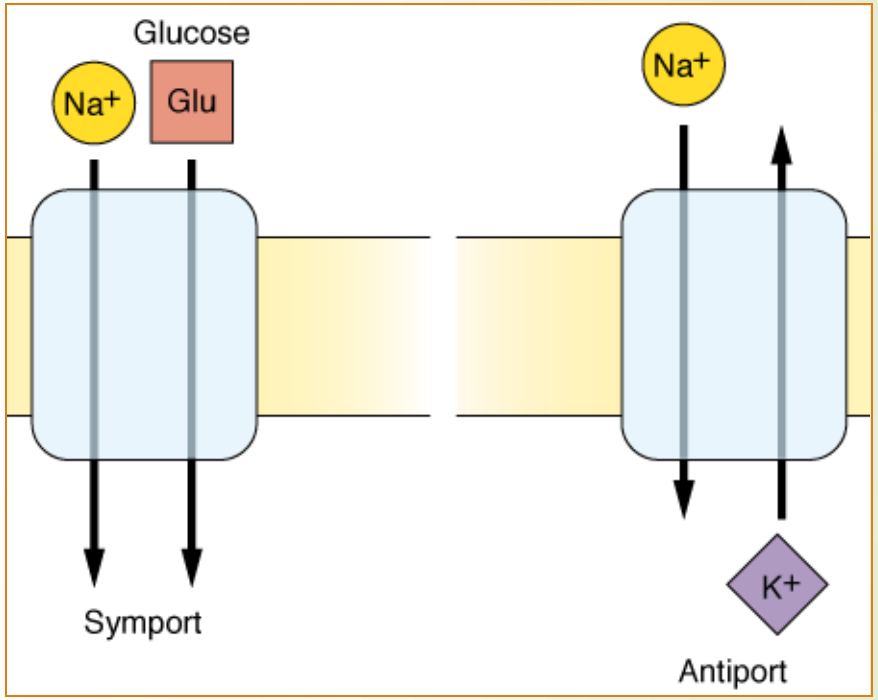
Cotransport

Symport

- Molecules are carried in same direction
- Examples: Glucose and Na^+

Antiport

- Molecules are carried in opposite direction
- Examples: Na^+/K^+ pump



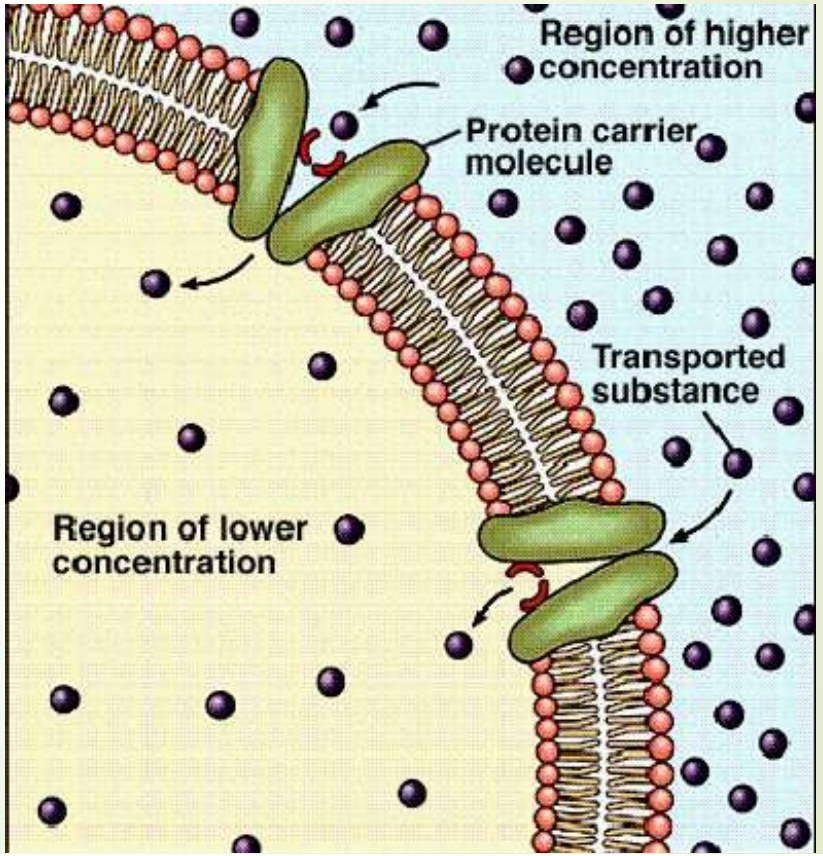
Facilitated Diffusion (as a form of carrier mediated transport)

Some characteristics same as simple diffusion

but also:

- specificity
- competition
- saturation

Figs 5-18/20



Active Transport

- Movement from low conc. to high conc.
- ATP needed
- Creates state of disequilibrium
- 1° (direct) active transport
  - ATPases or "pumps" (uniport and antiport)– examples?
- 2° (indirect) active transport
  - Symport and antiport

TABLE 5-2 Primary Active Transporters

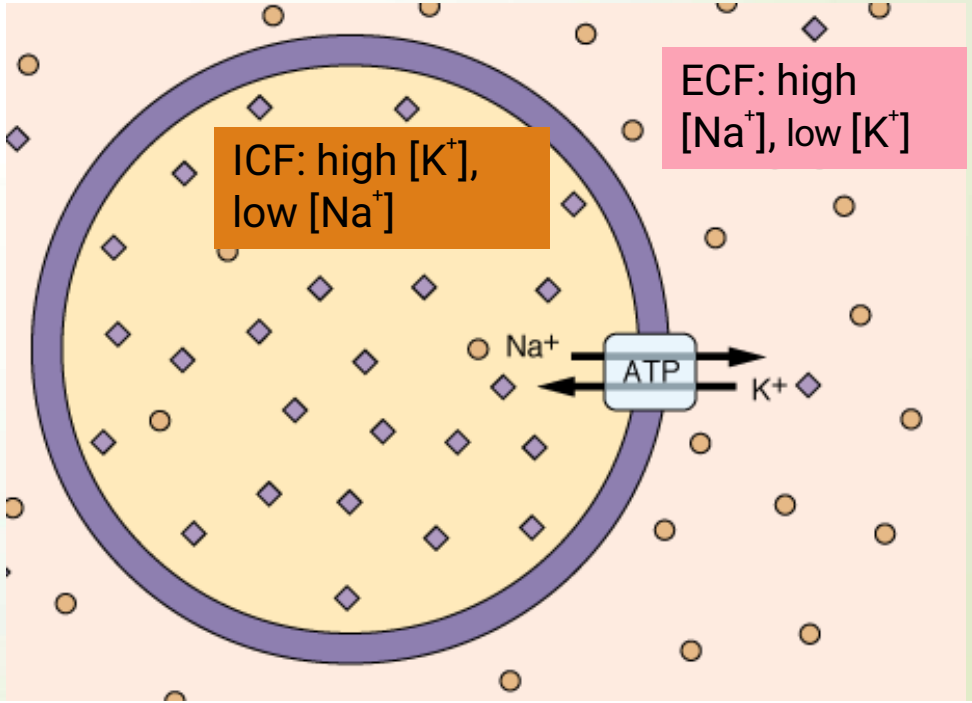
NAMES	TYPE OF TRANSPORT
Na^+-K^+-ATPase or sodium-potassium pump	Antiport
Ca^{2+}-ATPase	Uniport
H^+-ATPase or proton pump	Uniport
H^+-K^+-ATPase	Antiport

1° (Direct) Active Transport

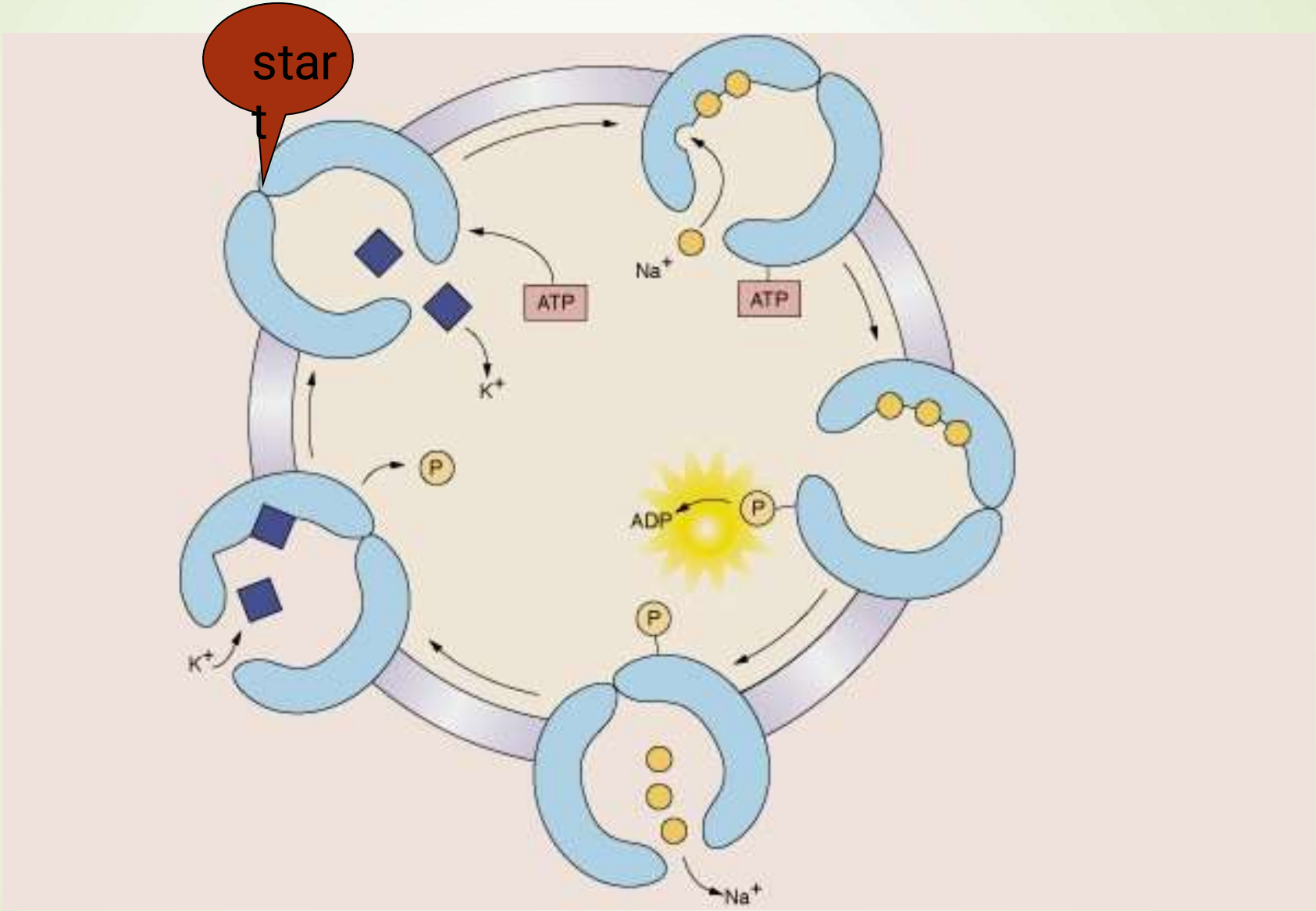
- ATP energy directly fuels transport
- Most important example: Na^+/K^+ pump = sodium-potassium ATPase (uses up to 30% of cell's ATP)

- Establishes Na+ conc. gradient $E_{pot.}$ can be harnessed for other cell functions

Fig 5-16



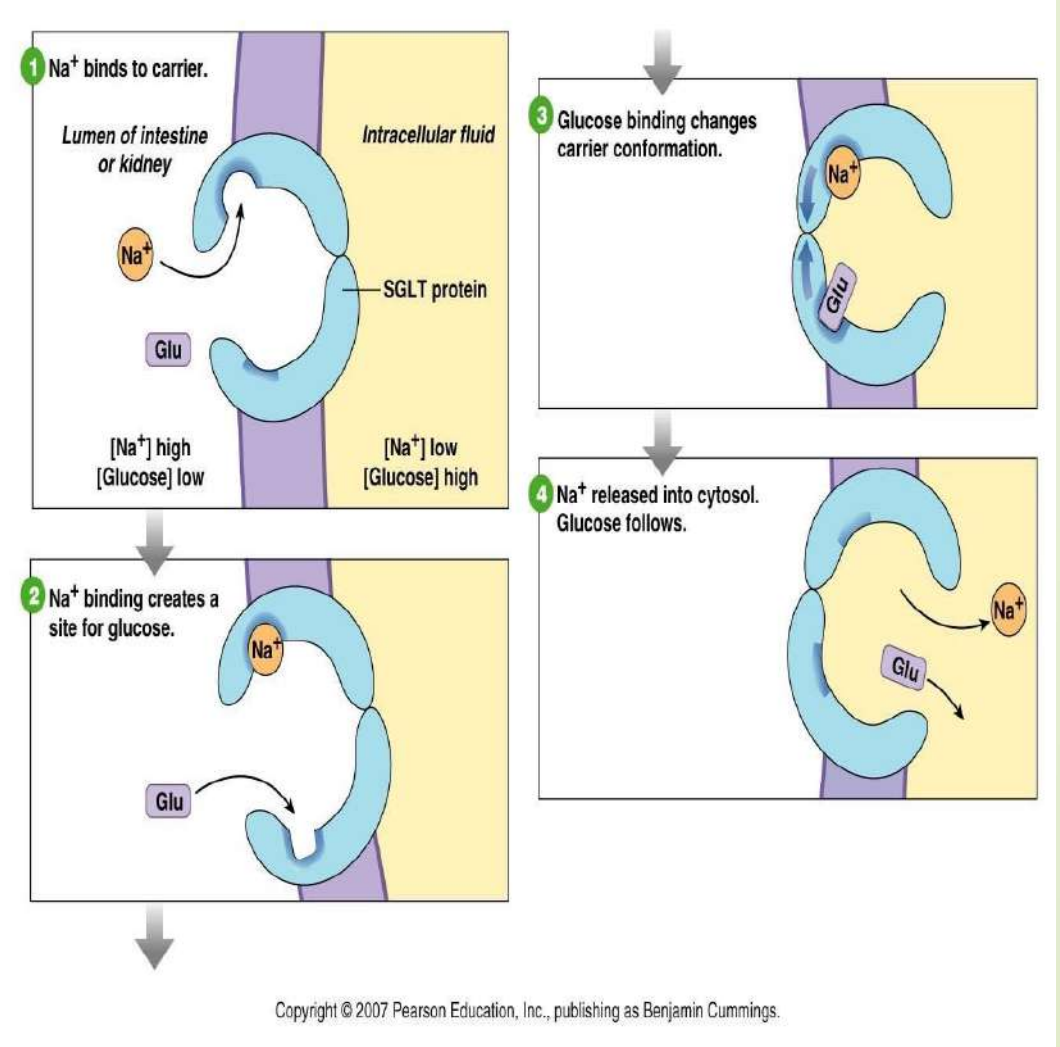
Mechanism of the Na^+/K^+-ATPase



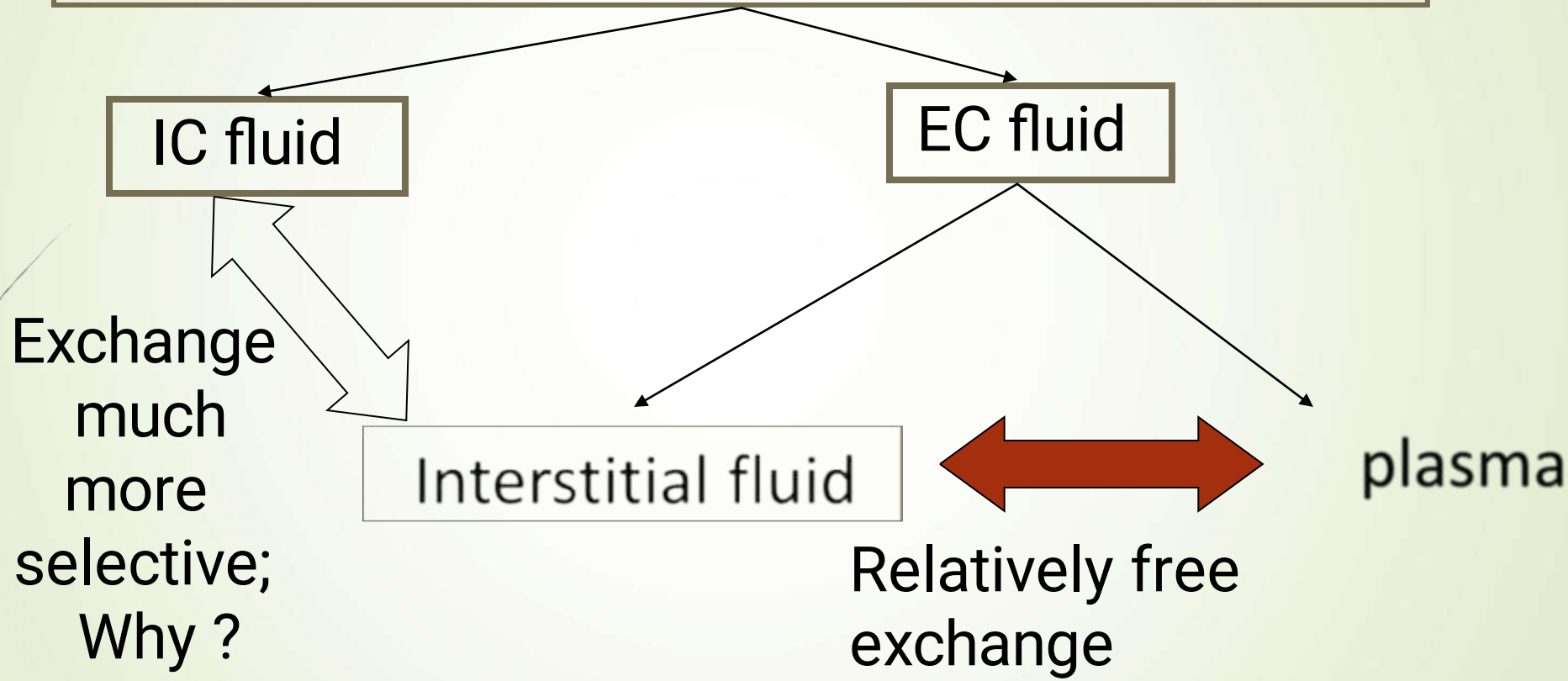
2° (Indirect) Active Transport

- Indirect ATP use: uses $E_{pot.}$ stored in concentration gradient (of Na^+ and K^+)
- Coupling of E_{kin} of one molecule with movement of another molecule
- Example: Na^+ / Glucose symporter

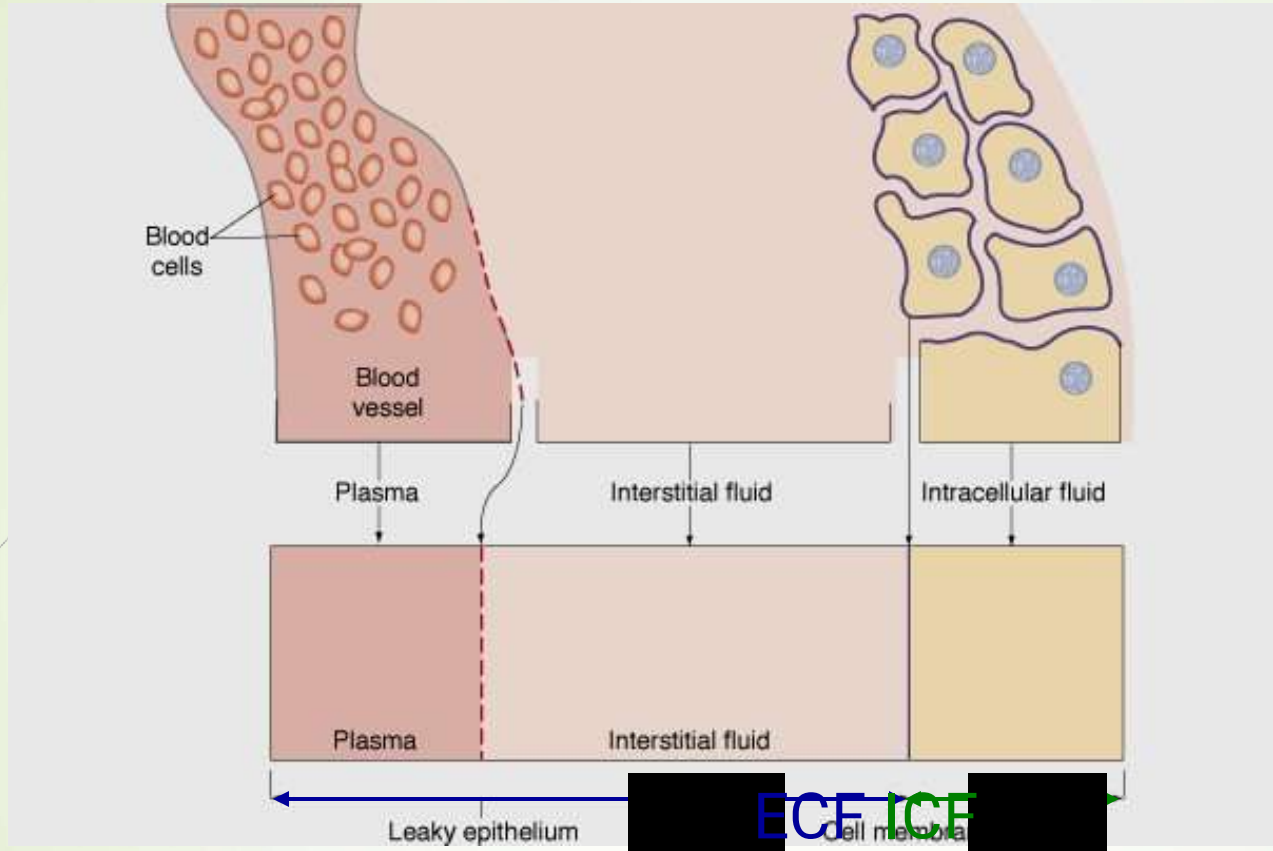
  other examples
- 2 mechanisms for Glucose transport



Body Fluid Compartments



Body Fluid Compartments:



Critical Thinking Question

What properties should a molecule have to be used as marker for one of the fluid compartments?
Do total H_2O; total EC and plasma. Then, how do you figure out ICF and interstitial fluid?

Table 5-4

Secondary Active Transporters

Sodium-dependent transporters

Symport Carriers	*Antiport Carriers*
Na^+/glucose	Na^+/H^+
Na^+/amino acids (several types)	Na^+/Ca^{2+}
$Na^+/K^+/2\,Cl^-$	
Na^+/bile salts (small intestine)	
Na^+/choline uptake (nerve cells)	
Na^+/neurotransmitter uptake (nerve cells)	

Nonsodium-dependent transporters

	HCO_3^-/Cl^-
	H^+/K^+

Vesicular Transport

Movement of macromolecules across cell membrane:

1. Phagocytosis (specialized cells only)

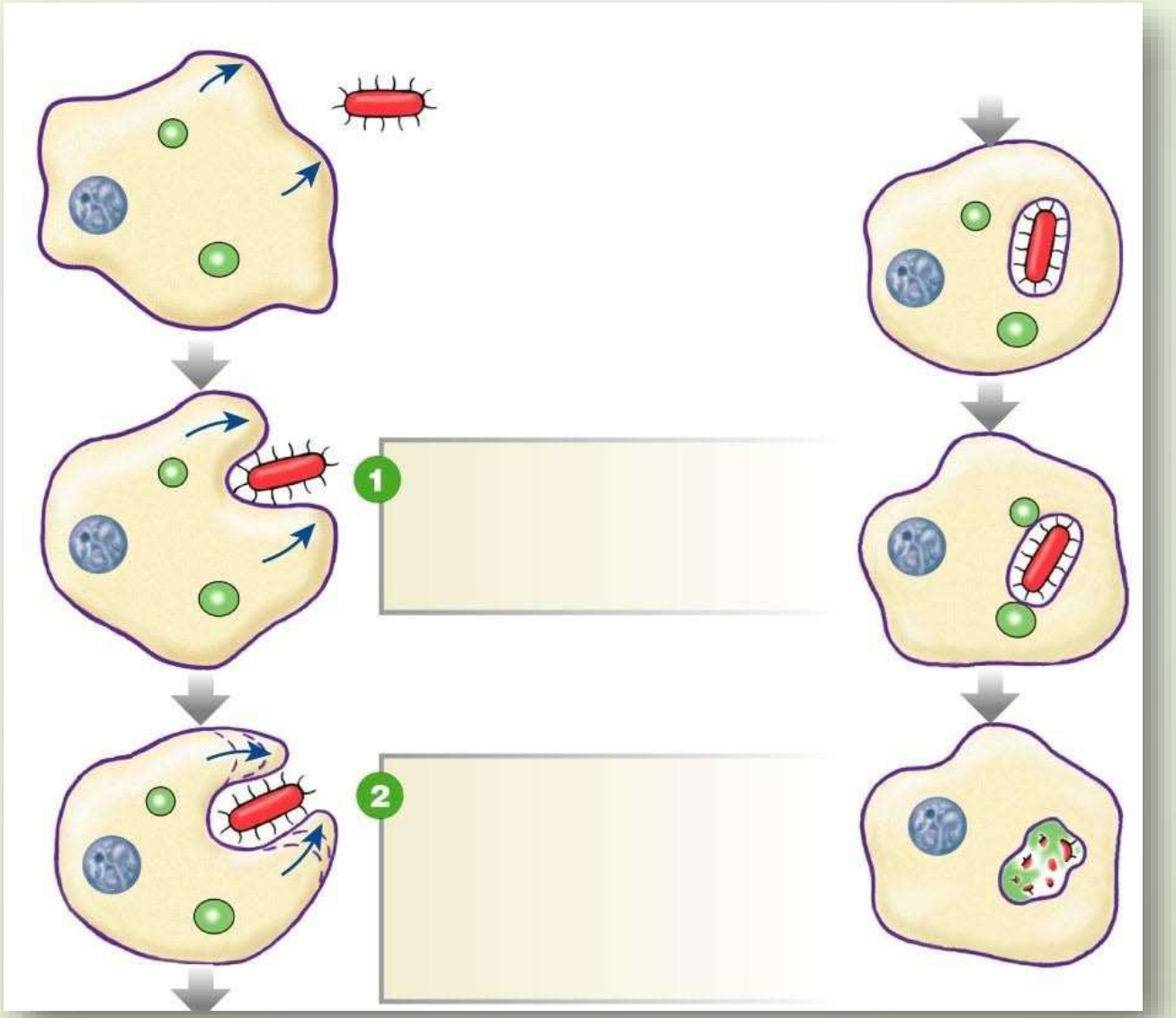
2. Endocytosis
   - Pinocytosis
   - Receptor mediated endocytosis
   - (Caveolae) Potocytosis

3. Exocytosis

1. Phagocytosis

- Requires energy
- Cell engulfs particle into vesicle via pseudopodia formation
- E.g.: some WBCs engulf bacteria
- Vesicles formed are much larger than those formed by endocytosis
- Phagosome fuses with lysosomes ? (see Fig. 5-23)

1. Phagocytosis



2. Endocytosis

- Requires energy
- No pseudopodia - Membrane surface indents (cell order)
- Smaller vesicles
- Nonselective: Pinocytosis for fluids & dissolved substances
- Selective:
  - Receptor Mediated Endocytosis via clathrin-coated pits - Example: LDL cholesterol and Familial Hypercholesterolemia
  - Podocytosis via caveolae

Fig 5-24

Note: Clathrin is a protein that plays a major role in the formation of coated vesicles.

Receptor Mediated Endocytosis and Membrane Recycling

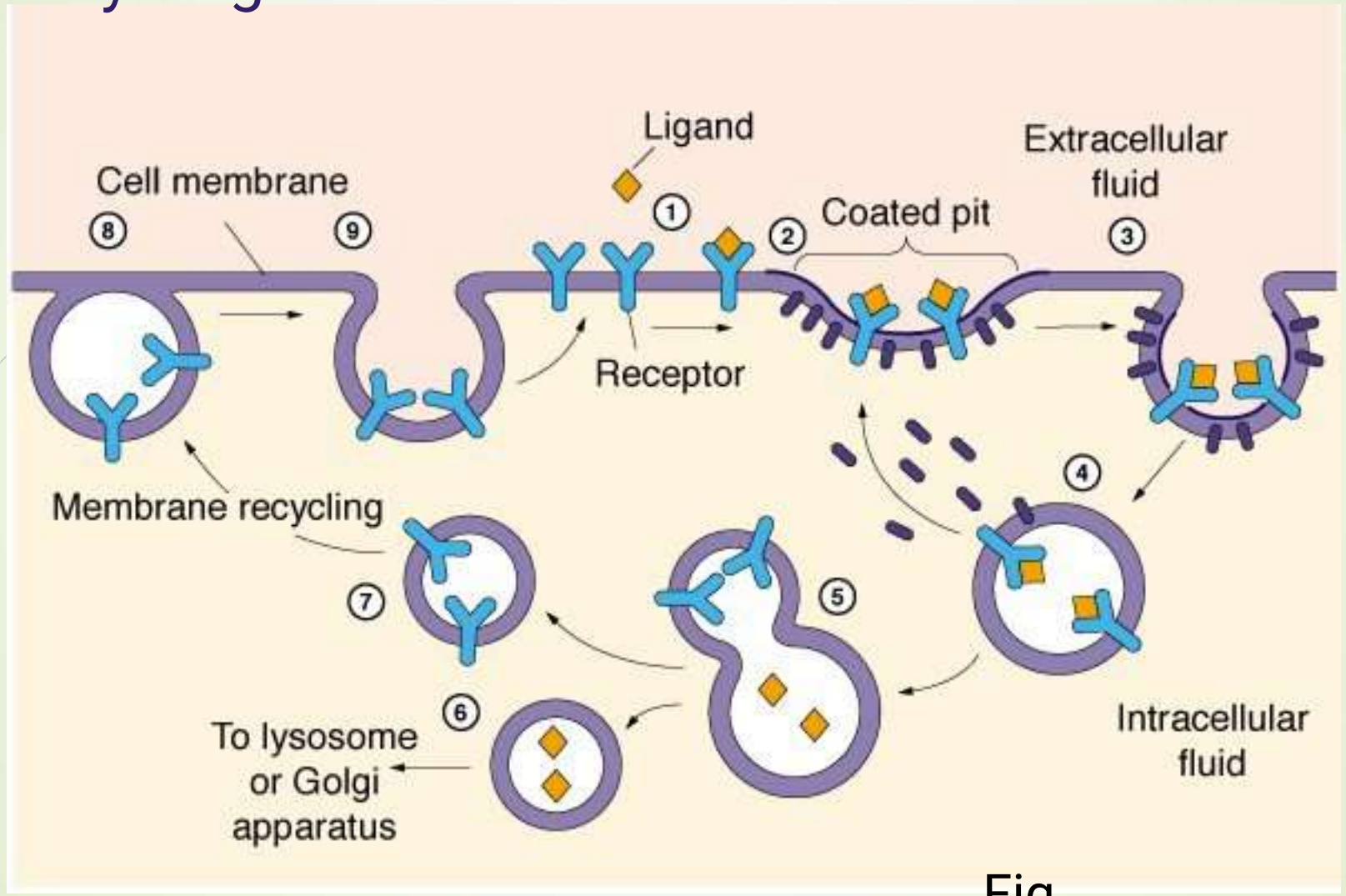


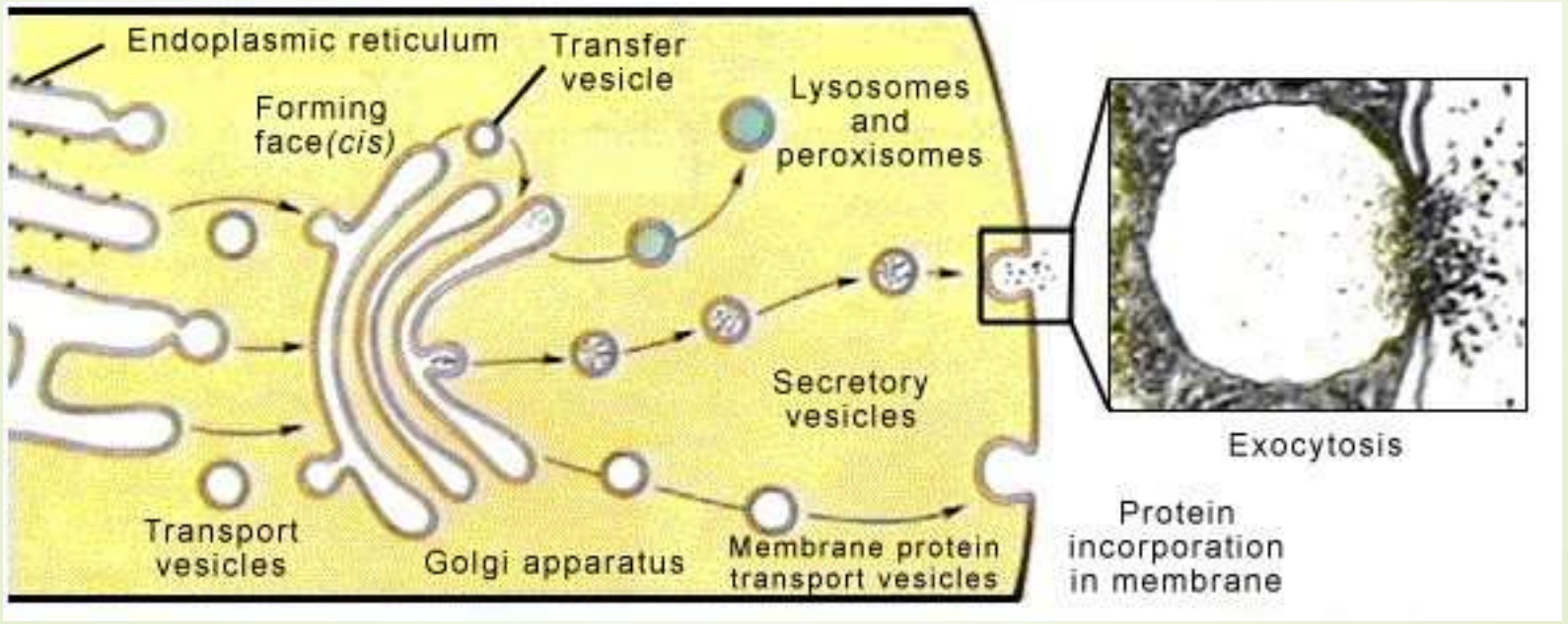
Fig 5-28

3. Exocytosis

Intracellular vesicle fuses with membrane

Requires energy (ATP) and Ca^{2+}

Examples: large lipophobic molecule secretion; receptor insertion; waste removal



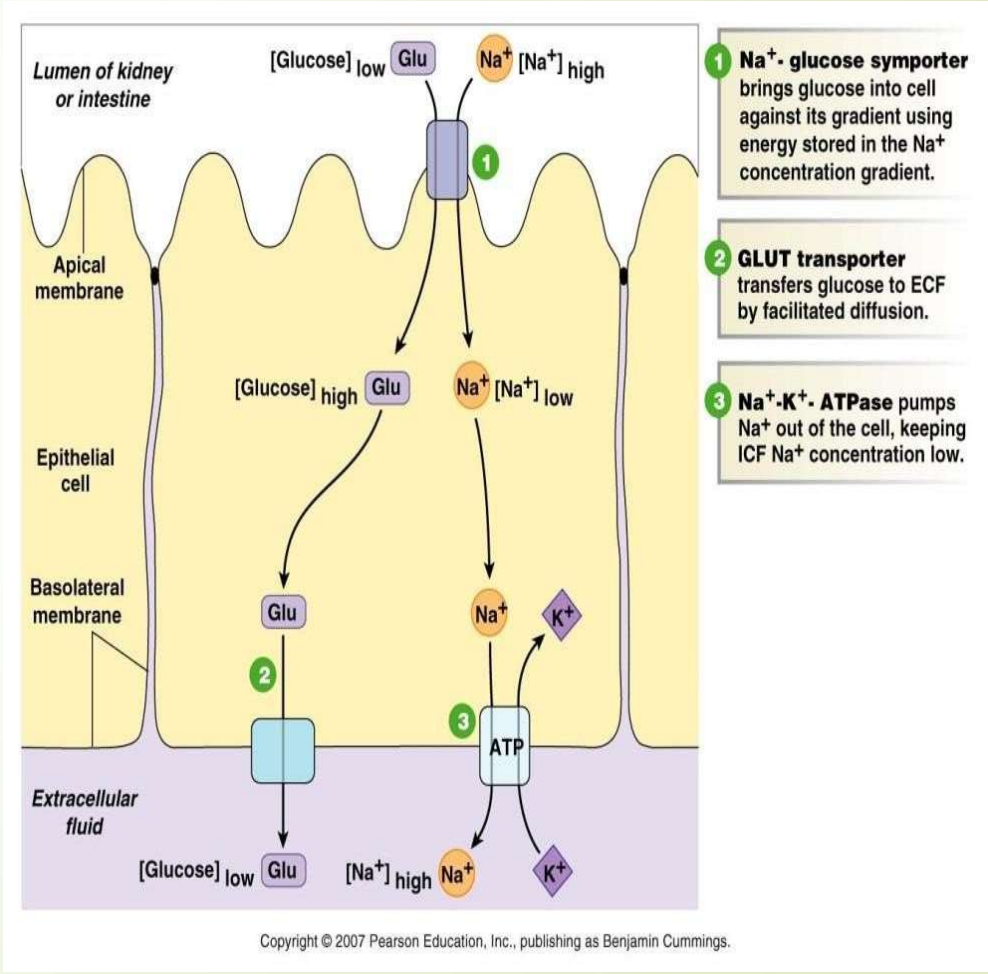
Movement through Epithelia: Transepithelial transport

Uses combination of active and passive transport

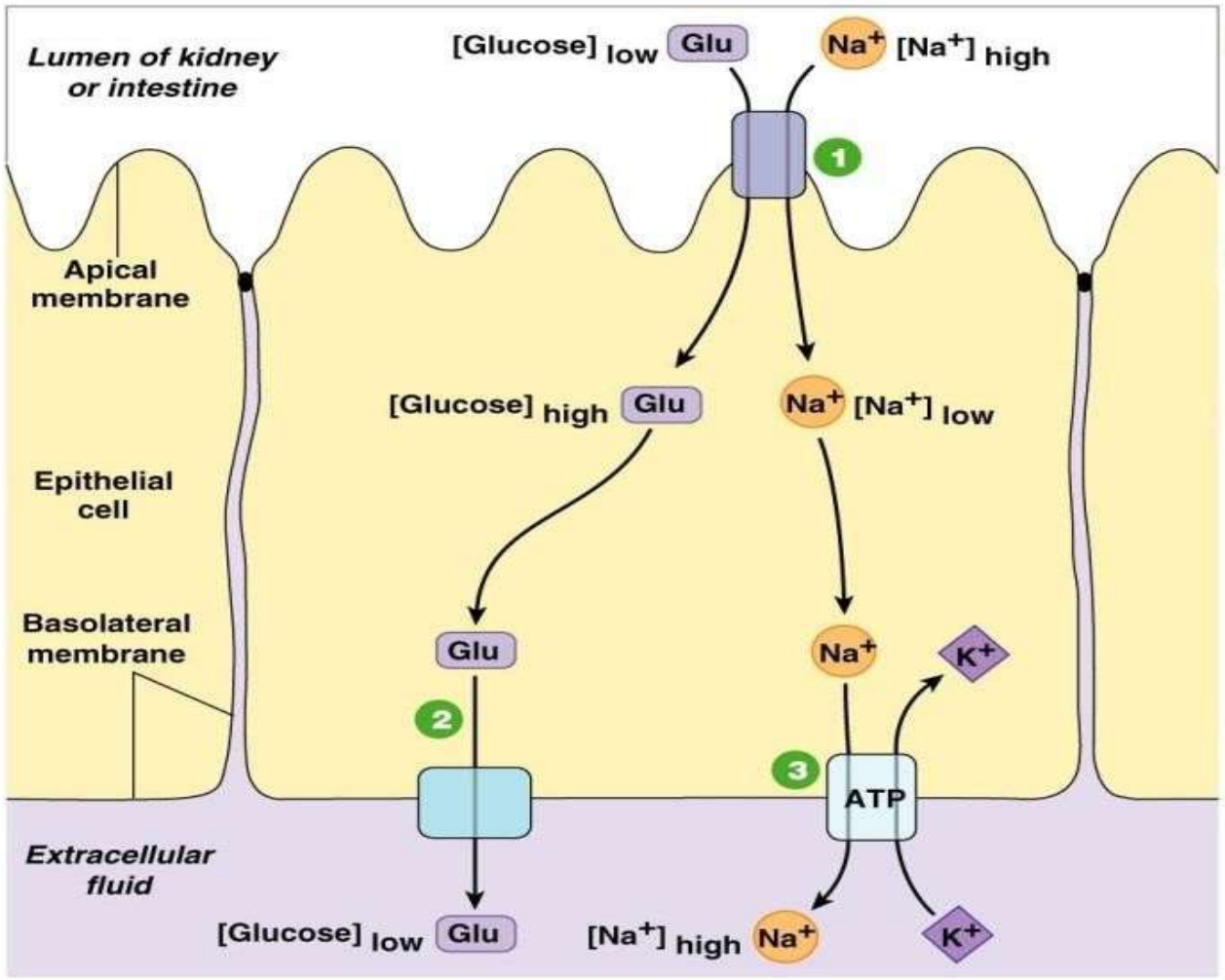
Molecule must cross two phospholipid bilayers

Apical and basolateral cell membranes have different proteins:

Na^+- glucose transporter on apical membrane Na^+/K^+-ATPase only on basolateral membrane



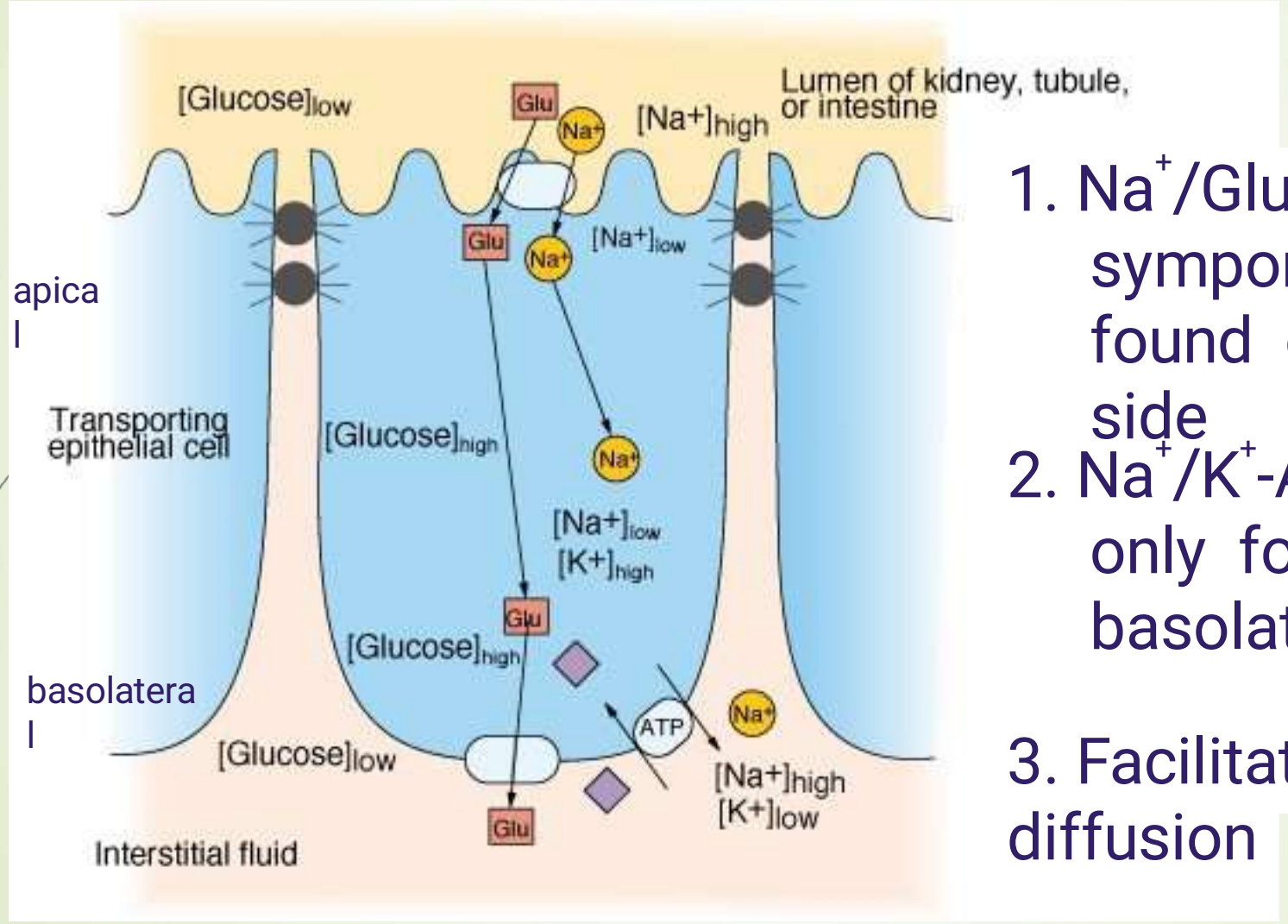
Transepithelial Transport of Glucose



1. **Na^+- glucose symporter** brings glucose into cell against its gradient using energy stored in the Na^+ concentration gradient.
2. **GLUT transporter** transfers glucose to ECF by facilitated diffusion.
3. **Na^+-K^+- ATPase** pumps Na^+ out of the cell, keeping ICF Na^+ concentration low.

Concept check: Apply Ouabain to either side of cell, what happens?

Transepithelial Transport of Glucose



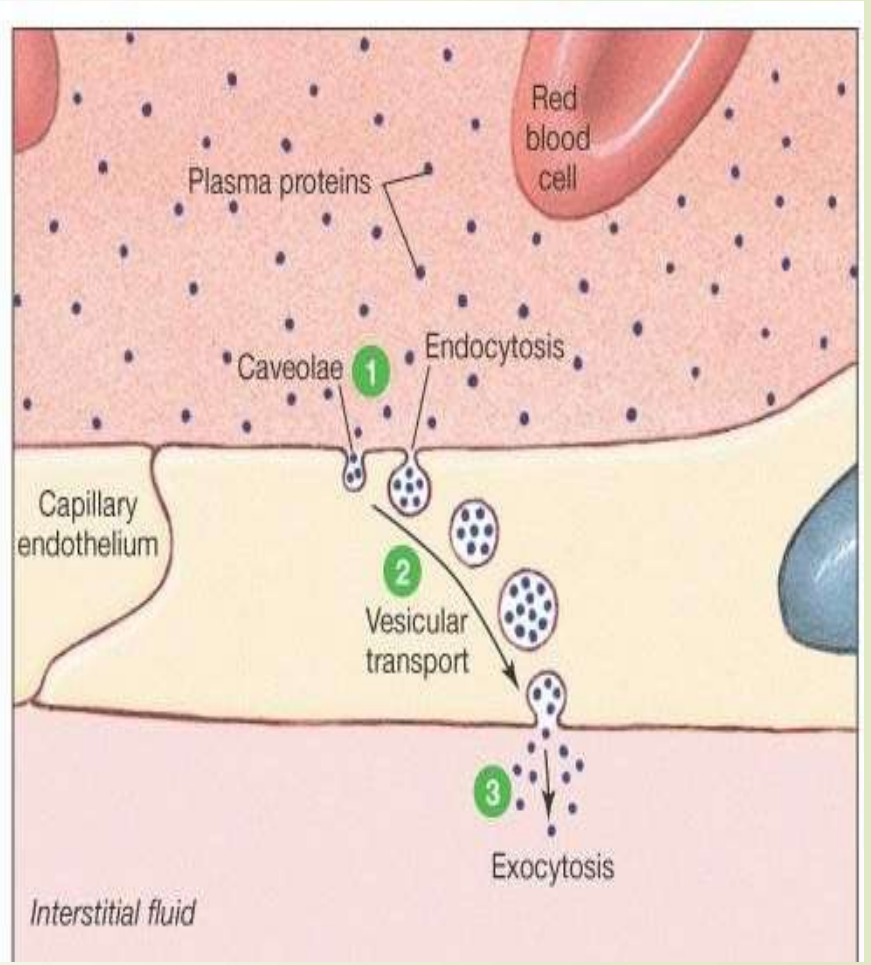
1. Na^+/Glucose symporter only found on apical side
2. Na^+/K^+-ATPase only found on basolateral side

3. Facilitated diffusion

Concept check: Apply Ouabain to either side of cell, what happens?

Transcytosis

- Endocytosis vesicular transport exocytosis
- Moves large proteins intact
- Examples:
  - Absorption of maternal antibodies from breast milk
  - Movement of proteins acros s capillary endothelium



Distribution of Solutes in Body

Depends on

- selective permeability of cell membrane
- transport mechanisms available

Water is in osmotic equilibrium (free movement across membranes)

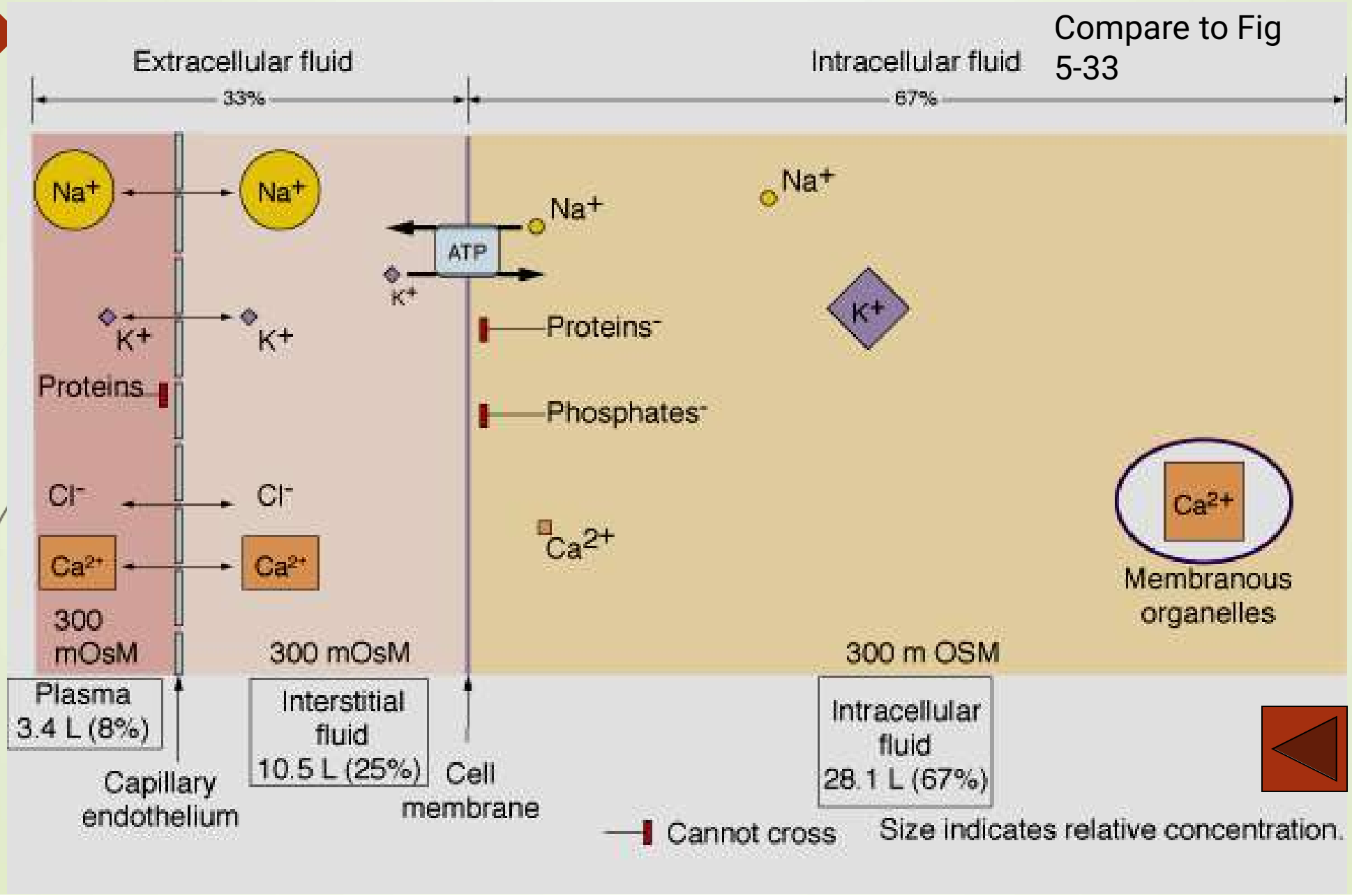
Ions and most solutes are in chemical disequilibrium (e.g., Na-K ATPase Pump)

Electrical disequilibrium between ECF and ICF

Fig 5-33

Distribution of Solutes in Body Fluid Compartments

Compare to Fig 5-33



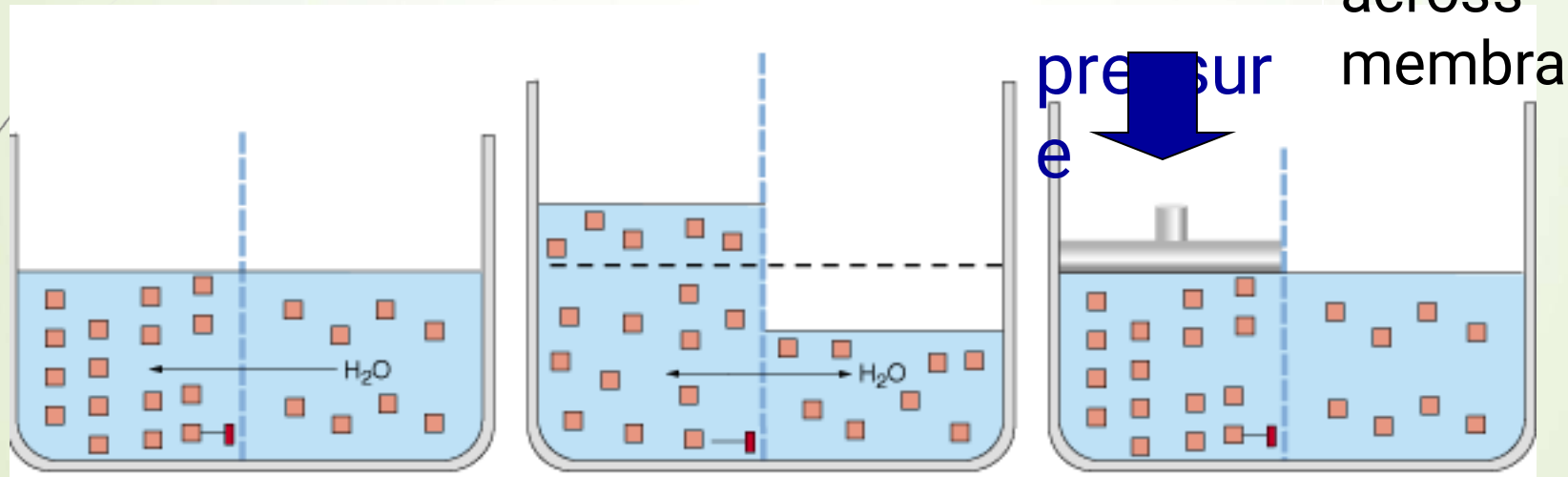
Osmosis

Compare to Fig. 5-29

Movement of water down its concentration gradient.

Osmotic pressure

Opposes movement of water across membrane



Water moves freely in body until osmotic equilibrium is reached

Molarity vs. Osmolarity

In chemistry:

- Mole / L
- Avogadro's # / L

In Physiology

Important is not # of molecules / L
but

# of particles / L: osmol/L or OsM

Why?

Osmolarity takes into account dissociation (solubility) of molecules in solution

Osmolality = OsM/Kg of sol'n

Convert Molarity to Osmolarity

Osmolarity = # of particles / L of solution

- 1 M glucose = 1 OsM glucose
- 1 M NaCl = 2 OsM NaCl
- 1 M $MgCl_2$ = 3 OsM $MgCl_2$
- Osmolarity of human body ~ 300 mOsM

- Compare isosmotic, hyperosmotic, hyposmotic

Tonicity

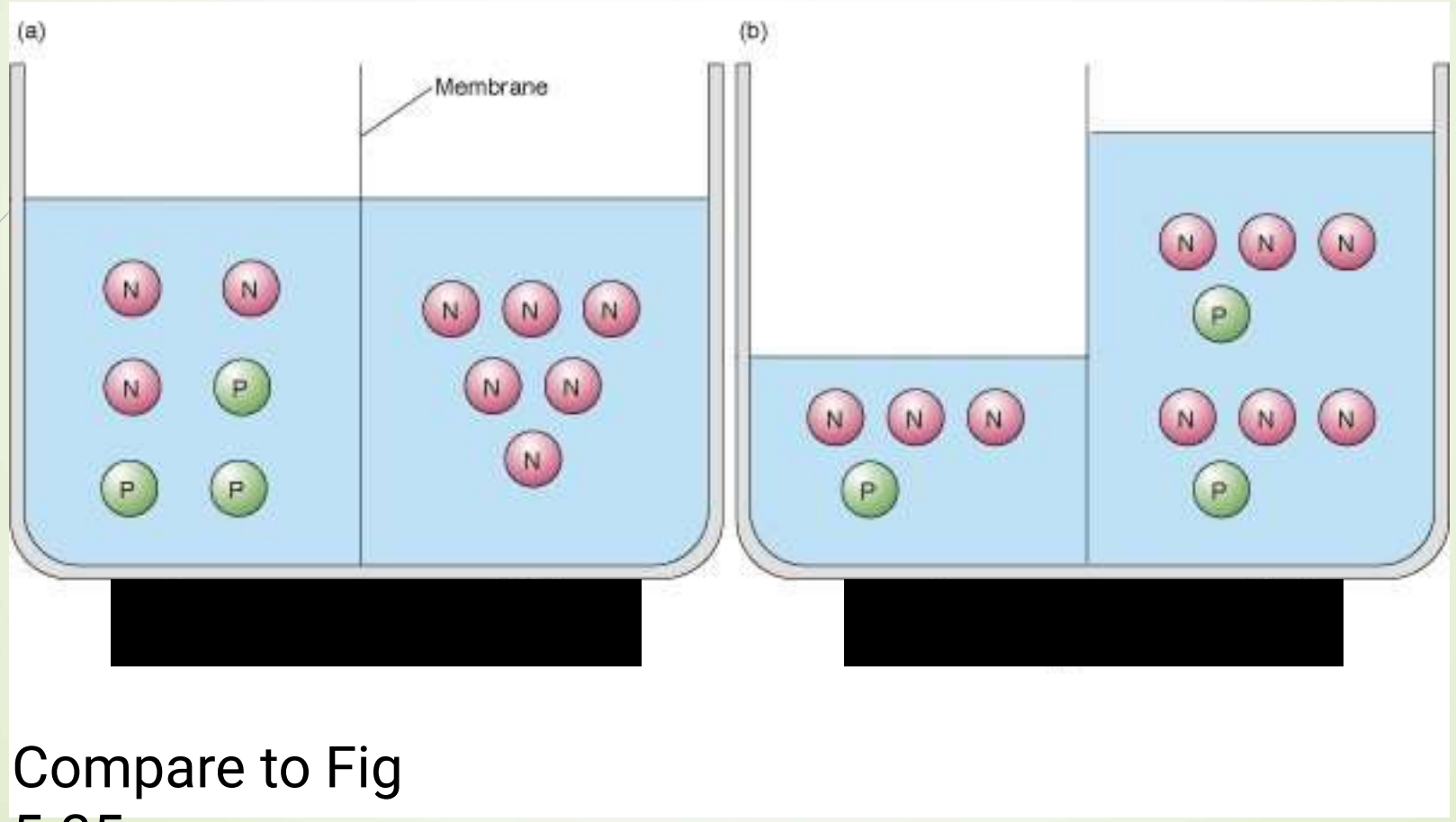
- Physiological term describing how cell volume changes if cell placed in the solution
- Always comparative. Has no units.
  - Isotonic sol'n = No change in cell
  - Hypertonic sol'n = cell shrinks
  - Hypotonic = cell expands
- Depends not just on osmolarity but on nature of solutes and permeability of membrane

Penetrating vs. Nonpenetrating Solutes

- Penetrating solute: can enter cell (glucose, urea)
- Nonpenetrating solutes: cannot enter cell (sucrose, NaCl*)
- Determine relative conc. of nonpenetrating solutes in solution and in cell to determine tonicity.
  - Water will move to dilute nonpenetrating solutes
  - Penetrating solutes will distribute to equilibrium

Fig 5-30

Osmolarity and Tonicity Comparison



Compare to Fig 5-35

IV Fluid Therapy

Table 5-9: Intravenous Solutions

SOLUTION	ALSO KNOWN AS	OSMOLARITY	TONICITY
0.9% saline*	Normal saline	Isosmotic	Isotonic
D_5—0.9% saline	5% dextrose** in normal saline	Hyperosmotic	Isotonic
D_5W	5% dextrose in water	Isosmotic	Hypotonic
0.45% saline	Half-normal saline	Hyposmotic	Hypotonic
D_5—0.45% saline	5% dextrose in half-normal saline	Hyperosmotic	Hypotonic

*Saline = NaCl. **Dextrose = glucose.

Electrical Disequilibrium and Resting Membrane Potential (pp.156-163) will be covered at the beginning of Ch 8

Which of the following is a way for solutes in a aqueous solution to move from an area of high solute concentration to an area of low solute concentration?

A. Facilitated diffusion
B. Osmosis
C. Active transport
D. A and B
E. None of these

Which of the following defines the term specificity?

A. movement of molecules by the use of vesicles
B. the energy required to move molecules
C. a group of carrier proteins operating at their maximum rate
D. carrier transport of a group of closely related molecules
E. none of these

Water will always move from _ situations to_situations.

A. Hyperosmotic, hyposmotic
B. Hyposmotic, hyperosmotic
C. Hyposmotic, isosmotic
D. Hyperosmotic, isosmotic

Which of the following pairs of molecular characteristics favors diffusion through the cell membrane?

A. Large, polar
B. Large, non-polar
C. Small, polar
D. Small, non-polar

Which of the following is a way for solutes in a aqueous solution to move from an area of high solute concentration to an area of low solute concentration?

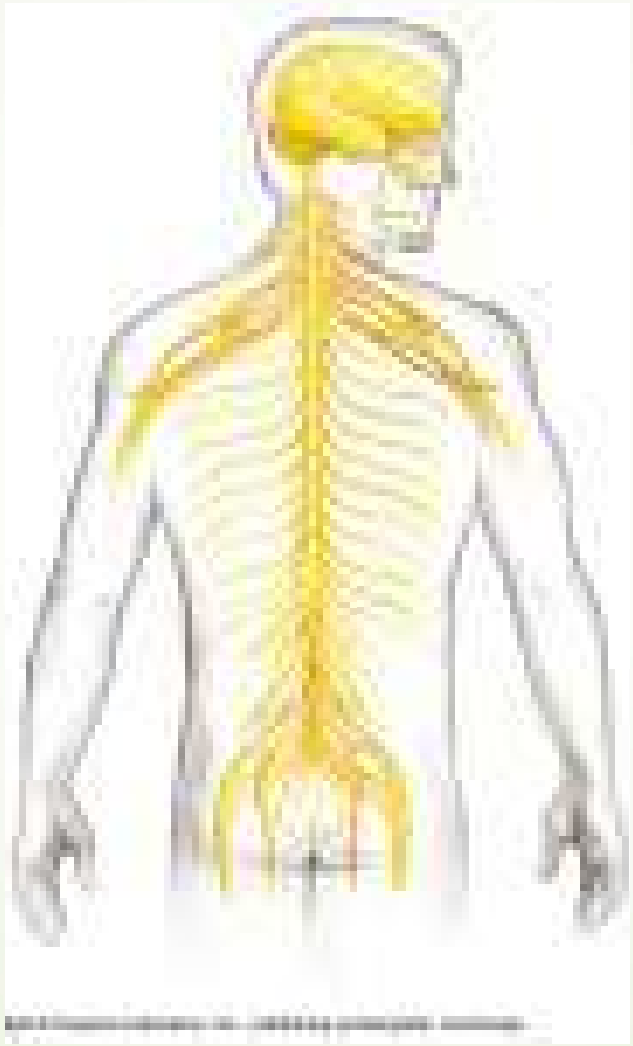
A. Facilitated diffusion
B. Osmosis
C. Active transport
D. A and B
E. None of these

The Nervous System

How Does It Work?

What parts do you know that are in the nervous system?

- Brain
- Spinal Cord
- Peripheral Nerves

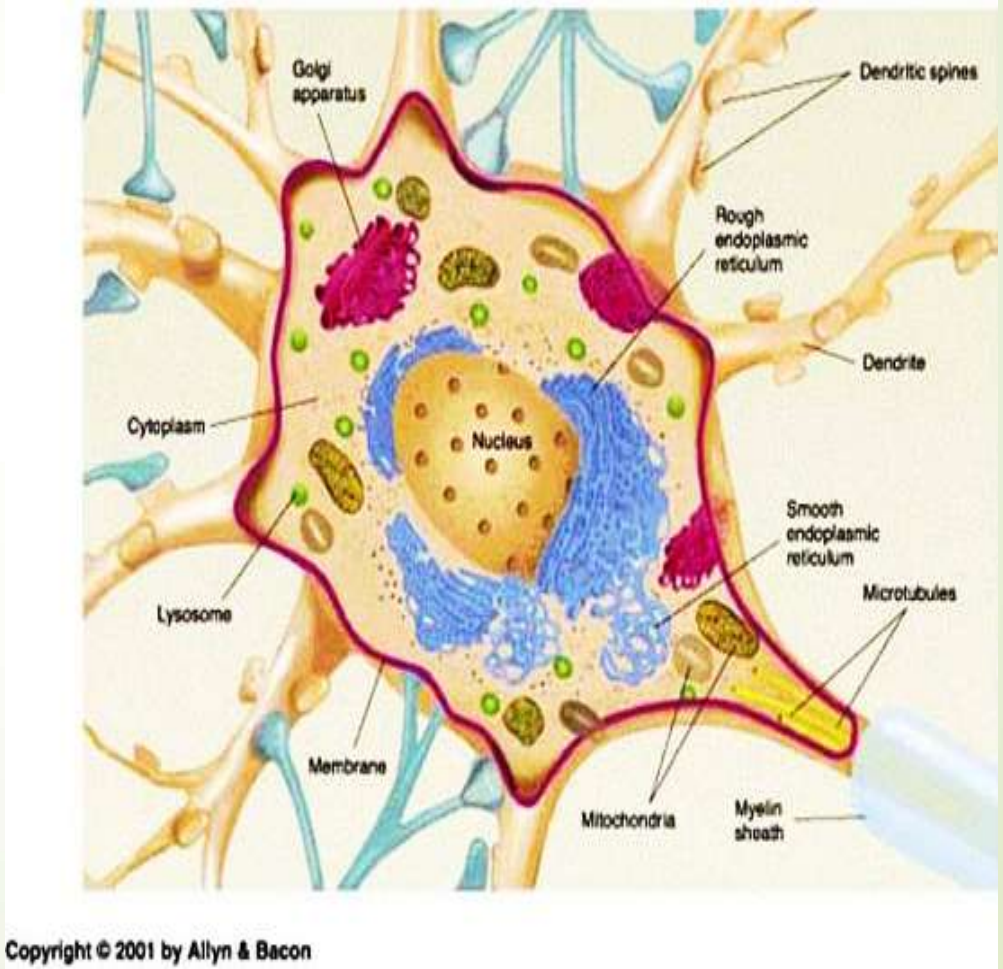


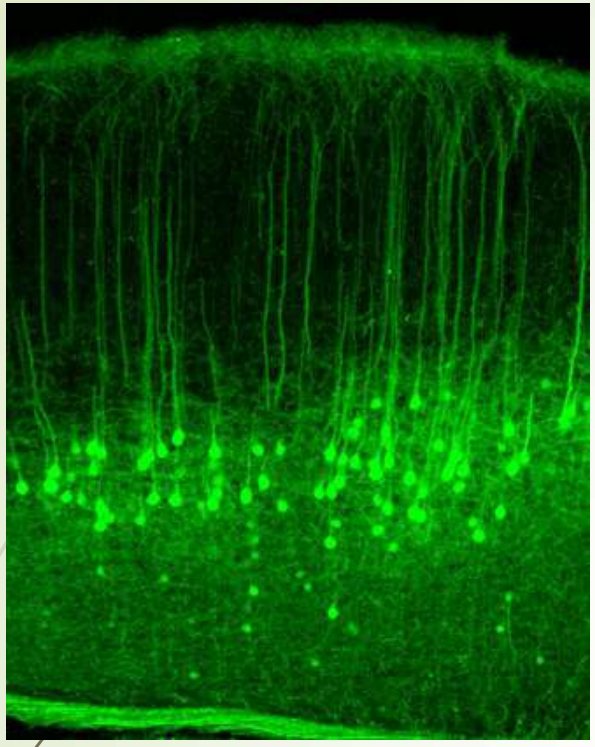
Your nervous system has three components…

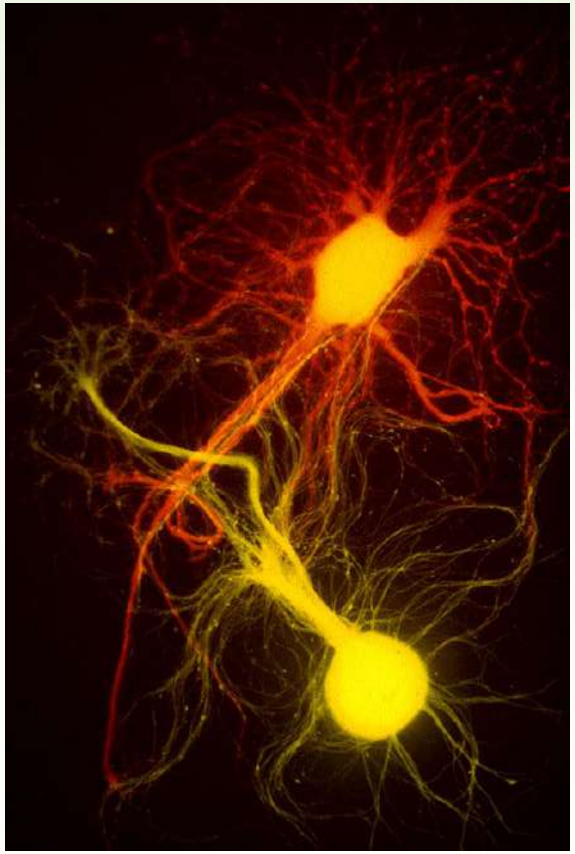
- Brain
- Nerves
- Spinal cord

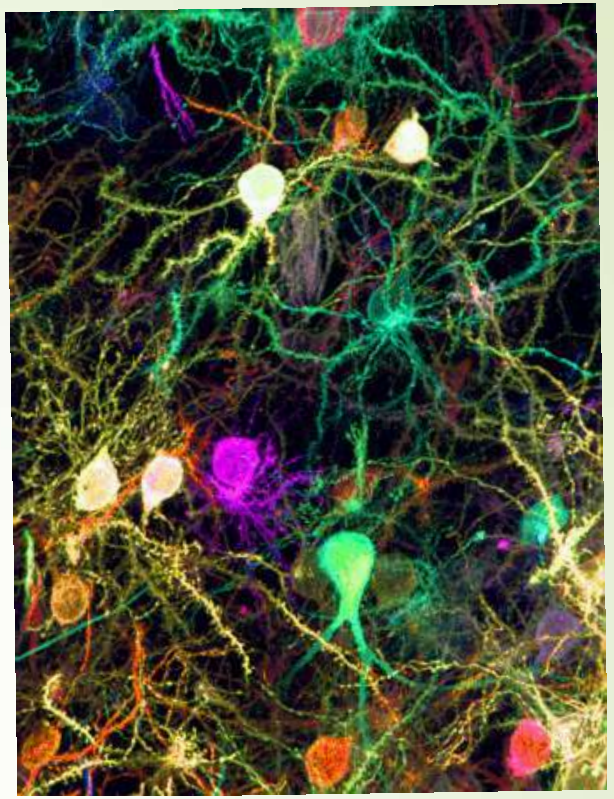
What makes up the brain, the spinal cord or your peripheral nerves?

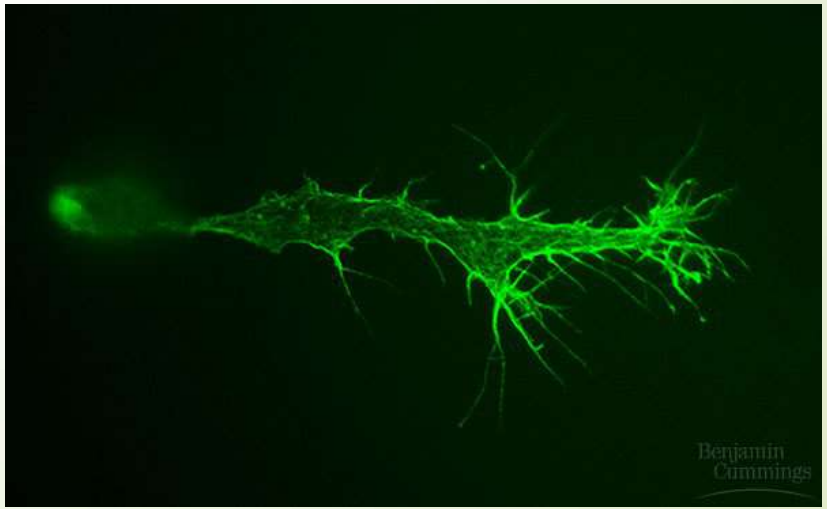
- Neurons are “the cell”
- Cell body
- Nucleus
- Axon
- Dendrite
- What do you think surrounds the cell?
- What other organelles would be needed?





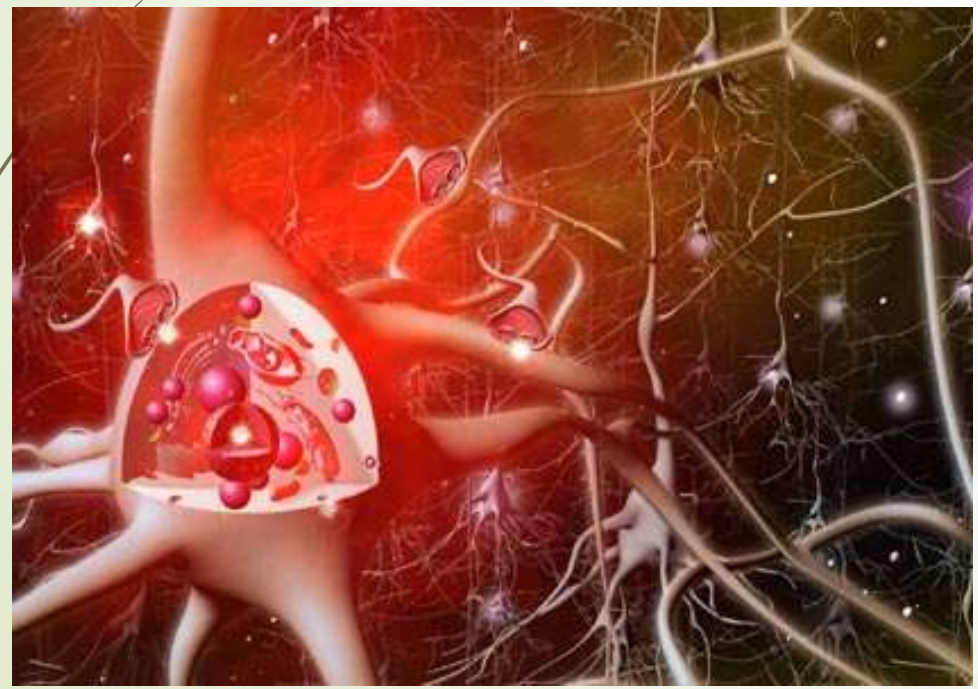


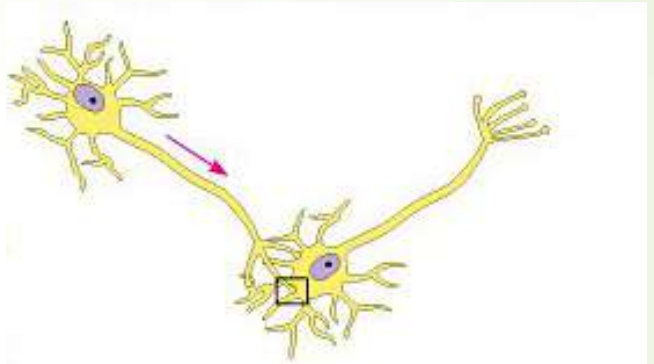


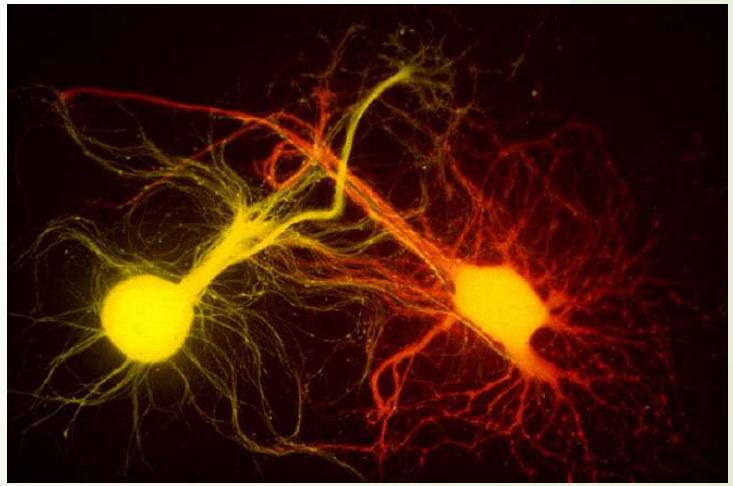

Benjamin
Cummings

How are neurons connected?

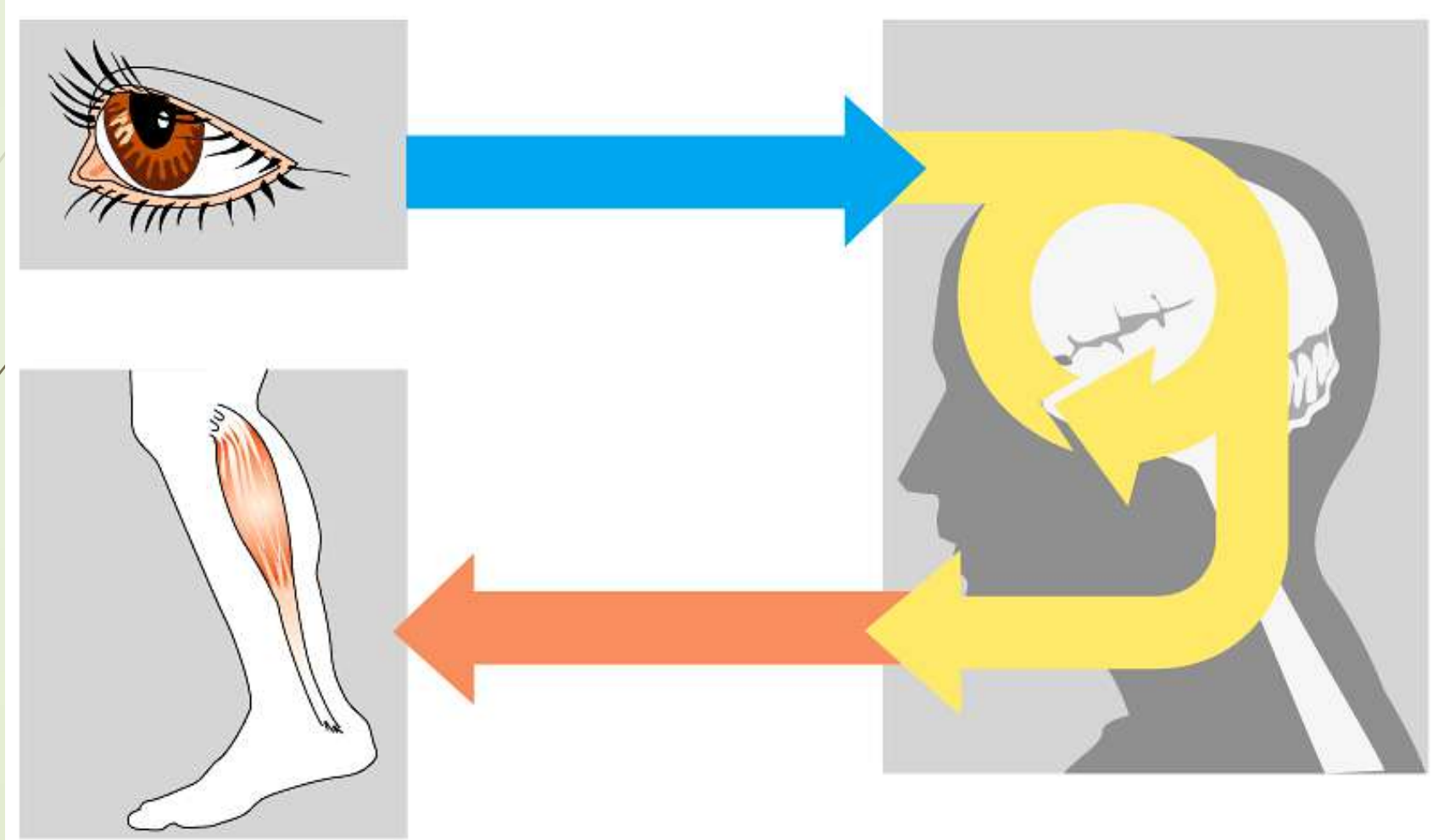
- Synapses!!



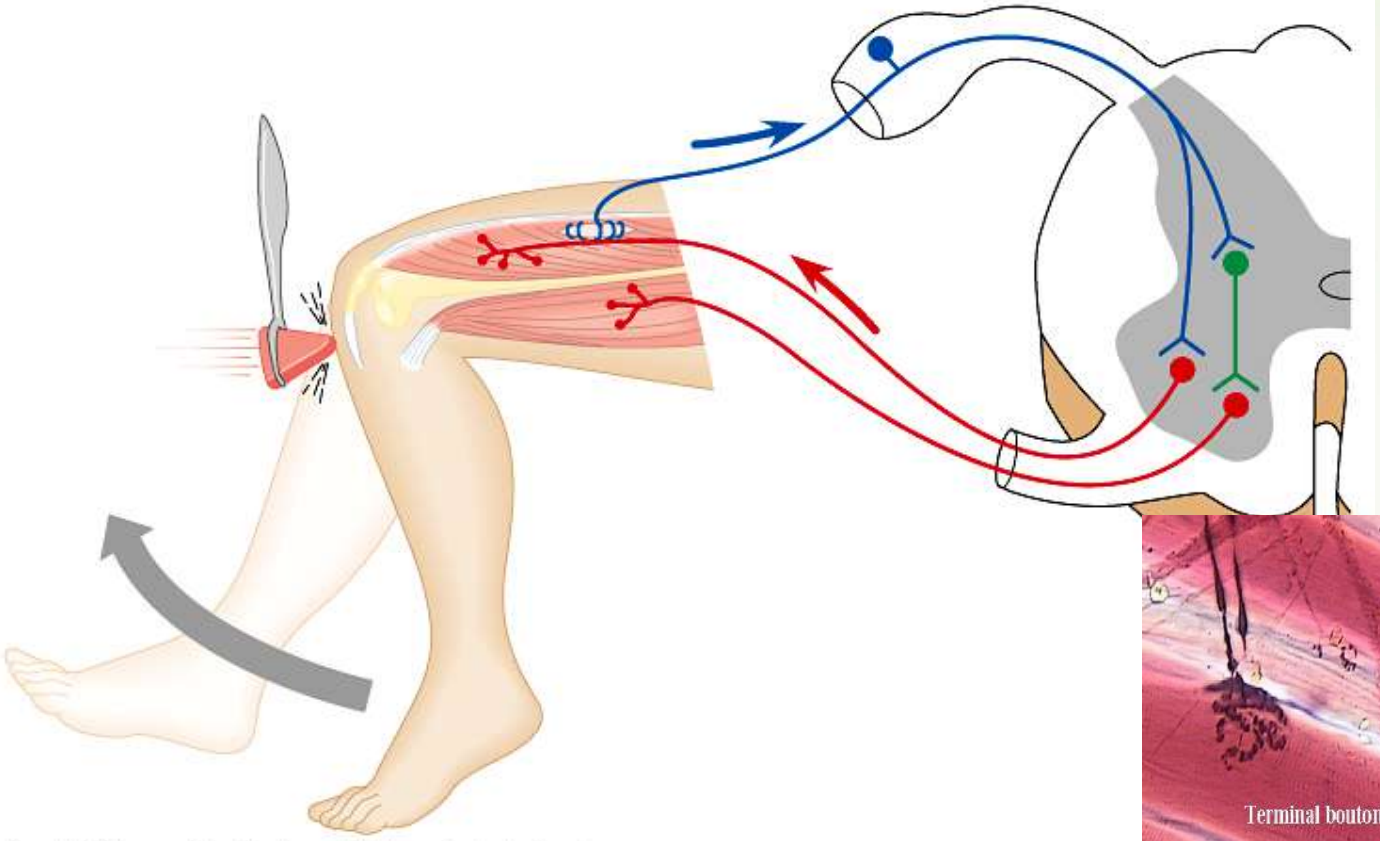


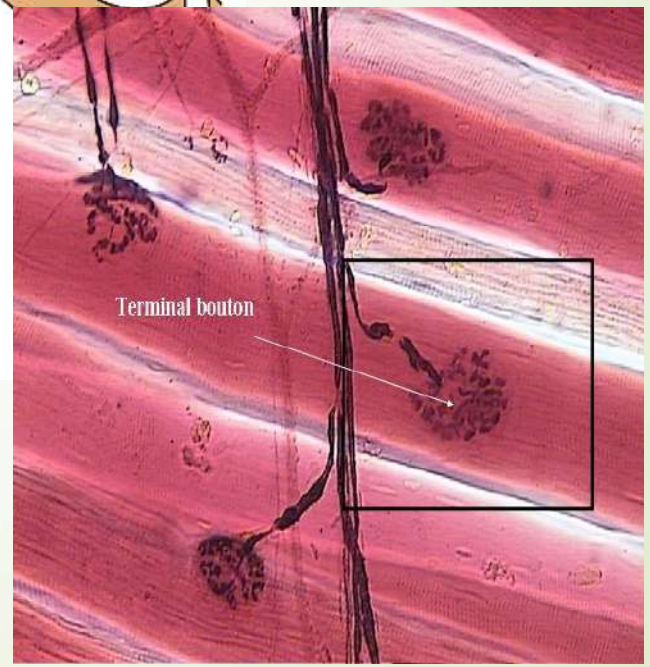


Why are neurons connected?

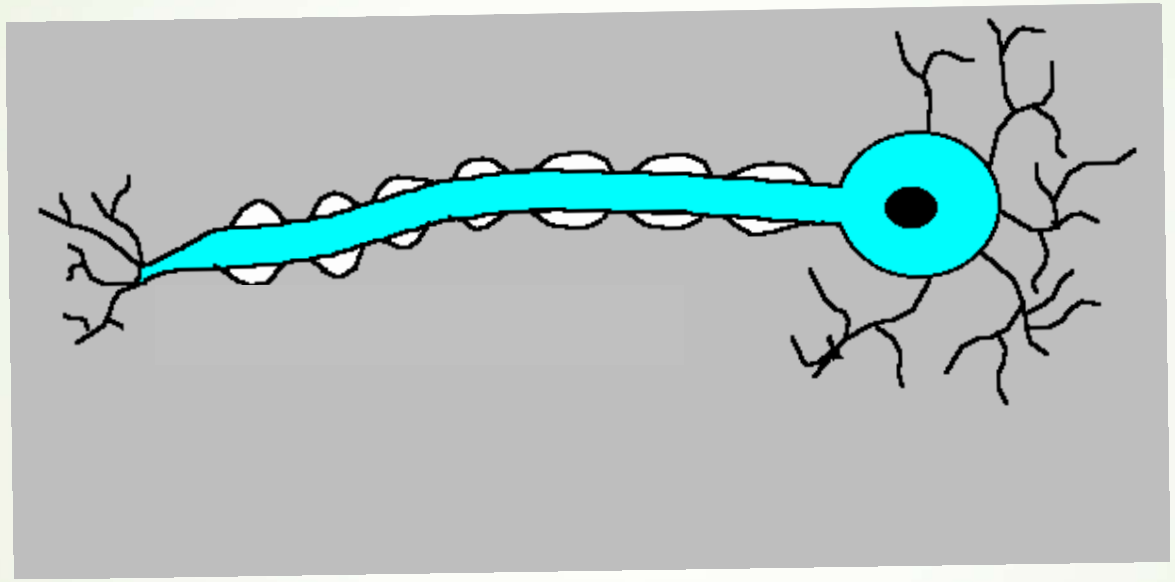


More neuron connections!





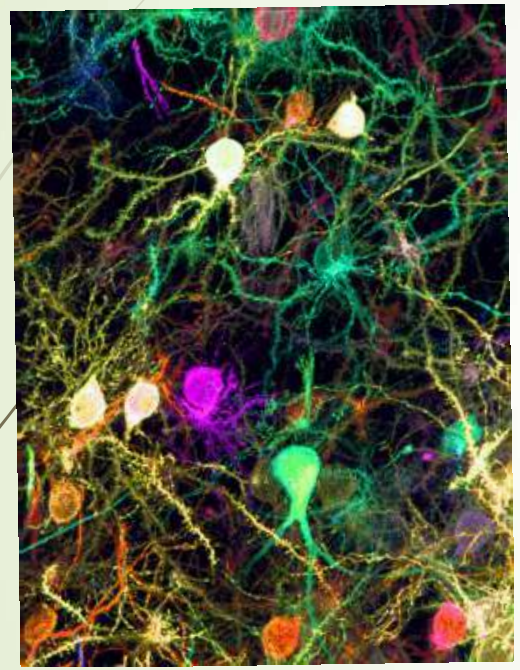
There are lots of proteins and chemicals in your body to do the work

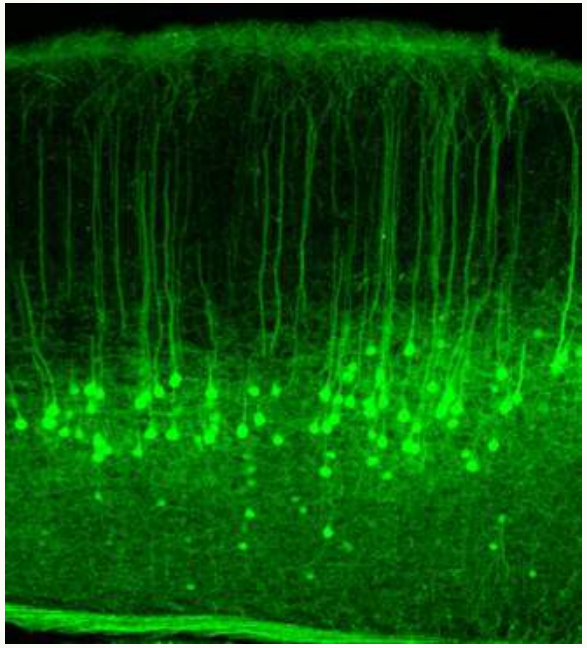


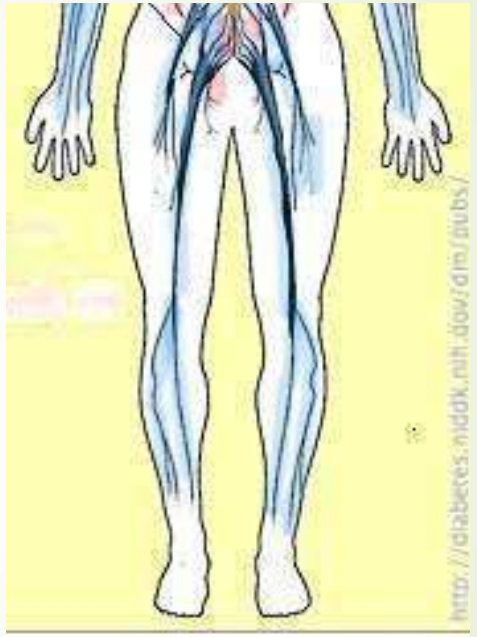
Why is it important that it is an electrical current?

Are all neurons equal in size?

- Brain vs spinal cord vs peripheral nerves?







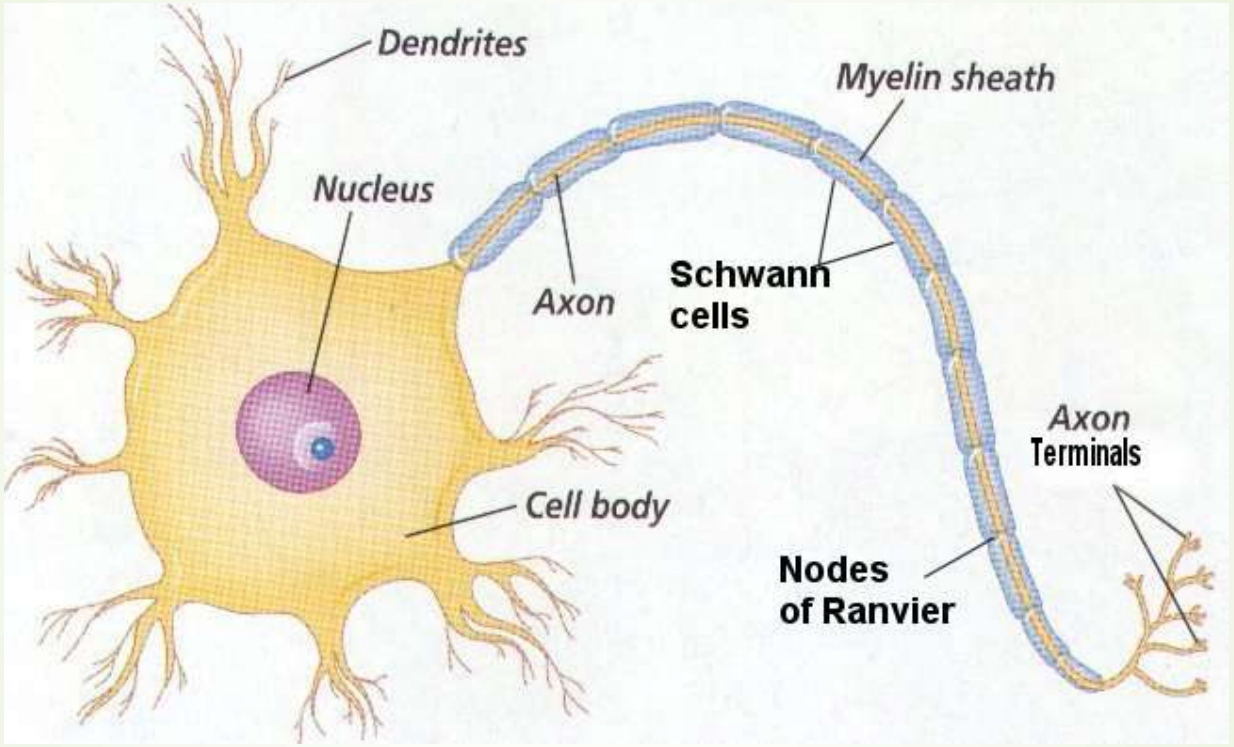
About how many neurons are in the human brain? 100 billion

About how many neurons are in the spinal cord? 1 billion

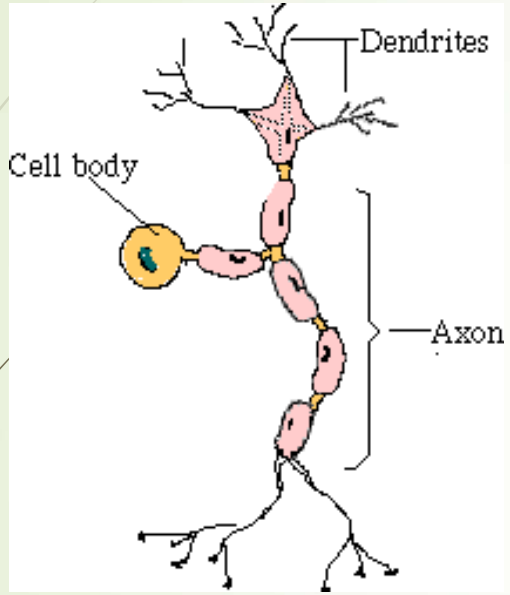
How long do you think the longest axon in the world is? around 15 feet

1 foot = 0.305 meter

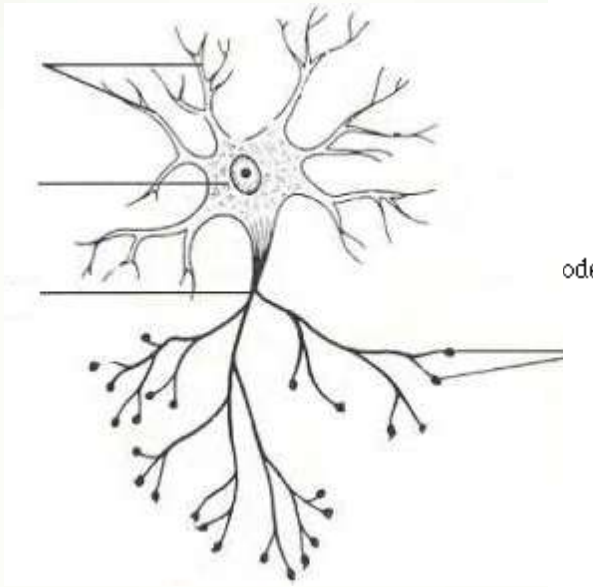
Basic nerve cell structure



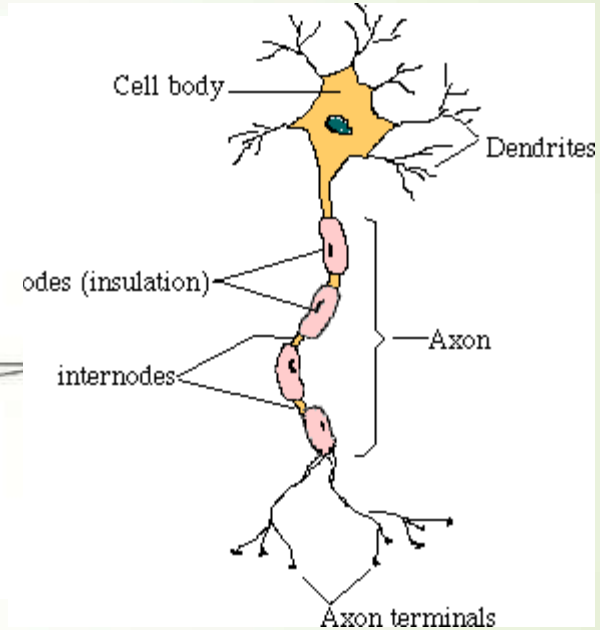
3 main types of nerve cells



sensory neurone

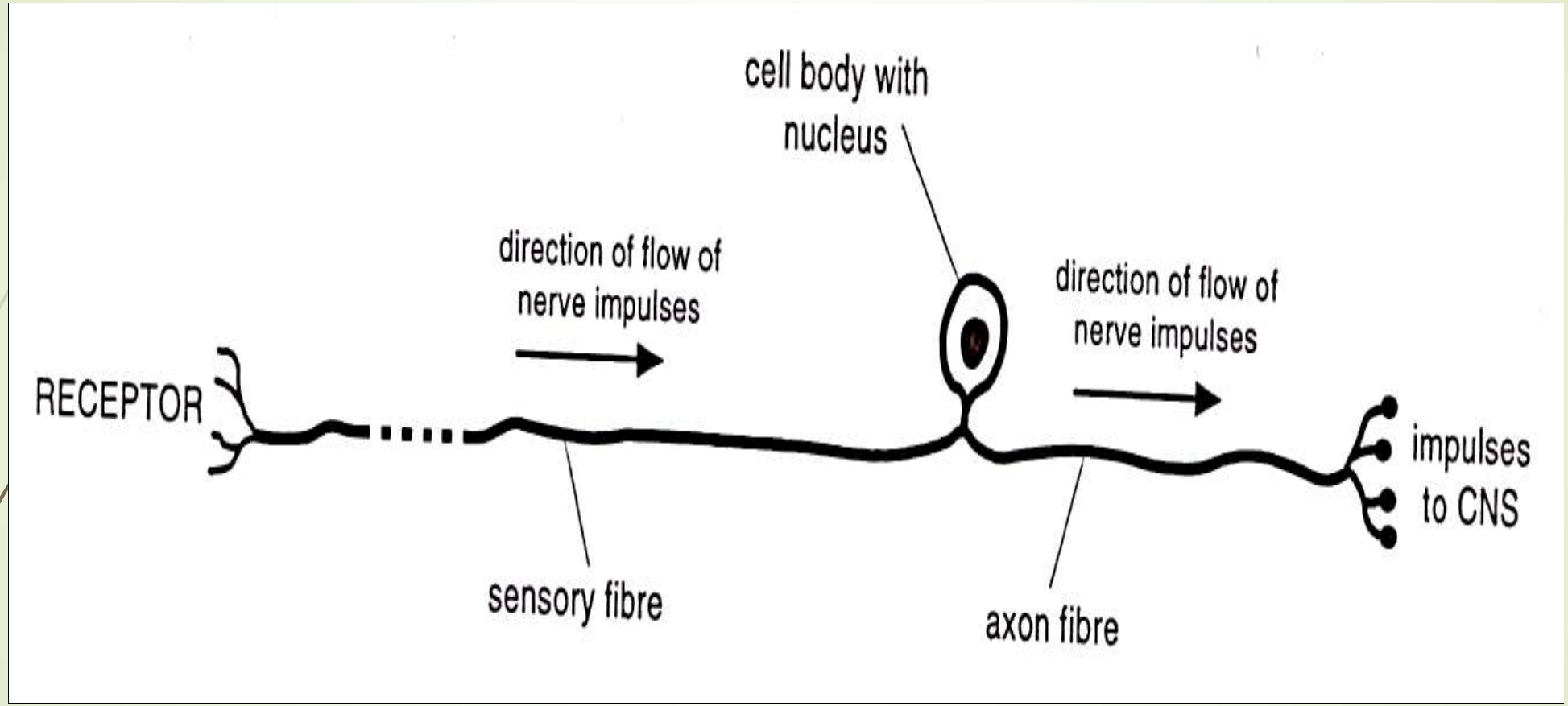


relay neurone



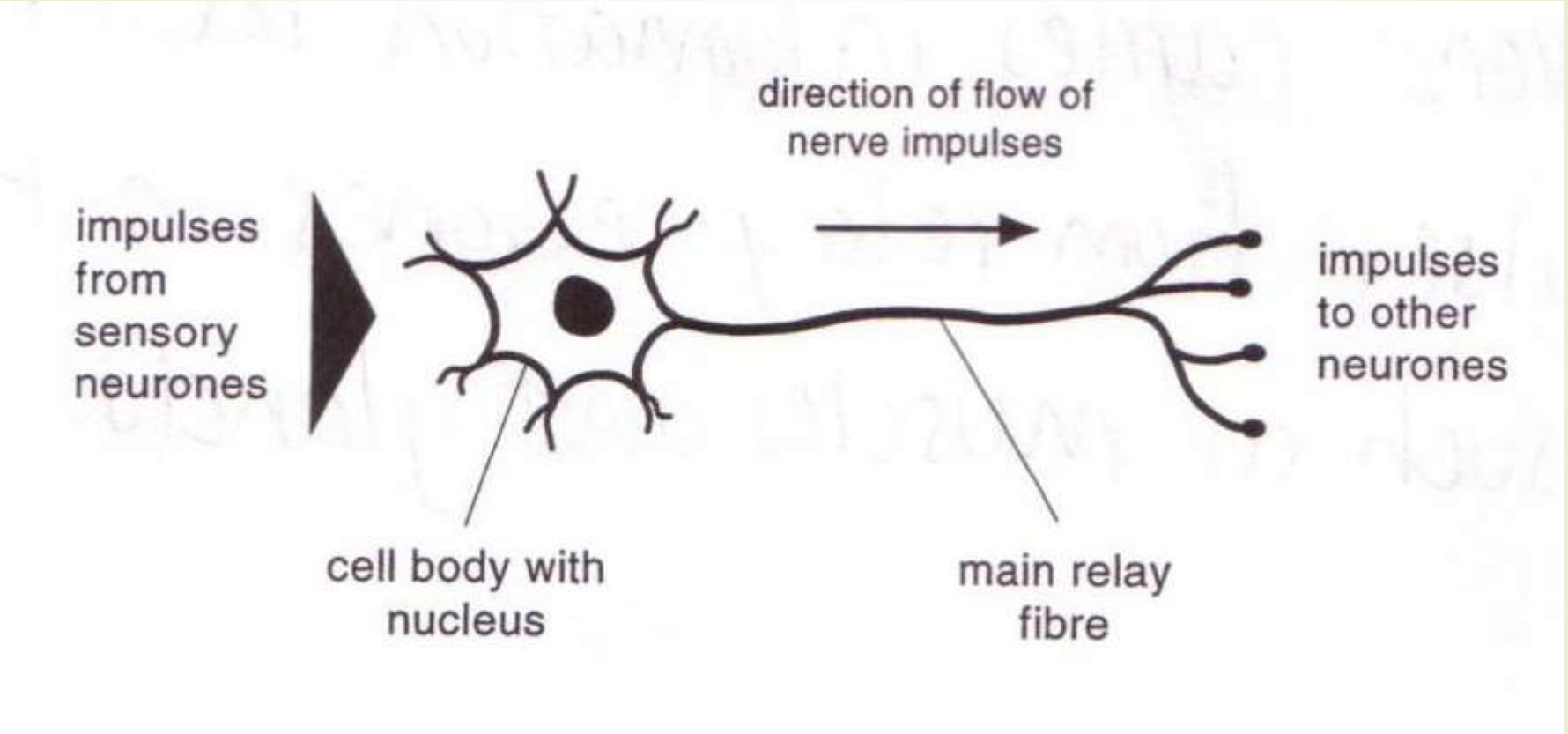
motor neurone

Sensory neurons



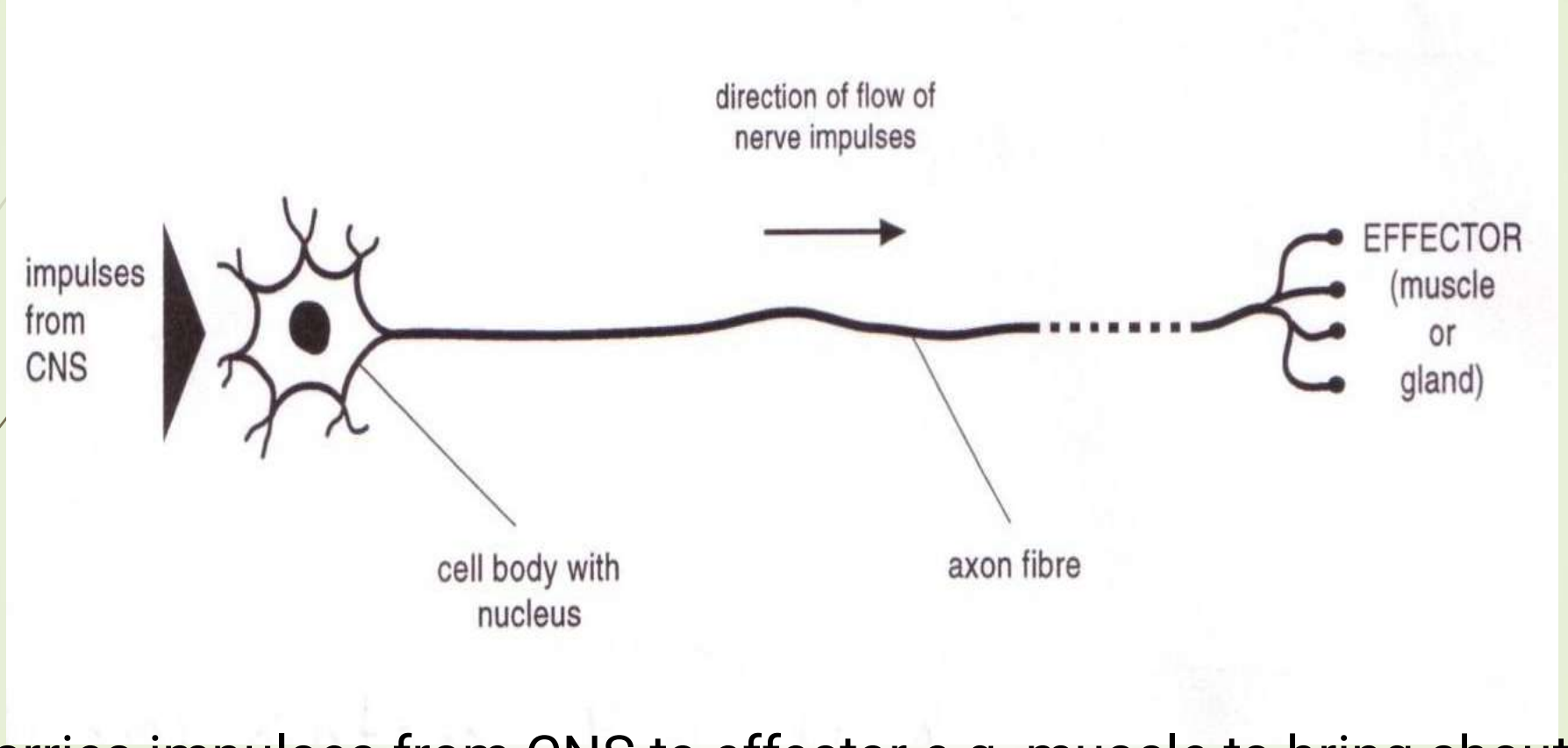
Carries impulses from receptors e.g pain receptors in skin to the CNS(brain or spinal cord)

Relay neuron



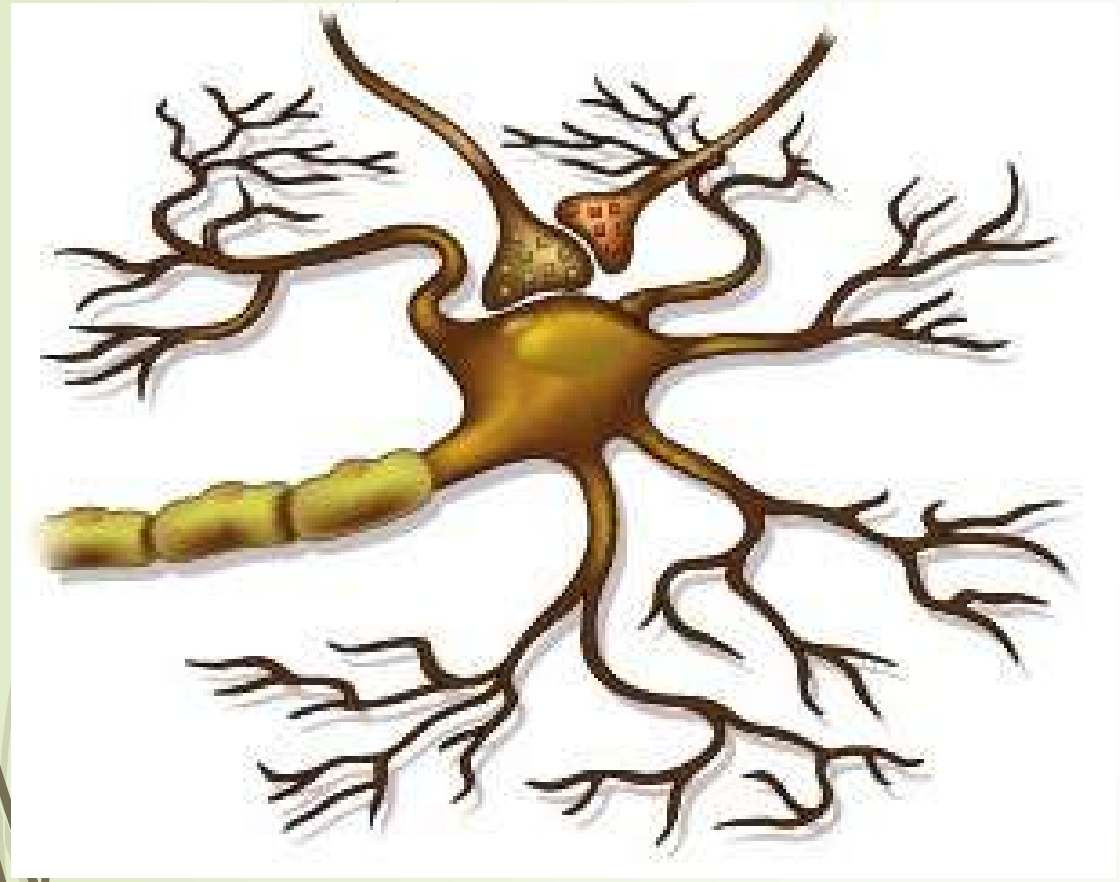
Carries impulses from sensory nerves to motor nerves.

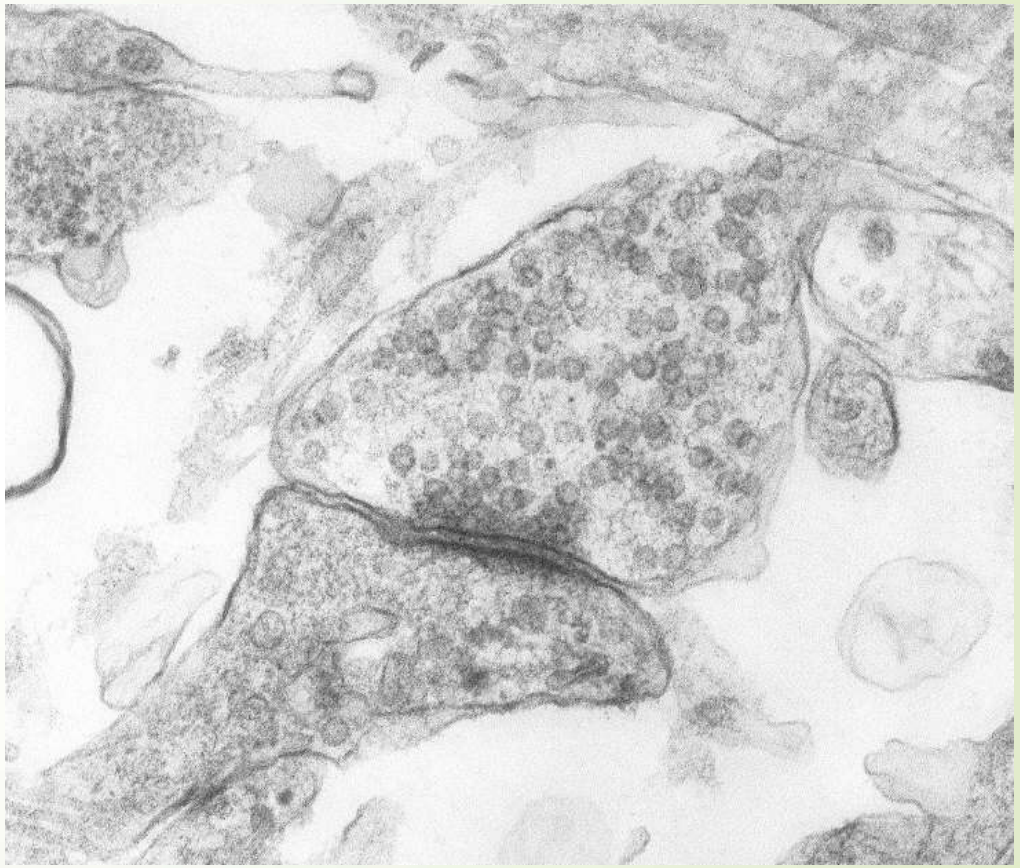
Motor neuron

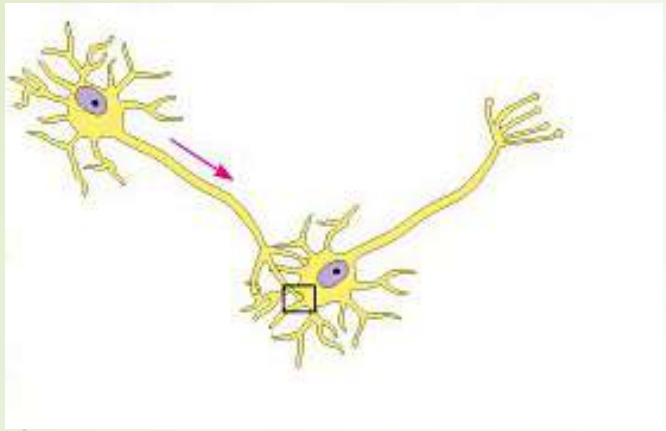


Carries impulses from CNS to effector e.g. muscle to bring about movement or gland to bring about secretion of hormone e.g ADH

Transmission of signals

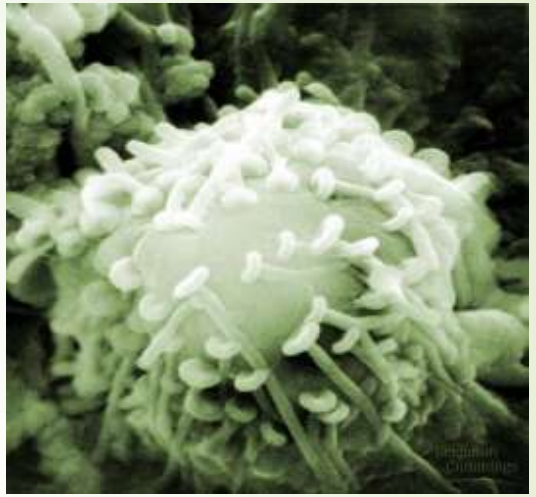


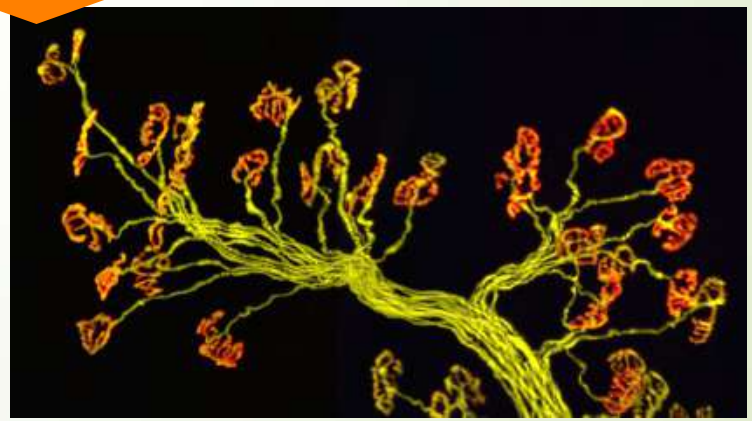




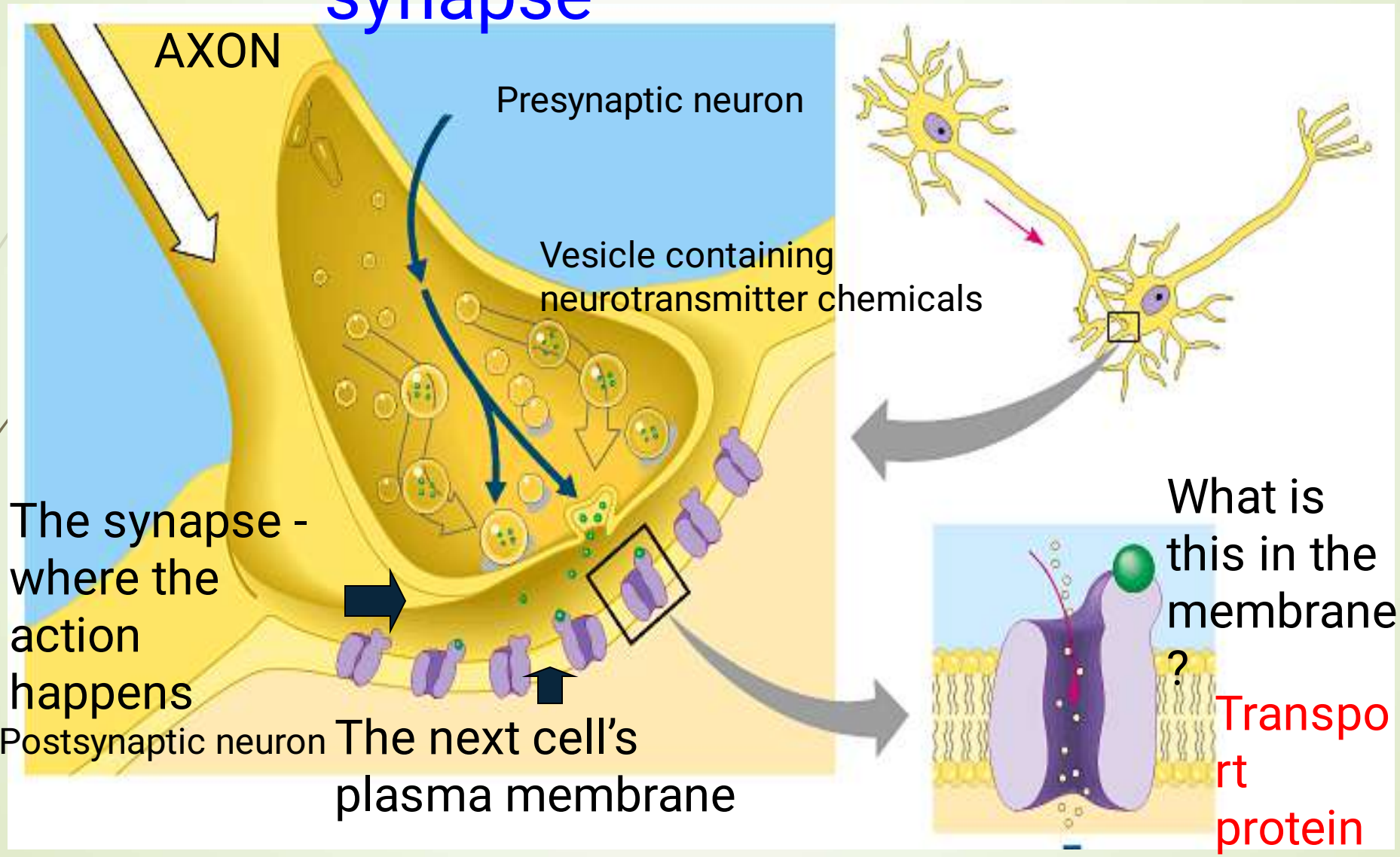
How many synapses are in one neuron?

1,000 to 10,000!!





Close up look at your synapse



End

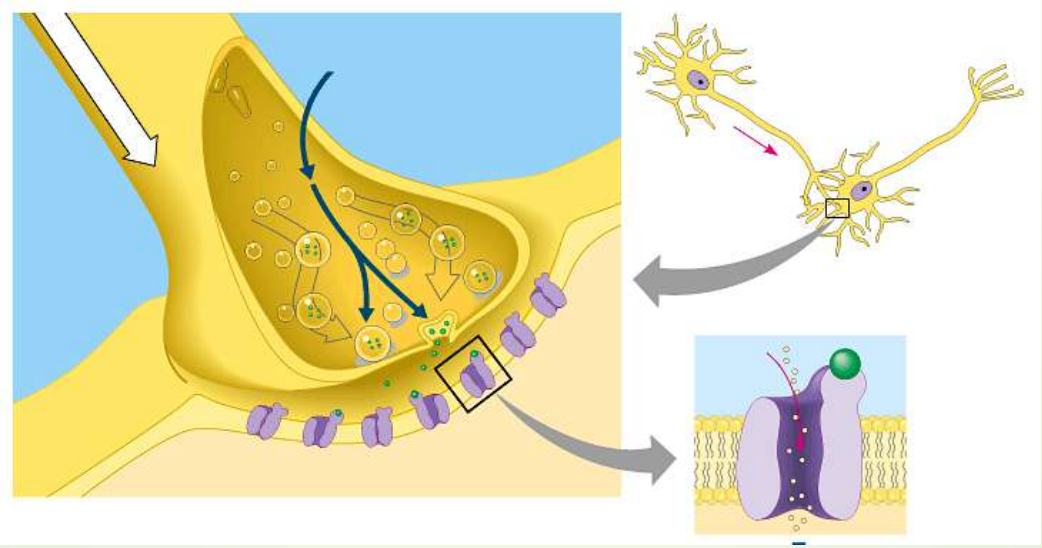
Thank you

The Nervous System

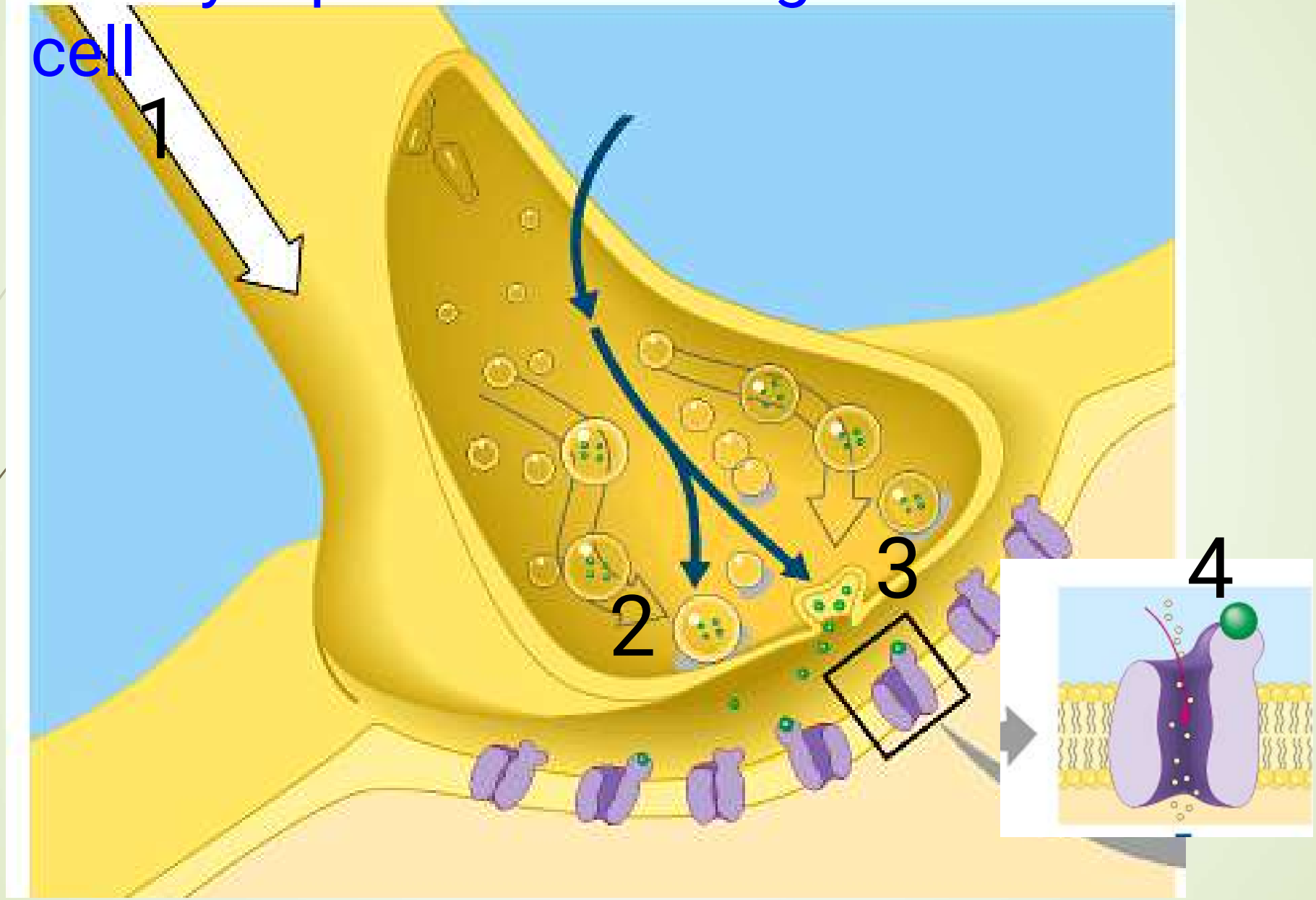
How Does It Work?

How does the Synapse carry the signal?

1. Electrical current travels down the axon
2. Vesicles with chemicals move toward the membrane - what is that called?
3. Chemicals are released and diffuse toward the next cell's plasma membrane
4. The chemicals open up the transport proteins and allow the signal to pass to the next cell - what type of diffusion is this?



The synapse carries a signal from cell to cell



Events at the Synapse

AP reaches axon terminal

↓

Voltage-gated Ca^{2+} channels open

↓

Ca^{2+} entry

↓

Exocytosis of neurotransmitter containing vesicles

Ca^{2+} = Signal for Neurotransmitter Release

Synapse

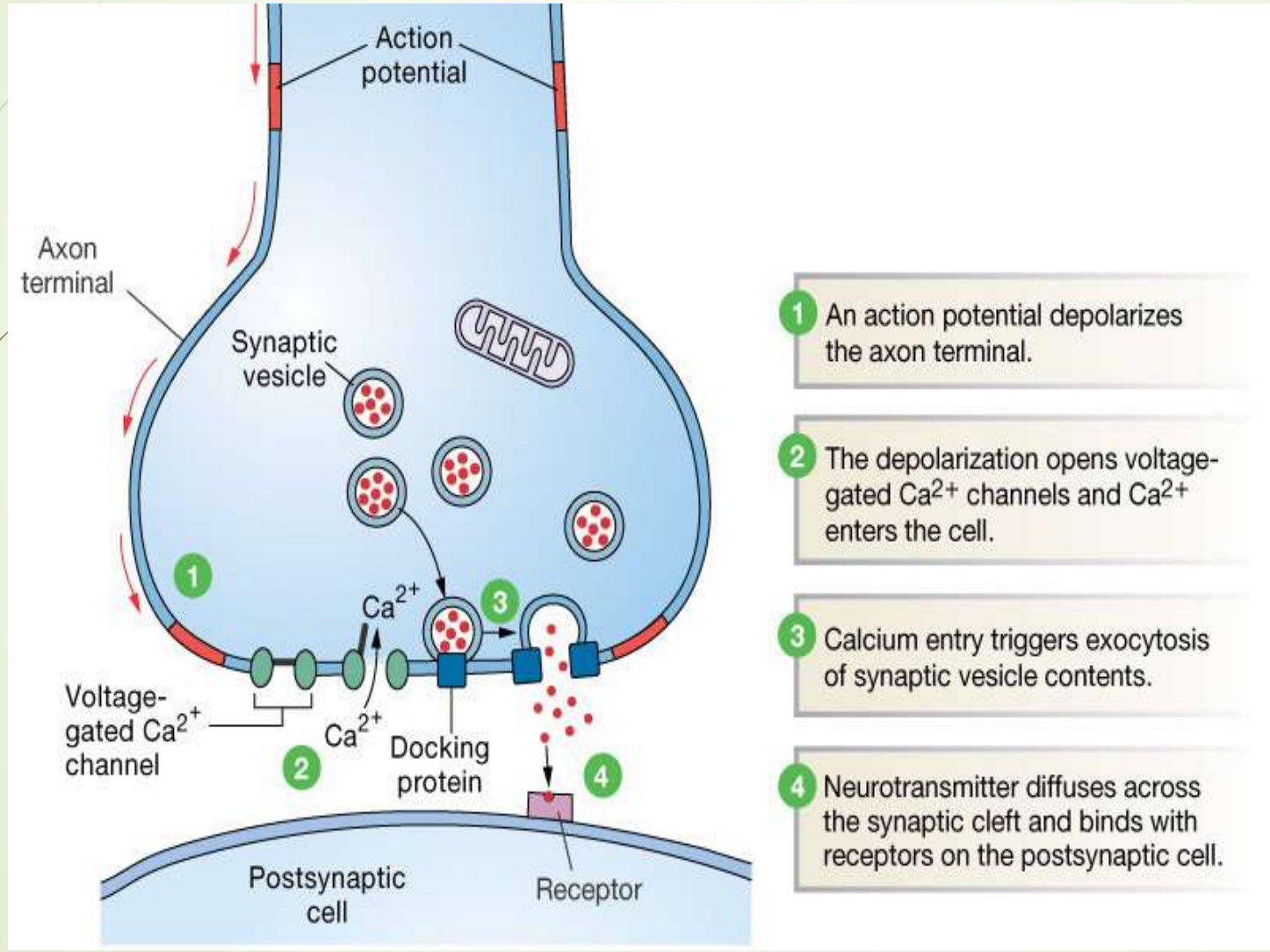


Fig 8-21

3 Classes of Neurotransmitters (of 7)

Fig 8-22

- Acetyl Choline (ACh)
  - Made from Acetyl CoA and choline
  - Synthesized in axon terminal
  - Quickly degraded by ACh-esterase
  - Cholinergic neurons and receptors – Nicotinic (agonistic) and muscarinic (antagonist)
- Amines
  - Serotonin (tryptophane) and Histamine (histidine)
    - SSRI = antidepressants
  - Dopamine and Norepinephrine (tyrosine)
  - Widely used in brain, role in emotional behavior (NE used in ANS)
  - Adrenergic neurons and receptors - and
- Gases
  - NO (nitric oxide) and CO
- Others: AA, (e.g., GABA), lipids, peptides, purines

Synthesis and Recycling of ACh at Synapse

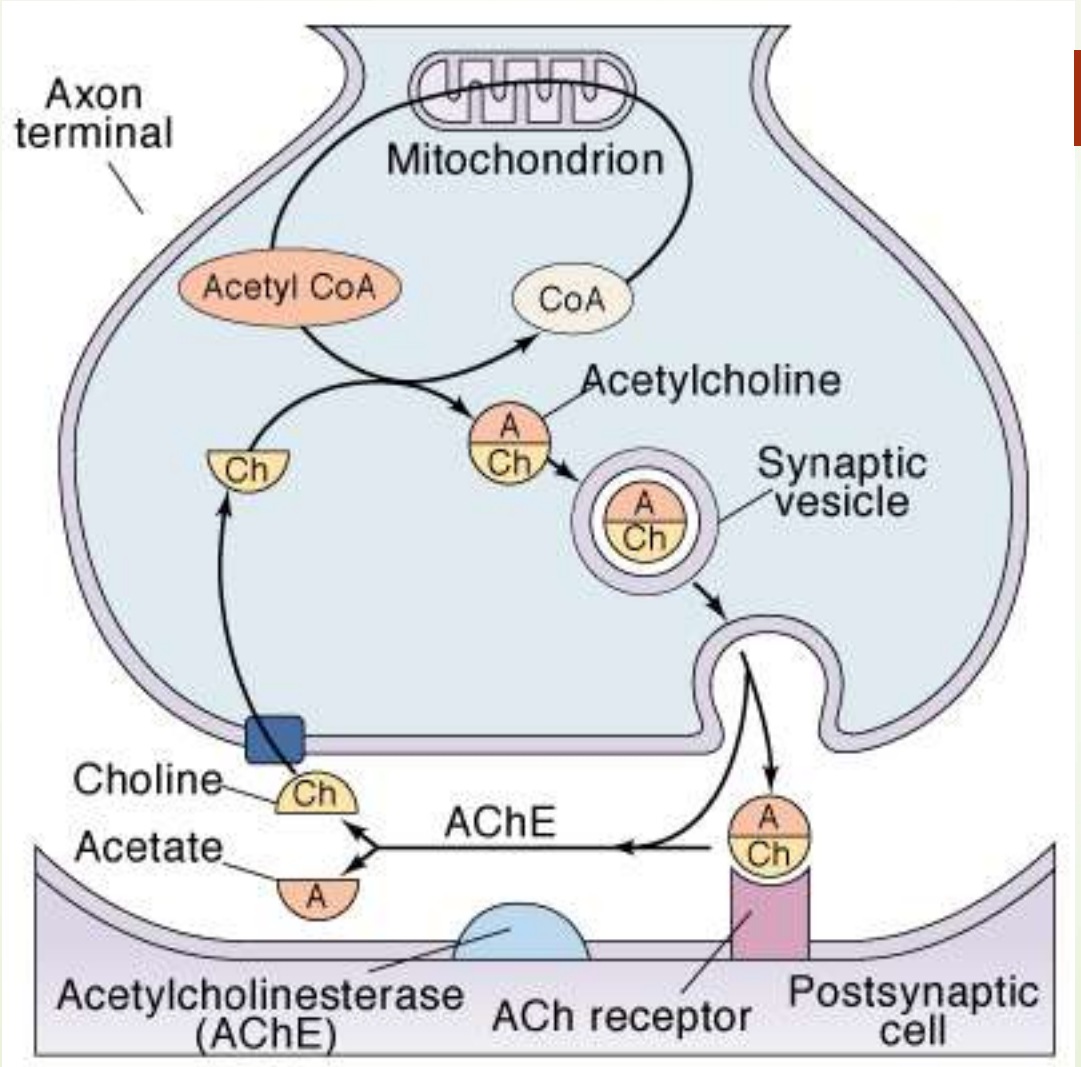
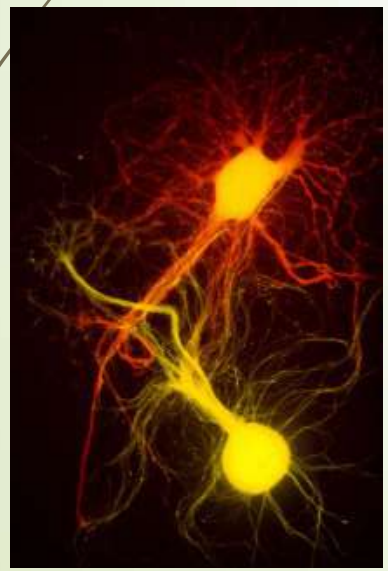
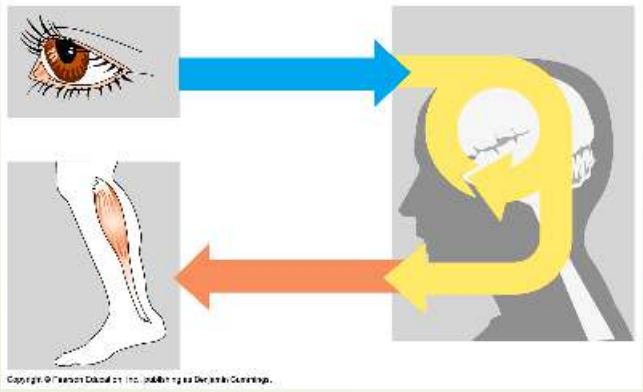


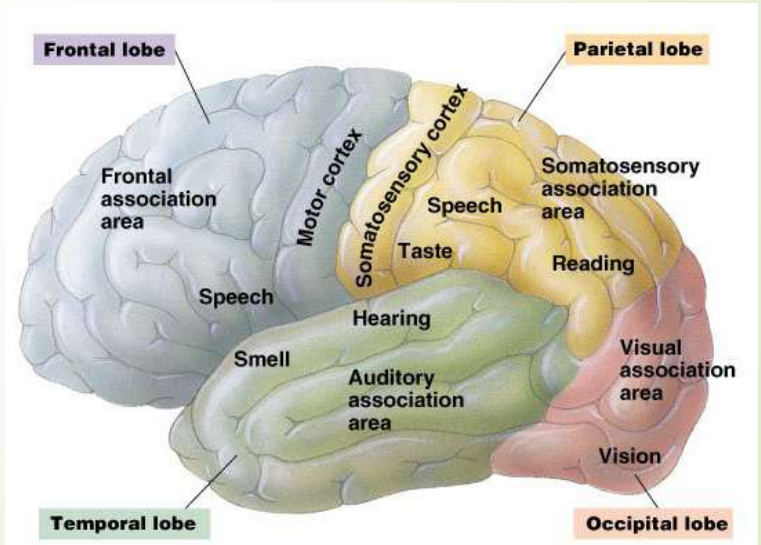
Fig 8-22

This science is called Neurobiology

- Looking at the actual cells - how do they work?
- Looking at the connections - how and when do they work?
- Looking at what can change normal cells and connections
- Looking at diseases that occur in the brain
- One of the largest areas still unknown
- The you that is you is because of your neurons connecting!







(b) Left side of brain

amin Cummings.

The Most Important Part of the Nervous System…

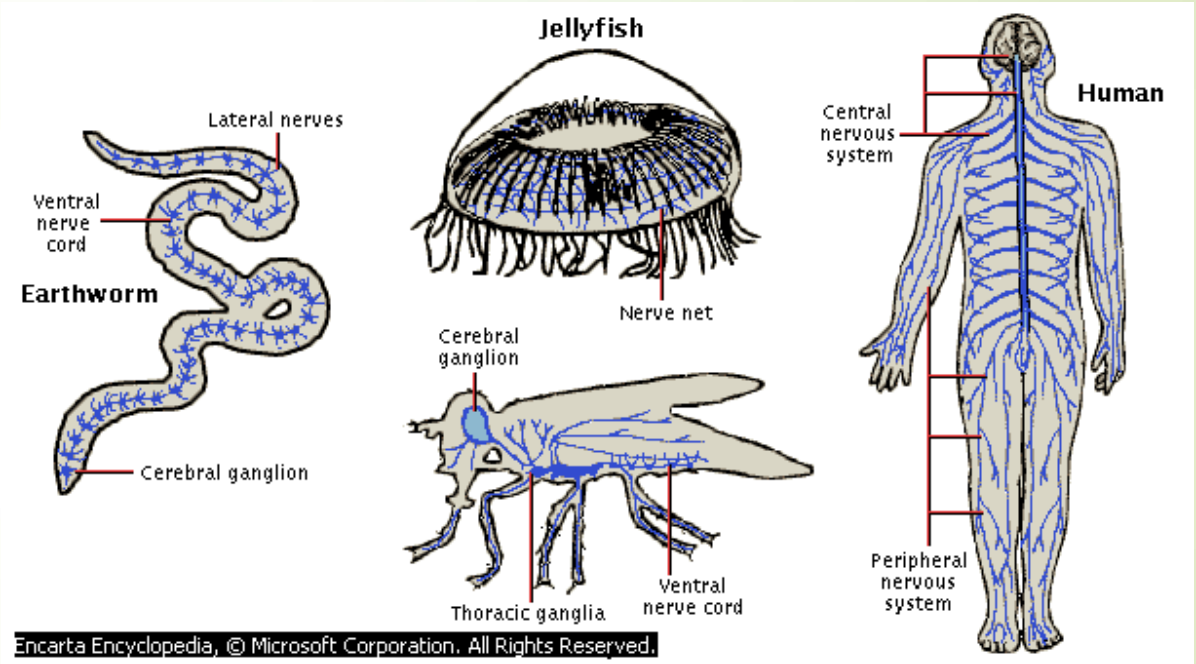
- Your brain controls everything that happens in your body.

The brain has two sides.

- The left side of the brain controls the right side of the body.
- The right side of the brain controls the left side of the body.

Nerves are like telephone lines.

- They send messages all over your body.
- These messages move through your body faster than you can blink your eyes.



Nerves travel through the spinal cord.

- Your spinal cord is like an extension cord that runs down the center of your back.
- It is protected by the backbone.

Interesting Facts

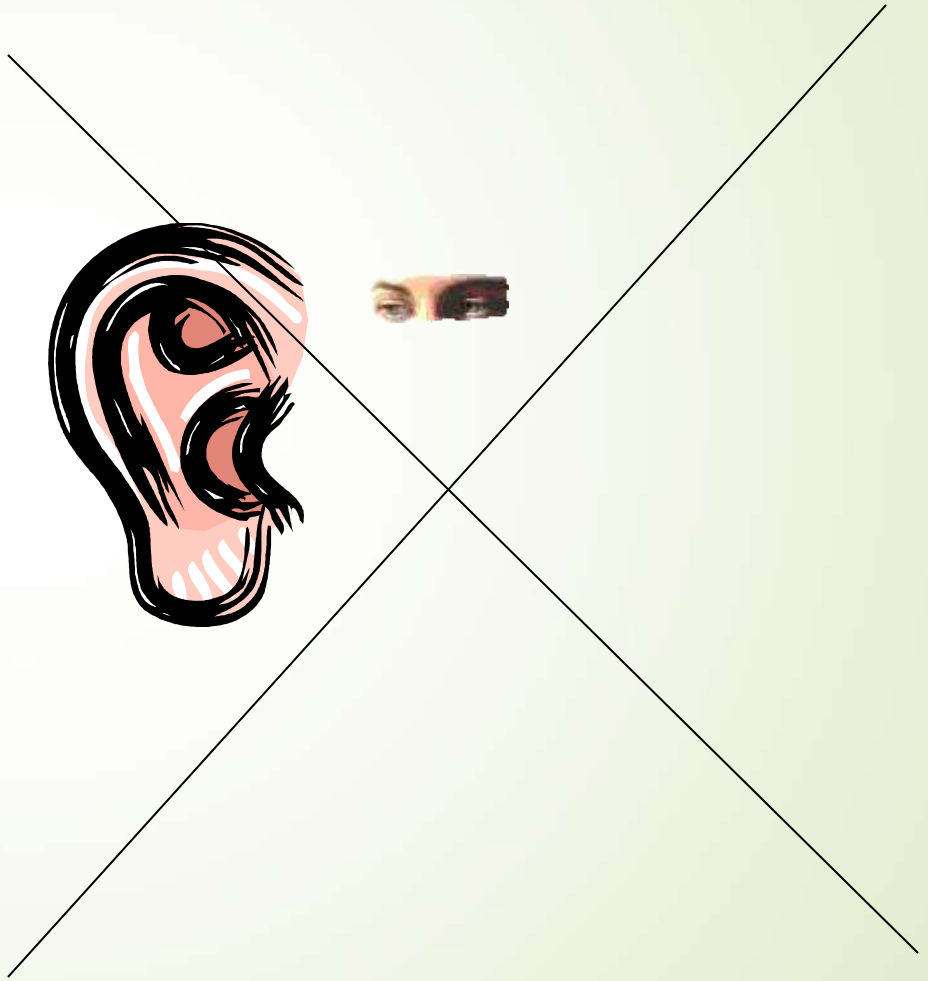
- Each side of the brain controls the opposite side of the body.
- Your brain is full grown by age 6.
- It weighs about three pounds.

1 pound = 433.59 grams

- Your brain is made mostly of water. (85%)

What if you had no brain or nerves?

- You wouldn’t be able to see, hear, smell, or talk.



Ways to keep your nervous system healthy…

Exercise

Read, Read, Read

THINK

Wear a helmet

Summary

Functions

- sends messages to the rest of the body
- controls all of the body functions

Components

- Brain – control center
- Nerves – carry messages
- Spinal cord – a thick bundle of nerves

Healthy Habits

- Exercise
- Do challenging activities that make you think
- read, read, read
- Lift things carefully – use your legs, not your back

End

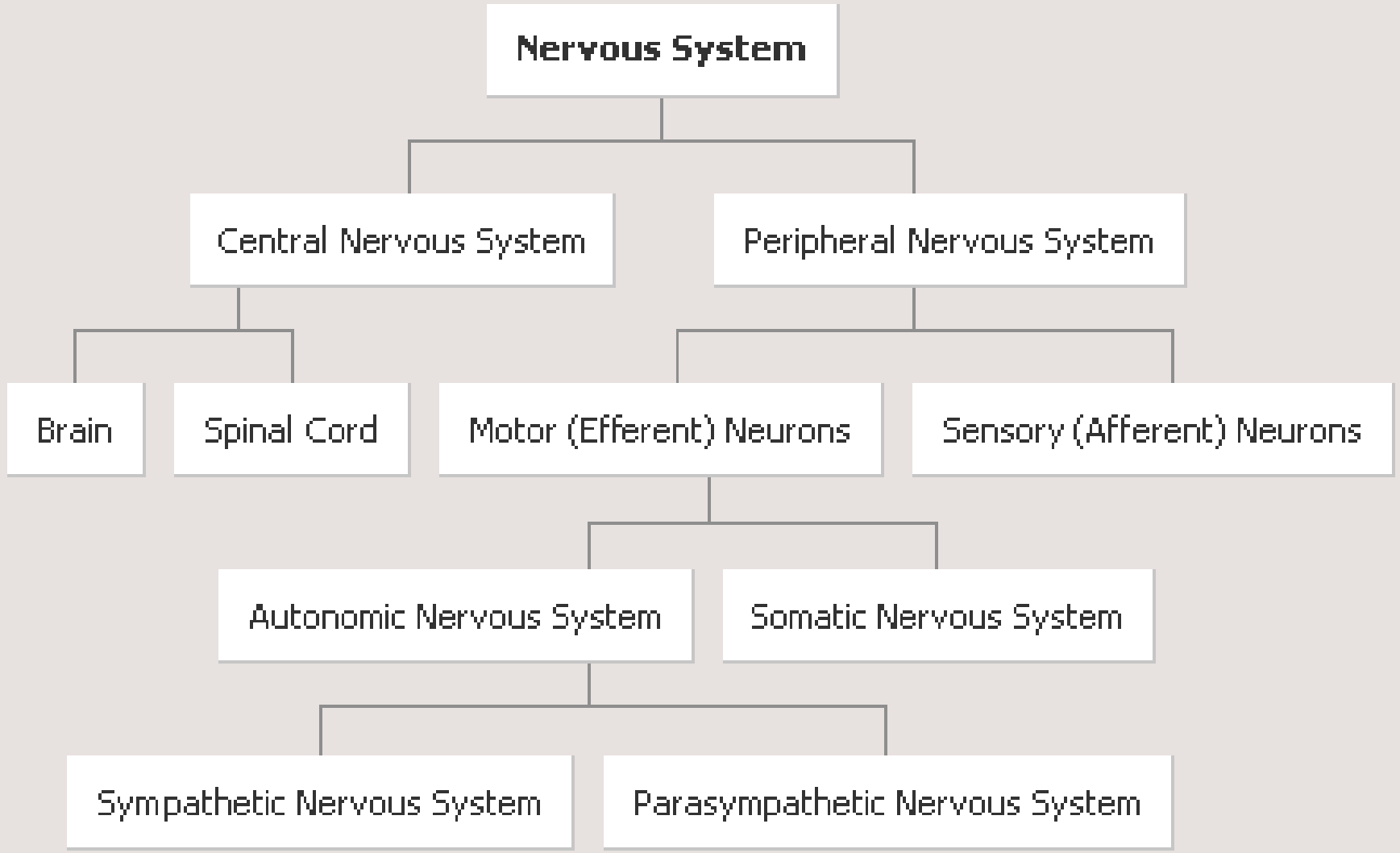
Thank you

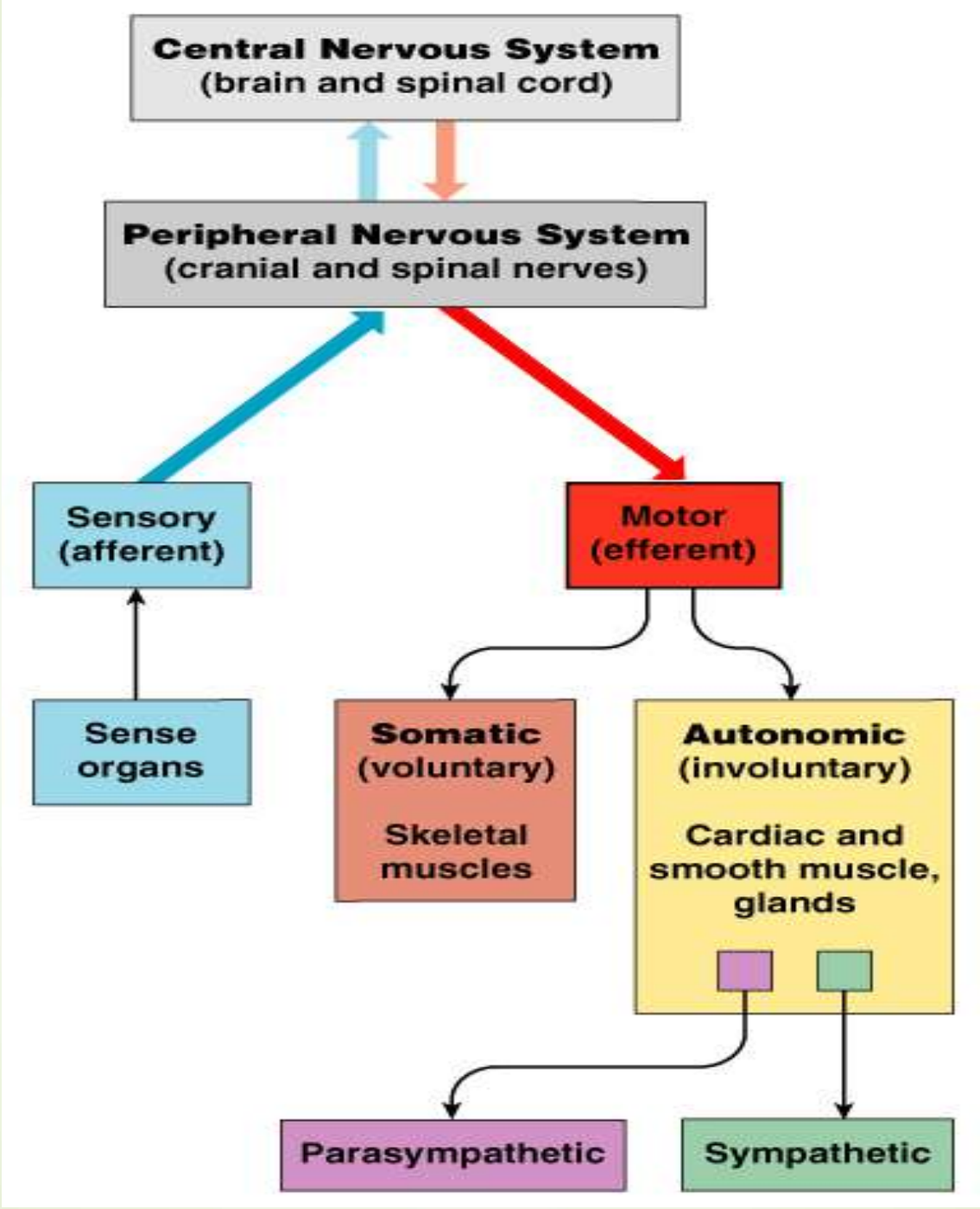
The Nervous System

How Does It Work?

The nervous system

- The nervous system (together with the endocrine system) controls and coordinates the functioning of the body.
- It provides the mechanism by which an individual can respond to changes in their internal and external environment.
- Every activity involving the nervous system includes:
  - A sensory function which detects, or senses, change and harmful stimuli.
  - An interpretive function which interprets sensory stimuli and organizes appropriate action.
  - A motor function which carries out the appropriate action.


Nervous System
Central Nervous System
Peripheral Nervous System
Brain
Spinal Cord
Motor (Efferent) Neurons
Sensory (Afferent) Neurons
Autonomic Nervous System
Somatic Nervous System
Sympathetic Nervous System
Parasympathetic Nervous System


Central Nervous System
(brain and spinal cord)
Peripheral Nervous System
(cranial and spinal nerves)
Sensory
(afferent)
Motor
(efferent)
Sense
organs
Somatic
(voluntary)
Skeletal
muscles
Autonomic
(involuntary)
Cardiac and
smooth muscle,
glands
Parasympathetic
Sympathetic

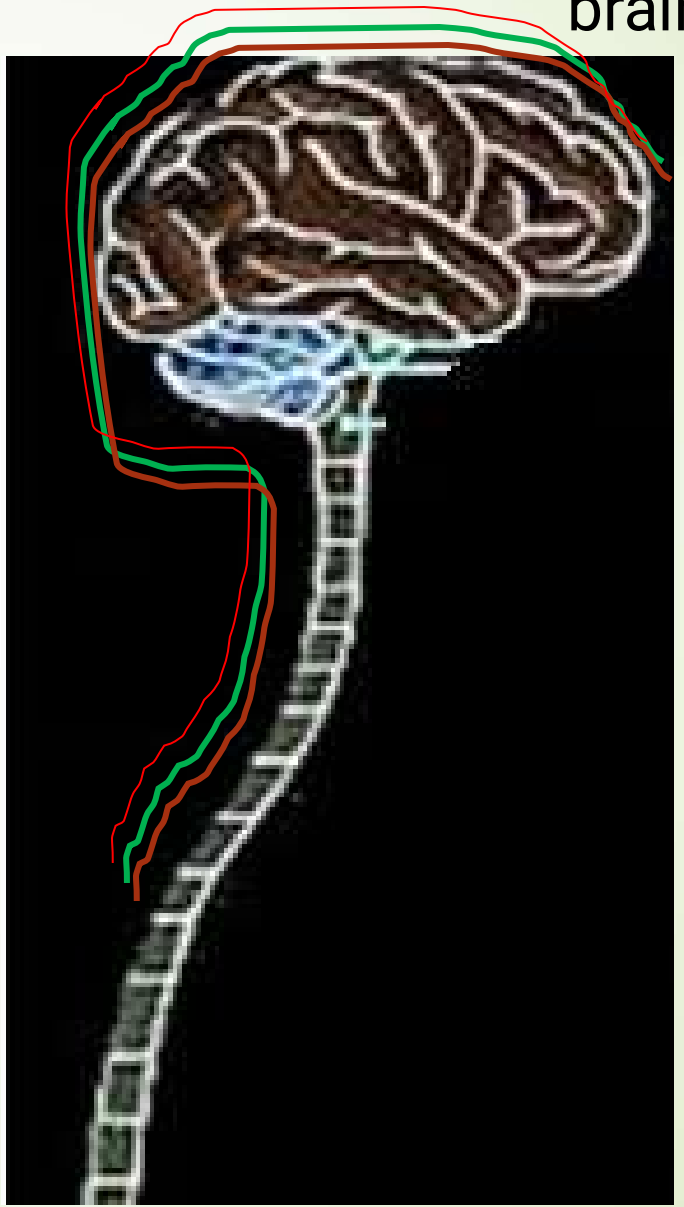
NERVOUS SYSTEM

CNS

The brain is protected by the cranium (skull), and the spinal cord by the vertebral column.

The brain and spinal cord are covered by three membrane called the meninges which consist of;

- An outer protective membrane called the dura mater.
- A middle membrane called the arachnoid mater.
- An inner membrane called the pia mater.



CSF

CEREBROSPINAL FLUID

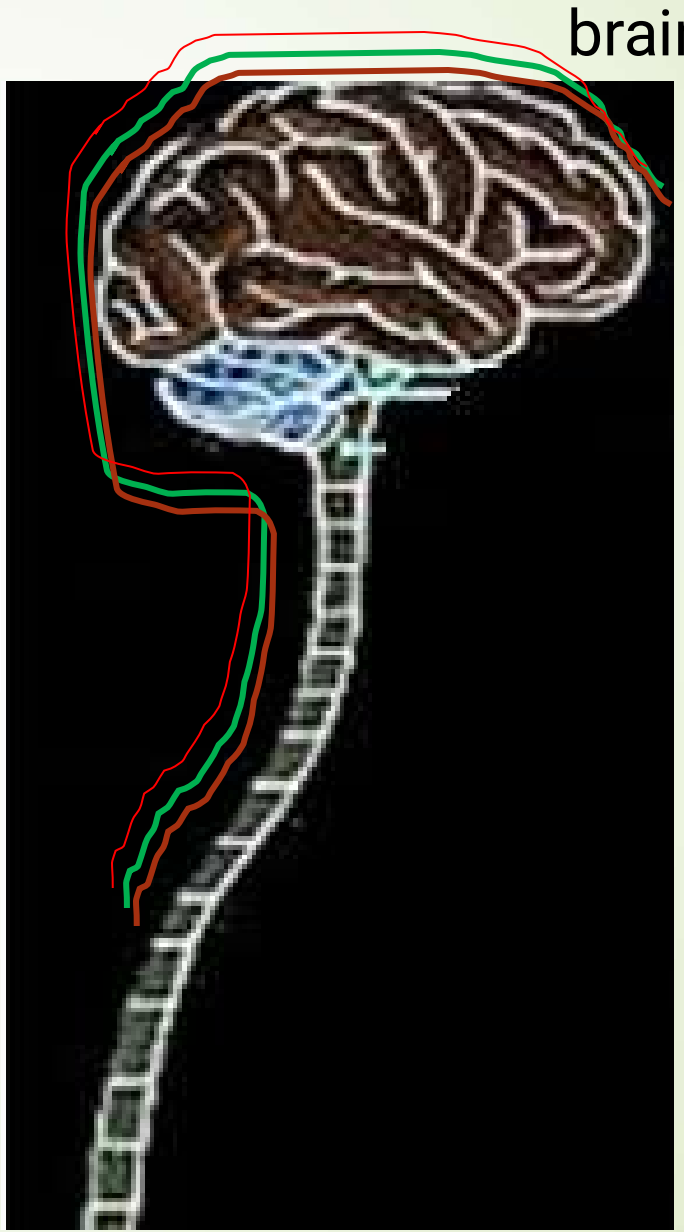
2-3 FOR SHOCK ABSORBENT

NERVOUS SYSTEM

CNS

Between the arachnoid mater and the pia mater there is a space called the Subarachnoid space.

This is filled with a fluid called cerebrospinal fluid which acts as a shock absorber and also as a circulatory system for the brain and spinal cord.



1- piamater

2- archunoid mater

3- dura mater

CSF

CERBROSPINAL FLUID

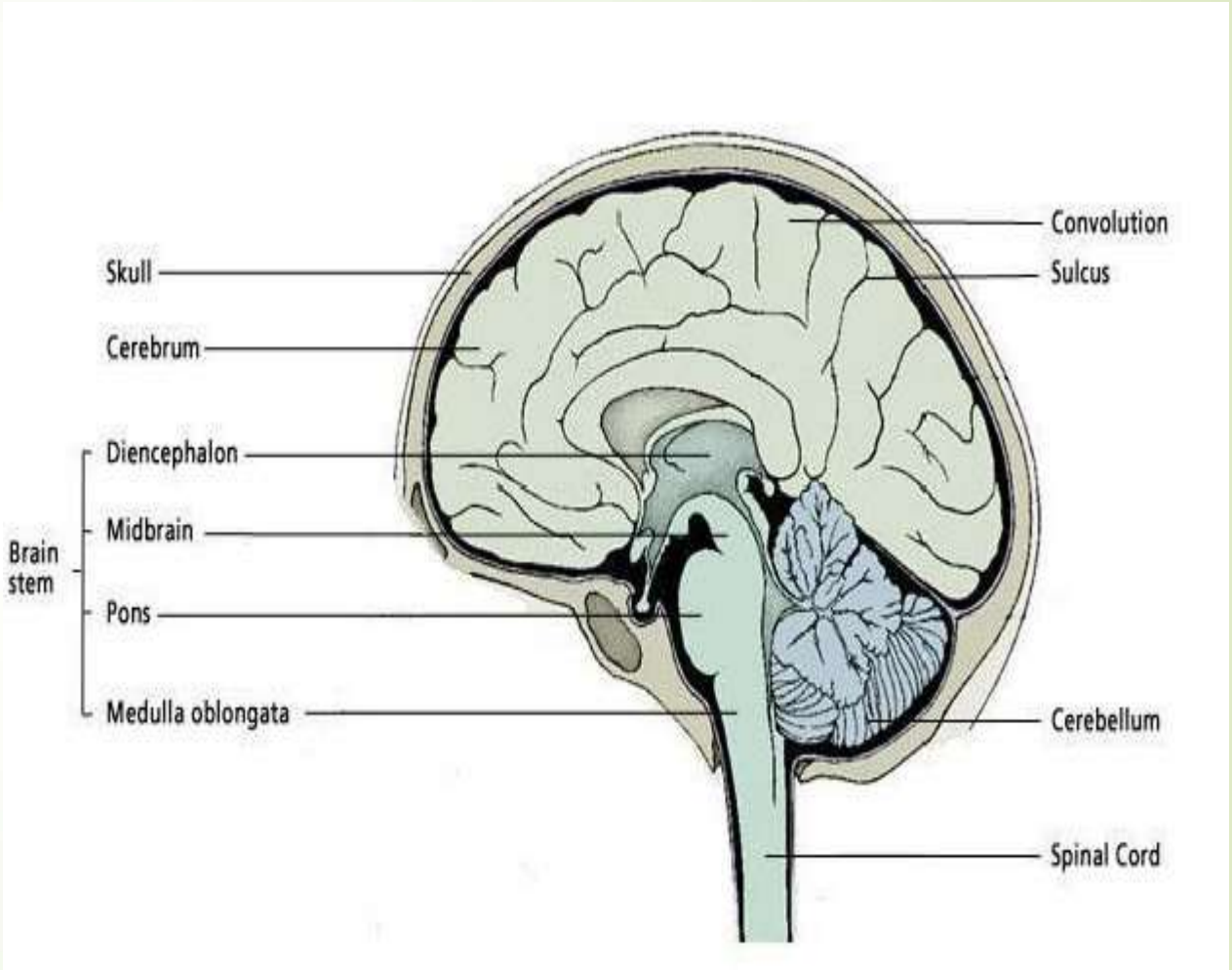
2-3 FOR SHOCK ABSORBENT

NERVOUS SYSTEM

Brain

The brain is the master control center for all nervous activity in the body

The main part's of the brain are



NERVOUS SYSTEM

cerebrum

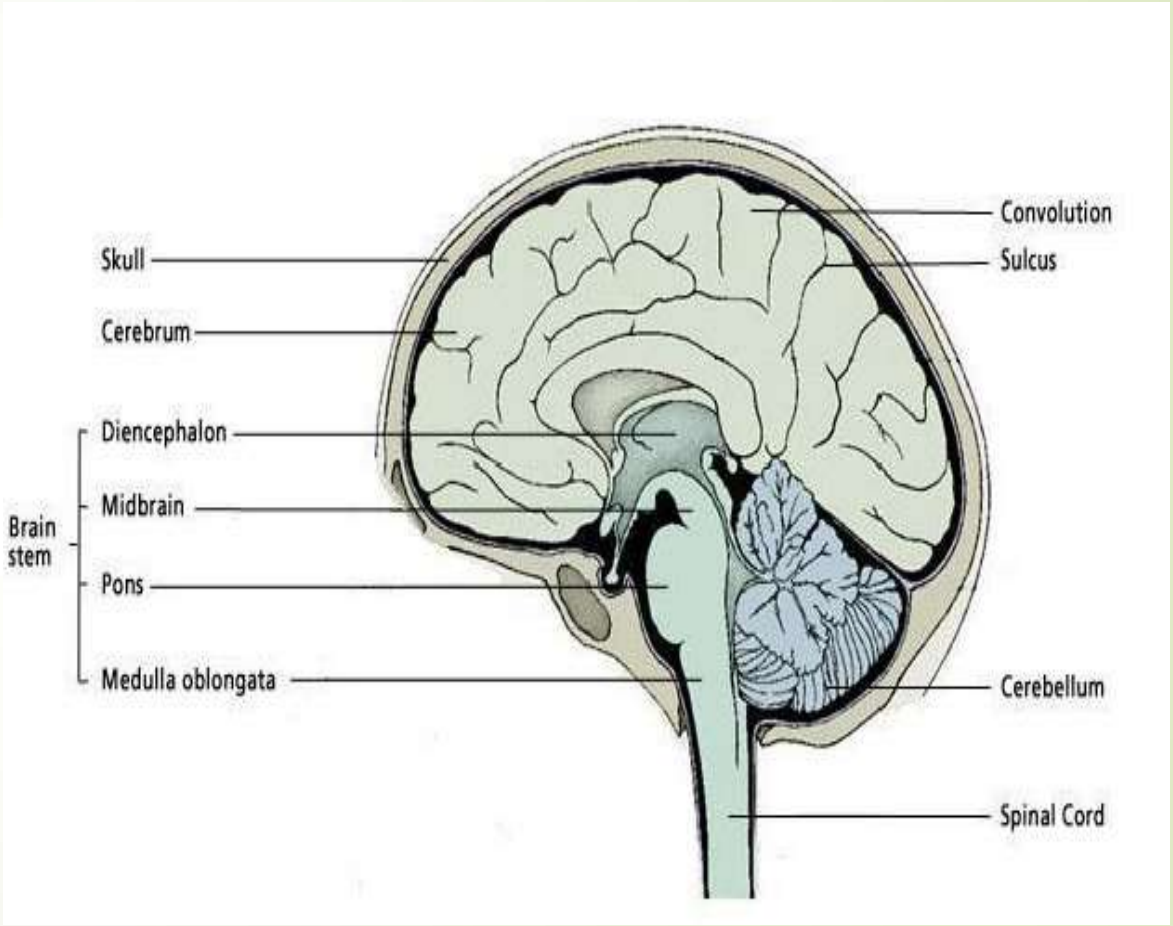
This is the largest part's of the brain,

it's made up of a mass of white nerve fibers covered by a folded (convoluted) grey layer called the cerebral cortex.

Cerebrum divided into tow similar halves (hemispheres).

The right halves coordinates activity of the left side of the body and

the left halves coordinates activity of the right side of the body

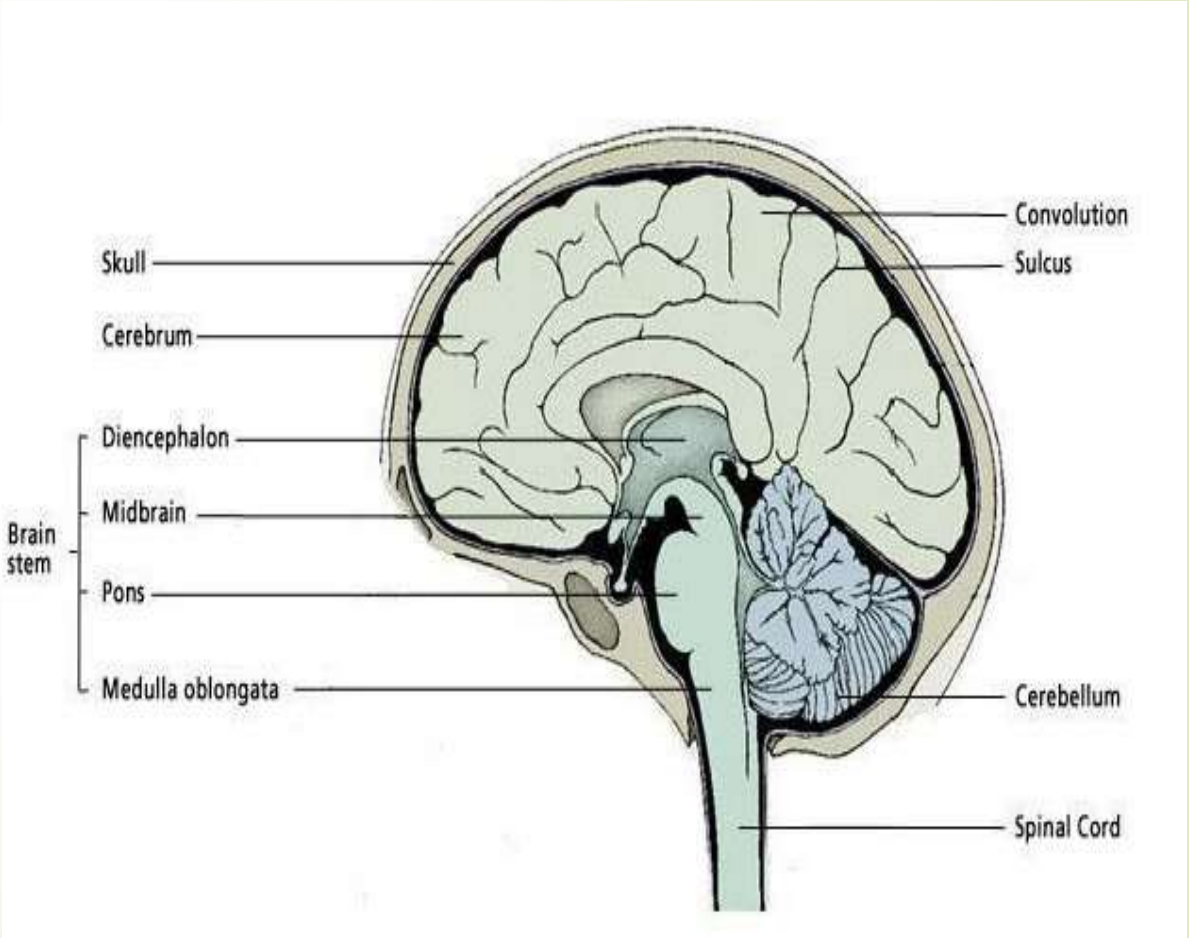


NERVOUS SYSTEM

cerebellum

- This part of the brain lies below and behind the cerebrum and is divided into tow lobes

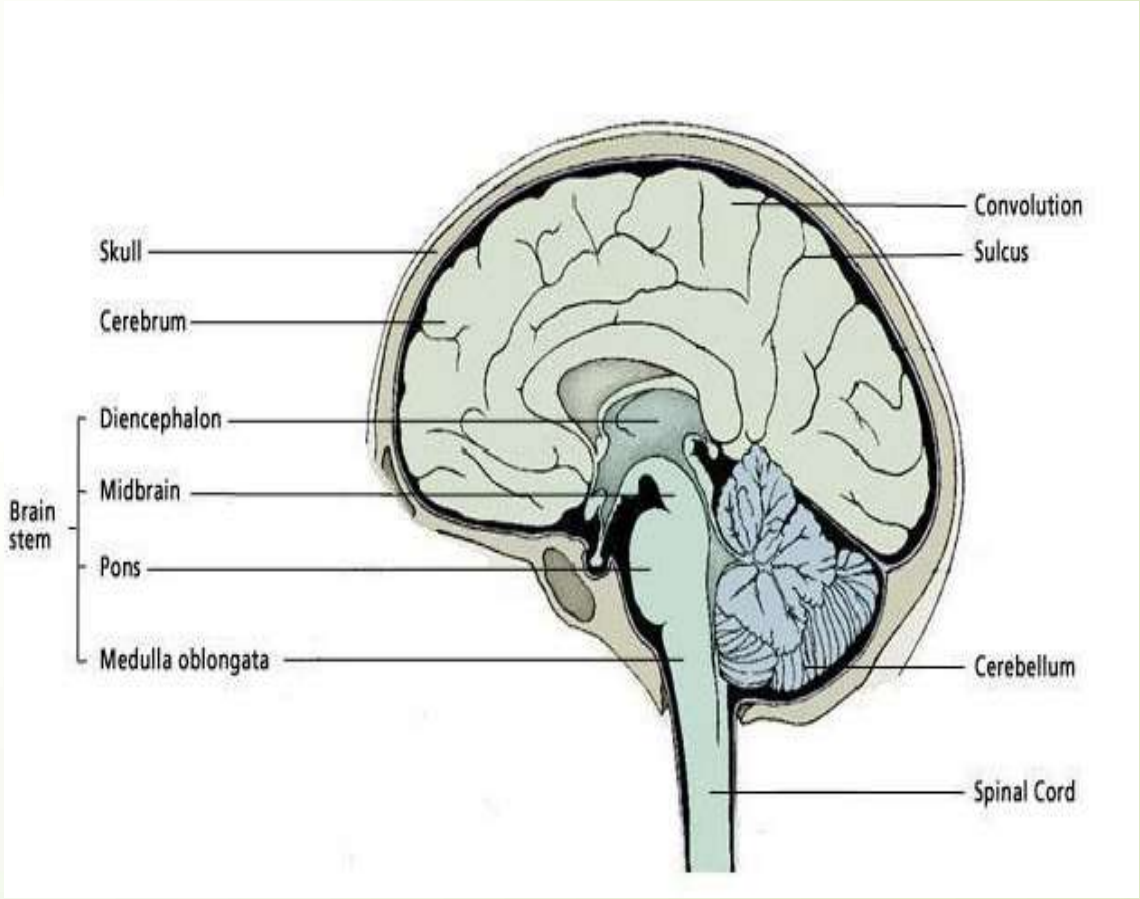
- It coordinates;
  - muscular activity,
  - posture and
  - balance in the body



NERVOUS SYSTEM

Pons varolii

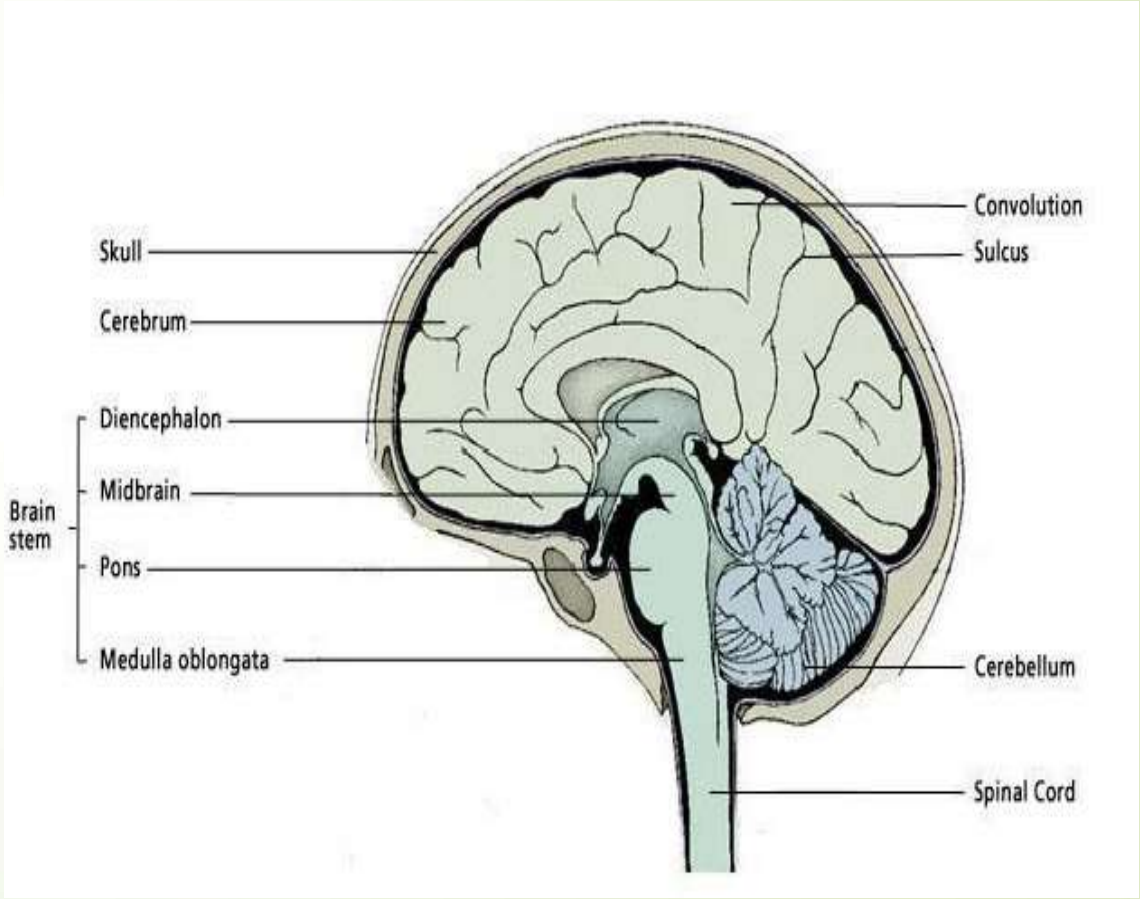
- This is situated at the base of the brain in front of the cerebellum,
- it's connects the various lobes of the brain.
- The groups of cells within it act as rely stations



NERVOUS SYSTEM

Medulla oblongata

- This is a small but very important part of the brain.
- It lies at the base of the brain and is continuous with the spinal cord.
- It is the part where most of the nuclei (collection of cells from which cranial nerves originate) of the 12 cranial nerves are found.
- The medulla oblongata controls the vital functions of the body including heart rate, respiration, body temperature, swallowing, and ingestion.



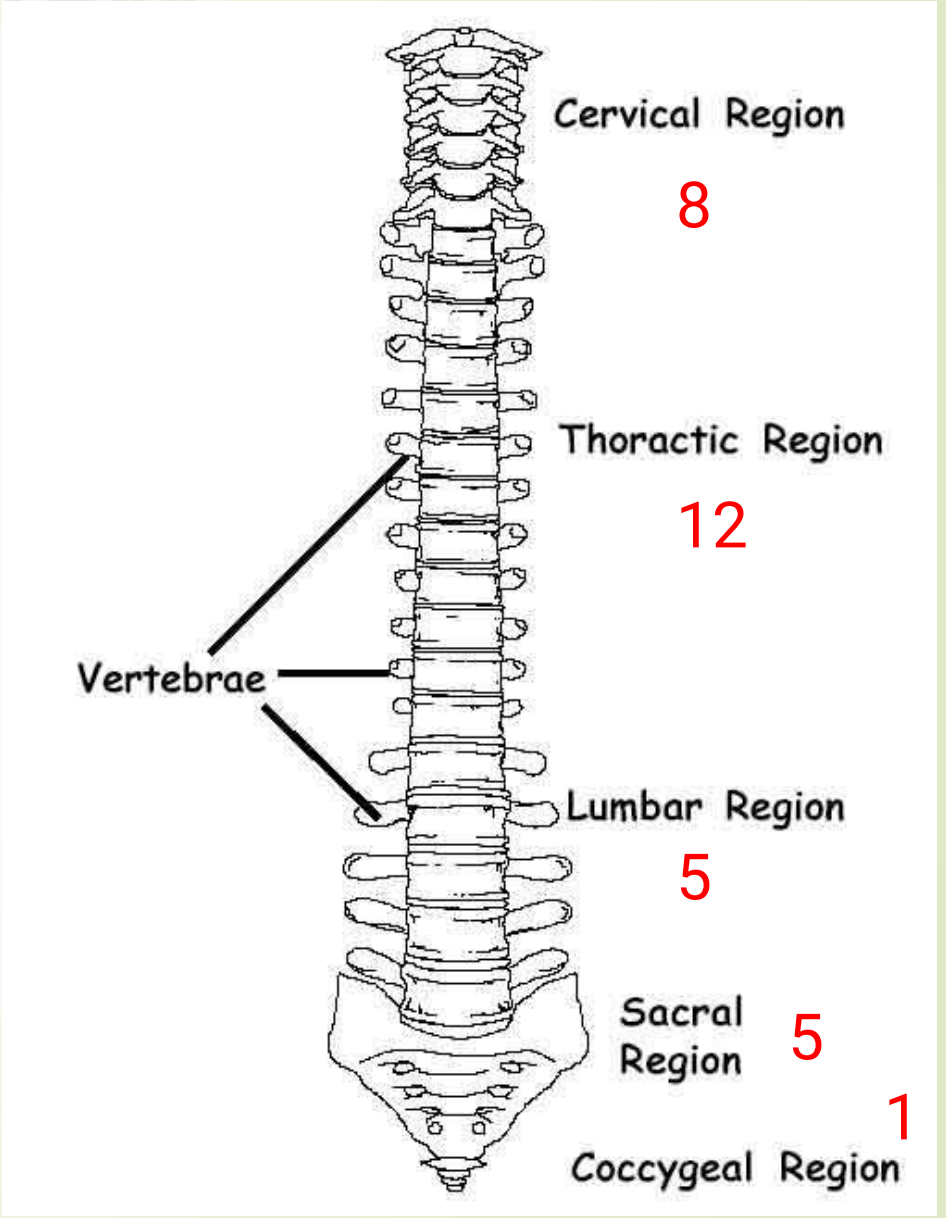
NERVOUS SYSTEM

Spinal cord

The spinal cord lies within the vertebral column and surrounded by cerbrpsoinal fluid and three meningeal membrane

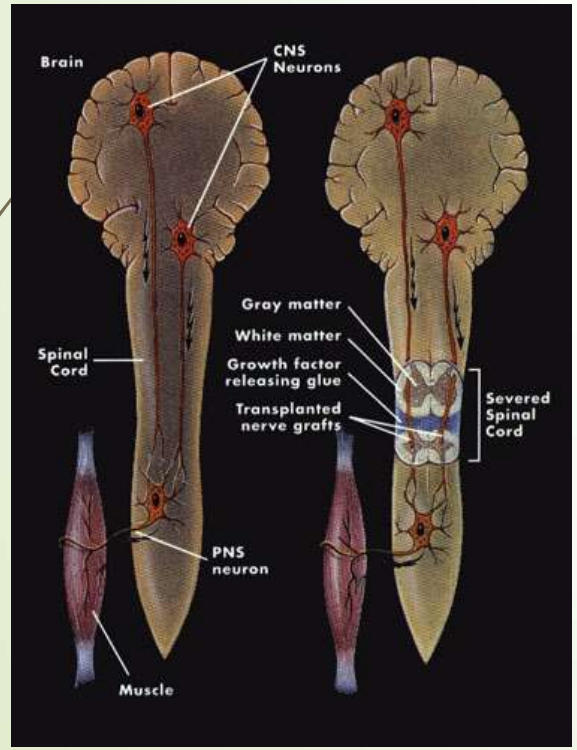
In the adult the spinal cord extends from the medulla oblongata to the level of the first or second lumber vertebra

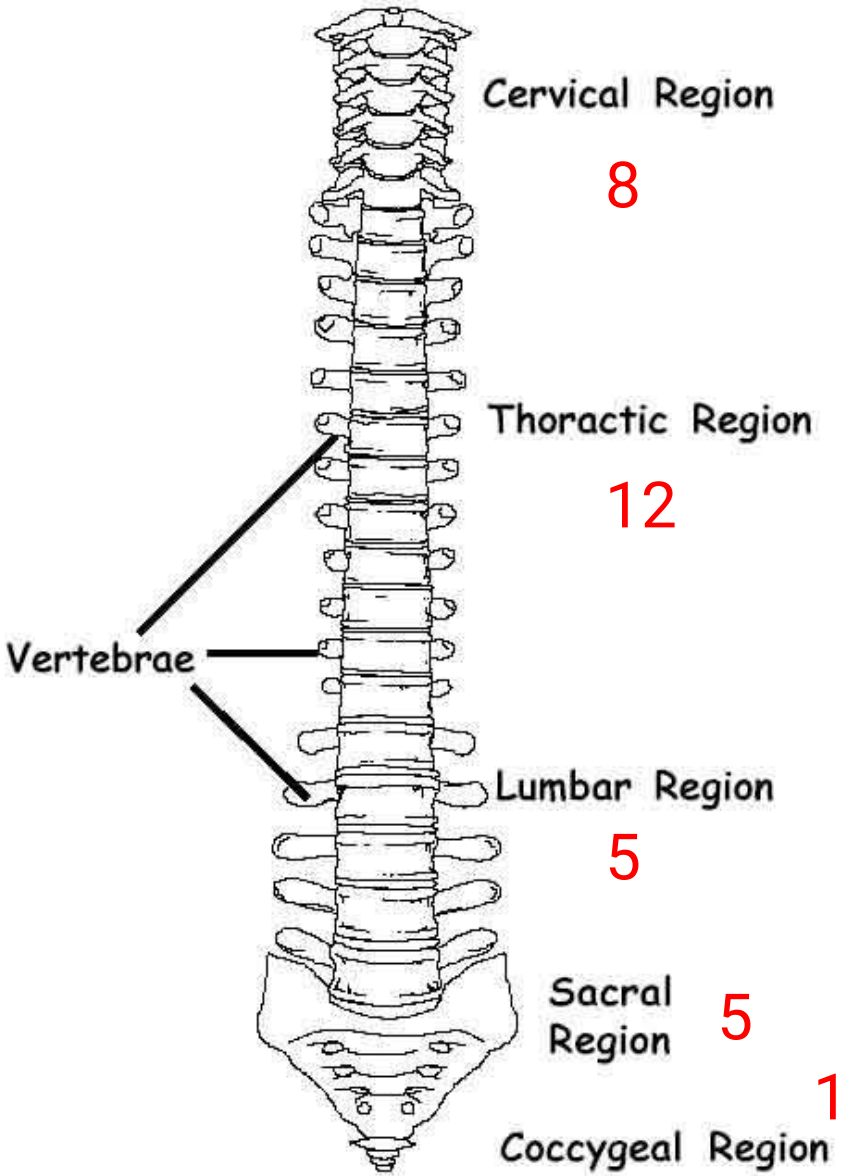
In new born child it extends to the level of the third lumber vertebra



NERVOUS SYSTEM

Spinal cord





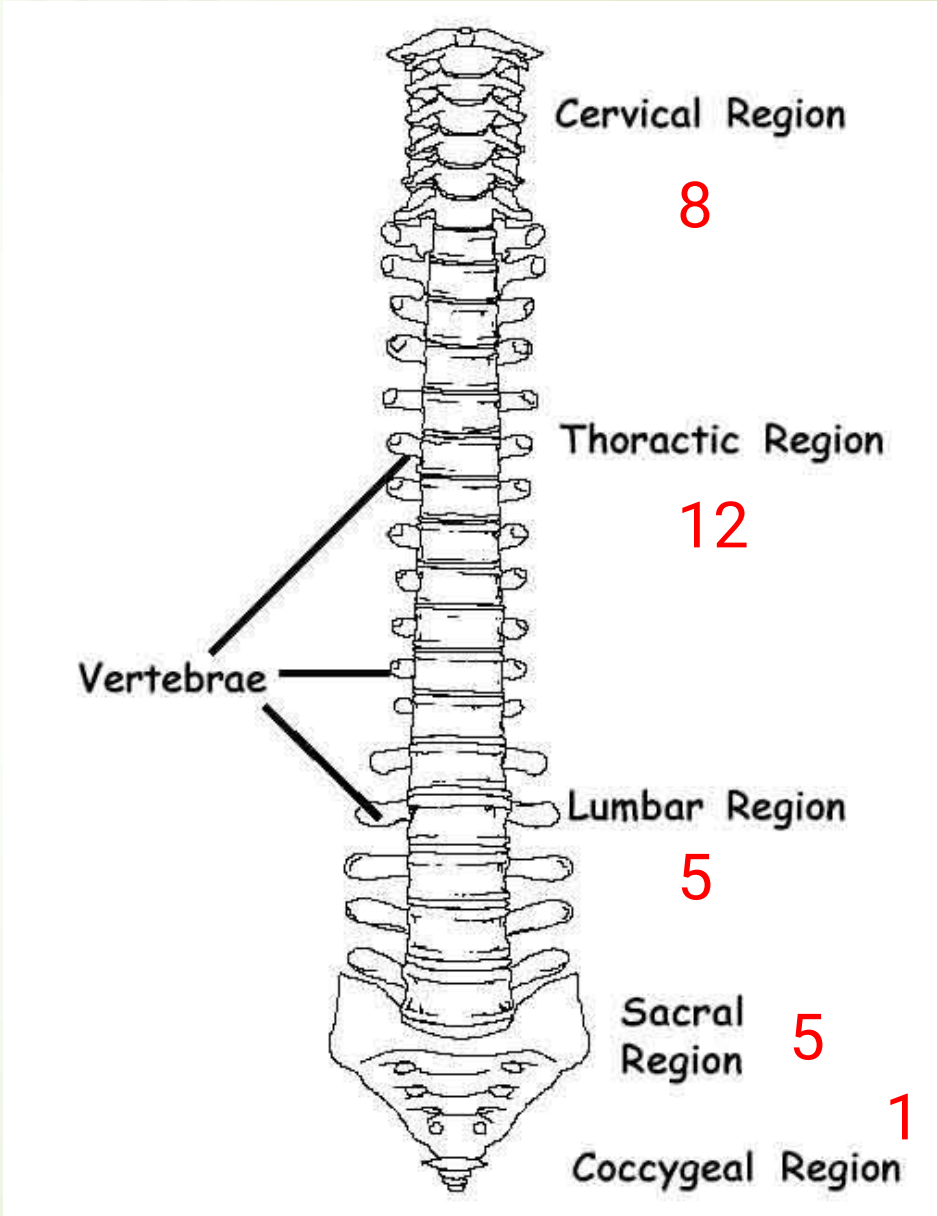
NERVOUS SYSTEM

Spinal cord

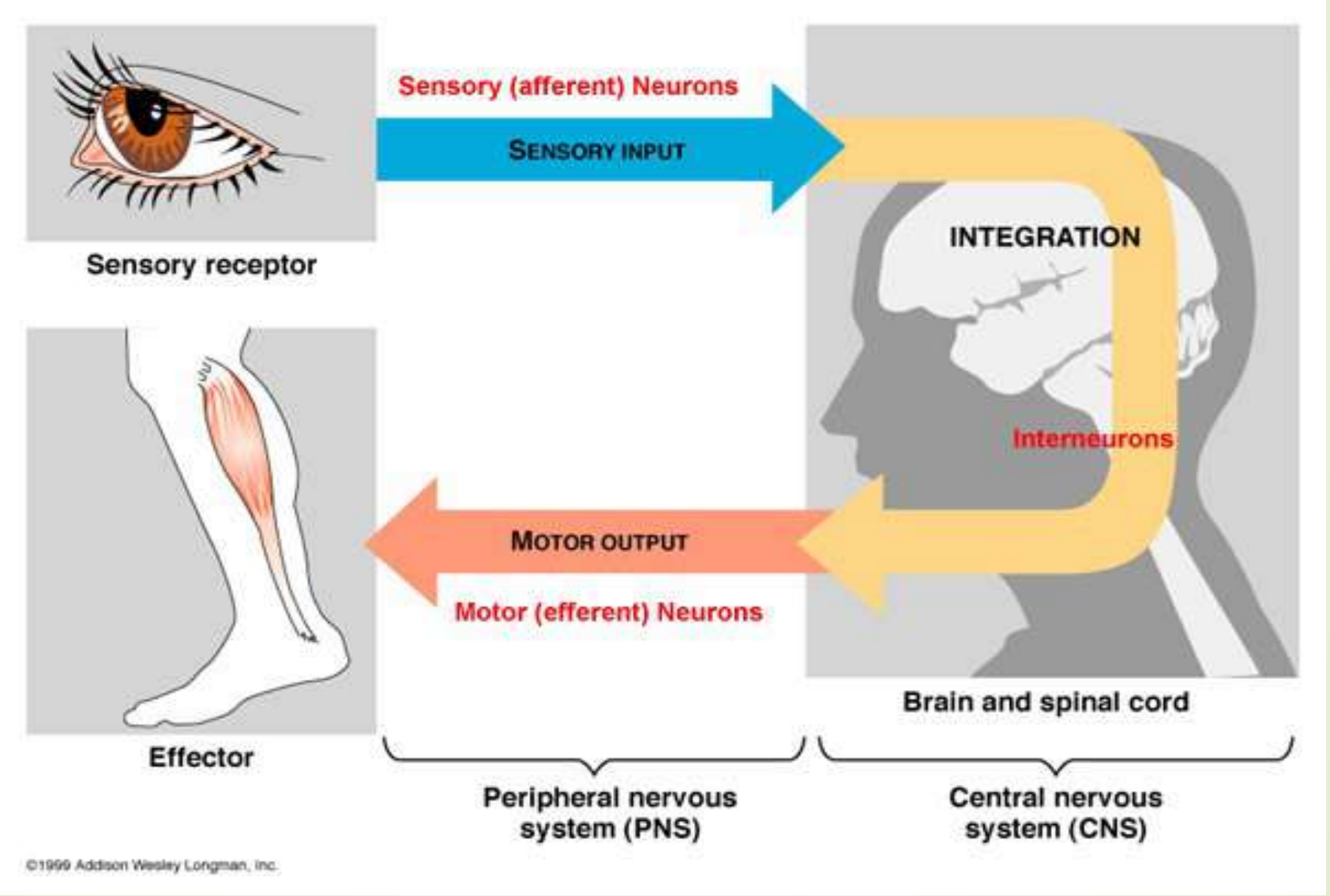
Arising laterally from the spinal cord are 31 pairs of spinal nerves which pick up and transmit to all parts of the body

Each spinal nerve has:

- Sensory fibers that carry the impulses from a sense organ to the CNS
- Motor fibers that carry the impulses from a CNS to muscle or gland



NERVOUS SYSTEM



NERVOUS SYSTEM

PERIPHERAL NERVOUS SYSTEM

NERVOUS SYSTEM

Peripheral nervous system

- The peripheral nervous system is composed of
- 12 pair of cranial nerves arising from the brain and
- 31 pairs of spinal nerves arising from the spinal cord

NERVOUS SYSTEM

Peripheral nervous system

Cranial nerve

12 pairs

Spinal nerve

31 pairs

NERVOUS SYSTEM

Peripheral nervous system

Cranial nerve

12 pairs

The cranial nervous are attached to the undersurface of the brain, mostly from the brain stem

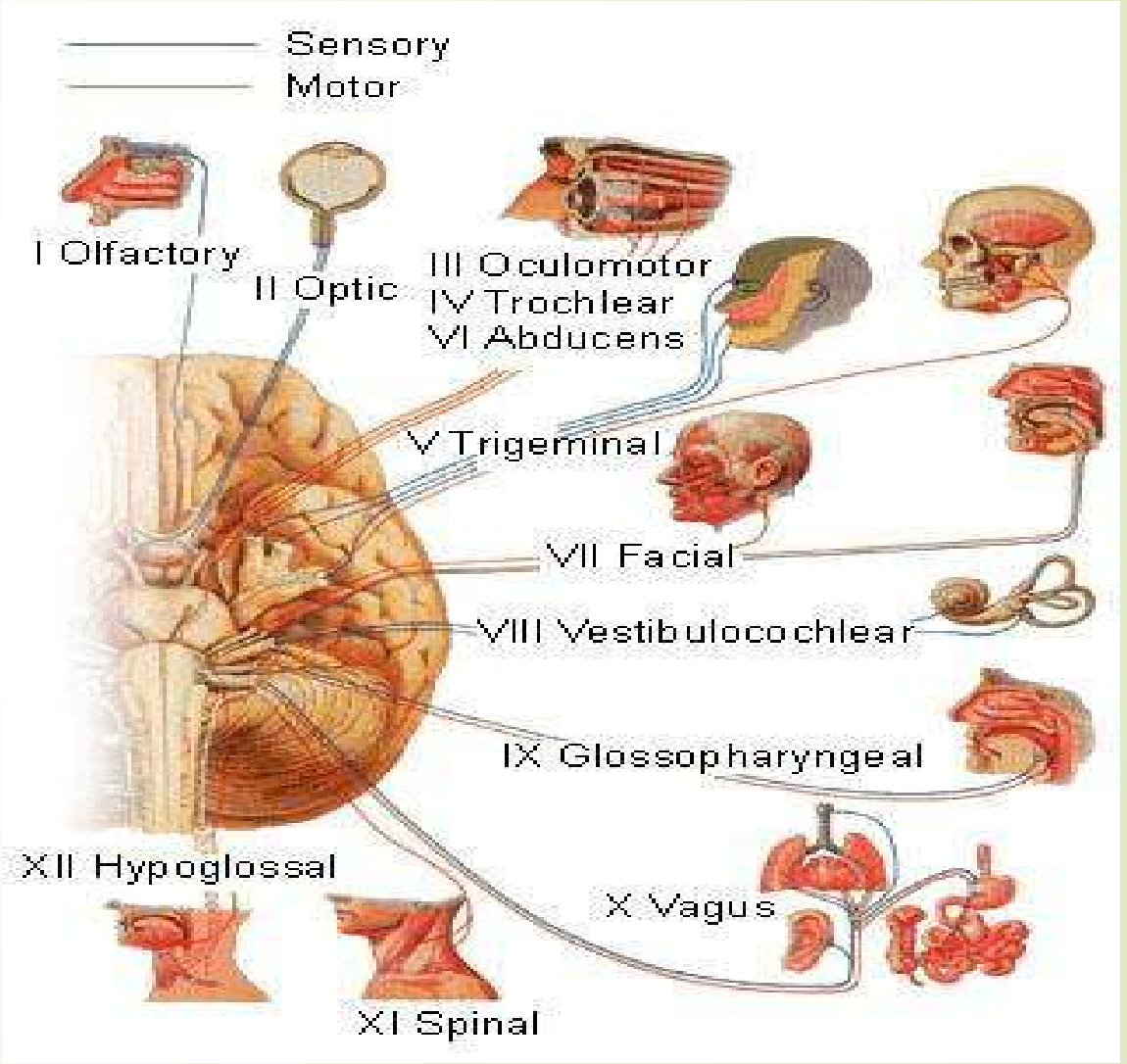
They have numbers I to XII and contain sensory fibers, motor fibers or mixed of both

NERVOUS SYSTEM

- Olfactory (sensory): senses smell.

- Optic (sensory): senses vision and balance.

- Oculomotor (motor): controls muscles for eye focusing and other eye movements.

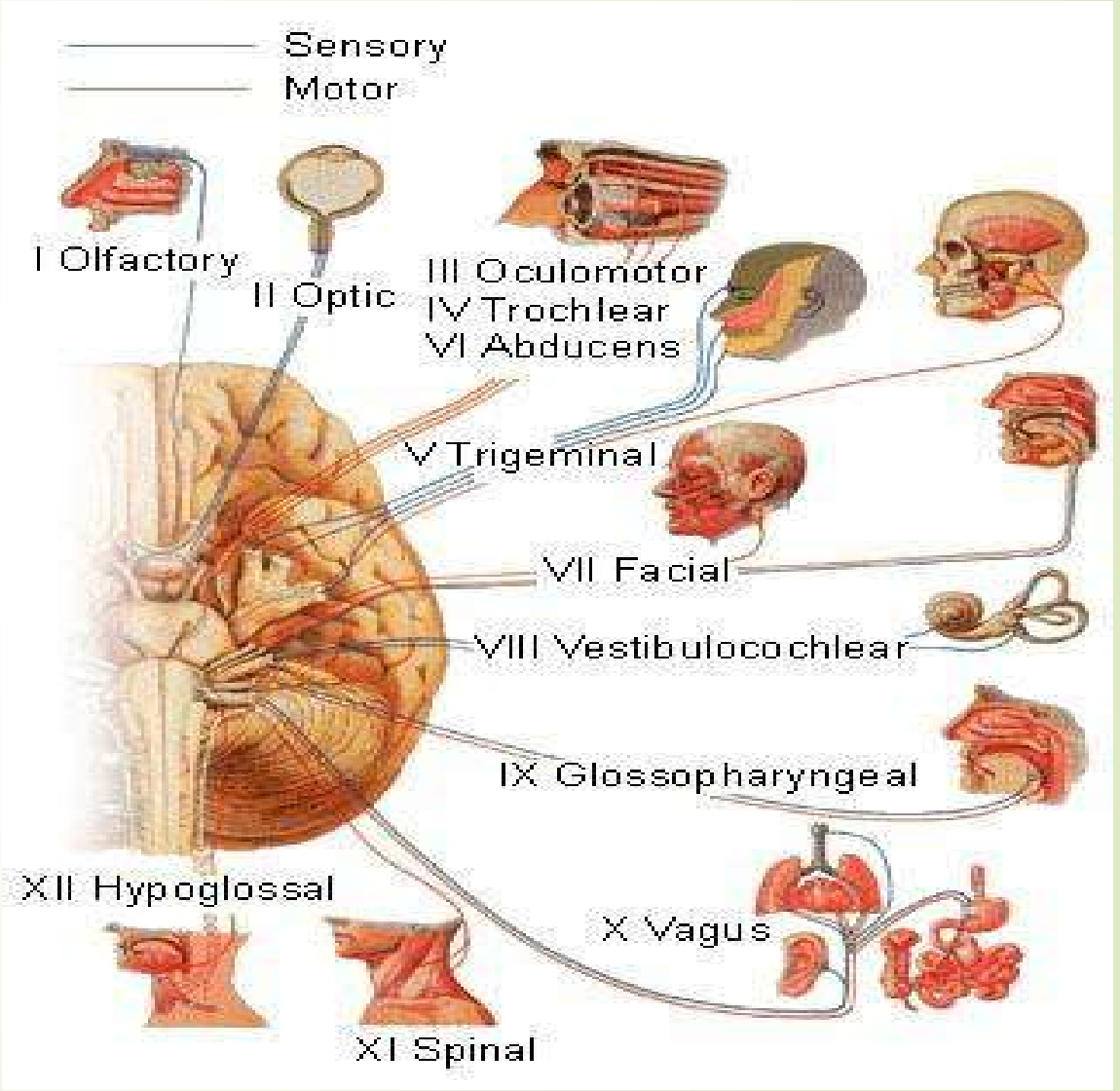


NERVOUS SYSTEM

- Trochlear (motor): controls muscles that move eyeballs.

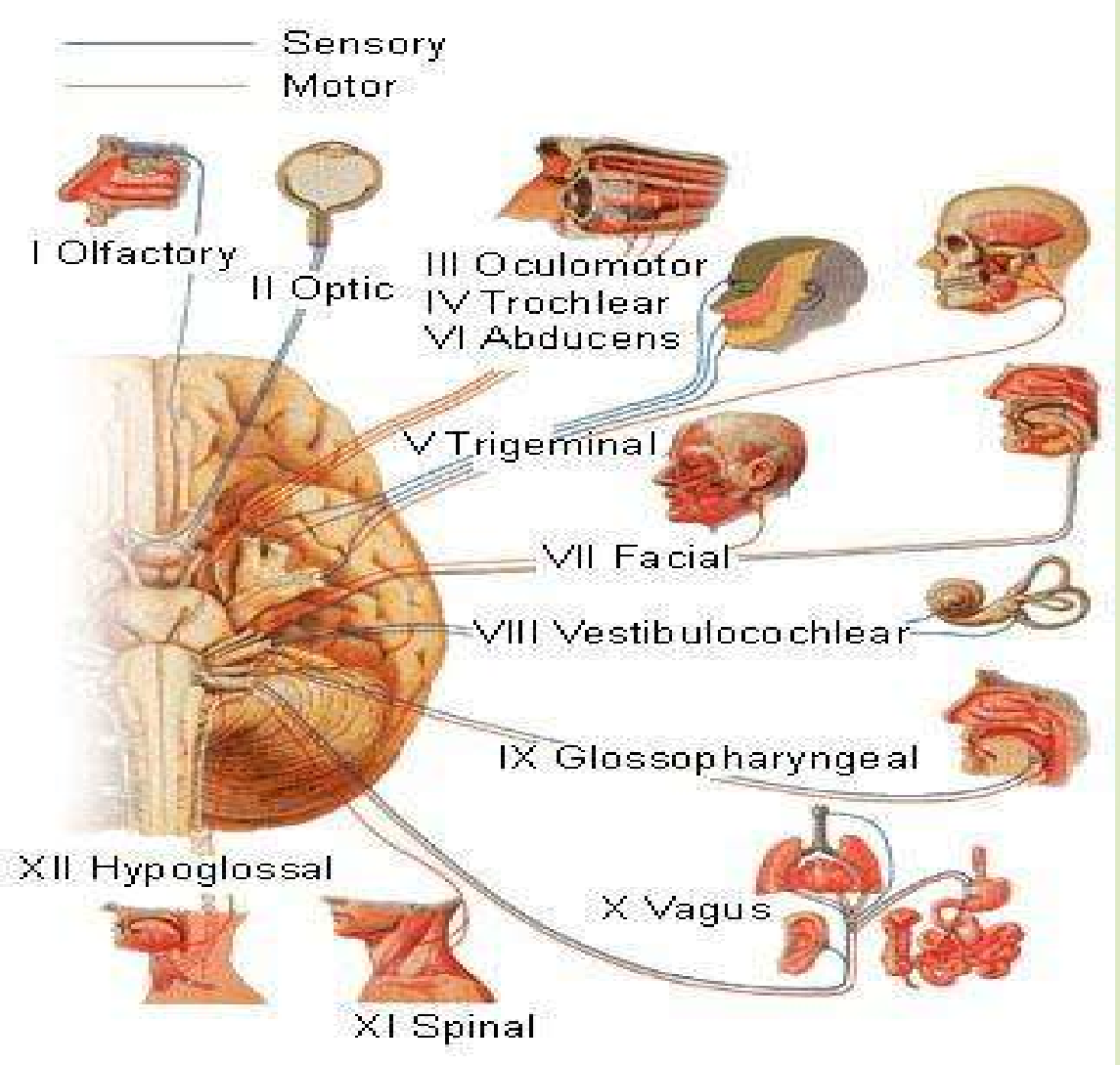
- Trigeminal (mixed): receives impulses of touch, temperature and pain and controls muscles involved in chewing.

- Abducens (motor): controls muscles that turn eyes outwards.



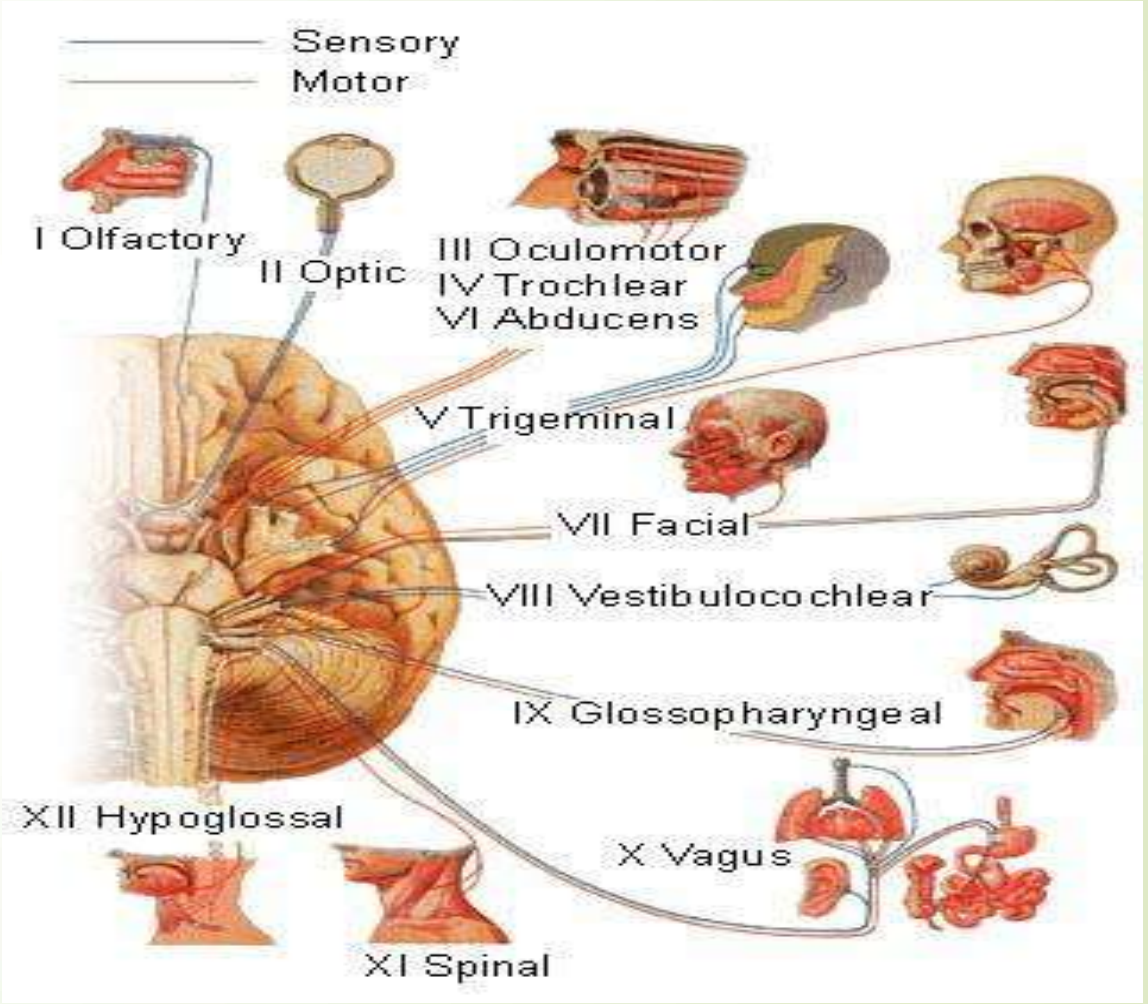
NERVOUS SYSTEM

- Facial (mixed): senses taste and controls muscles of facial expression.
- Vestibulochlear (sensory): senses balance, movement, and hearing.
- Glossopharyngeal (mixed): senses taste, swallowing, and stimulates saliva secretion.



NERVOUS SYSTEM

- Vagus (mixed): involved in taste, swallowing, voice, heartbeat, peristalsis and other impulses from abdominal organs.
- Accessory (motor): controls muscles that move the head and shoulders.
- Hypoglossal (motor): controls muscles that move the tongue.



NERVOUS SYSTEM

Peripheral nervous system

Spinal nerve

31 pairs

The 31 pairs of nerves are attached to spinal cord, they pass out from the vertebra canal through the spaces between the arches of the vertebra

conduct impulse between the spinal cord and the parts of the body not supplied with the cranial nerves

Spinal nerve are identified by letters and numbers witch related to the area of their attachment

NERVOUS SYSTEM

Peripheral nervous system

Spinal nerve

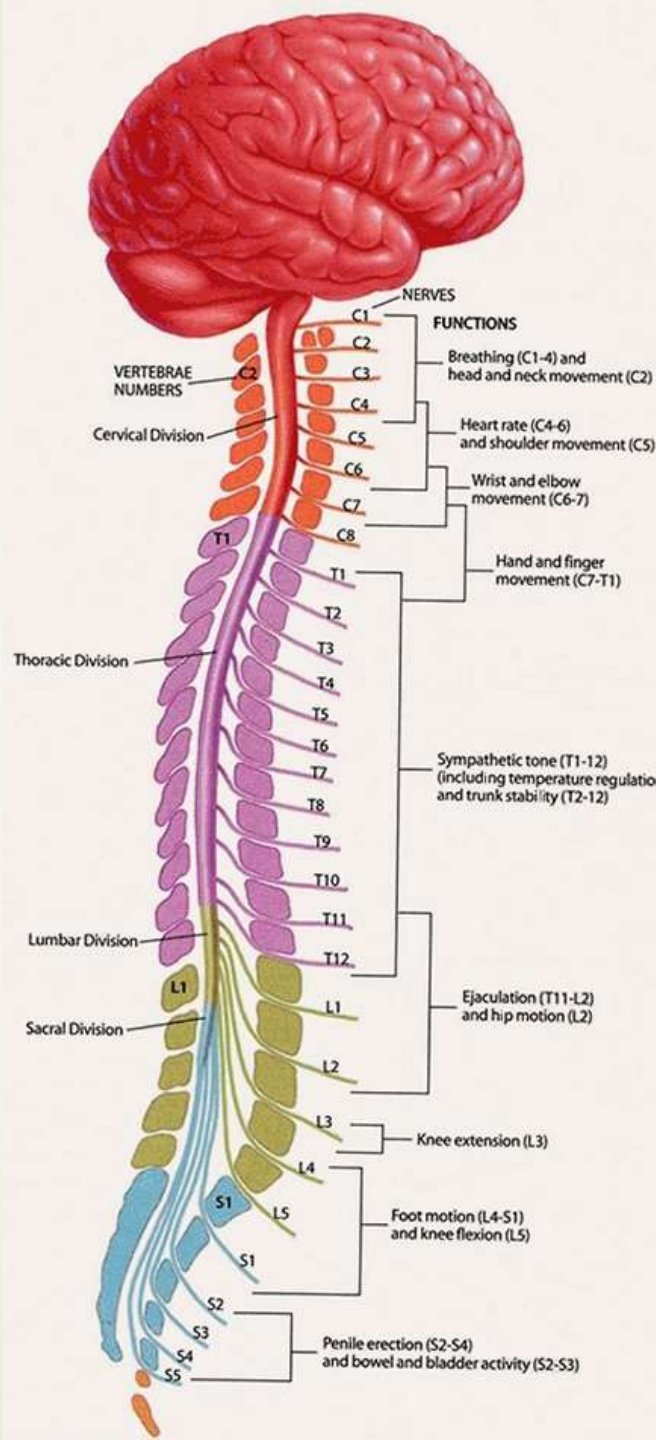
31 pairs

For example spinal nerve C1 to C8 are cervical nerves, T1 to T12 the thoracic nerves

L1 To L5 the lumber nerve

S1 to S5 sacral nerve

And C0 to one coccygeal nerve



NERVOUS SYSTEM

AUTONOMIC NERVOUS SYSTEM

NERVOUS SYSTEM

Autonomic nervous system

The autonomic nervous system regulates those bodily functions of which a person is not normally aware such as breathing, heart rate, glandular activity, contraction and dilatation of blood vessels, variation in size of the eye's pupil, and movements in the gastrointestinal tract.

The autonomic system is made up of two systems that balance each other

NERVOUS SYSTEM

Autonomic nervous system

Two divisions:

- sympathetic
- Parasympathetic

Control involuntary functions

- heartbeat
- blood pressure
- respiration
- perspiration
- digestion

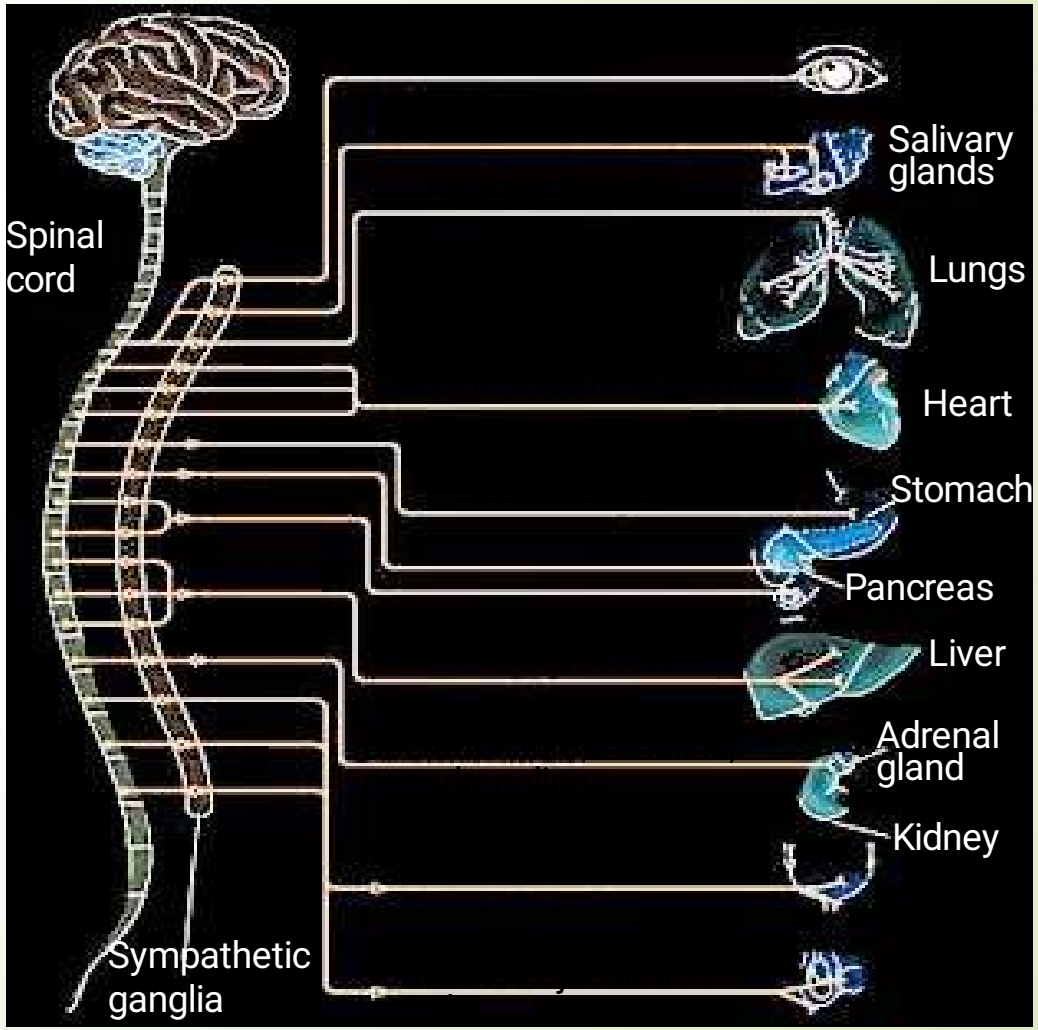
Can be influenced by thought and emotion

NERVOUS SYSTEM

Autonomic nervous system

Sympathetic

" Fight or flight" response
Release adrenaline and noradrenaline
Increases heart rate and blood pressure
Increases blood flow to skeletal muscles
Inhibits digestive functions



NERVOUS SYSTEM

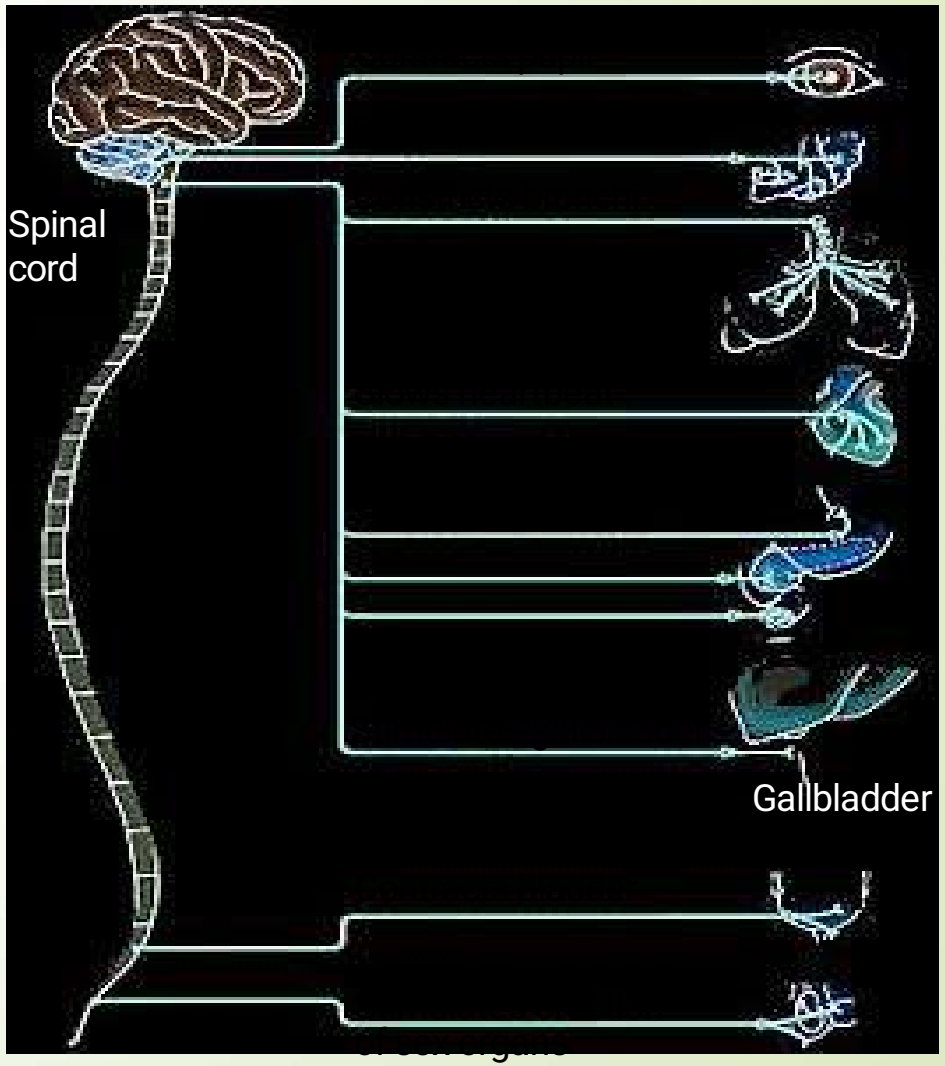
Autonomic nervous system

Para Sympathetic

“ Rest and digest ” system
Calms body to conserve and maintain energy

Lowers heartbeat,

breathing rate, blood pressure



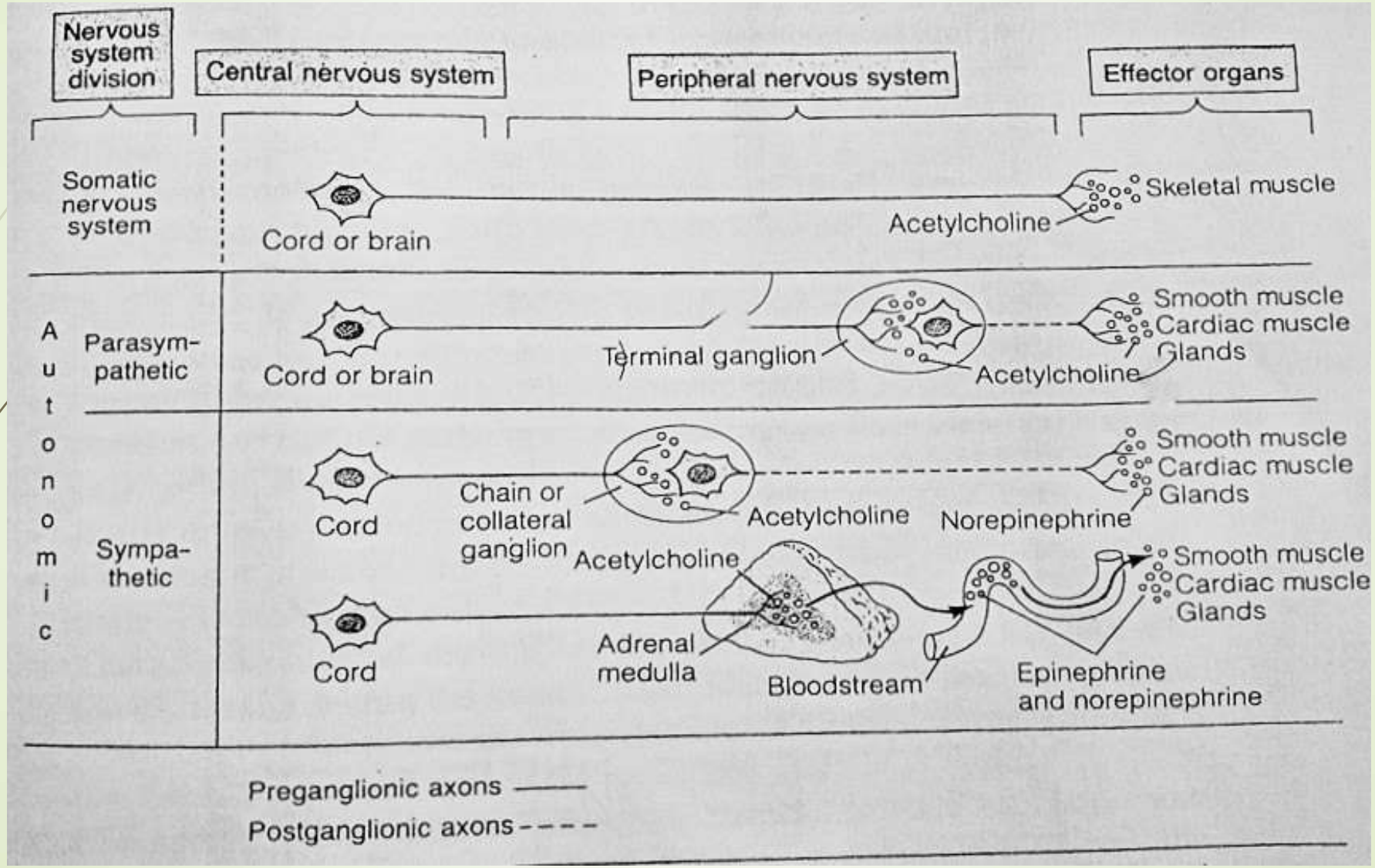
NERVOUS SYSTEM

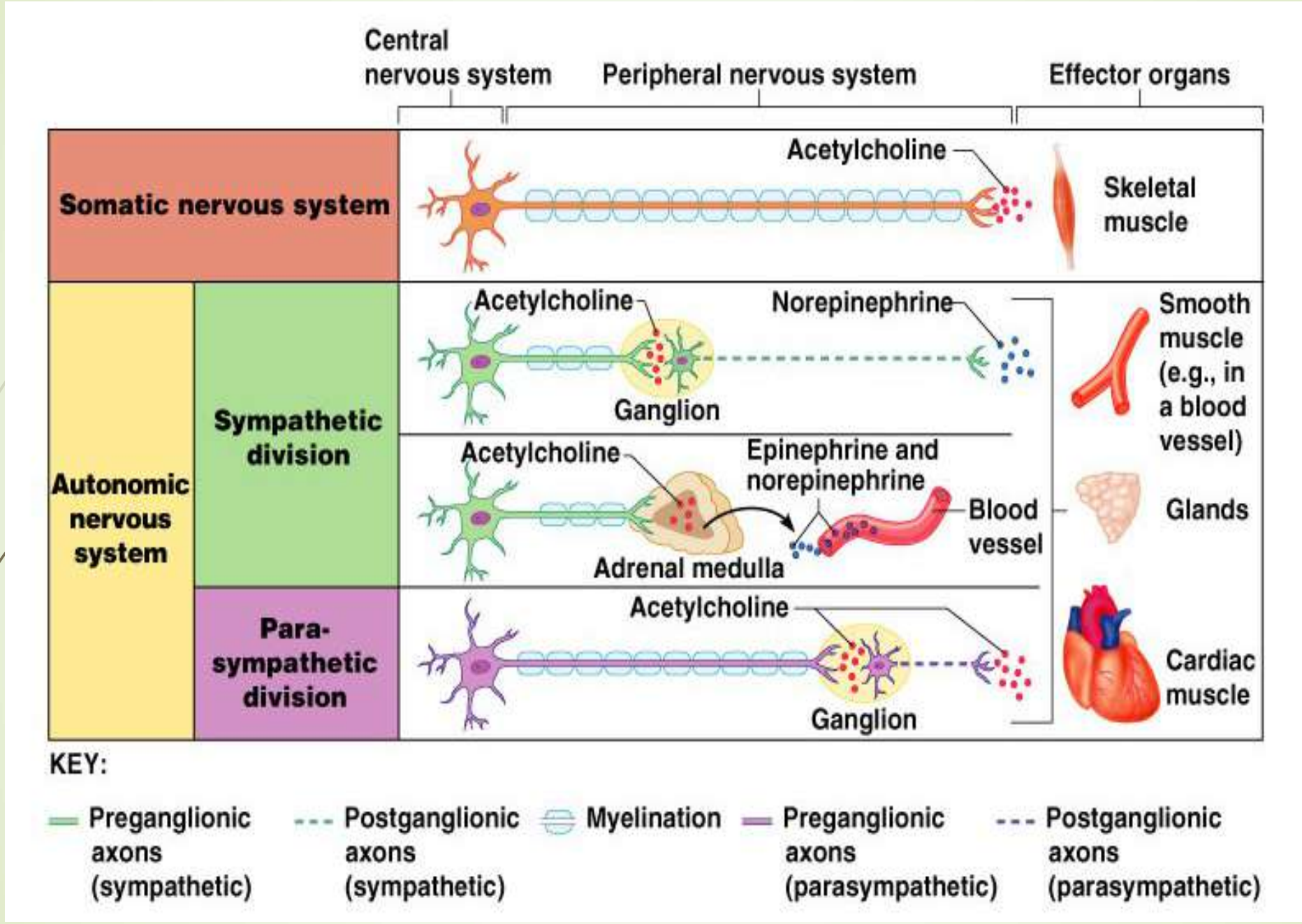
Autonomic nervous system

Autonomic nervous system controls physiological arousal

Sympathetic division (arousing)		Parasympathetic division (calming)
Pupils dilate	EYES	Pupils contract
Decreases	SALVATION	Increases
Perspires	SKIN	Dries
Increases	RESPERATION	Decreases
Accelerates	HEART	Slows
Inhibits	DIGESTION	Activates
Secrete stress hormones	ADRENAL GLANDS	Decrease secretion of stress hormones

NERVOUS SYSTEM




Central nervous system
Peripheral nervous system
Effector organs
Somatic nervous system
Acetylcholine
Skeletal muscle
Autonomic nervous system
Sympathetic division
Acetylcholine
Norepinephrine
Ganglion
Smooth muscle (e.g., in a blood vessel)
Acetylcholine
Epinephrine and norepinephrine
Blood vessel
Adrenal medulla
Glands
Para-sympathetic division
Acetylcholine
Ganglion
Cardiac muscle
KEY:
Preganglionic axons (sympathetic)
Postganglionic axons (sympathetic)
Myelination
Preganglionic axons (parasympathetic)
Postganglionic axons (parasympathetic)

End

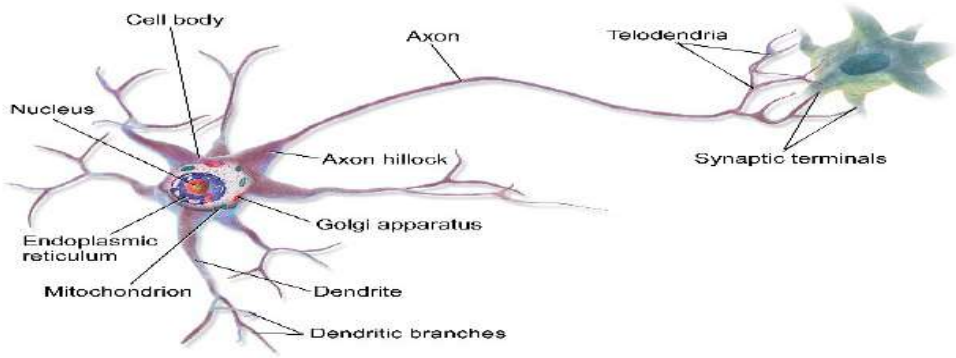
Thank you

THE NERVE IMPULSE

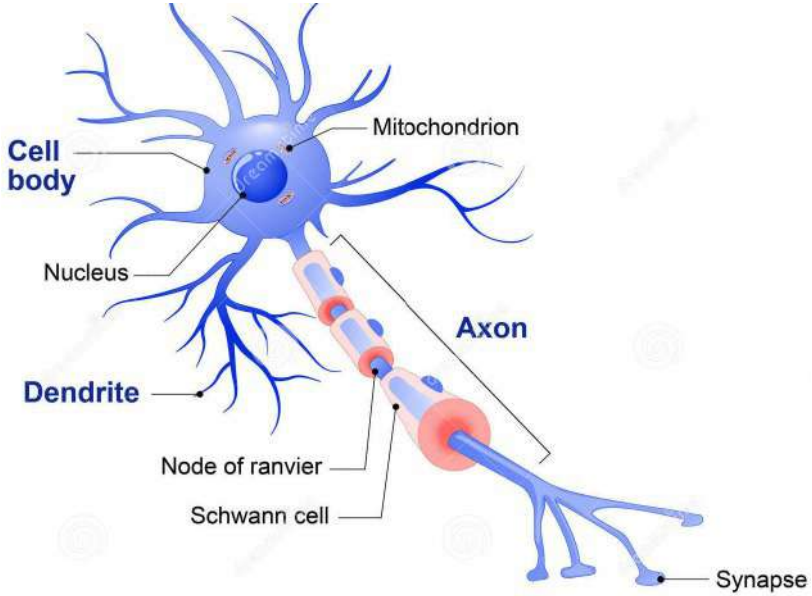
Action Potential

Stimuli

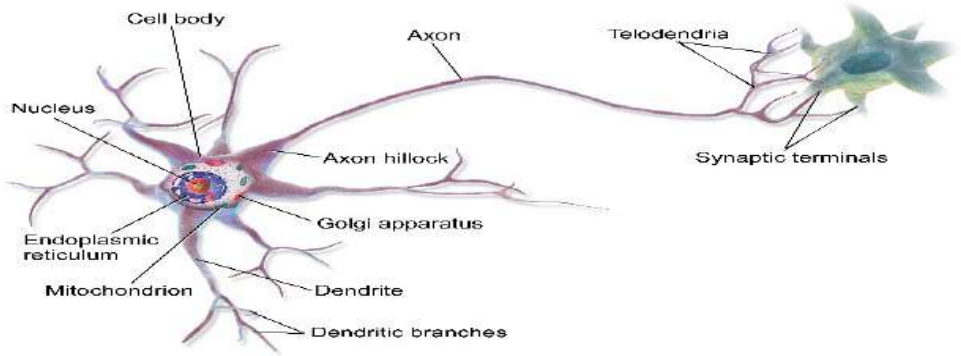
The Nerve Impulse



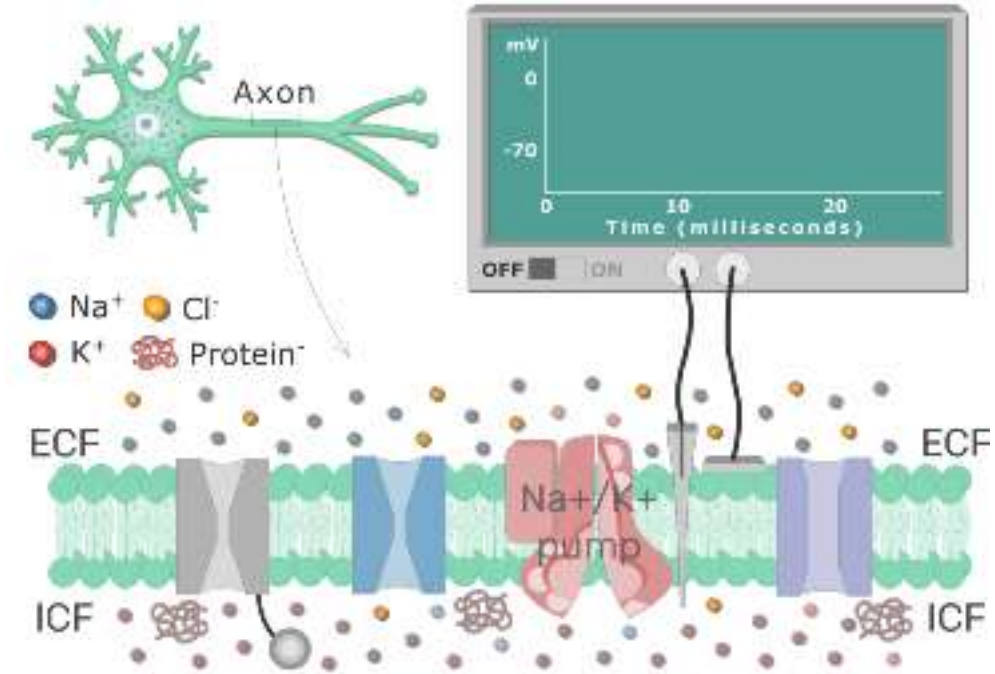
- A nerve impulse is the electrical message that is transmitted down the axon of a neuron.
- The impulse does not travel directly down the axon but is regenerated at points along the axon.
- The speed of nerve impulses ranges from approximately 1 m/s to 100 m/s.



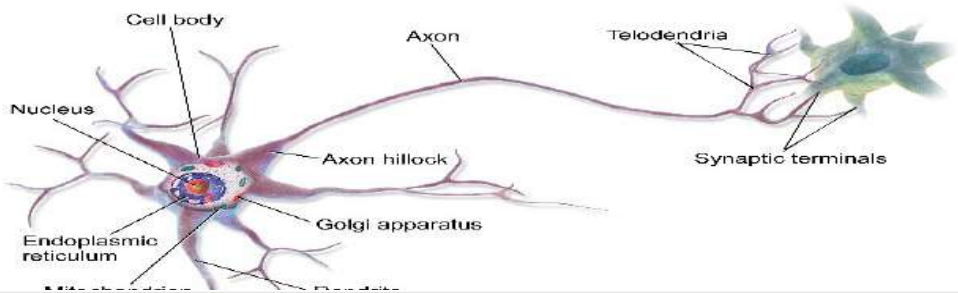
The Nerve Impulse



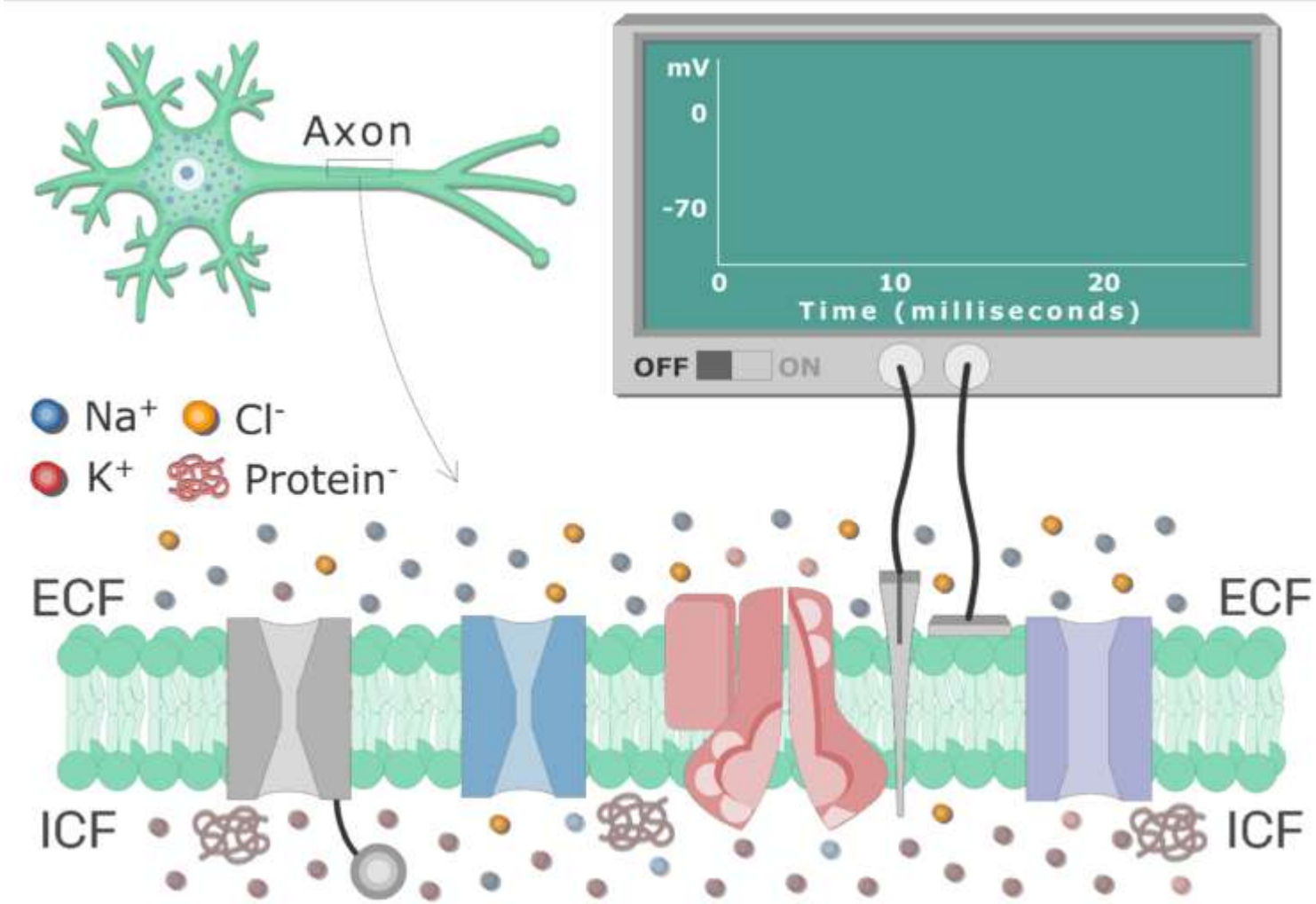
- The plasma membranes of resting axons are slightly polarized due to;
- the unequal distribution of Na+, K+, Cl- and protein- ions in ECF and ICF.



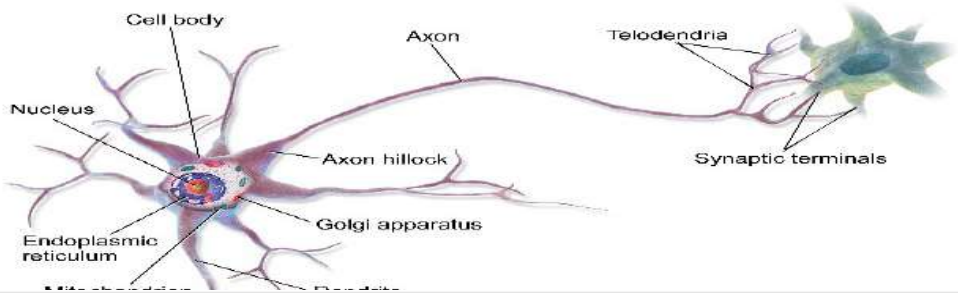
The Nerve Impulse



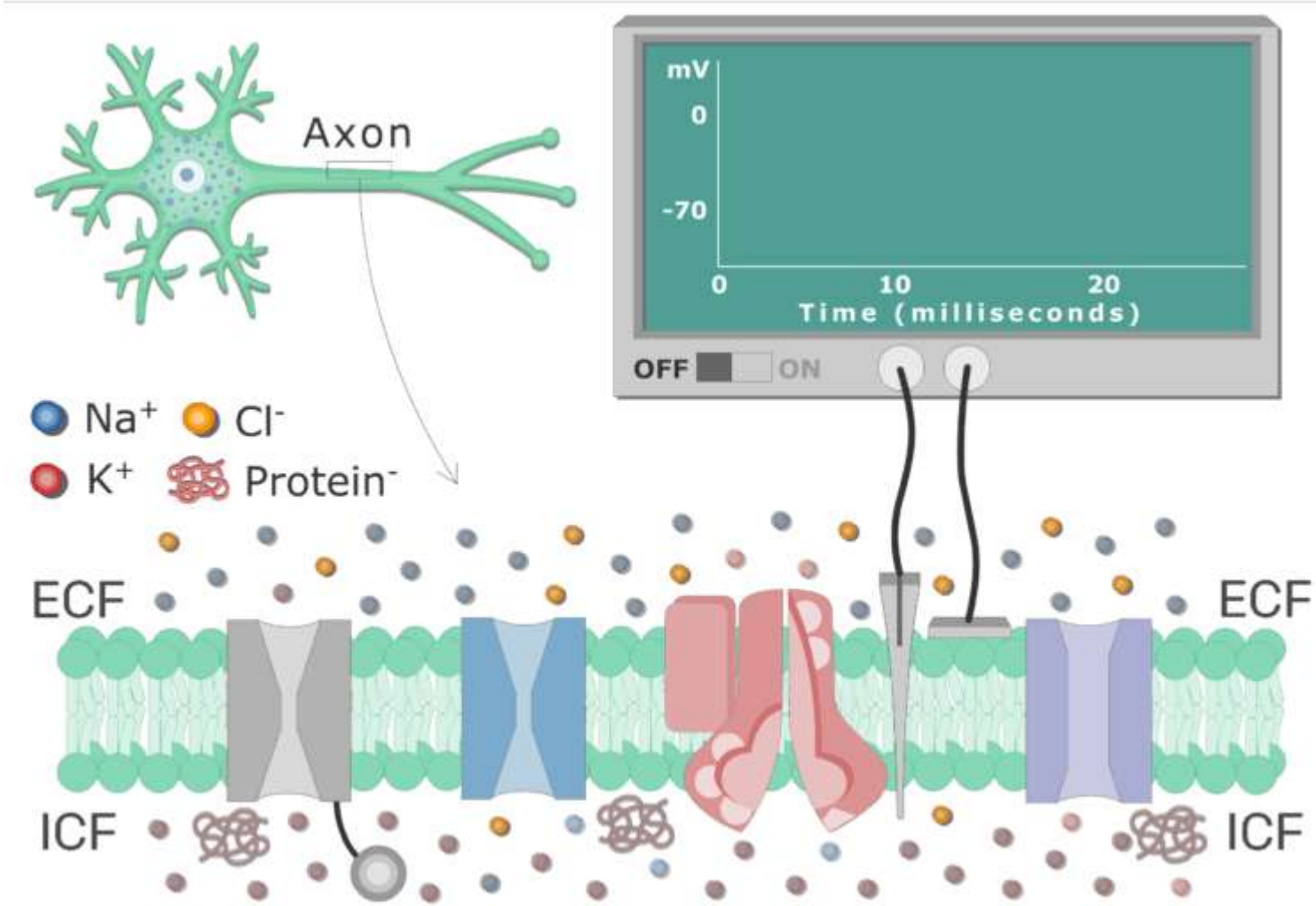
- The resting potential of a neuron refers to the state of the neuron prior to the sending of a nerve impulse.



The Nerve Impulse

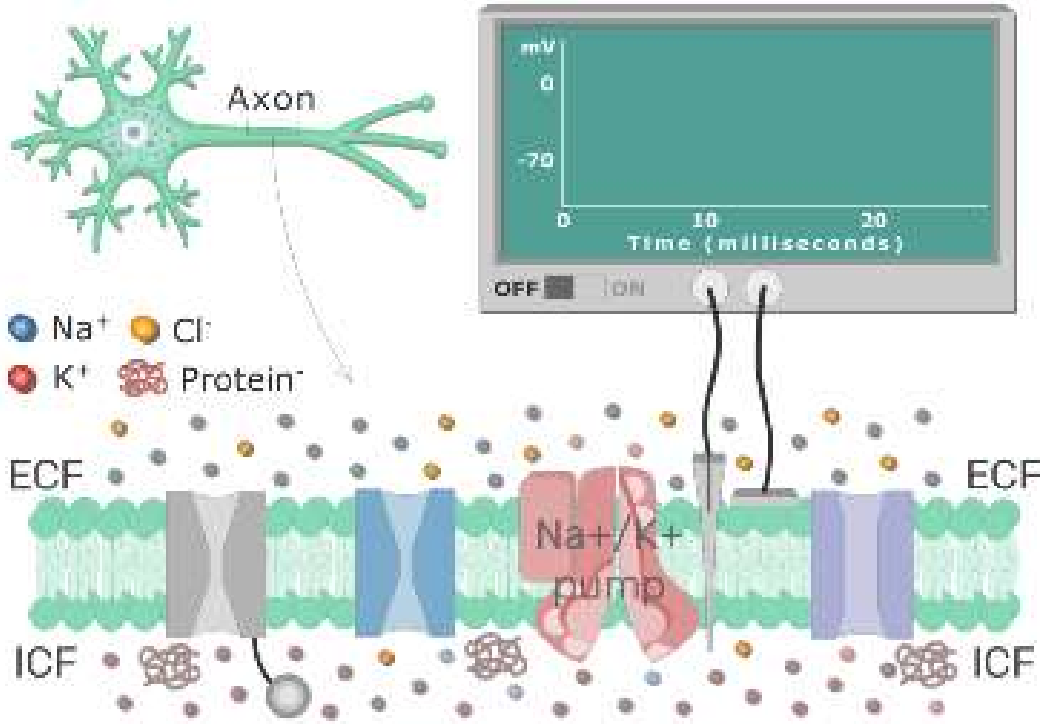


- The membrane of a neuron maintains an electrical gradient which is a difference in the electrical charge inside and outside of the cell.



The Nerve Impulse

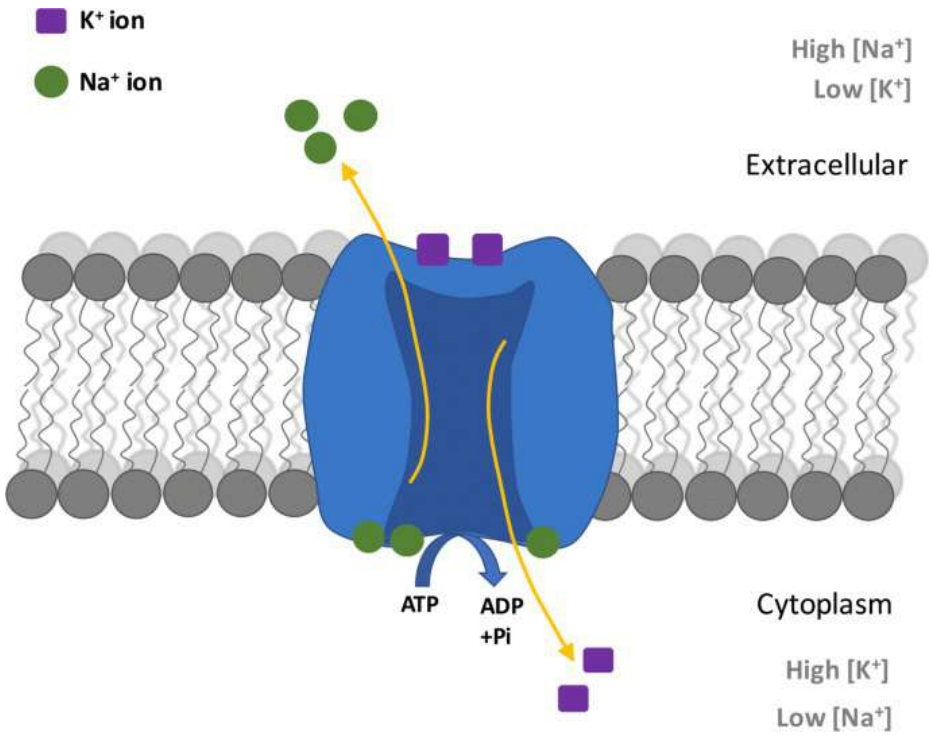
- Several factors play a role in creating the resting membrane potential.
  - Na+/K+ pumps (or Na+/K+-ATPases) move Na+ and K+ ions to opposite sides of the membrane.



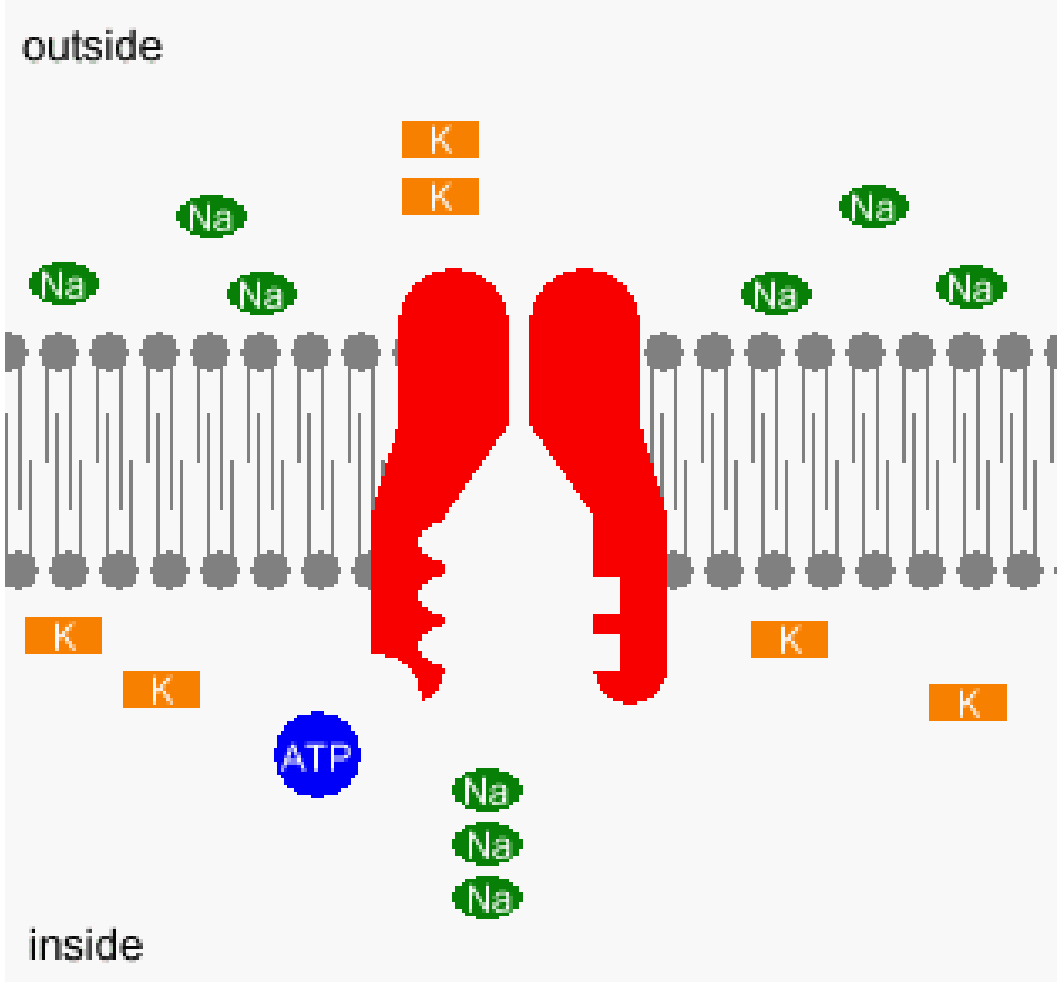
The Nerve Impulse

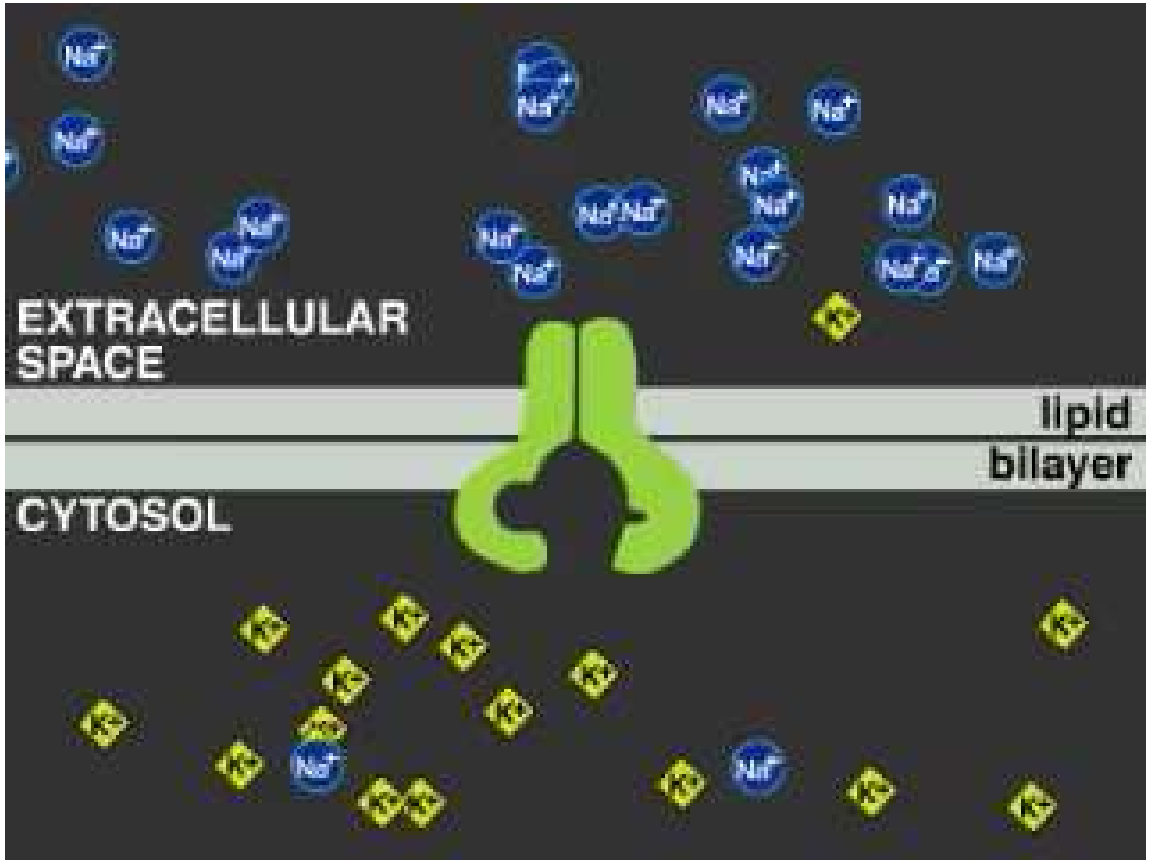
- Each pump protein uses one molecule of ATP to transfer 3 Na+ ions out of the cell and 2 K+ ions in.

- As a result, Na+ ions are concentrated outside the axon membrane and K+ ions are concentrated inside.



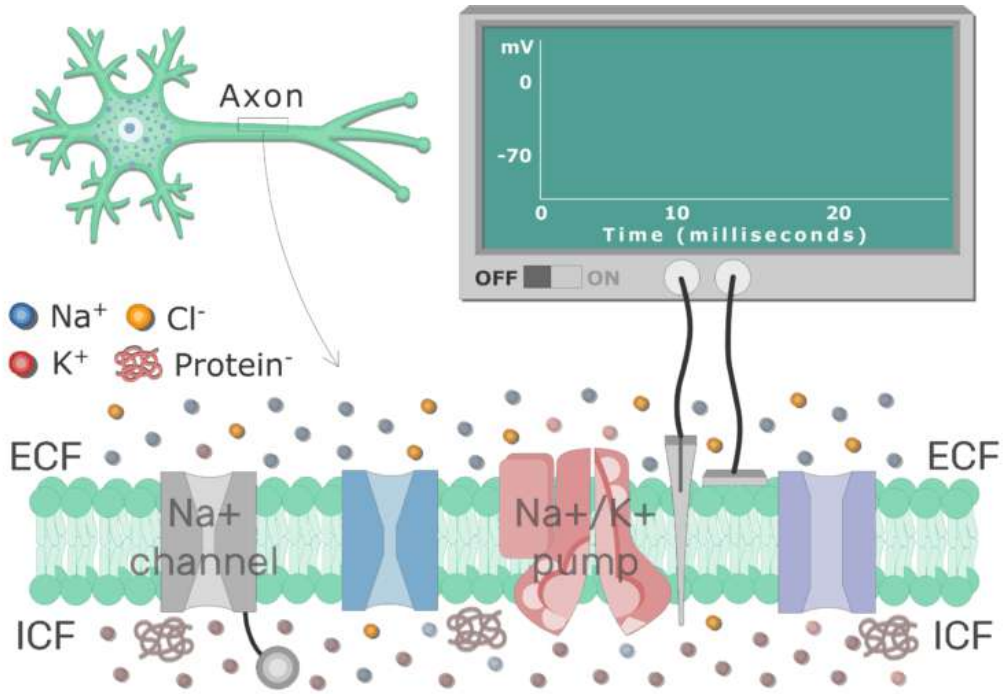
NERVOUS SYSTEM





The Nerve Impulse

- The unequal transfer of ions also contributes slightly to the polarity of the resting membrane.
- Very few of the Na+ ions can diffuse back into the cell because most of the gated Na+ channels are closed.



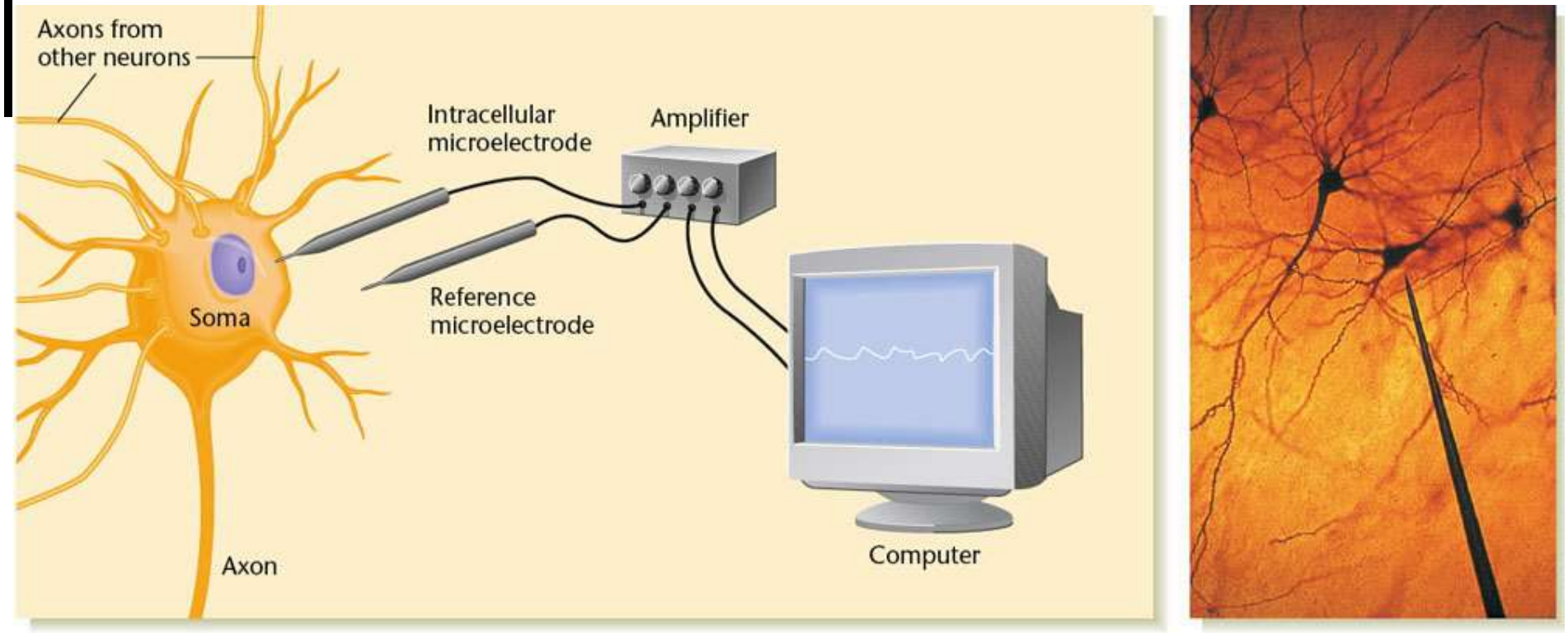
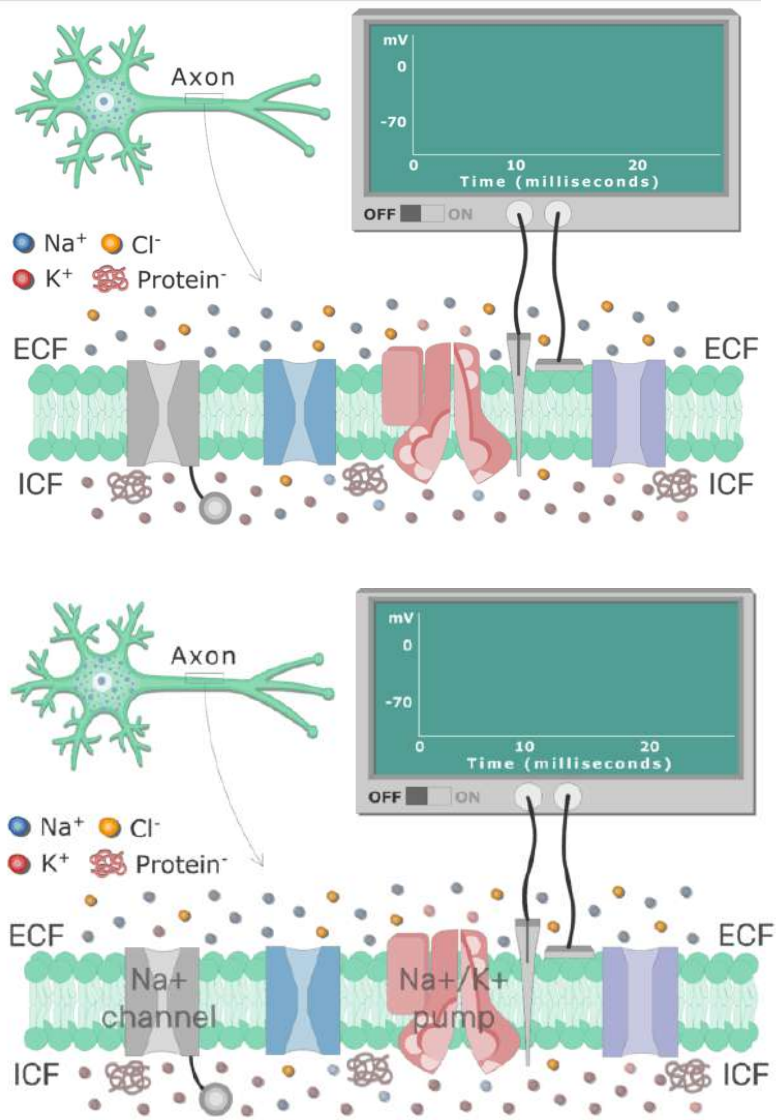


Figure 2.13: Methods for recording activity of a neuron.
(a) Diagram of the apparatus and a sample recording. (b) A microelectrode and stained neurons magnified hundreds of times by a light microscope.

Cells and membrane potentials

- All animal cells generate a small voltage across their membranes
- This is because there is a large amount of small organic molecules in the cytoplasm
- To balance this, animal cell pump Na^+ out of the cel
- This regulates osmosis but it leaves a large numbe of organic molecules
- These are overall negatively changed (anions) in th cytoplasm
- Thus the cell has a potential difference (voltage) across its membrane



When a channel opens, it permits one kind of ion to cross the membrane. When it closes, it prevents passage of that ion.

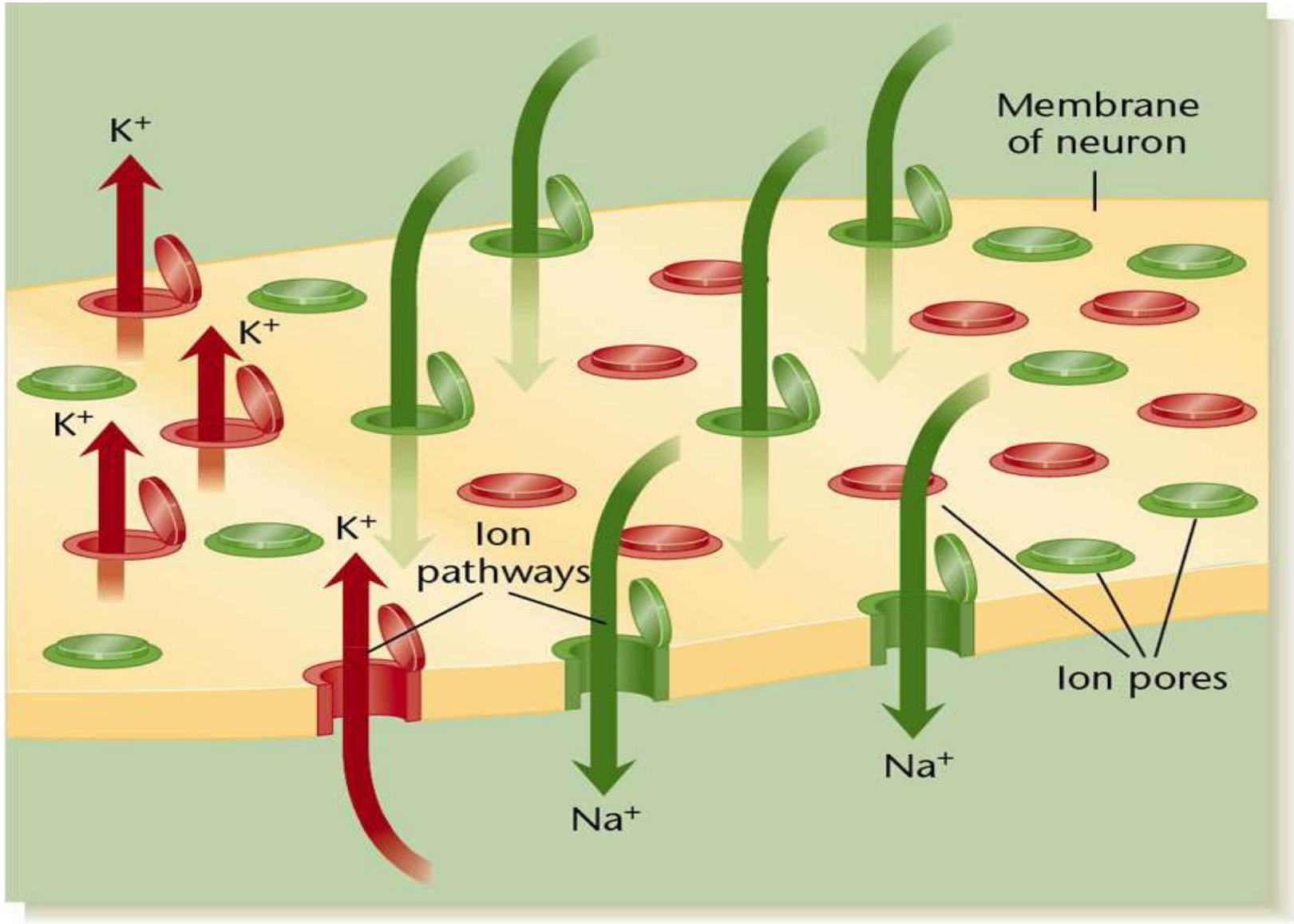
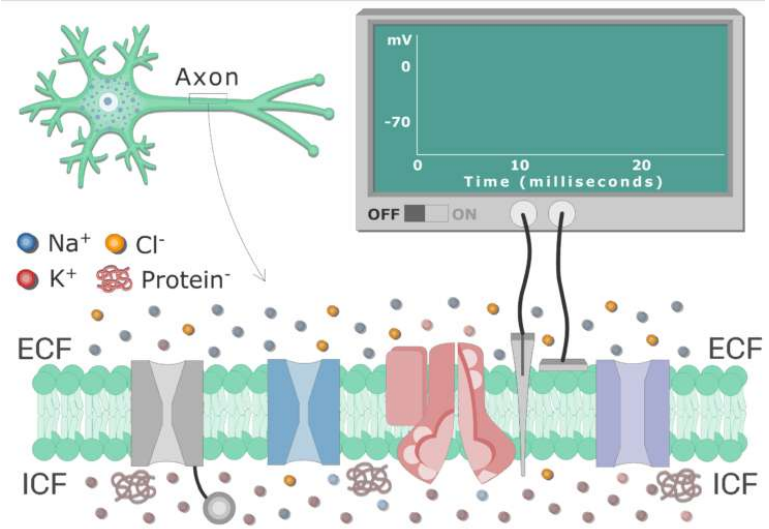
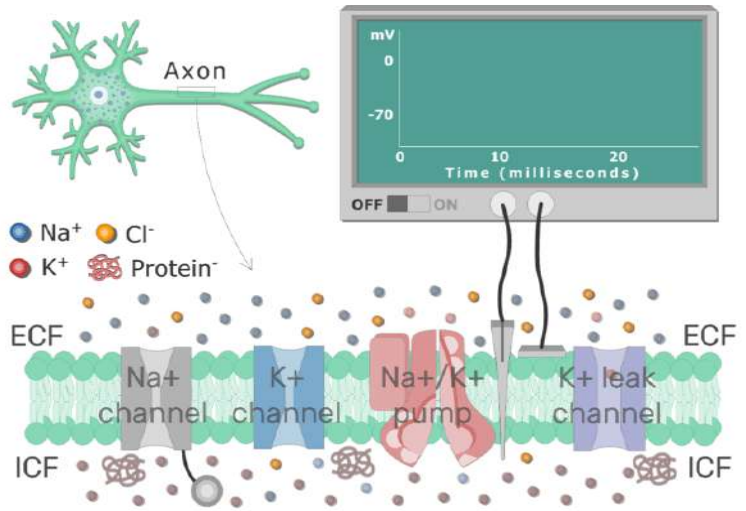


Fig. 2-14, p. 40

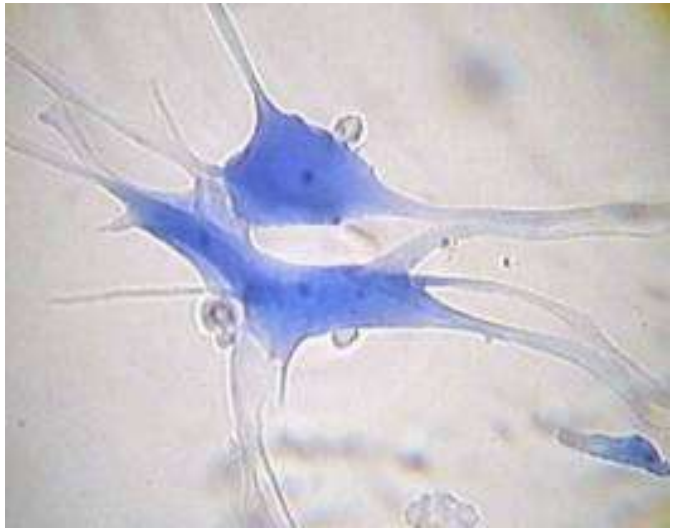
The resting potential

- Most gated K+ channels are also closed.
- However, many leak channels remain open, which increases the membrane's permeability to K+ ions.
- K^+ ions slowly leak through K^+ pore channels
- The membrane has a poor permeability to Na^+ ions so they cannot get in to the neurone
- This brings about the membrane potential of neurones
- As the K^+ diffuse out the inside of the resting cell becomes more negatively charged and the exterior more positive.





The neurone



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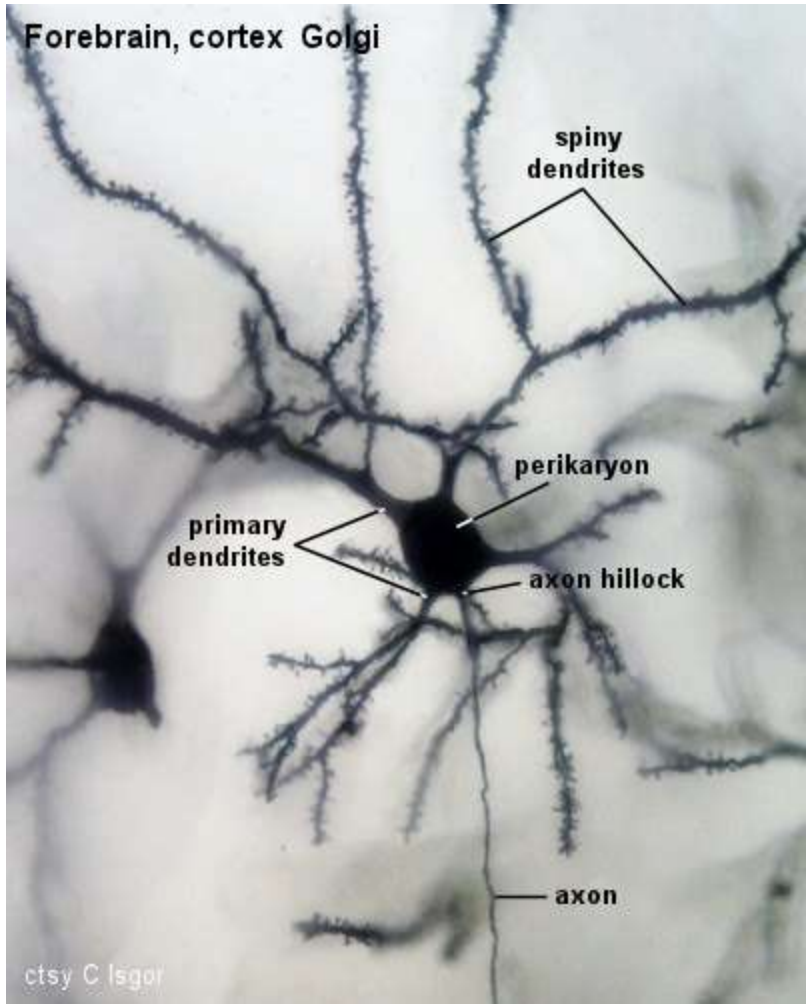
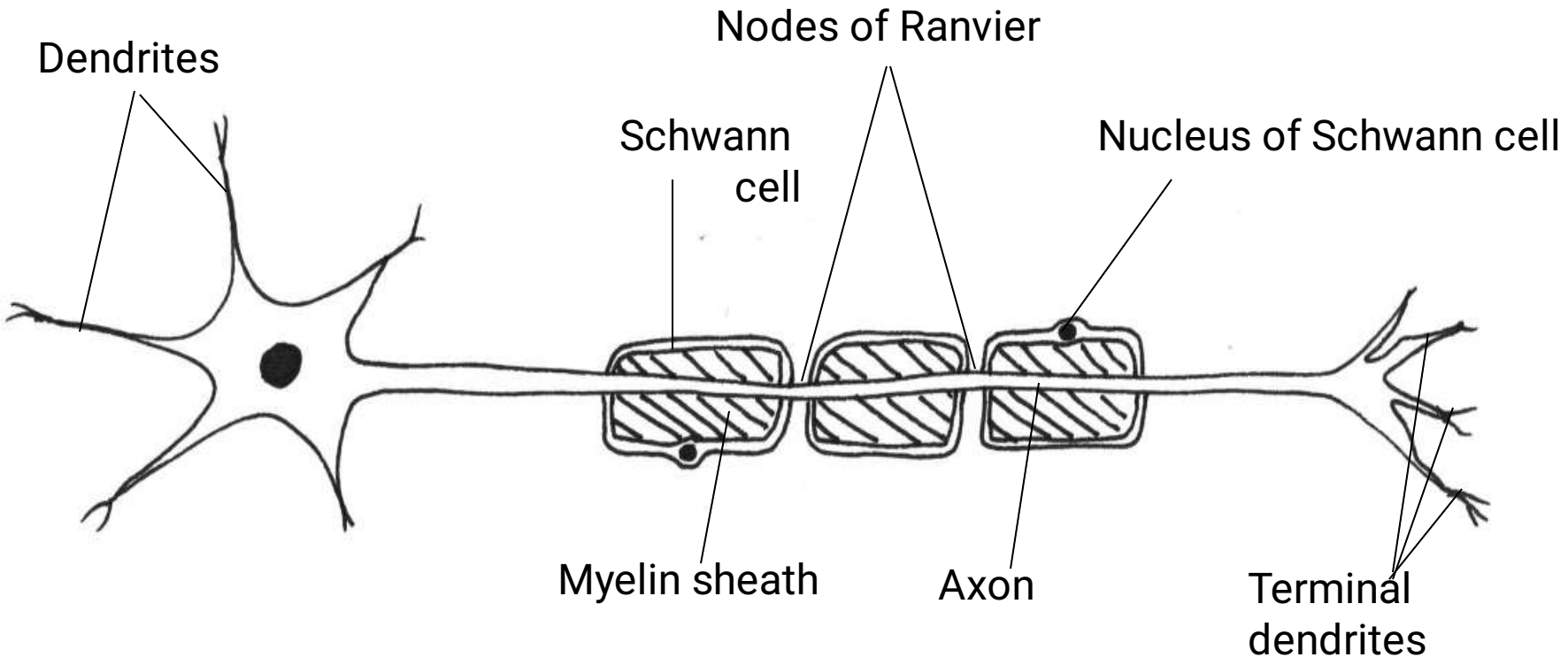


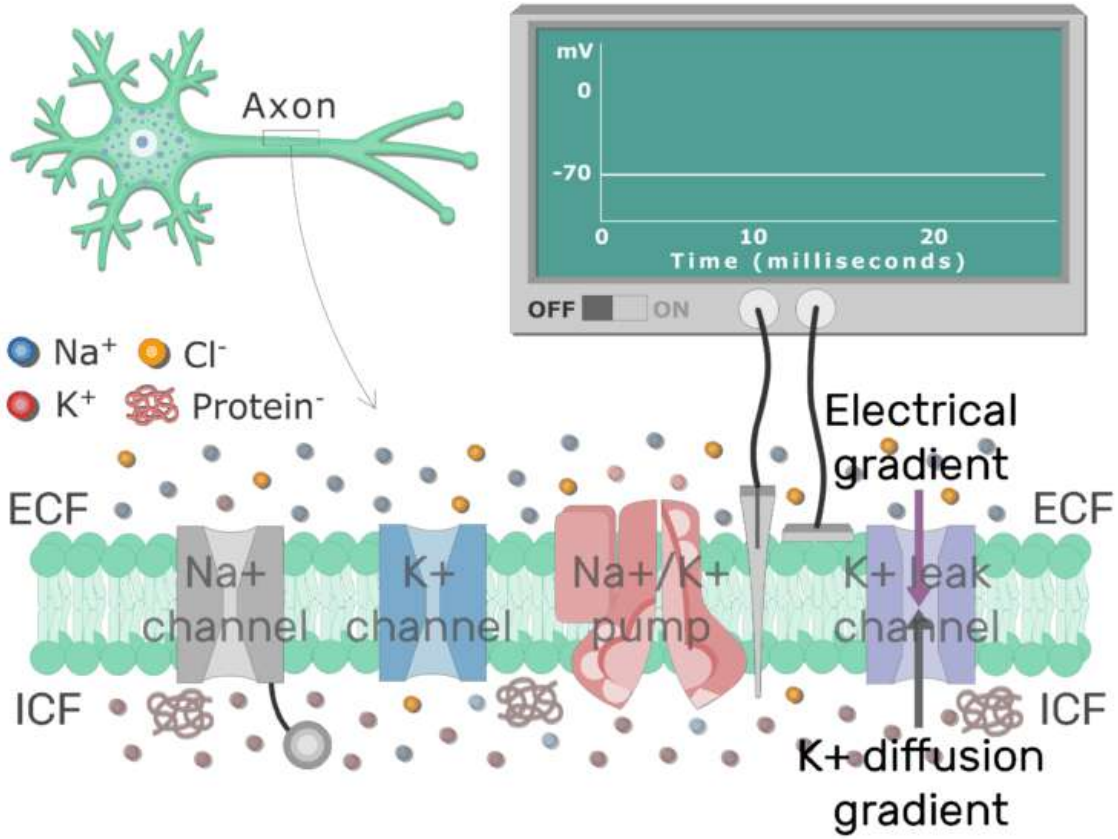
School of Anatomy and Human Biology – The University of Western Australia

The neurone


Dendrites
Nodes of Ranvier
Schwann cell
Nucleus of Schwann cell
Myelin sheath
Axon
Terminal dendrites

Neurones

- Neurones like other cells are more negatively charged inside than outside
- This results in a membrane potential of about – 70 milliVolts
- This is called the resting potential of the neurone
- This has an effect on the passive movement of K^+ and Na^+ across the neurone's plasma membrane



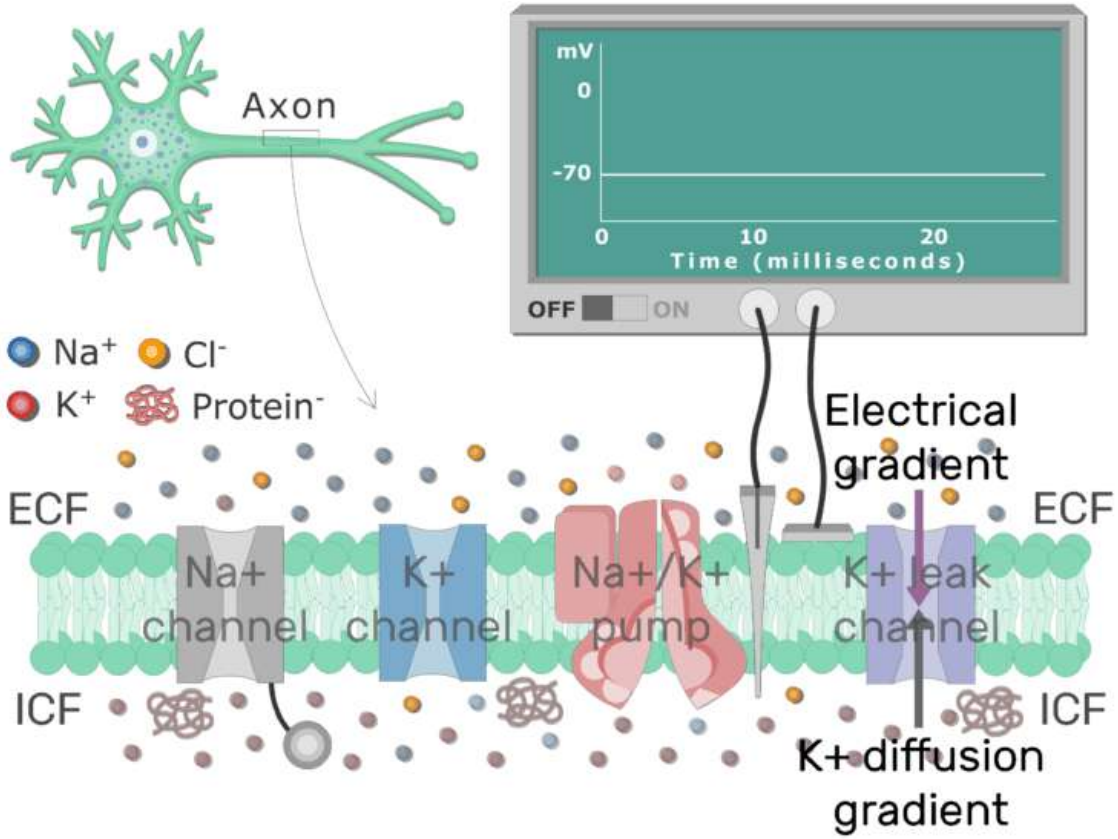
Passive movement of ions across a cell membrane

- The concentration gradient:
  causing the ions to diffuse down their concentration gradient

- The electrical potential:
  causing ions to be attracted to the opposite charge to the one they carry

Potassium & Sodium Ions

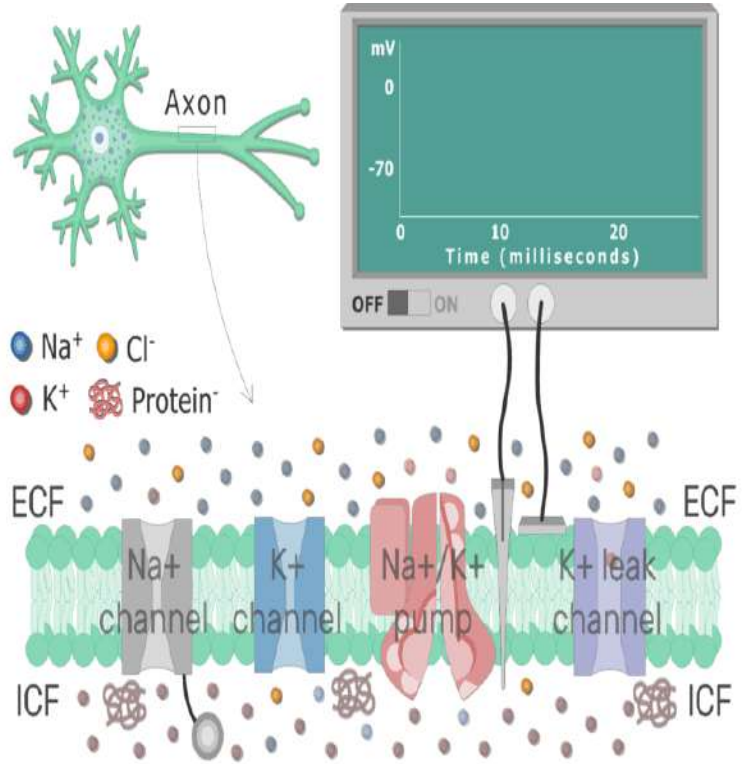
- The two important ions in a nerve cell (neurone or neuron) are K^+ and Na^+
- Both are cations (positively charged ions)
- Na+ ions move more slowly across the membrane than K^+ or Cl^- ions
- This is because although the Na^+ ion is smaller than the K^+ ion
  Na^+ has a larger coating of water molecules giving it a bigger diameter
- This makes the plasma membrane 25 times more permeable to K^+ than Na^+



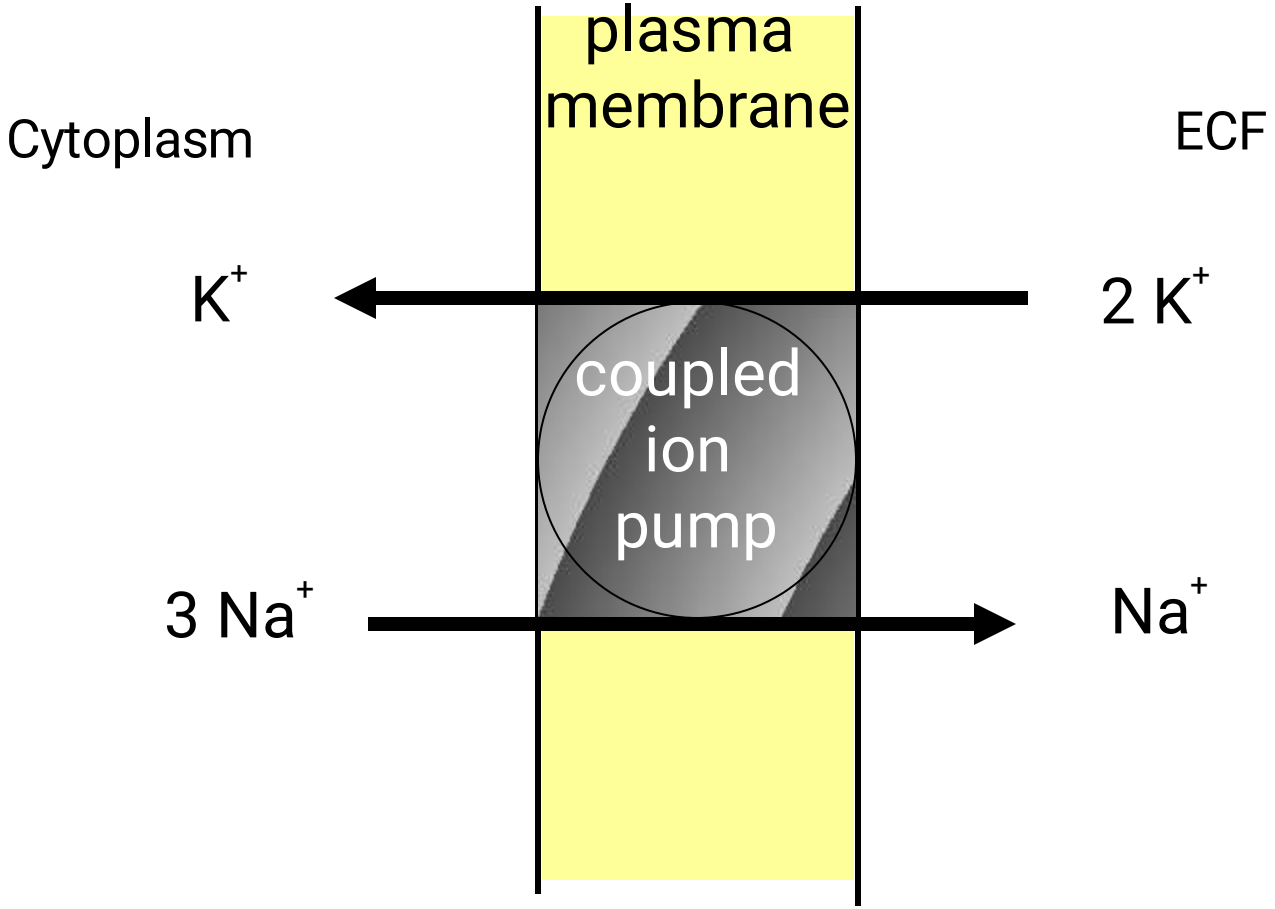
Potassium & Sodium Ions

- In addition to this K^+ ions leak out of K^+ ion pores when the nerve cell is at rest
- So to maintain the high concentration of K^+ inside the cell, it has to be actively pumped inwards a bit when the cell is at rest

- The result is that the resting potential of the neurone is almost at the equilibrium for K^+ ions
- K^+ leak out a bit and need pumping in
- Na^+ ions, however, are actively pumped out and kept out



A coupled Na^+-K^+ pump



Getting excited!

- As the neurone’s membrane at rest is more negative inside than outside, it is said to be polarised
- Neurones are excitable cells
- The cells are excited when their membranes become depolarised

Depolarisation

Depolarising membranes may be achieved by:

- a stimulus arriving at a receptor cell (e.g. vibration of a hair cell in the ear)
- a chemical fitting into a receptor site (e.g. a neurotransmitter)
- a nerve impulse travelling down a neurone

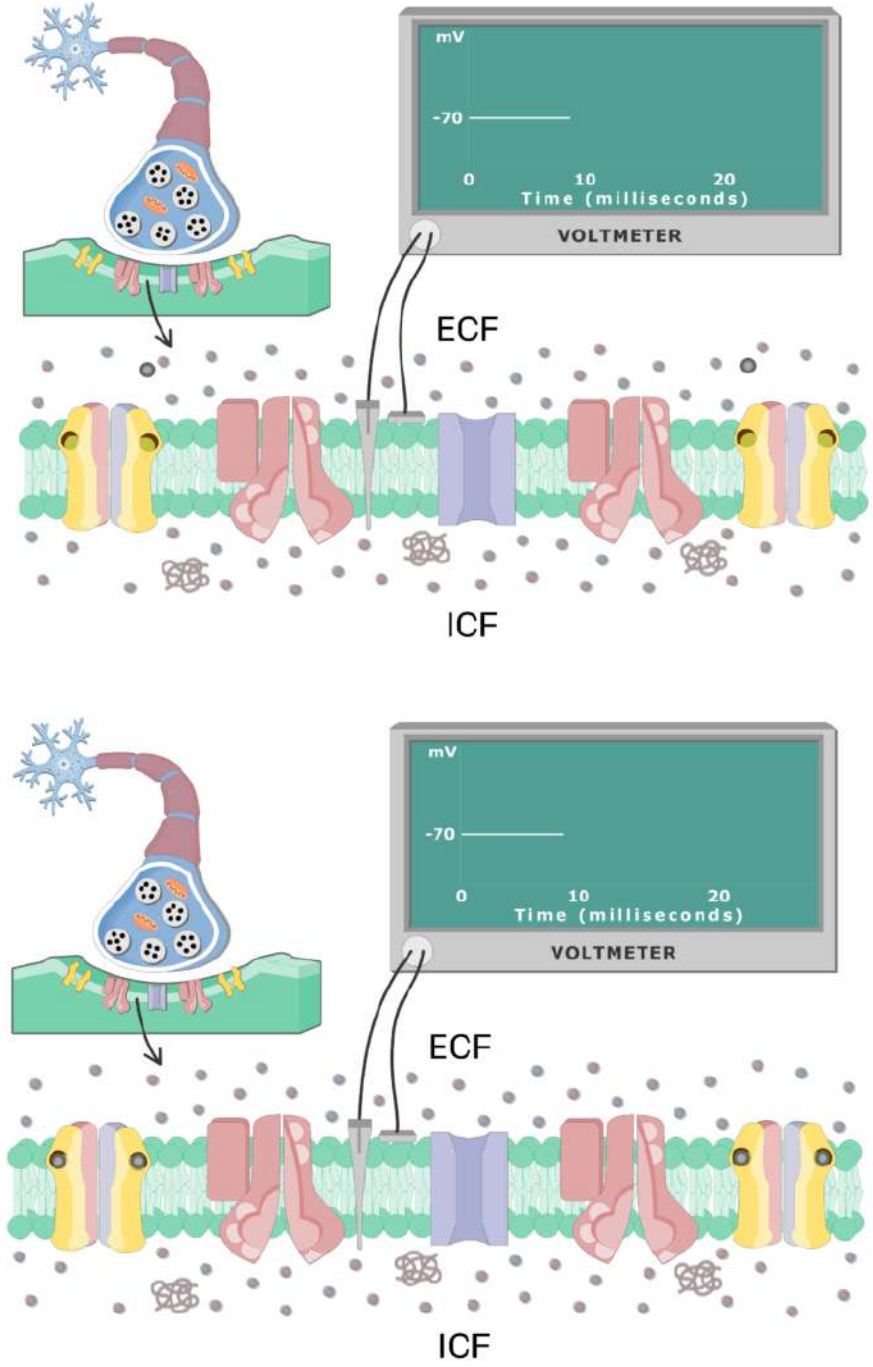
Nerve impulses

- Nerve impulses are self-propagating like a trail of gunpowder
- Localised currents in the ions occur just ahead of the impulse causing localised depolarisation
- Nerve impulses are not like electrical signals travelling down a wire

Depolarisation

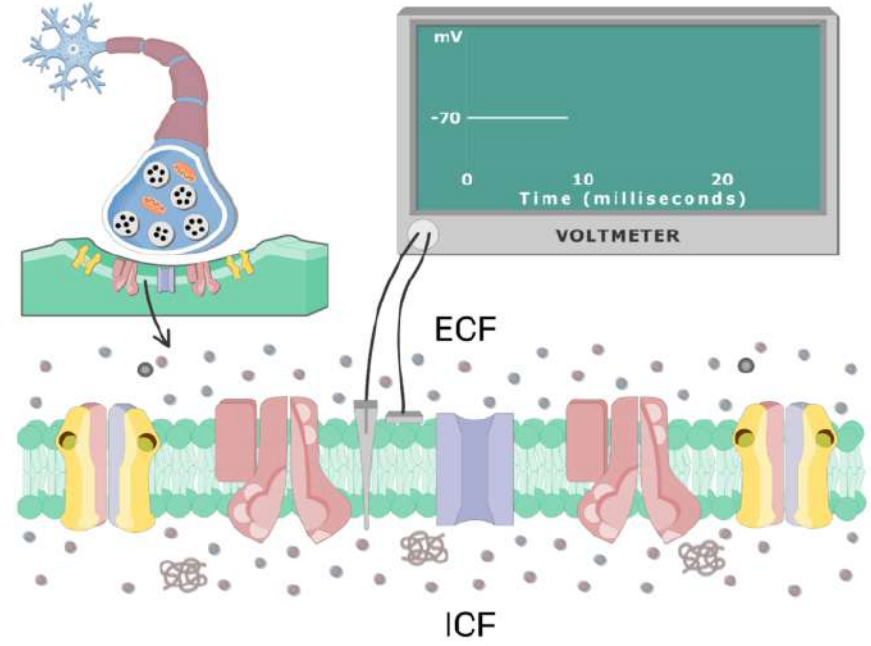
Depolarising membranes may be achieved by:

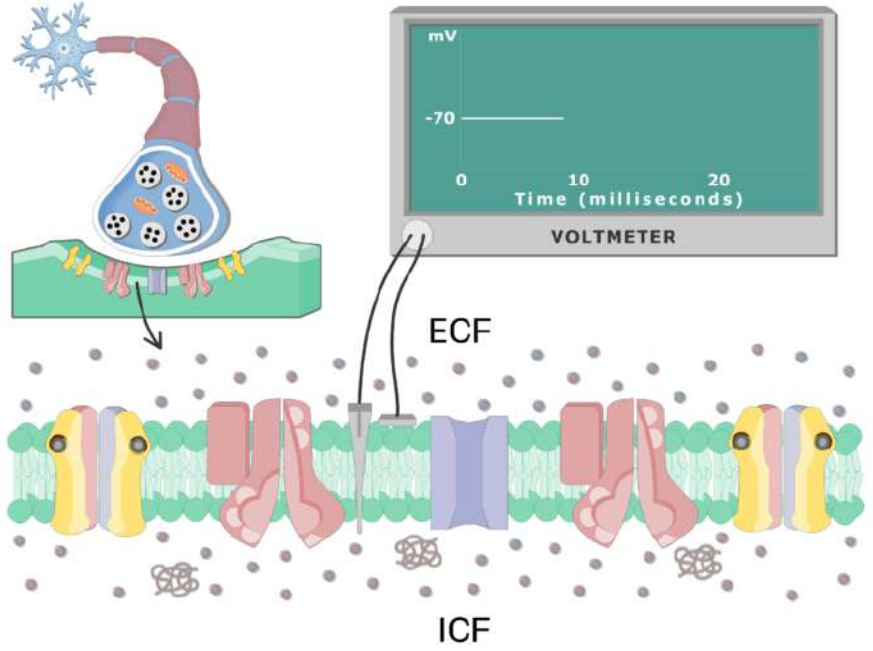
- a stimulus arriving at a receptor cell (e.g. vibration of a hair cell in the ear)
- a chemical fitting into a receptor site (e.g. a neurotransmitter)
- a nerve impulse travelling down a neurone



Nerve impulses

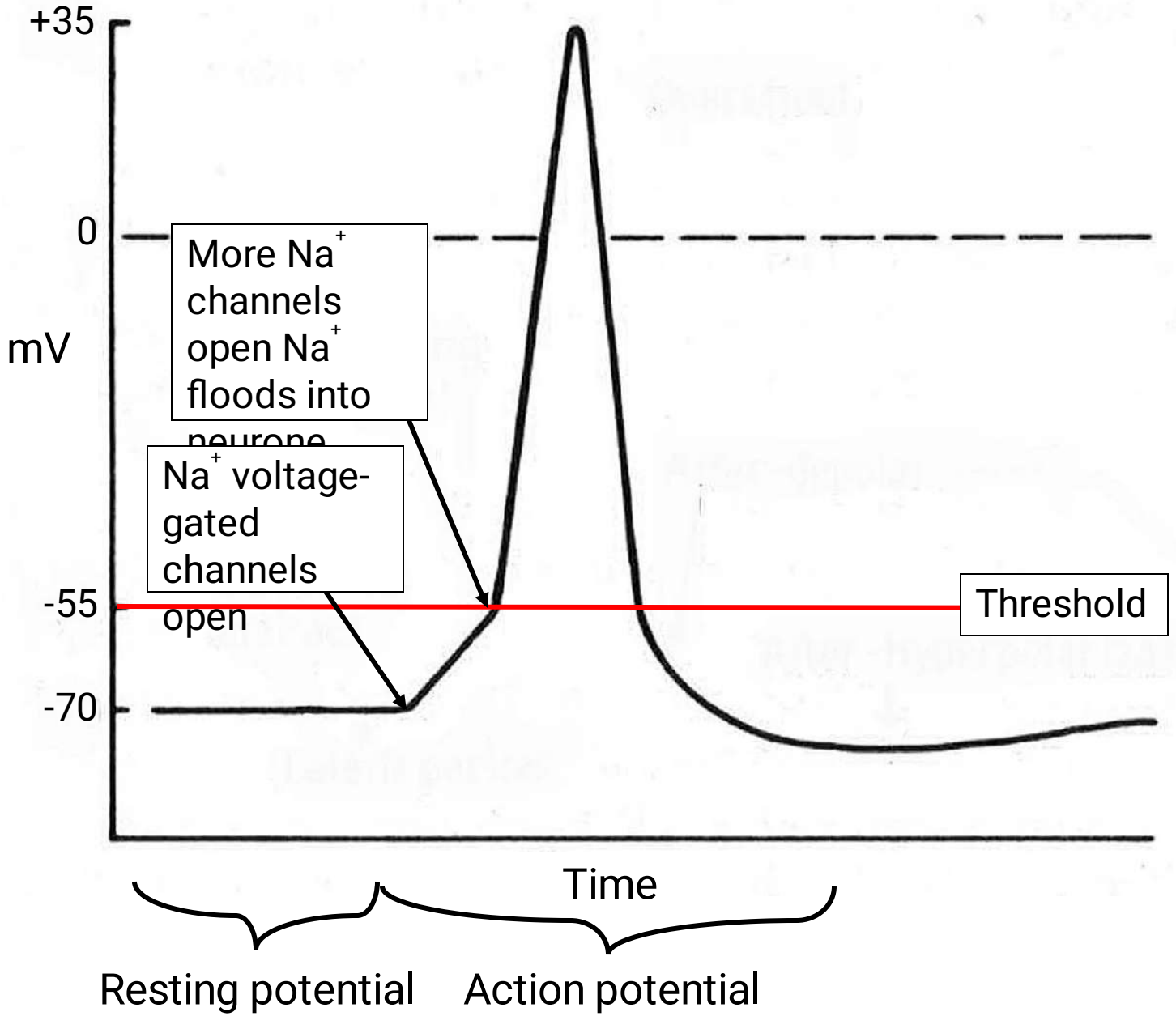
- Depolarization of the postsynaptic membrane begins when ACh is released by the presynaptic neuron and binds to receptors in the postsynaptic membrane.
- Chemical gates open in response and the receptors form water-filled channels, which Na+ and K+ ions pass through.
- Because of favorable diffusion and electrical gradients, more Na+ ions enter the cell than K+ ions exit.





The action potential

- The action potential is the state of the neurone membrane when a nerve impulse passes by
- A small change in the membrane voltage will depolarise the membrane enough to flip open Na^+ channels
- These are called voltage-gated Na^+ channels
- As Na^+ moves into the cell more and more Na^+ channels open
- A small change in the membrane permeability to Na^+ results in a big change in membrane potential
- This is because the volume of the axon is minute compared to the volume of the extracellular fluid


+35
0
mV
-55
-70
More Na+ channels open Na+ floods into neurone
Na+ voltage-gated channels open
Threshold
Time
Resting potential
Action potential

All-or-nothing

- As Na^+ moves in the cell will become more positive with respect to the outside

- The ion pumps resist the change in the membrane potential but it only has to rise by 15mV and the pumps cannot restore the equilibrium
- Na^+ floods in

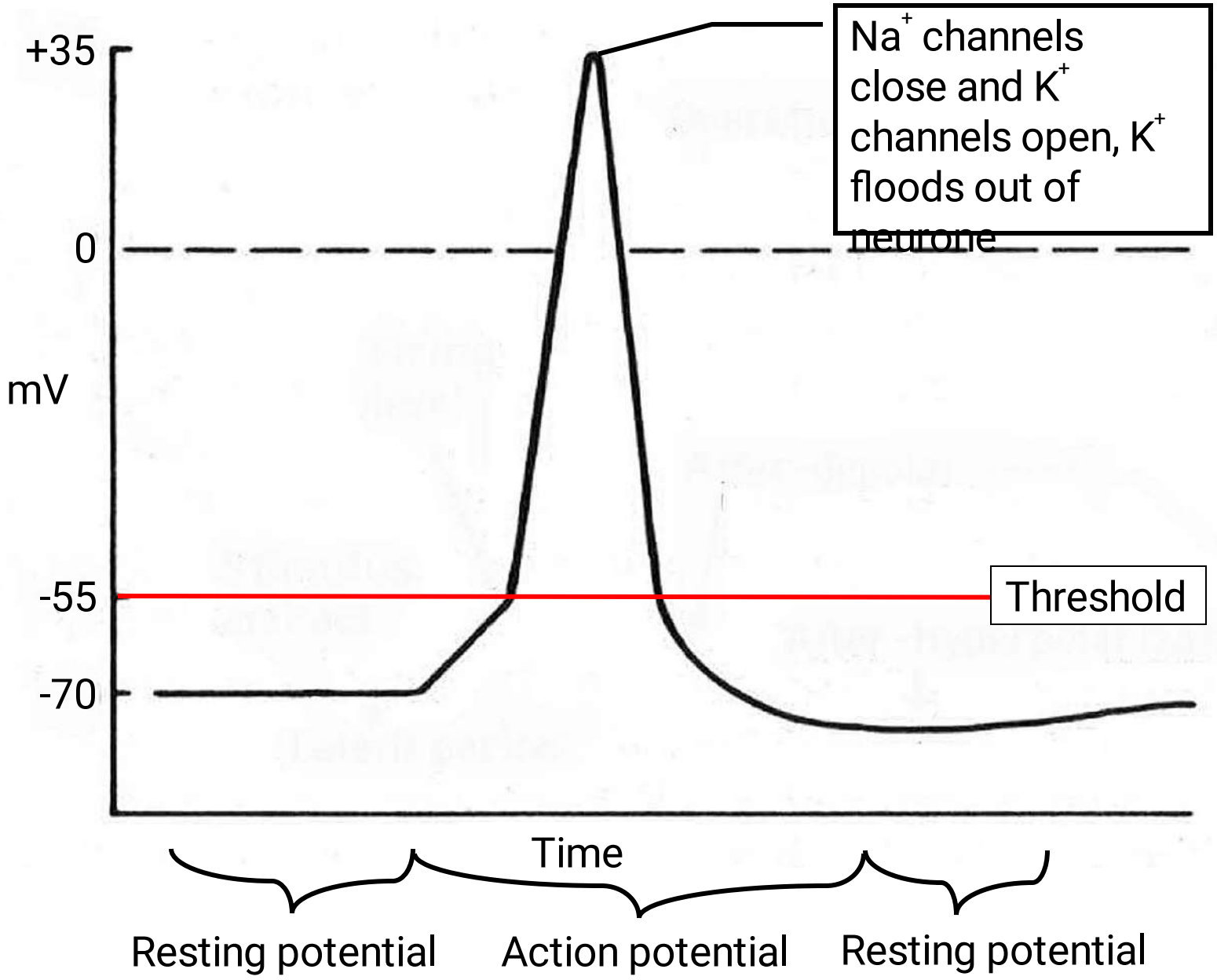
- Nerve impulses all look the same, there are not big ones and little ones
- This is the all-or-nothing law

The threshold

- −55mV represents the threshold potential
- Beyond this we get a full action potential

- The membrane potential rises to +35mV this is the peak of the action potential

- The cells are almost at the equilibrium for Na^+ ions


+35
0
mV
-55
-70
Na+ channels close and K+ channels open, K+ floods out of neurone
Threshold
Time
Resting potential
Action potential
Resting potential

Potassium takes over

- After Na^+ moves in passively until the Na^+ channels start to close
- At the same time K^+ permeability increases as voltage-gated K^+ channels open – they are a bit slower to respond to the depolarisation than the Na^+ channels
- The K^+ ions move out
- This makes the cell negative inside with respect to outside again
- The membrane potential falls

Hyperpolarisation

- The membrane potential falls below the resting potential of –70mV
- It is said to be hyperpolarised
- Gradually active pumping of the ions (K^+ in and Na^+ out) restores the resting potential
- During this period no impulses can pass along that part of the membrane
- This is called the refractory period

The Nerve Impulse

- Saltatory conduction is the word used to describe this “jumping” of the action potential from node to node.
  - Provides rapid conduction of impulses
  - Conserves energy for the cell
- Multiple sclerosis is disease in which the myelin sheath is destroyed and associated with poor muscle coordination.

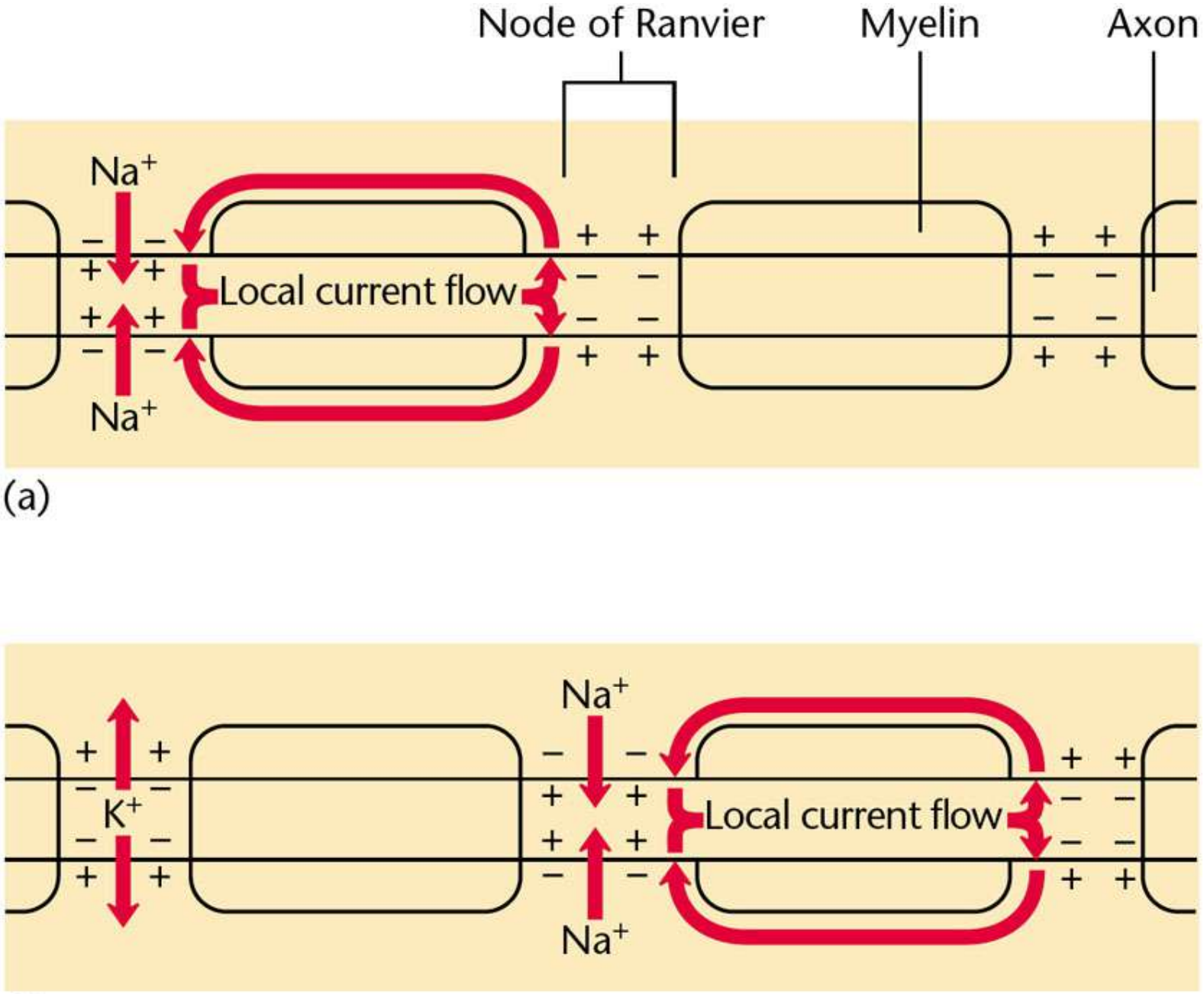


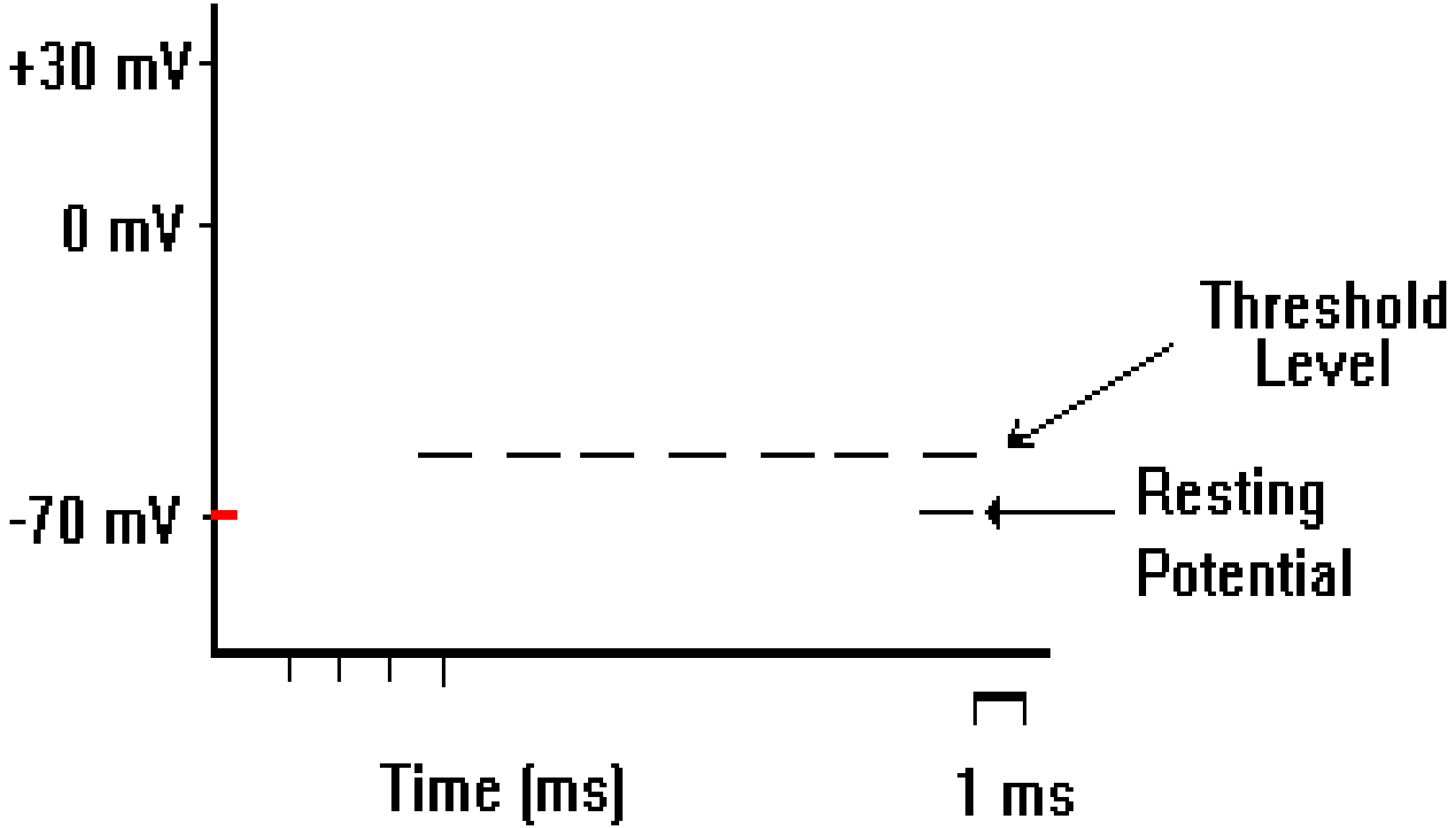
Fig. 2-19, p. 46

The Nerve Impulse

- Not all neurons have lengthy axons.
- Local neurons have short axons, exchange information with only close neighbors, and do not produce action potentials.
- When stimulated, local neurons produce graded potentials which are membrane potentials that vary in magnitude and do not follow the all-or-none law,.
- A local neuron depolarizes or hyperpolarizes in proportion to the stimulation.

NERVOUS SYSTEM

ACTION POTENTIAL



NEURAL TRANSMISSION

RESPONSE TO ENVIRONMENTAL STIMULI

CLICK TO BEGIN.

How does the pain you experience when you burn your hand result so quickly in an action by your muscles?

Muscles Physiology

Overview of Muscular Tissue

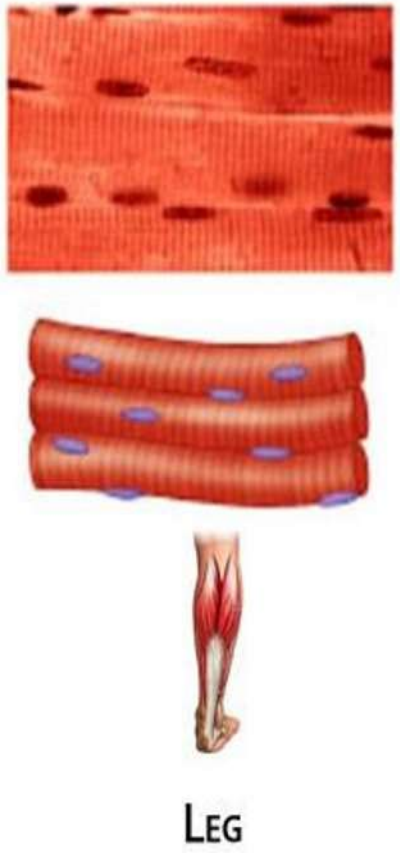
- Types of Muscular Tissue

The three types of muscular tissue

1. Skeletal
2. Cardiac
3. Smooth

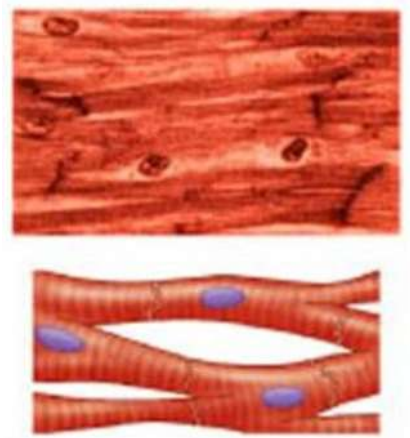
Overview of Muscular Tissue

- Skeletal Muscle Tissue
  - So named because most skeletal muscles move bones
  - Skeletal muscle tissue is striated:
    - Alternating light and dark bands (striations) as seen when examined with a microscope
  - Skeletal muscle tissue works mainly in a voluntary manner
    - Its activity can be consciously controlled
  - Most skeletal muscles also are controlled subconsciously to some extent
    - Ex: the diaphragm alternately contracts and relaxes without conscious control



Overview of Muscular Tissue

- Cardiac Muscle Tissue
  - Found only in the walls of the heart
  - Striated like skeletal muscle
  - Action is involuntary
    - Contraction and relaxation of the heart is not consciously controlled
    - Contraction of the heart is initiated by a node of tissue called the “pacemaker”



HEART

Overview of Muscular Tissue

- Smooth Muscle Tissue
  - Located in the walls of hollow internal structures
    - Blood vessels, airways, and many organs
  - Lacks the striations of skeletal and cardiac muscle tissue
  - Usually involuntary

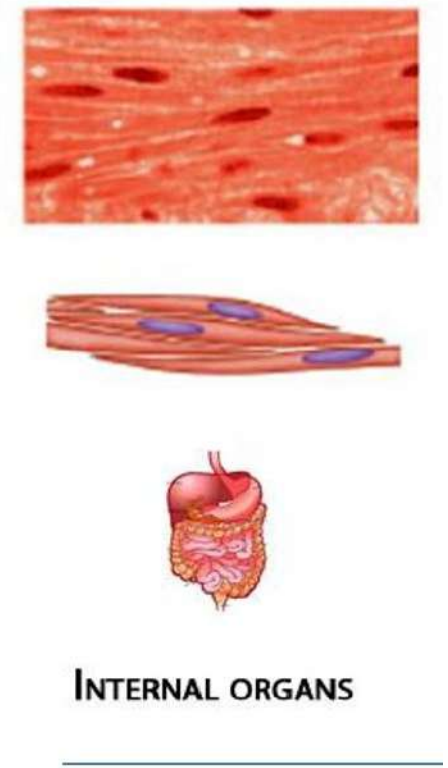
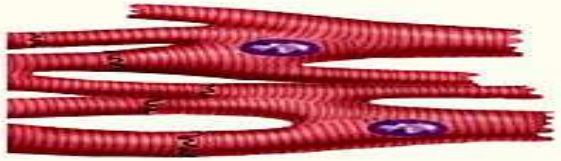


TABLE 10.4

Summary of the Major Features of the Three Types of Muscular Tissue

CHARACTERISTIC	SKELETAL MUSCLE	CARDIAC MUSCLE	SMOOTH MUSCLE
Microscopic appearance and features	Long cylindrical fiber with many peripherally located nuclei; striated. 	Branched cylindrical fiber with one centrally located nucleus; intercalated discs join neighboring fibers; striated. 	Fiber is thickest in middle, tapered at each end, and has one centrally positioned nucleus; not striated. 
Location	Most commonly attached by tendons to bones.	Heart.	Walls of hollow viscera, airways, blood vessels, iris and ciliary body of eye, arrector pili muscles of hair follicles.
Fiber diameter	Very large (10–100 μm).	Large (10–20 μm).	Small (3–8 μm).
Connective tissue components	Endomysium, perimysium, and epimysium.	Endomysium and perimysium.	Endomysium.
Fiber length	100 μm–30 cm.	50–100 μm.	30–200 μm.
Contractile proteins organized into sarcomeres	Yes.	Yes.	No.
Sarcoplasmic reticulum	Abundant.	Some.	Very little.
Transverse tubules present	Yes, aligned with each A–I band junction.	Yes, aligned with each Z disc.	No.
Junctions between fibers	None.	Intercalated discs contain gap junctions and desmosomes.	Gap junctions in visceral smooth muscle; none in multiunit smooth muscle.
Autorhythmicity	No.	Yes.	Yes, in visceral smooth muscle.
Source of Ca^{2+} for contraction	Sarcoplasmic reticulum.	Sarcoplasmic reticulum and interstitial fluid.	Sarcoplasmic reticulum and interstitial fluid.
Regulator proteins for contraction	Troponin and tropomyosin.	Troponin and tropomyosin.	Calmodulin and myosin light chain kinase.
Speed of contraction	Fast.	Moderate.	Slow.
Nervous control	Voluntary (somatic nervous system).	Involuntary (autonomic nervous system).	Involuntary (autonomic nervous system).
Contraction regulated by:	Acetylcholine released by somatic motor neurons.	Acetylcholine and norepinephrine released by autonomic motor neurons; several hormones.	Acetylcholine and norepinephrine released by autonomic motor neurons; several hormones; local chemical changes; stretching.
Capacity for regeneration	Limited, via satellite cells.	Limited, under certain conditions.	Considerable, via pericytes (compared with other muscle tissues, but limited compared with epithelium).

Click

Table 10.04 Tortora - PAP 12/e

TABLE 10.4

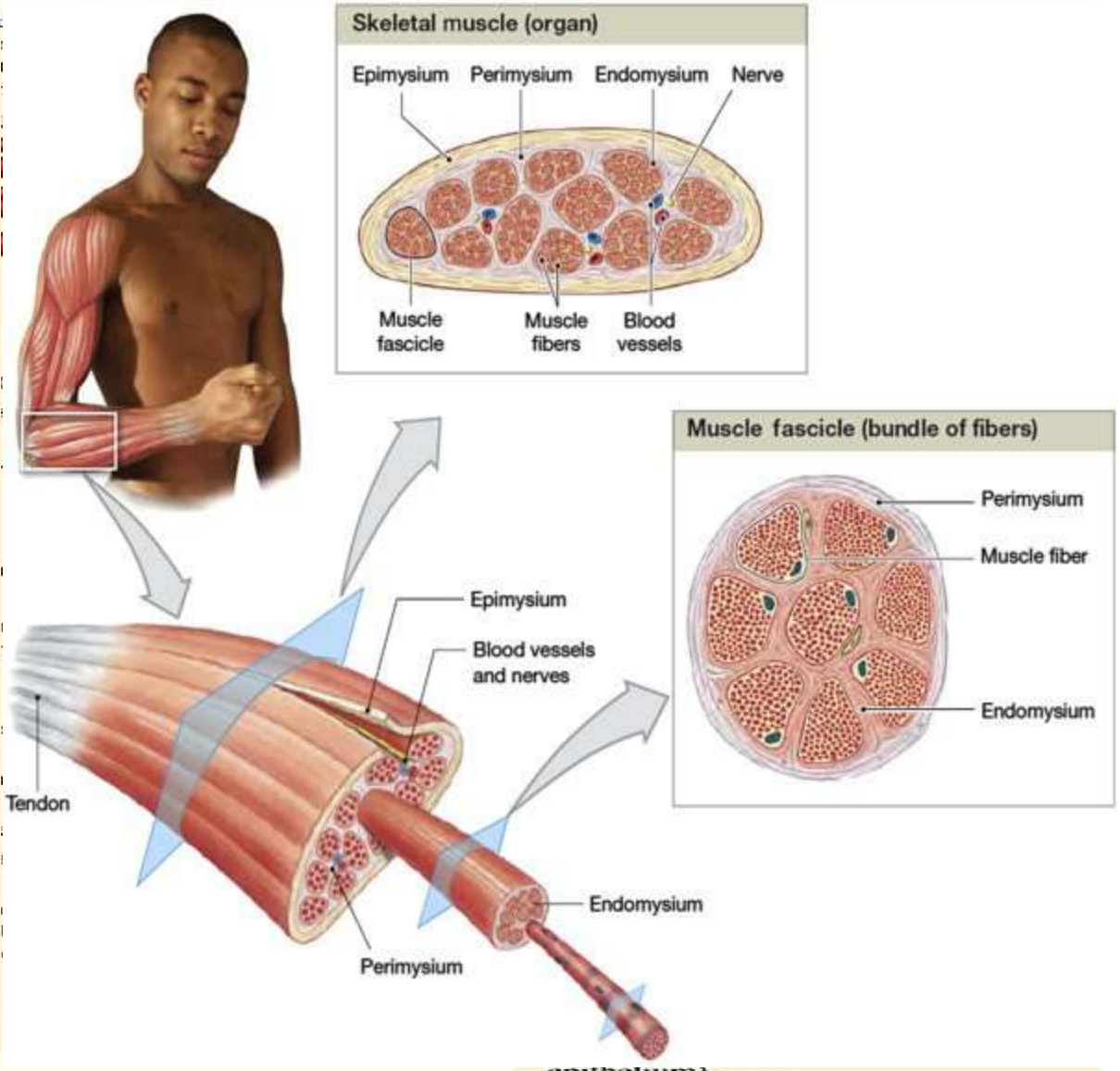
Summary of the Major Features of the Three Types of Muscular Tissue

CHARACTERISTIC	SKELETAL MUSCLE	CARDIAC MUSCLE	SMOOTH MUSCLE
Microscopic appearance	Long cylindrical fiber with	Branched	

1. The epimysium: is the dense connective tissue that surrounds the entire muscle tissue.

2. The perimysium: is the connective tissue that surrounds each bundle of muscle fibers.

3. The endomysium: is the connective tissue that covers each single muscle fiber or myofiber or muscle cell



epithelium).

Table 10.04 Tortora - PAP 12/e

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Capacity for regeneration	Limited, via satellite cells.	Limited, under certain conditions.	Considerable, via pericytes (compared with other muscle tissues, but limited compared with epithelium).

Table 10.04 Tortora - PAP 12/e

Overview of Muscular Tissue

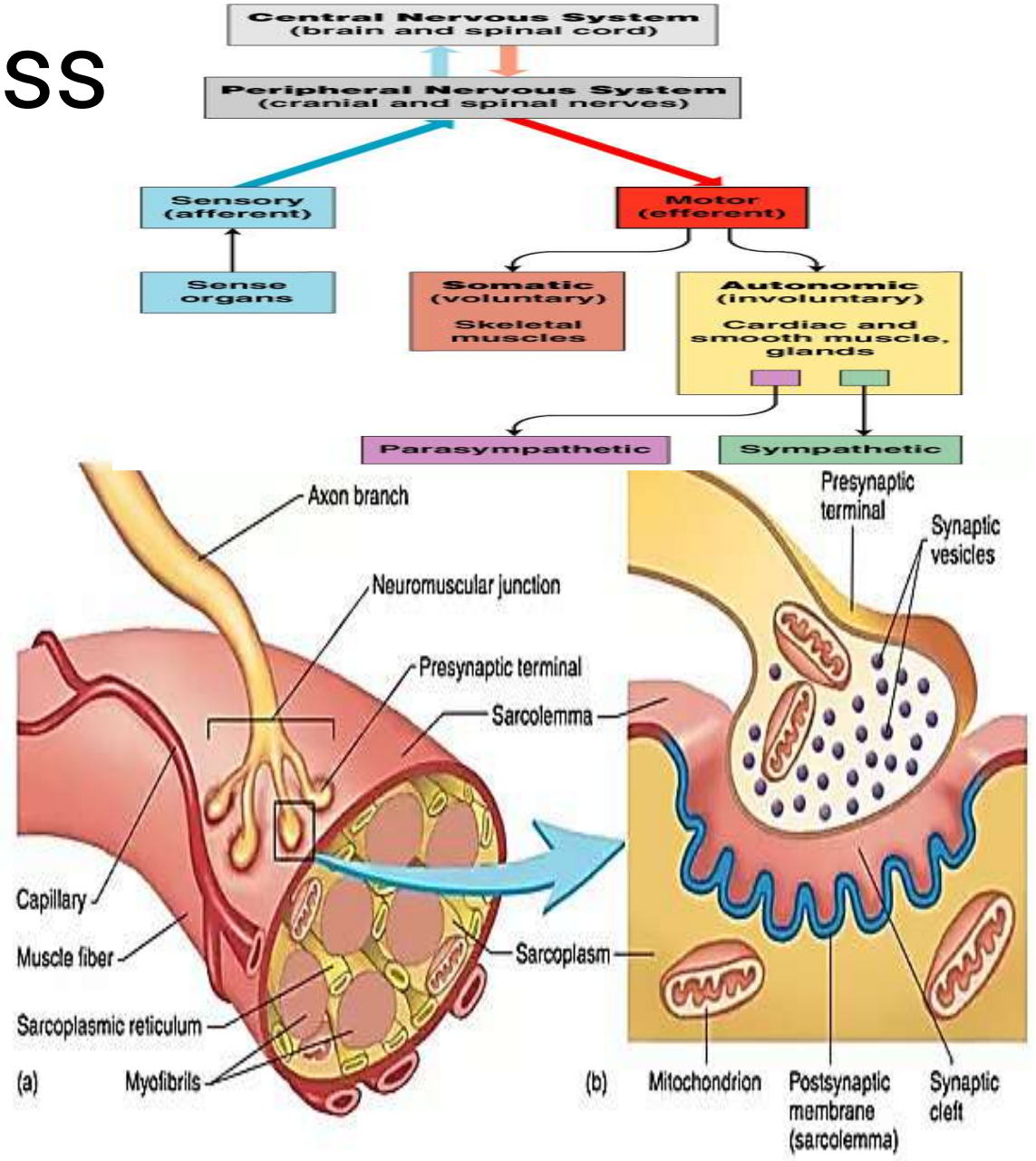
- Functions of Muscular Tissue
  - Producing Body Movements
    - Walking and running
  - Stabilizing Body Positions
    - Posture
  - Moving Substances Within the Body
    - Heart muscle pumping blood
    - Moving substances in the digestive tract
  - Generating heat
    - Contracting muscle produces heat
    - Shivering increases heat production

Overview of Muscular Tissue

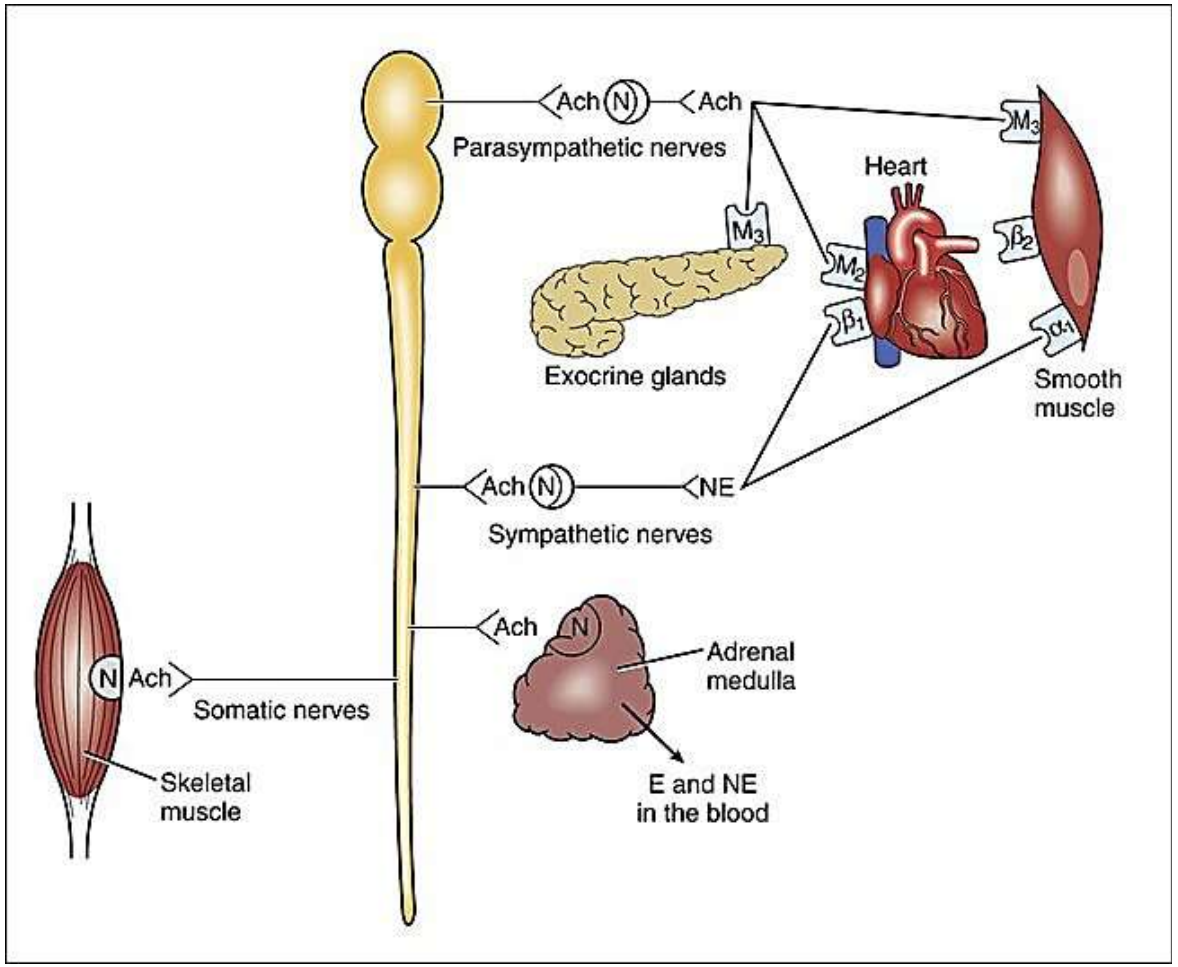
- Properties of Muscular Tissue
  - Properties that enable muscle to function and contribute to homeostasis
    - Excitability
      - Ability to respond to stimuli
    - Contractility
      - Ability to contract forcefully when stimulated
    - Extensibility
      - Ability to stretch without being damaged
    - Elasticity
      - Ability to return to an original length

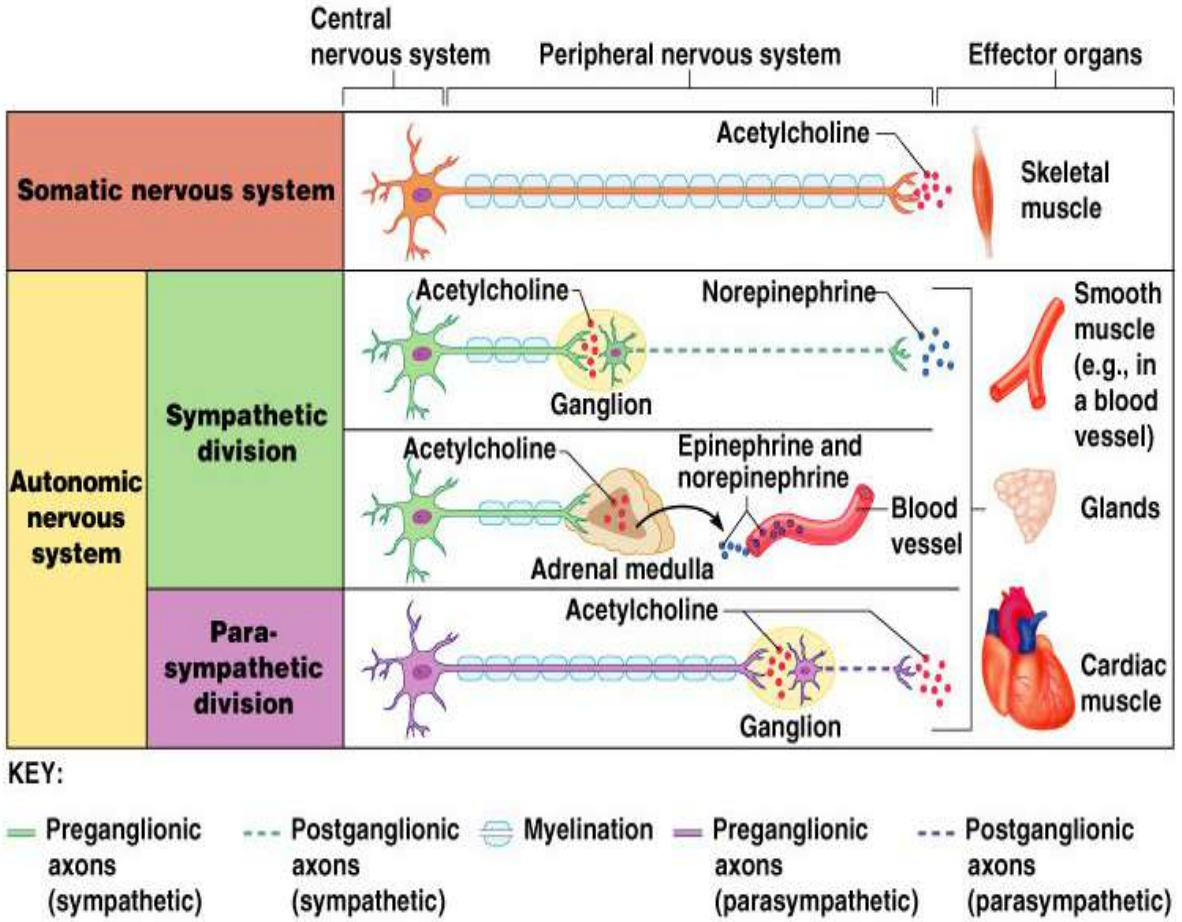
Skeletal Muscle Tiss

- Nerve and Blood Supply
  - Neurons that stimulate skeletal muscle to contract are somatic motor neurons
  - The axon of a somatic motor neuron typically branches many times
    - Each branch extending to a different skeletal muscle fiber
  - Each muscle fiber is in close contact with one or more capillaries



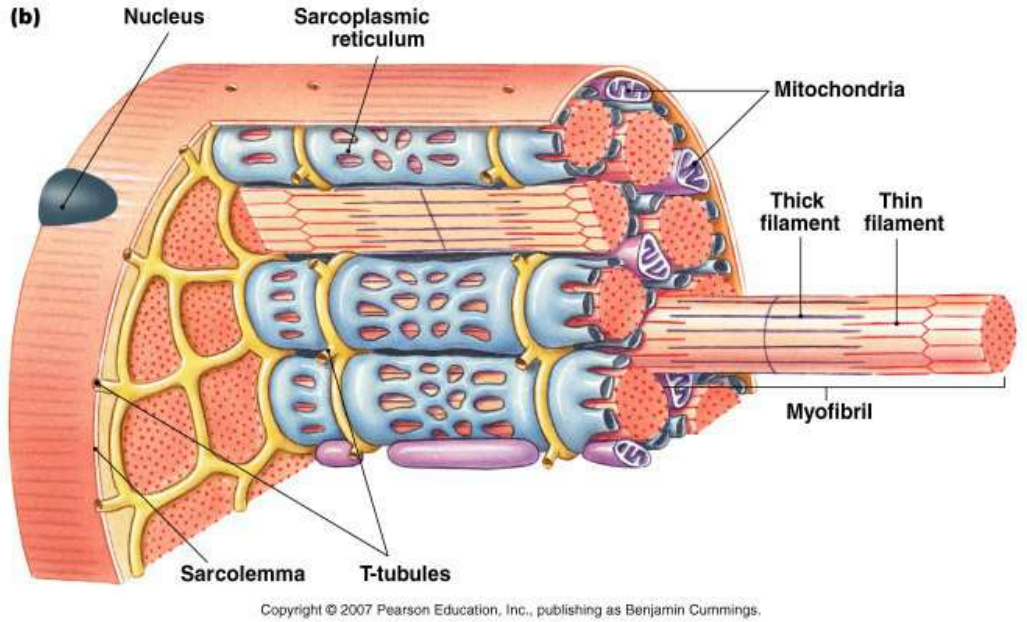
Skeletal Muscle Tissue

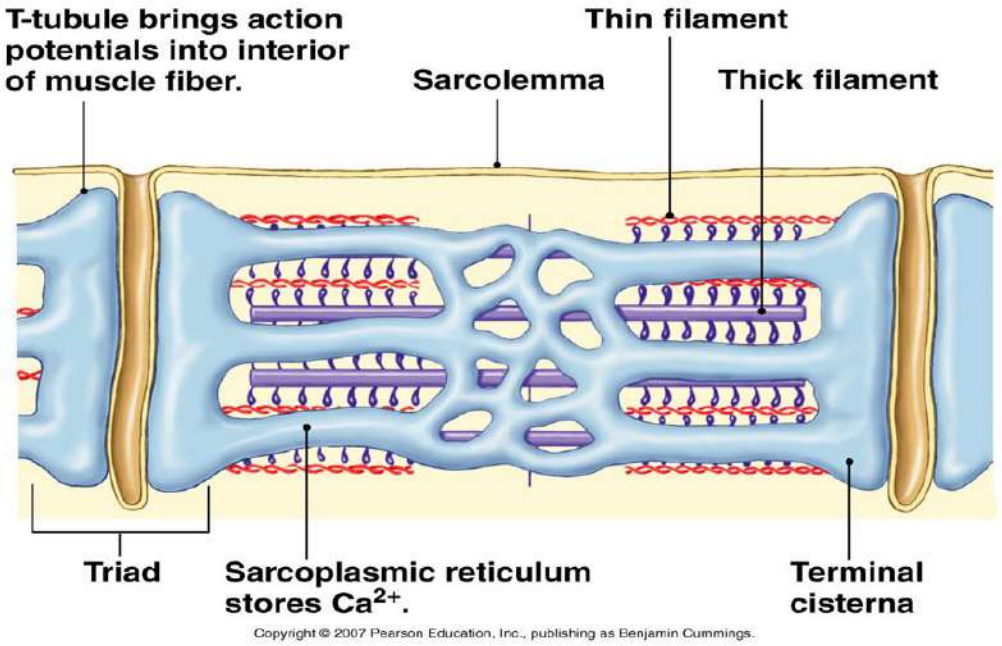




Skeletal Muscle Tissue

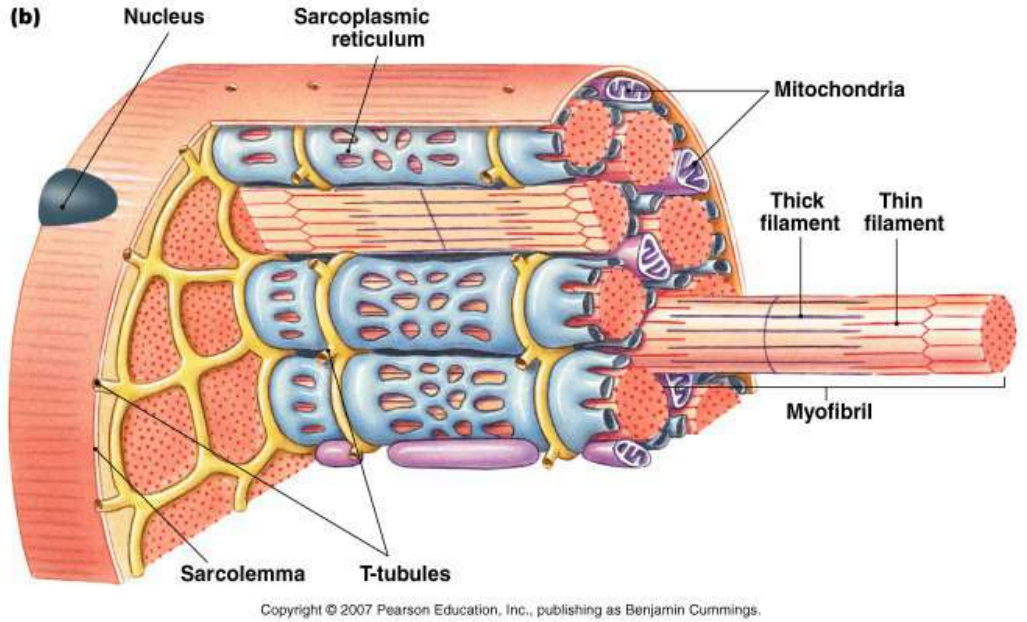
- Microscopic Anatomy
  - The number of skeletal muscle fibers is set before you are born
    - Most of these cells last a lifetime
  - Muscle growth occurs by hypertrophy
    - An enlargement of existing muscle fibers
  - Testosterone and human growth hormone stimulate hypertrophy
  - Satellite cells (muscle stem cells) retain the capacity to regenerate damaged muscle fibers

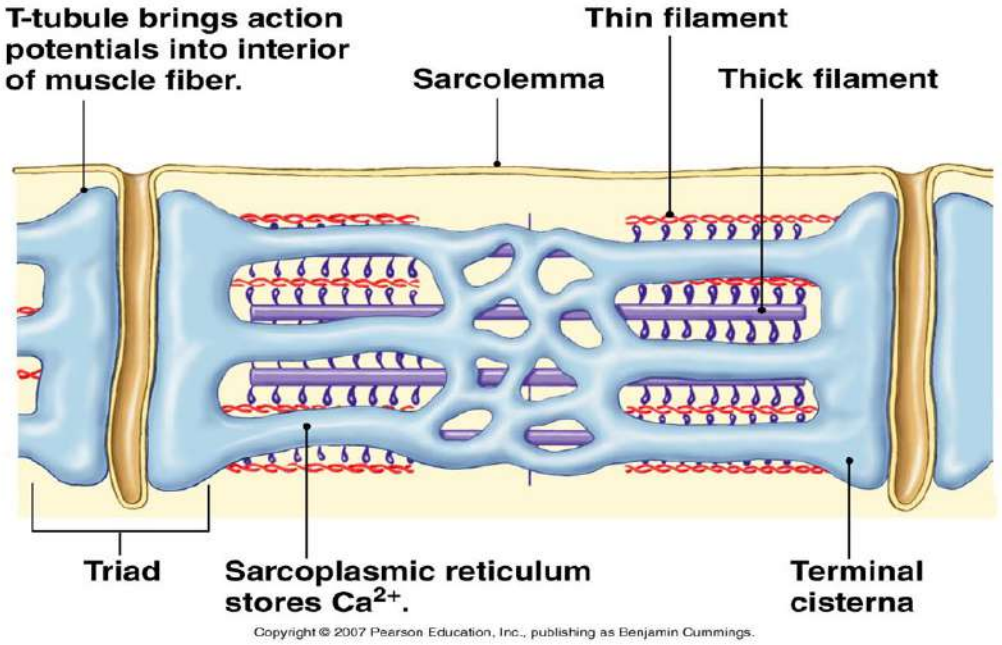




Skeletal Muscle Tiss

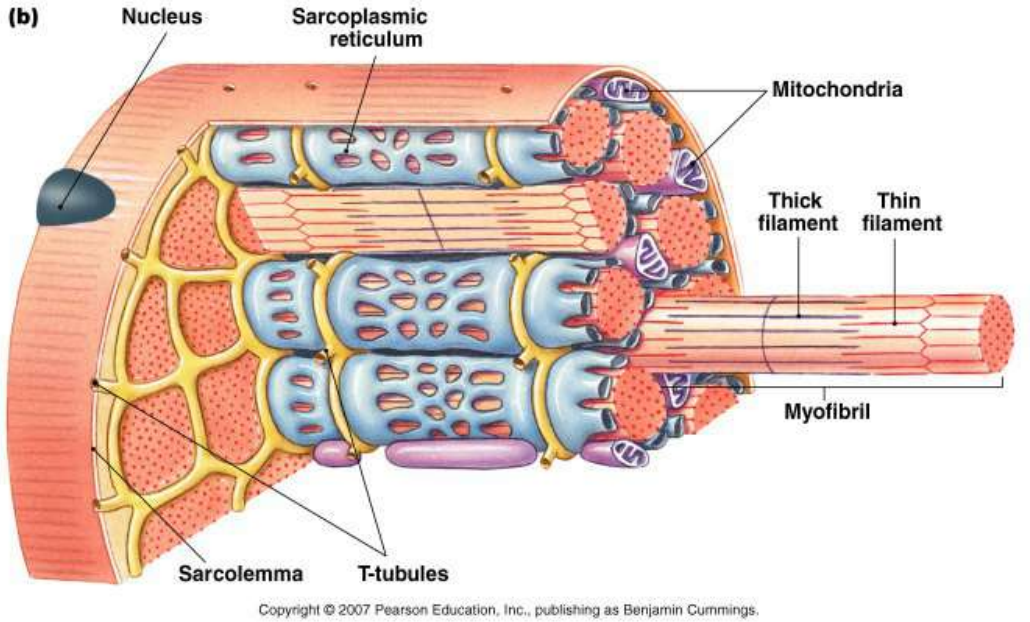
- Sarcolemma
  - The plasma membrane of a muscle cell
- Transverse (T tubules)
  - Tunnel in from the plasma membrane
  - Muscle action potentials travel through the T tubules
- Sarcoplasm, the cytoplasm of a muscle fiber
  - Sarcoplasm includes glycogen used for synthesis of ATP and a red-colored protein called myoglobin which binds oxygen molecules
  - Myoglobin releases oxygen when it is needed for ATP production

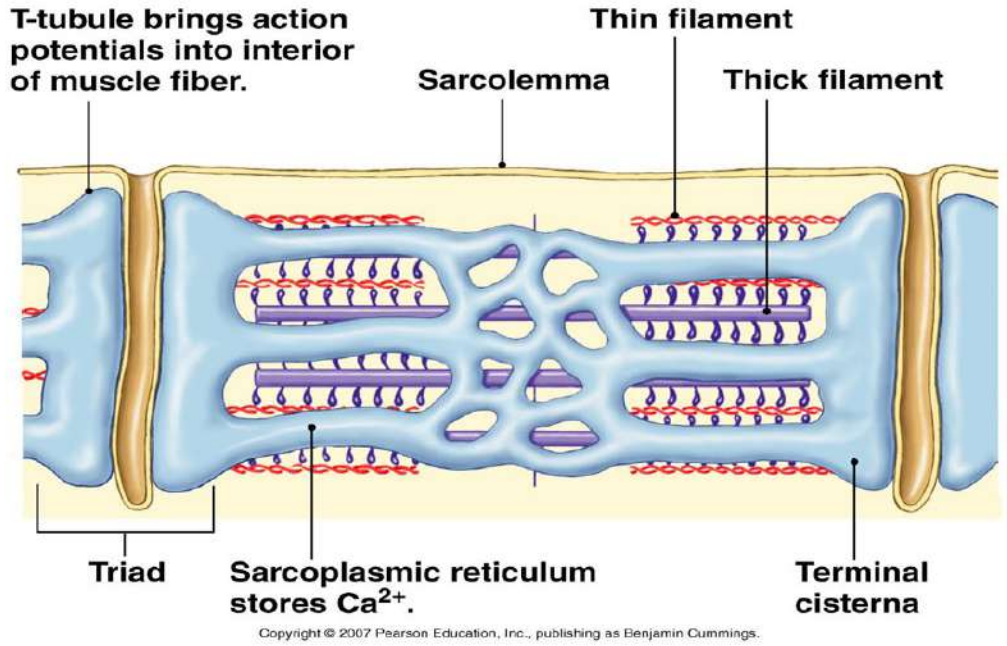




Skeletal Muscle Tiss

- Myofibrils
  - Thread like structures which have a contractile function
- Sarcoplasmic reticulum (SR)
  - Membranous sacs which encircles each myofibril
  - Stores calcium ions (Ca^{++})
  - Release of Ca^{++} triggers muscle contraction
- Filaments
  - Function in the contractile process
  - Two types of filaments (Thick and Thin)
  - There are two thin filaments for every thick filament





Skeletal Muscle Tissue

- Sarcomeres
  - Compartments of arranged filaments
  - Basic functional unit of a myofibril
- Z discs
  - Separate one sarcomere from the next
  - Thick and thin filaments overlap one another
- A band
  - Darker middle part of the sarcomere
  - Thick and thin filaments overlap
- I band
  - Lighter, contains thin filaments but no thick filaments
  - Z discs passes through the center of each I band
- H zone
  - Center of each A band which contains thick but no thin filaments
- M line
  - Supporting proteins that hold the thick filaments together in the H zone

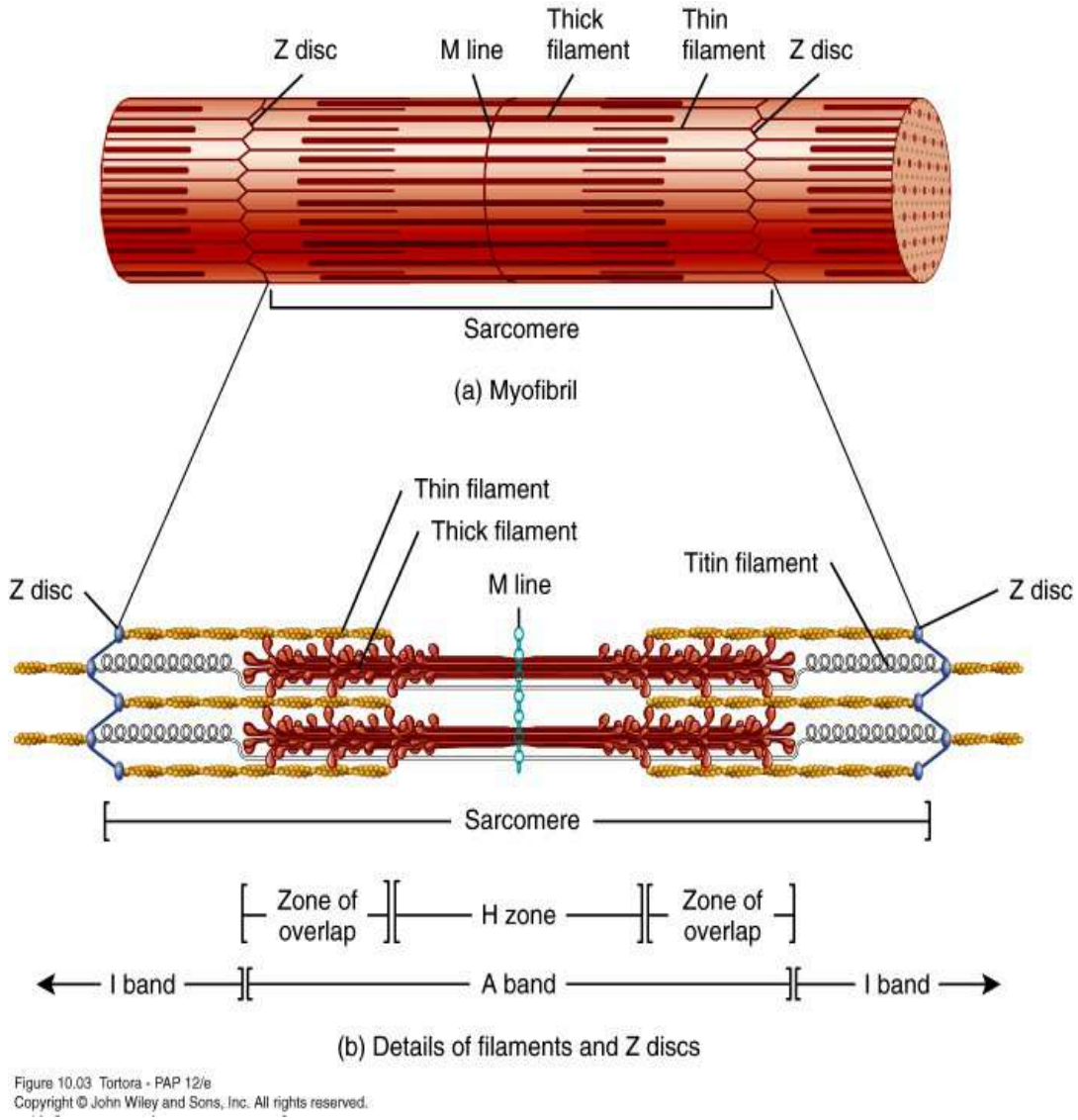


Figure 10.03 Tortora - PAP 12/e

Skeletal Muscle Tissue

- Muscle Proteins
  - Myofibrils are built from three kinds of proteins
    1) Contractile proteins
       - Generate force during contraction

    2) Regulatory proteins
       - Switch the contraction process on and off

    3) Structural proteins
       - Align the thick and thin filaments properly
       - Provide elasticity and extensibility
       - Link the myofibrils to the sarcolemma

Myofibrils = Contractile Organelles of Myofiber

Contain 6 types of protein:

- Actin
- Myosin
- Tropomyosin
- Troponin
- Titin
- Nebulin

Contractile

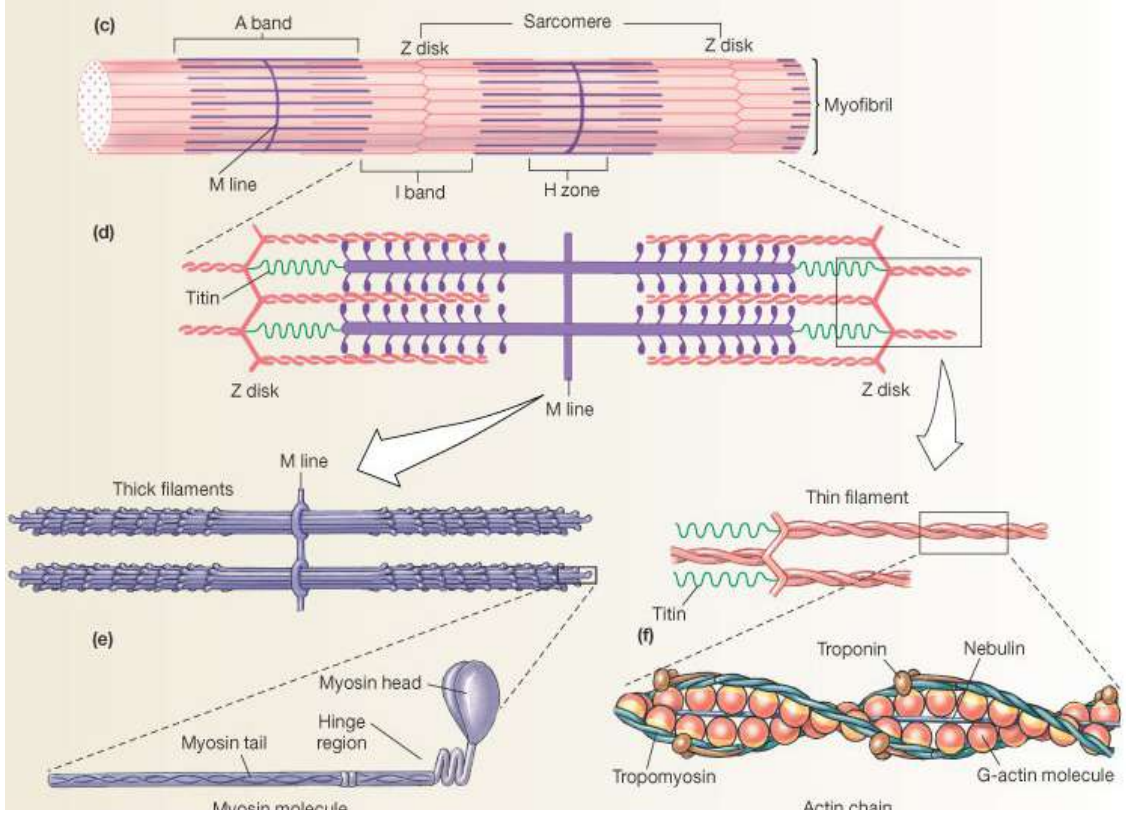
Regulatory

Accessory

Skeletal Muscle Tissue

- Contractile Proteins

- Myosin
  - Thick filaments
  - Functions as a motor protein which can achieve motion
  - Convert ATP to energy of motion
  - Projections of each myosin
  - molecule protrude outward (myosin head)

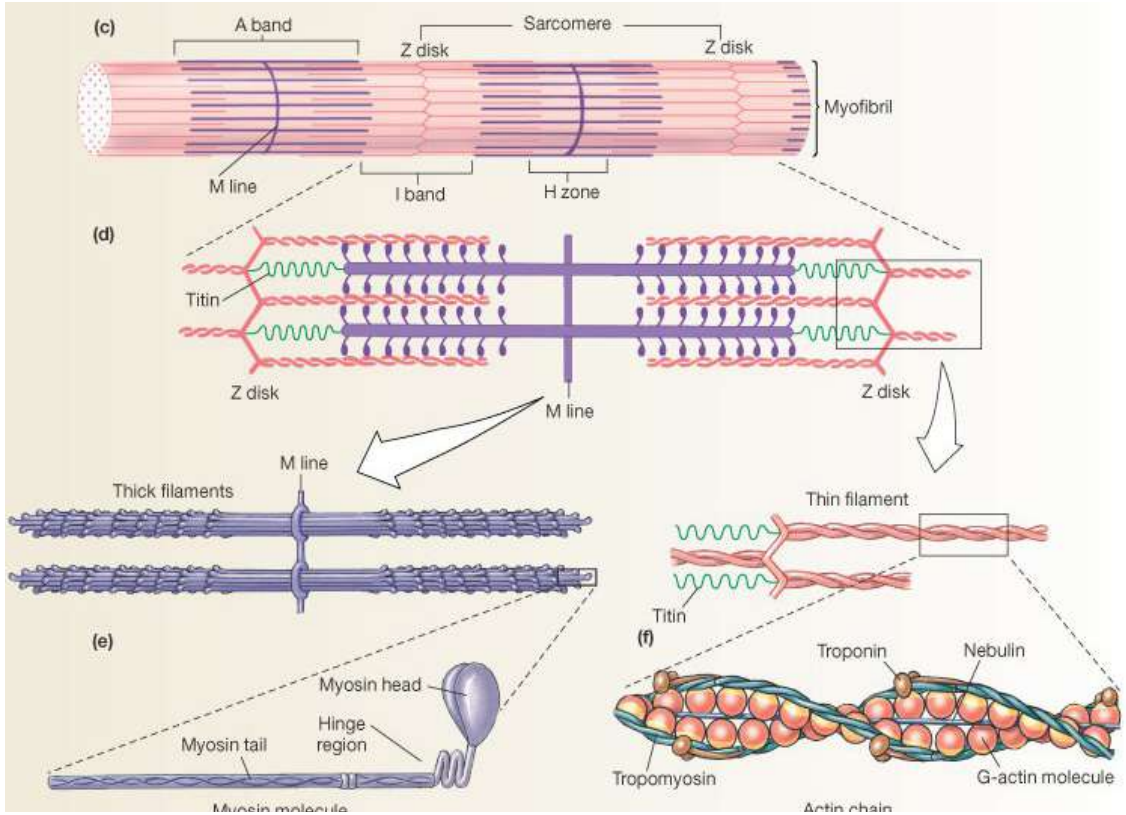


Skeletal Muscle Tissue

- Contractile Proteins
- Actin
  - Thin filaments
  - Actin molecules provide a site where a myosin head can attach
  - Tropomyosin and troponin are also part of the thin filament

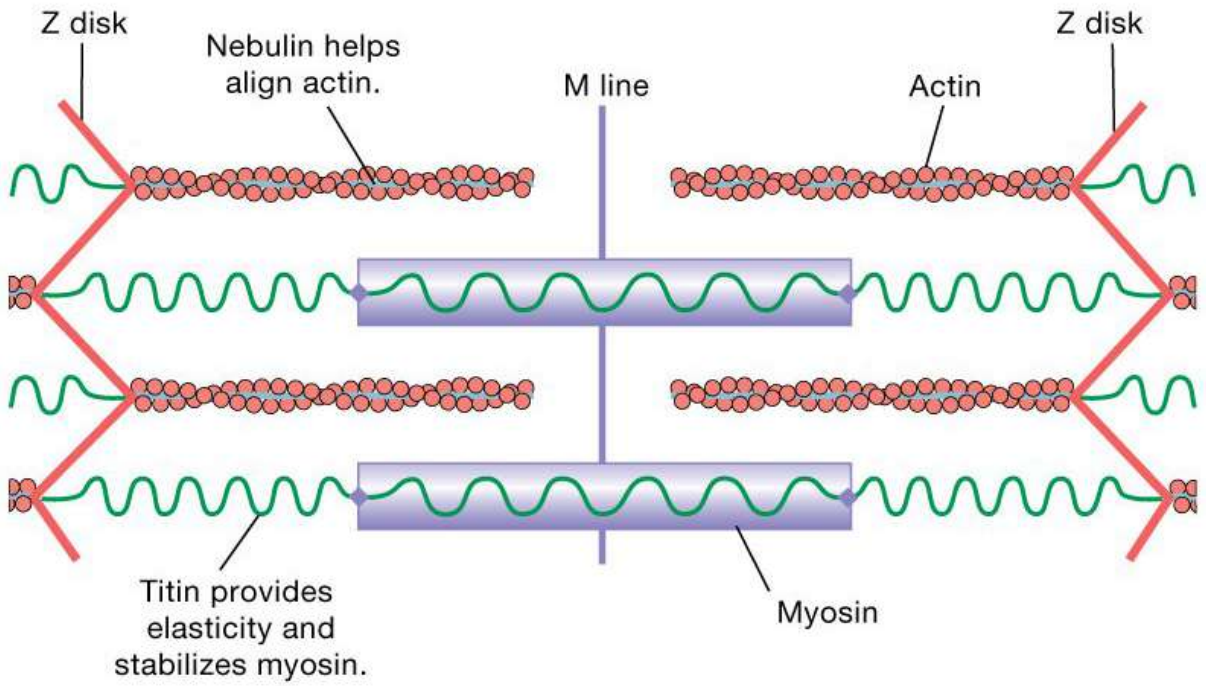
In relaxed muscle

- Myosin is blocked from binding to actin
- Strands of tropomyosin cover the myosin-binding sites
- Calcium ion binding to troponin moves tropomyosin away from myosin-binding sites
- Allows muscle contraction to begin as myosin binds to actin



Titin and Nebulin

- Titin: biggest protein known (25,000 aa); elastic!
  - Stabilizes position of contractile filaments
  - Return to relaxed location
- Nebulin: inelastic giant protein
  - Alignment of A & M



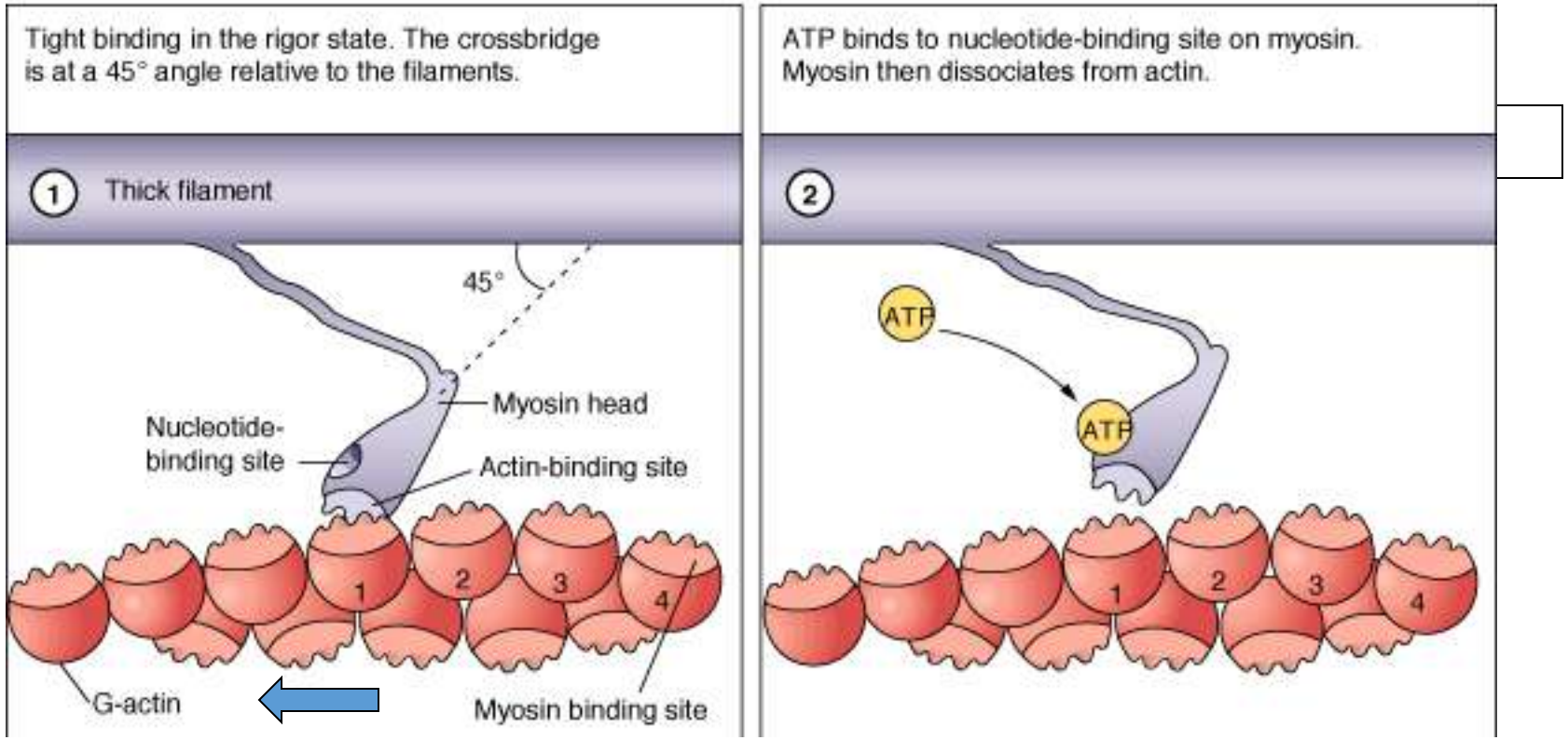
Contraction and Relaxation of Skeletal Muscle

- The Contraction Cycle
  - The onset of contraction begins with the SR releasing calcium ions into the muscle cell
  - Where they bind to actin opening the myosin binding sites

The Molecular Basis of Contraction

Rigor State

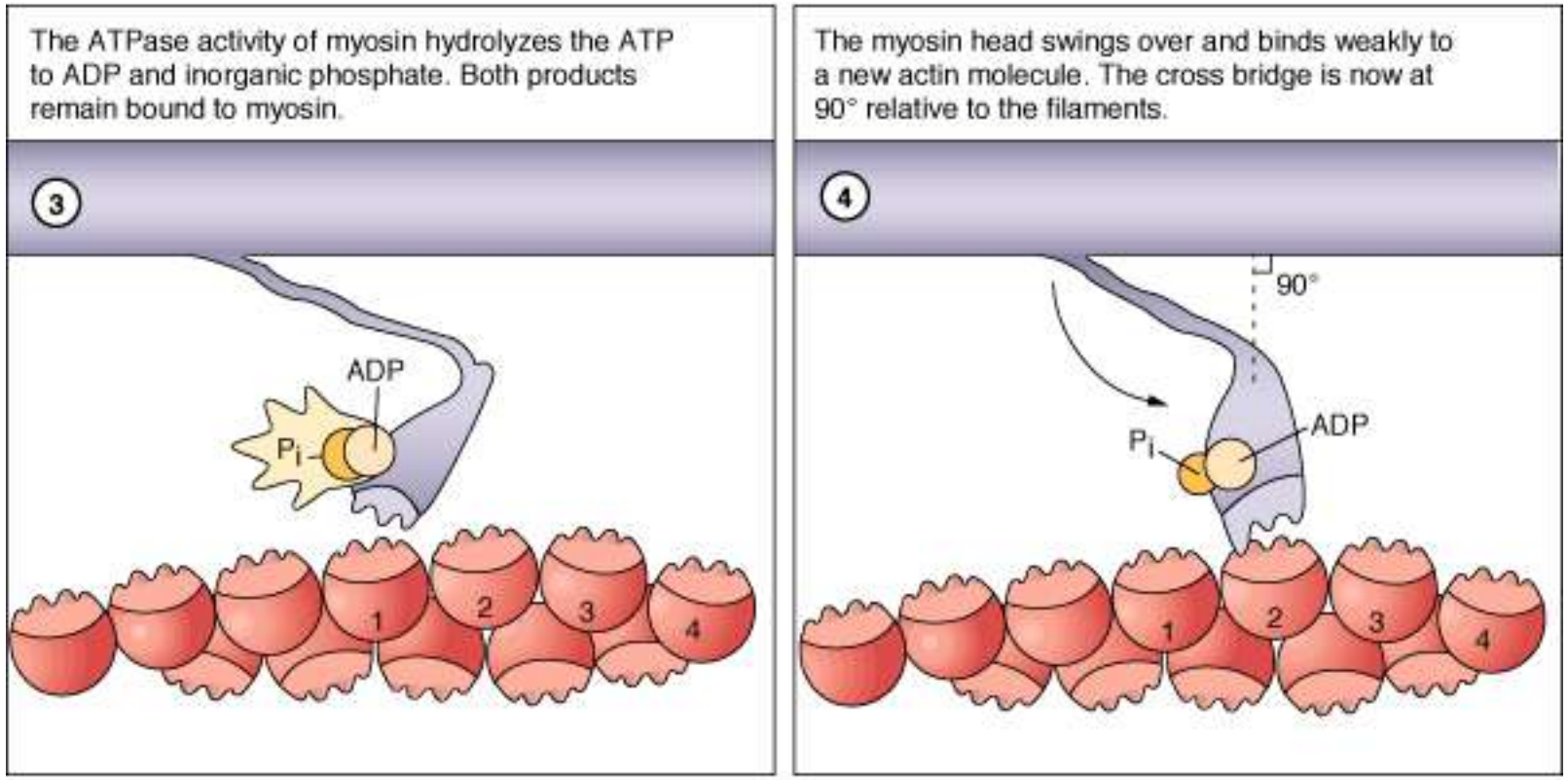
Compare to Fig 12-9



- Tight binding between G-actin and myosin
- No nucleotide bound

ATP binds
dissociation

Released energy changes angle between head & long axis of myosin



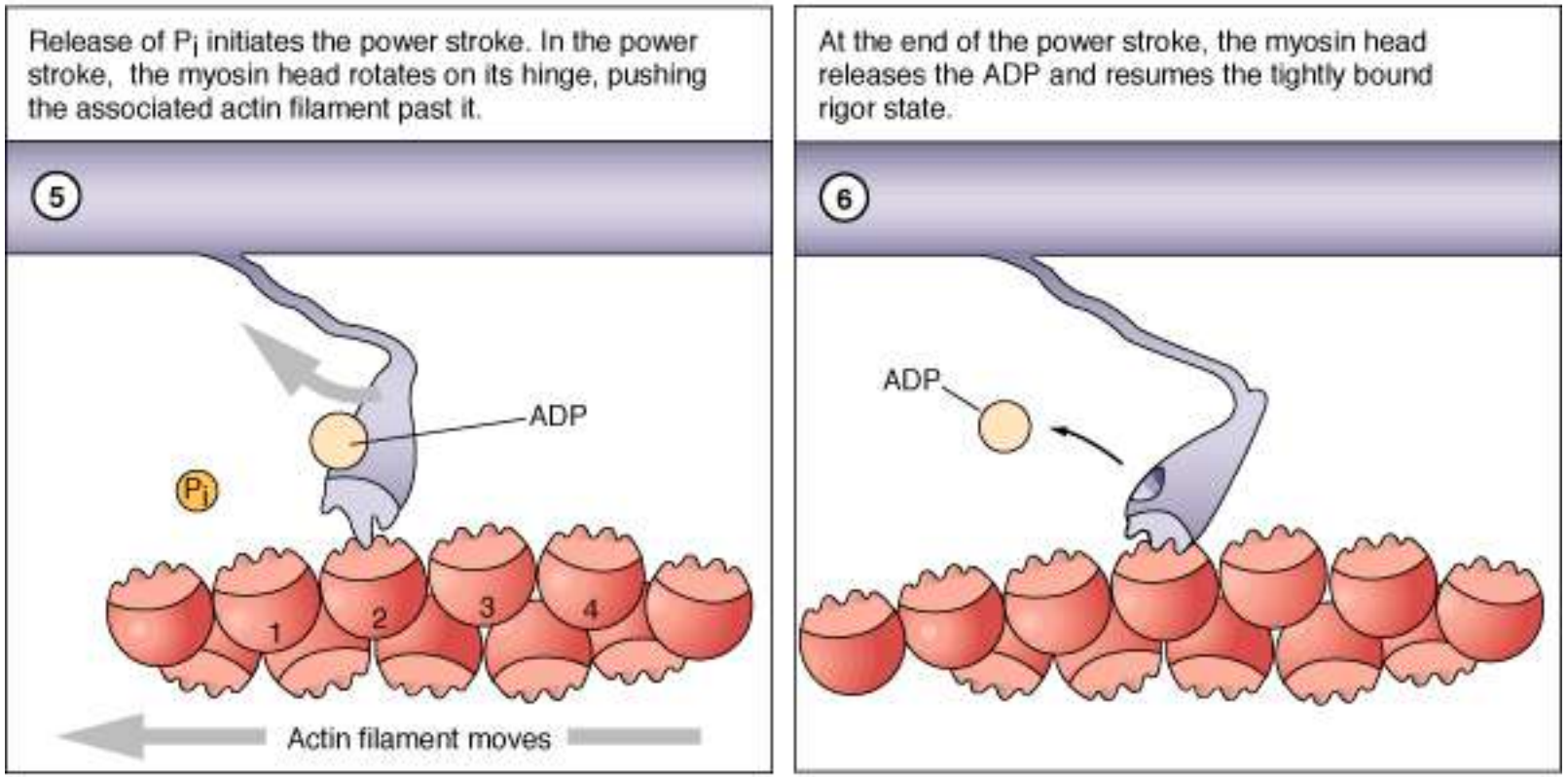
Myosin head acts as ATPase

Rotation and weak binding to new G-actin

Relaxed muscle state when sufficient ATP

Power stroke begins as P_i released

ADP released



Tight binding to actin

Myosin crossbridge movement pushes actin

Regulation of Contraction by Troponin and Tropomyosin

- Tropomyosin blocks myosin binding site (weak binding possible but no powerstroke)
- Troponin controls position of tropomyosin and has Ca^{2+} binding site
  - Ca^{2+} present: binding of A & M
  - Ca^{2+} absent: relaxation

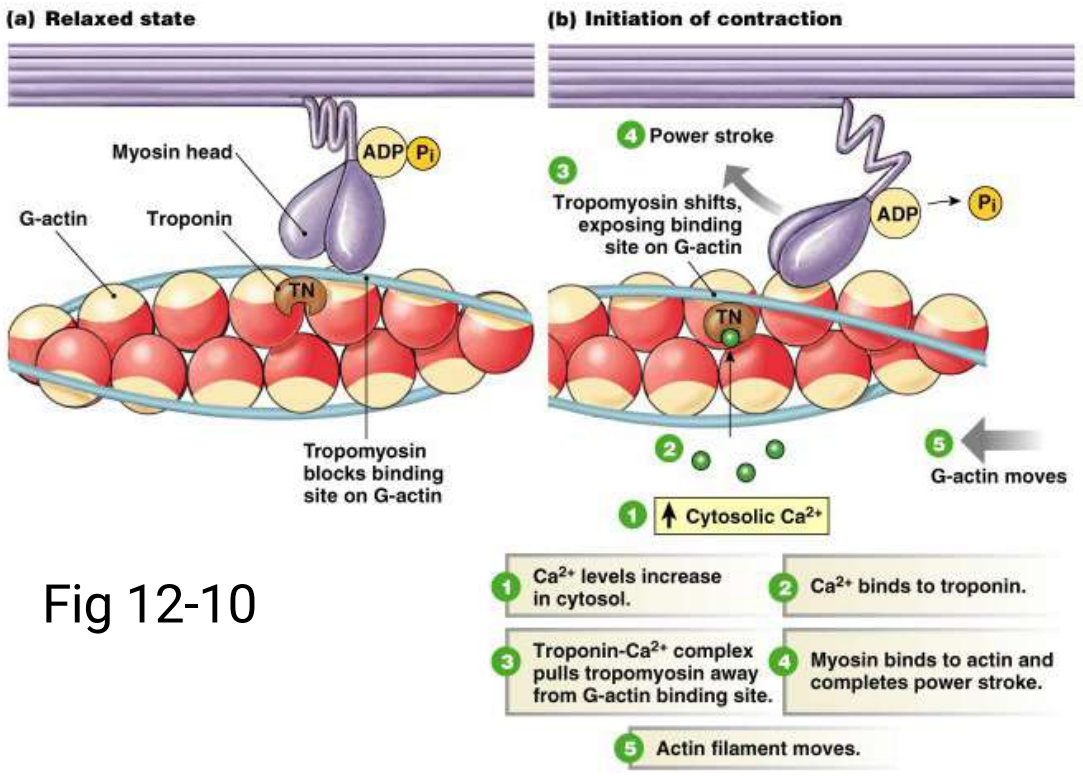
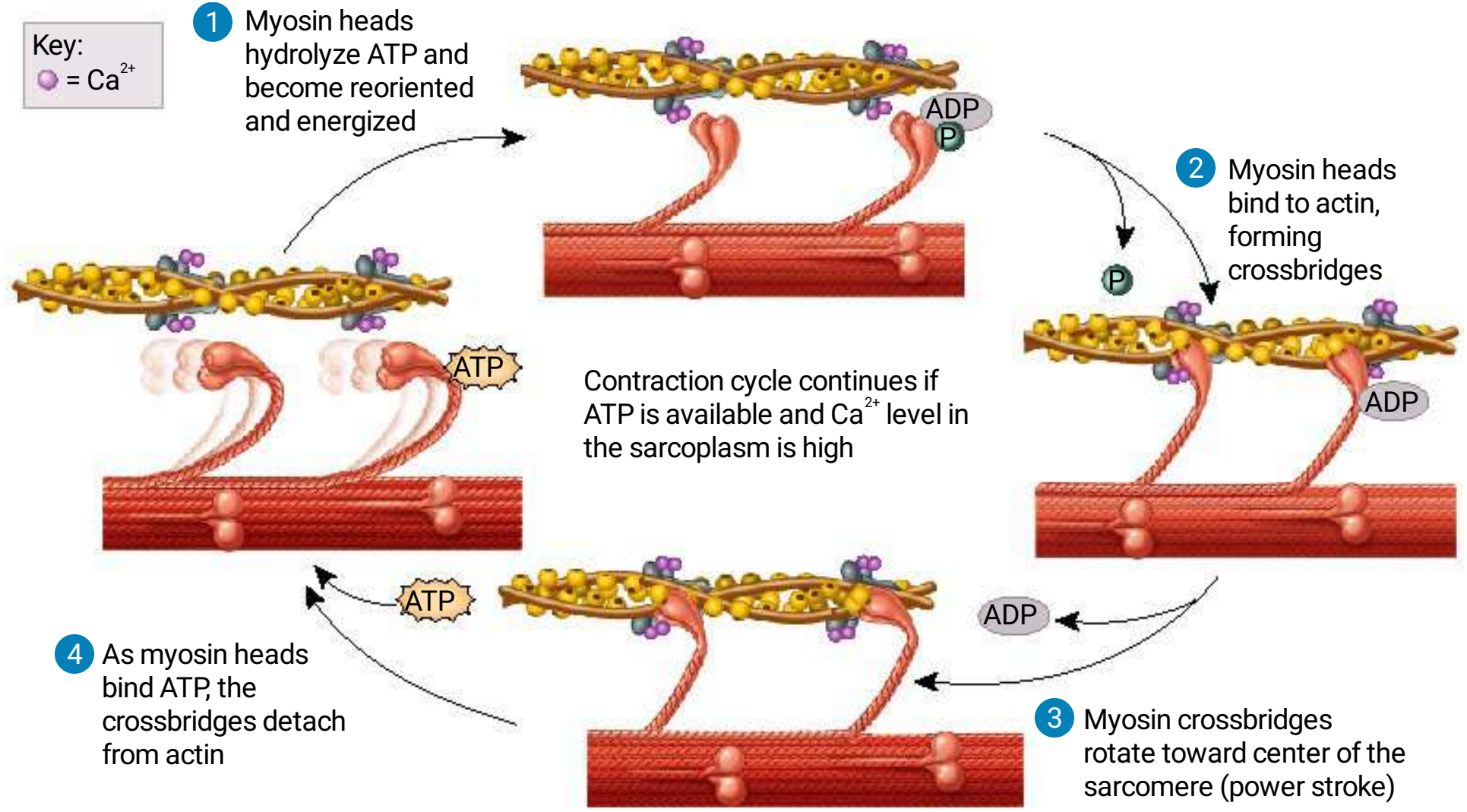


Fig 12-10


Key:
= Ca^{2+}
1 Myosin heads hydrolyze ATP and become reoriented and energized
ADP
P
2 Myosin heads bind to actin, forming crossbridges
P
ADP
ATP
Contraction cycle continues if ATP is available and Ca^{2+} level in the sarcoplasm is high
ATP
ADP
4 As myosin heads bind ATP, the crossbridges detach from actin
3 Myosin crossbridges rotate toward center of the sarcomere (power stroke)

Contraction and Relaxation of Skeletal Muscle

- The contraction cycle consists of 4 steps
  - 1) ATP hydrolysis
    - Hydrolysis of ATP reorients and energizes the myosin head
  - 2) Formation of cross-bridges
    - Myosin head attaches to the myosin-binding site on actin
  - 3) Power stroke
    - During the power stroke the crossbridge rotates, sliding the filaments
  - 4) Detachment of myosin from actin
    - As the next ATP binds to the myosin head, the myosin head detaches from actin
    - The contraction cycle repeats as long as ATP is available and the Ca^{++} level is sufficiently high
    - Continuing cycles applies the force that shortens the sarcomere

Contraction and Relaxation of Skeletal Muscle

- Excitation–Contraction Coupling
  - An increase in Ca^{++} concentration in the muscle starts contraction
  - A decrease in Ca^{++} stops it
  - Action potentials causes Ca^{++} to be released from the SR into the muscle cell
  - Ca^{++} moves tropomyosin away from the myosin-binding sites on actin allowing cross-bridges to form
  - The muscle cell membrane contains Ca^{++} pumps to return Ca^{++} back to the SR quickly
    - Decreasing calcium ion levels
  - As the Ca^{++} level in the cell drops, myosin-binding sites are covered and the muscle relaxes

Contraction and Relaxation of Skeletal Muscle

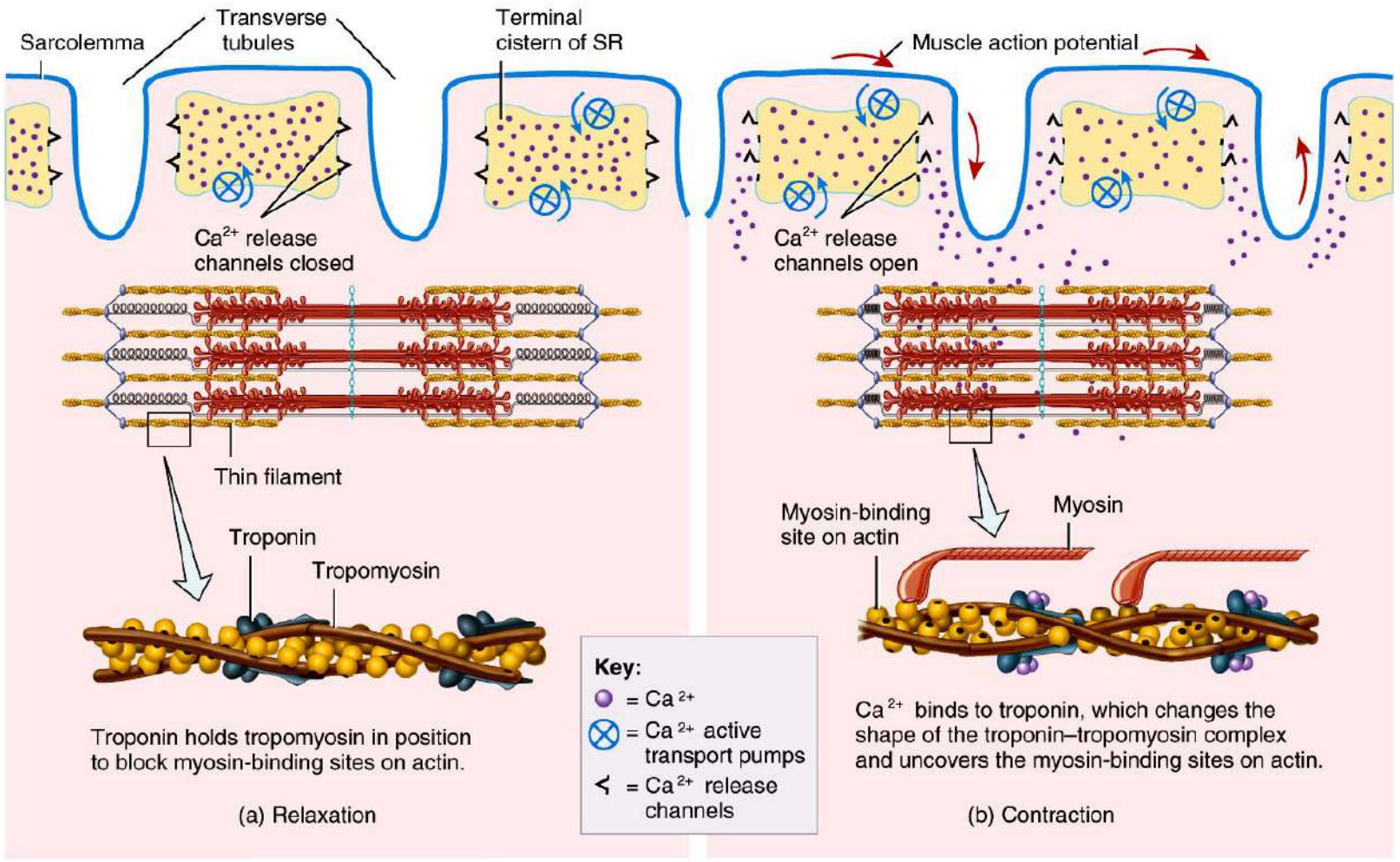
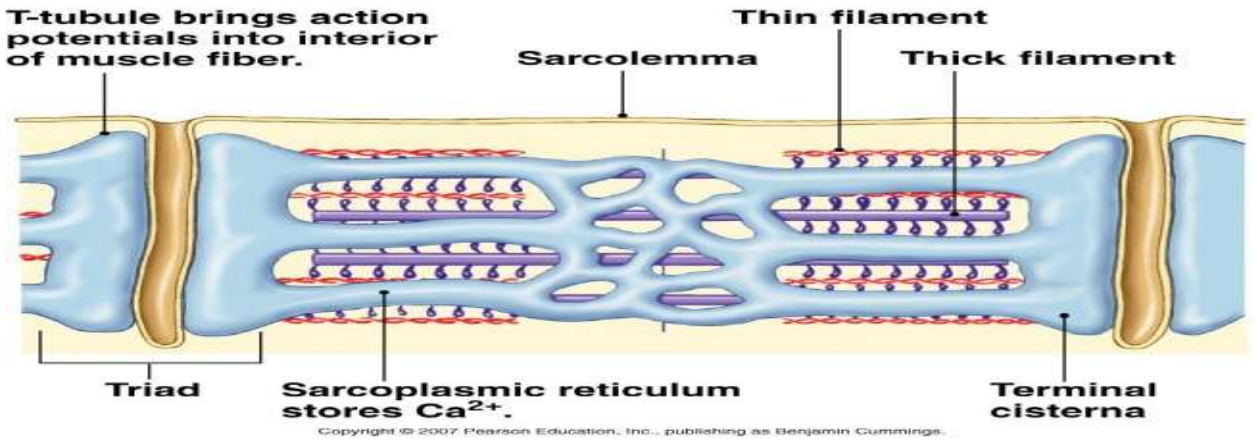
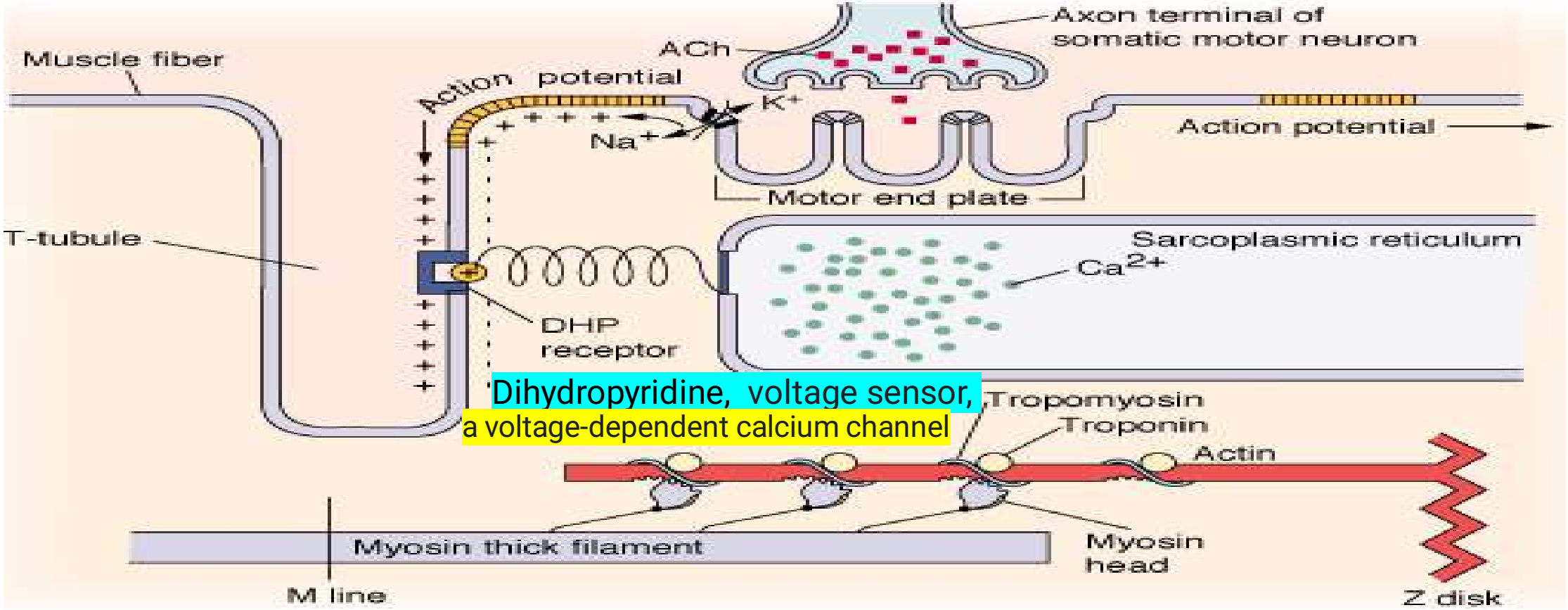


Figure 10.08 Tortora - PAP 12/e

Excitation-Contraction Coupling





Initiation of Contraction

Excitation-Contraction Coupling explains how you get from AP in axon to contraction in sarcomere

ACh released from somatic motor neuron at the Motor End Plate

↓

AP in sarcolemma and T-Tubules

↓

Ca^{2+} release from sarcoplasmic reticulum

↓

Ca^{2+} binds to troponin

↓

DHP (dihydropyridine) receptors open Ca^{2+} channels in t-tubules

↓

Intracytosolic [Ca^{2+}]

↓

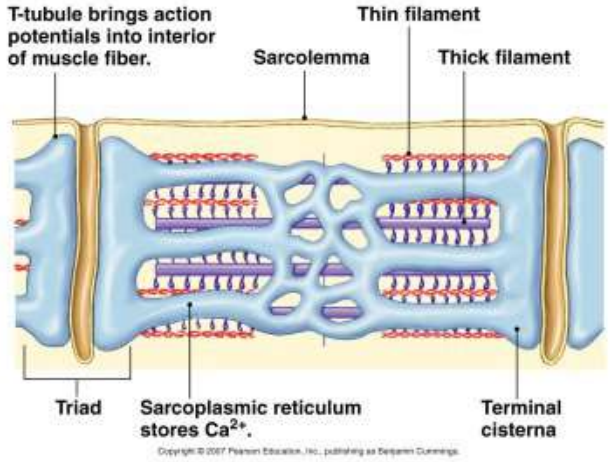
Contraction

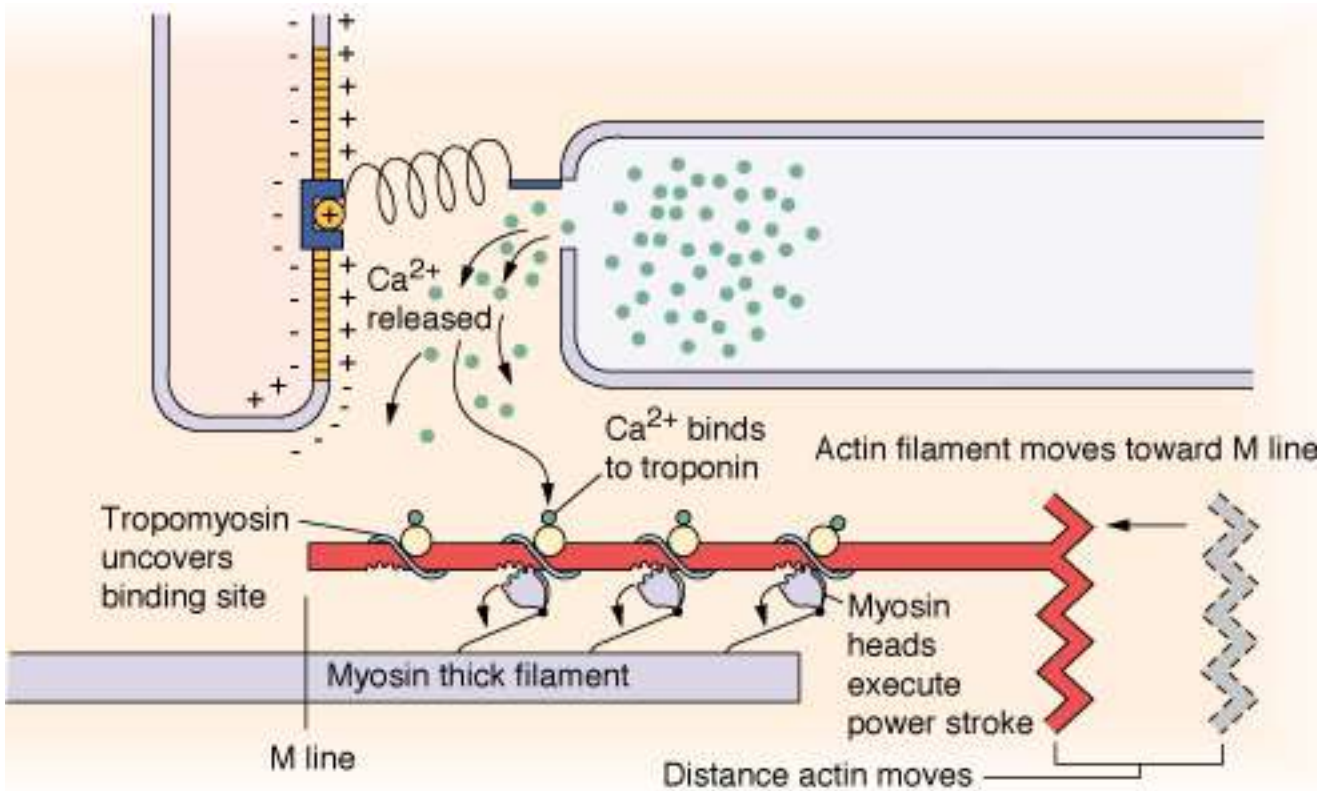
↓

Ca^{2+} re-uptake into SR

↓

Relaxation

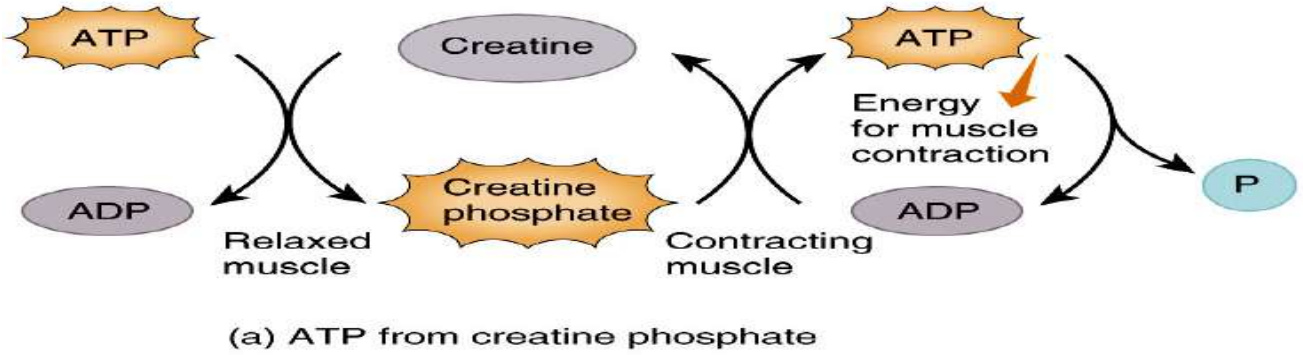




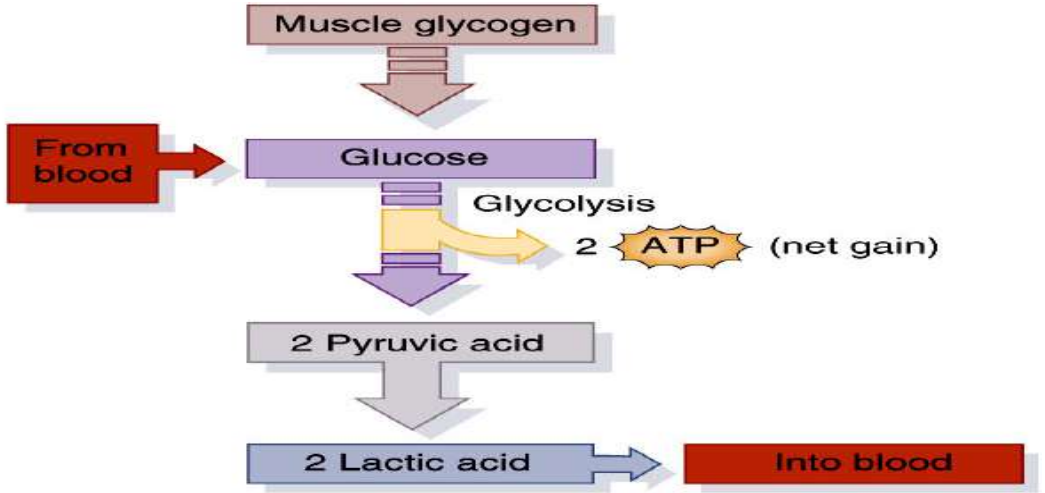
Muscle Metabolism

- Production of ATP in Muscle Fibers
  - A huge amount of ATP is needed to:
    - Power the contraction cycle
    - Pump Ca^{++} into the SR
  - The ATP inside muscle fibers will power contraction for only a few seconds
  - ATP must be produced by the muscle fiber after reserves are used up
  - Muscle fibers have three ways to produce ATP
    - 1) From creatine phosphate
    - 2) By anaerobic cellular respiration
    - 3) By aerobic cellular respiration

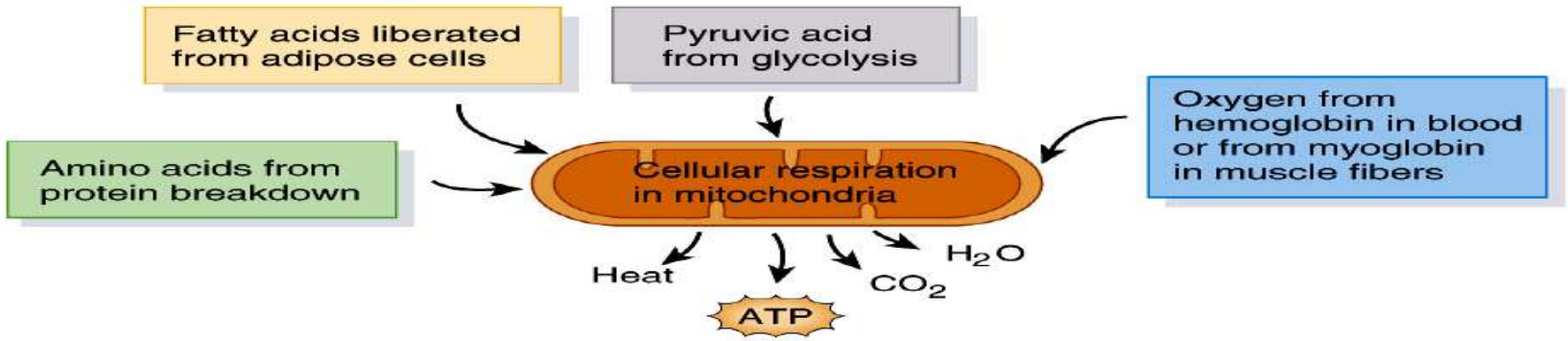
Muscle Metabolism



(a) ATP from creatine phosphate



(b) ATP from anaerobic glycolysis

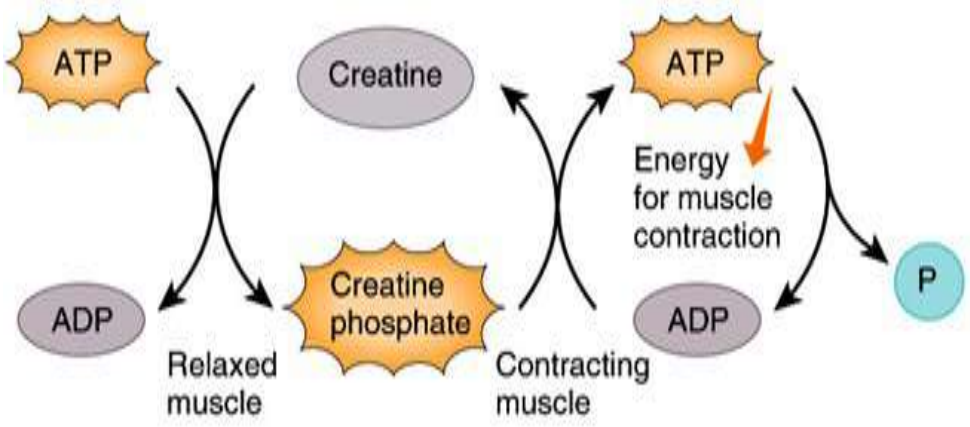


(c) ATP from aerobic cellular respiration

Figure 10.12 Tortora - PAP 12/e

Muscle Metabolism

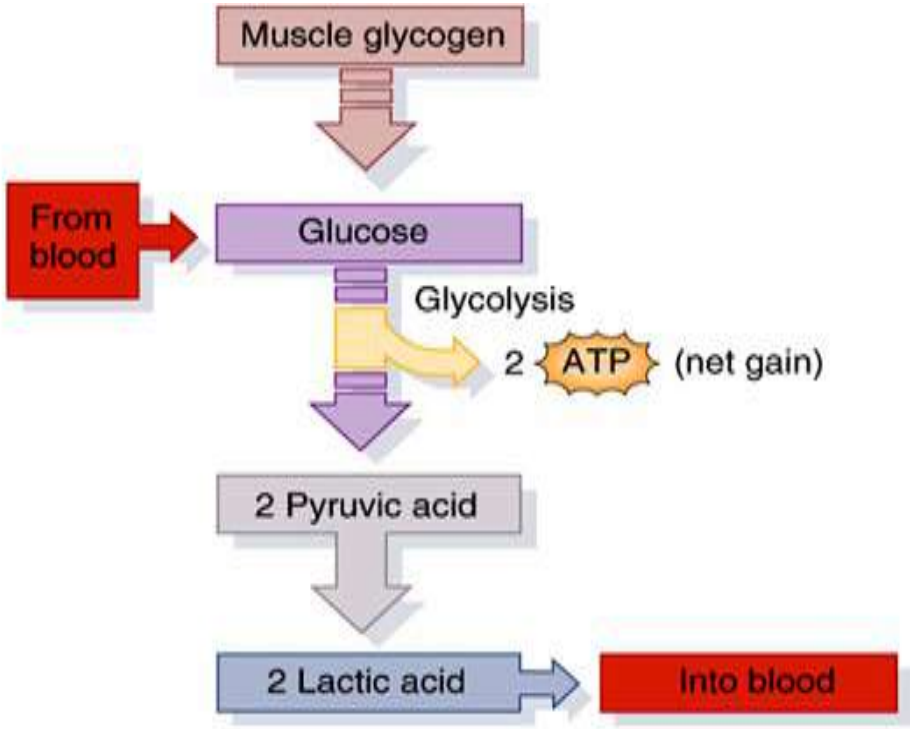
- Creatine Phosphate
  - Excess ATP is used to synthesize creatine phosphate
    - Energy-rich molecule
  - Creatine phosphate transfers its high energy phosphate group to ADP regenerating new ATP
  - Creatine phosphate and ATP provide enough energy for contraction for about 15 seconds



(a) ATP from creatine phosphate

Muscle Metabolism

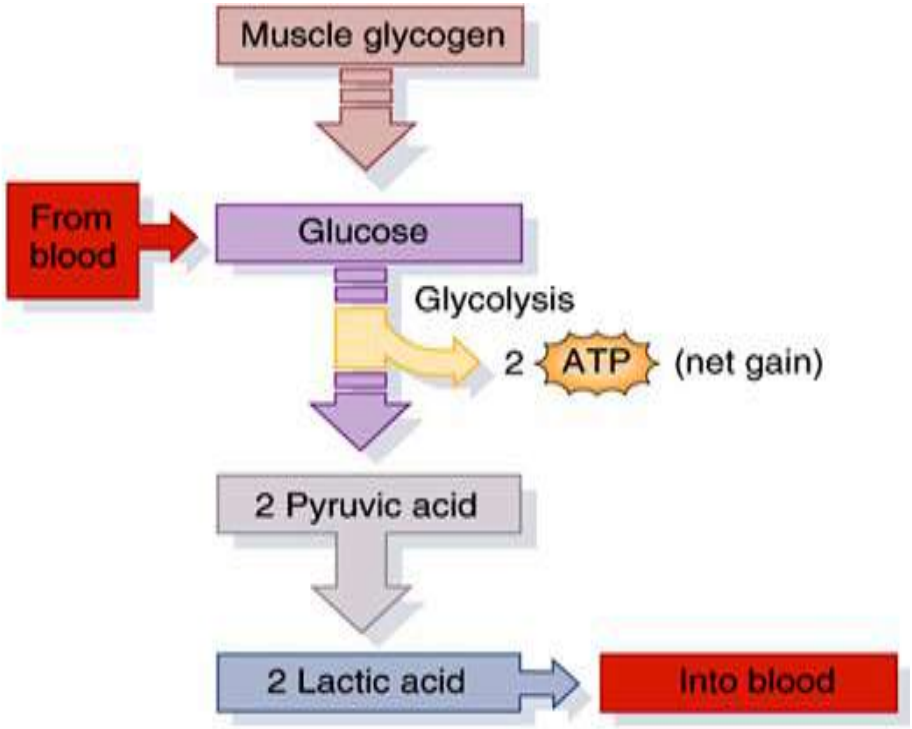
- Anaerobic Respiration
  - Series of ATP producing reactions that do not require oxygen
  - Glucose is used to generate ATP when the supply of creatine phosphate is depleted
  - Glucose is derived from the blood and from glycogen stored in muscle fibers
  - Glycolysis breaks down glucose into molecules of pyruvic acid and produces two molecules of ATP



(b) ATP from anaerobic glycolysis

Muscle Metabolism

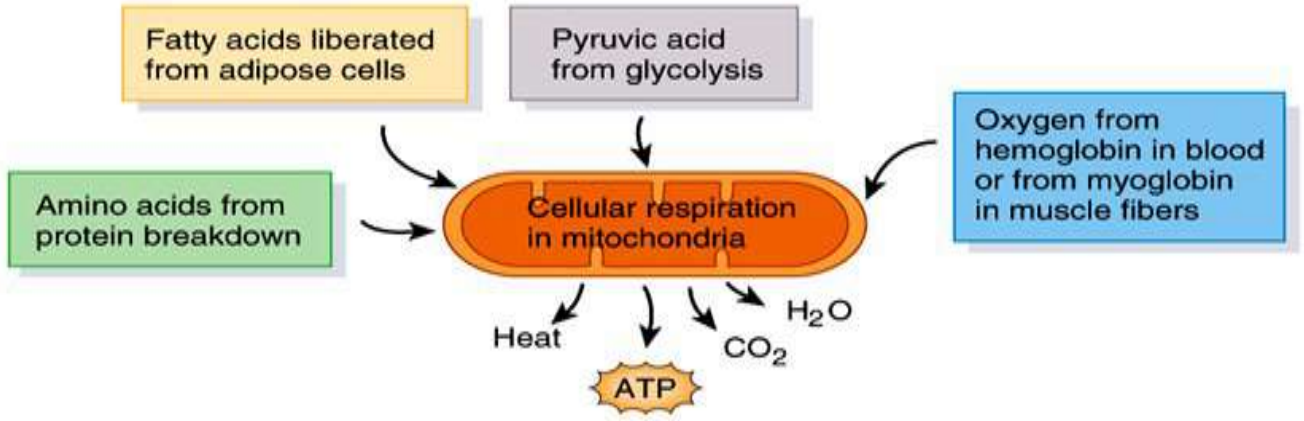
- Anaerobic Respiration
  - If sufficient oxygen is present, pyruvic acid formed by glycolysis enters aerobic respiration pathways producing a large amount of ATP
  - If oxygen levels are low, anaerobic reactions convert pyruvic acid to lactic acid which is carried away by the blood
  - Anaerobic respiration can provide enough energy for about 30 to 40 seconds of muscle activity



(b) ATP from anaerobic glycolysis

Muscle Metabolism

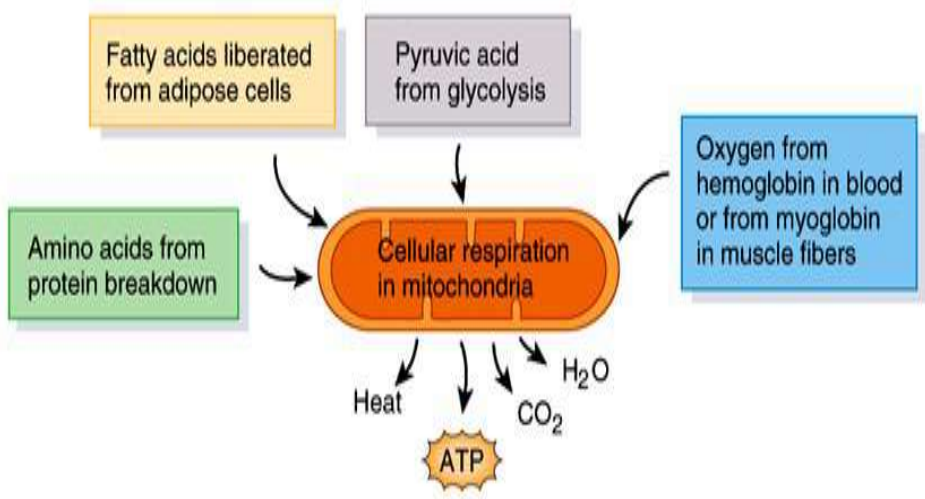
- Aerobic Respiration
  - Activity that lasts longer than half a minute depends on aerobic respiration
  - Pyruvic acid entering the mitochondria is completely oxidized generating
    - ATP
    - carbon dioxide
    - Water
    - Heat
  - Each molecule of glucose yields about 36 molecules of ATP



(c) ATP from aerobic cellular respiration

Muscle Metabolism

- Aerobic Respiration
  - Muscle tissue has two sources of oxygen
    - 1) Oxygen from hemoglobin in the blood
    - 2) Oxygen released by myoglobin in the muscle cell
  - Myoglobin and hemoglobin are oxygen-binding proteins
  - Aerobic respiration supplies ATP for prolonged activity
  - Aerobic respiration provides more than 90% of the needed ATP in activities lasting more than 10

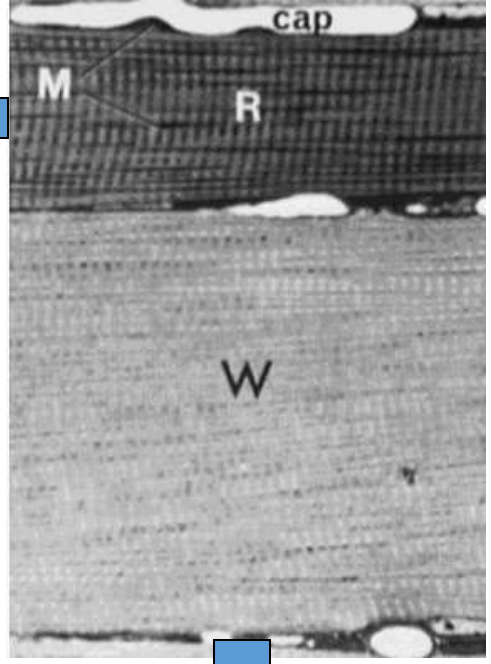


(c) ATP from aerobic cellular respiration

Slow-twitch Fibers

Oxidative only

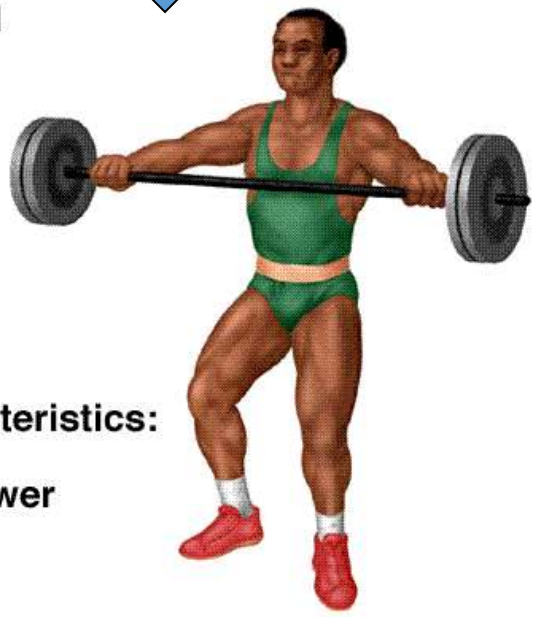
Muscle fiber characteristics:
- Is aerobic
- Has steady power
- Has endurance



Muscle Fiber Classification

Fast-twitch Fibers

Oxidative or glycolytic



Muscle fiber characteristics:
- Is anaerobic
- Has explosive power
- Fatigues easily

Muscle Adaptation to Exercise

Endurance training:

- More & bigger mitochondria
- More enzymes for aerobic respiration
- More myoglobin

↓

no hypertrophy

Resistance training:

- More actin & myosin proteins & more sarcomeres
- More myofibrils

↓

muscle hypertrophy

Force of Contraction (all-or-none)

- Increases With
  - muscle-twitch summation
  - recruitment of motor units

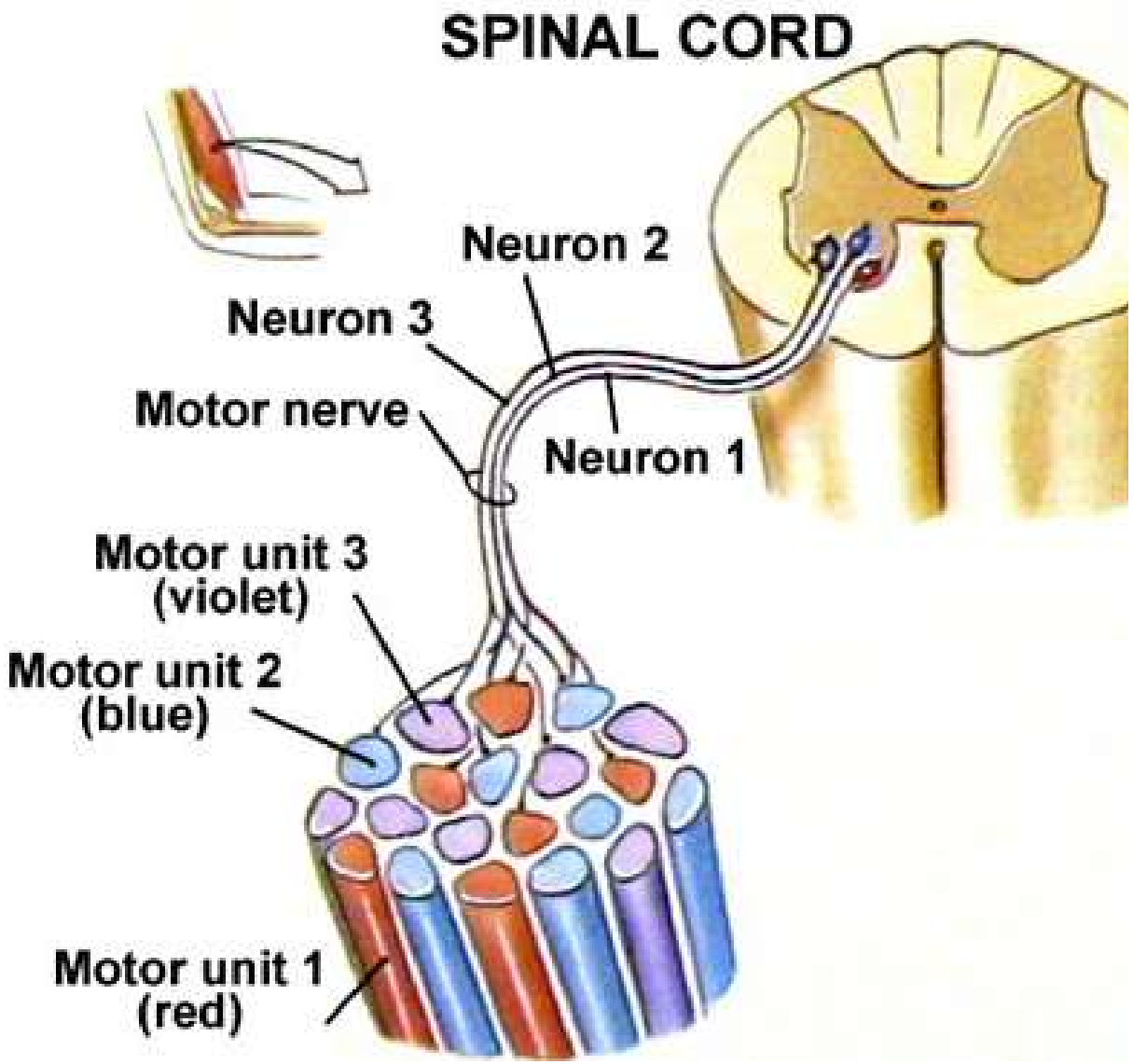
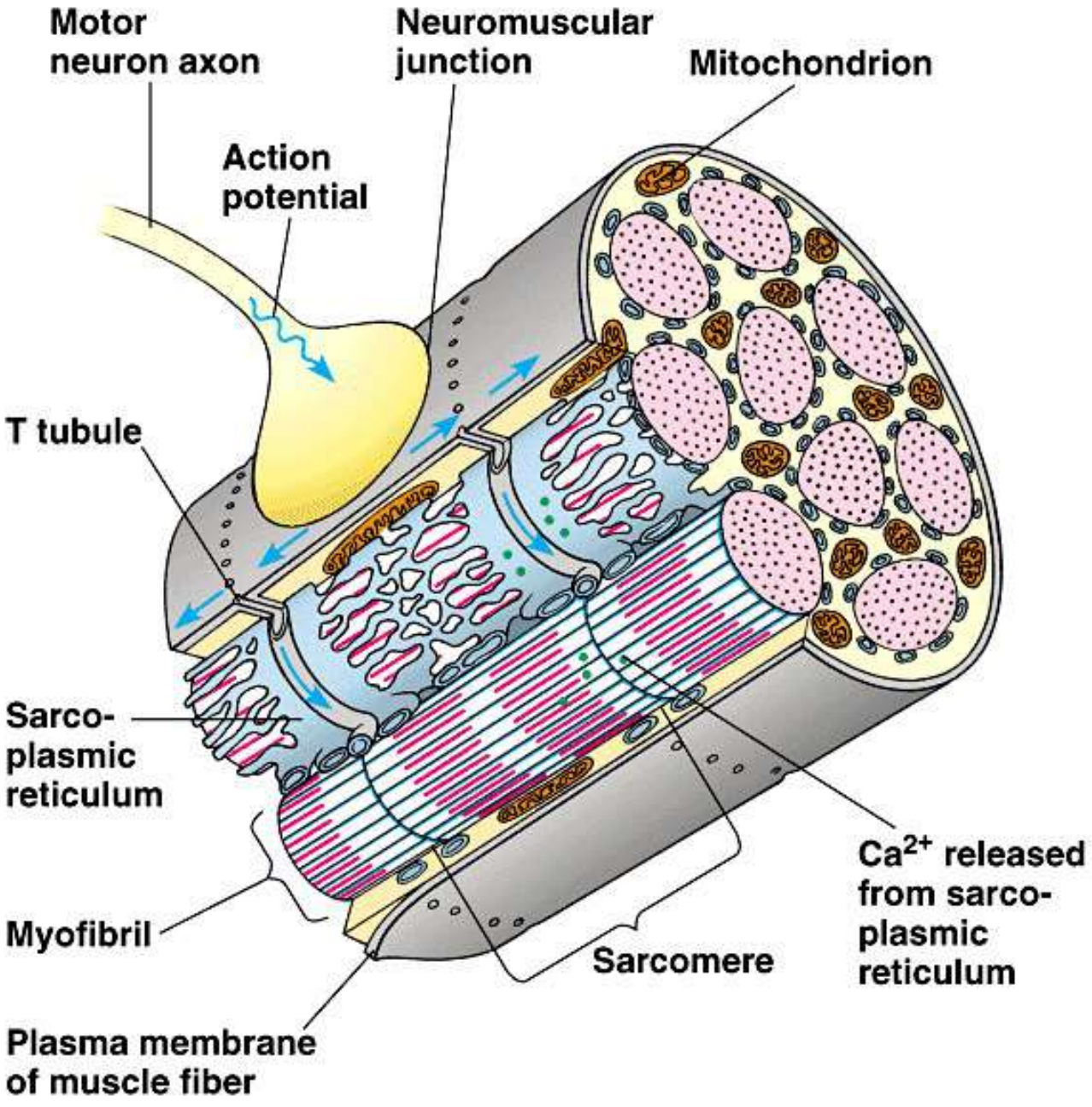
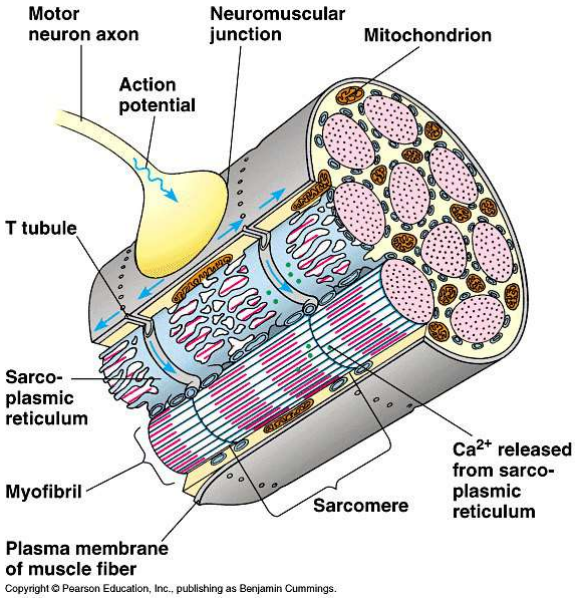


Figure 49.35 The roles of the muscle fiber's sarcoplasmic reticulum and T tubules in contraction



Contraction and Relaxation of Skeletal Muscle

- Nerve impulses elicit a muscle action potential in the following way



1) Release of acetylcholine

- Nerve impulse arriving at the synaptic end bulbs causes many synaptic vesicles to release ACh into the synaptic cleft

2) Activation of ACh receptors

- Binding of ACh to the receptor on the motor end plate opens an ion channel
- Allows flow of Na^{+} to the inside of the muscle cell

3) Production of muscle action potential

- The inflow of Na^{+} makes the inside of the muscle fiber more positively charged triggering a muscle action potential
- The muscle action potential then propagates to the SR to release its stored Ca^{++}

4) Termination of ACh activity

- Ach effects last only briefly because it is rapidly broken down by acetylcholinesterase (AChE)

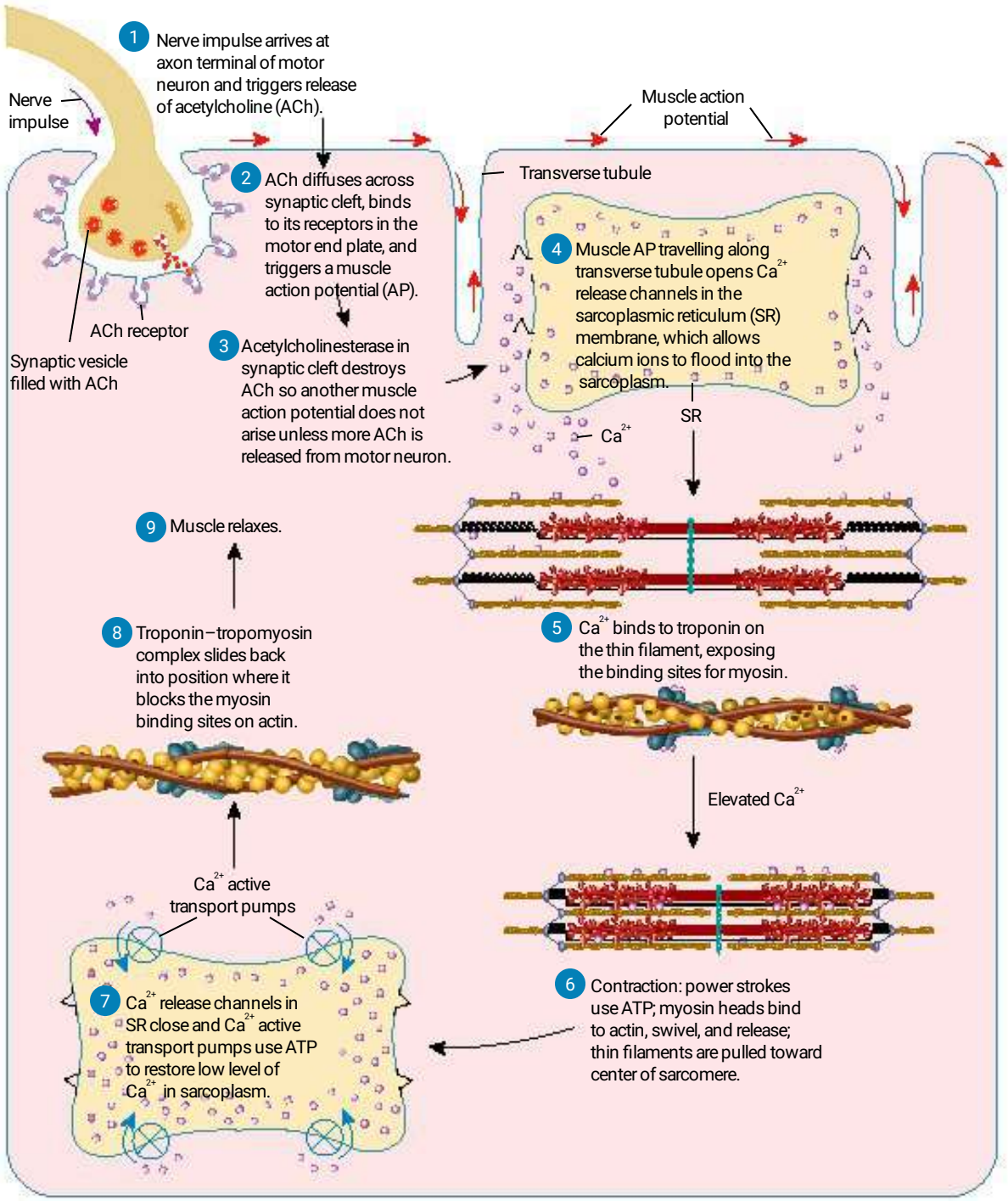
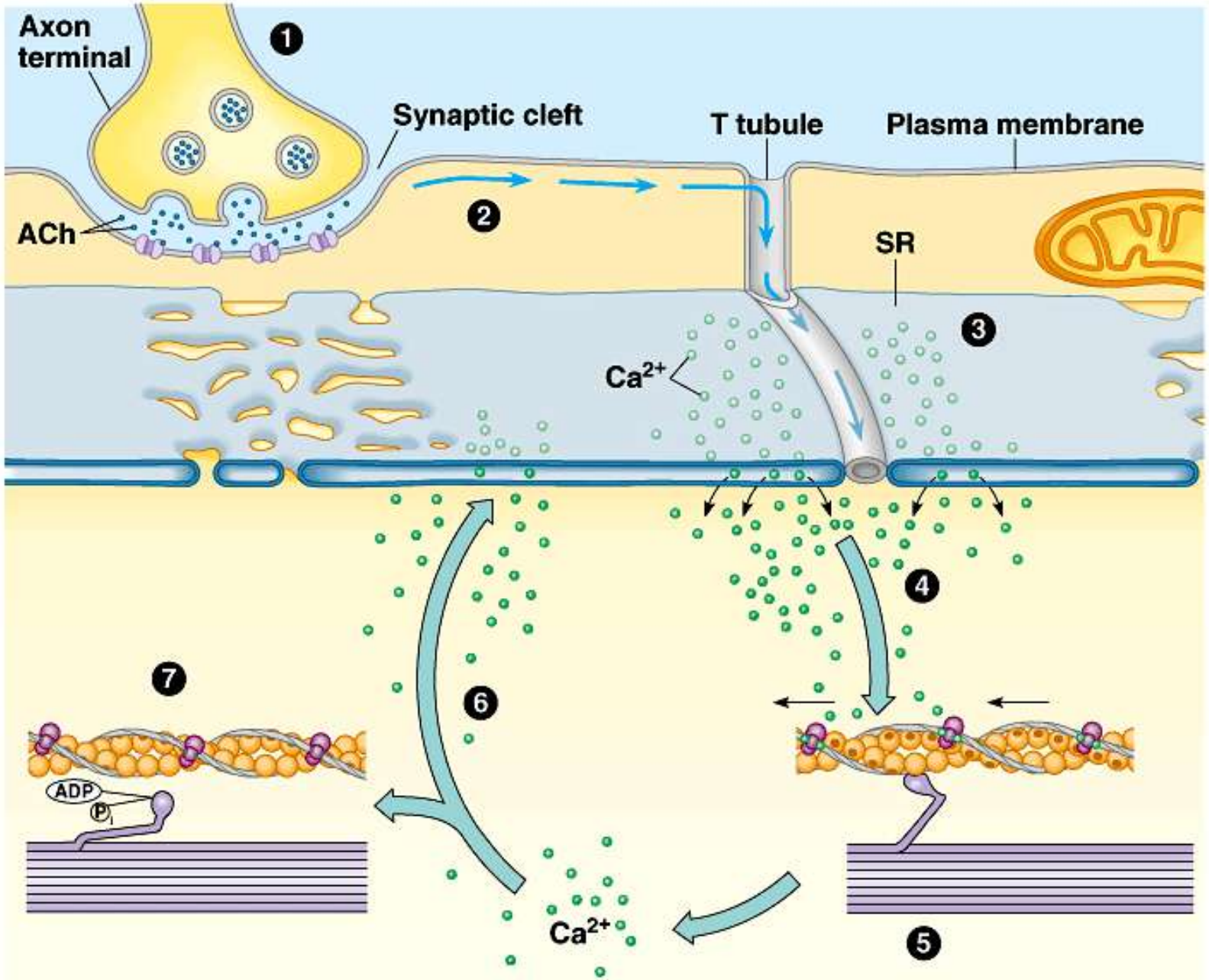

1 Nerve impulse arrives at axon terminal of motor neuron and triggers release of acetylcholine (ACh).
Nerve impulse
2 ACh diffuses across synaptic cleft, binds to its receptors in the motor end plate, and triggers a muscle action potential (AP).
ACh receptor
Synaptic vesicle filled with ACh
3 Acetylcholinesterase in synaptic cleft destroys ACh so another muscle action potential does not arise unless more ACh is released from motor neuron.
Muscle action potential
Transverse tubule
4 Muscle AP travelling along transverse tubule opens Ca2+ release channels in the sarcoplasmic reticulum (SR) membrane, which allows calcium ions to flood into the sarcoplasm.
SR
Ca2+
5 Ca2+ binds to troponin on the thin filament, exposing the binding sites for myosin.
Elevated Ca2+
6 Contraction: power strokes use ATP; myosin heads bind to actin, swivel, and release; thin filaments are pulled toward center of sarcomere.
7 Ca2+ release channels in SR close and Ca2+ active transport pumps use ATP to restore low level of Ca2+ in sarcoplasm.
Ca2+ active transport pumps
8 Troponin–tropomyosin complex slides back into position where it blocks the myosin binding sites on actin.
9 Muscle relaxes.

Figure 49.36 Review of skeletal muscle contraction



End

Muscles Physiology

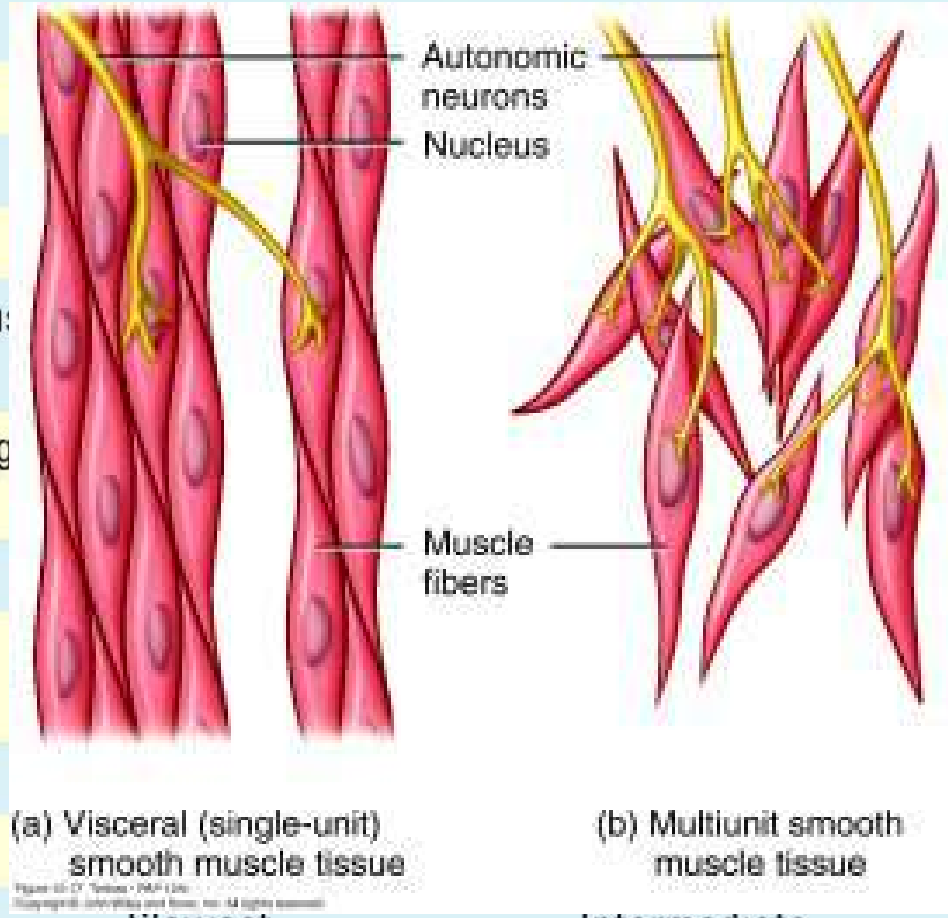
Smooth muscle

Comparisons Among Skeletal, Smooth, and Cardiac Muscle

Property	Skeletal	Smooth (single-unit)	Smooth (multi-unit)	Cardiac
Striations (sarcomeres)	Yes	No	No	Yes
Actin and myosin	Yes	Yes	Yes	Yes
Level of control	Voluntary	Involuntary	Involuntary	Involuntary
Neural input	Somatic	Autonomic	Autonomic	Autonomic
Neuroeffector junction	Neuromuscular junction—specific	Varicosities—diffuse	Varicosities—diffuse	Varicosities—diffuse
Hormonal control	None	Several, depending on location	Several, depending on location	Epinephrine
Source of calcium	SR	SR and ECF	SR and ECF	SR and ECF
Regulatory protein that binds calcium	Troponin	Calmodulin	Calmodulin	Troponin
Gap junctions	No	Yes	No (or few)	Yes
Pacemaker activity	No	Yes	No	Yes
Myosin ATPase activity	Fastest	Slowest	Slowest	Intermediate
Recruitment	Yes	No	Yes	No

Comparisons Among Skeletal, Smooth, and Cardiac Muscle

Property	Skeletal	Smooth (single-unit)	Smooth (multi-unit)	Cardiac
Striations (sarcomeres)	Yes	No		
Actin and myosin	Yes	Yes		
Level of control	Voluntary	Involuntary		
Neural input	Somatic	Autonomic		
Neuroeffector junction	Neuromuscular junction—specific	Varicosities—diffu		
Hormonal control	None	Several, depending on location		
Source of calcium	SR	SR and ECF		
Regulatory protein that binds calcium	Troponin	Calmodulin		
Gap junctions	No	Yes		
Pacemaker activity	No	Yes		
Myosin ATPase activity	Fastest	Slowest	Slowest	Intermediate
Recruitment	Yes	No	Yes	No

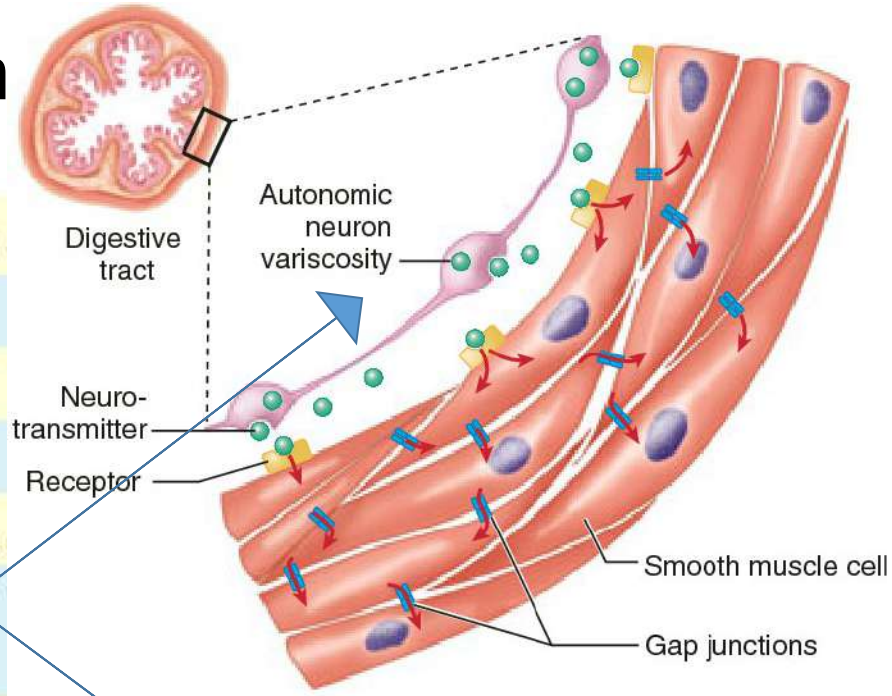


Comparisons Among Skeletal, Smooth, and Cardiac Muscle

Property	Skeletal	Smooth (single-unit)	Smooth (multi-unit)	Cardiac
Striations (sarcomeres)	Yes	No	No	Yes
Actin and myosin	Yes	Yes	Yes	Yes
Level of control	Voluntary	Involuntary	Involuntary	Involuntary
Neural input	Somatic	Autonomic	Autonomic	Autonomic
Neuroeffector junction	Neuromuscular junction—specific	Varicosities—diffuse	Varicosities—diffuse	Varicosities—diffuse
Hormonal control	None	Several, depending on location	Several, depending on location	Epinephrine
Source of calcium	SR	SR and ECF	SR and ECF	SR and ECF
Regulatory protein that binds calcium	Troponin	Calmodulin	Calmodulin	Troponin
Gap junctions	No	Yes	No (or few)	Yes
Pacemaker activity	No	Yes	No	Yes
Myosin ATPase activity	Fastest	Slowest	Slowest	Intermediate
Recruitment	Yes	No	Yes	No

Comparisons Among Skeletal, Smooth Muscle

Property	Skeletal	Smooth (single-unit)
Striations (sarcomeres)	Yes	No
Actin and myosin	Yes	Yes
Level of control	Voluntary	Involuntary
Neural input	Somatic	Autonomic
Neuroeffector junction	Neuromuscular junction—specific	Varicosities—diffuse
Hormonal control	None	Several, depending on location
Source of calcium	SR	SR and ECF
Regulatory protein that binds calcium	Troponin	Calmodulin
Gap junctions	No	Yes
Pacemaker activity	No	Yes
Myosin ATPase activity	Fastest	Slowest
Recruitment	Yes	No



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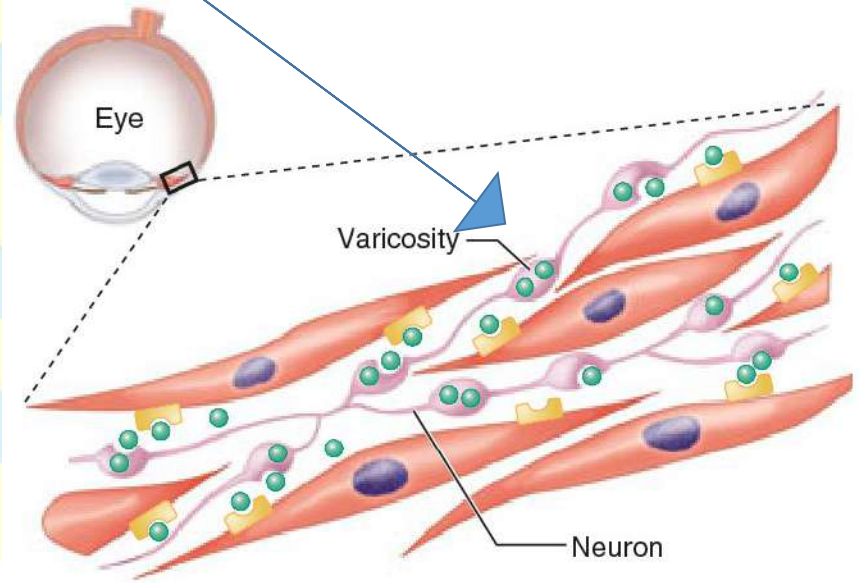
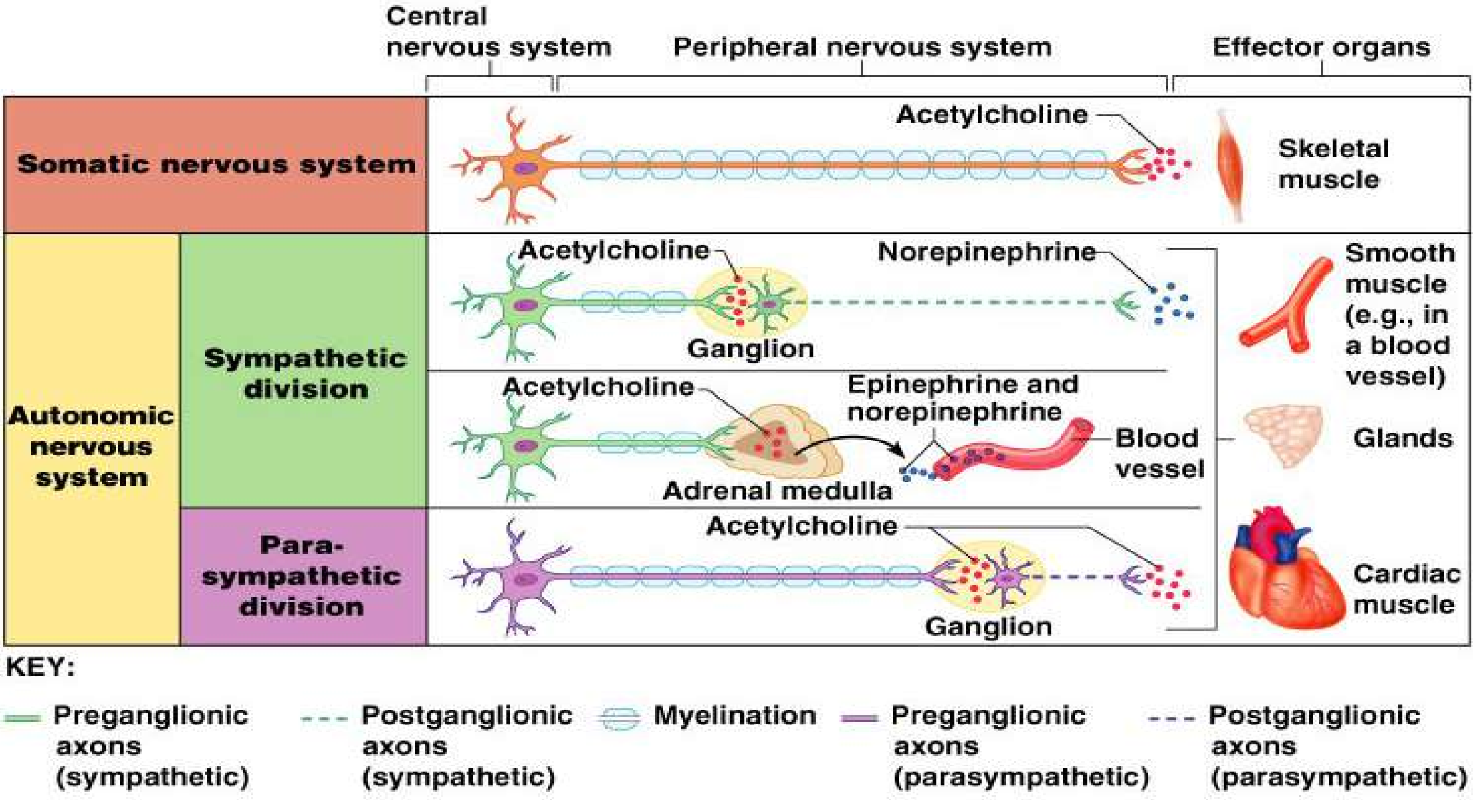


B

Comparisons Among Skeletal, Smooth, and Cardiac Muscle

Property	Skeletal	Smooth (single-unit)	Smooth (multi-unit)	Cardiac
Striations (sarcomeres)	Yes	No	No	Yes
Actin and myosin	Yes	Yes	Yes	Yes
Level of control	Voluntary	Involuntary	Involuntary	Involuntary
Neural input	Somatic	Autonomic	Autonomic	Autonomic
Neuroeffector junction	Neuromuscular junction—specific	Varicosities—diffuse	Varicosities—diffuse	Varicosities—diffuse
Hormonal control	None	Several, depending on location	Several, depending on location	Epinephrine
Source of calcium	SR	SR and ECF	SR and ECF	SR and ECF
Regulatory protein that binds calcium	Troponin	Calmodulin	Calmodulin	Troponin
Gap junctions	No	Yes	No (or few)	Yes
Pacemaker activity	No	Yes	No	Yes
Myosin ATPase activity	Fastest	Slowest	Slowest	Intermediate
Recruitment	Yes	No	Yes	No

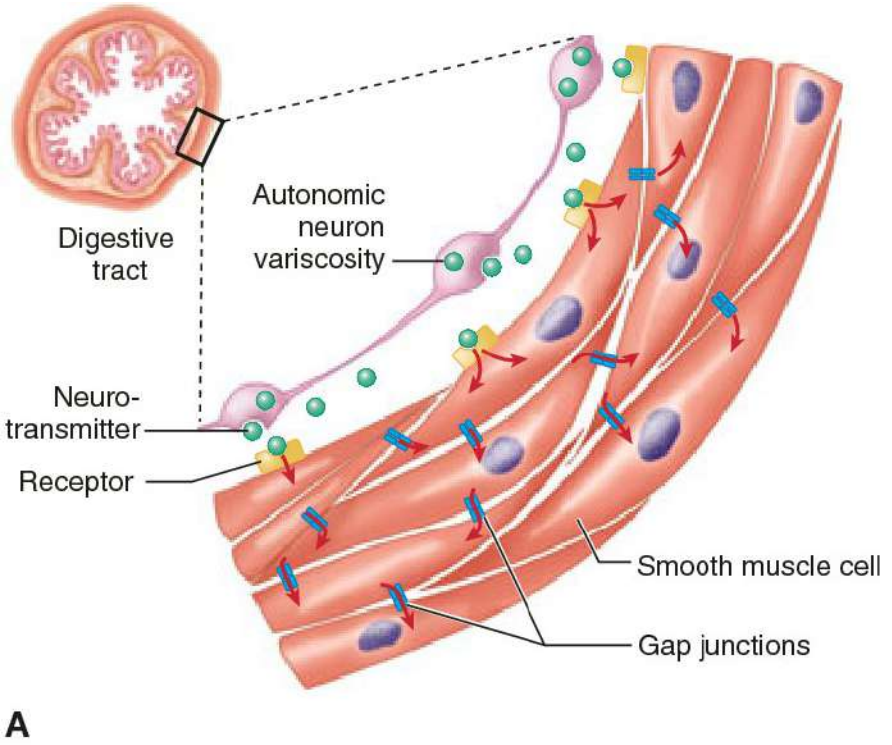

Central nervous system
Peripheral nervous system
Effector organs
Somatic nervous system
Acetylcholine
Skeletal muscle
Autonomic nervous system
Sympathetic division
Acetylcholine
Norepinephrine
Ganglion
Smooth muscle (e.g., in a blood vessel)
Acetylcholine
Epinephrine and norepinephrine
Blood vessel
Glands
Adrenal medulla
Para-sympathetic division
Acetylcholine
Ganglion
Cardiac muscle
KEY:
Preganglionic axons (sympathetic)
Postganglionic axons (sympathetic)
Myelination
Preganglionic axons (parasympathetic)
Postganglionic axons (parasympathetic)

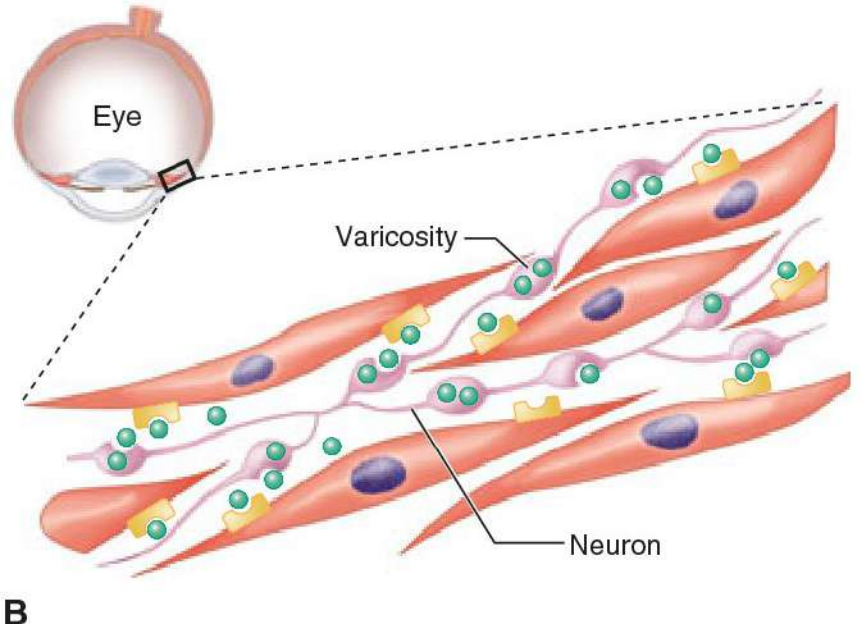
Smooth Muscle Tissue

- Usually activated involuntarily
- Action potentials are spread through the fibers by gap junctions

- Fibers are stimulated by certain neurotransmitter, hormone, or autorhythmic signals

- Found in the
  - Walls of arteries and veins
  - Walls of hollow organs
  - Walls of airways to the lungs
  - Muscles that attach to hair follicles
  - Muscles that adjust pupil diameter
  - Muscles that adjust focus of the lens in the eye

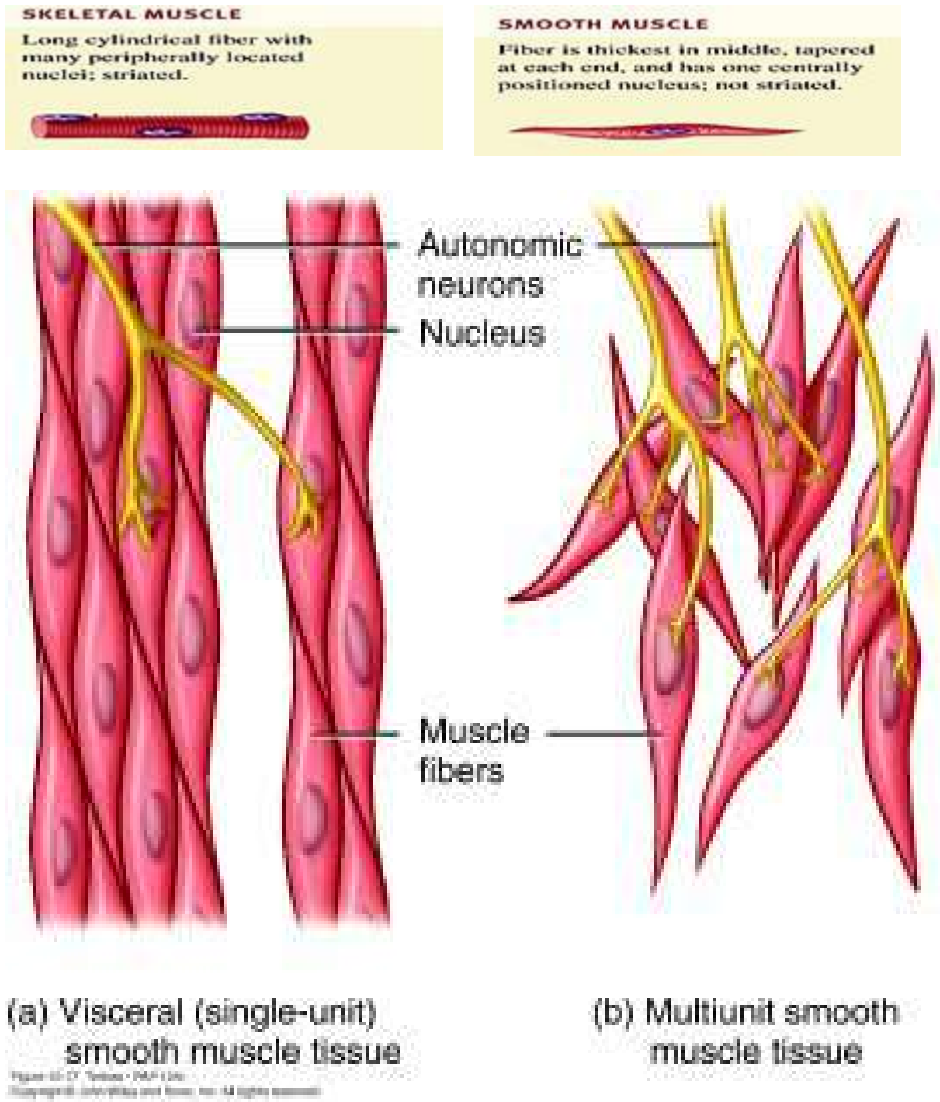




Single unit Smooth Muscle Tissue

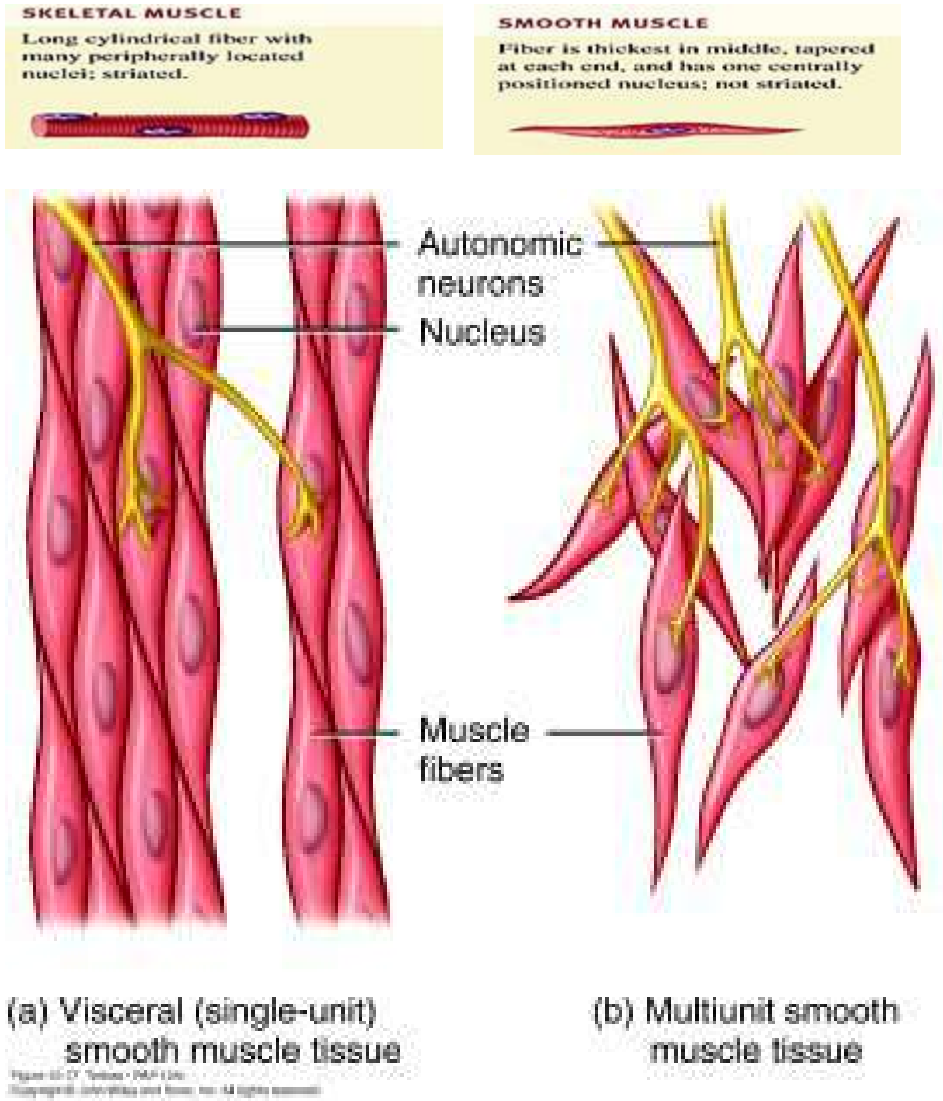
- Smooth muscle fibers are spindle-shaped and, unlike skeletal muscle fibers, have a single nucleus; individual cells range in size from 30 to 200 µm.

- Smooth muscle fibers are often found forming sheets of tissue and function in a coordinated fashion due to the presence of gap junctions between the cells.



Single unit Smooth Muscle Tissue

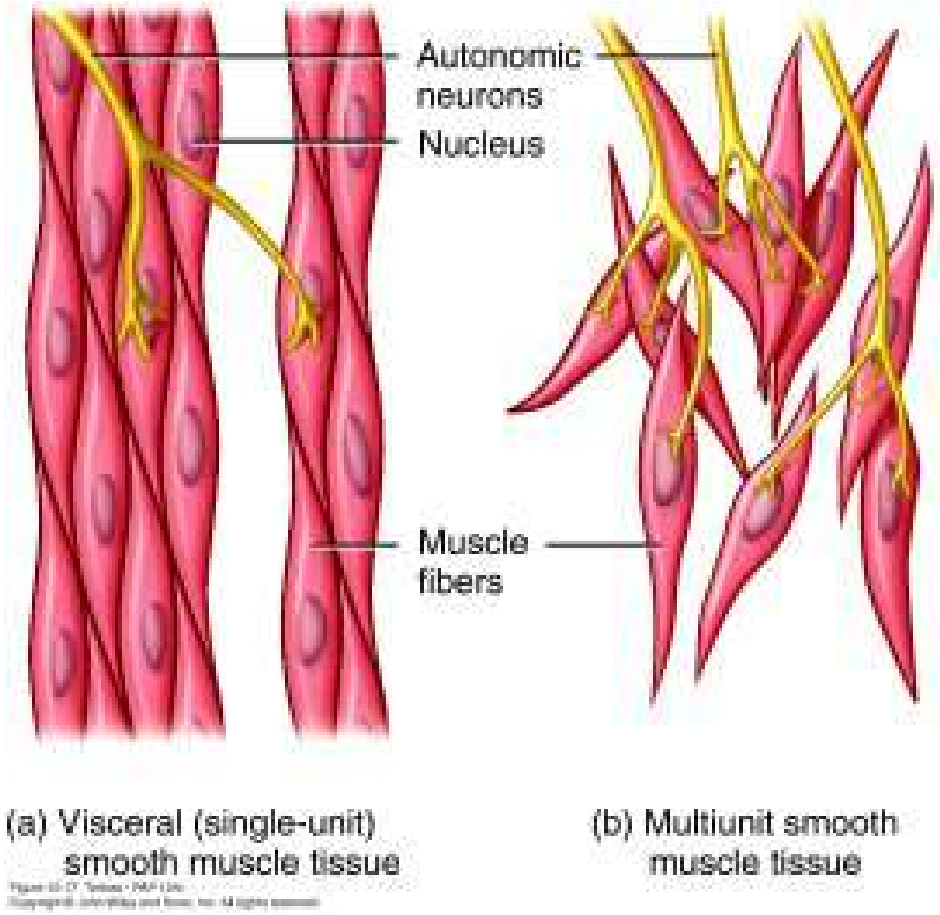
- Termed unitary smooth muscle or visceral muscle, this type of smooth muscle is the most common observed in the human body, forming the walls of hollow organs.
- Hollow organs; visceral organ that is a hollow tube, such as Stomach, Intestines, uterus, and urinary bladder
- Single-unit smooth muscle produces slow, steady contractions that allow substances, such as food in the digestive tract, to move through the body.



Multiunit Smooth Muscle Tissue

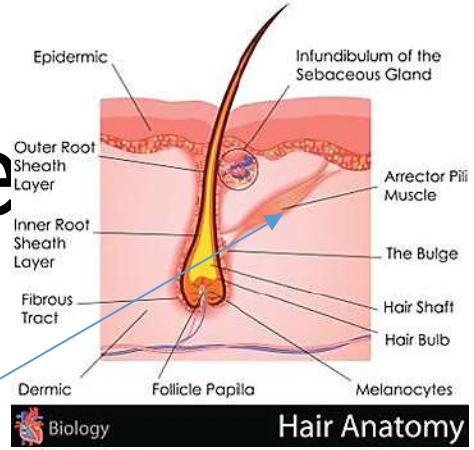
- Multi-unit smooth muscle, the second type of smooth muscle observed, are composed of cells that rarely possess gap junctions, and thus are not electrically coupled.

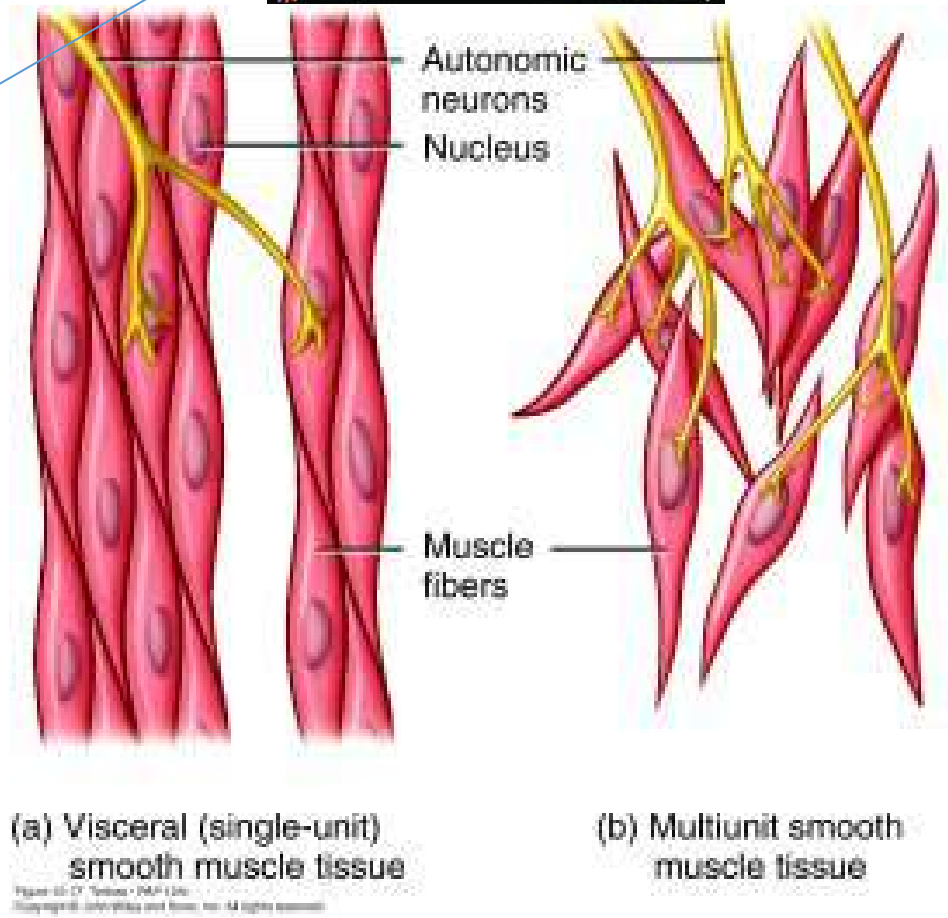
- As a result, contraction does not spread from one cell to the next, but is instead confined to the cell that was originally stimulated.



Multiunit Smooth Muscle Tissue

- This type of smooth muscle is observed;
  - in the large airways to the lungs,
  - in the large arteries, the arrector pili muscles associated with hair follicles,
  - and the internal eye muscles which regulate light entry and lens shape.





Smooth Muscle Tissue

- Microscopic Anatomy of Smooth Muscle
  - Contains both thick filaments and thin filaments
    - Not arranged in orderly sarcomeres
  - No regular pattern of overlap thus not striated
  - Contain only a small amount of stored Ca^{++}

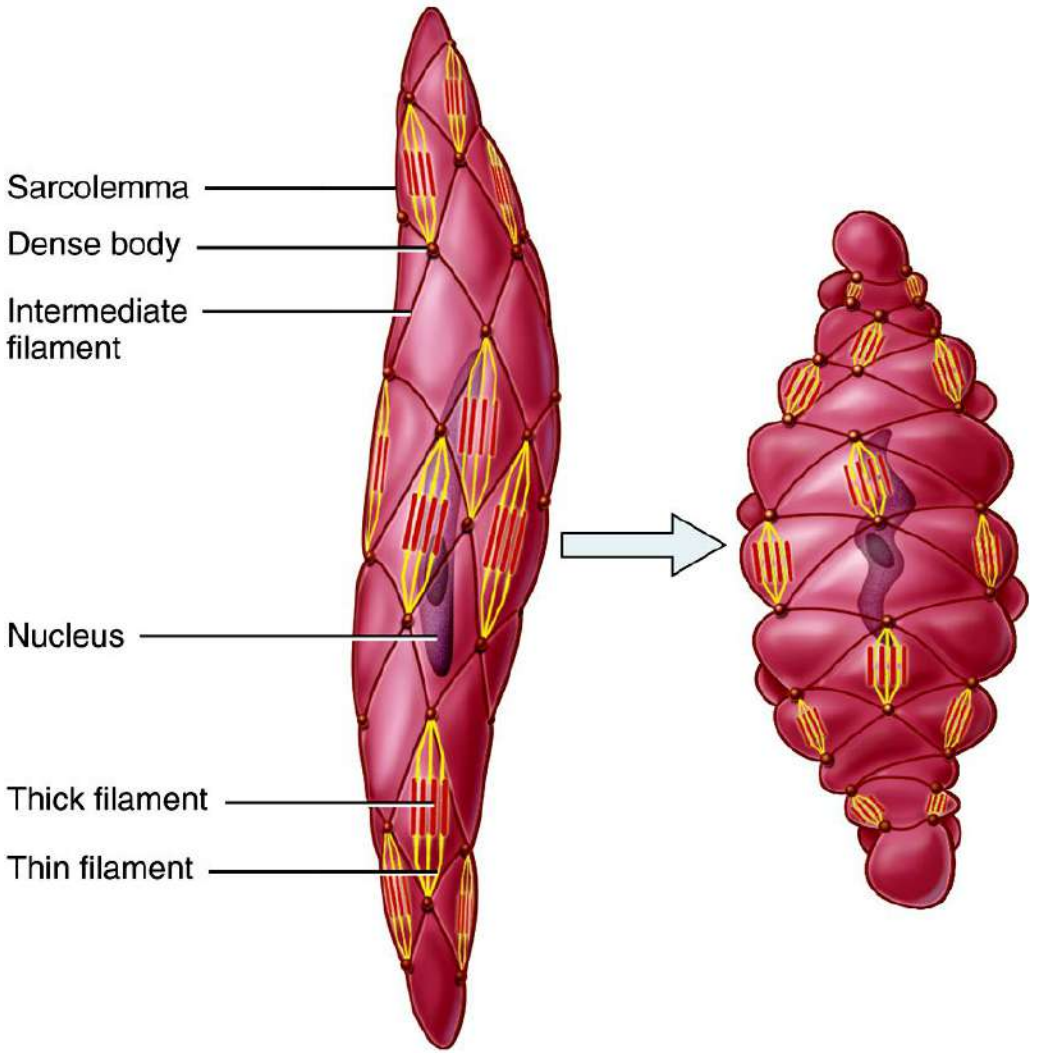


Figure 10.18 Tortora - PAP 12/e

Smooth Muscle Tissue

- Microscopic Anatomy of Smooth Muscle
  - Filaments attach to dense bodies and stretch from one dense body to another
  - Dense bodies
    - Function in the same way as Z discs
    - During contraction the filaments pull on the dense bodies causing a shortening of the muscle fiber

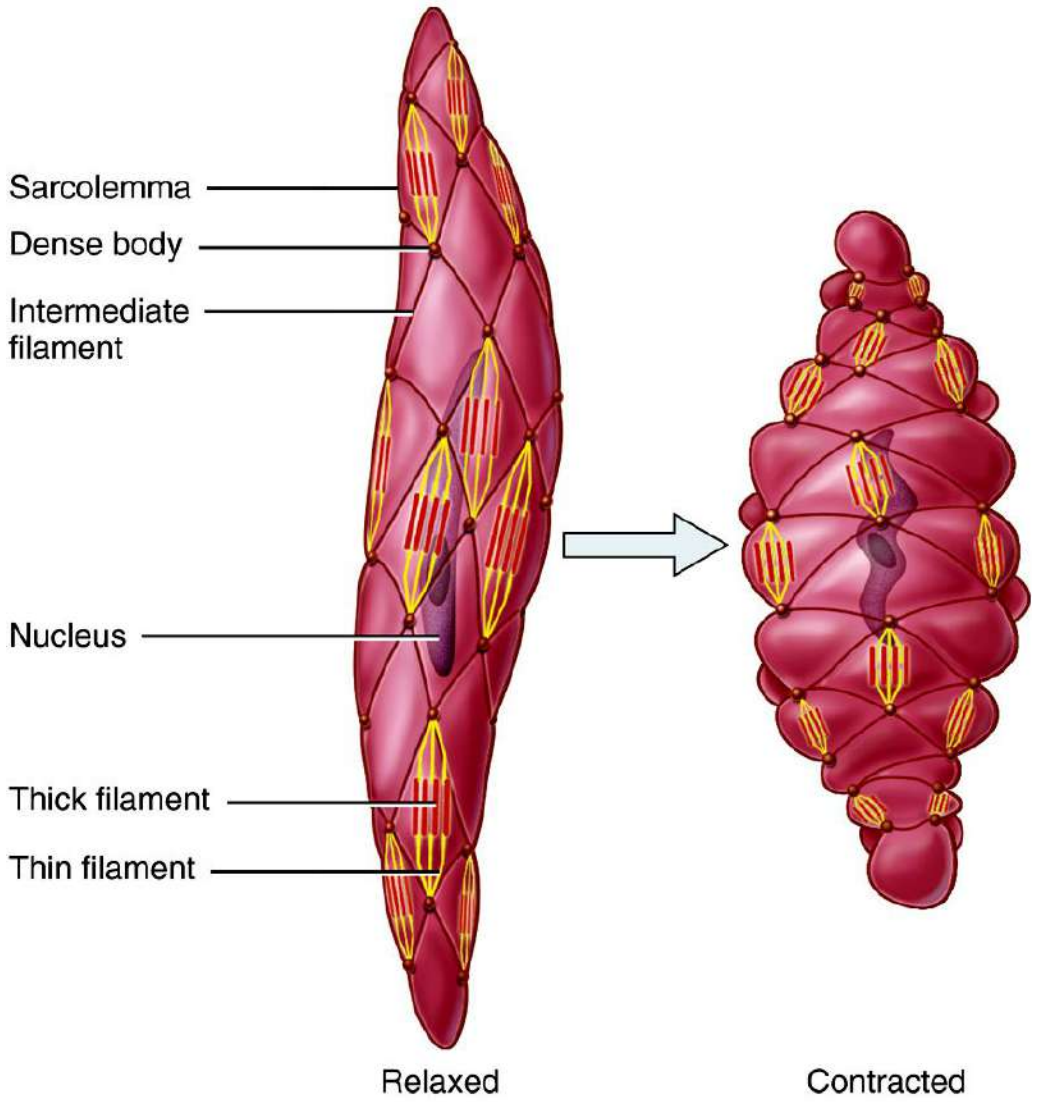
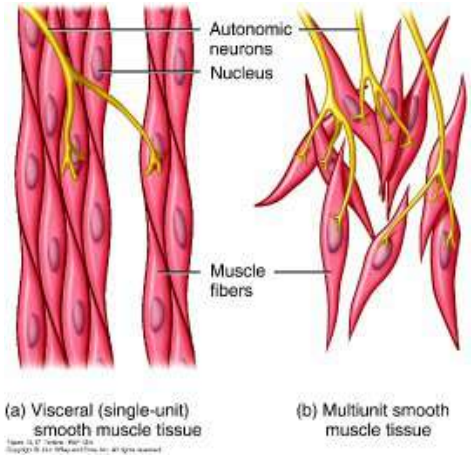


Figure 10.18 Tortora - PAP 12/e

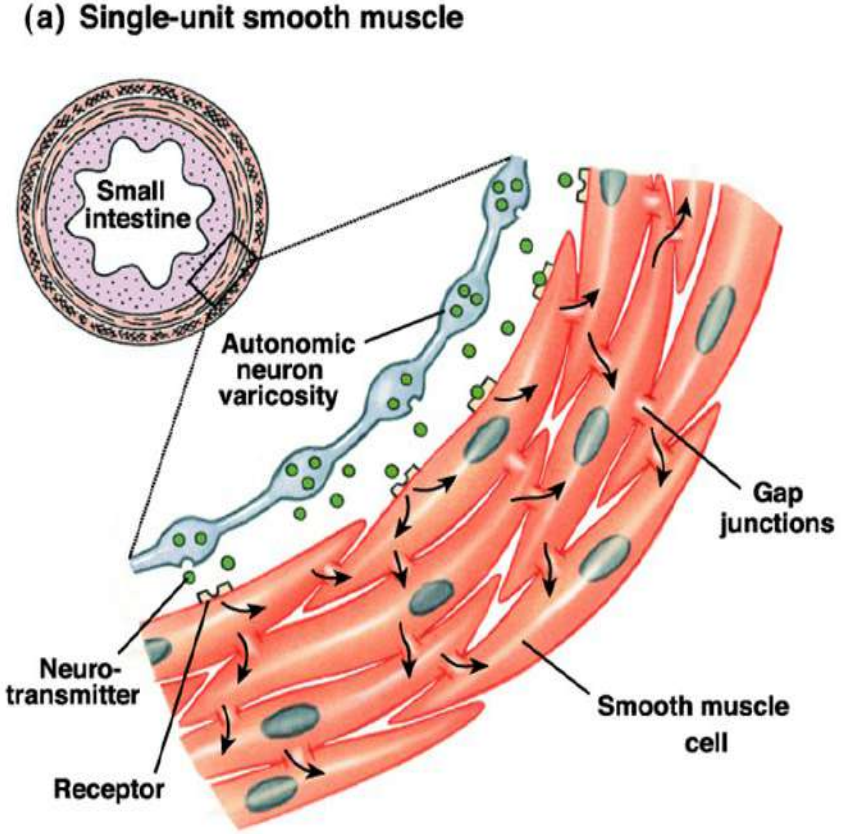
Smooth Muscle

Unstriated muscle associated with visera.



(Compare to skeletal muscle)

- Controlled by autonomic nervous system, hormones and paracrine.

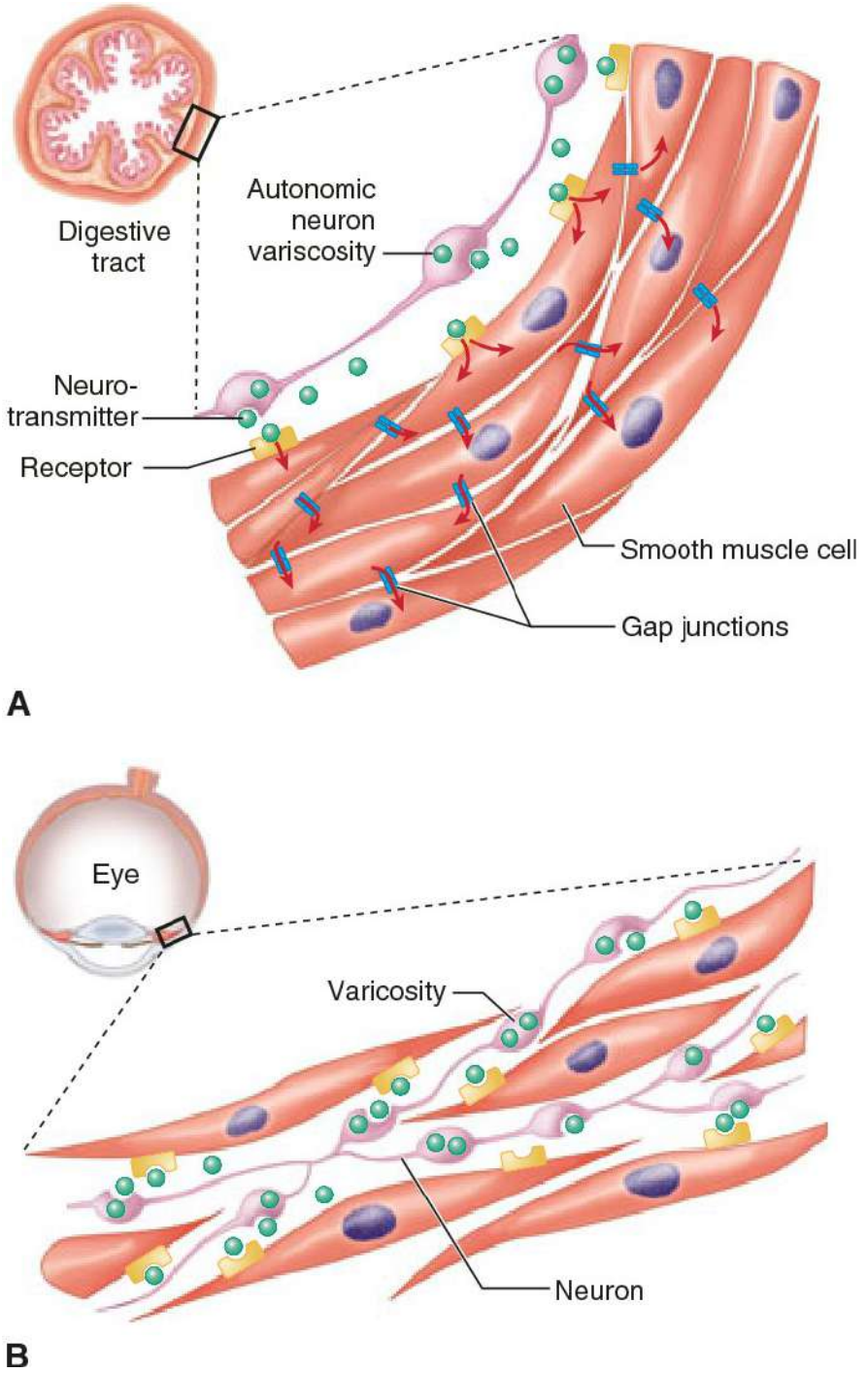


- actin/myosin structure allows sustained contraction in different directions

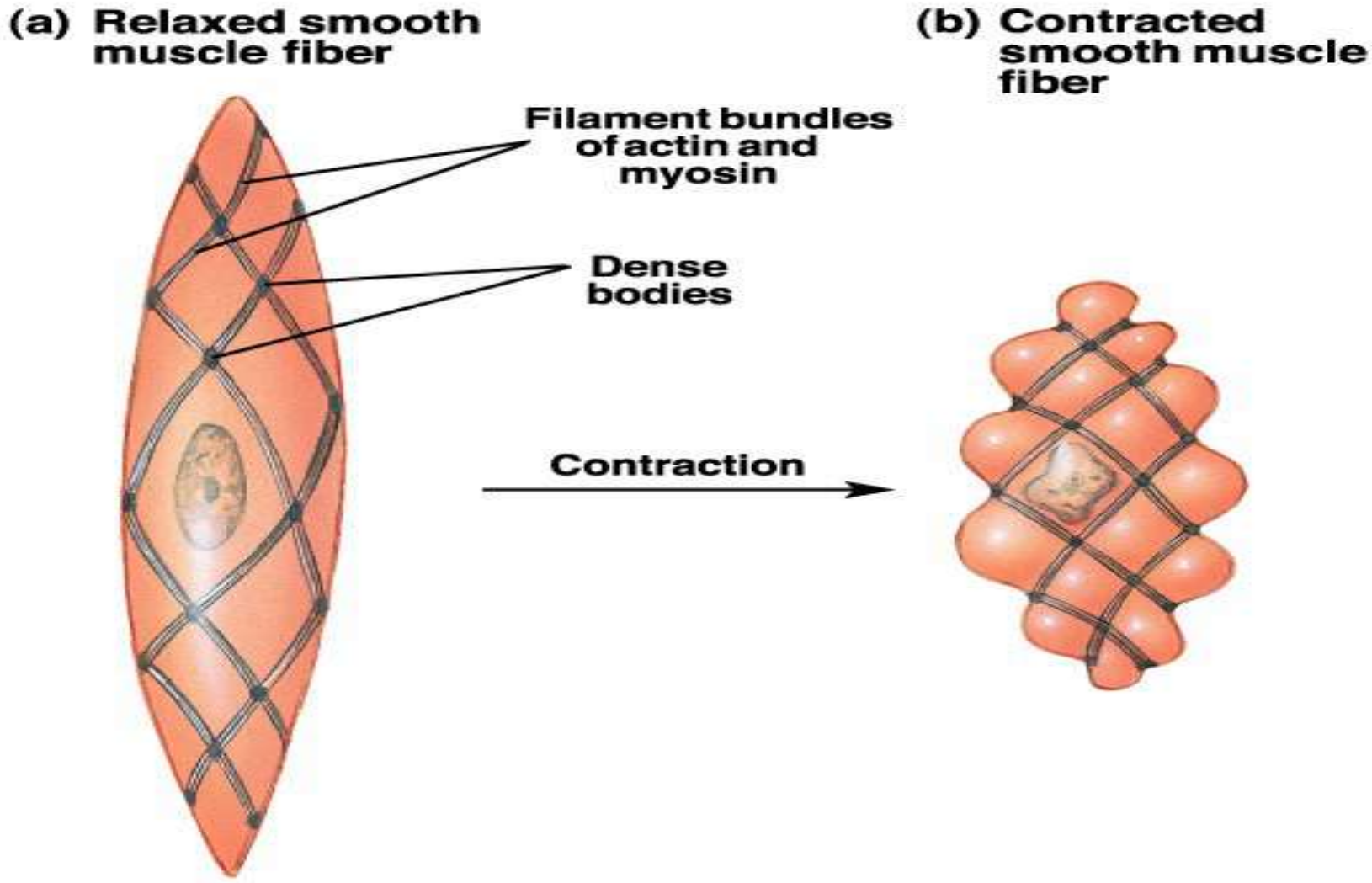
- role of calcium in contraction

Smooth Muscle

- Found in walls of hollow organs and tubes, where its contraction will change the shape of an organ
- Generates force to move material through the lumen of an organ
- Smooth muscle is controlled by hormones and paracrines, as well as autonomic nervous system neurotransmitters

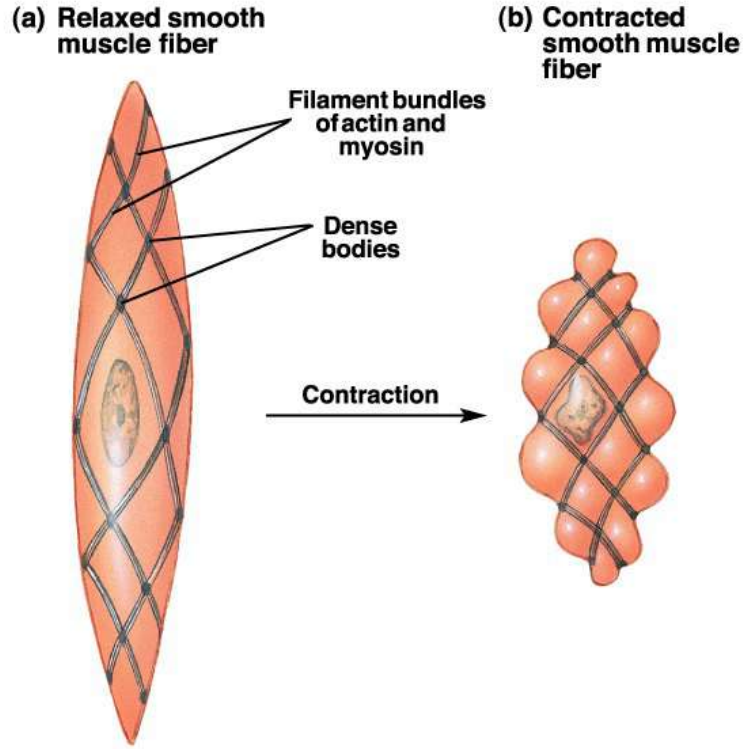


Contractile fibers are arranged in oblique bundles rather than in parallel sarcomeres



Smooth Muscle Tissue

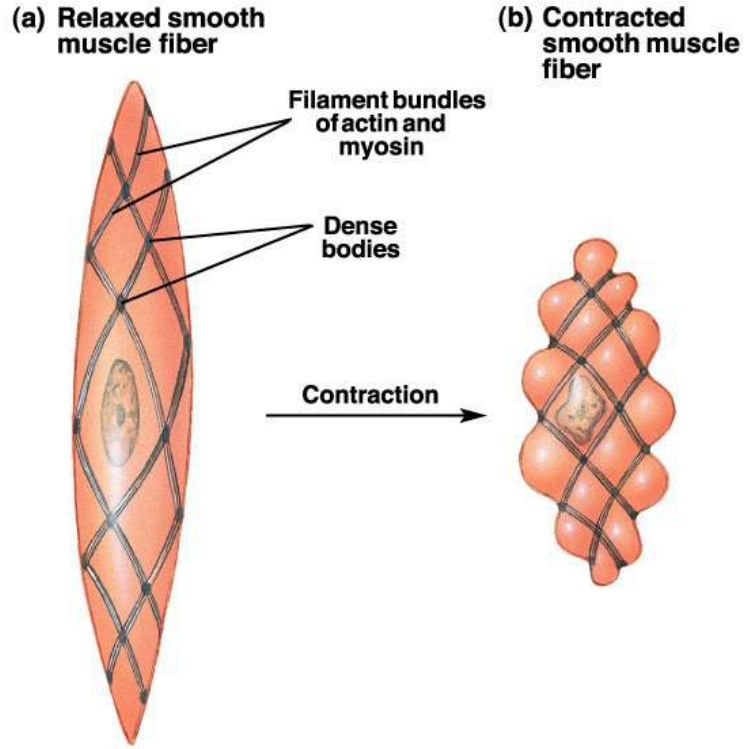
- Physiology of Smooth Muscle
  - Contraction lasts longer than skeletal muscle contraction
  - Contractions are initiated by Ca^{+} flow primarily from the interstitial fluid
  - Ca^{++} move slowly out of the muscle fiber delaying relaxation



Contractile fibers are arranged in oblique bundles rather than in parallel sarcomeres

Smooth Muscle Tissue

- Physiology of Smooth Muscle
    - Able to sustain long-term muscle tone
        - Prolonged presence of Ca^{++} in the cell provides for a state of continued partial contraction
- Important in the:
- Gastrointestinal tract where a steady pressure is maintained on the contents of the tract
- In the walls of blood vessels which maintain a steady pressure on blood



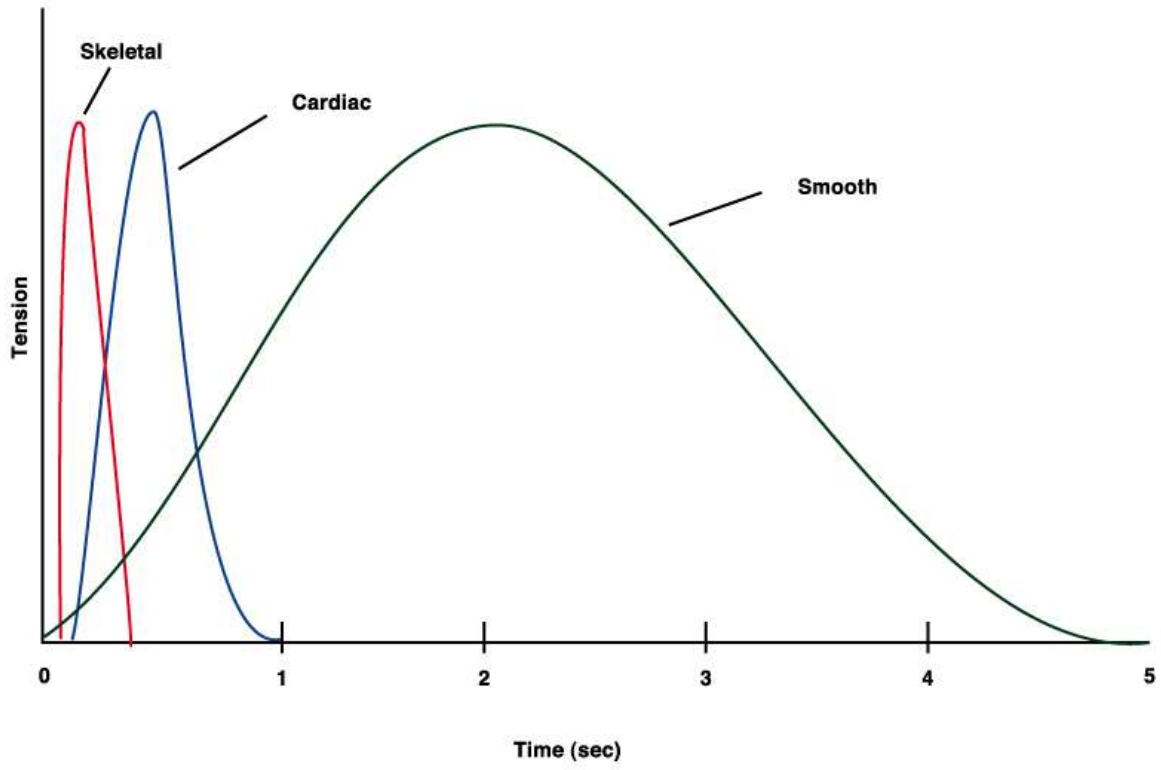
Contractile fibers are arranged in oblique bundles rather than in parallel sarcomeres

Smooth Muscle Tissue

- Physiology of Smooth Muscle
  - Most smooth muscle fibers contract or relax in response to:
    - Action potentials from the autonomic nervous system
      - Pupil constriction due to increased light energy
    - In response to stretching
      - Food in digestive tract stretches intestinal walls initiating peristalsis
    - Hormones
      - Epinephrine causes relaxation of smooth muscle in the air-ways and in some blood vessel walls
    - Changes in pH, oxygen and carbon dioxide levels

Smooth Muscle:

- Slower in developing tension
- Sustain contractions for extended periods without fatigue
- Allows the walls of organs to maintain tension with a continued load



Smooth Muscle

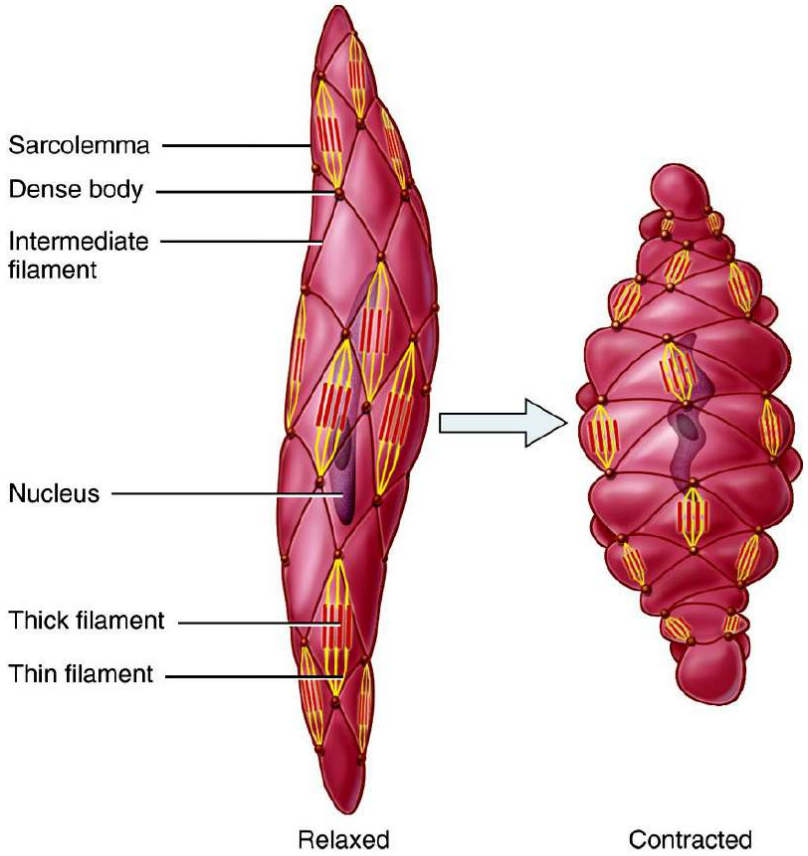
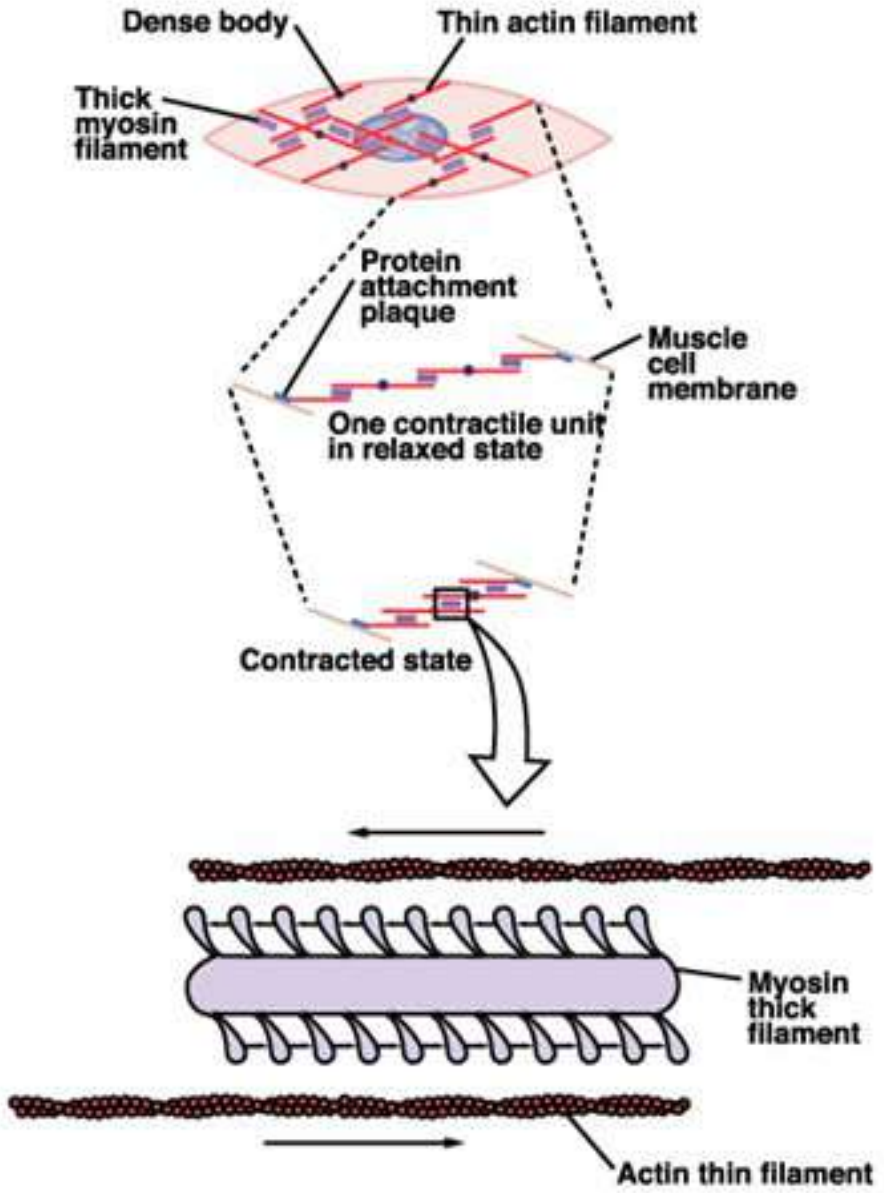
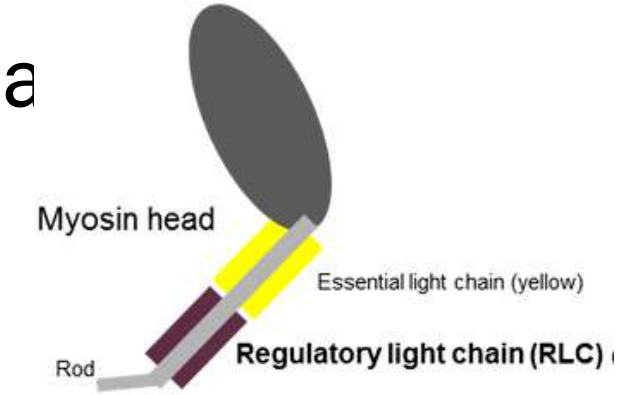


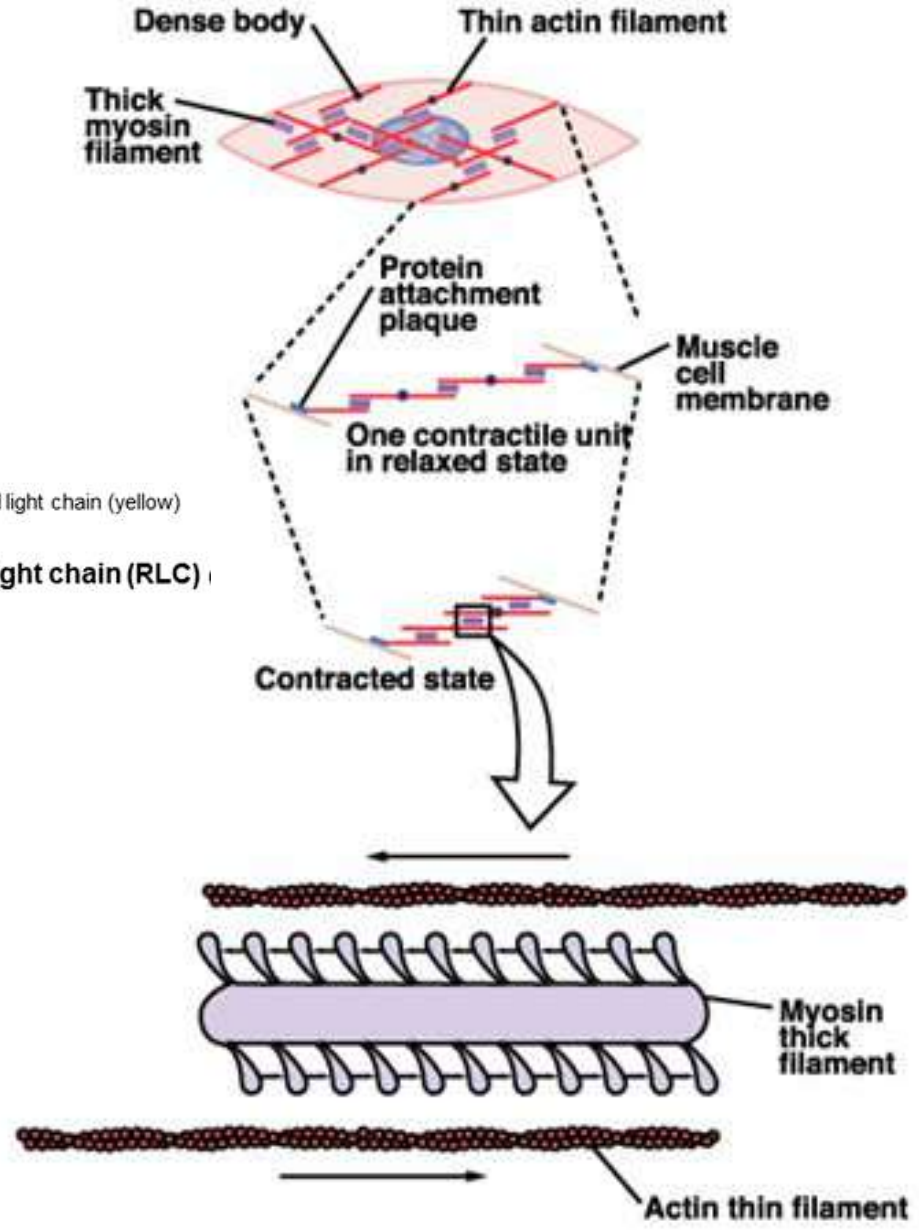
Figure 10.18 Tortora - PAP 12/e



Myosin of Smooth Muscle

- Different isoform than tha found in skeletal muscle
- Smooth muscle myosin ATPase activity is much slower, contraction is longer
- Myosin light chain in the myosin head regulates contraction and relaxation





Anatomy (cont.)

- Relatively little sarcoplasmic reticulum
- Lacks T-tubules

- Chemically linked to the cell membrane, rather than mechanically linked

- Ca^{+2} storage is supplemented by caveolae , small vesicles that cluster close to the cell membrane. Voltage/ligand gated Ca^{+2} channels

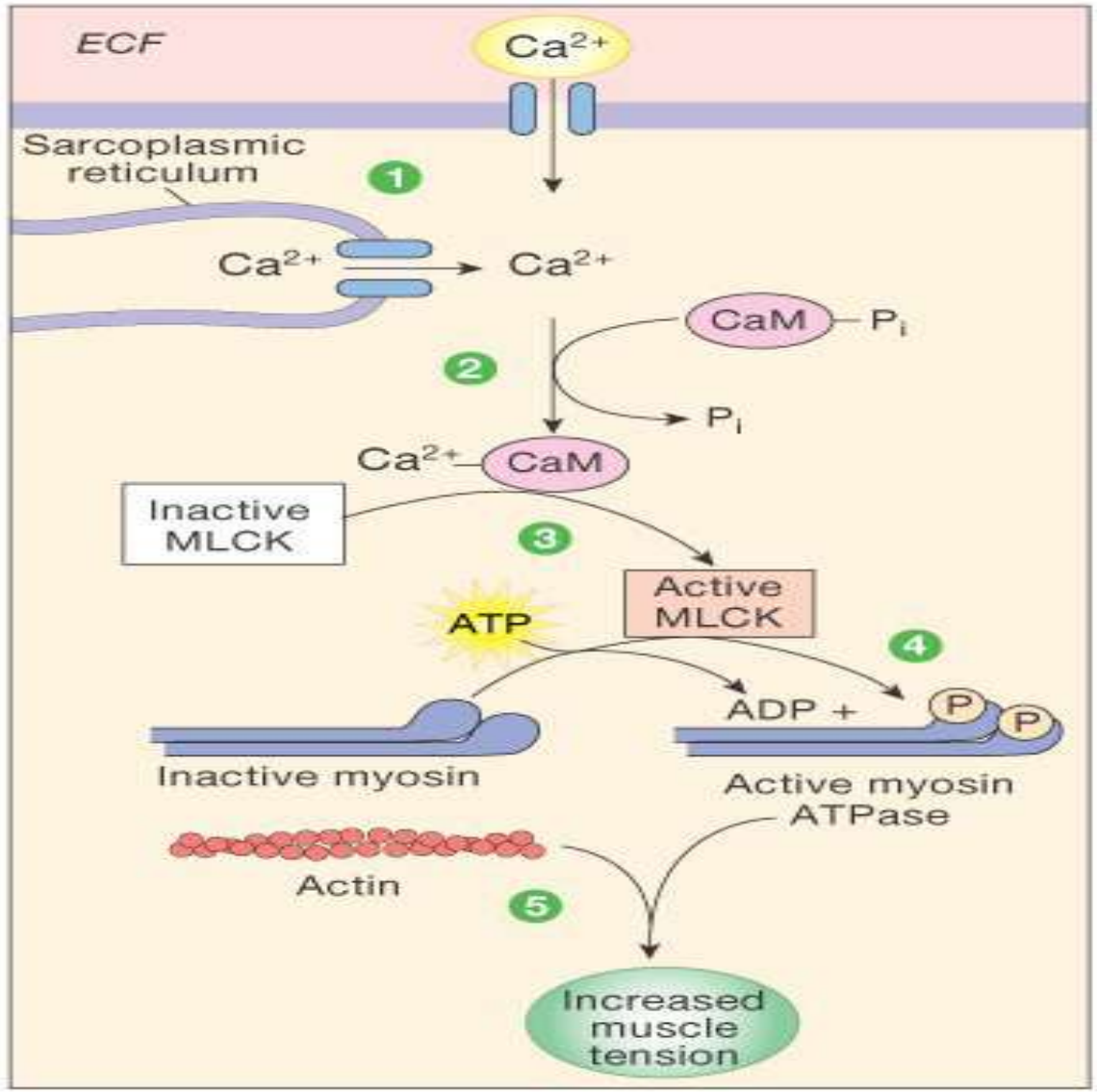
Response of Smooth Muscle to Stimuli

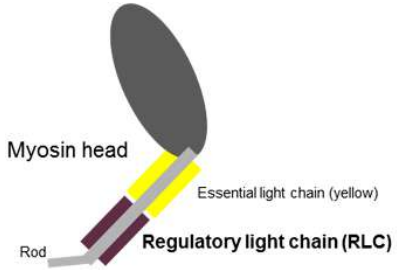
- Neurotransmitters and hormones acting on smooth muscle can INHIBIT contraction as well as stimulated it.

- Ca^{+2} influx through sarcolemma voltage gated Ca^{+2} channels is the signal for SR Ca^{+2} release

- Ca^{+2} storage is supplemented by caveolae , small vesicles that cluster close to the cell membrane.

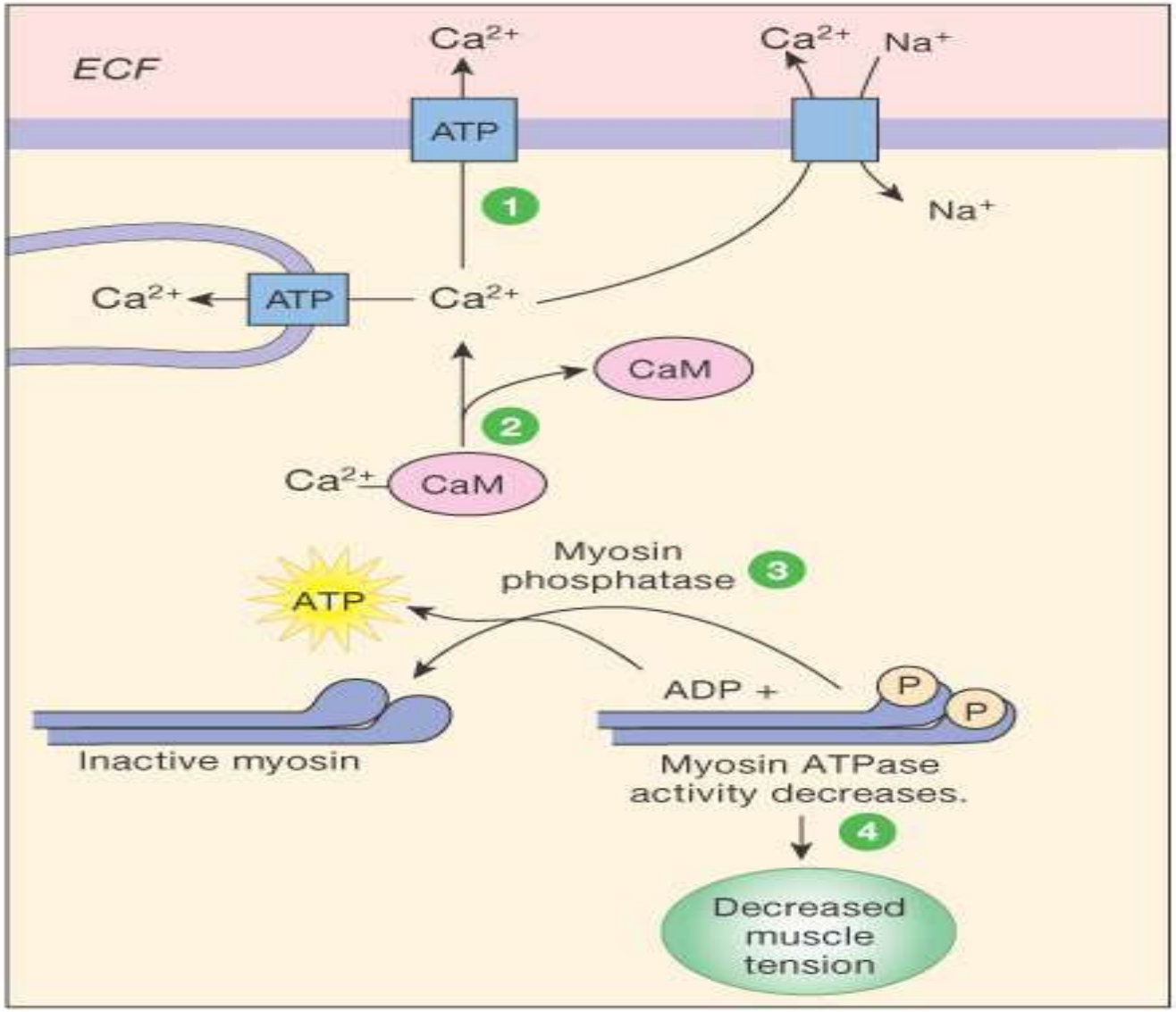
Smooth Muscle Contraction: Mechanism





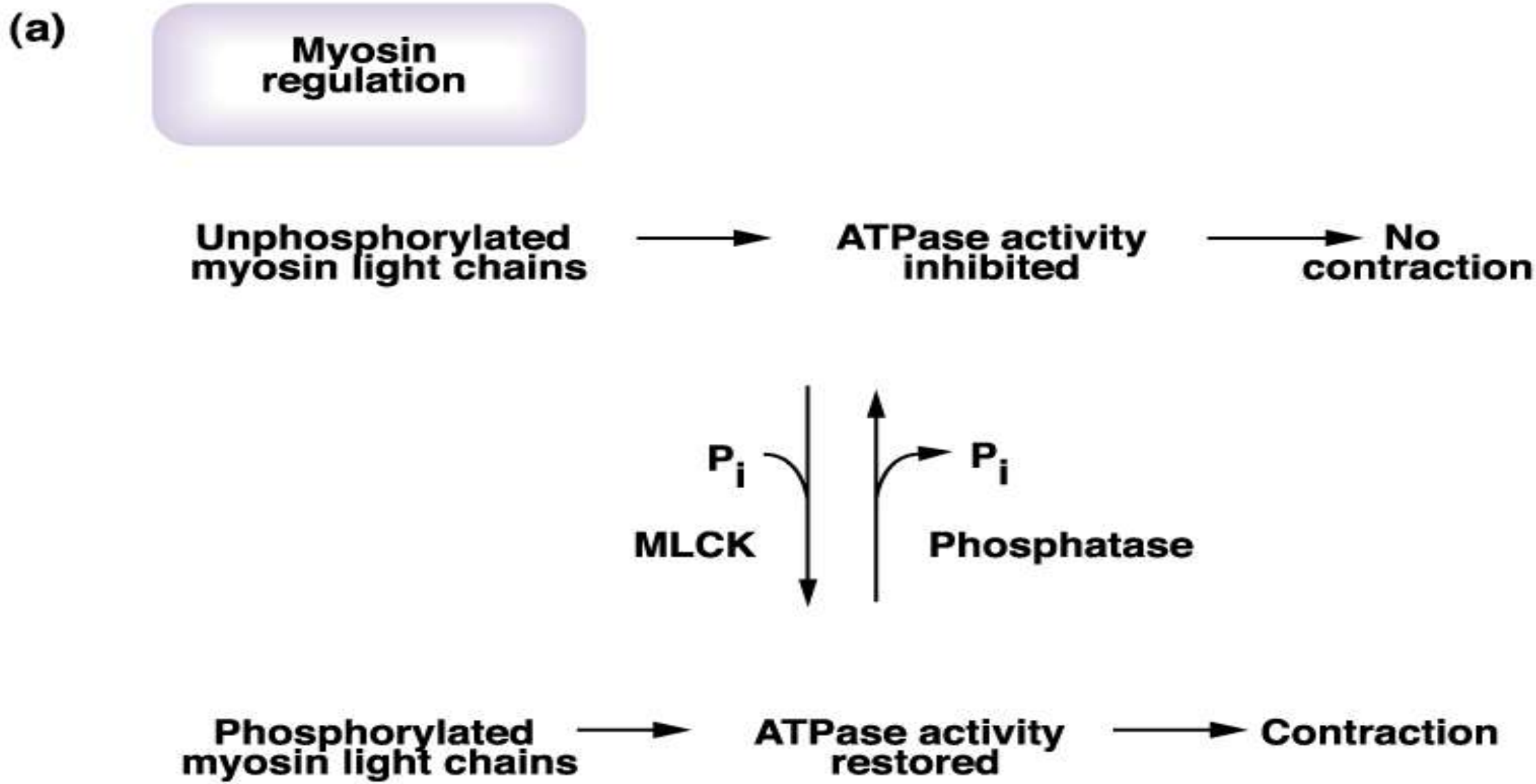
1. Intracellular Ca^{2+} concentrations increase when Ca^{2+} enters cell and is released from sarcoplasmic reticulum.
2. Ca^{2+} binds to calmodulin (CaM).
3. Ca^{2+}–calmodulin activates myosin light chain kinase (MLCK).
4. MLCK phosphorylates light chains in myosin heads and increases myosin ATPase activity.
5. Active myosin crossbridges slide along actin and create muscle tension.

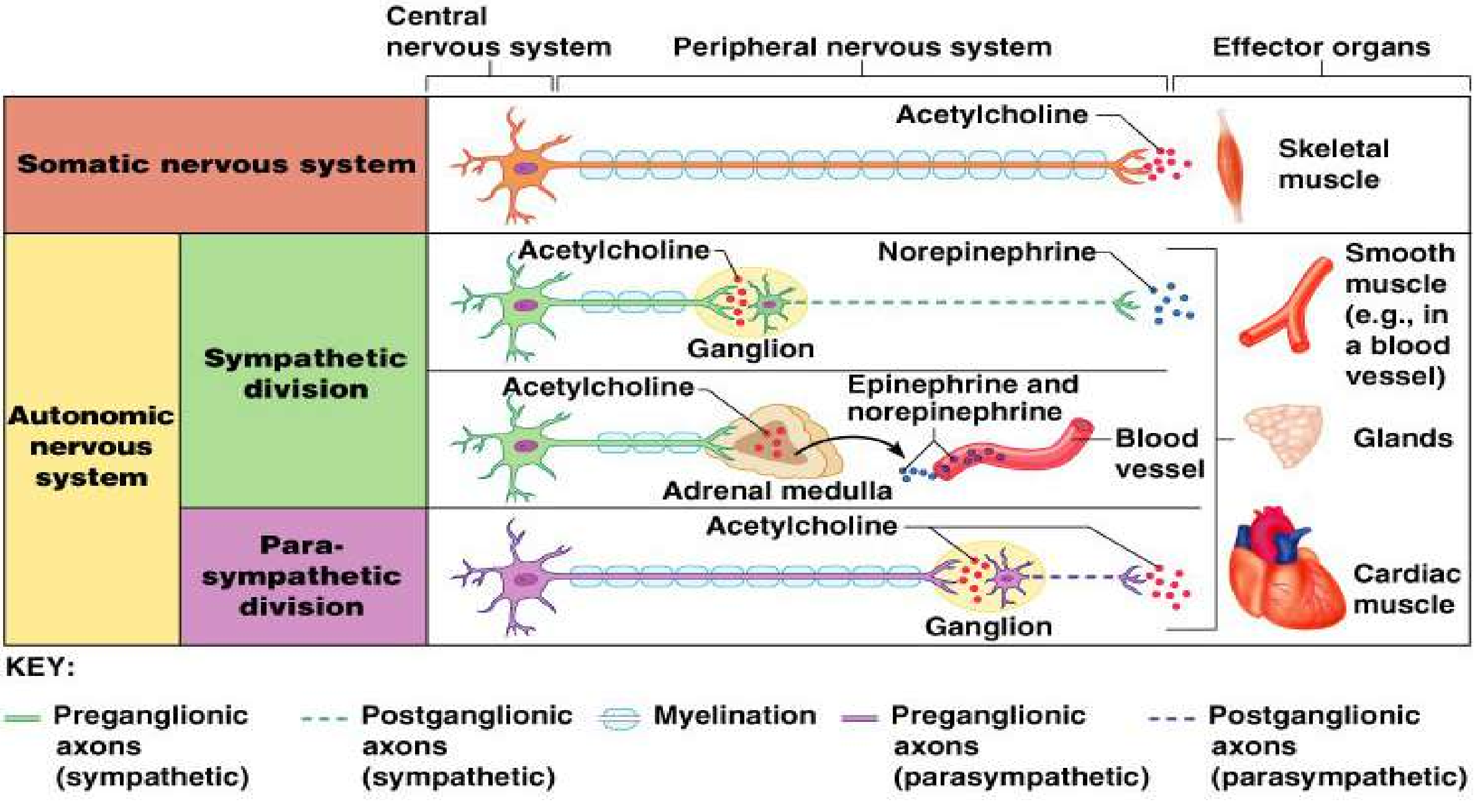
Smooth Muscle Relaxation: Mechanism



1. Free Ca^{2+} in cytosol decreases when Ca^{2+} is pumped out of the cell or back into the sarcoplasmic reticulum.
2. Ca^{2+} unbinds from calmodulin (CaM).
3. Myosin phosphatase removes phosphate from myosin, which decreases myosin ATPase activity.
4. Less myosin ATPase results in decreased muscle tension.

(a)


Myosin regulation
Unphosphorylated myosin light chains
ATPase activity inhibited
No contraction
P_i
MLCK
P_i
Phosphatase
Phosphorylated myosin light chains
ATPase activity restored
Contraction


Central nervous system
Peripheral nervous system
Effector organs
Somatic nervous system
Acetylcholine
Skeletal muscle
Autonomic nervous system
Sympathetic division
Acetylcholine
Norepinephrine
Ganglion
Smooth muscle (e.g., in a blood vessel)
Acetylcholine
Epinephrine and norepinephrine
Blood vessel
Glands
Adrenal medulla
Para-sympathetic division
Acetylcholine
Ganglion
Cardiac muscle
KEY:
Preganglionic axons (sympathetic)
Postganglionic axons (sympathetic)
Myelination
Preganglionic axons (parasympathetic)
Postganglionic axons (parasympathetic)

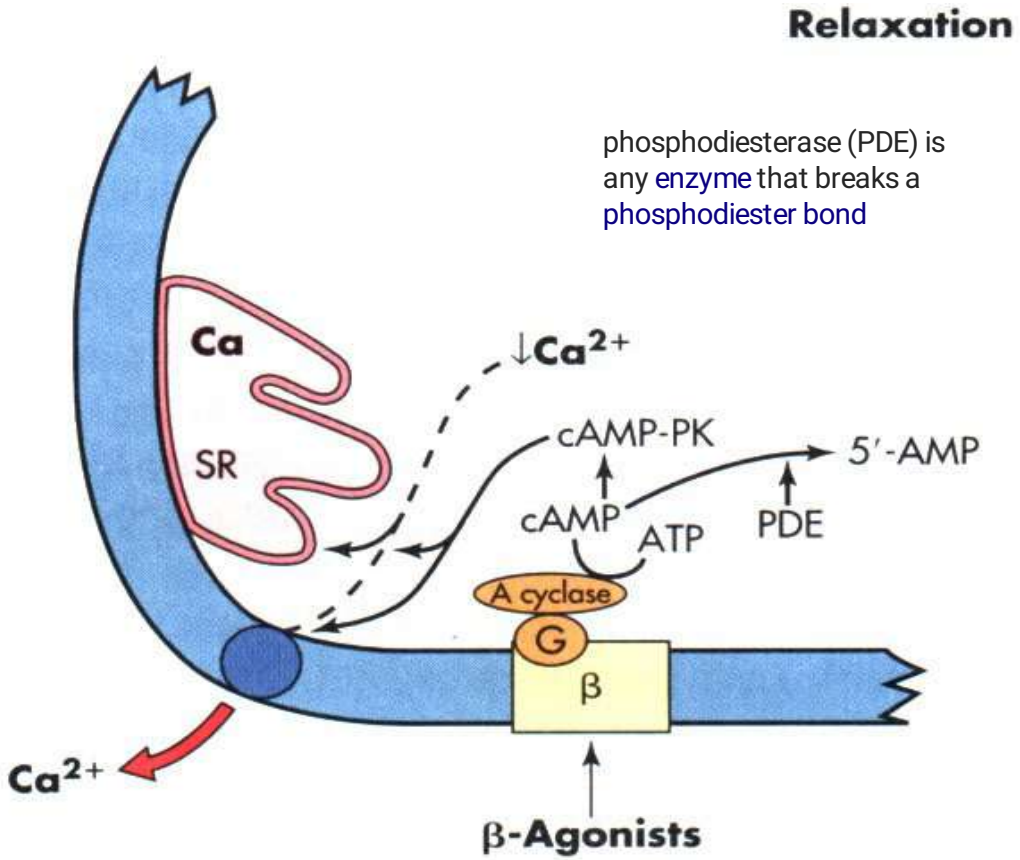
Beta Blockers

Beta blockers, also known as beta-adrenergic blocking agents,

are medications that reduce blood pressure.

Beta Blockers; any class of drugs which prevent the stimulation of the adrenergic receptors

Beta blockers work by blocking the effects of the hormone epinephrine, also known as adrenaline.



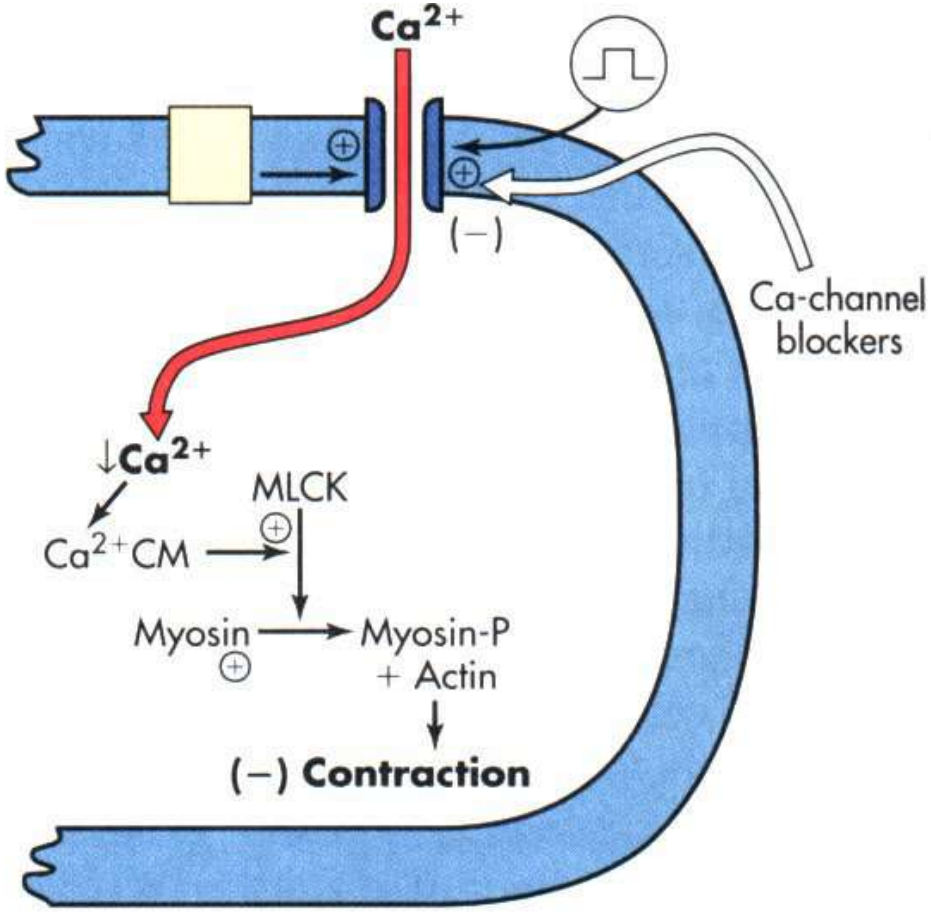
Calcium channel blockers

Calcium channel blockers are medications used to lower blood pressure.

They work by preventing calcium from entering the cells of the heart and arteries.

Calcium causes the heart and arteries to squeeze (contract) more strongly.

By blocking calcium, calcium channel blockers allow blood vessels to relax and open.

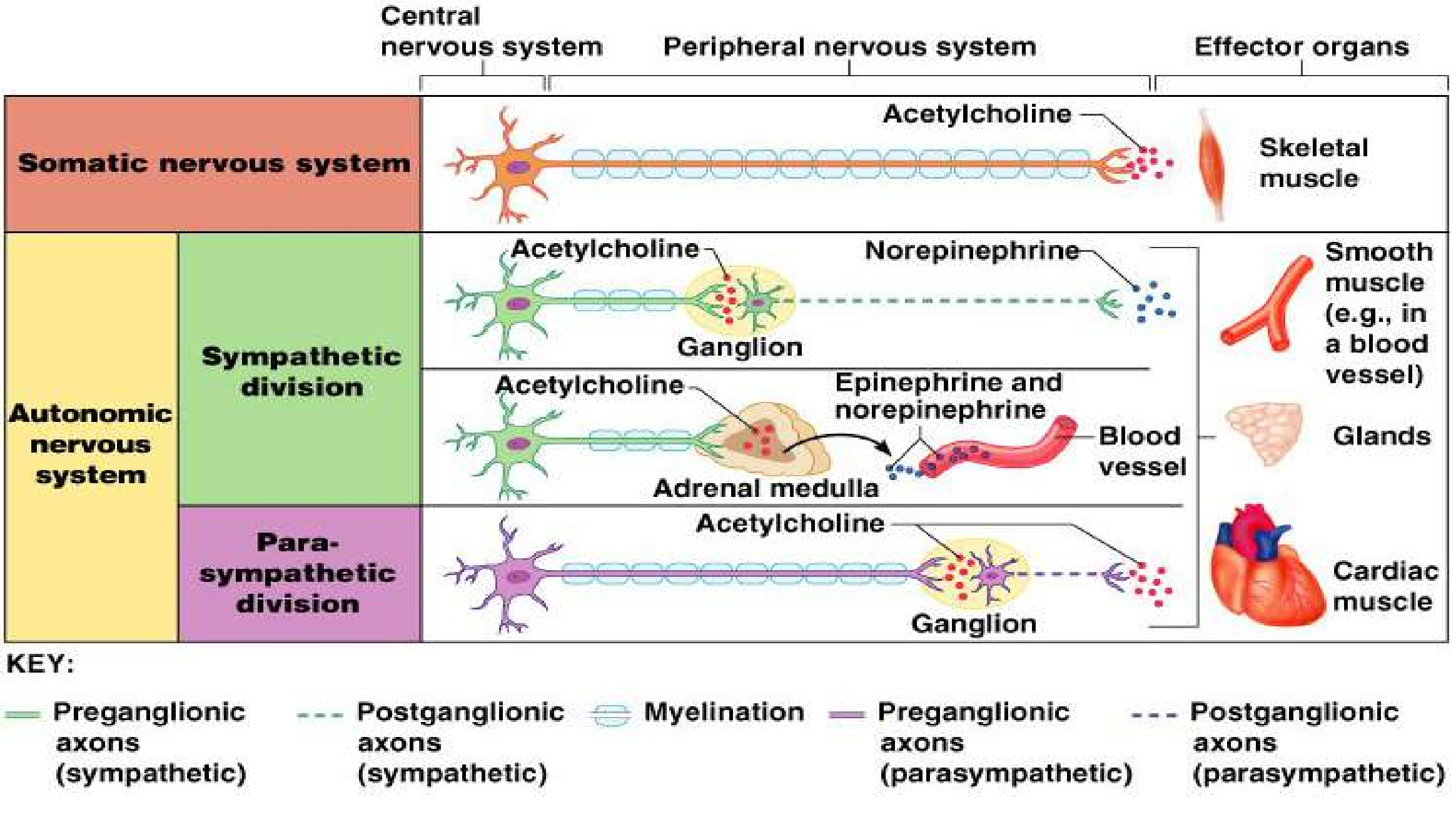


End

Thank you

Muscles Physiology

Cardiac muscle


Central nervous system
Peripheral nervous system
Effector organs
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Blood vessel
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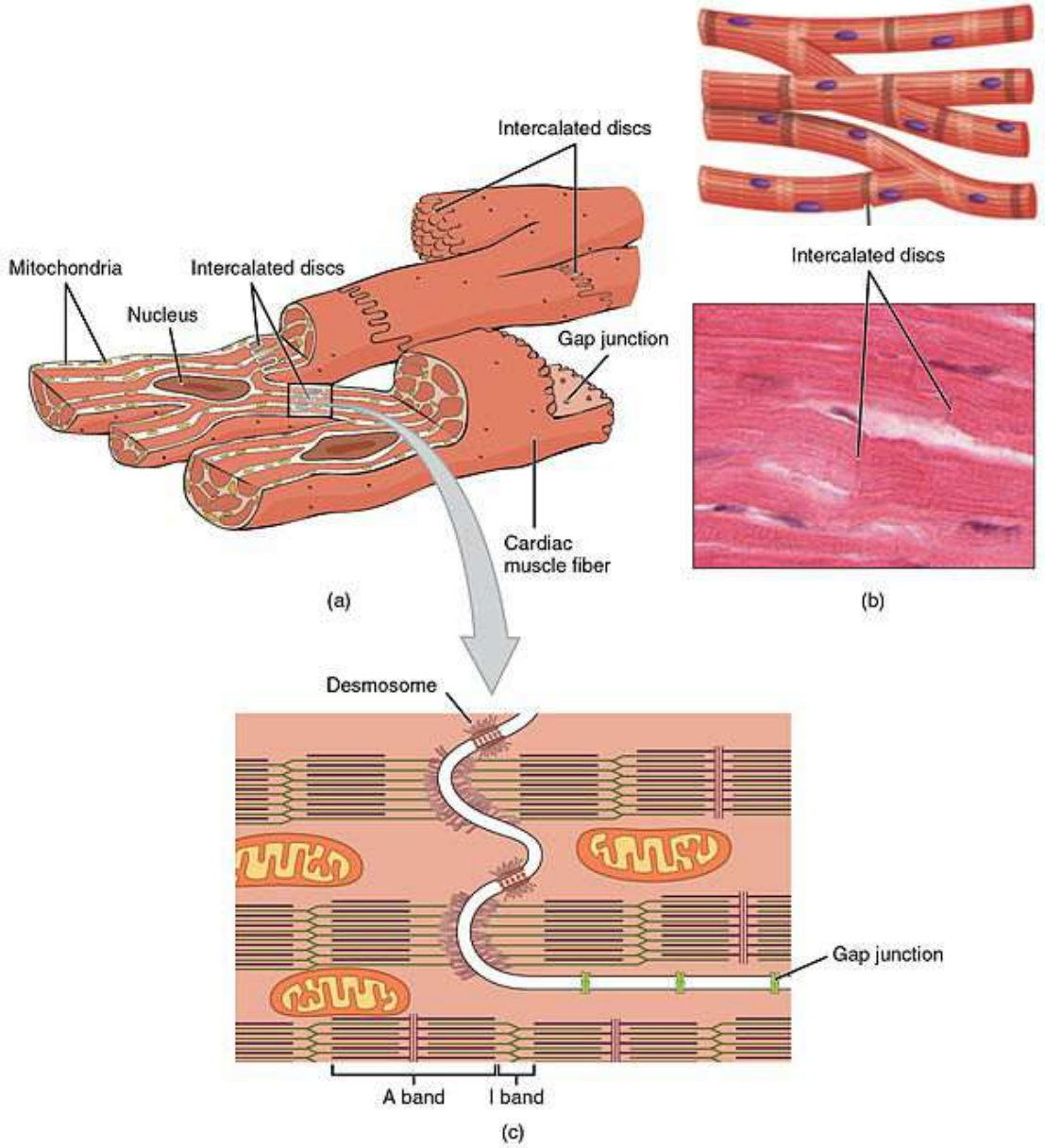
Adrenal medulla
Para-sympathetic division
Acetylcholine
Ganglion
Cardiac muscle
KEY:
Preganglionic axons (sympathetic)
Postganglionic axons (sympathetic)
Myelination
Preganglionic axons (parasympathetic)
Postganglionic axons (parasympathetic)

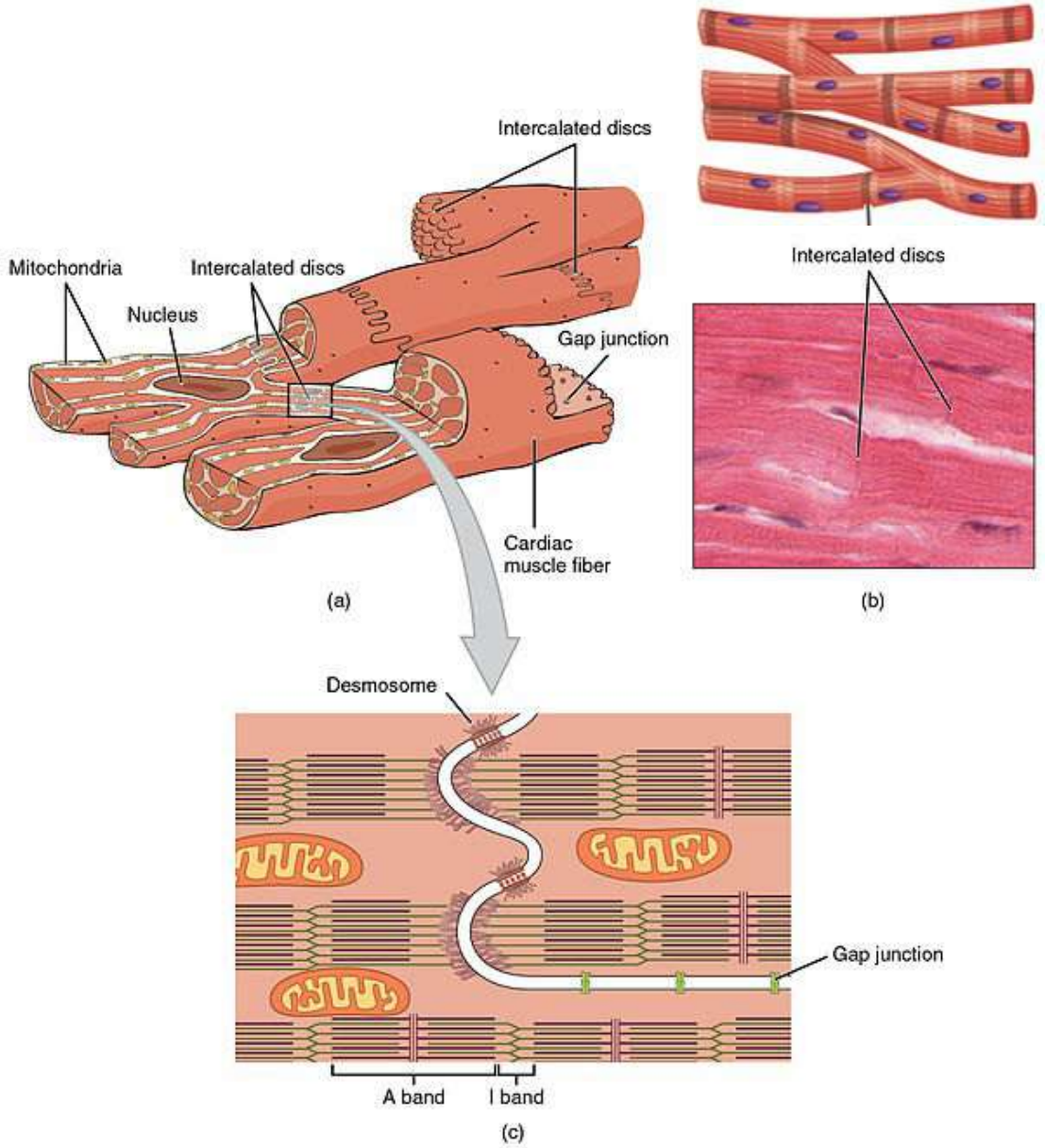
Cardiac Muscle Tissue

- The heart is composed of cardiac muscle cells which have specialized features that relates to their function:
- Cardiac muscle cells contract without stimulation by the central nervous system (contraction is myogenic)
- Cardiac muscle cells are branched, allowing for faster signal propagation and contraction in three dimensions



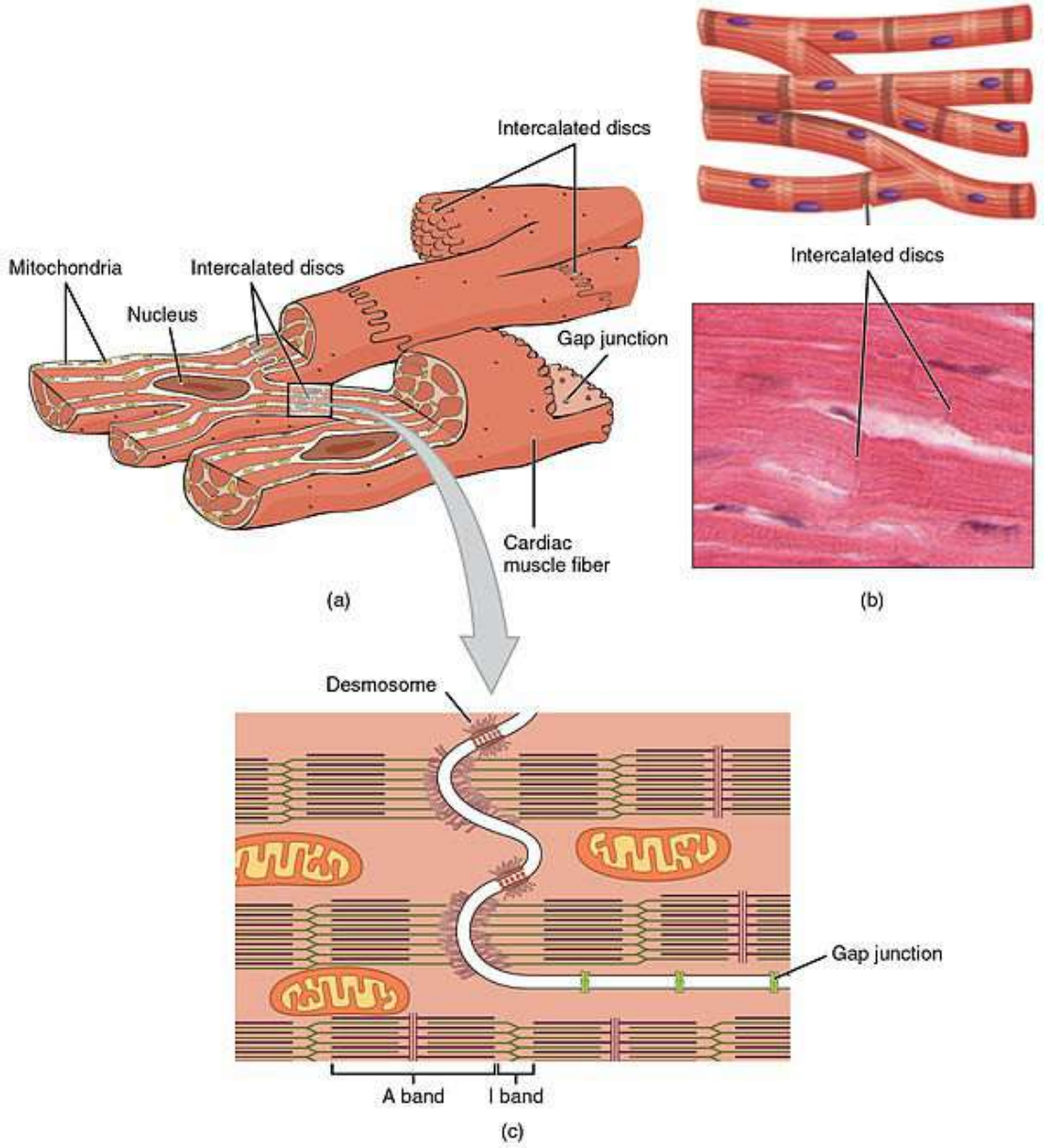
Cardiac Muscle Tissue

- The heart is composed of cardiac muscle cells which have specialized features that relates to their function:
- Cardiac muscles cells are not fused together, but are connected by gap junctions at intercalated discs
- Cardiac muscle cells have more mitochondria, as they are more reliant on aerobic respiration than skeletal muscle



Cardiac Muscle Tissue

- Principal tissue in the heart wall
  - Intercalated discs connect the ends of cardiac muscle fibers to one another
    - Allow muscle action potentials to spread from one cardiac muscle fiber to another

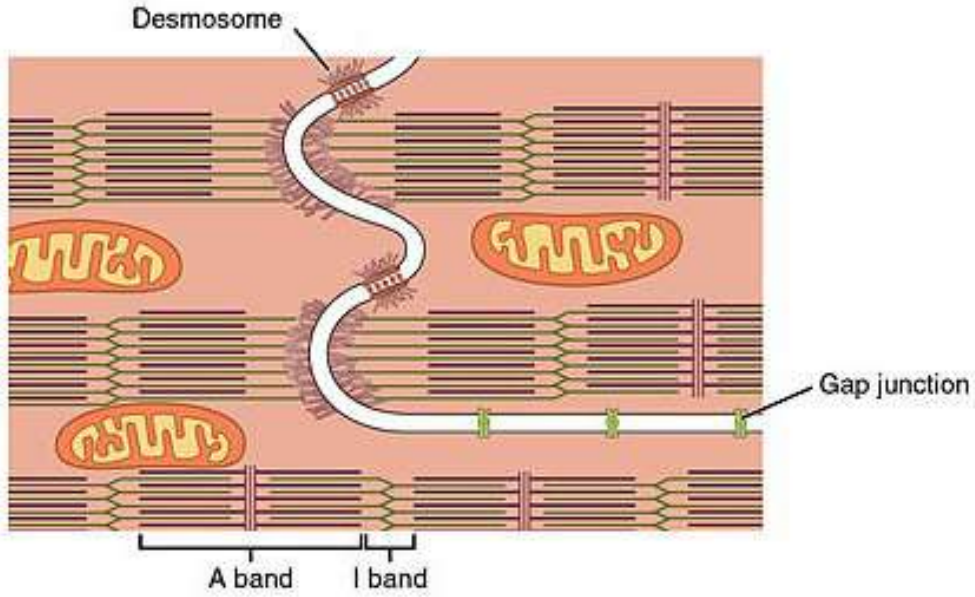


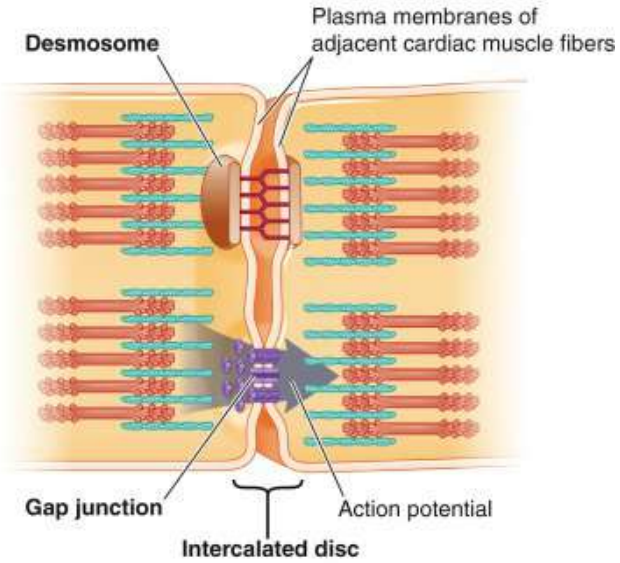
Cardiac Muscle Fibers

- Interconnected by intercalated discs and form functional syncytia;

syncytia; from Greek: σύν (syn) = "together" + κύτος (kytos) = "box, i.e. cell

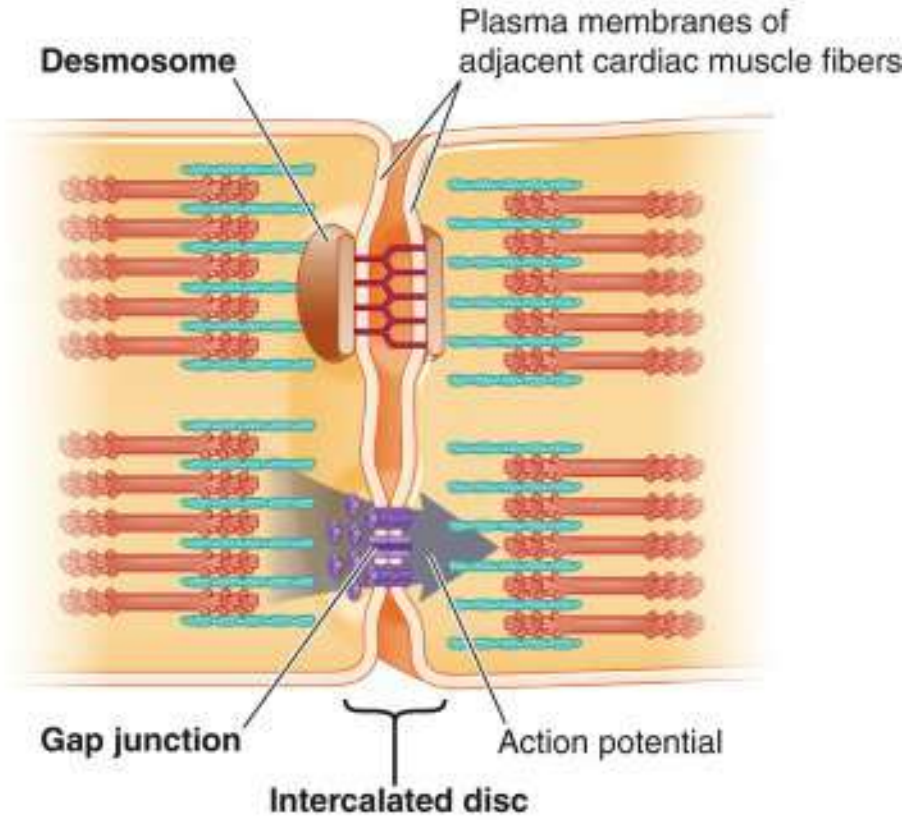
- Within intercalated discs – two kinds of membrane junctions
  - Desmosomes
  - Gap junctions



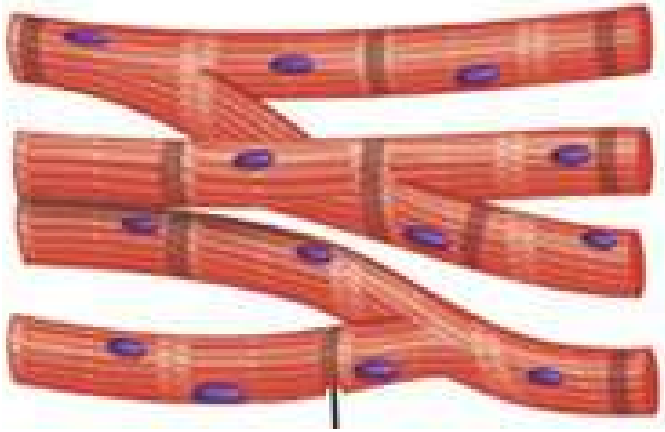


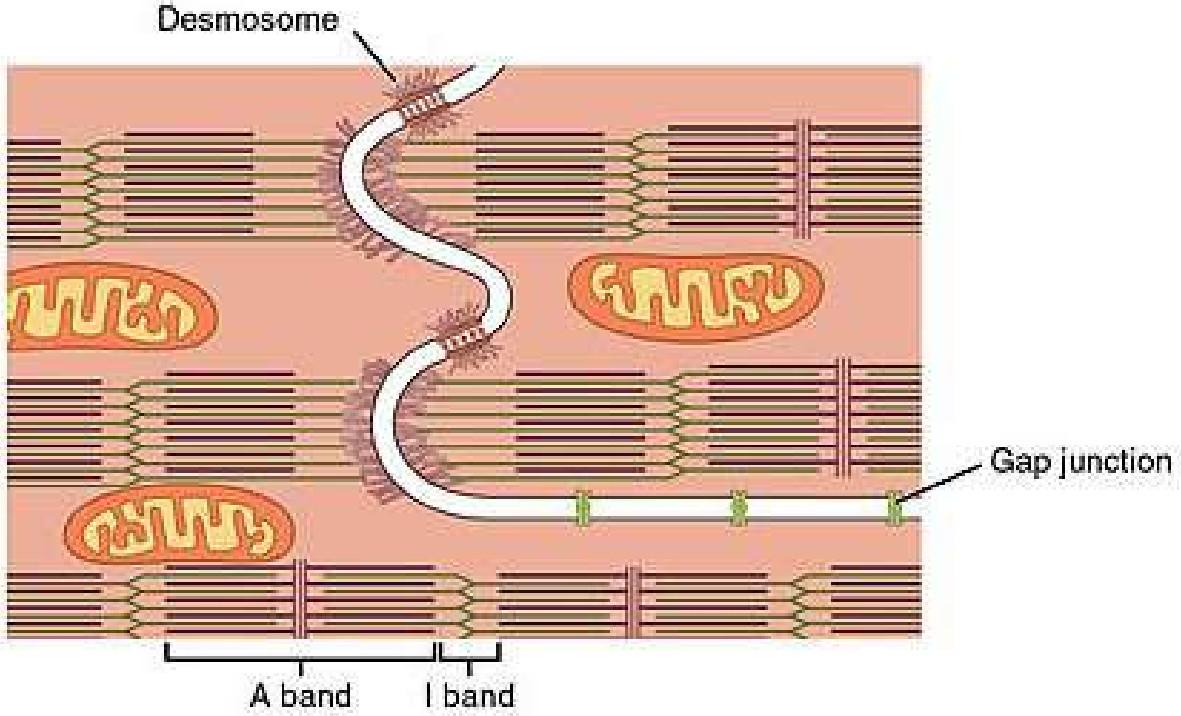
(c) Intercalated discs contain two types of membrane junctions: mechanically important desmosomes and electrically important gap junctions.

Intercalated discs



(c) Intercalated discs contain two types of membrane junctions: mechanically important desmosomes and electrically important gap junctions.

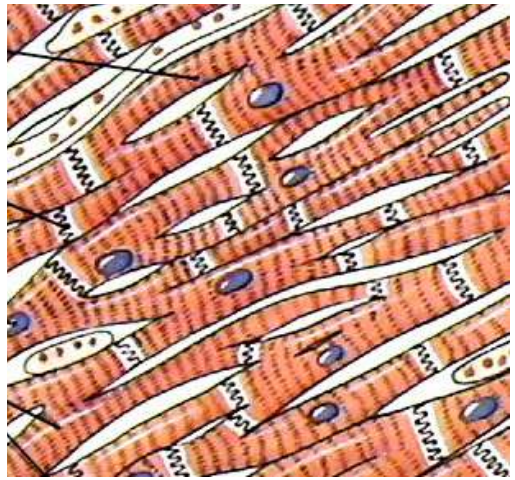


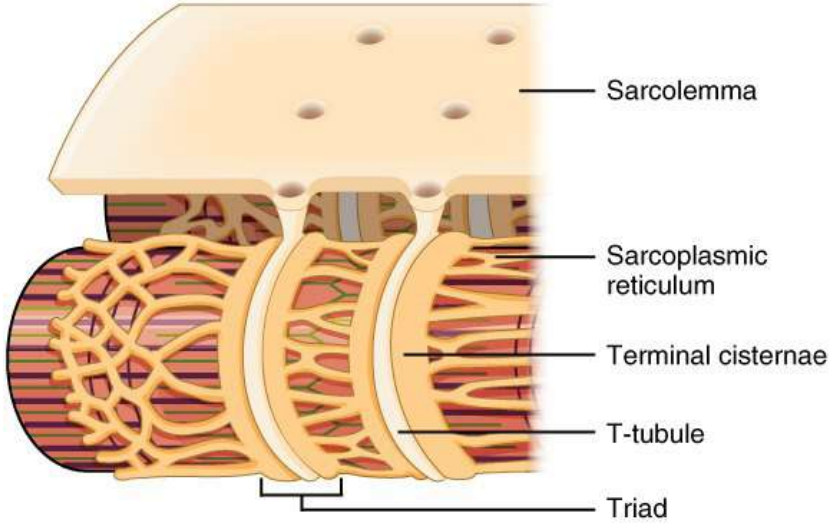


Cardiac Muscle Tissue

Unique Microanatomy of Cardiac Muscle Cells

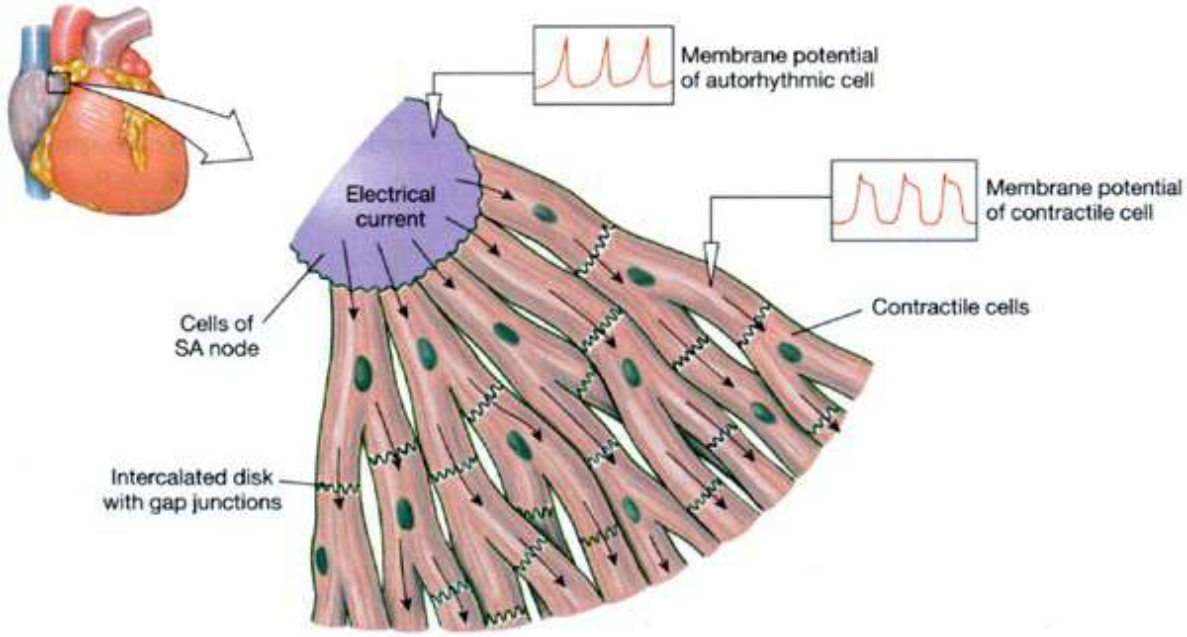
- 1% of cardiac cells are autorhythmic
  - Signal to contract is myogenic
- Intercalated discs with gap junctions and desmosomes
  - Electrical link and strength
- SR smaller than in skeletal muscle
  - Extracellular Ca^{2+} initiates contraction (like smooth muscle)
- Abundant mitochondria extract about 80% of O_2





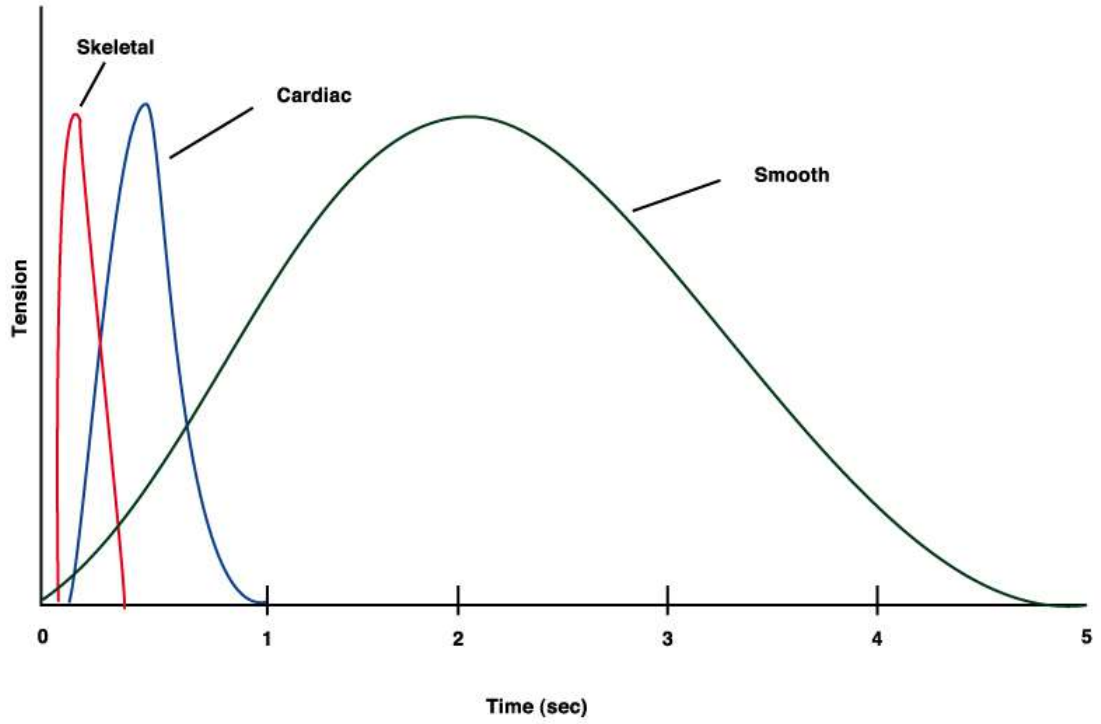
Cardiac Muscle Tissue

- Principal tissue in the heart wall
  - Cardiac muscle tissue contracts when stimulated by its own autorhythmic muscle fibers
    - Continuous, rhythmic activity is a major physiological difference between cardiac and skeletal muscle tissue



Cardiac Muscle Tissue

- Principal tissue in the heart wall
  - Contractions lasts longer than a skeletal muscle twitch
  - Have the same arrangement of actin and myosin as skeletal muscle fibers
  - Mitochondria are large and numerous



Cardiac Muscle Tissue

- Principal tissue in the heart wall
  - Depends on aerobic respiration to generate ATP
    - Requires a constant supply of oxygen
    - Able to use lactic acid produced by skeletal muscle fibers to make ATP

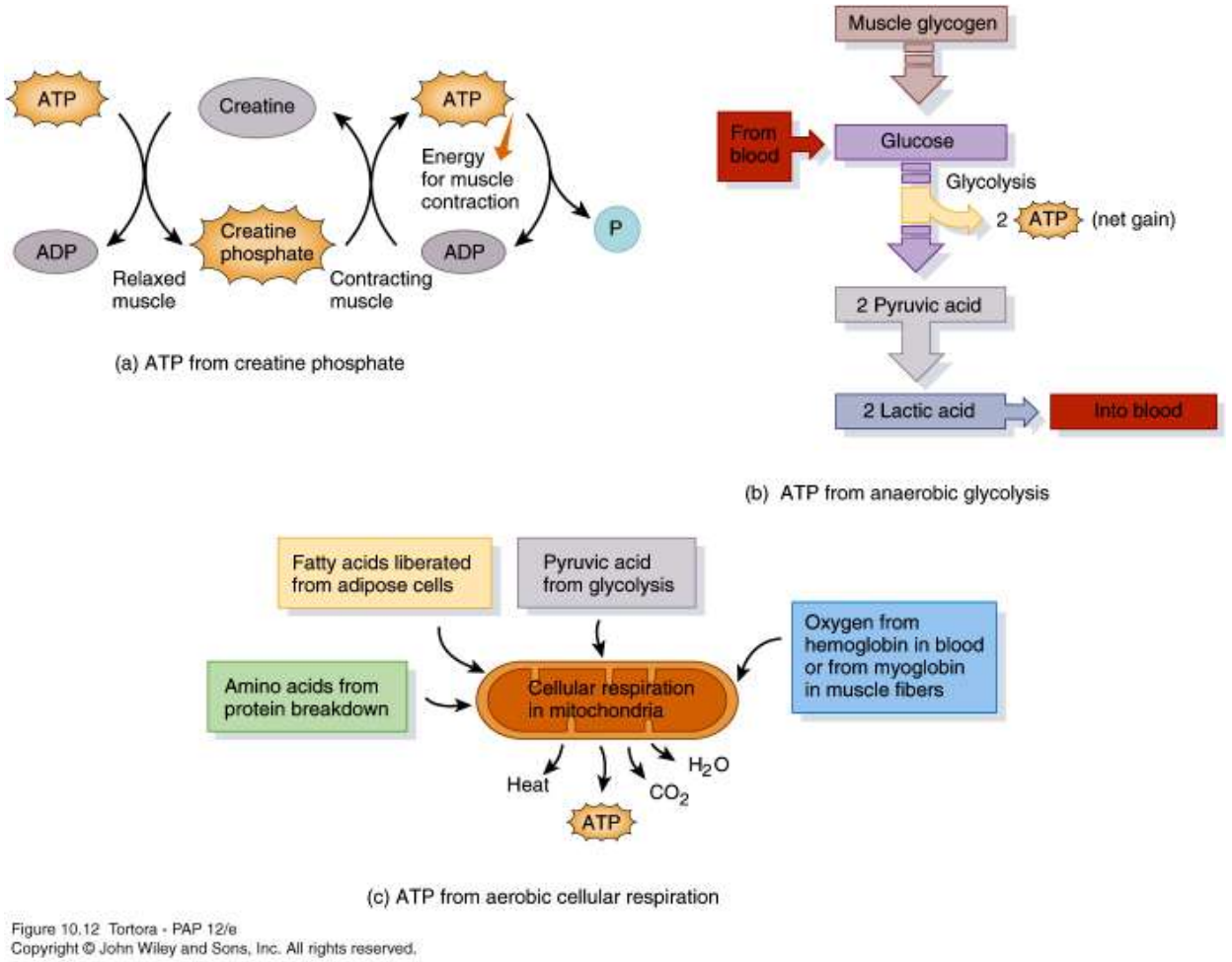
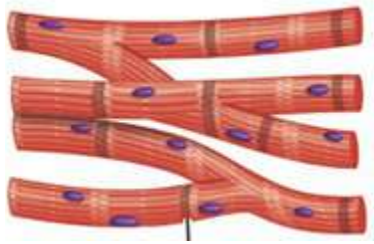
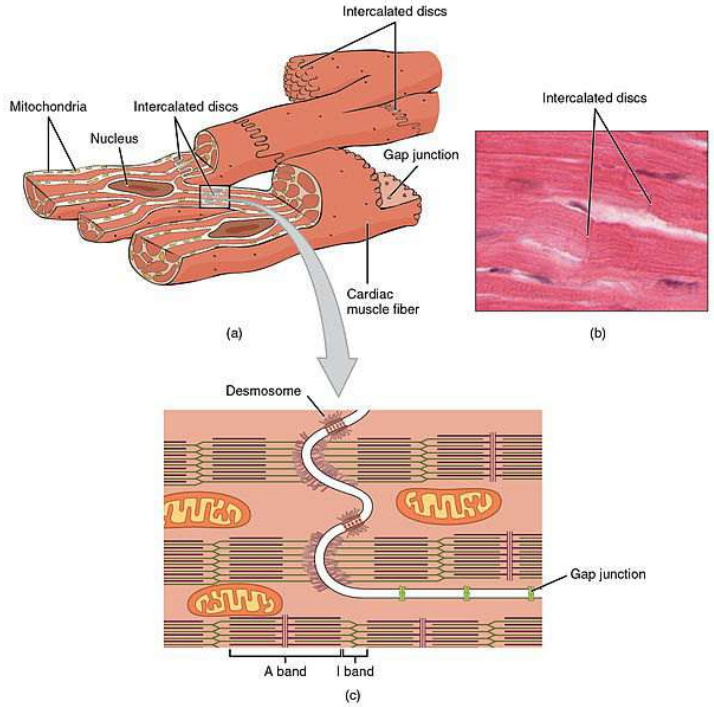


Figure 10.12 Tortora - PAP 12/e

Cardiac Muscle Tissue



- These structural features contribute to the unique functional properties of the cardiac tissue:
- Cardiac muscle has a longer period of contraction and refraction, which is needed to maintain a viable heart beat
- The heart tissue does not become fatigued (unlike skeletal muscle), allowing for continuous, life long contractions
- The interconnected network of cells is separated between atria and ventricles, allowing them to contract separately



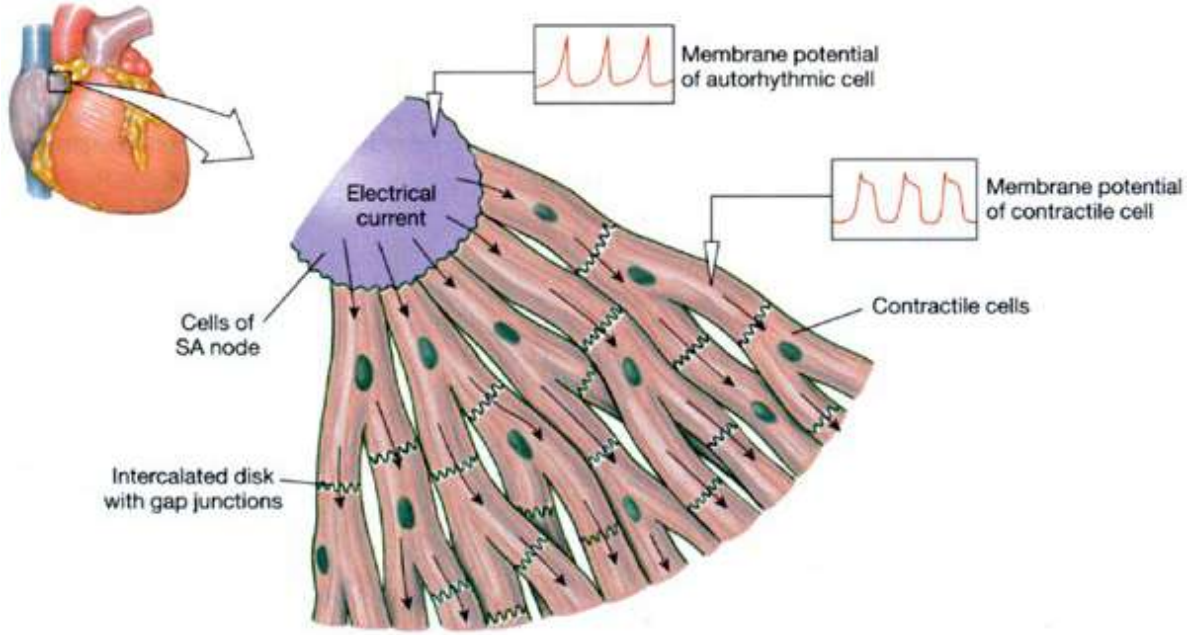
Types of Cardiac Cells

- Auto-rhythmic cells = pacemaker cells (depolarize spontaneously)
- Contractile cells – myofibrils –connected well together to form “functional Syncitium” for myocardium contraction

Ease of movement between cells (conductivity)

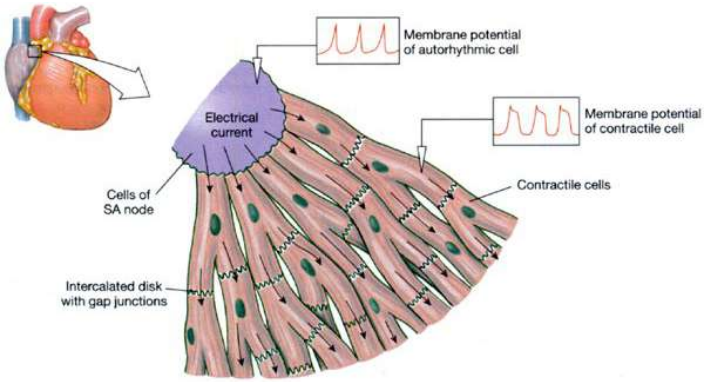
CARDIAC MUSCLE

- Atrial muscle
- Ventricular muscle
- Specializes excitatory &conductive muscle fibers



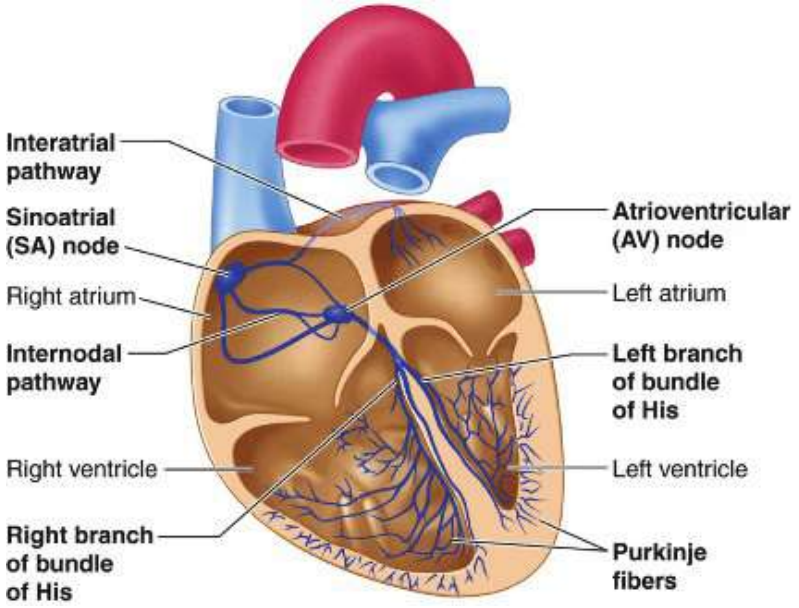
Electrical Activity of Heart

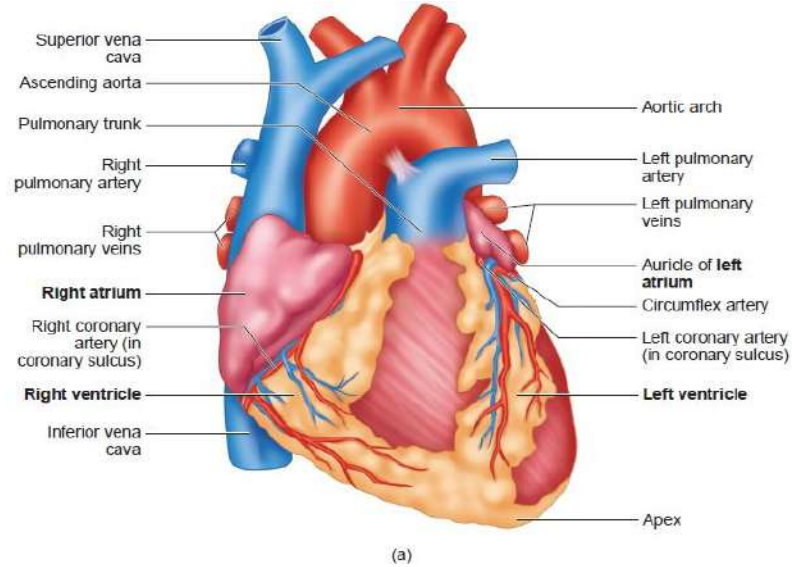
- Heart beats rhythmically as result of action potentials it generates by itself
- Two specialized types of cardiac muscle cells
  - Contractile cells
    - 99% of cardiac muscle cells
    - Do mechanical work of pumping
    - Normally do not initiate own action potential
  - Autorhythmic cells
    - Do not contract
    - Specialized for initiating and conducting action potentials responsible for contraction of working cells



Mechanical and Electrical

- Critical to remember that there is mechanical aspects to heart function=myofibrils and electrical aspect
  - Pacemaker cells and
  - Resulting AP from these cells to working muscle cells causes depolarization and repolarization





Conduction System of Heart

<u>Autorhythmic Cells</u>

Cells fire spontaneously, act as pacemaker and form conduction system for the heart

- SA node
  - cluster of cells in wall of Rt. Atria
  - begins heart activity that spreads to both atria
  - excitation spreads to AV node
- AV node
  - in atrial septum, transmits signal to bundle of His

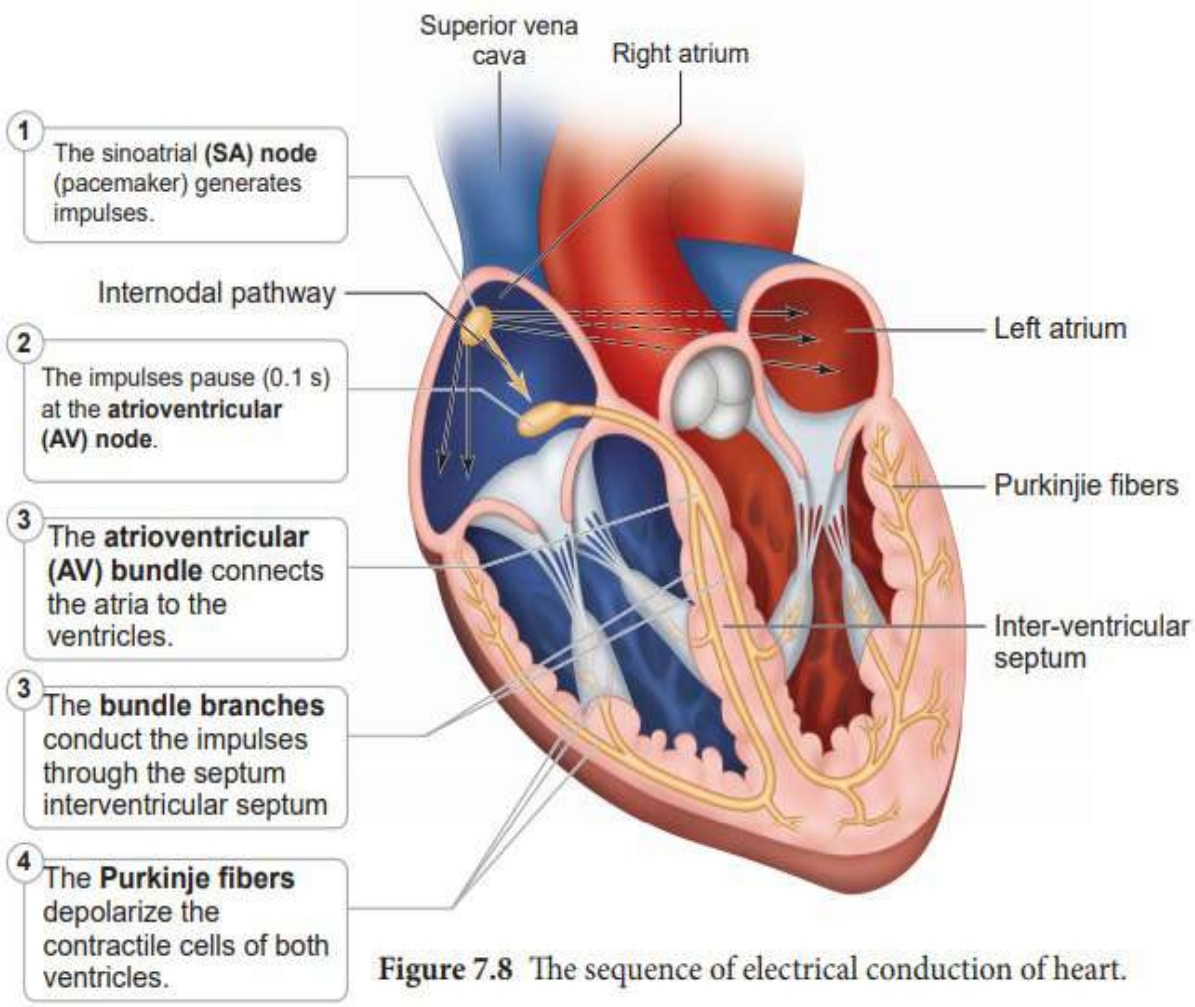


Figure 7.8 The sequence of electrical conduction of heart.

Conduction System of Heart

<u>Autorhythmic Cells</u>

Cells fire spontaneously, act as pacemaker and form conduction system for the heart

- AV bundle of His
  - the connection between atria and ventricles
- Bundle branches
  - To right and left side of heart along ventricular septum
- Purkinje fibers,
  - large diameter fibers that conduct signals quickly in ventricles

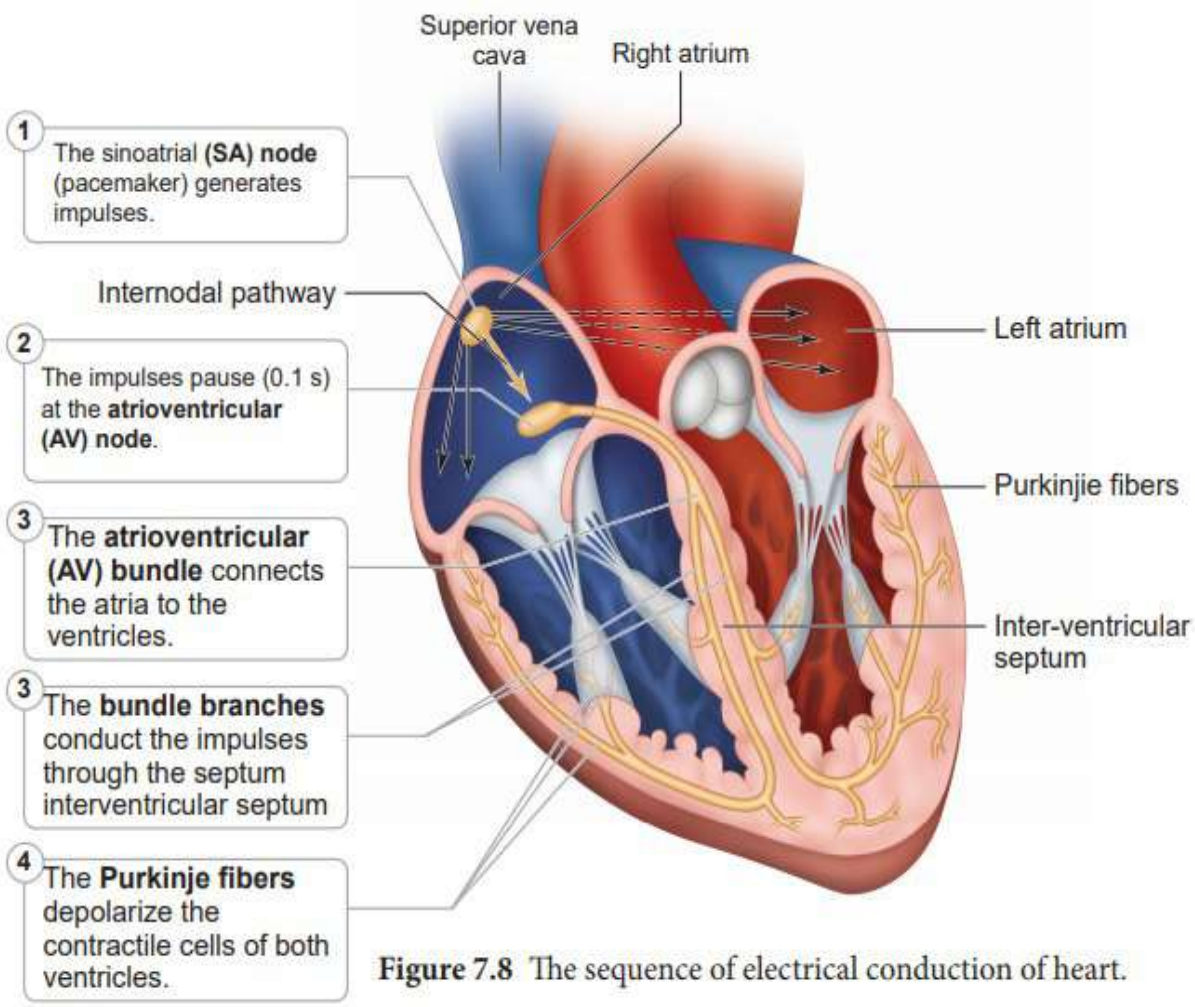
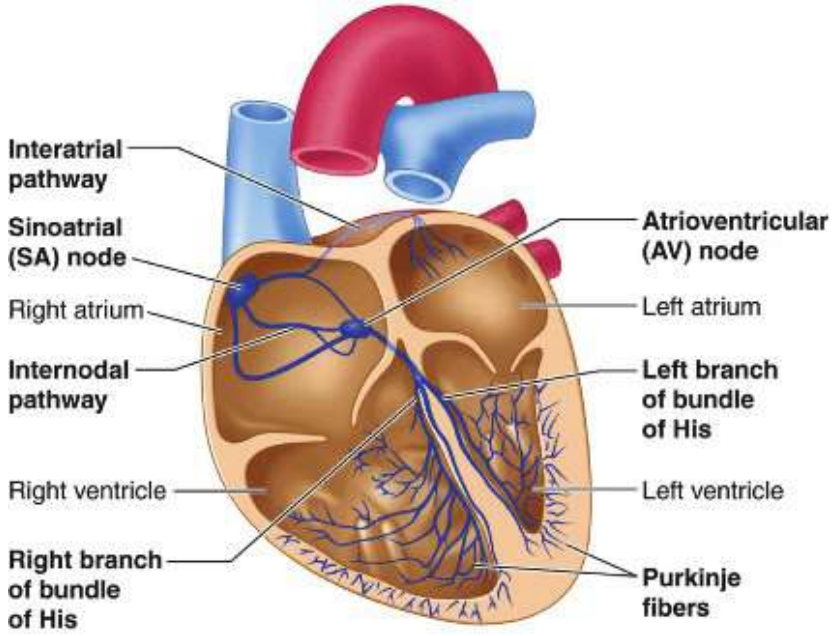


Figure 7.8 The sequence of electrical conduction of heart.

Rhythm of Conduction System

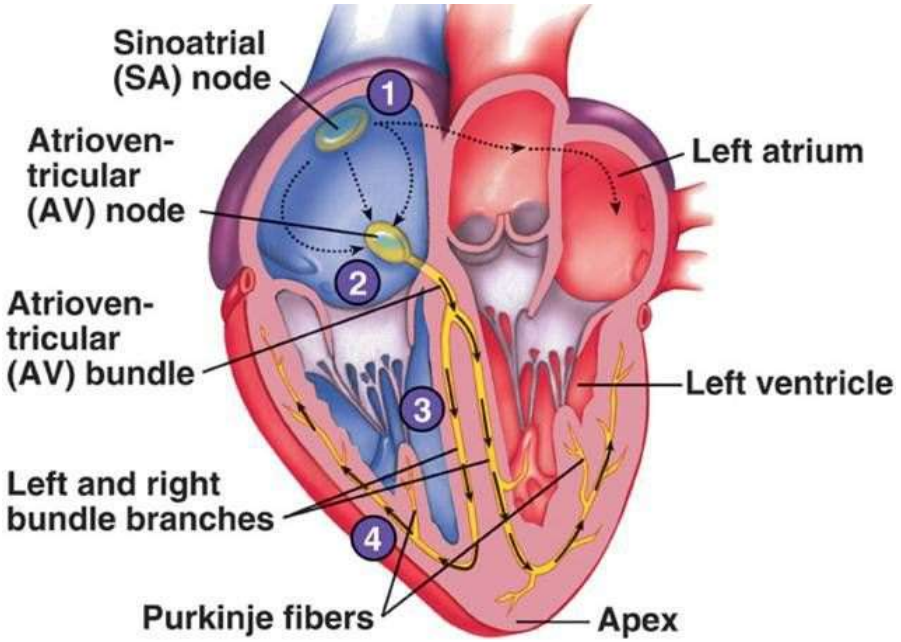
- SA node fires spontaneously 80-100 times per minute
- AV node fires at 40-60 times per minute
- If both nodes are suppressed fibers in ventricles by themselves fire only 20-40 times per minute
- Artificial pacemaker needed if pace is too slow
- Extra beats forming at other sites are called ectopic pacemakers
  - caffeine & nicotine increase activity



How does these cells automatically fire??

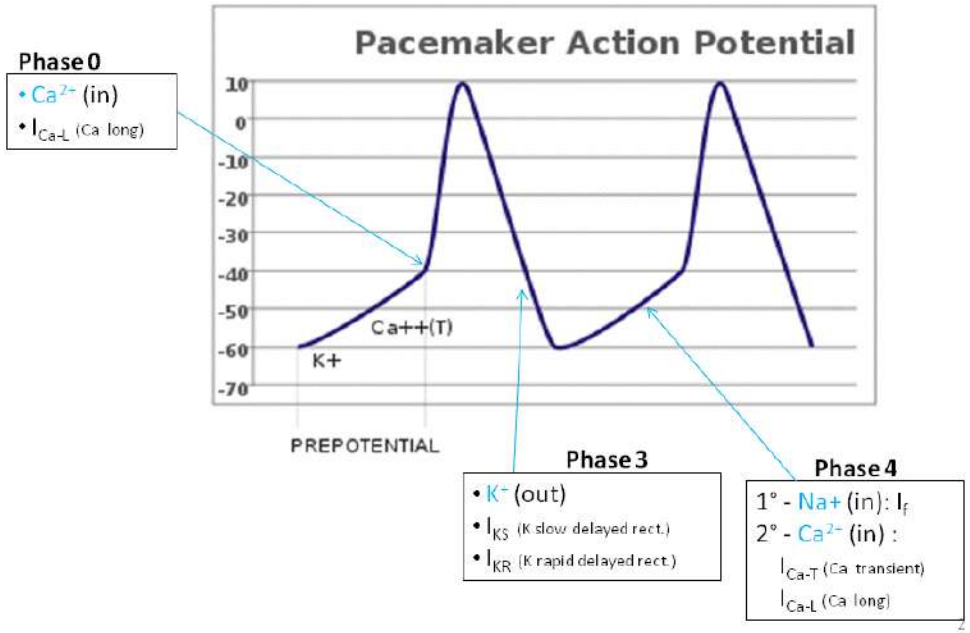
Timing of Atrial & Ventricular Excitation

- SA node setting pace since is the fastest
- In 50 msec excitation spreads through both atria and down to AV node
- 100 msec delay at AV node due to smaller diameter fibers- allows atria to fully contract filling ventricles before ventricles contract
- In 50 msec excitation spreads through both ventricles simultaneously



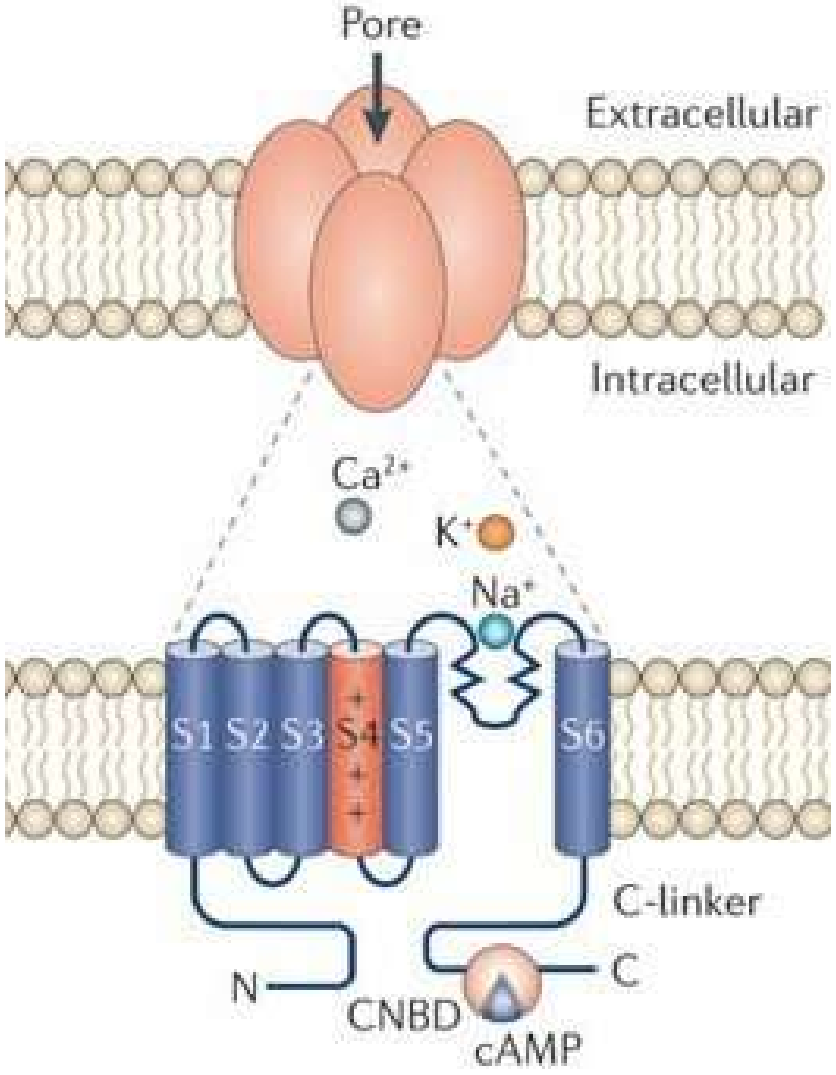
Pacemaker Potential

- The pacemaker potential occurs at the end of one action potential and just before the start of the next.
- It is the slow depolarization of the pacemaker cells e.g. cells of the sinoatrial node, towards threshold.
- This is sometimes referred to as the ‘funny’ current, or I_f.



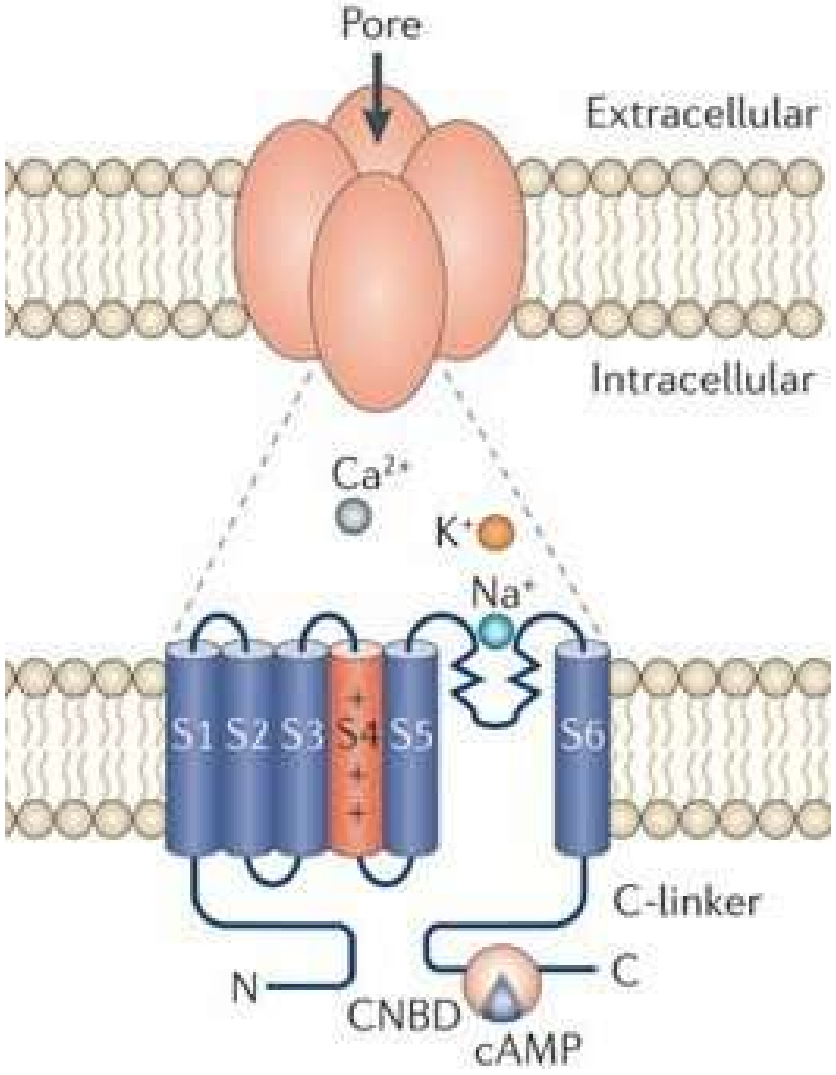
Pacemaker Potential

- The pacemaker potential is achieved by activation of HCN channels (hyperpolarization activated cyclic nucleotide gated channels).
- Hyperpolarization-activated cyclic nucleotide–gated (HCN) channels are integral membrane proteins that serve as nonselective voltage-gated cation channels in the plasma membranes of heart and brain cells.
- HCN channels are sometimes referred to as pacemaker channels because they help to generate rhythmic activity within groups of heart and brain cells



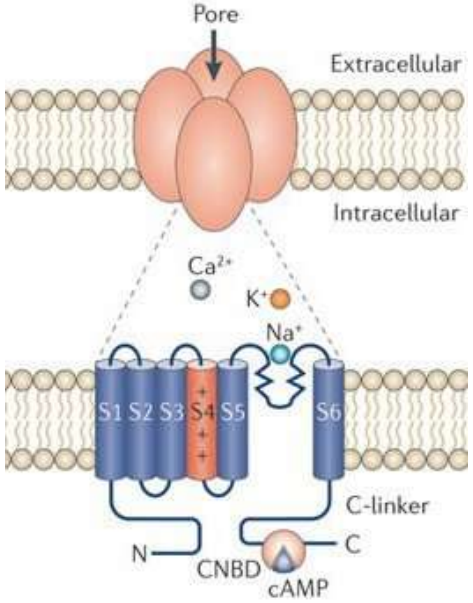
Pacemaker Potential

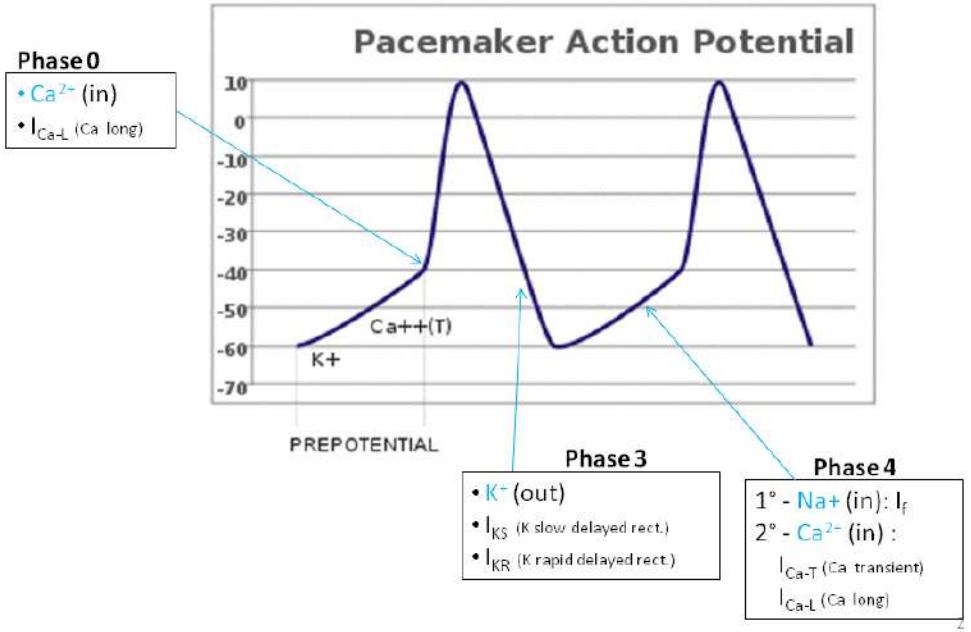
- These allow Na+ entry into the cells, enabling slow depolarization.
- These channels are activated at membrane potentials which are more negative than -50mV.
- Once the membrane potential has reached the threshold, an action potential can be fired.



SA Node Action Potential

- Once the HCN channels have brought the membrane potential to around -40mV, voltage gated calcium channels open.
- This allows an influx of Ca2+ which produces a faster rate of depolarization to reach a positive membrane potential (responsible for the upstroke of the action potential).
- HCN channels start to inactivate.
- At the peak of the action potential, Ca2+ channels inactivate, and K+ channels open.



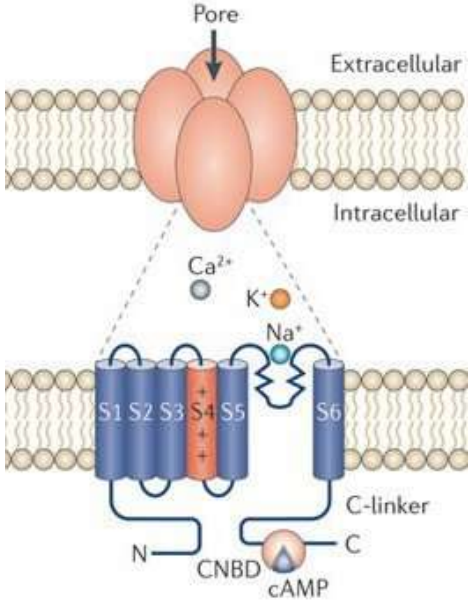


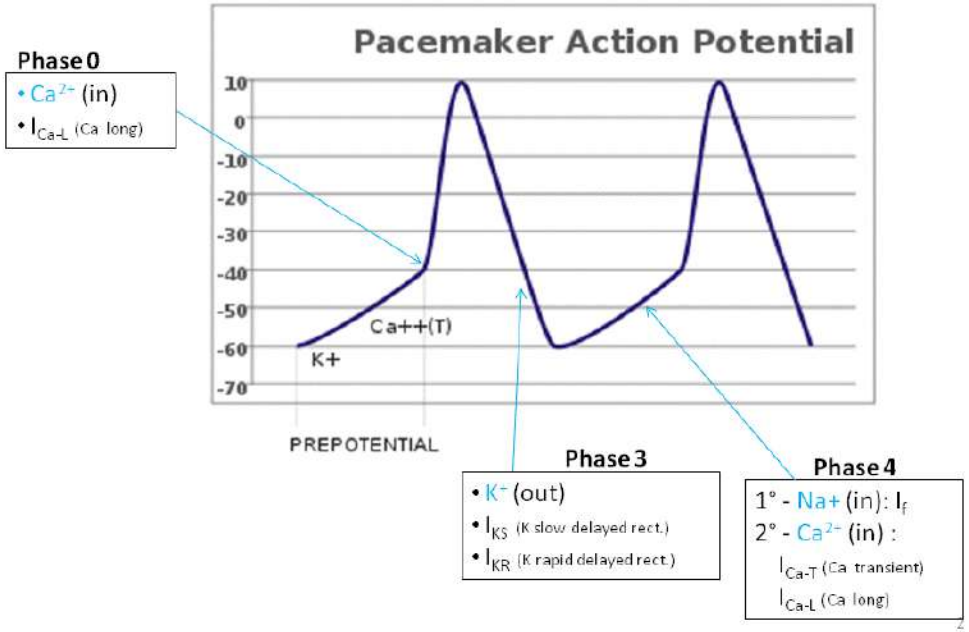
SA Node Action Potential

- This allows an efflux of K+ ions out of the cells. The membrane repolarizes and this is seen as the downstroke of the action potential.

- Unlike the ventricular action potential, the opening of Ca2+ channels is not sustained, and there is no ‘plateau’ stage, hence the action potential is triangular in shape.

- After the action potential, repolarization must occur and the membrane potential must reach negative values in order for the HCN channels to get reactivated again, enabling another action potential to be generated.

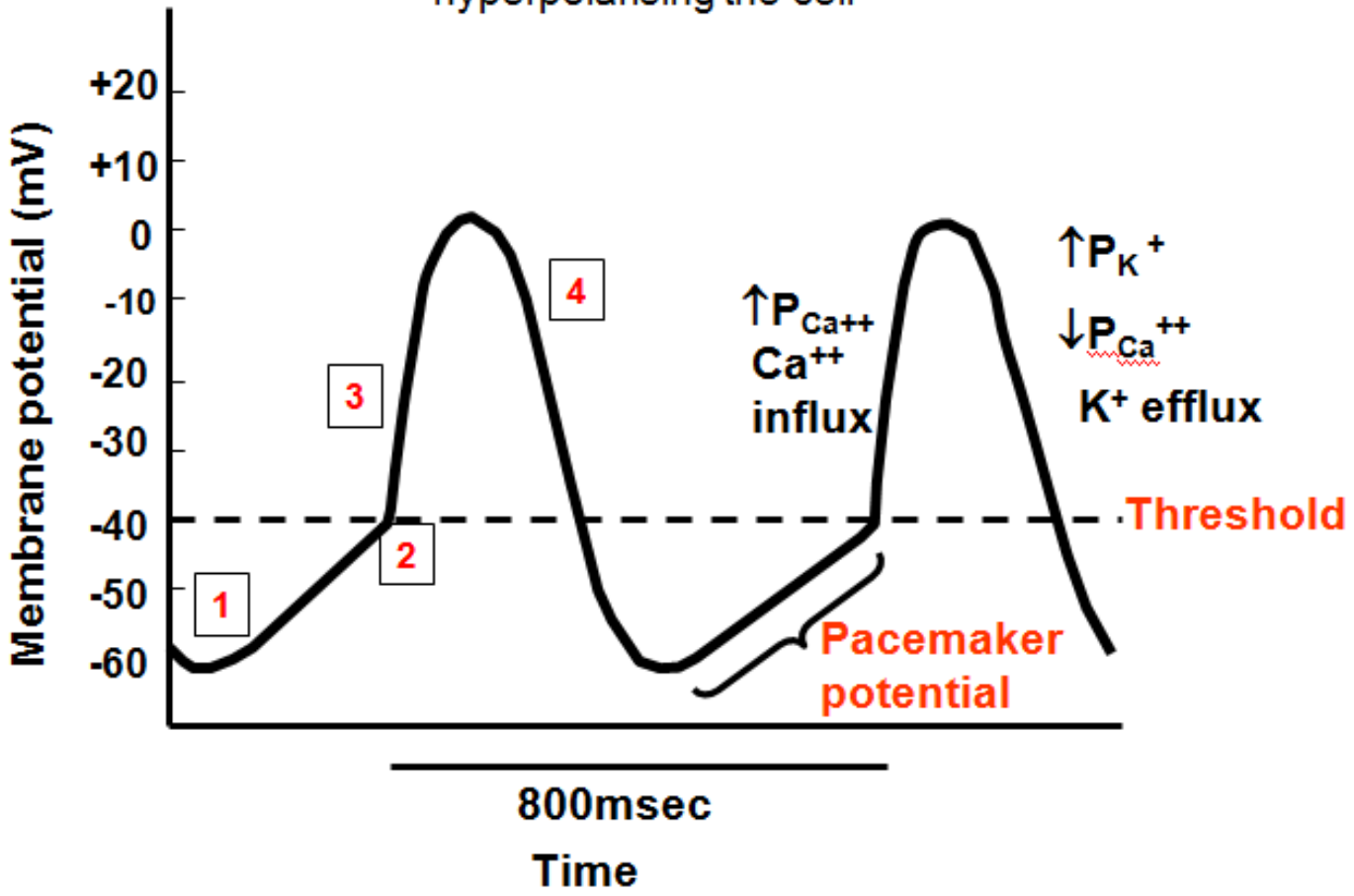




SA Node Action Potential

- "Funny" currents (phase 4); slow Na channels that initiate spontaneous depolarization
- No fast sodium channels
- Calcium channels (slow)
  - Long-lasting, L-type
  - Transient, T-type
- Potassium channels

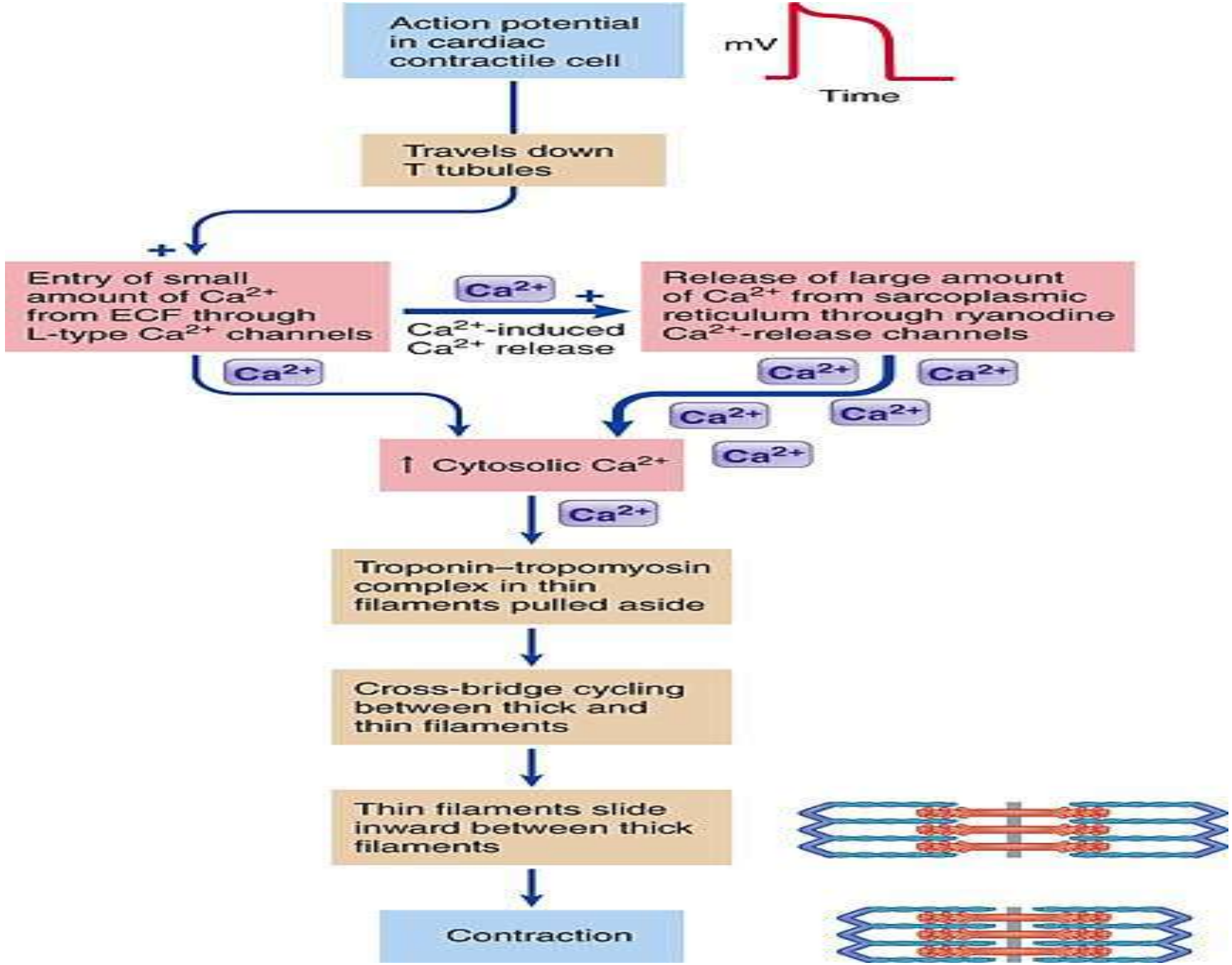
1. 'Funny' sodium channels (I_f channels) are open ($\uparrow P_{Na}^{+}$); and closing K^+ channels.
2. Transient Ca^{2+} (T-type) channels open, pushing the membrane potential to threshold.
3. Long-lasting Ca^{2+} (L-type) channels open, giving rise to the action potential.
4. Opening of K^+ channels, ($\uparrow P_{K}^{+}$), and closing of Ca^{2+} (L-type) channels, hyperpolarising the cell



Electrical Activity of Heart

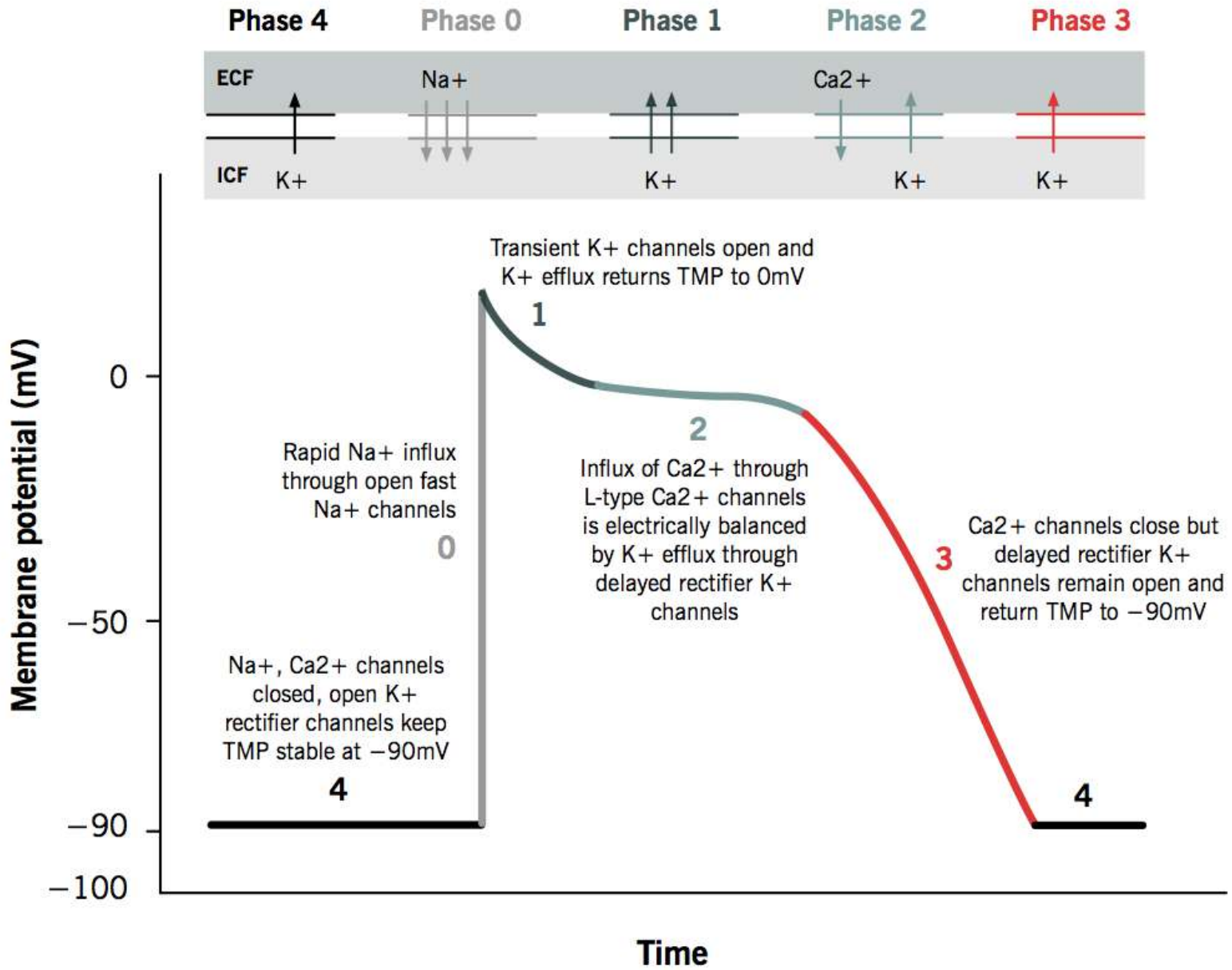
- Ca^{2+} entry through L-type channels in T tubules triggers larger release of Ca^{2+} from sarcoplasmic reticulum
  - Ca^{2+} induced Ca^{2+} release leads to cross-bridge cycling and contraction

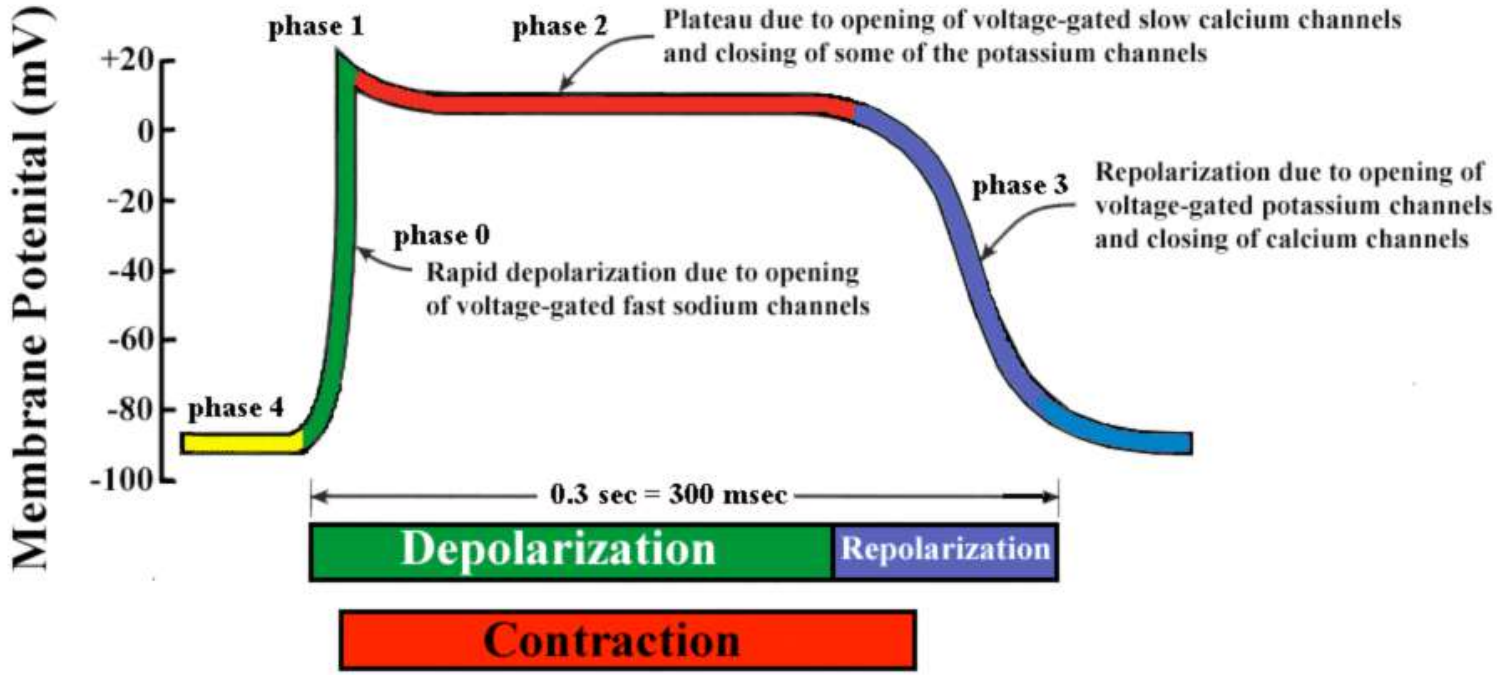
Excitation-Contraction Coupling in Cardiac Contractile Cells

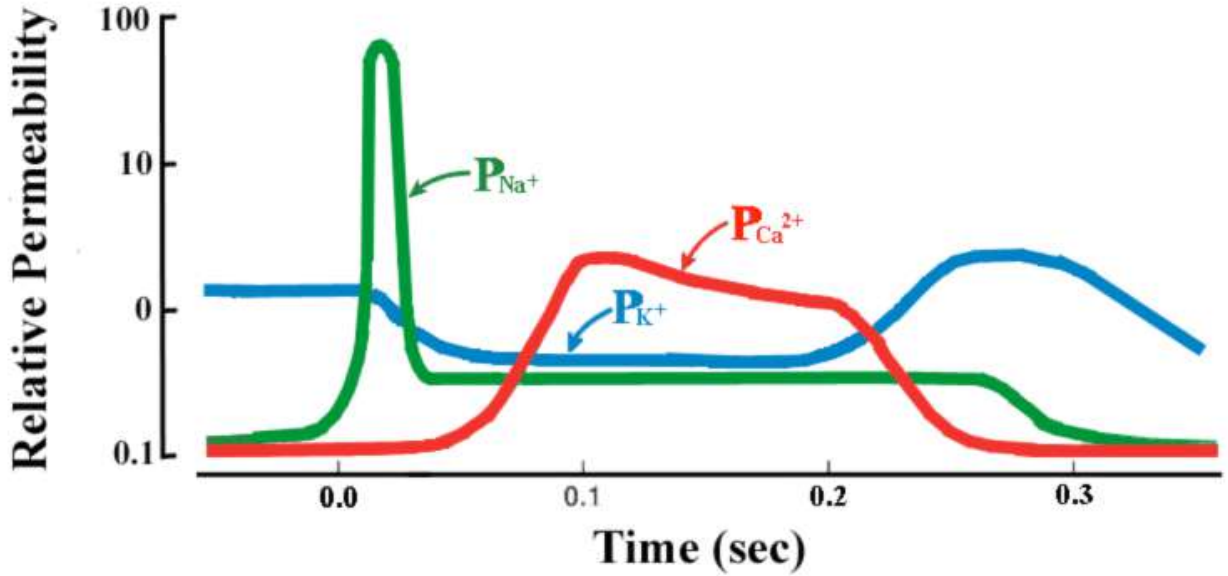


Action potential of cardiac muscles

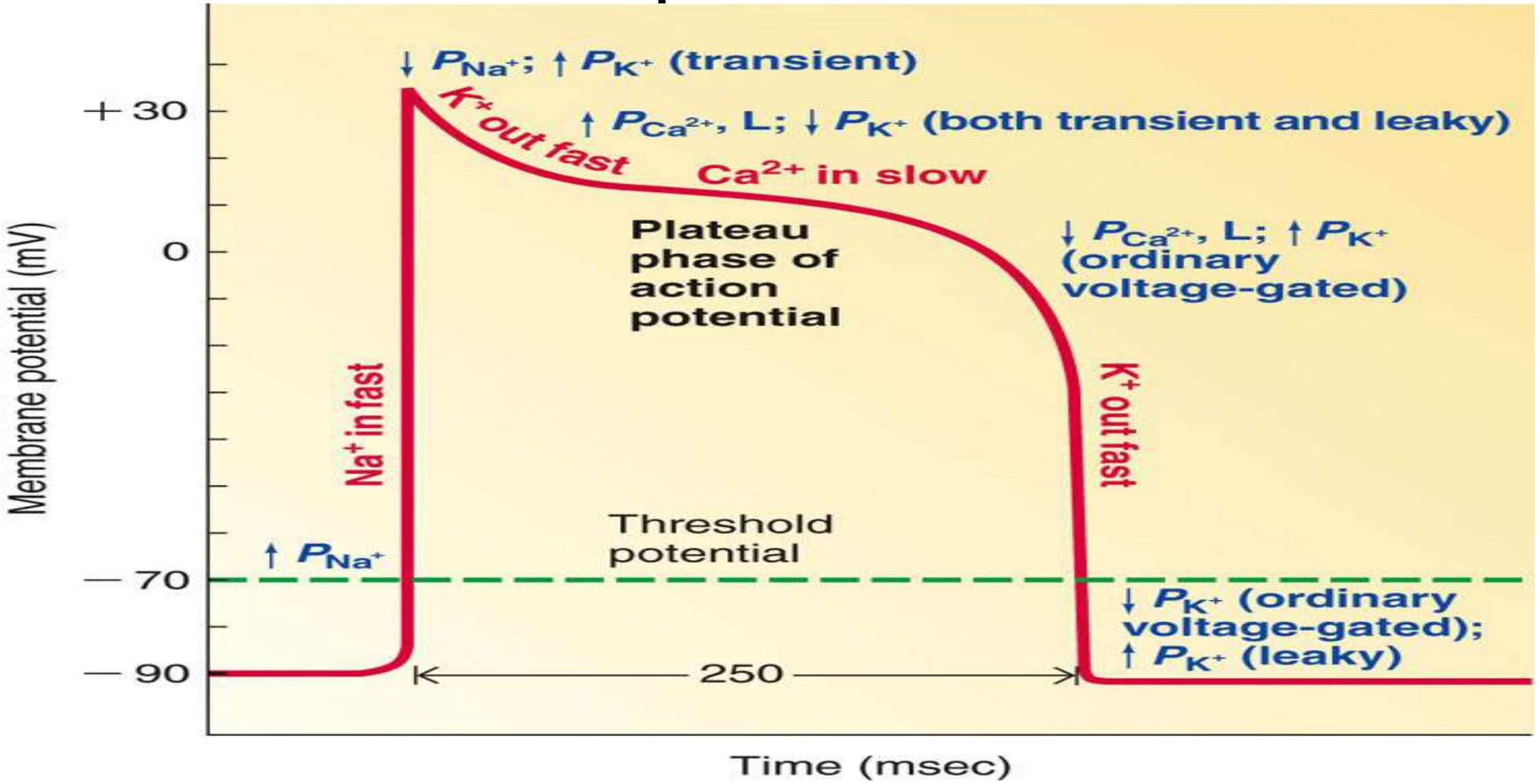
Grigoriy Ikonnikov and Eric Wong




Membrane Potenital (mV)
+20
0
-20
-40
-60
-80
-100
phase 1
phase 2
Plateau due to opening of voltage-gated slow calcium channels
and closing of some of the potassium channels
phase 3
Repolarization due to opening of
voltage-gated potassium channels
and closing of calcium channels
phase 0
Rapid depolarization due to opening
of voltage-gated fast sodium channels
phase 4
0.3 sec = 300 msec
Depolarization
Repolarization
Contraction

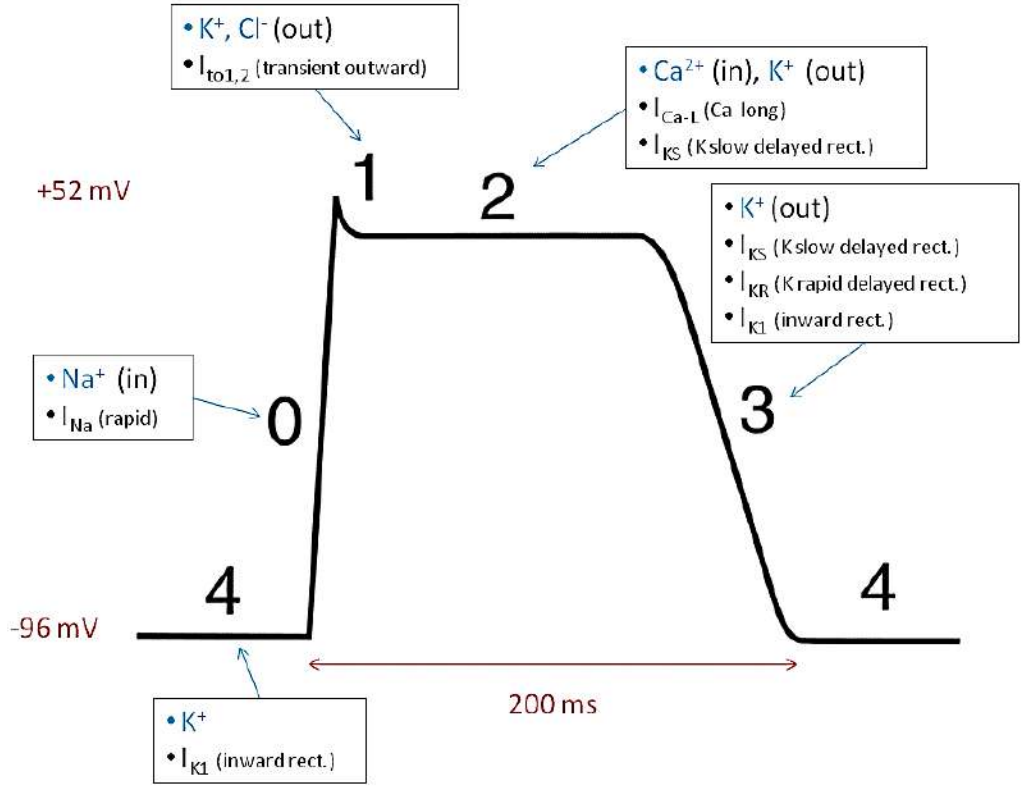

Relative Permeability
100
10
0
0.1
P_{Na^+}
$P_{Ca^{2+}}$
P_{K^+}
0.0
0.1
0.2
0.3
Time (sec)

Ventricular action potential



APs in Contractile Myocardial C

- Similar to skeletal muscle
- Phase 4: Stable resting pot. ~ -90 mV



- Phase 0: Depolarization due to voltage
  movement?)
- Phase 1: Partial Repolarization as Na^+ channels close and voltage-gated K^+ channels open (K^+ movement?)
- Phase 2: Plateau: K^+ permeability and Ca^{2+} permeability
- Phase 3: Repolarization: Back to resting potential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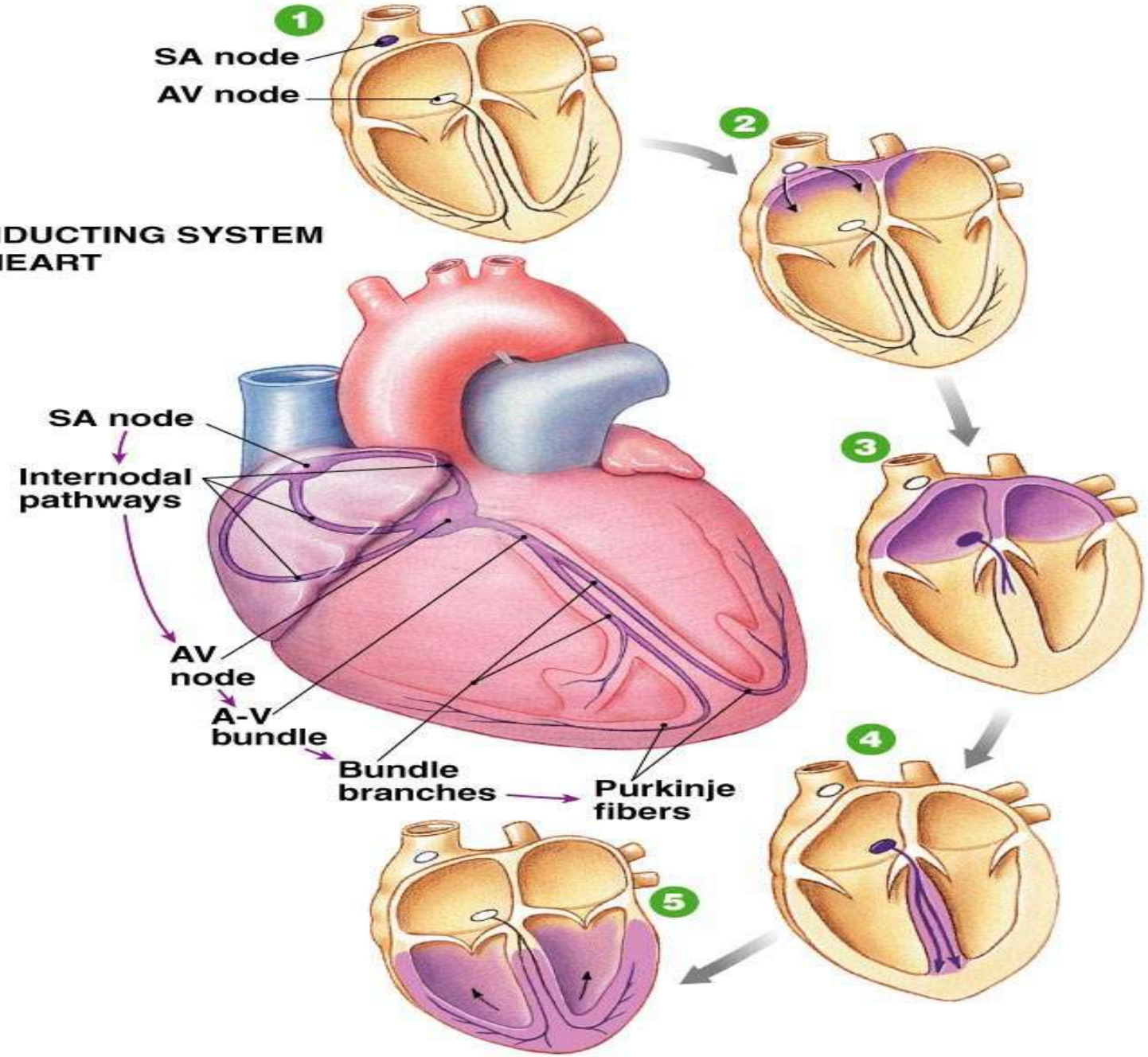
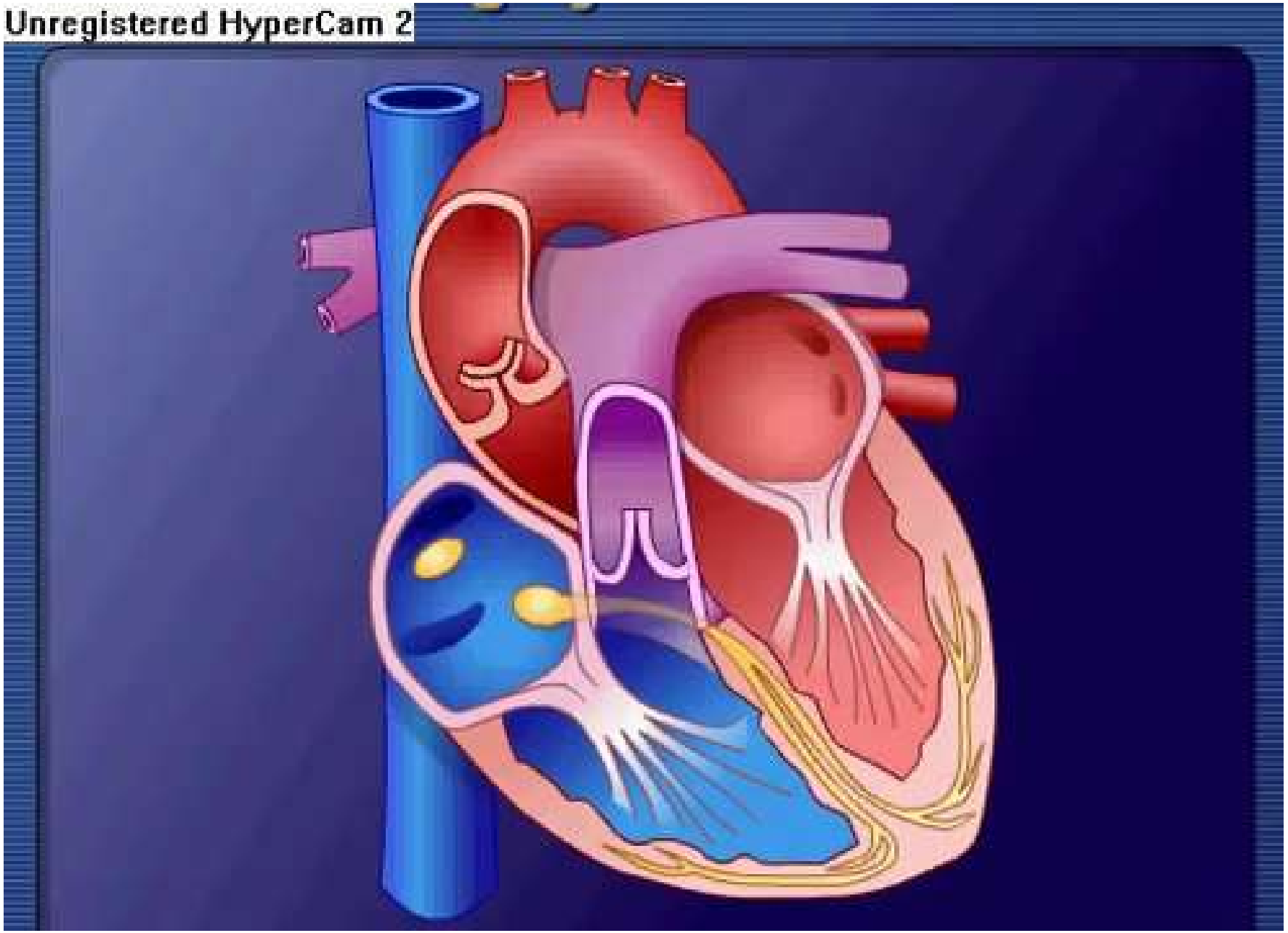
THE CONDUCTING SYSTEM OF THE HEART



1. SA node depolarizes.
2. Electrical activity goes rapidly to AV node via internodal pathways.
3. Depolarization spreads more slowly across atria. Conduction slows through AV node.
4. Depolarization moves rapidly through ventricula conducting system to the apex of the heart.
5. Depolarization wave spreads upward from the apex.

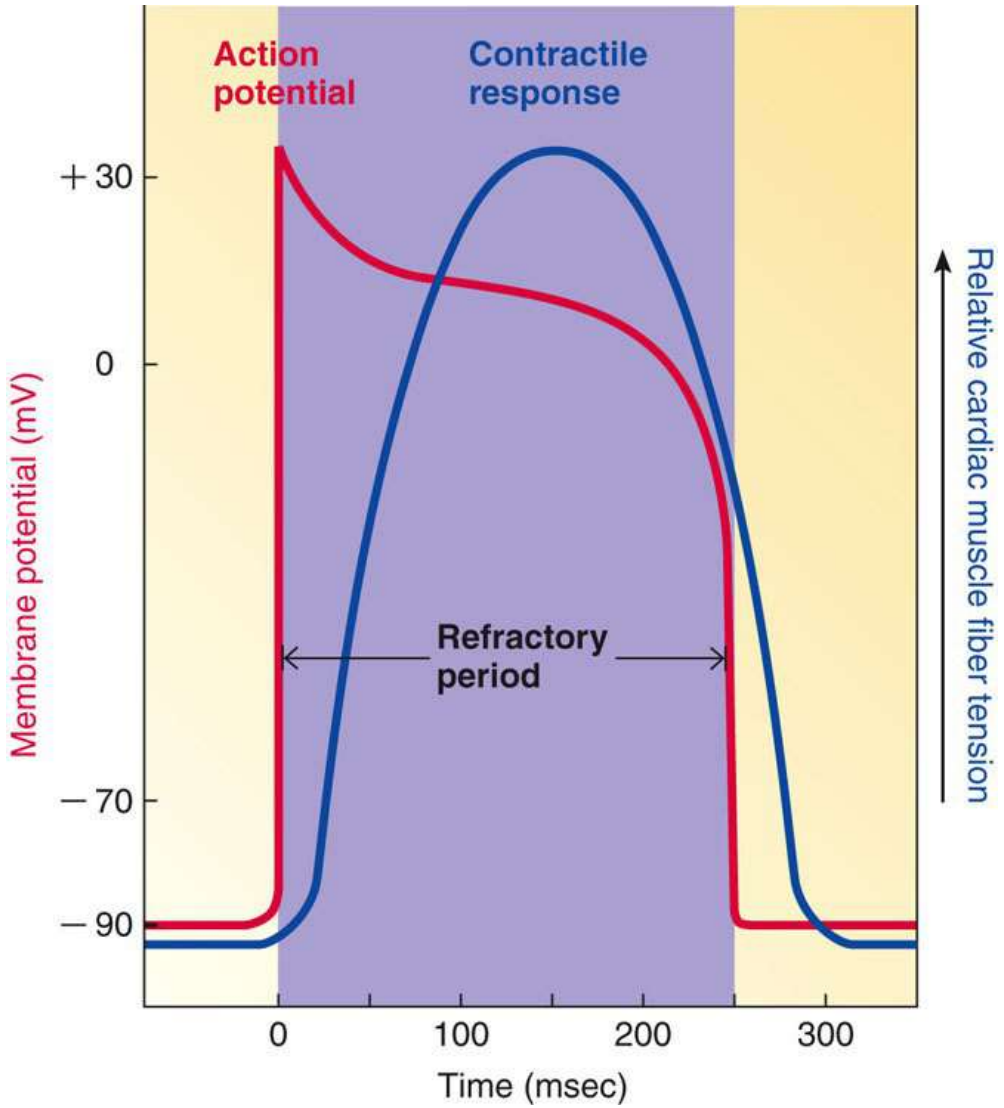
video



Electrical Activity of Heart

- Because long refractory period occurs in conjunction with prolonged plateau phase, summation and tetanus of cardiac muscle is impossible
  - Ensures alternate periods of contraction and relaxation which are essential for pumping blood

Relationship of an Action Potential and the Refractory Period to the Duration of the Contractile Response in Cardiac Muscle



Aging and Muscular Tissue

- Aging
  - Brings a progressive loss of skeletal muscle mass
  - A decrease in maximal strength
  - A slowing of muscle reflexes
  - A loss of flexibility

- With aging, the relative number of slow oxidative fibers appears to increase
- Aerobic activities and strength training can slow the decline in muscular performance

Comparisons Among Skeletal, Smooth, and Cardiac Muscle

Property	Skeletal	Smooth (single-unit)	Smooth (multi-unit)	Cardiac
Striations (sarcomeres)	Yes	No	No	Yes
Actin and myosin	Yes	Yes	Yes	Yes
Level of control	Voluntary	Involuntary	Involuntary	Involuntary
Neural input	Somatic	Autonomic	Autonomic	Autonomic
Neuroeffector junction	Neuromuscular junction—specific	Varicosities—diffuse	Varicosities—diffuse	Varicosities—diffuse
Hormonal control	None	Several, depending on location	Several, depending on location	Epinephrine
Source of calcium	SR	SR and ECF	SR and ECF	SR and ECF
Regulatory protein that binds calcium	Troponin	Calmodulin	Calmodulin	Troponin
Gap junctions	No	Yes	No (or few)	Yes
Pacemaker activity	No	Yes	No	Yes
Myosin ATPase activity	Fastest	Slowest	Slowest	Intermediate
Recruitment	Yes	No	Yes	No

End

Cardiovascular System

Cardiovascular Physiology

Cardiovascular Physiology

concepts:

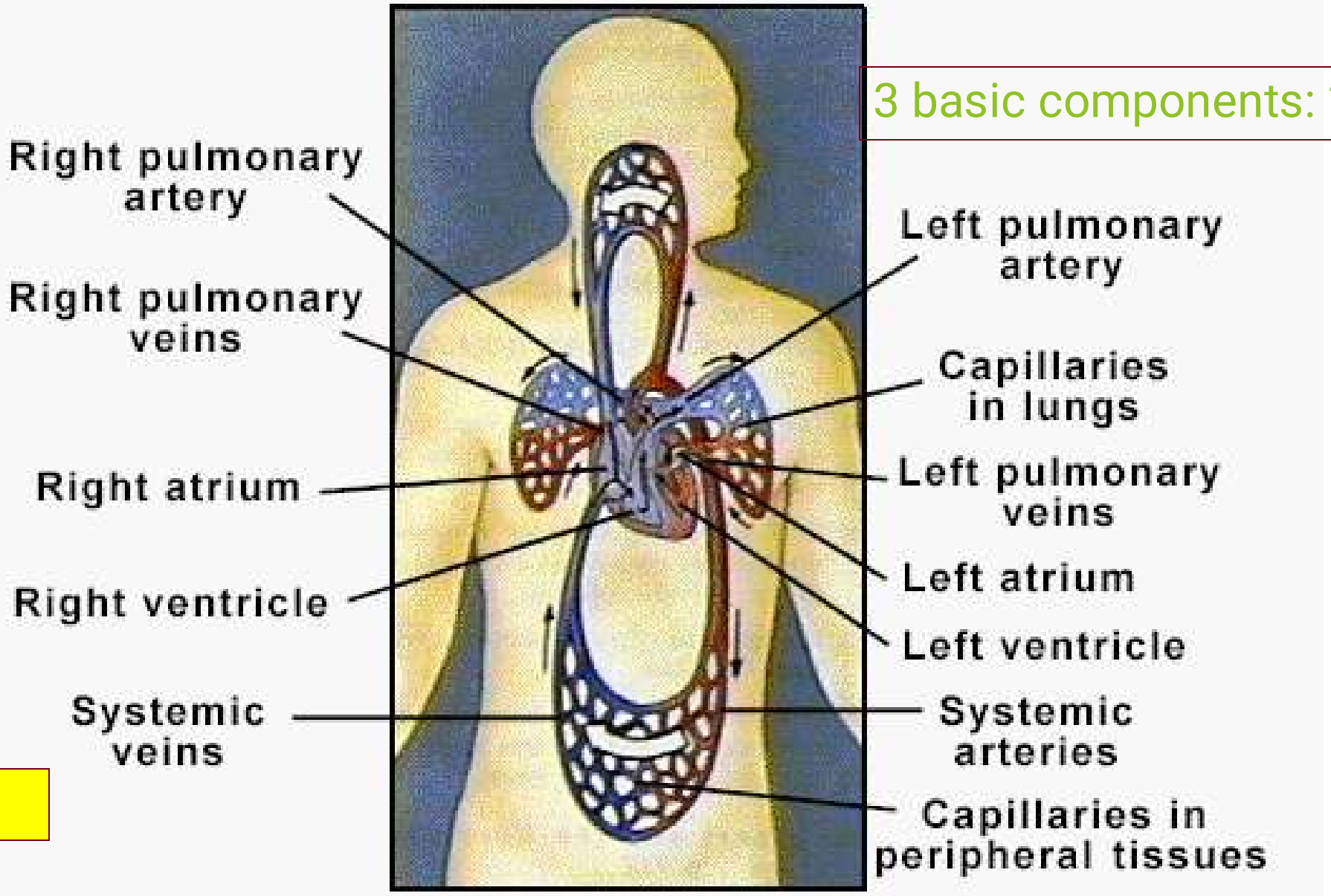
- Fluid flow
- APs in contractile & autorhythmic cells
- Cardiac cycle (elec. & mech. events)
- HR regulation
- Stroke volume & cardiac output
- ECG

Overview of Cardiovascular System

Focus:

The cardiovascular system is built to rapidly transport blood to every living cell in the body.

The heart is a dual pump!



3 basic components: ?

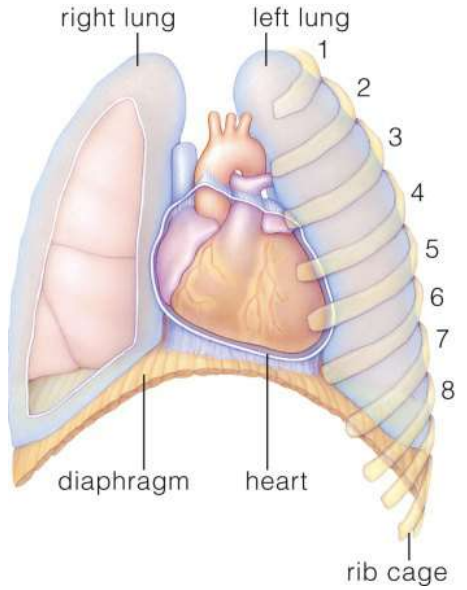
Introduction

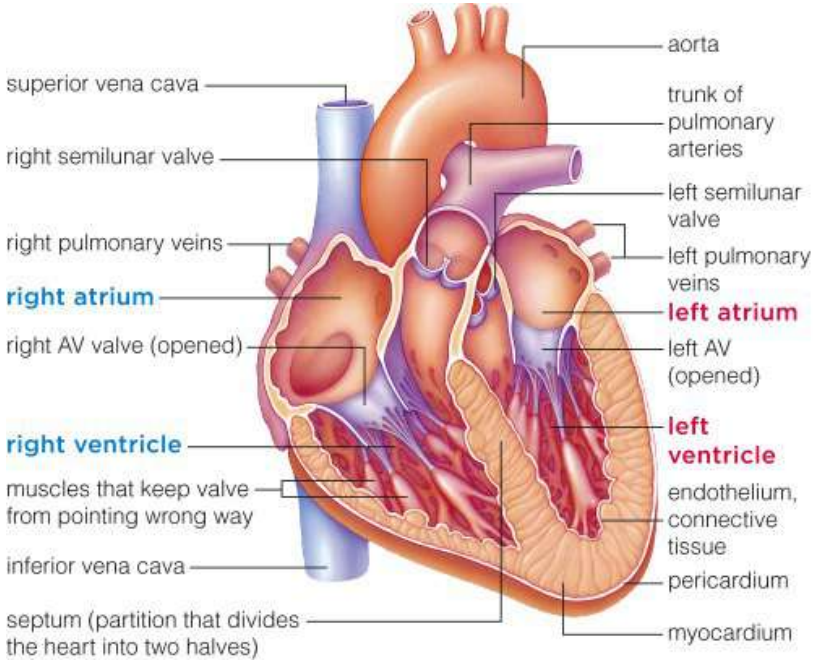
- The cardiovascular system consists of:
  - The heart; main pumping organ,
  - Blood vessels types; arteries, Arterioles, capillaries and veins, Venioles
  - Blood

- A functional cardiovascular system is vital for supplying oxygen and nutrients to tissues and removing wastes from them.

Heart

- Structure of the Heart
  - The heart is a hollow, cone-shaped, muscular pump within the thoracic cavity.
  - The average adult heart is 14 cm long and 9 cm wide.
  - The heart lies in the mediastinum under the sternum; its apex extends to the fifth intercostal space.





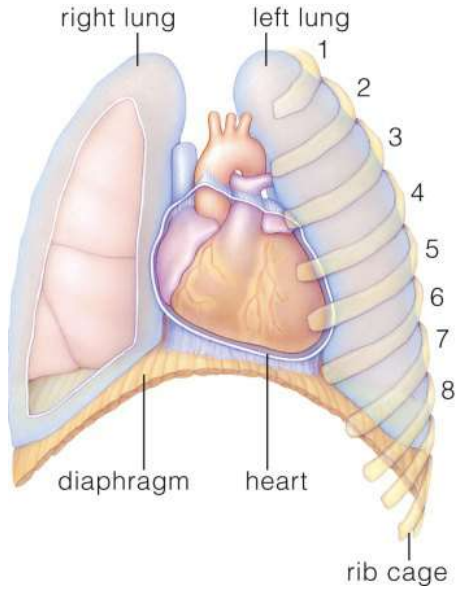
Heart

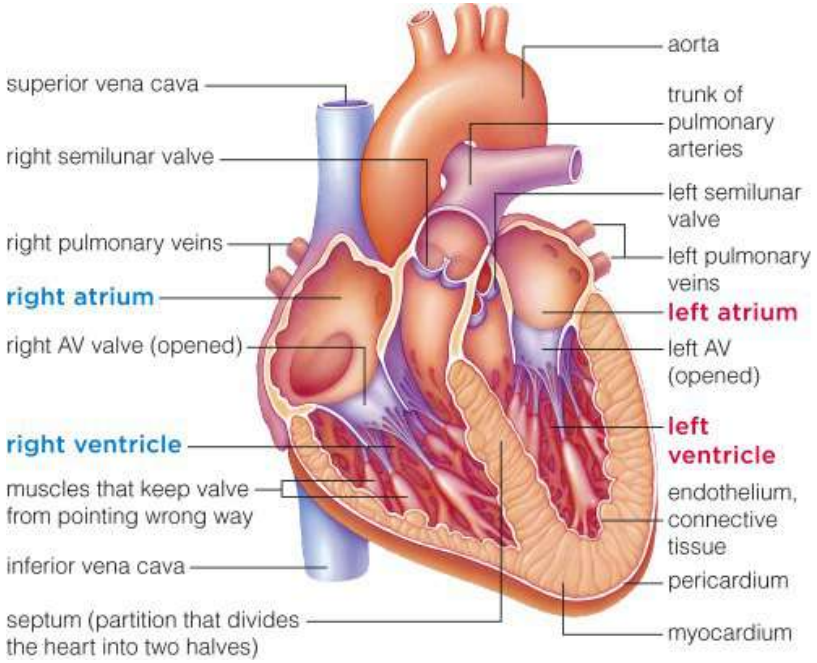
- Heart; A Double Pump

Focus:

√ In a lifetime of 70 years, the human heart beats some 2.5 billion times.

√ This durable pump is the centerpiece of the cardiovascular system.



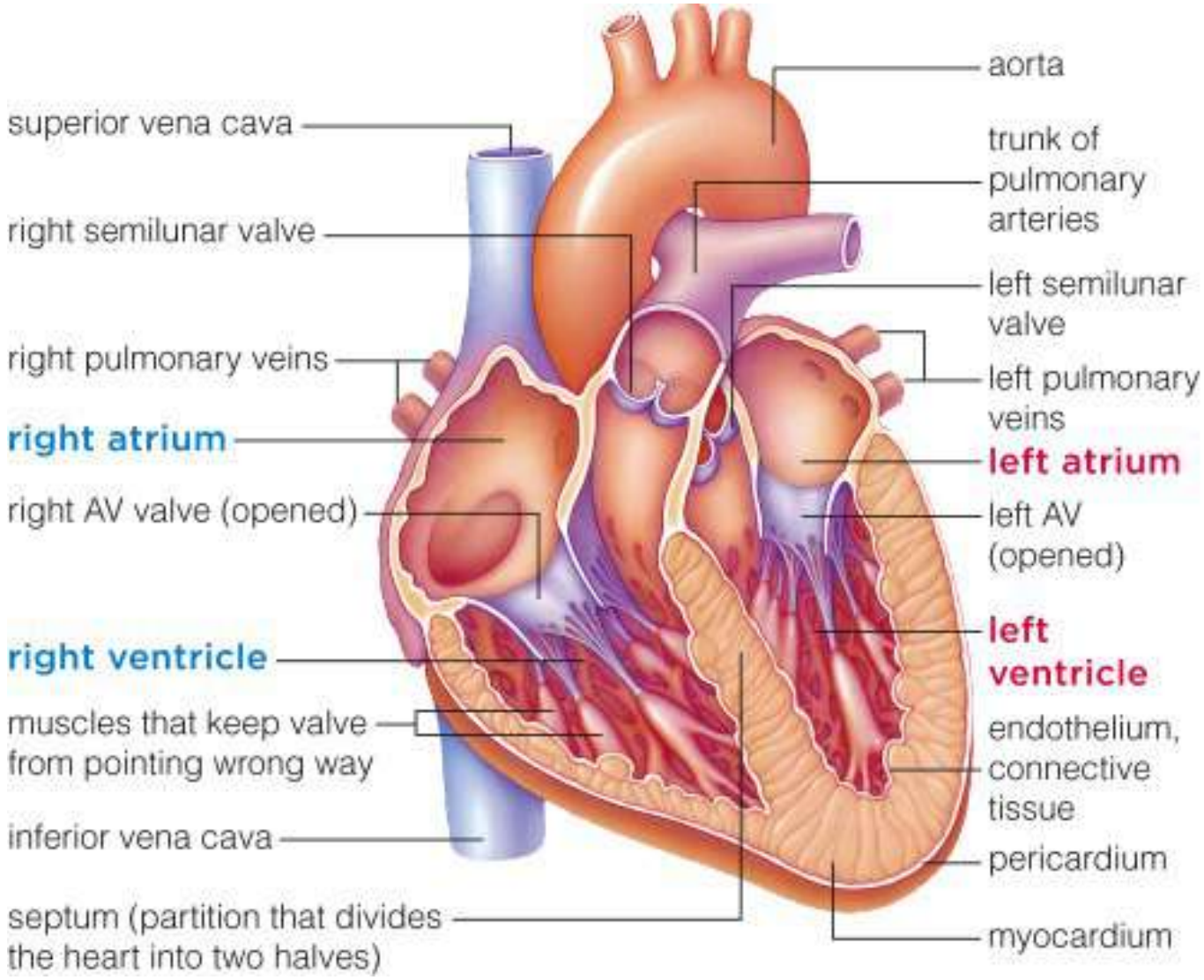


Heart

The Heart Has Two Halves and Four Chambers

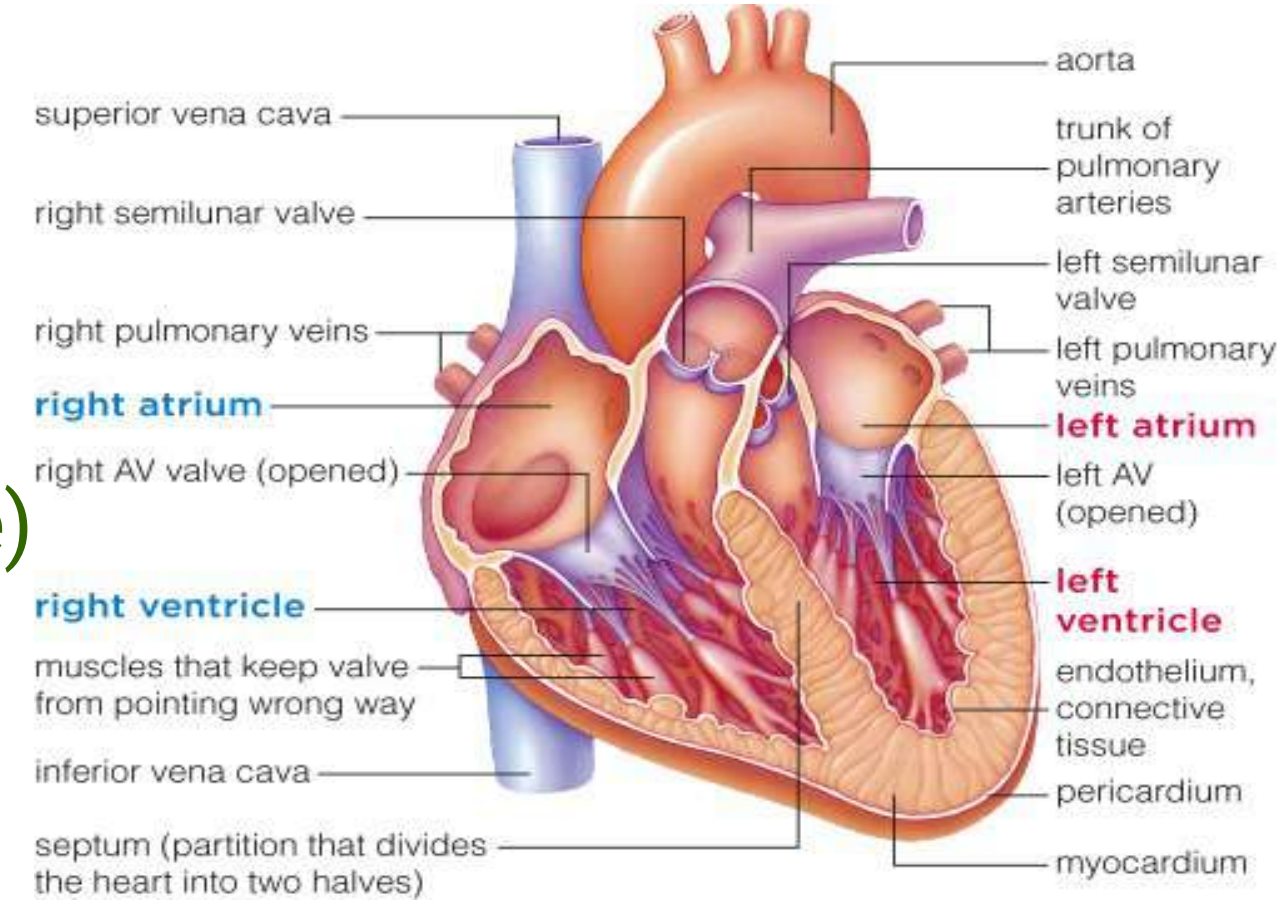
- Septum: thick wall divides heart in half

- Chambers of the heart:
  - Left and Right Atrium
  - Left and Right Ventricle



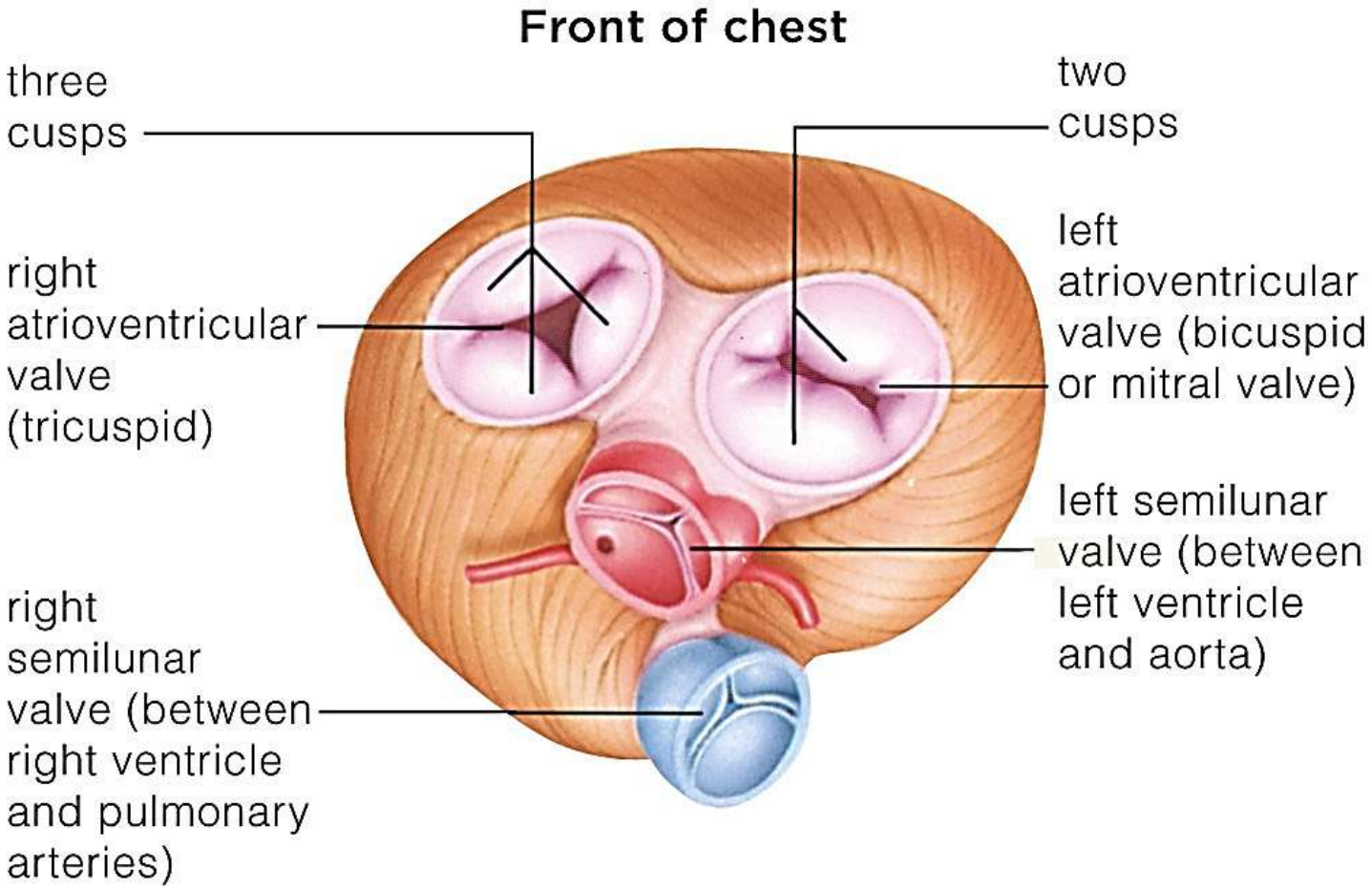
Heart

- Valves:
  - Atrioventricular:
    - Tricuspid (right side) and
    - bicuspid (left side)



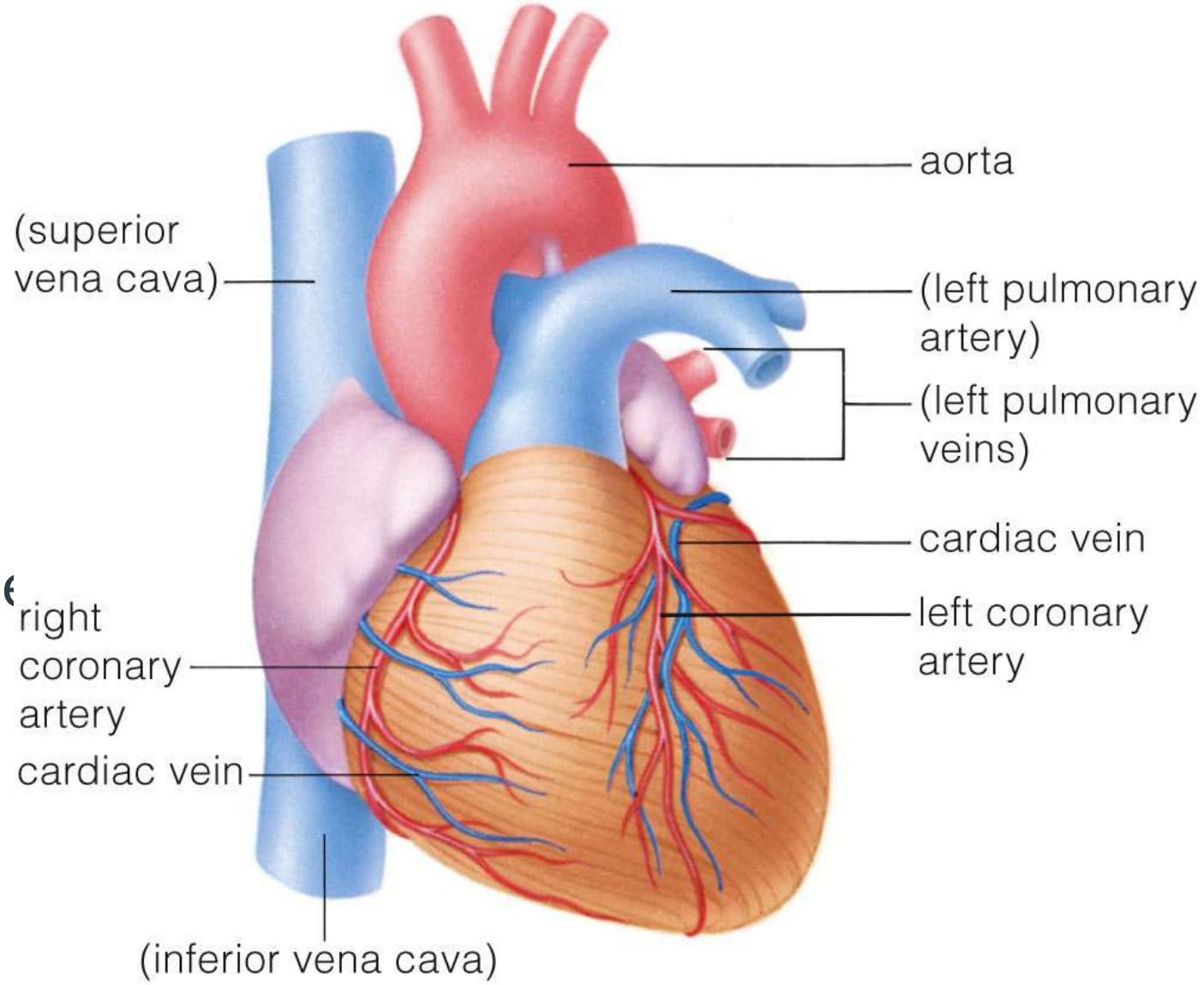
Heart

- Valves:
  - Semilunar
  - Right semilunar valve
  - Left semilunar valve



Heart

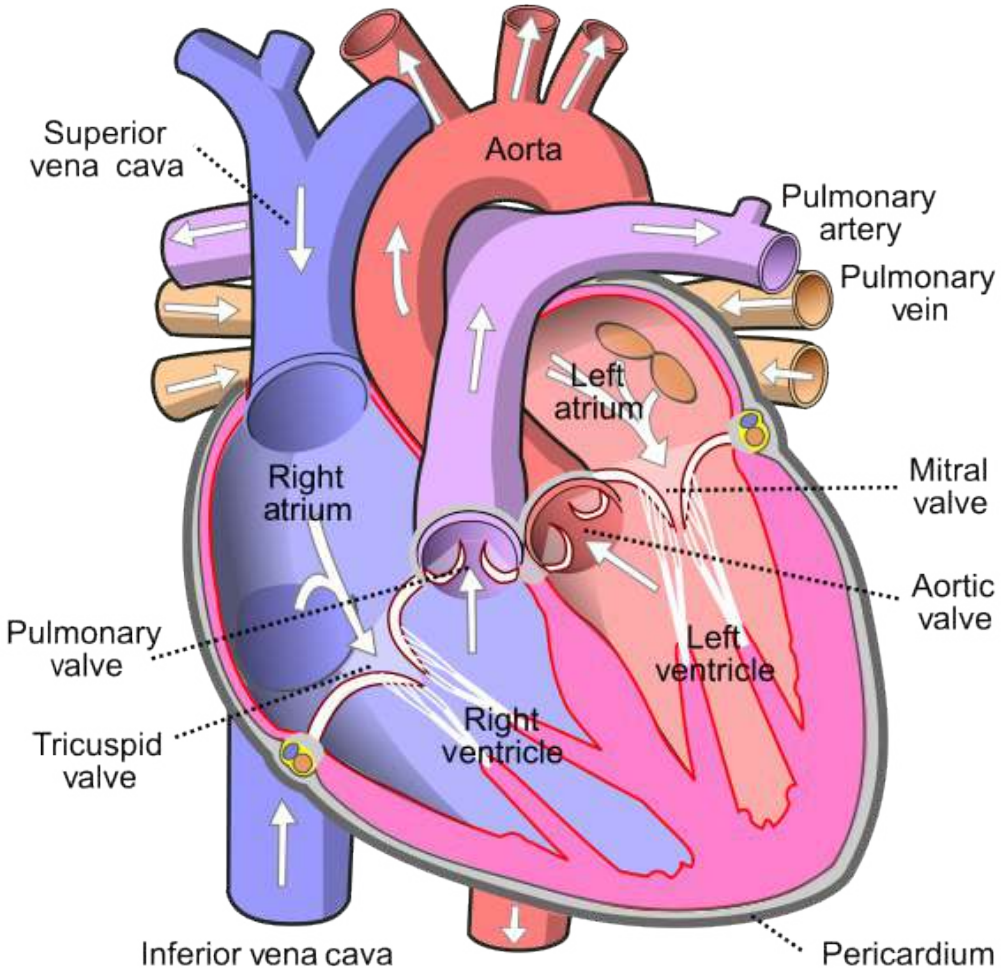
- Coronary arteries:
- branch off of the aorta
- Delivers blood & oxygen to the heart



Path of Blood through the Heart

- Blood low in oxygen returns to the right atrium via the venae cavae and coronary sinus.

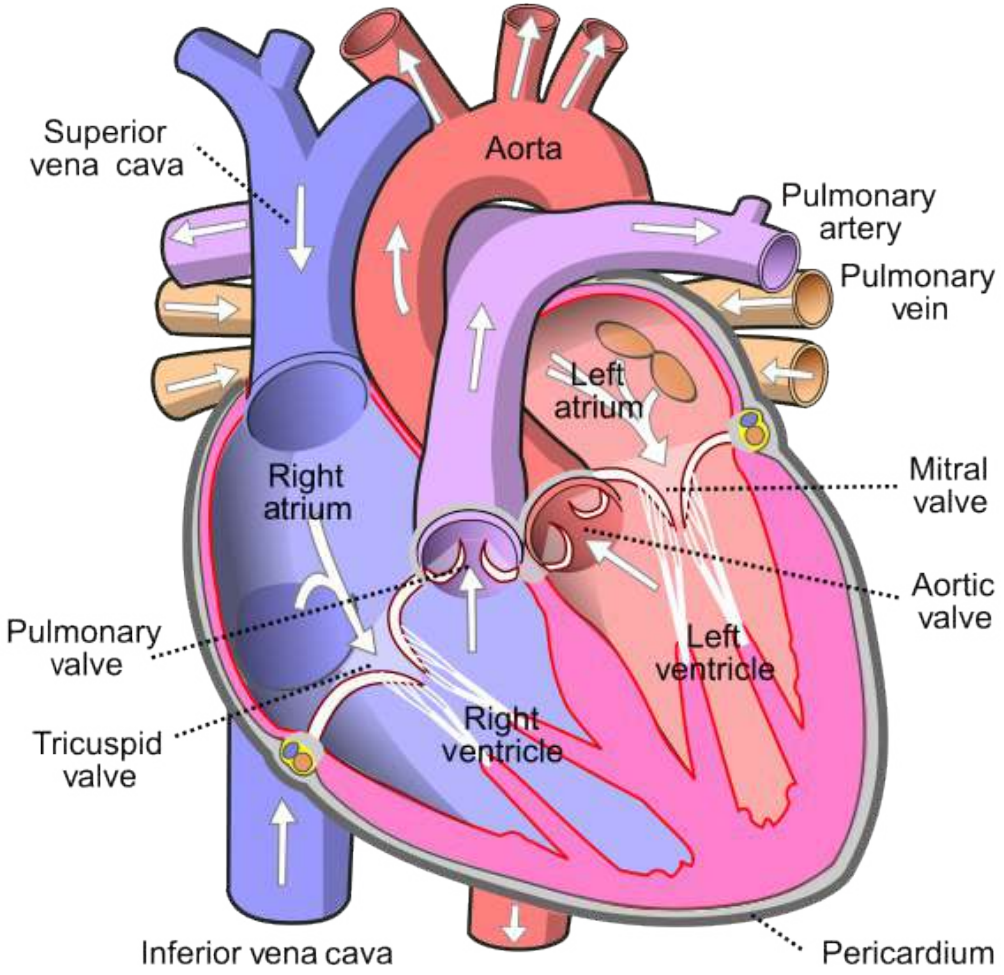
- The right atrium contracts, forcing blood through the tricuspid valve into the right ventricle.



Path of Blood through the Heart

- The right ventricle contracts, closing the tricuspid valve, and forcing blood through the pulmonary valve into the pulmonary trunk and arteries.

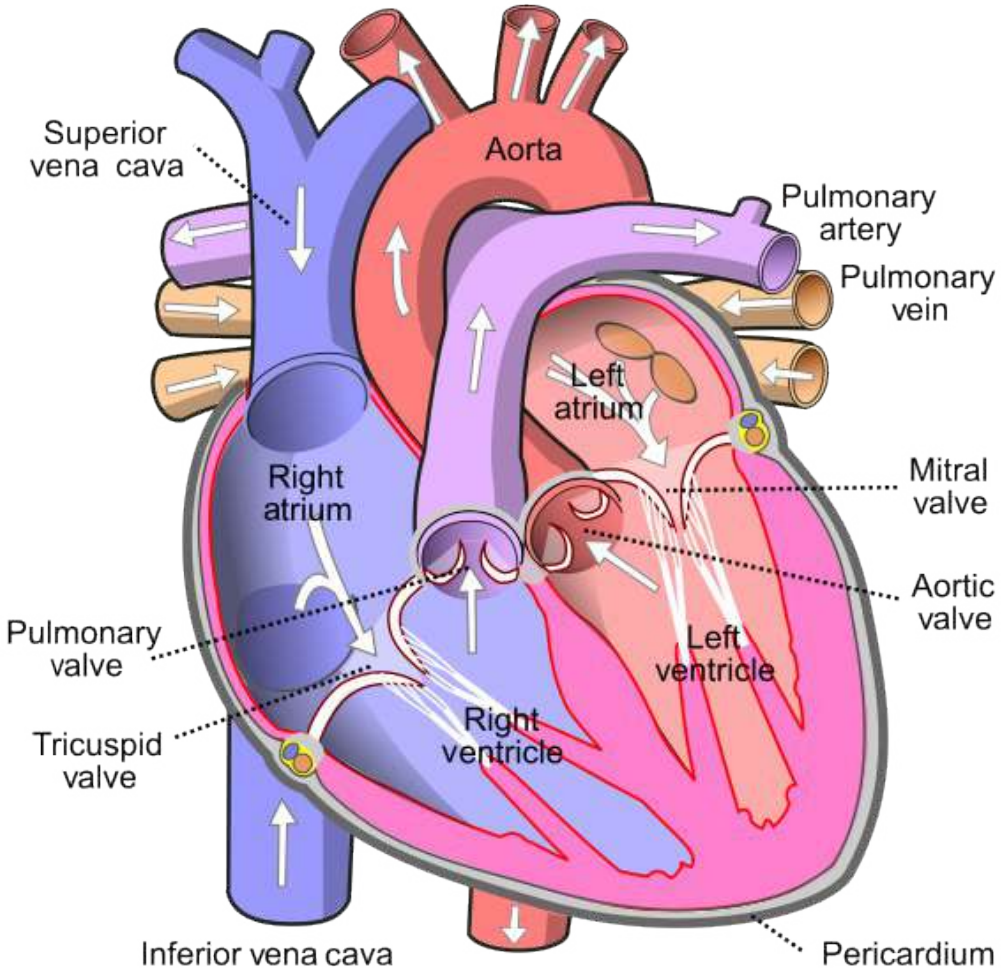
- The pulmonary arteries carry blood to the lungs where it can rid itself of excess carbon dioxide and pick up a new supply of oxygen.



Path of Blood through the Heart

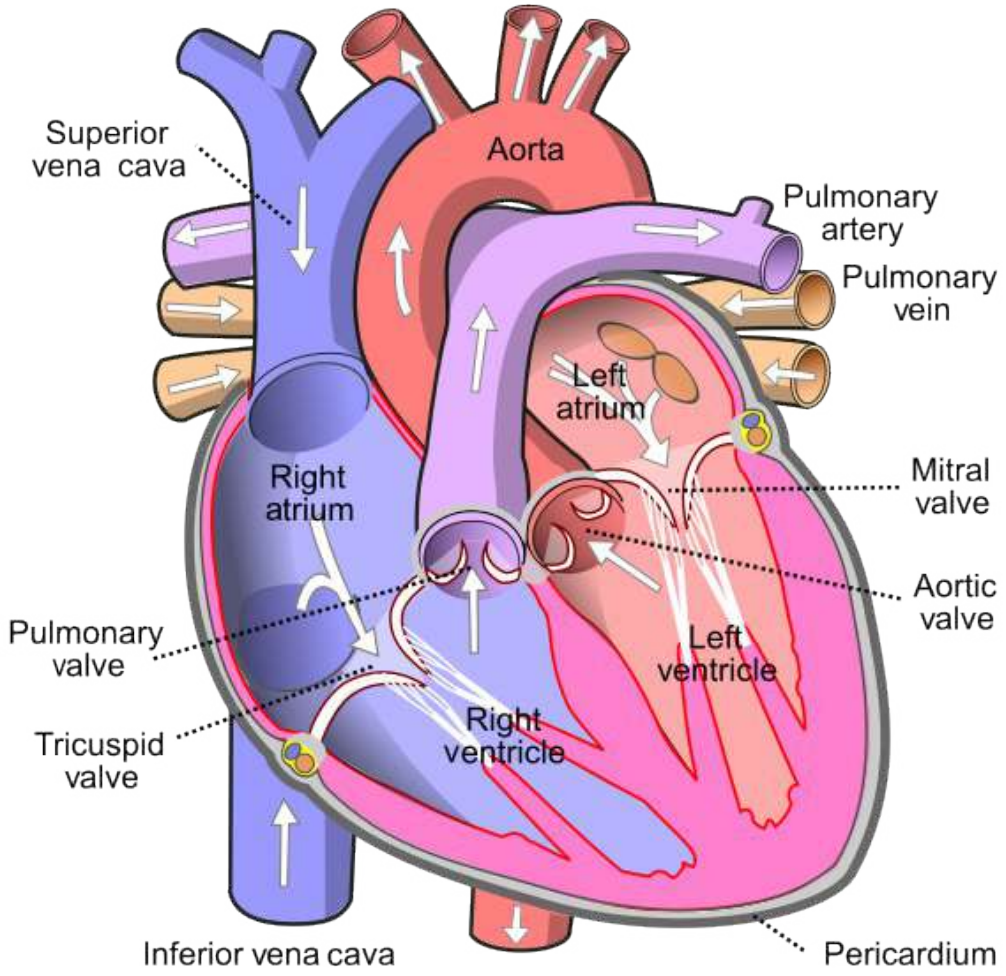
- Freshly oxygenated blood is returned to the left atrium of the heart through the pulmonary veins.

- The left atrium contracts, forcing blood through the left bicuspid valve into the left ventricle.

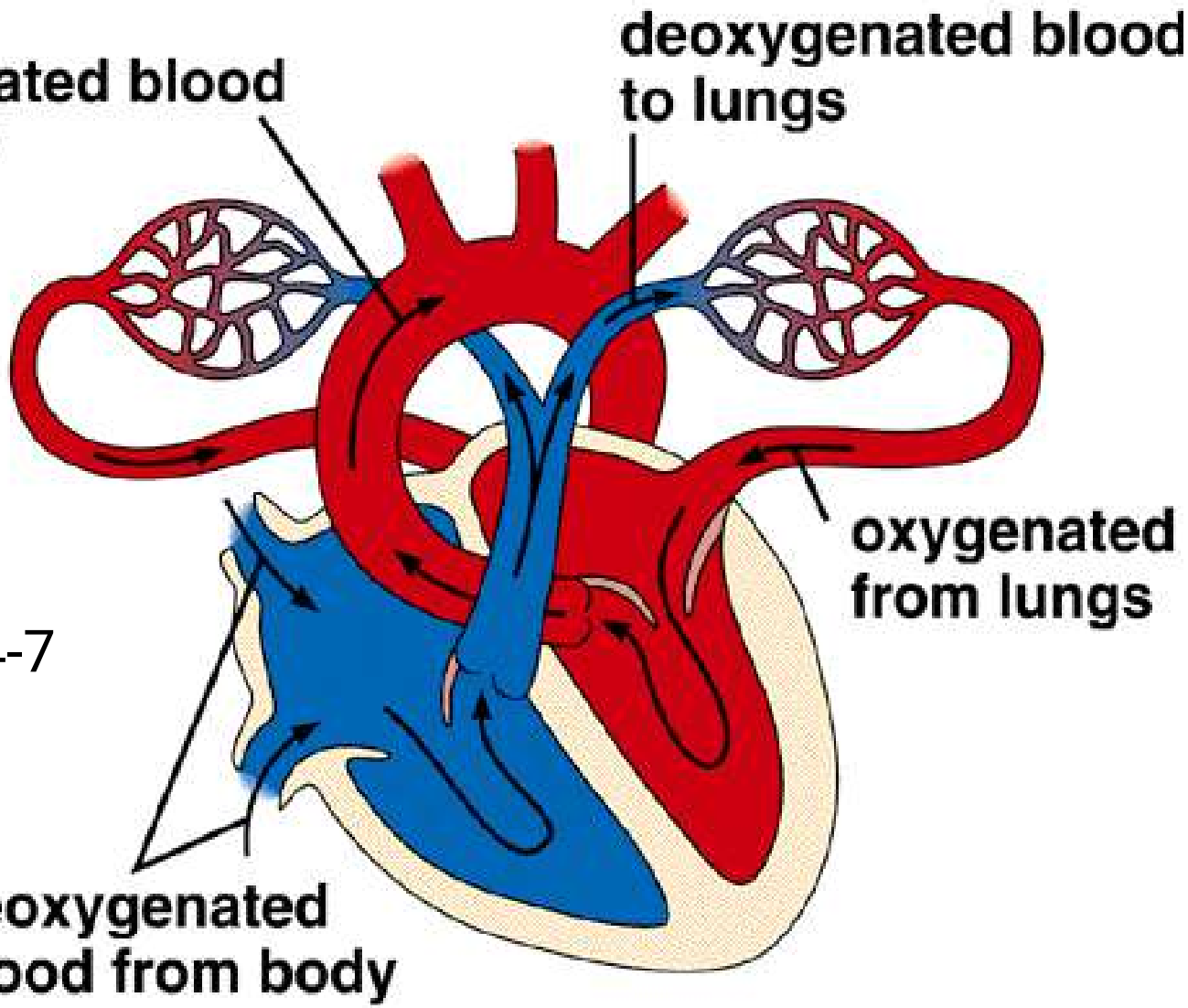


Path of Blood through the Heart

- The left ventricle contracts, closing the bicuspid valve and forcing open the aortic valve as blood enters the aorta for distribution to the body.



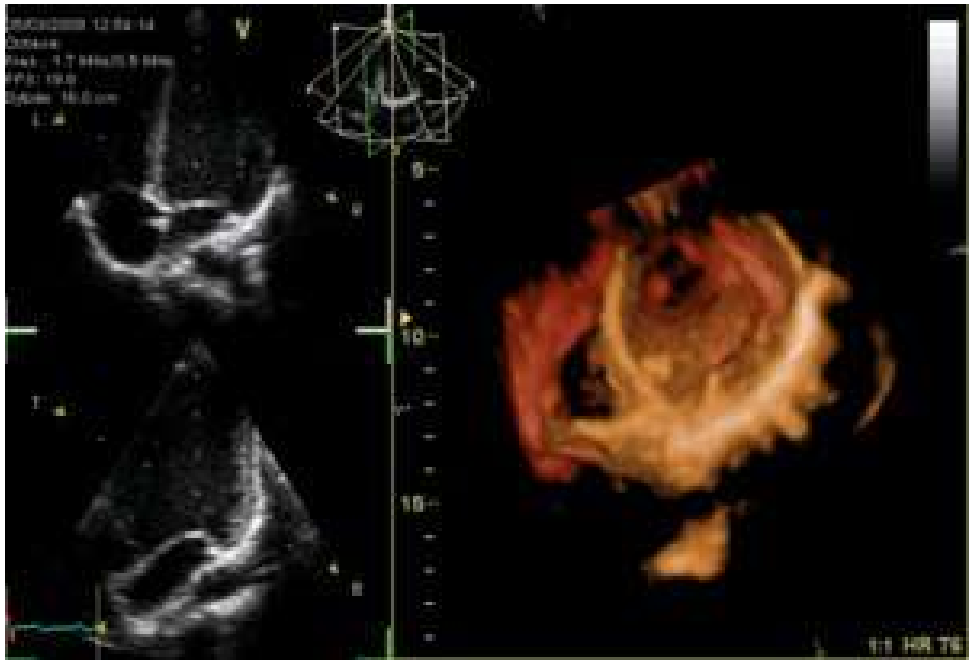
Follow Path of Blood through Heart



Compare to Fig 14-7

Heart Sounds

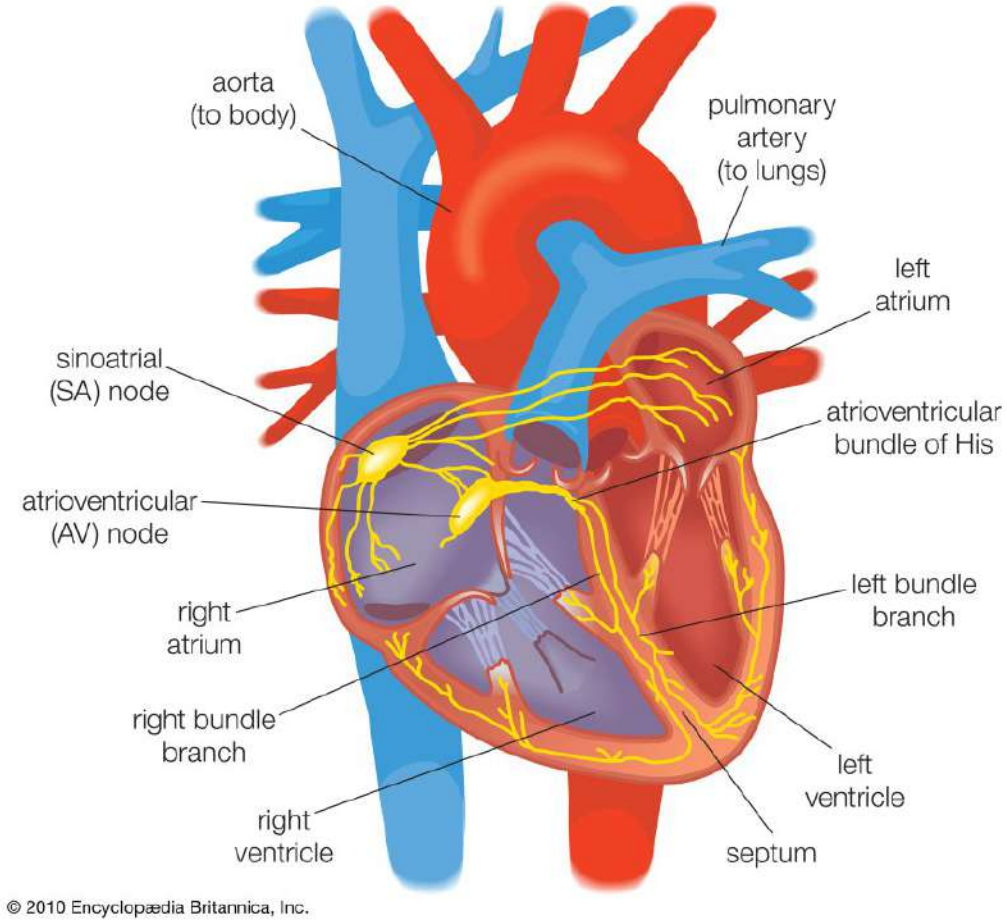
- Heart sounds are due to vibrations in heart tissues as blood rapidly changes velocity within the heart.
  - The first sound (lubb) occurs as ventricles contract and A-V valves are closing; mitral valve and the tricuspid valve.
  - The second sound (dupp) occurs as ventricles relax and semilunar valves close; aortic and pulmonary valves are closing.



Sounds caused by vibrations within ventricle and major artery walls during valve closure - not by valves snapping shut.

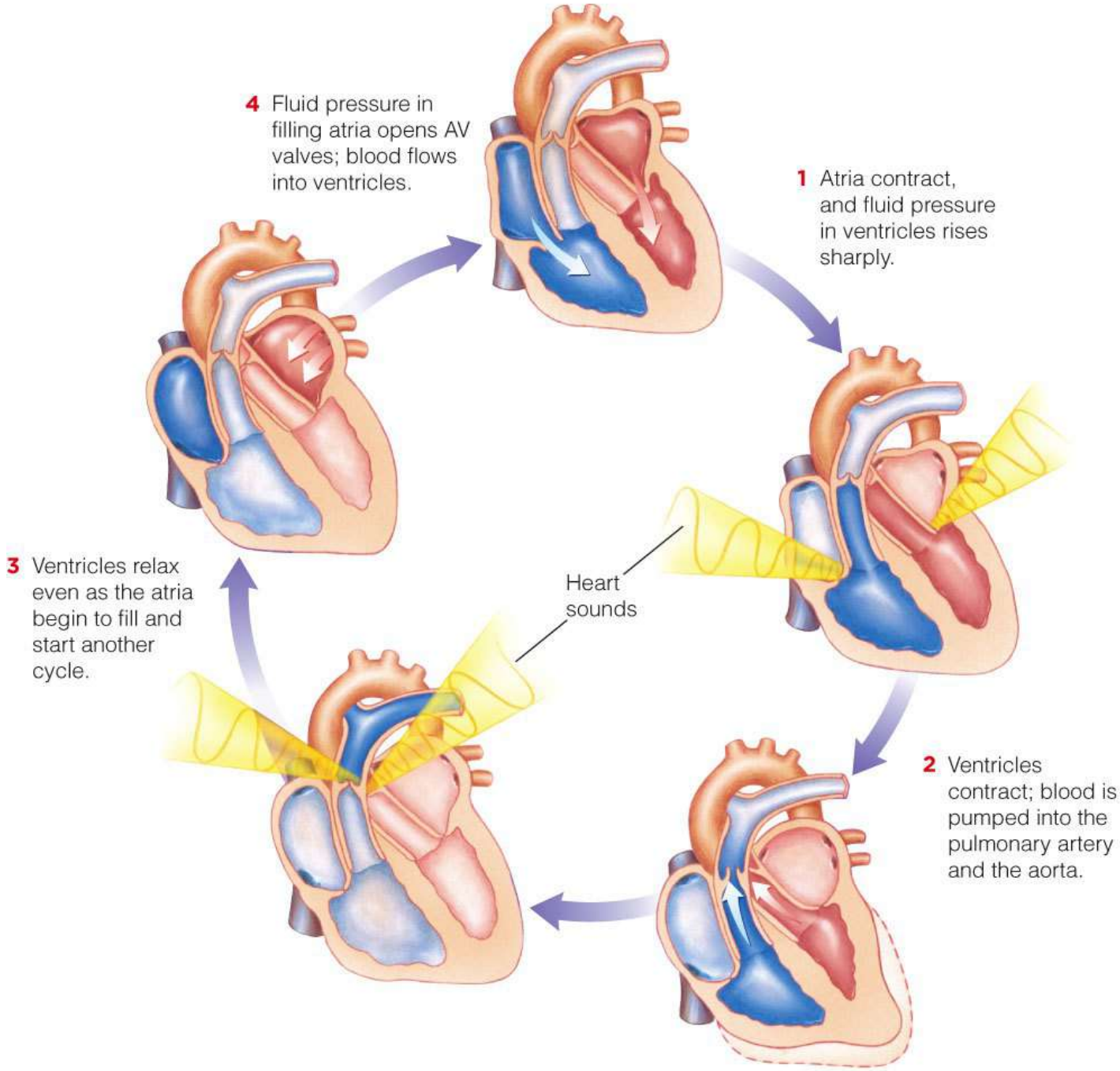
Cardiac Conduction System

- A self-exciting mass of specialized cardiac muscle called the sinoatrial node (S-A node or pacemaker), located on the posterior right atrium, generates the impulses for the heartbeat.
- Impulses spread through the atria, causing atrial contraction, to the atrioventricular node (A-V node) located in the septum causing the ventricles to contract.



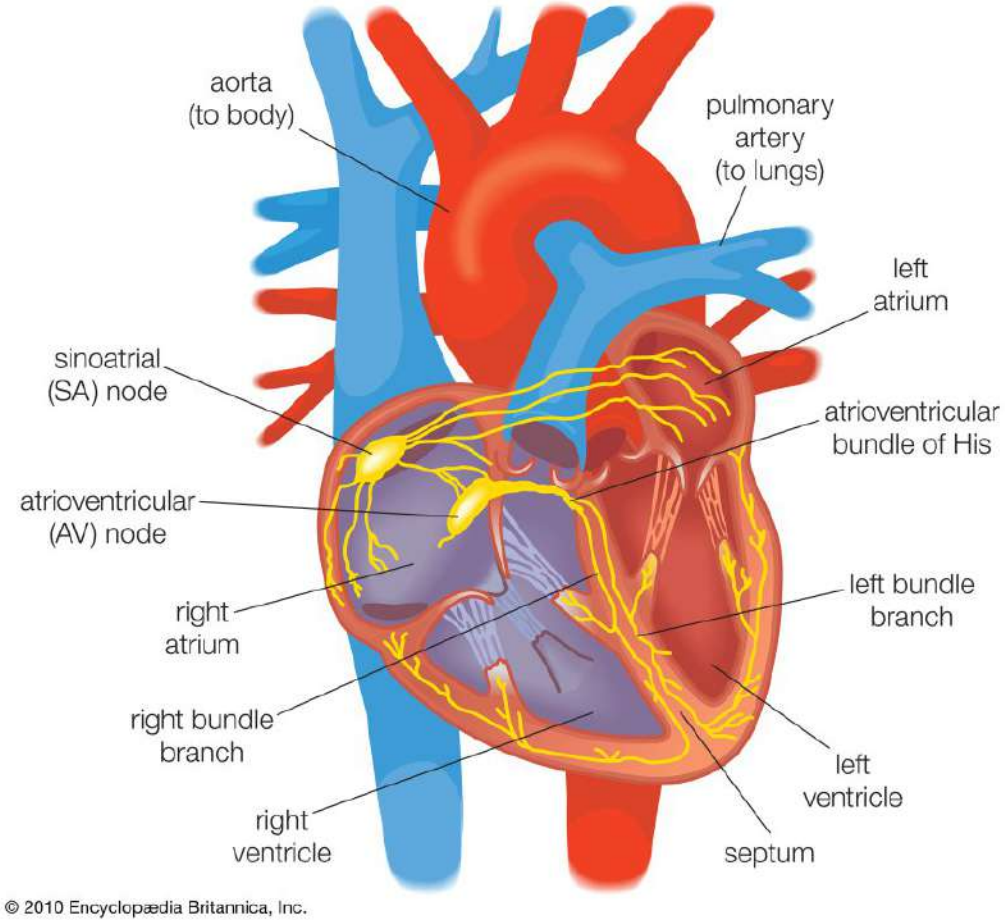
Cardiac Cycle

The Heart Beats in a Sequence Called the Cardiac Cycle



Cardiac Cycle

- In a Heartbeat, the Heart's Chambers Contract, Then Relax
- Heartbeat: one cycle of contraction and relaxation of the heart chambers



Cardiac cycle

Systole: contraction

Diastole: period of time when the heart fills with blood after systole

Relaxation

"Lub-dup" sound

Cardiac output

Every 60 seconds ~5 liters/ventricle

Cardiac Cycle: some definitions

- Systole (time during which cardiac muscle contracts)
  - atrial
  - ventricular
- Diastole (time during which cardiac muscle relaxes)
  - atrial
  - ventricular\
- EDV = End diastolic volume; 135 mL
- ESV = End systolic volume; 65 mL
- SV = Stroke Volume—that which is pumped in one stroke
- Heart at rest: atrial & ventricular diastole

Cardiac output

Every 60 seconds ~5 liters/ventricle

CO = HR x SV calculate for average person!

SV = EDV - ESV
70mL = 135 mL - 65 mL

Cardiac Output (CO) – a Measure of Cardiac Performance

CO = HR x SV calculate for average person!

- HR controlled by ANS
  - parasympathetic influence ?
  - sympathetic influence ?
  - without ANS, SA node fires 90-100x/min
- What happens with ANS when resting HR goes up (e.g. during exercise)?

Foxglove for a Failing Heart

- Cardiac glycosides from Digitalis purpurea

↓

digoxin

- Highly toxic in large dosage: destroys all Na^+/K^+ pumps
- In low dosage: partial block of Na^+ removal from myocardial cells

Explain mechanism of action !

Foxglove for a Failing Heart

- Cardiac glycosides from Digitalis purpurea are used therapeutically mainly in the treatment of cardiac failure.
- These effects are caused by the ability to increase cardiac output by increasing the force of contraction by increasing intracellular calcium, increasing calcium-induced calcium release and thus contraction.
- Drugs such as ouabain and digoxin are cardiac glycosides.
- digoxin from the foxglove plant is used clinically, whereas ouabain is used only experimentally due to its extremely high potency.

Blood Flow

- Why does blood flow through cardiovascular system? (teleological vs. mechanistic answers)
- Teleological: (function) Because diffusion is too slow to support a large and complex organism
- Mechanistic: (processes) Because the contractions of the heart produce a hydrostatic pressure gradient and the blood wants to flow to the region of lesser pressure. Therefore, the Pressure gradient (P) is main driving force for flow through the vessels

Hydrostatic pressure is what exerted by a liquid when it is at rest.

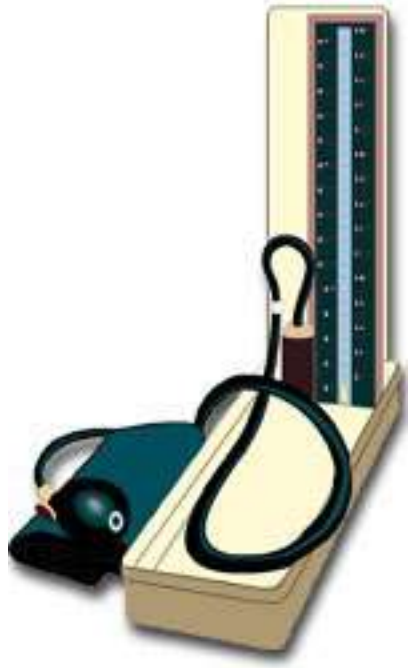
Blood Flow Rate P/ R

P; pressure deference

R; resistance

Pressure

- Hydrostatic pressure is in all directions
  - Measured in mmHg: The pressure to raise a 1 cm column of Hg 1 mm
  - Sphygmomanometer
- Flow is produce by Driving Pressure
- Pressure of fluid in motion decreases over distance because of energy loss due to friction



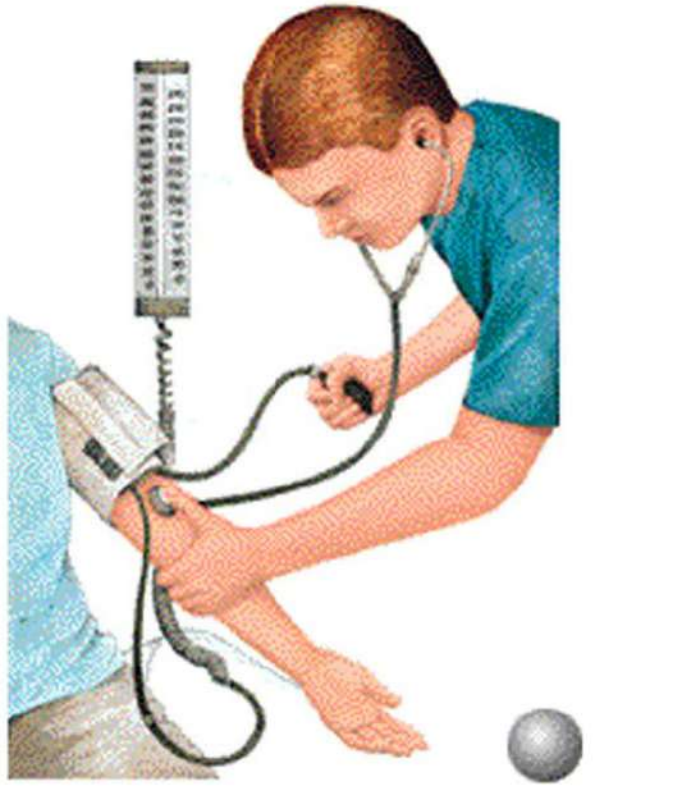
Blood Flow Rate P/ R

Pressure

- Blood pressure: fluid pressure that blood exerts against vessel walls

- Systolic (ventricular contraction) and diastolic pressure (ventricular relaxation):
  - Normal: 120/80

- Hypertension
  - Chronically elevated blood pressure
- Hypotension
  - Abnormally low blood pressure



Blood Flow Rate P/ R

Blood Pressure Values (mm of Hg)

TABLE 7.1 Blood Pressure Values (mm of Hg)

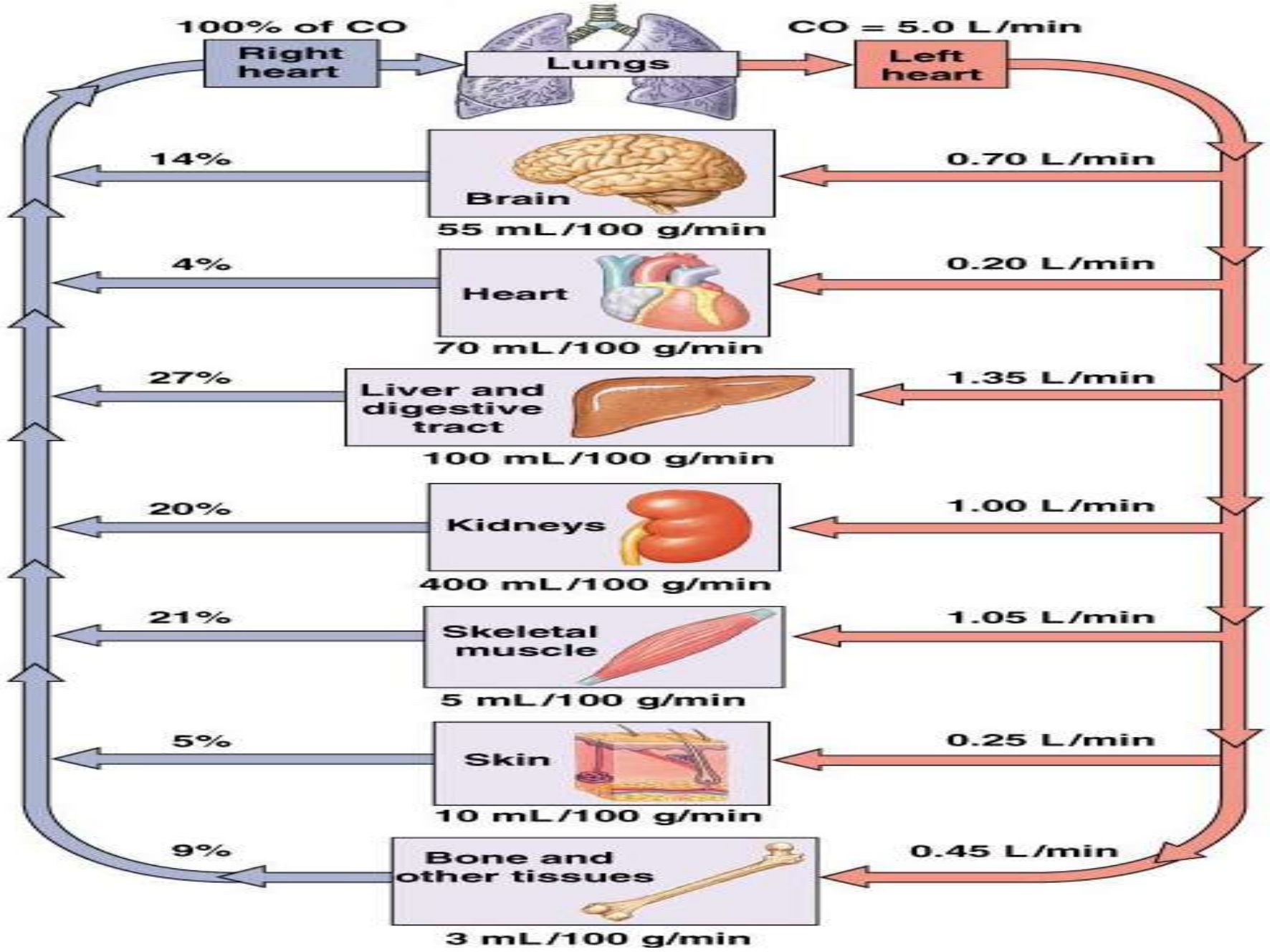
	Systolic	Diastolic
Normal	100–119	60–79
Hypotension	Less than 100	Less than 60
Prehypertension	120–139	80–139
Hypertension	140 and up	90 and up

A Variety of Factors May Cause Hypertension

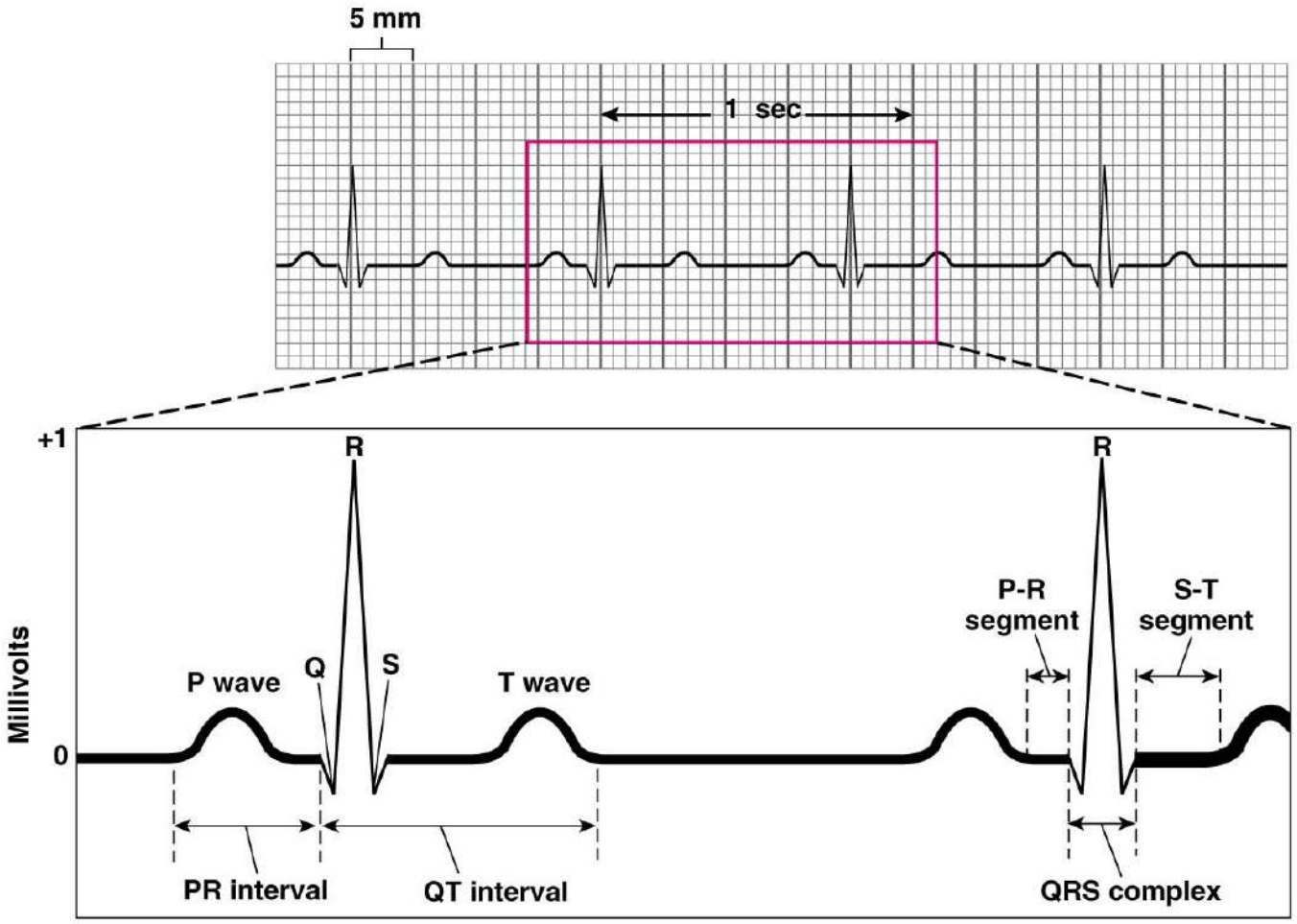
Risk Factors for Hypertension

1. Smoking
2. Obesity
3. Sedentary lifestyle
4. Chronic stress
5. A diet low in fruits, vegetables, dairy foods, and other sources of potassium and calcium
6. Excessive salt intake (in some individuals)
7. Poor salt management by the kidneys, usually due to disease

Distribution of Blood



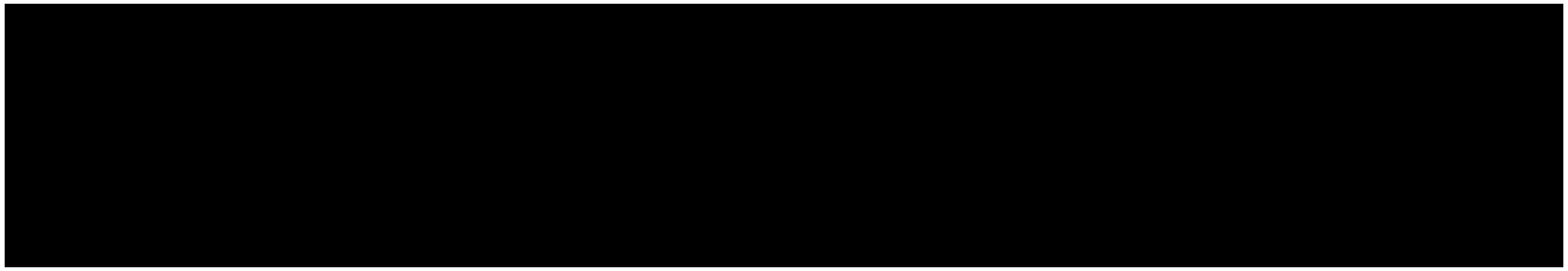
Electrocardiogram ECG (EKG)



Electrocardiogram ECG (EKG)

- Surface electrodes record electrical activity deep within body - How possible?

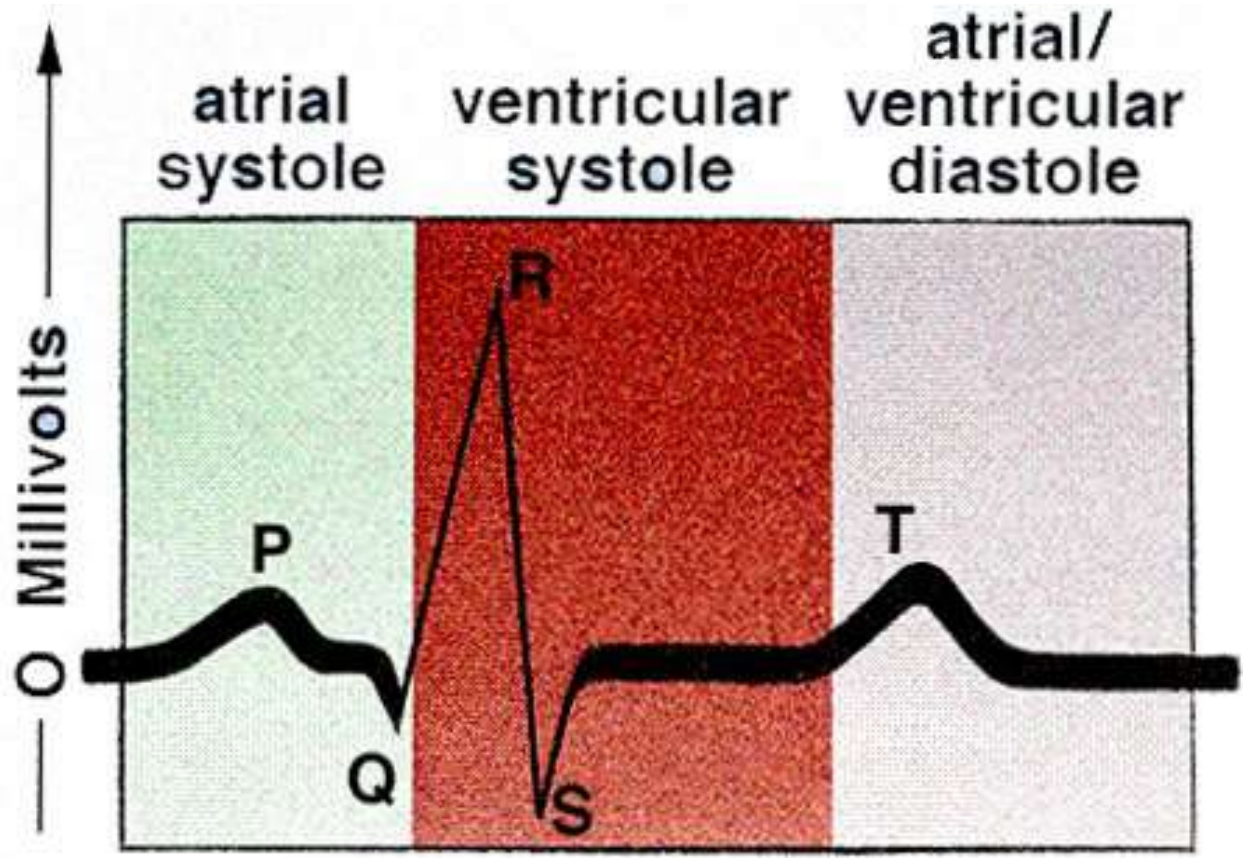
- Reflects electrical activity of whole heart not of single cell!
- EC fluid = “salt solution” (NaCl) good conductor of electricity to skin surface
- Signal very weak by time it gets to skin
  - ventricular AP = ? mV
  - ECG signal amplitude = 1mV
- EKG tracing = of all electrical potentials generated by all cells of heart at any given moment



Since:

Depolarization = signal for contraction

Segments of EKG reflect mechanical heart events

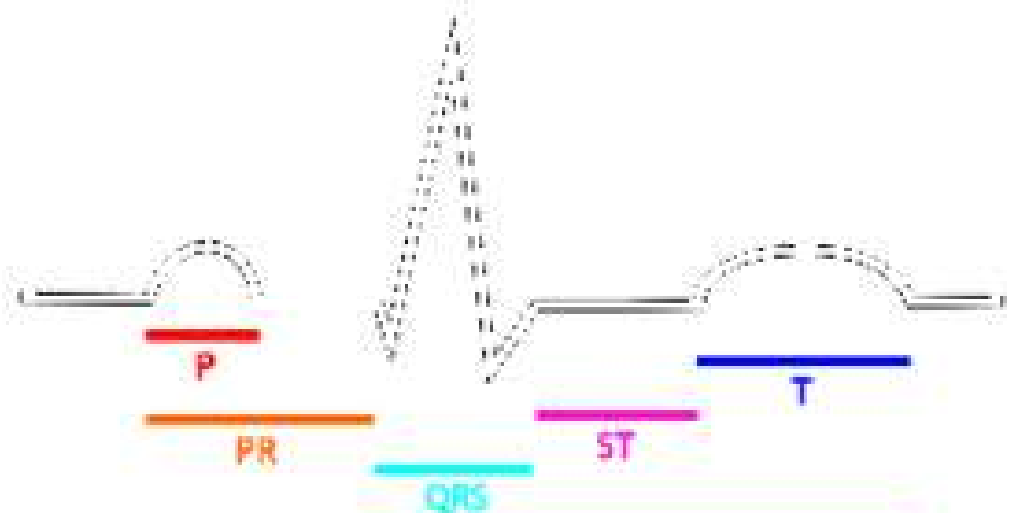


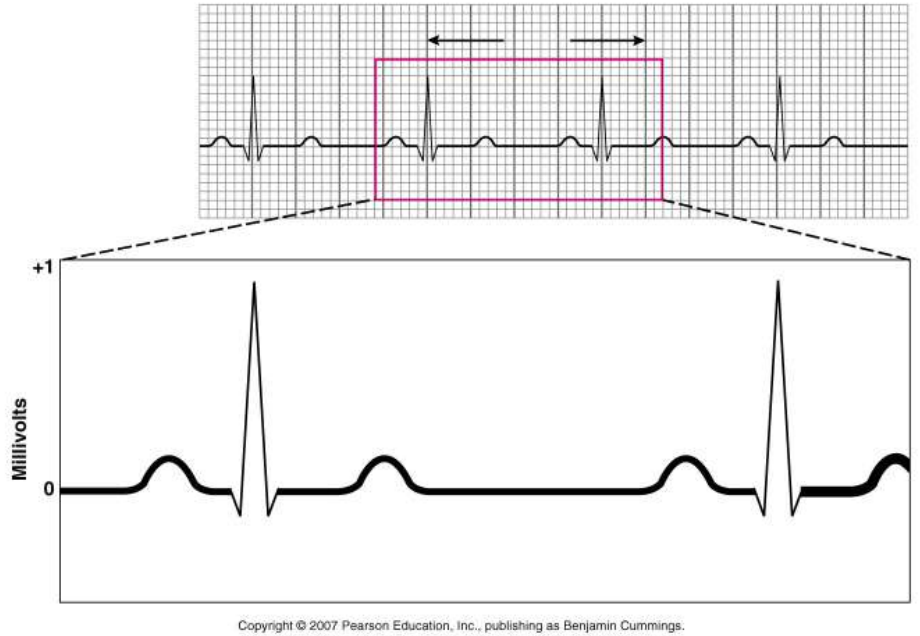
Components of EKG

- Waves ;
- (P, QRS, T)

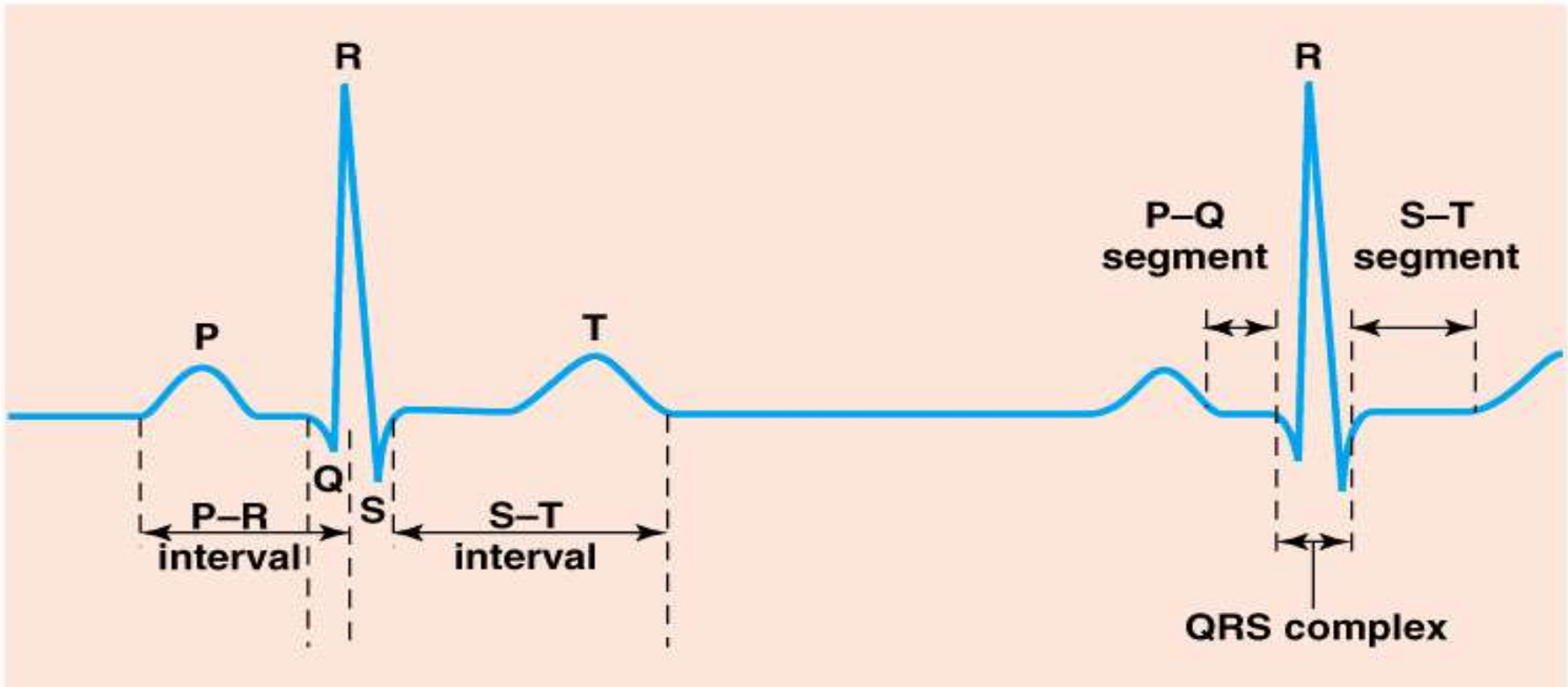
- Segments
- (PR, ST)

- Intervals
- (wave- segment combos: PR, QT)



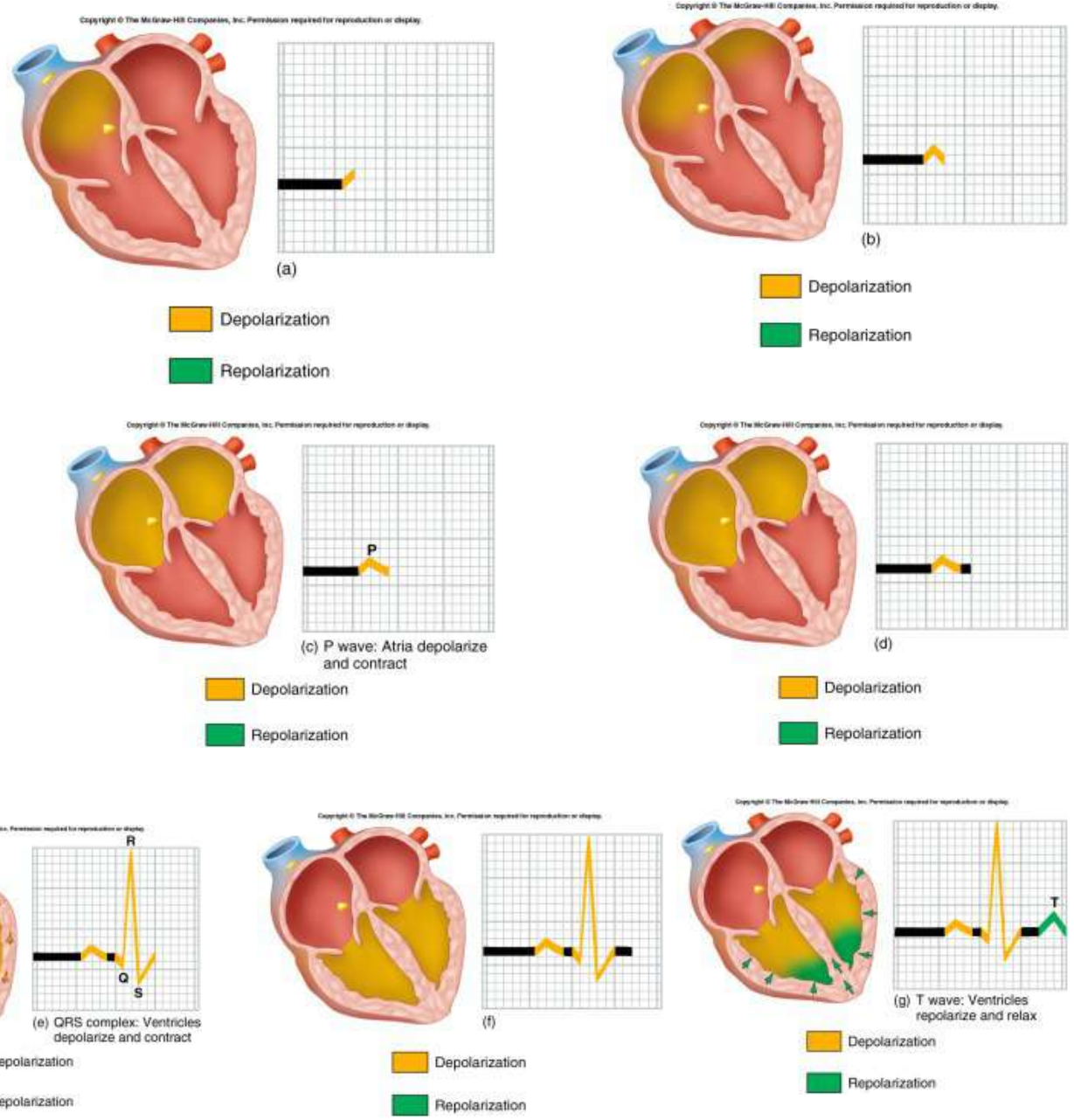


(b)

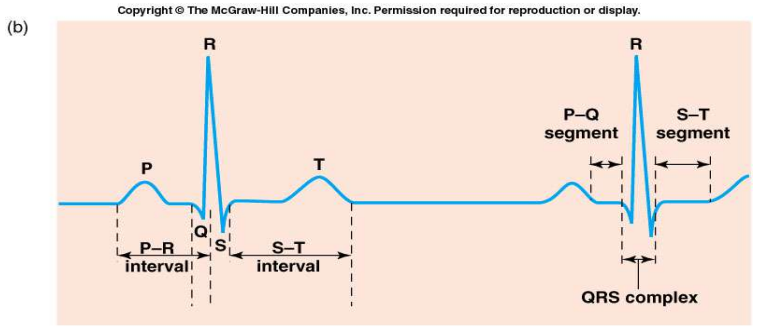


ECG

- 3 distinct waves are produced during cardiac cycle
- P wave caused by atrial depolarization
- QRS complex caused by ventricular depolarization
- T wave results from ventric repolarization



Elements of the ECG:

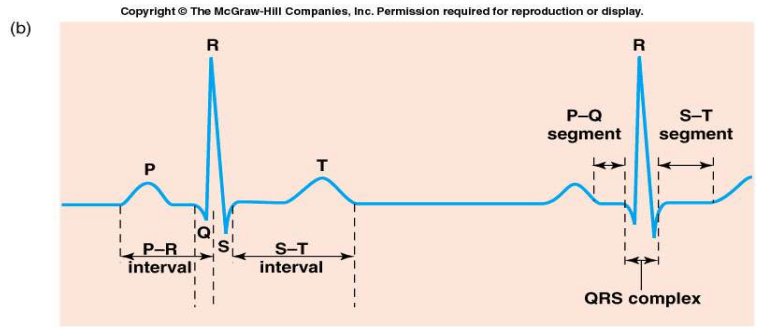


P wave: Depolarization of both atria;

- Relationship between P and QRS helps distinguish various cardiac arrhythmias
- Shape and duration of P may indicate atrial enlargement

- PR interval: from onset of P wave to onset of QRS
  - Normal duration = 0.12-2.0 sec (120-200 ms) (3-4 horizontal boxes)
  - Represents atria to ventricular conduction time (through His bundle)
  - Prolonged PR interval may indicate a 1st degree heart block

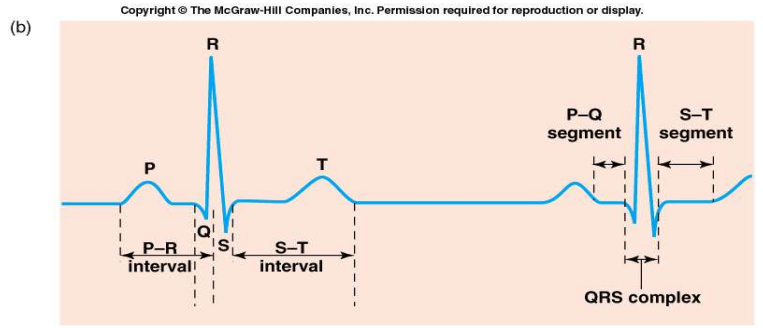
Elements of the ECG:



QRS complex: Ventricular depolarization

- Larger than P wave because of greater muscle mass of ventricles
- Normal duration = 0.08-0.12 seconds
- Its duration, amplitude, and morphology are useful in diagnosing cardiac arrhythmias, ventricular hypertrophy, MI, electrolyte derangement, etc.
- Q wave greater than 1/3 the height of the R wave, greater than 0.04 sec are abnormal and may represent MI

Elements of the ECG:



ST segment:

- Connects the QRS complex and T wave
- Duration of 0.08-0.12 sec (80-120 msec

T wave:

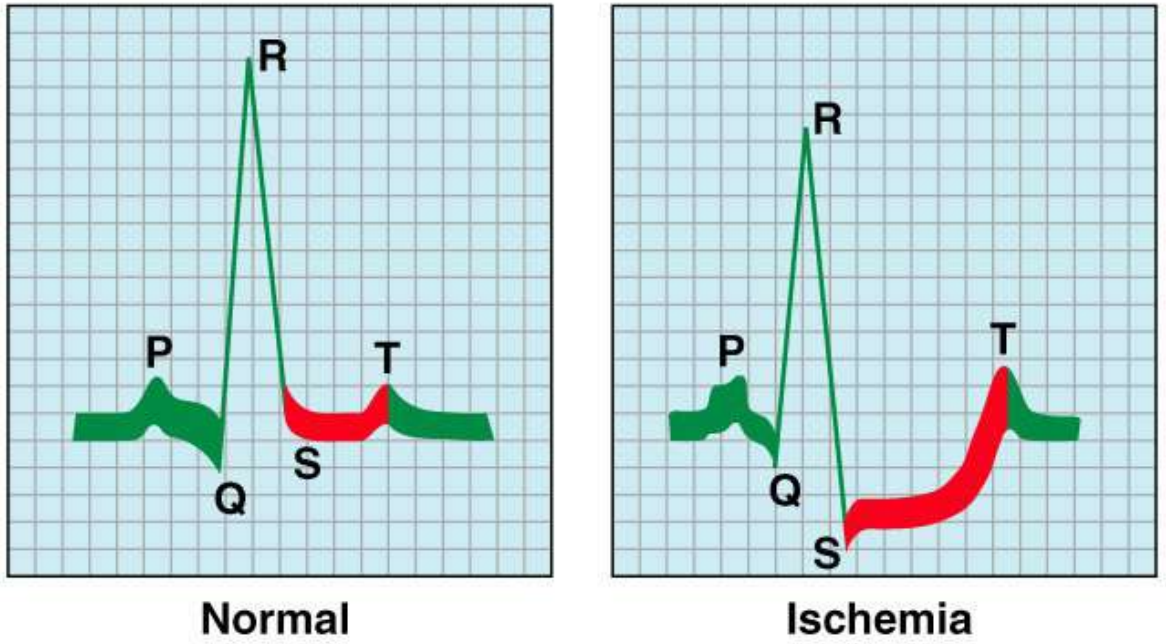
- Represents repolarization or recovery of ventricles
- Interval from beginning of QRS to apex of T is referred to as the absolute refractory period

QT Interval

- Measured from beginning of QRS to the end of the T wave
- Normal QT is usually about 0.40 sec
- QT interval varies based on heart rate

Heart Disease

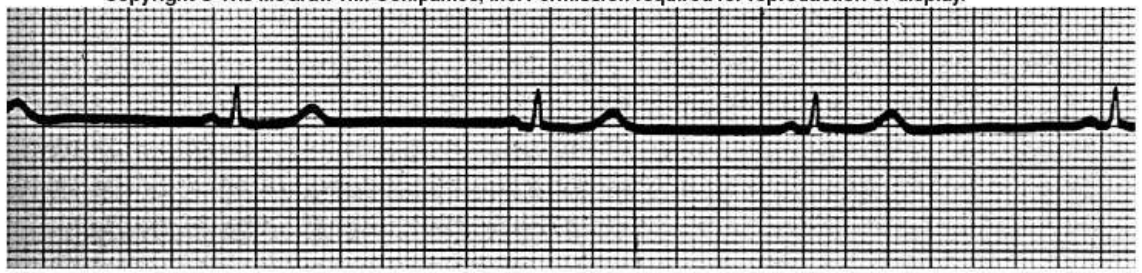
- Detectable by changes in S-T segment of ECG
- Myocardial infarction (MI) is a heart attack
  - Diagnosed by high levels of creatine phosphate (CPK) & lactate dehydrogenase (LDH)



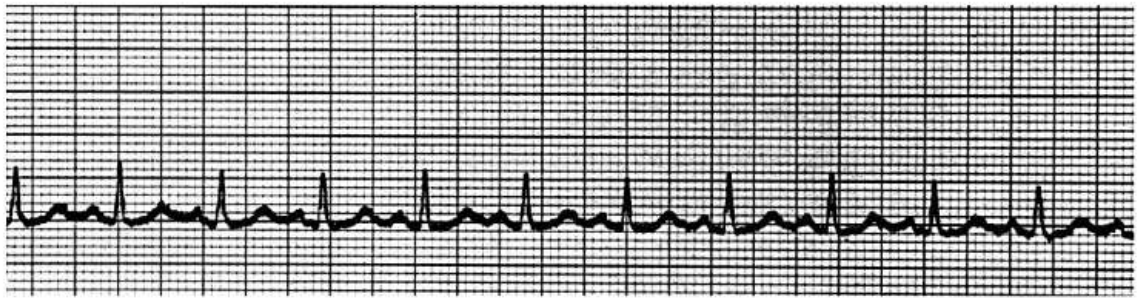
Arrhythmias Detected on ECG

- Arrhythmias are abnormal heart rhythms
- Heart rate <60/min is bradycardia; >100/min is tachycardia

Fig 13.35

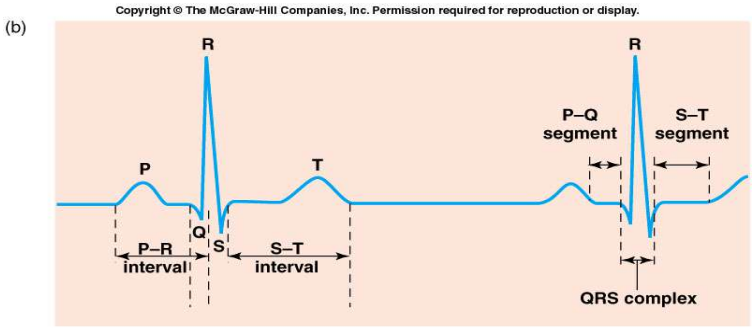


Sinus bradycardia



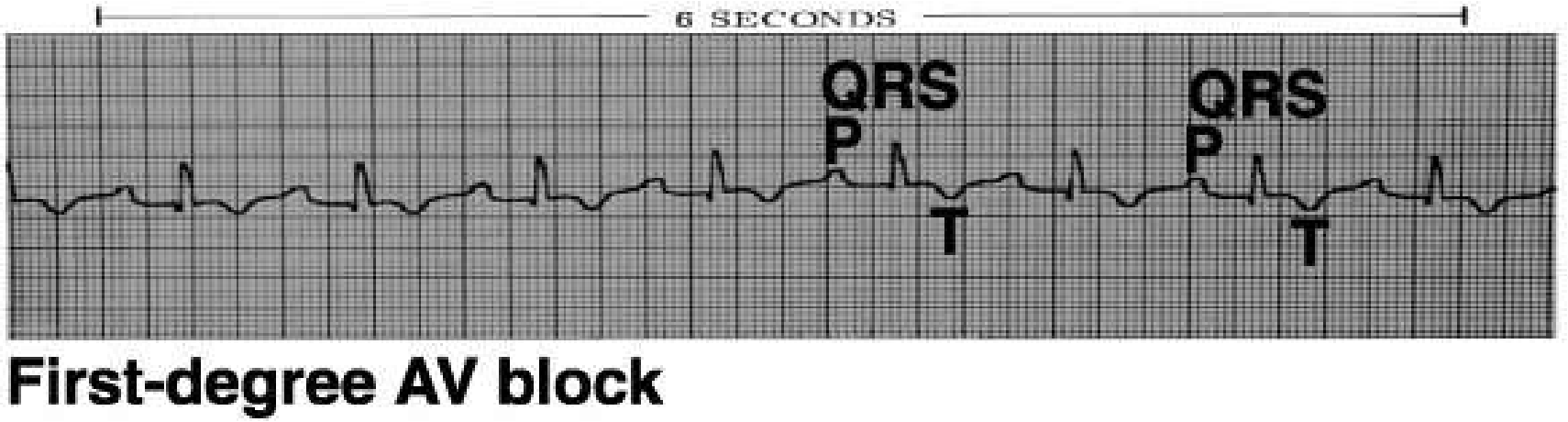
(a) Sinus tachycardia

Arrhythmias Detected on ECG co

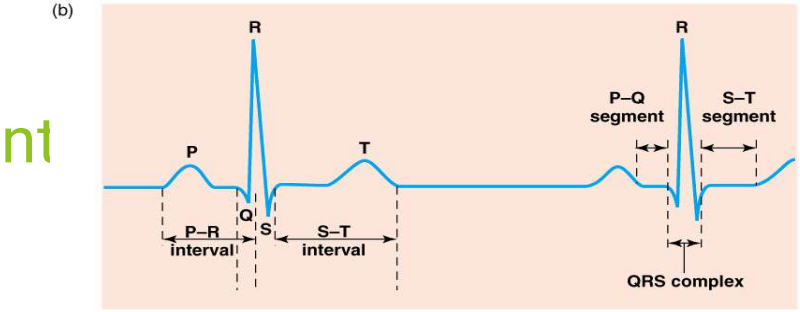


- AV node block occurs when node is damaged
- First–degree AV node block is when conduction thru AV node > 0.2 sec
  - Causes long P-R interval

Fig 13.36

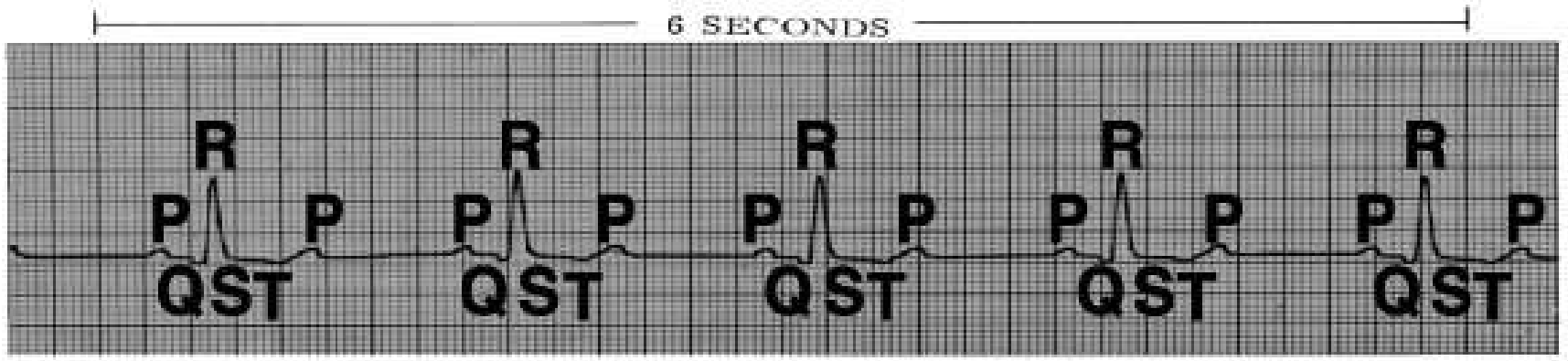


Arrhythmias Detected on ECG cont

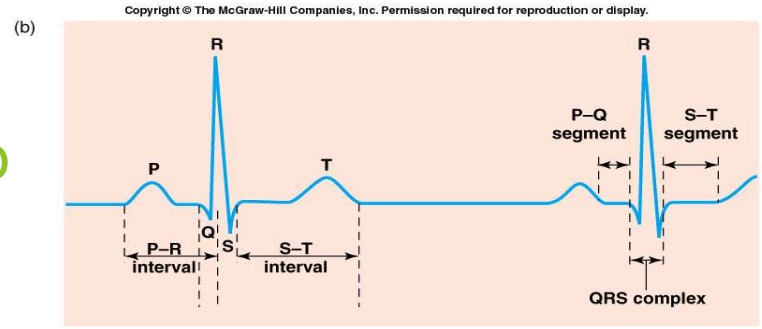


- Second-degree AV node block is when only 1 out of 2-4 atrial APs can pass to ventricles
  - Causes P waves with no QRS

Fig 13.36

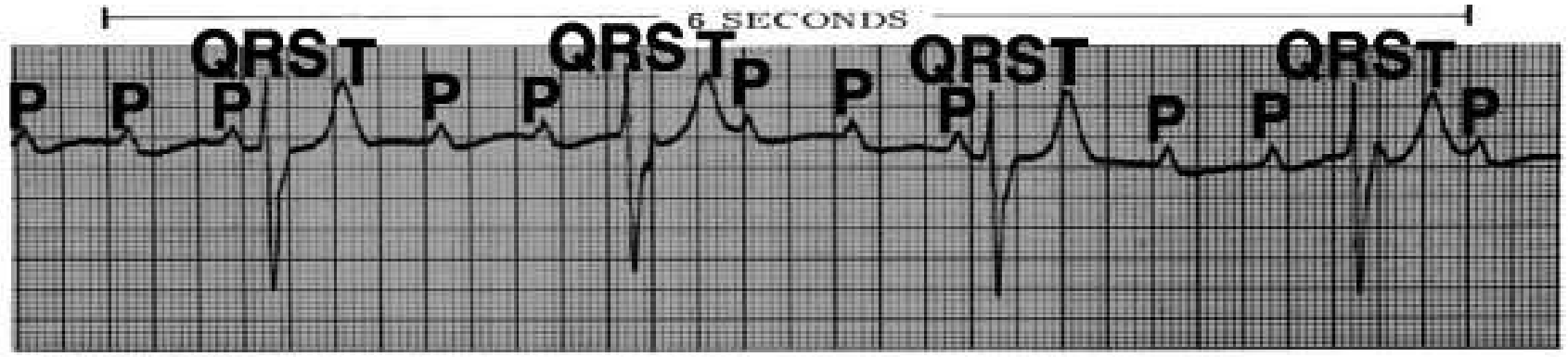


Arrhythmias Detected on ECG co

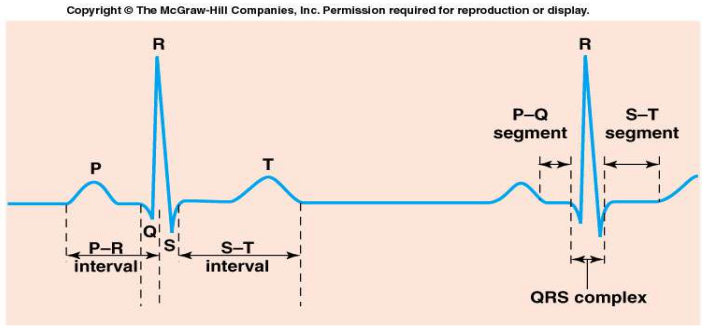


- In third-degree or complete AV node block, no atrial activity passes to ventricles
  - Ventricles are driven slowly by bundle of His or Purkinjes

Fig 13.36

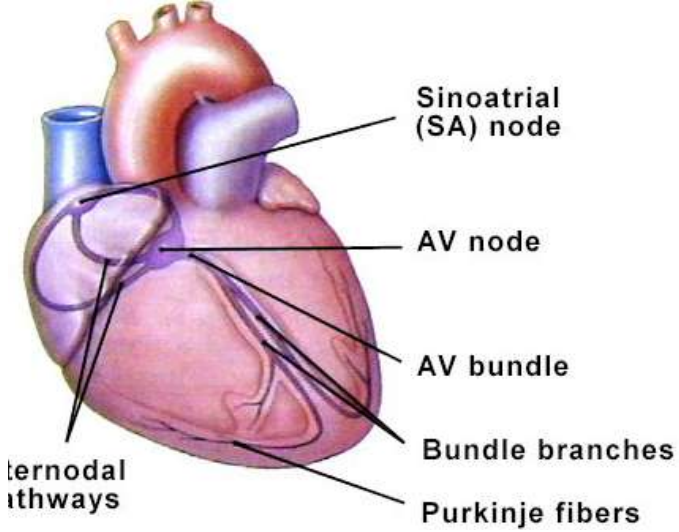


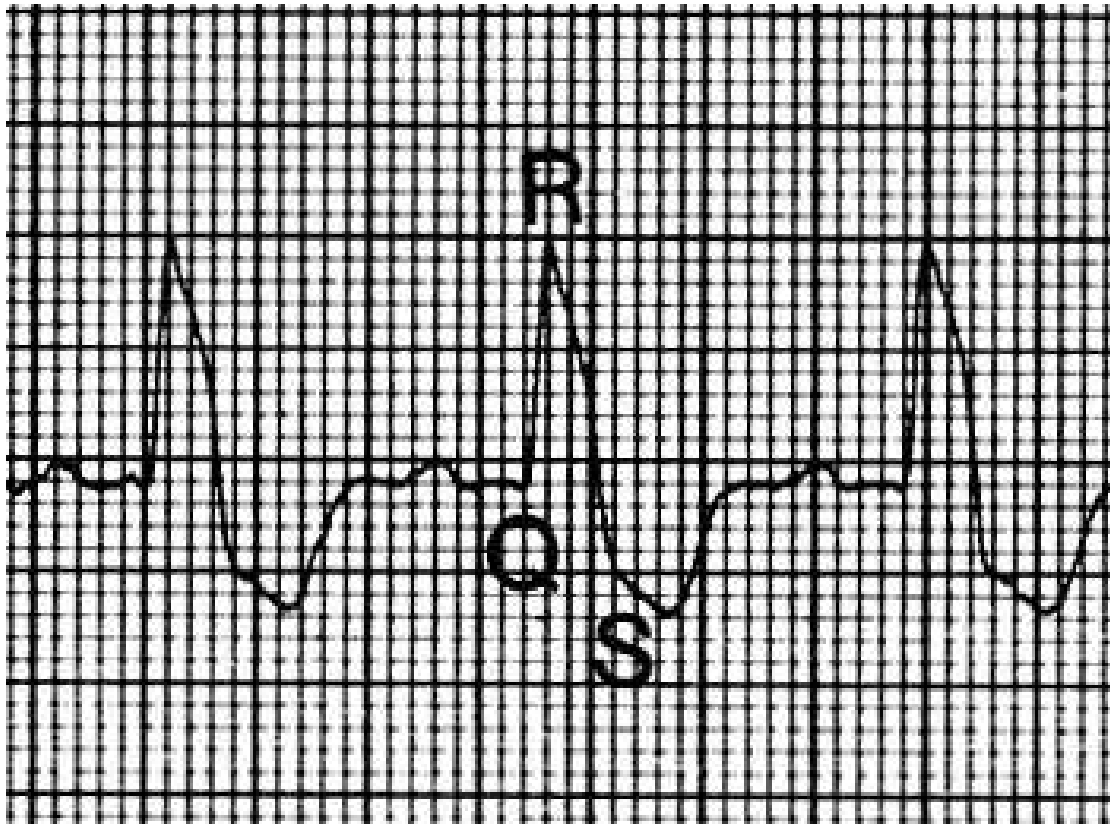
Arrhythmias Detected on ECG cor



- AV node block occur when node is damaged
- First–degree AV node block is when conduction through AV node > 0.2 sec
  - Causes long P-R interval
- Second-degree AV node block is when only 1 out of 2-4 atrial APs can pass to ventricles
  - Causes P waves with no QRS
- In third-degree or complete AV node block no atrial activity passes to ventricles
  - Ventricles driven slowly by bundle of His or Purkinjes

Prolonged QRS complex





Injury to AV bundle can increase duration of QRS complex (takes longer for impulse to spread throughout ventricular walls).

Fig 14-23

Myocardial Infarction

The End

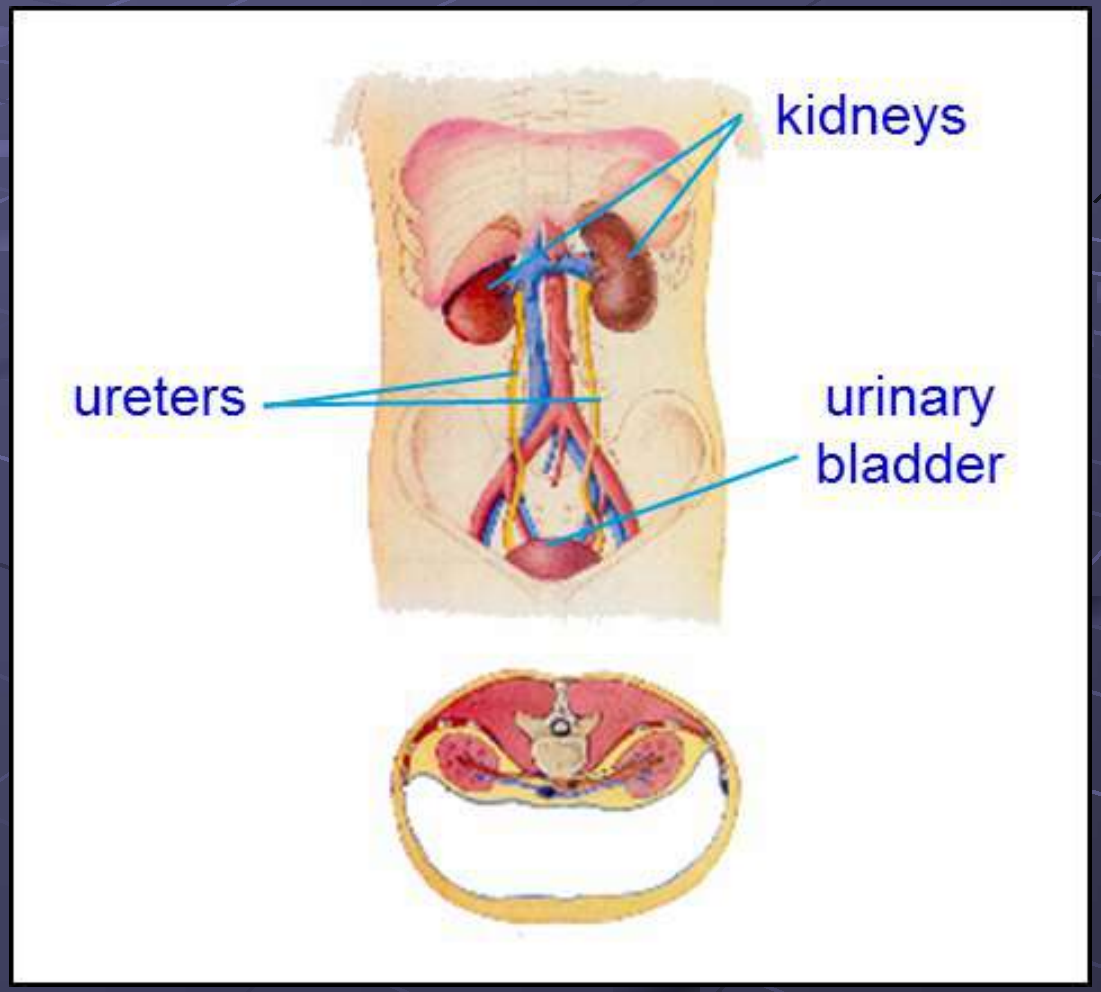
Urinary System

The urinary system

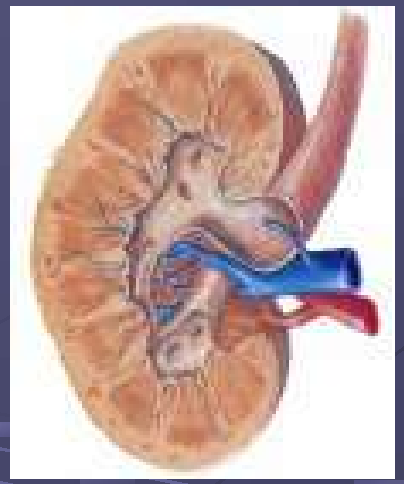
- Urinary system is one of the excretory systems of the body,
- Plays a major role in the elimination of metabolic waste products and toxic substances,
- Regulating the rates of elimination of water and electrolytes from the body.

The urinary system consists of;

- The kidneys which filter blood and secrete urine.
- The ureters which transport urine the bladder
- The urinary bladder where urine collects and temporarily stored.
- The urethra through which the urine is discharged to the exterior.

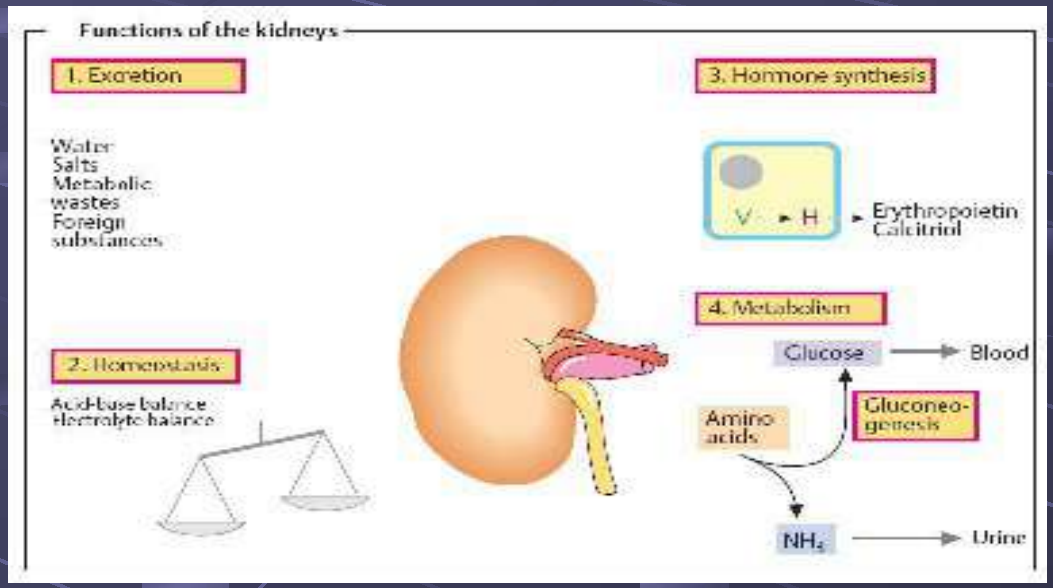


The Kidneys

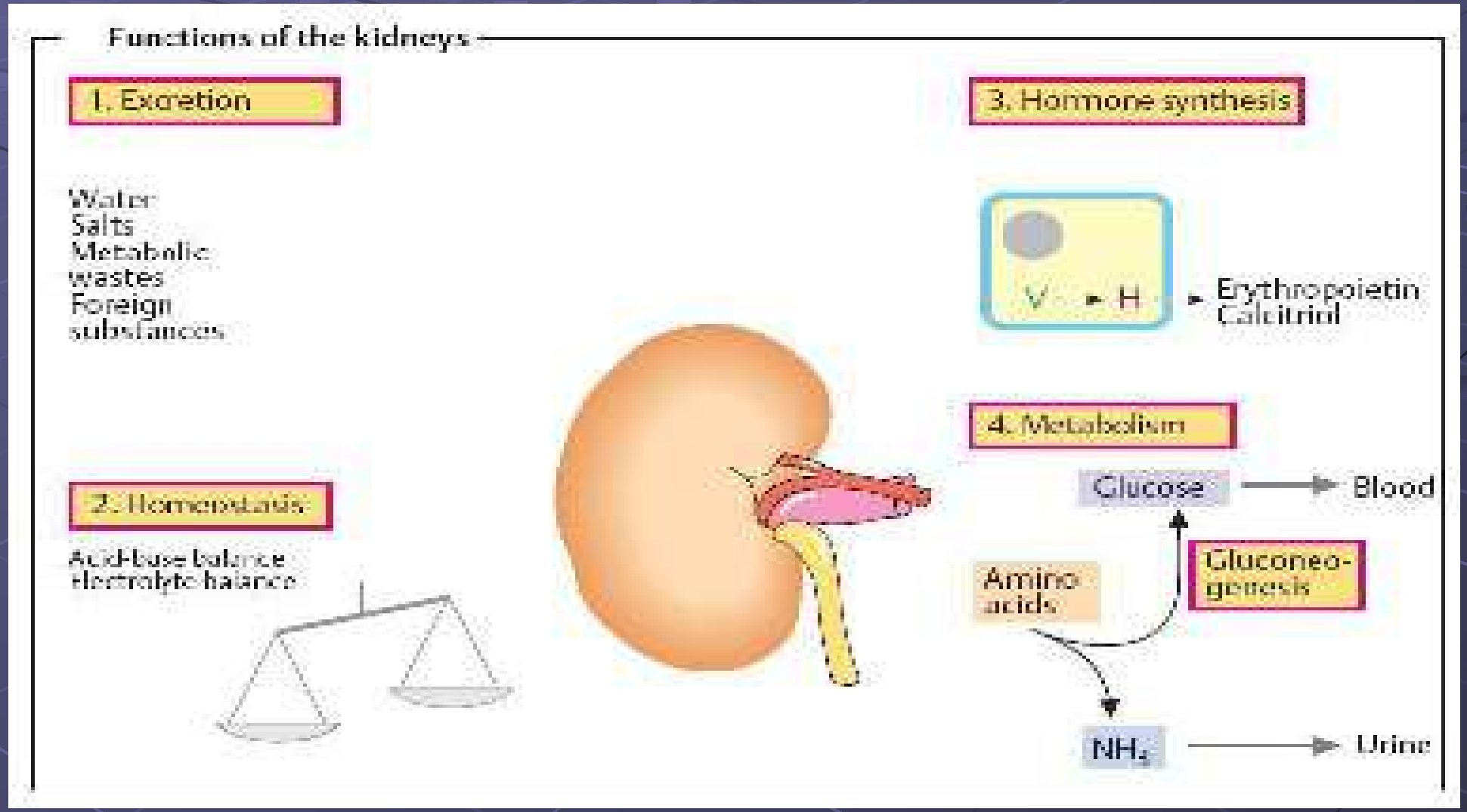


Homeostatic regulation of
ECF volume and BP
Osmolarity
    290 mOsm
Ion balance
    Na+ and K+, etc.
pH (acid-base balance
Excretion of wastes & foreign substances
Hormone production
    EPO
    Renin

Functional unit of kidneys: ??



Functions of the kidney

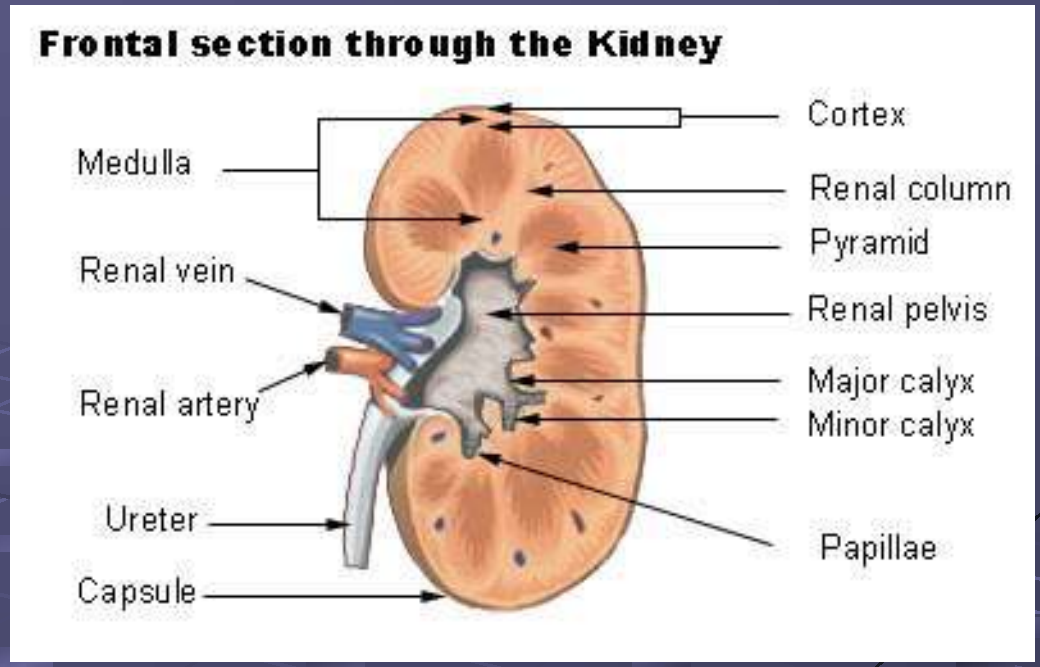


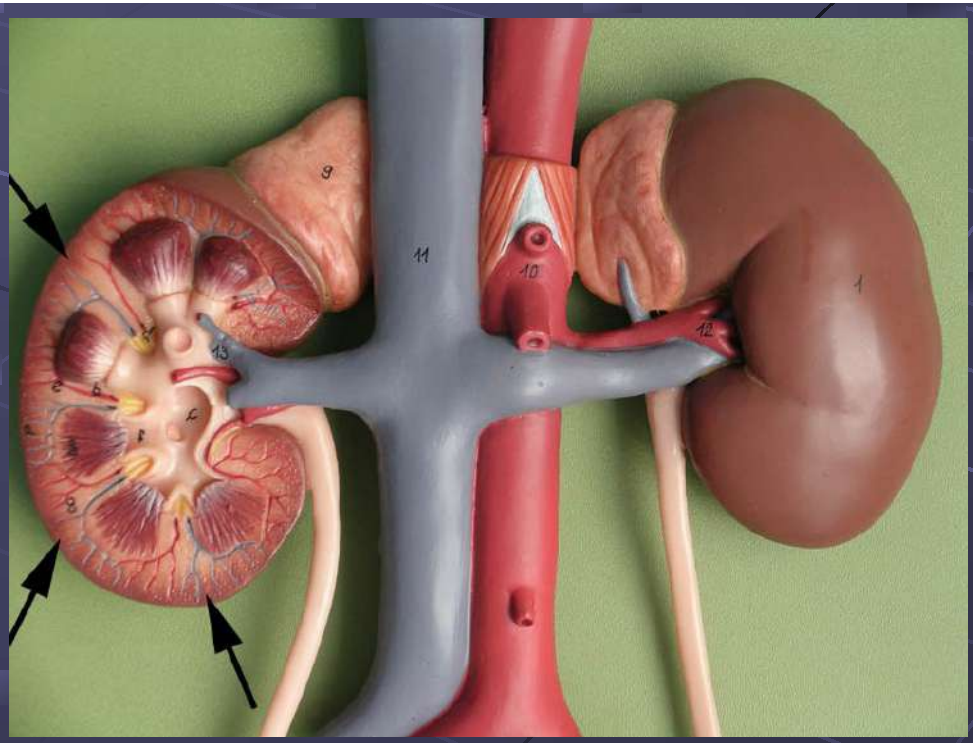
Kidneys;

- The kidneys are two bean-shaped organs situated behind the peritoneum on the posterior wall of the abdominal cavity, on either side of the vertebral column.

- The kidneys extend from approximately the 12th thoracic vertebra to the third lumber vertebra.

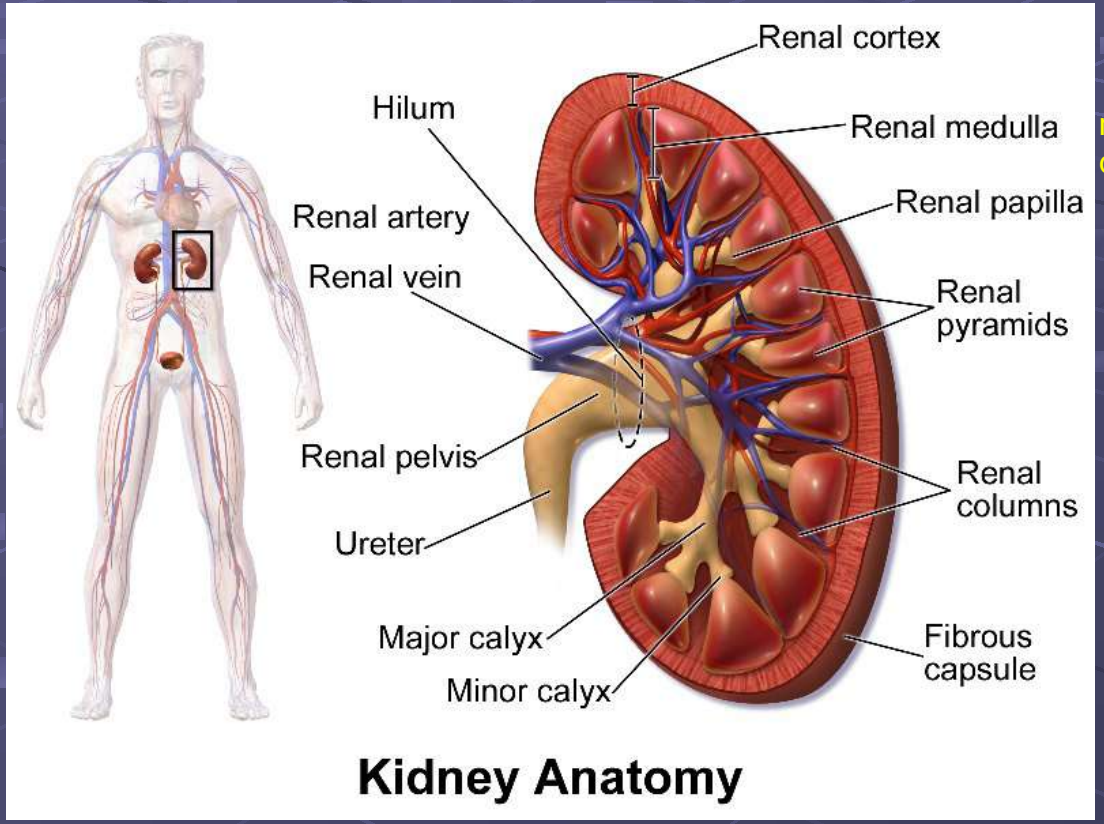
- The right kidney is situated a little lower than the left, due to the heavy liver on it.
- Kidney weights between 120-170g, is from 10-13cm in length, 5-6cm wide, and 3-4cm thick. About the size of a large bar of soap.

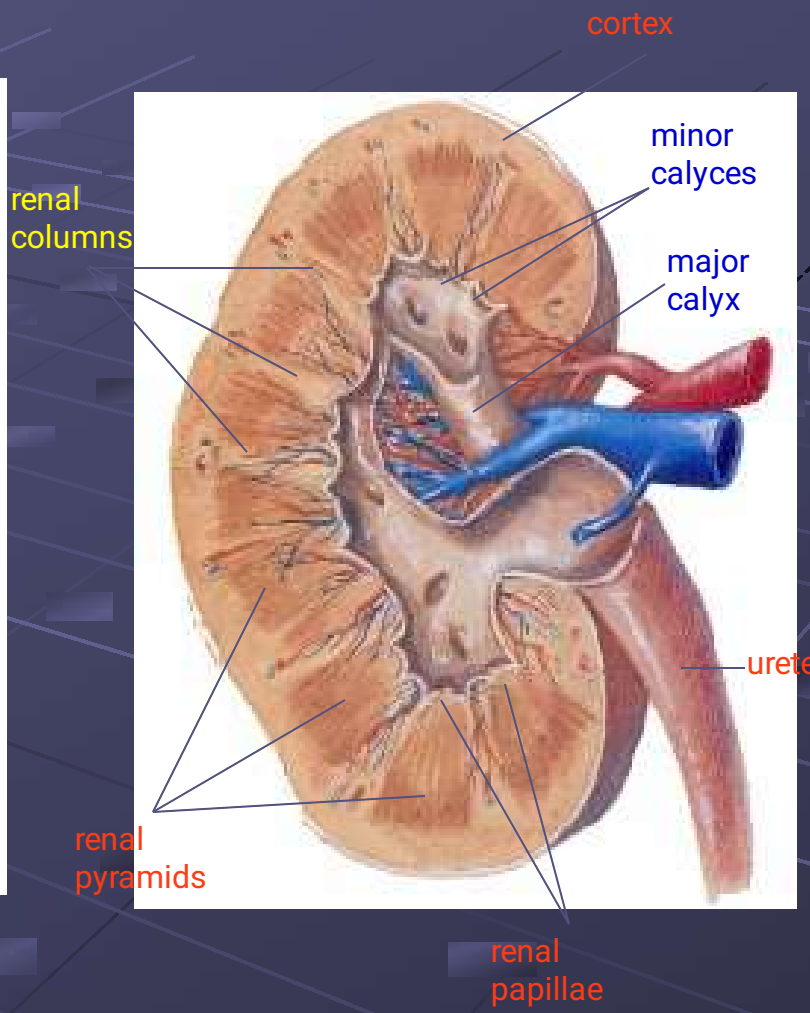




INTERNAL ANATOMY OF THE KIDNEY

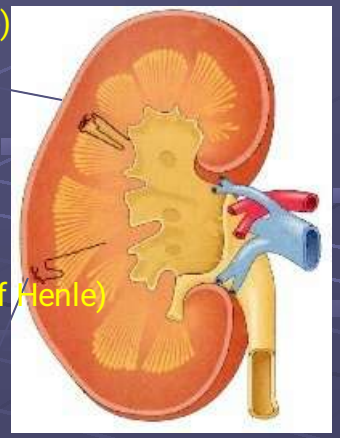
- Renal cortex
  - renal columns
  - nephrons
- Renal medulla
  - renal pyramids
  - renal papillae
- Renal sinus
- Renal pelvis
  - minor calyces
  - major calyx

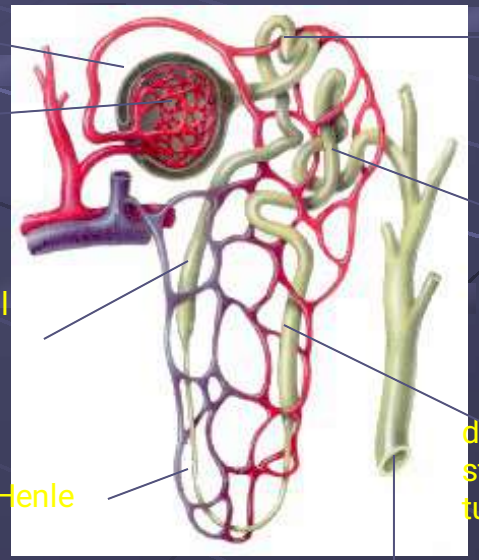


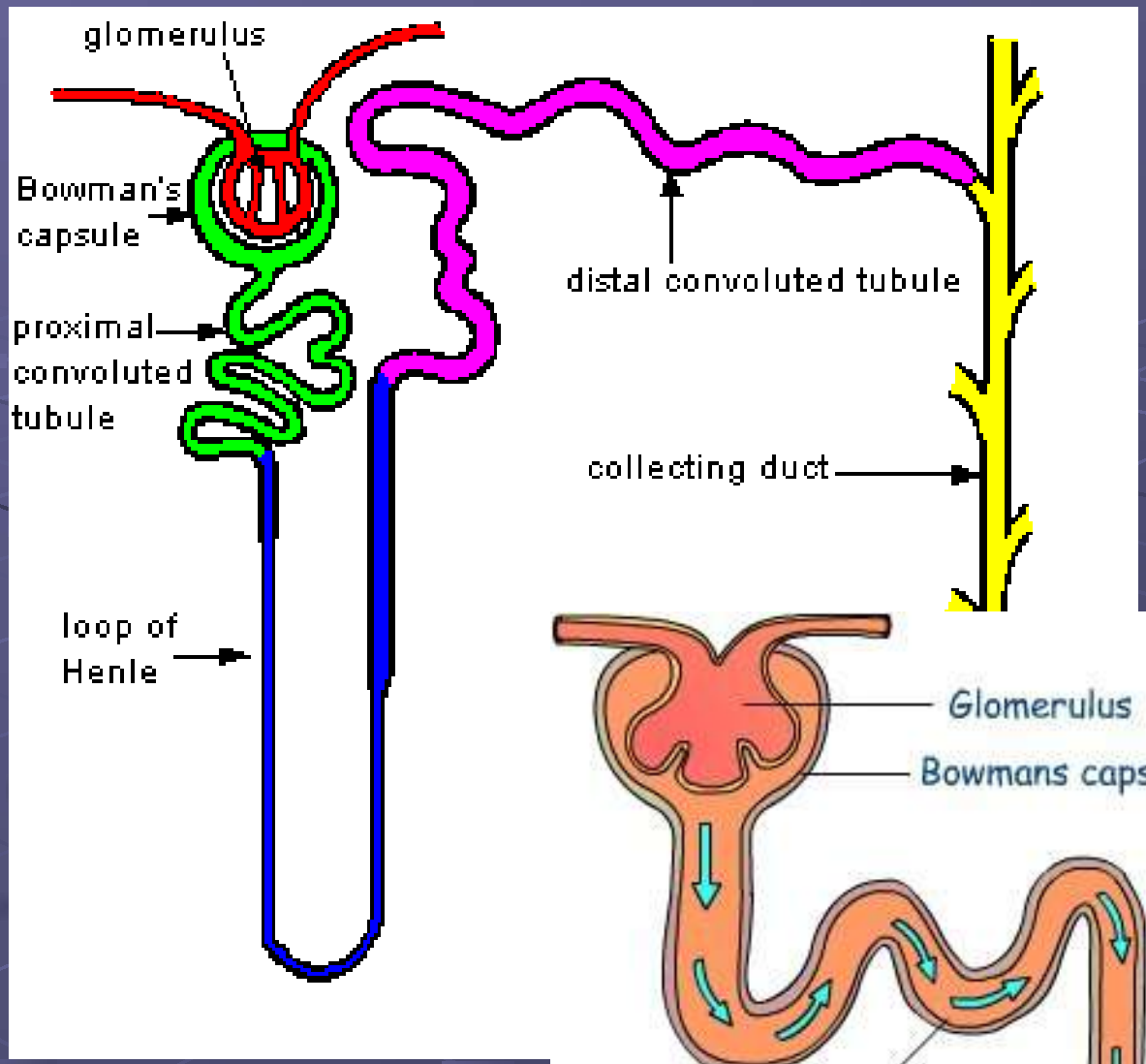


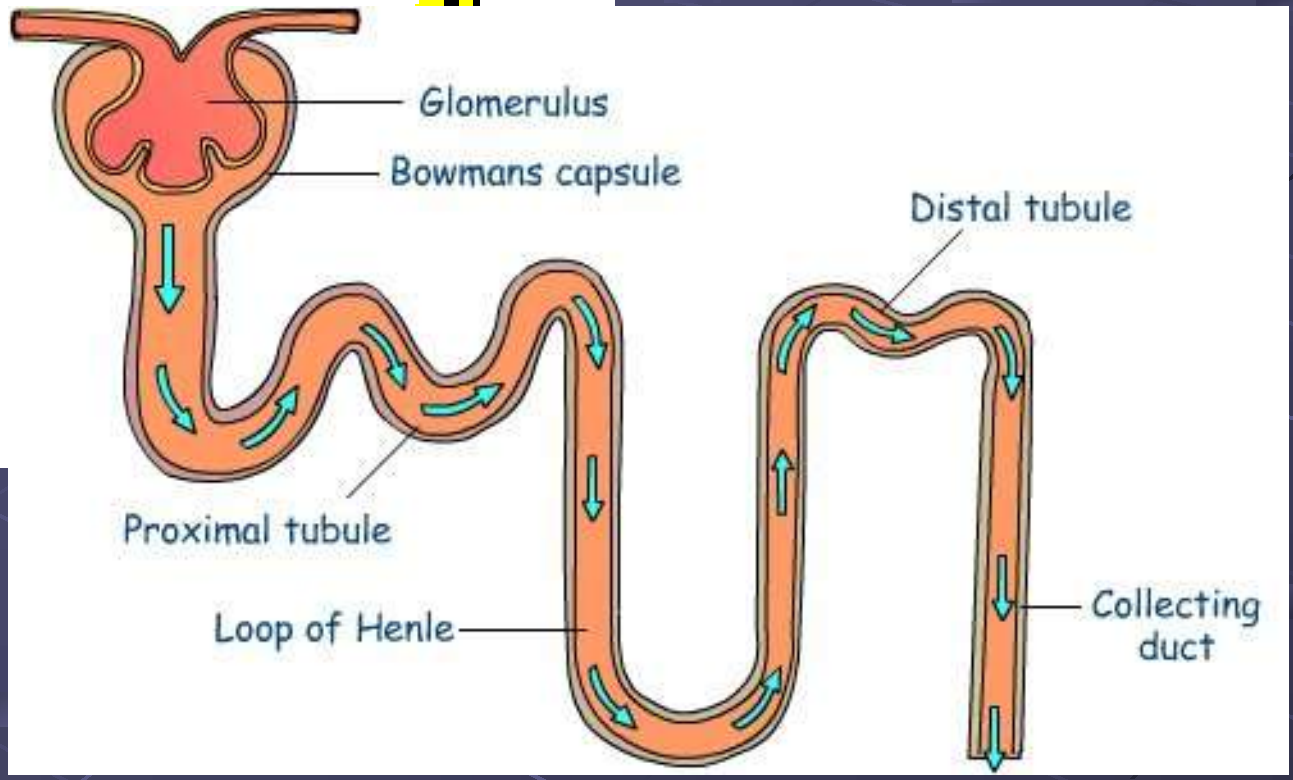
NEPHRON

- Functional unit of kidneys
  - filtration
  - reabsorption
  - secretion
- Types of nephrons
  - cortical (85%)
  - juxtamedullary (15)
- Subdivisions
  - renal corpuscle
    - glomerulus
    - Bowman's capsule
      - (parietal vs. visceral layer)
  - renal tubule
    - proximal convoluted
    - straight loop of Henle
    - distal convoluted
    - straight






glomerulus
Bowman's capsule
proximal convoluted tubule
loop of Henle
distal convoluted tubule
collecting duct


Glomerulus
Bowmans capsule
Distal tubule
Proximal tubule
Loop of Henle
Collecting duct

BASIC FUNCTIONS OF THE NEPHRON

Control blood concentration and volume
Regulate blood pH
Remove toxic wastes from the blood

So what do nephrons accomplish?

THREE PROCESSES IN URINE FORMATION

Glomerular filtration by the renal corpuscle
Tubular reabsorption by the renal tubule
Tubular secretion by the renal tubule

SUMMARY OF NEPHRON FUNCTIONS

PROXIMAL TUBULE

Reabsorbs:
- water (osmosis)
- sodium (active transport
- potassium (active transport)
- glucose (active transport)
- amino acids (active transport)
- chloride (simple diffusion)
- bicarbonate (simple diffusion)
- urea (simple diffusion)

Secretes:
- hydrogen
- ammonium
- urea
- creatinine

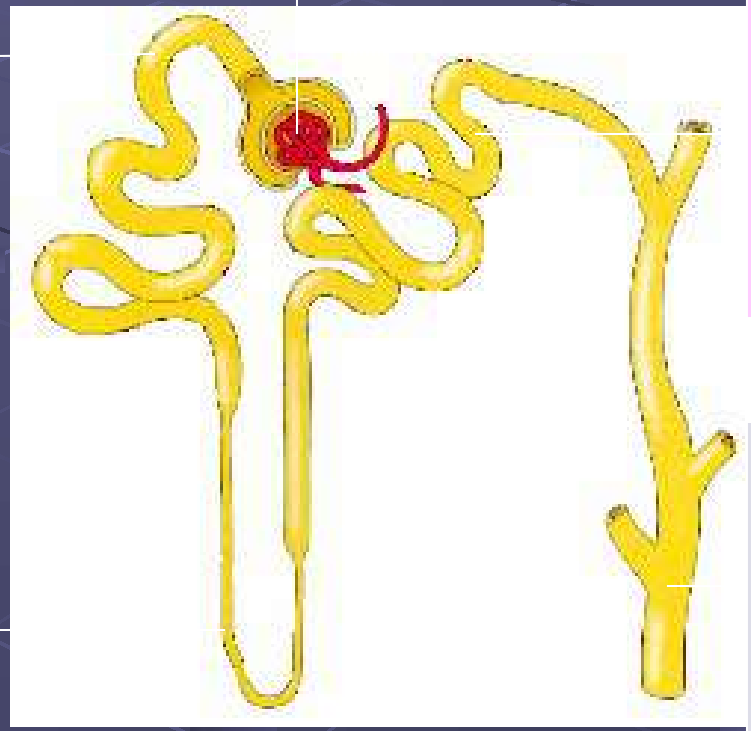
LOOP OF HENLE

Reabsorbs:
- water (osmosis)
- sodium (active transport
- potassium (active transport)
- chloride (active transport)

Secretes:
- urea

RENAL CORPUSCLE

Filtration = 125 ml/min
Filtrate includes all solutes in plasma except plasma proteins
Controlled by: autoregulation, angiotensin II, sympathetic neurons



DISTAL TUBULE

Reabsorbs:
- water (osmosis)
- sodium (active transport
- chloride (active transport)

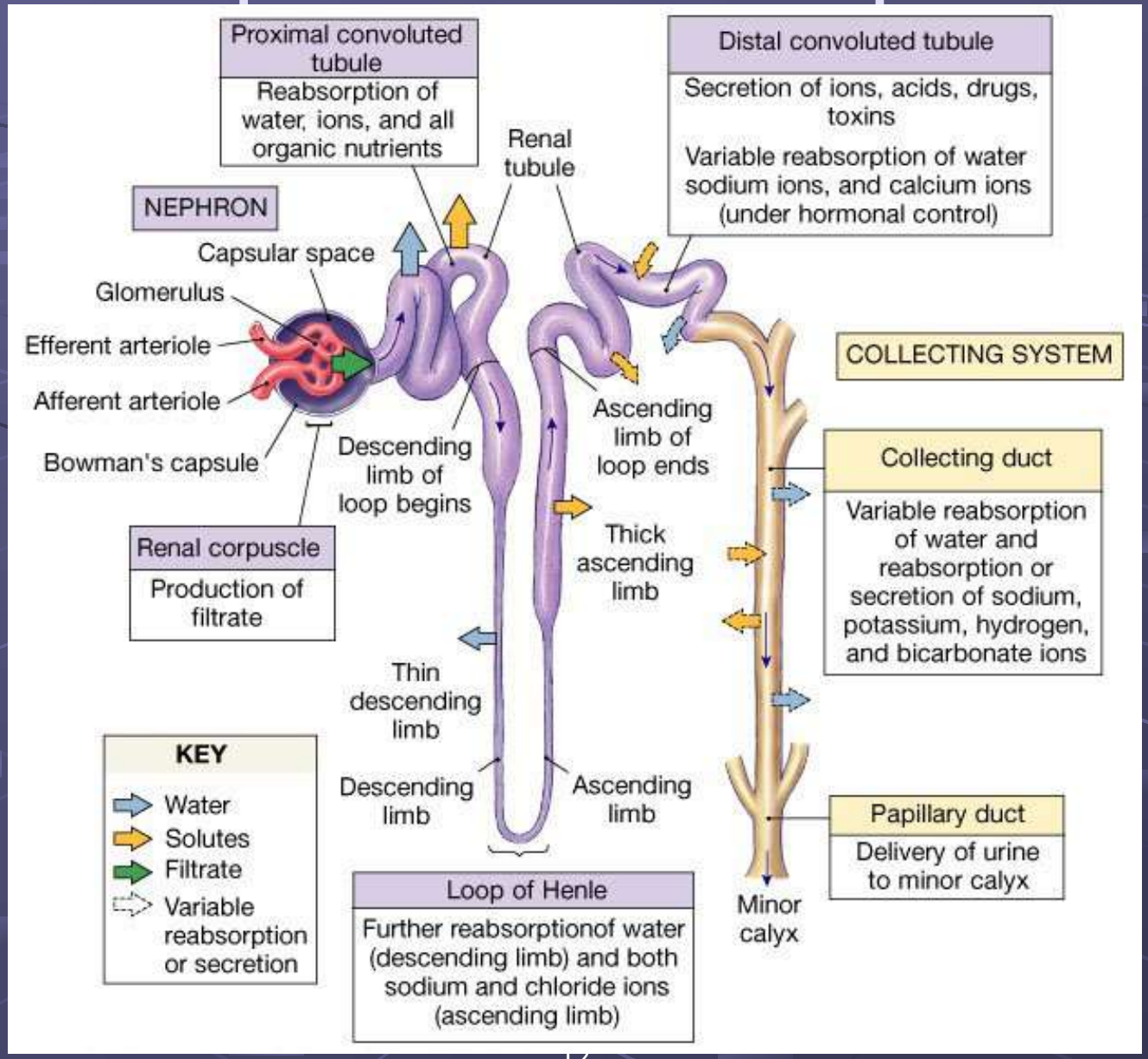
Secretes:
- potassium

COLLECTING DUCT

Reabsorbs:
- bicarbonate
- urea

Secretes:
- hydrogen

A Representative Nephron



Five Processes of Urinary System

- Filtration,
- Reabsorption,
- Secretion,
- Excretion
- Micturition; Urination

180 L / day filtered,

>99% reabsorbed,

1.5 L/day excreted

Figs 19-2/3

1) Filtration

= Movement of fluid from blood to lumen of nephron (rel. nonspecific process)

Once in lumen – consider it outside body

Composition of filtrate?

Fig 19-4

1) Filtration, cont'd: Passage across 3 Barriers

- Capillary endothelium is fenestrated
- Basal lamina
  - Filters proteins
- Bowman's capsule epithelium (visceral layer), including podocytes

Some small molecules (Ca^{2+}, low m.w. fatty acids) bind to plasma proteins ?

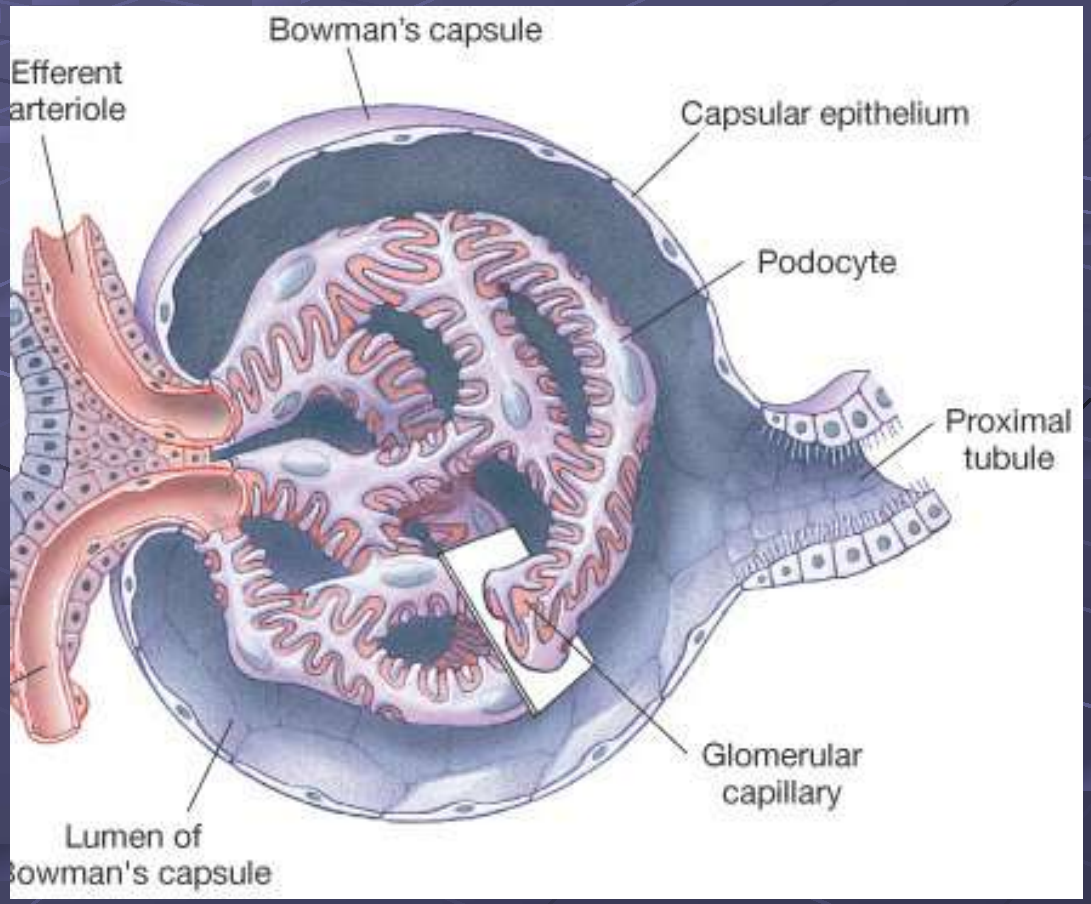


Fig 19-4

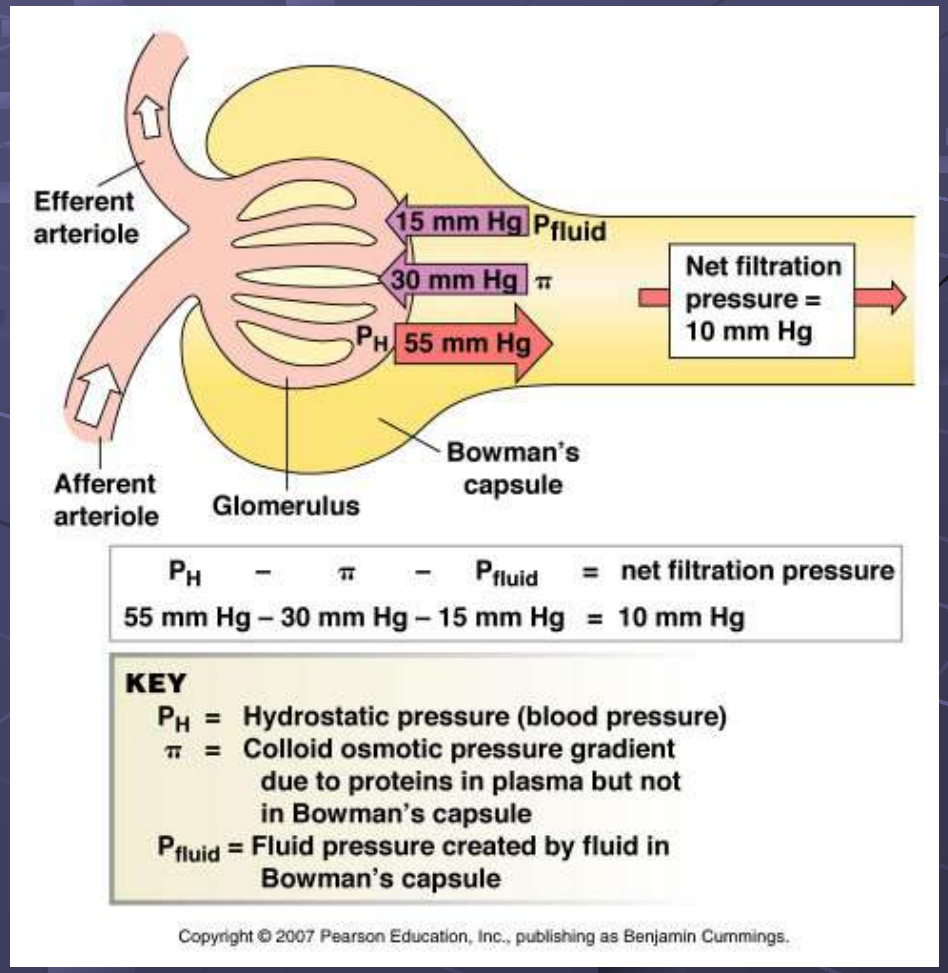
Cause of Filtration

Three types of pressures are at work:

- Hydrostatic pressure in capillaries (see exchange in tissues)
- Osm. $P_{capillaries}$ > Osm. $P_{Bowman's\ capsule}$
- Hydrostatic fluid P from presence of fluid in Bowman's capsule

Net (?) driving pressure: ~ 10 mmHg

Fig 19-6



GFR = Glomerular Filtration Rate

Fig 19-5

Describes filtration efficiency: Amount of fluid filtered per unit of time

Average GFR ~ 180 L/day!

Filtration Coefficient is influenced by

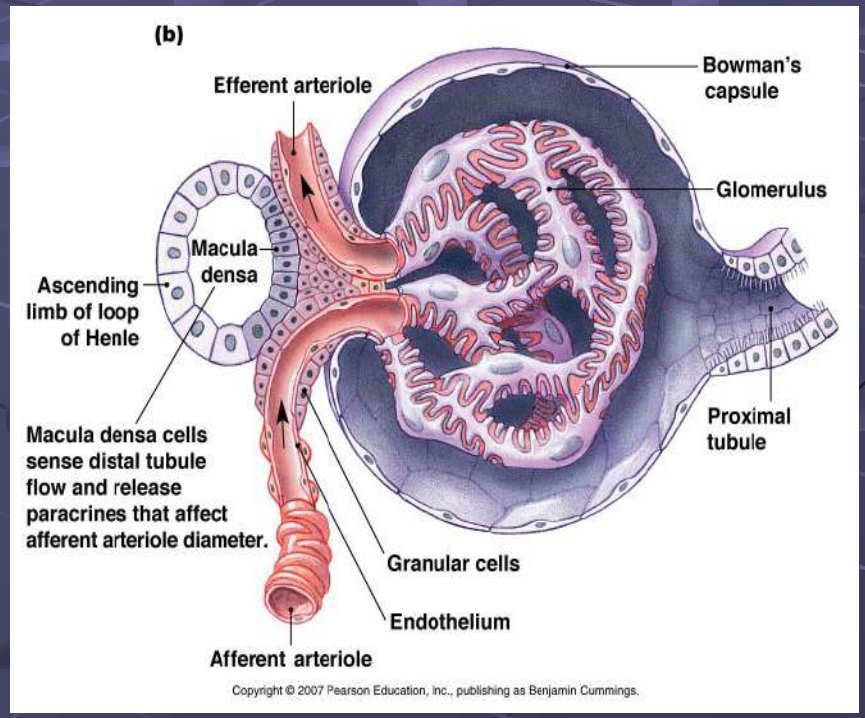
- Net filtration pressure
- Available surface area of glomerular capillaries

GFR is closely regulated to remain constant over range of BPs (80 - 180 mm Hg)

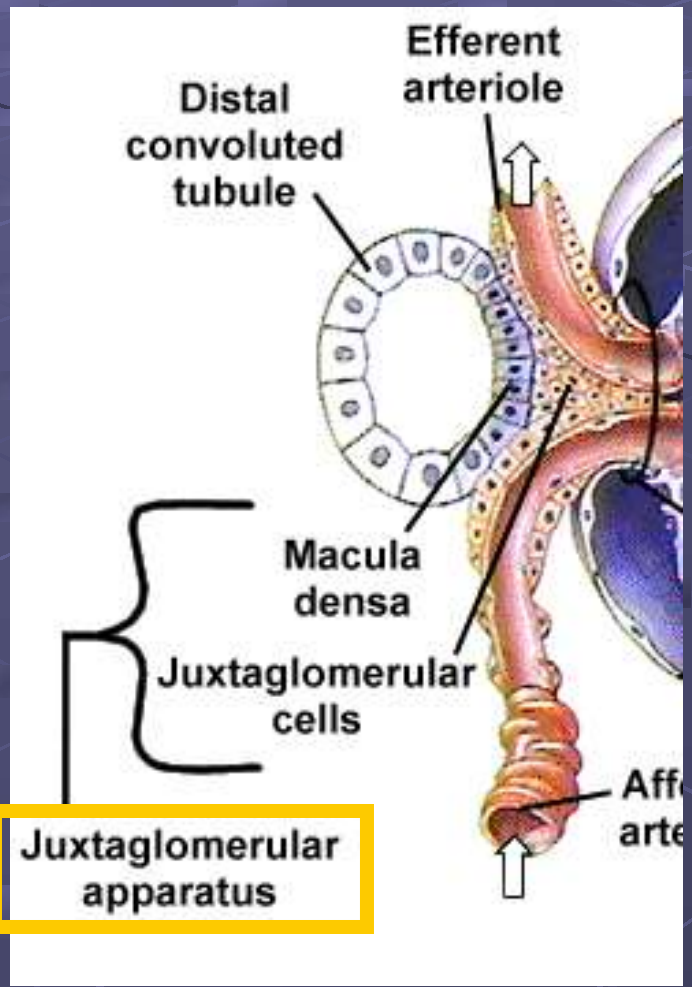
Goal is to control blood flow though both afferent and efferent arterioles – via ?

Regulation of GFR

- Several mechanisms provide close control of GFR;
  - Filtration Pressure (BP)
    - Hydrostatic, colloid
    - Resistance in afferent vs. efferent arterioles
  - Tubuloglomerular feedback
    - JG Apparatus
  - Hormones and ANS
    - Angiotensin II (vasoconstrictor)
    - Prostaglandins (vasodilator)



Regulation of GFR via Tubuloglomerular Feedback



As GFR , flow through DCT

↓

Macula densa cells: release paracrines

↓

juxtaglomerular cells (smooth muscle fibers from afferent arteriole): contract

↓

Thus GFR

Fig 19-10

2) Tubular Reabsorption (99% of filtrate)

Highly selective and variable

Amount of filtrate / day?

Urine production / day?

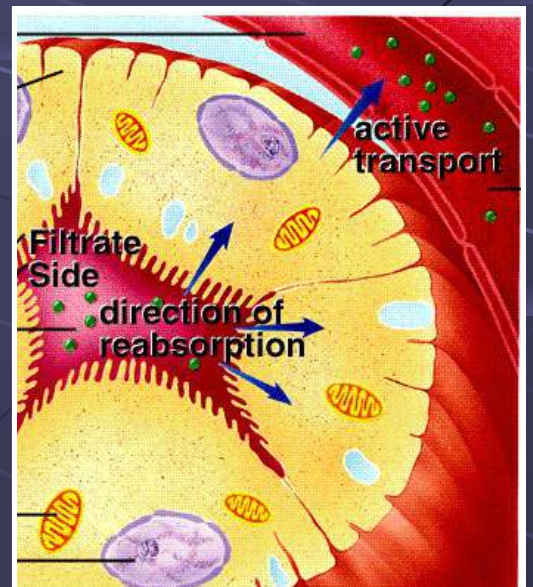
% reabsorbed?

Fig 19-5

Mostly transepithelial transport
(examples: Sodium and glucose)

Reabsorption may be active (Na^+, glucose) or passive (urea)

Figs 19-12/13



2) Tubular Reabsorption (99% of filtrate)

- May be active
  - Na^+ transport
    - Recall Antiports and Symports
- or Passive (think concentration and osmotic gradients)
  - Paracellular
  - E.g., urea
- Transcytosis
  - Proteins

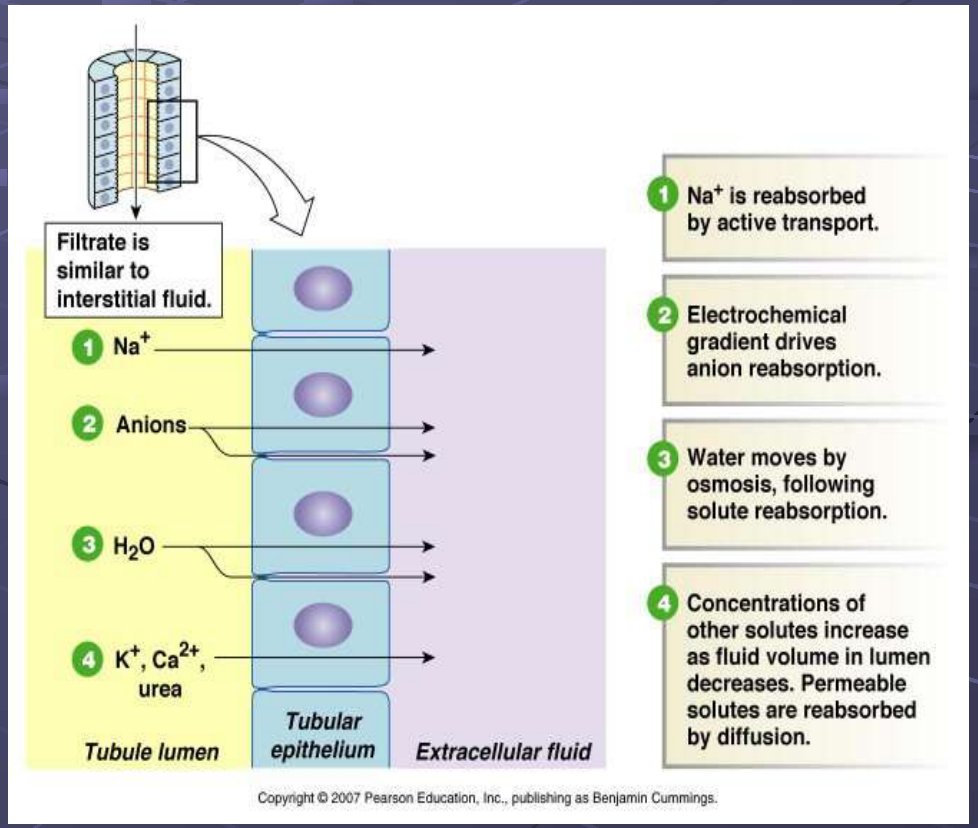
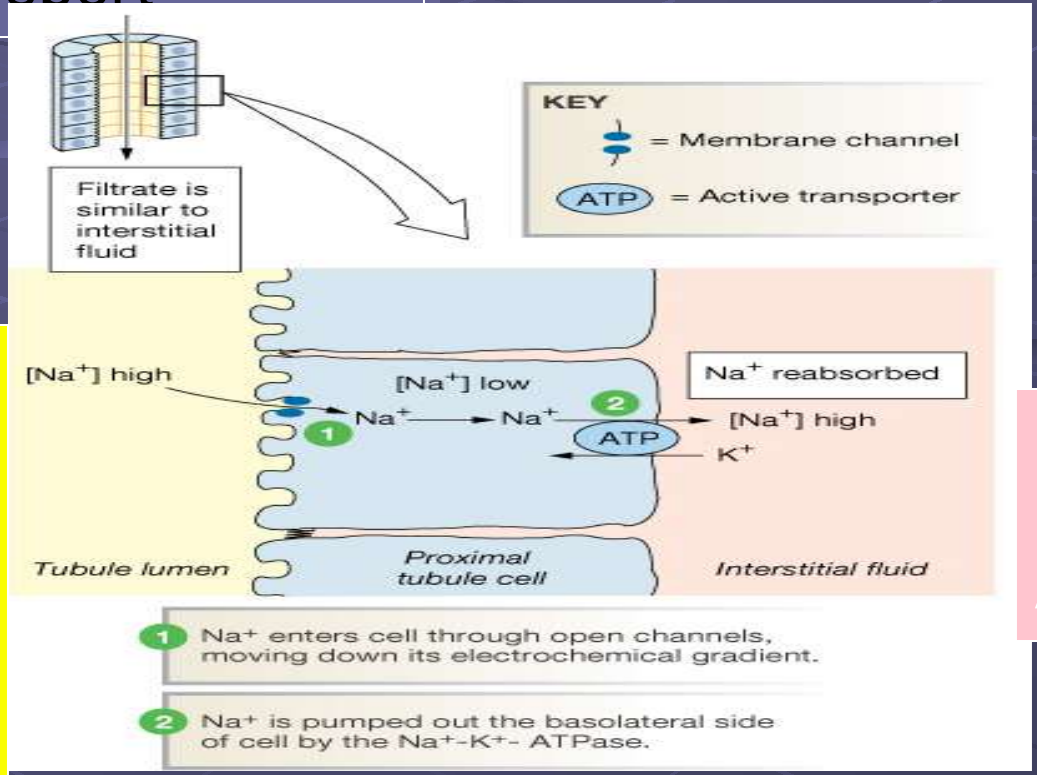


Fig 19-11

Na^+ Reabsorption in PCT: Transepithelial Transport

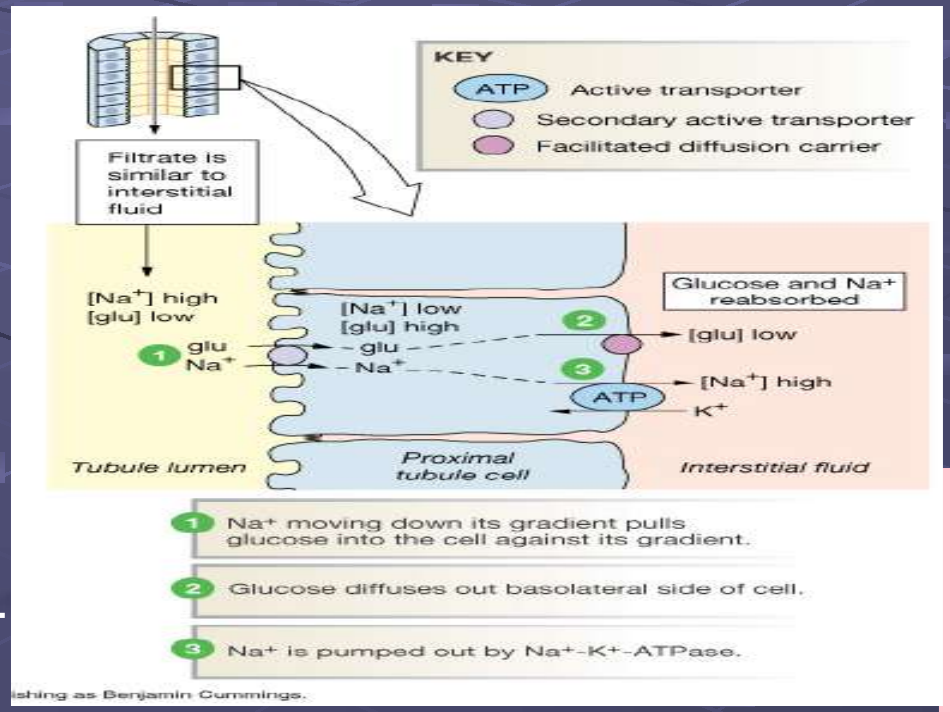
Apical: Leak channels for Na^+. Movement down conc. gradient.



Basolateral: Na^+/K^+ ATPase.

Fig 19-12

Na^+ Linked Glucose Reabsorption



Apical: Na^+-glucose cotransport

Basolateral: Glucose diffusion down conc. gradient

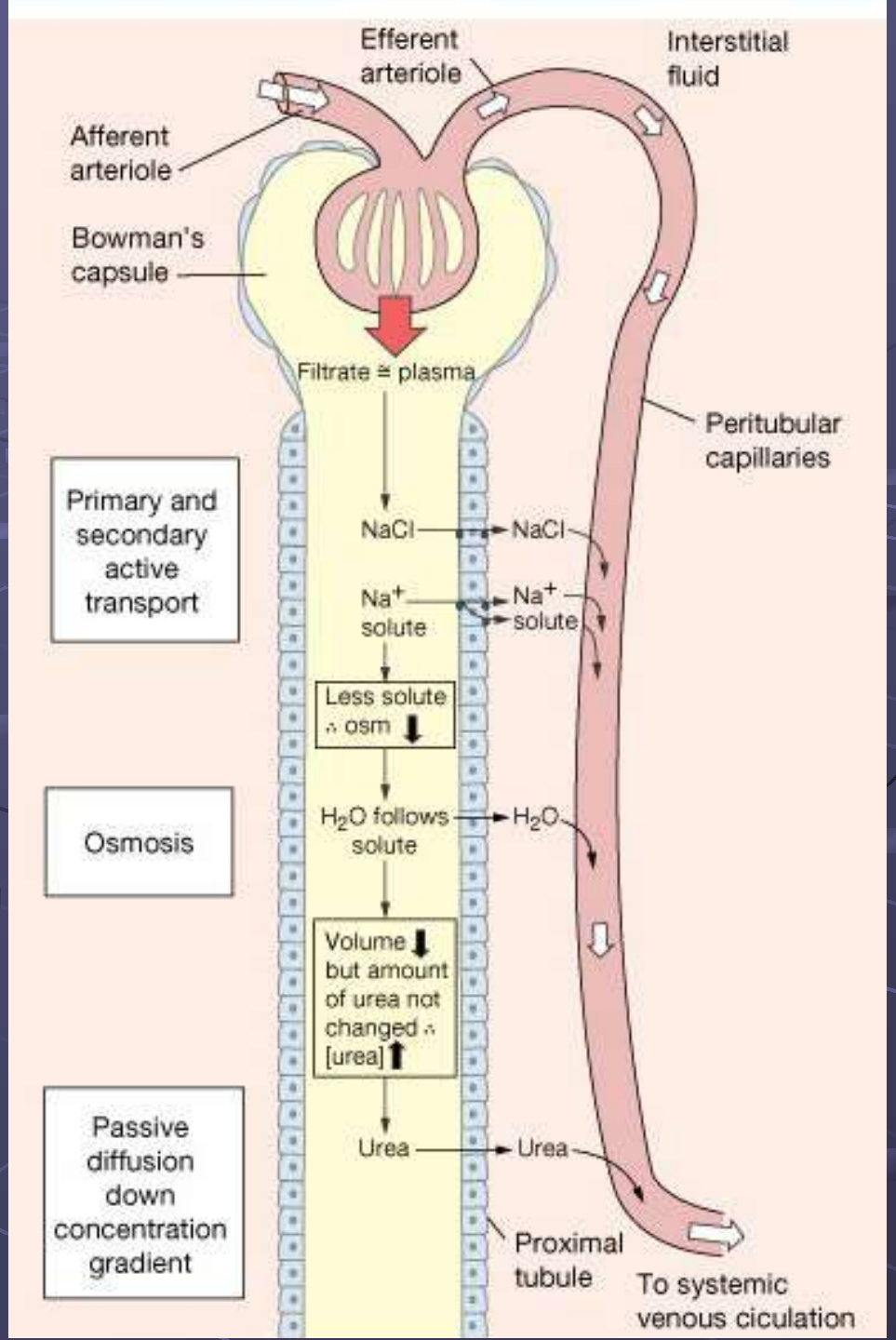
Fig 19-13

Passive Urea Reabsorption

Na^+ actively reabsorbed

H_2O follows passively

[urea] passive reabsorption (diffusion into blood)



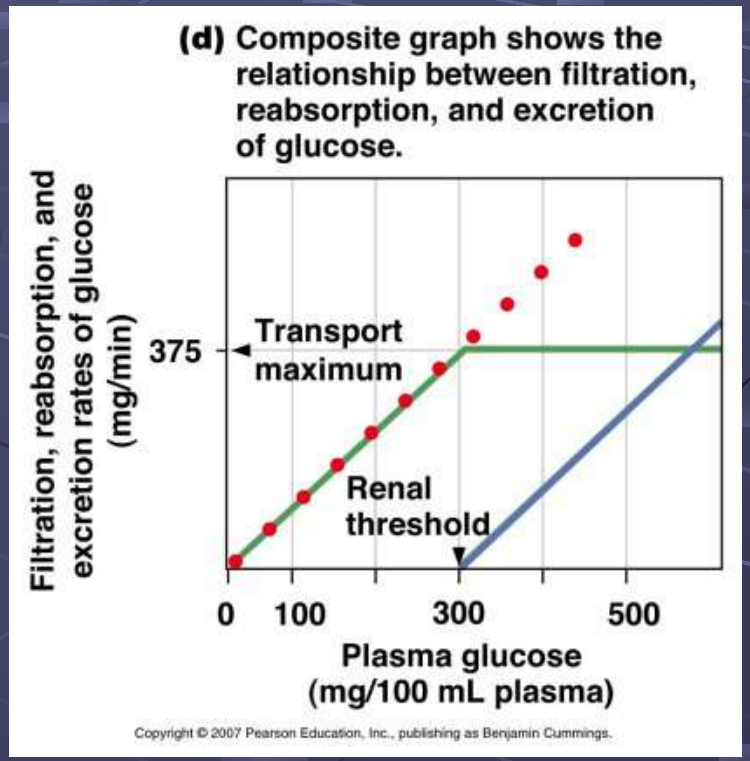
Saturation of Renal Transport

Saturation = Maximum rate of transport (t_m)

Same 3 characteristics as discussed in mediated transport

Transport maximum determined by

- Saturation Renal Threshold
- Specificity
- Competition



(Fig 19-15d)

3) Secretion

- 2^{nd} route of entry (from ECF) into tubules for selected molecules
- Mostly transepithelial transport (analogous to reabsorption). Depends mostly on active membrane transport systems
- Provides mechanism for rapid removal of substances (most important for H^+, K^+, foreign organic ions and drugs such as penicillin etc.)

4) Excretion = Urine Output

- Excretion of excess ions, H_2O, toxins, “foreign molecules” “nitrogenous waste” (NH_4^+, urea)
- Depends on Filtration, Reabsorption, Secretion
  - E = F – R + S
- Direct measurement of F, R, S impossible
  - infer from comparison of blood & urinalysis
- For any substance: (Renal) Clearance = plasma volume completely cleared of that substance per minute
  - Typically expressed as ml/min

Clinical Importance of GFR and Clearance

- GFR is indicator for overall kidney function
- Clearance non-invasive way to measure GFR
  - Inulin (research use)
    - Neither secreted nor reabsorbed
  - Creatinine (clinically useful)
- If a substance is filtered and reabsorbed but not secreted clearance rate < GFR
- If a substance is filtered and secreted but not reabsorbed clearance rate > GFR

5. Micturition

Spinal cord integration: 2 simultaneous efferent signals

In infant just simple spinal reflex

Later: learned reflex under conscious control from higher brain centers

Various subconscious factors affect reflex

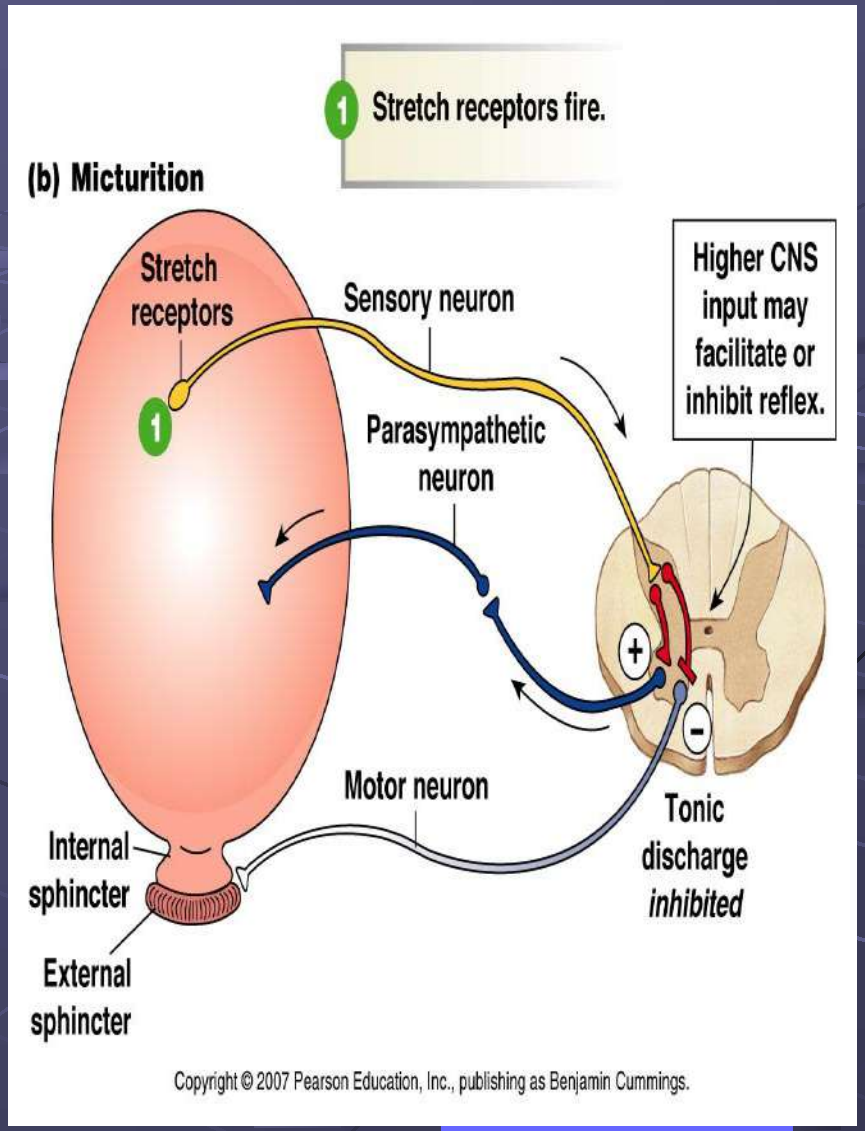


Fig 19-18

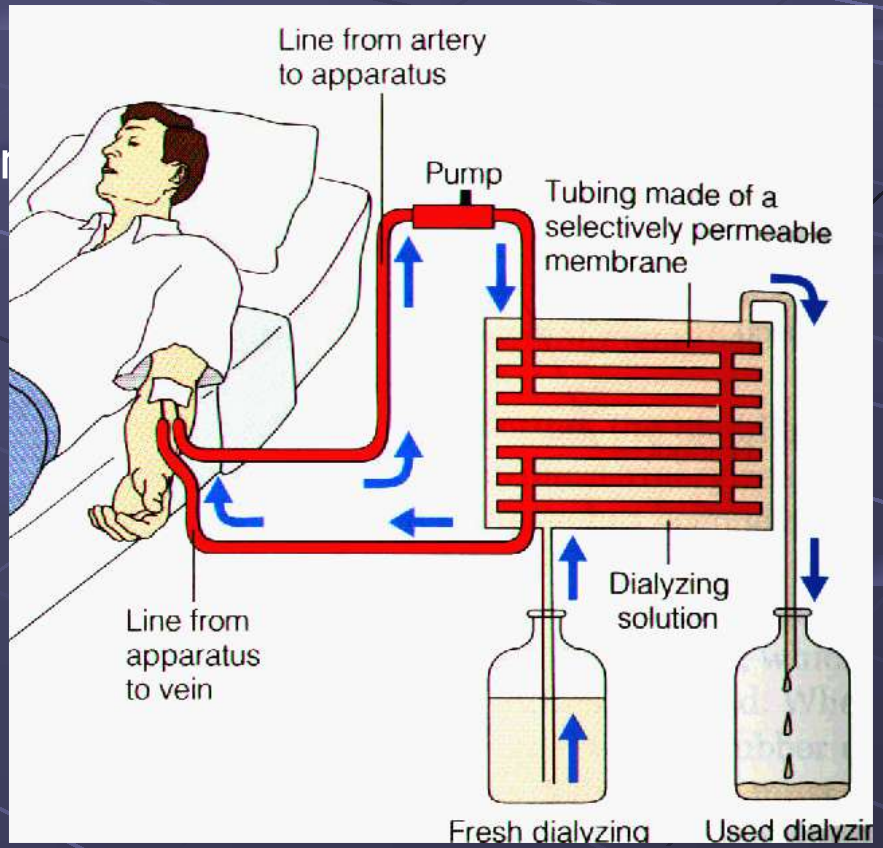
Renal Failure & Artificial Kidney

Symptoms when < 25% functional nephrons

due to:

- Kidney infections
- Chemical poisoning (lead, paint-thinner etc.

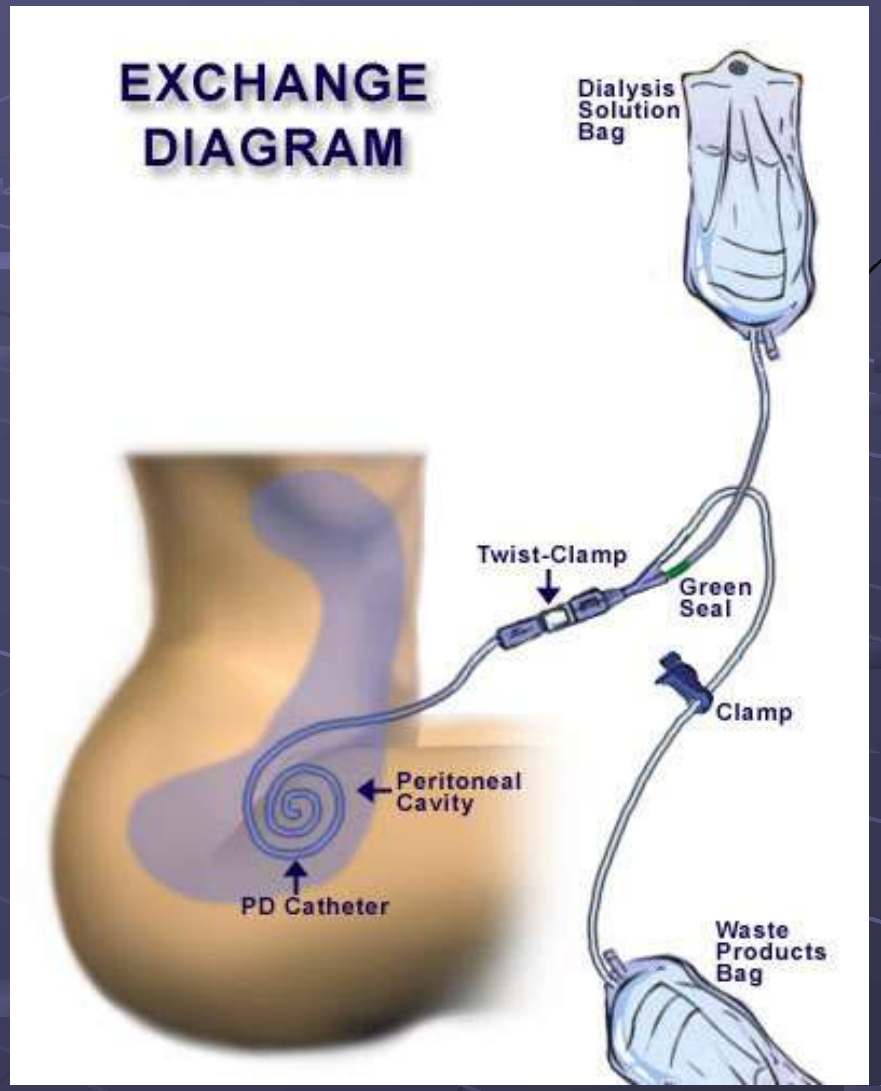
Hemodialysis: 3/week
4-8h/session



Alternative: CAPD

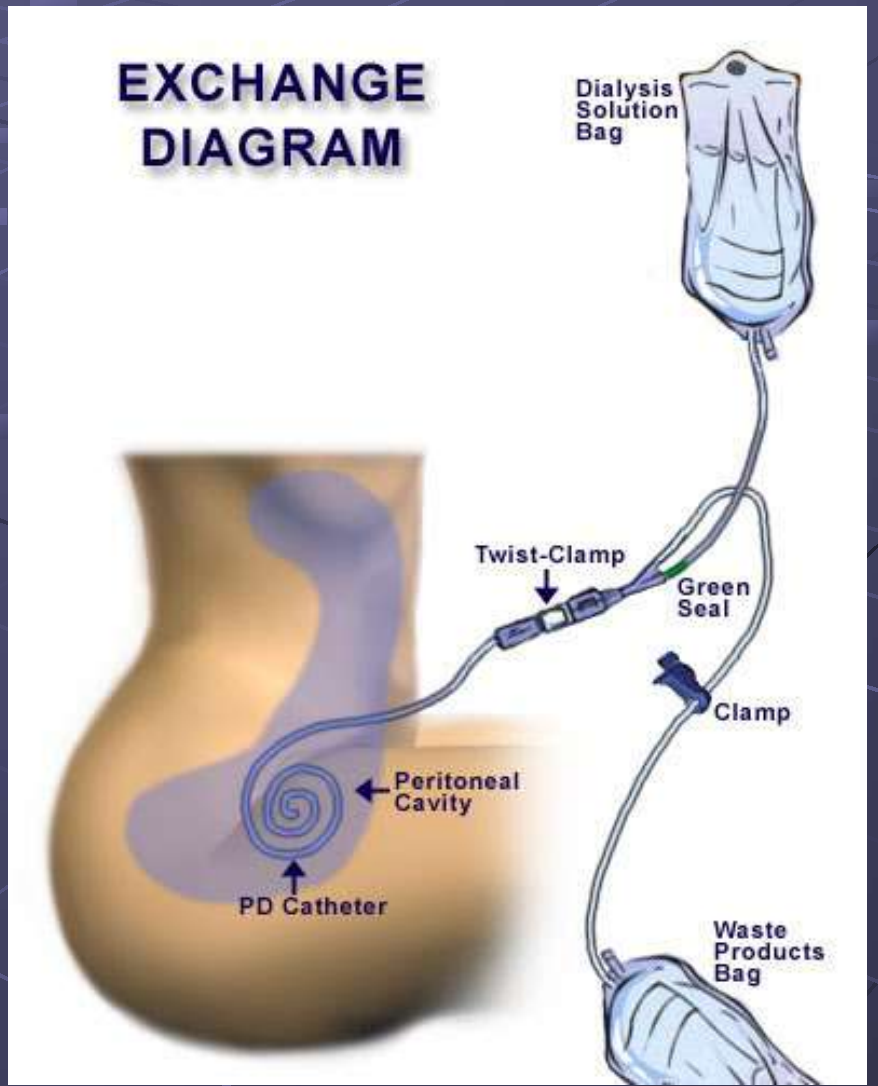
CAPD: permanently implanted catheter to abdominal cavity. 2 L of dialysis fluid are inserted and removed several times a day.
Advantage: patients can self-administer it. Blood is continuously purified and adjusted. Patient can engage in normal activities while dialysis is being accomplished.
Disadvantage: increased risk of peritoneal infections.

C Continuous Dialysis carries on all the time.
A Ambulatory Unlike Haemodialysis you can move around as normal and carry out your daily activities.
P Peritoneal An enclosed layer of tissue where Dialysis takes place. The Peritoneal surrounds your intestines.
D Dialysis Dialysis removes waste products from your blood.



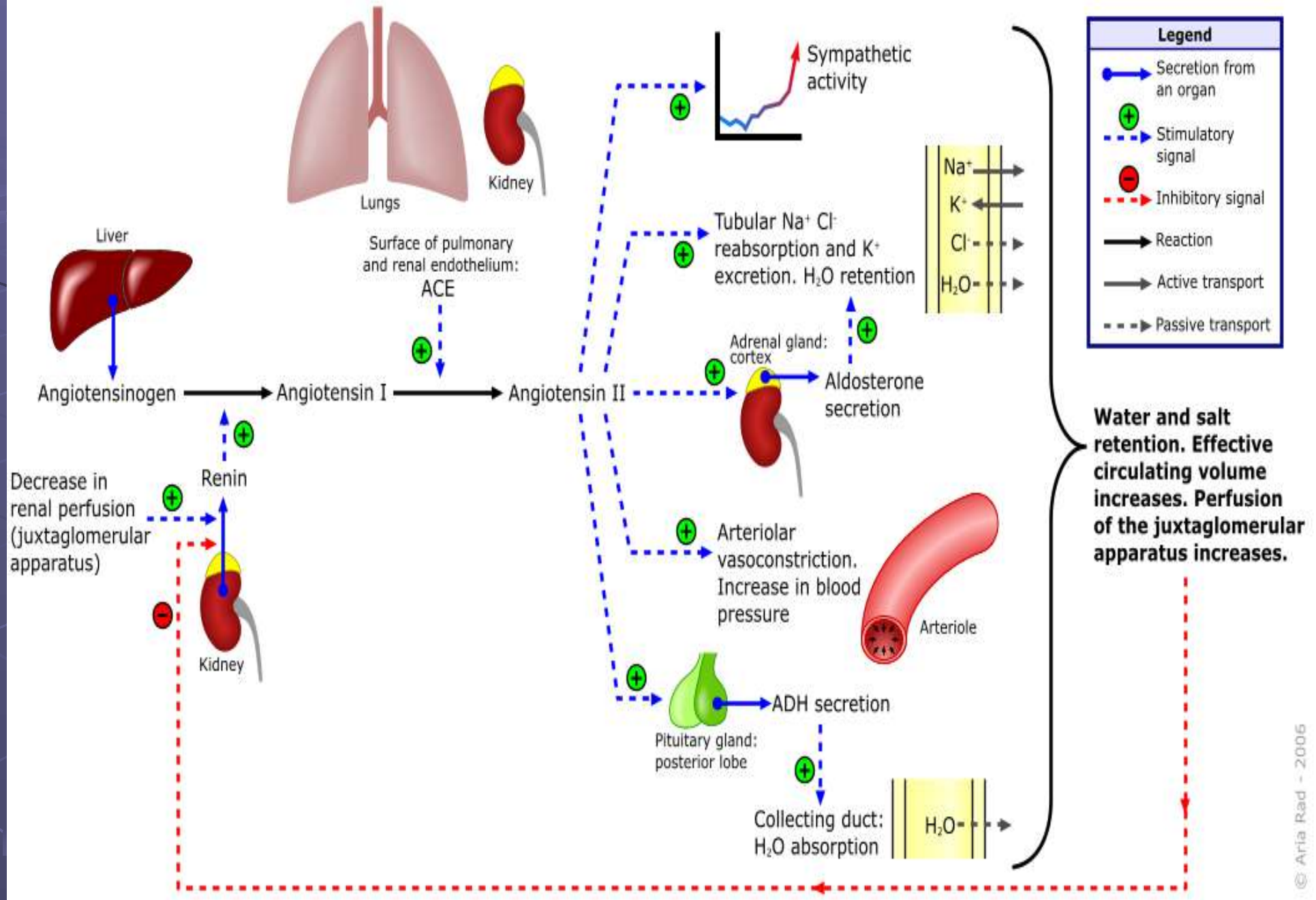
Alternative: CAPD

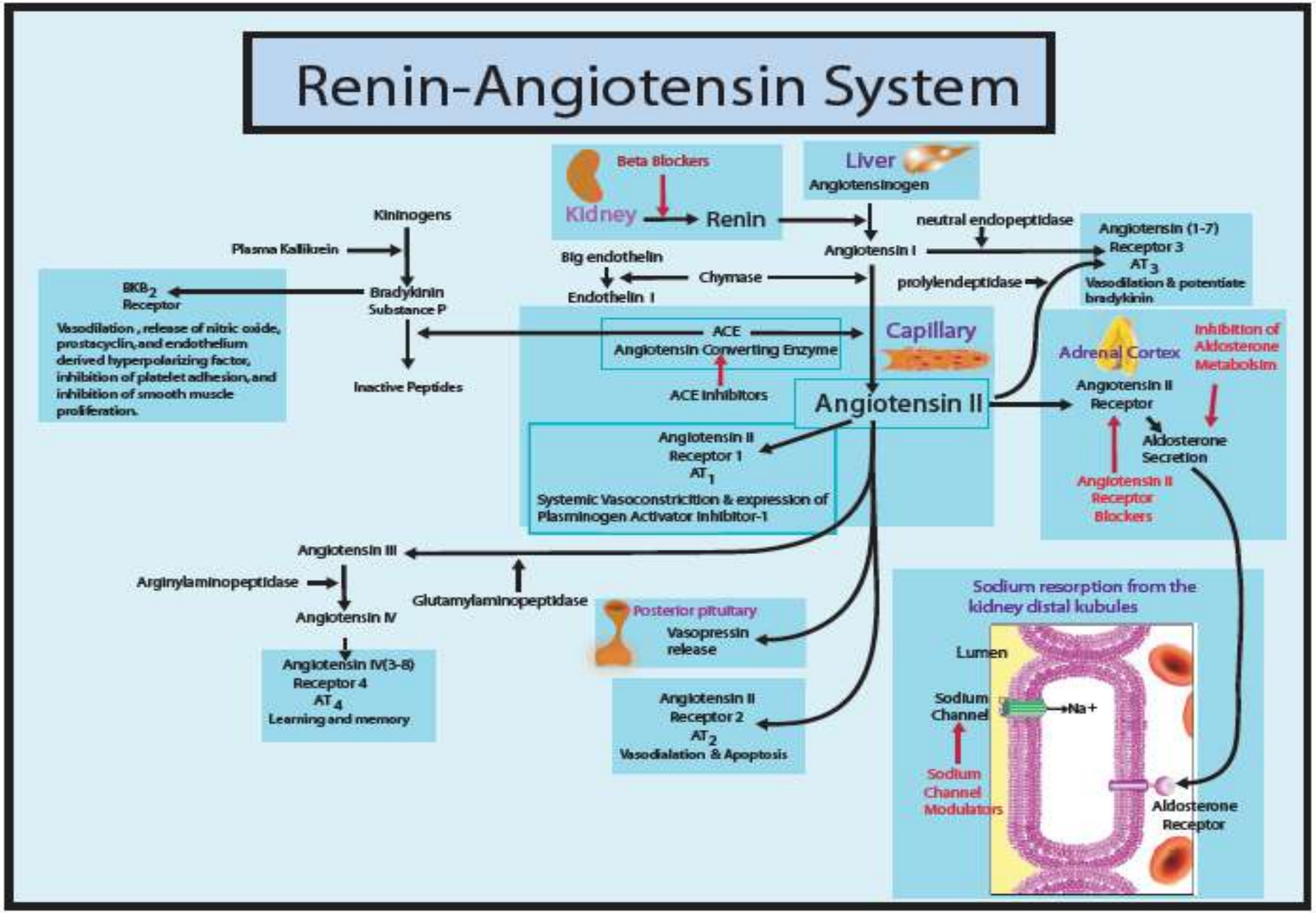
Continuous
Ambulatory
Peritoneal
Dialysis

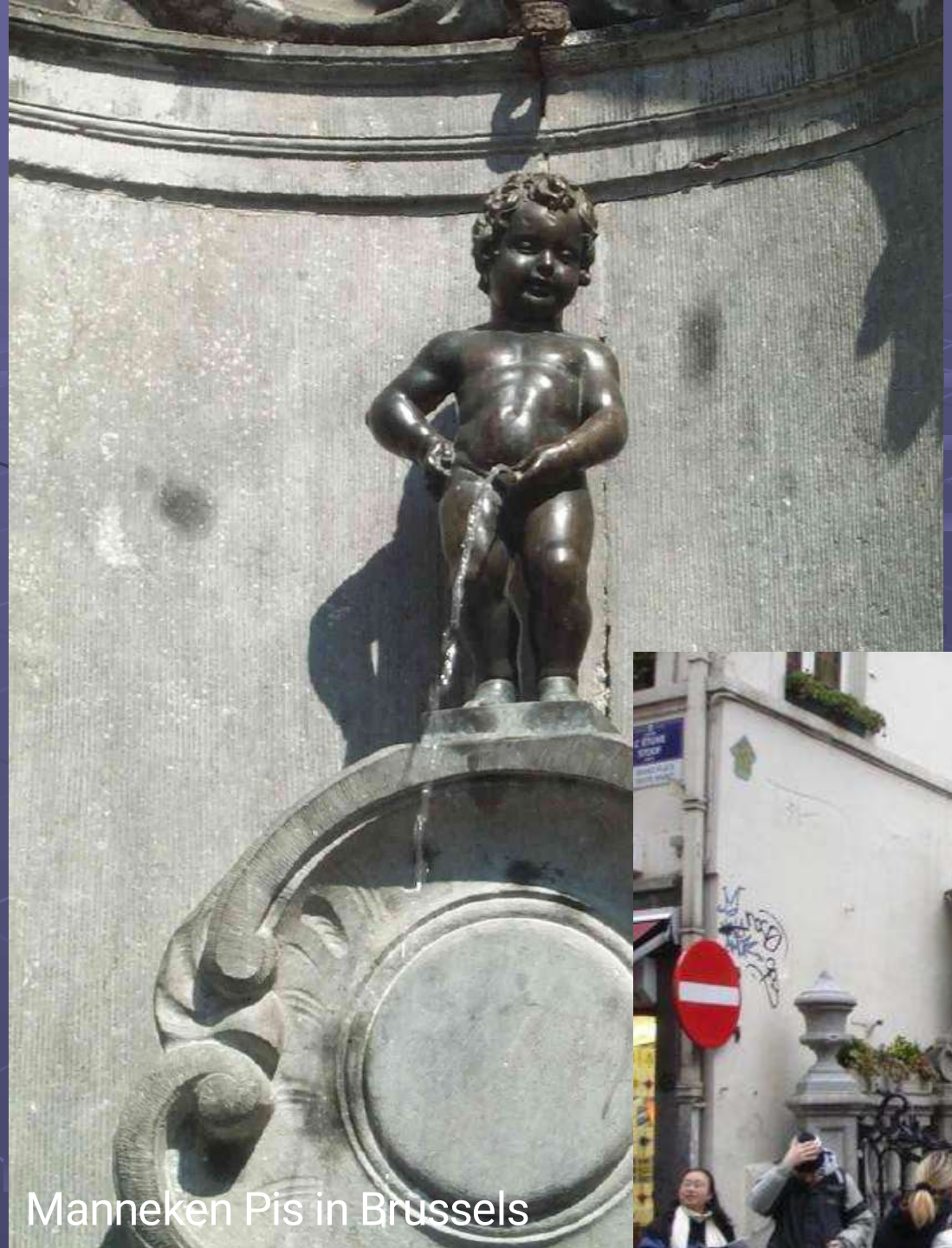


Renin-Angiotensin-Aldosterone System

Renin-angiotensin-aldosterone system




Renin-Angiotensin System
Beta Blockers
Kidney
Renin
Liver
Angiotensinogen
Kininogens
Plasma Kallikrein
Bradykinin
Substance P
Inactive Peptides
BKB2 Receptor
Vasodilation , release of nitric oxide, prostacyclin, and endothelium derived hyperpolarizing factor, inhibition of platelet adhesion, and inhibition of smooth muscle proliferation.
Big endothelin
Endothelin I
Chymase
neutral endopeptidase
Angiotensin I
prolylendeptidase
Angiotensin (1-7)
Receptor 3
AT3
Vasodilation & potentiate bradykinin
ACE
Angiotensin Converting Enzyme
ACE Inhibitors
Capillary
Angiotensin II
Adrenal Cortex
Inhibition of Aldosterone Metabolism
Angiotensin II Receptor
Aldosterone Secretion
Angiotensin II Receptor Blockers
Angiotensin II
Receptor 1
AT1
Systemic Vasoconstriction & expression of Plasminogen Activator Inhibitor-1
Angiotensin III
Arginylaminopeptidase
Angiotensin IV
Glutamylaminopeptidase
Posterior pituitary
Vasopressin release
Angiotensin IV(3-8)
Receptor 4
AT4
Learning and memory
Angiotensin II
Receptor 2
AT2
Vasodilation & Apoptosis
Sodium resorption from the kidney distal kubules
Lumen
Sodium Channel
Na+
Sodium Channel Modulators
Aldosterone Receptor



Manneken Pis in Brussels

the end

Neurotransmitters and The Synapse

Synapse

sin-aps, si-naps

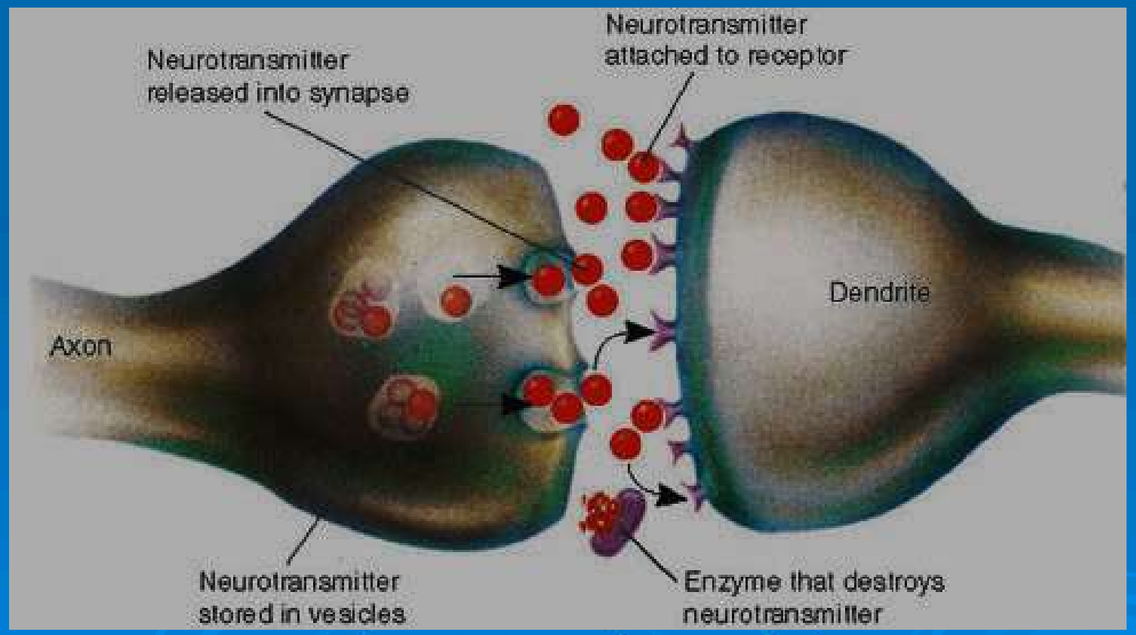
Synapse

(noun) Small gap between nerve cells

Use in a sentence: A synapse is cool.

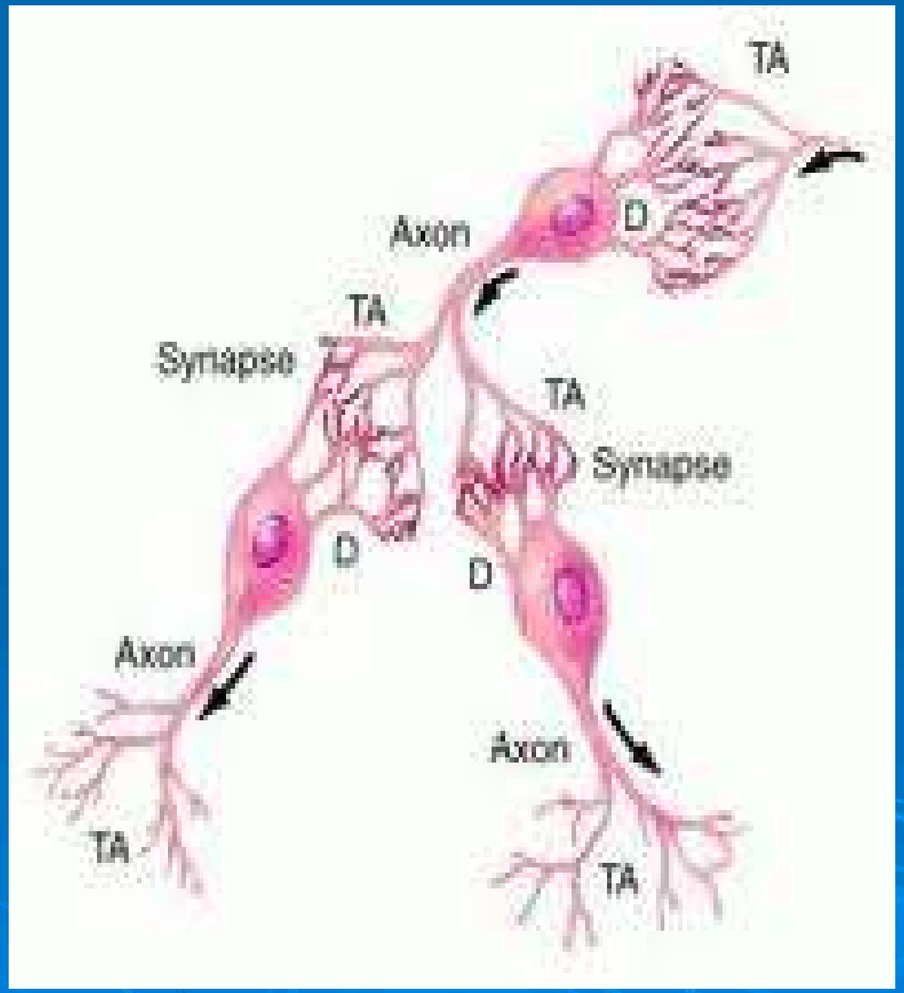
Synapse

- Synapse: unique junction that mediates information flow from one neuron to another or effector cell…



synapse

- Most synapses occur between axon of one nerve and the dendrite of another…



Synapse

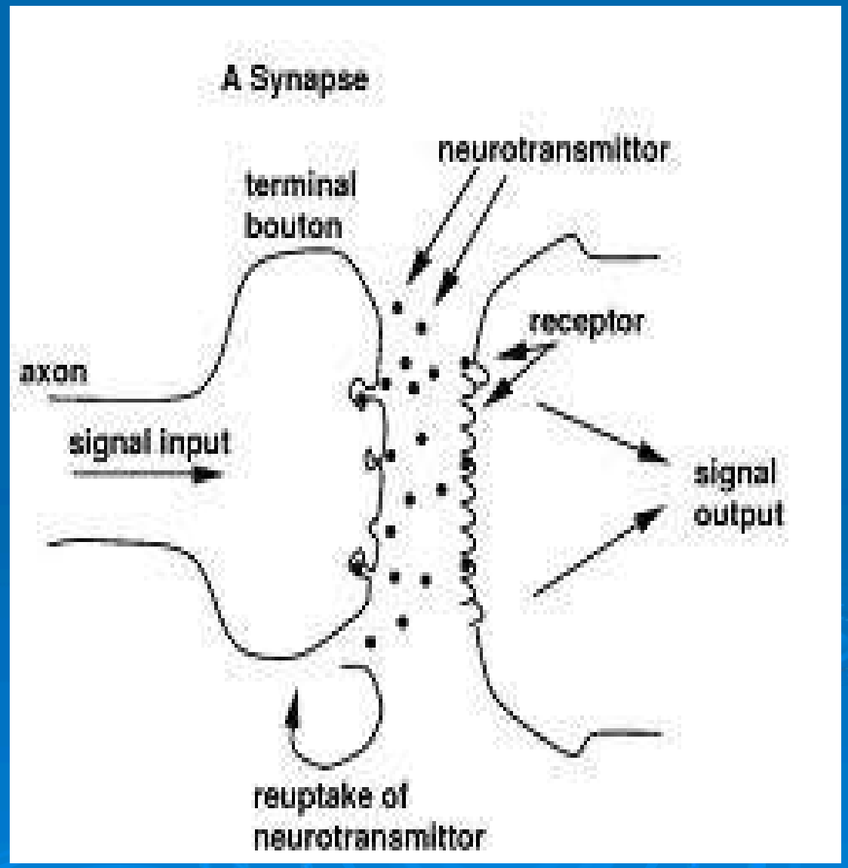
- Synapses are one of the means by which excitable cells communicate with one another.

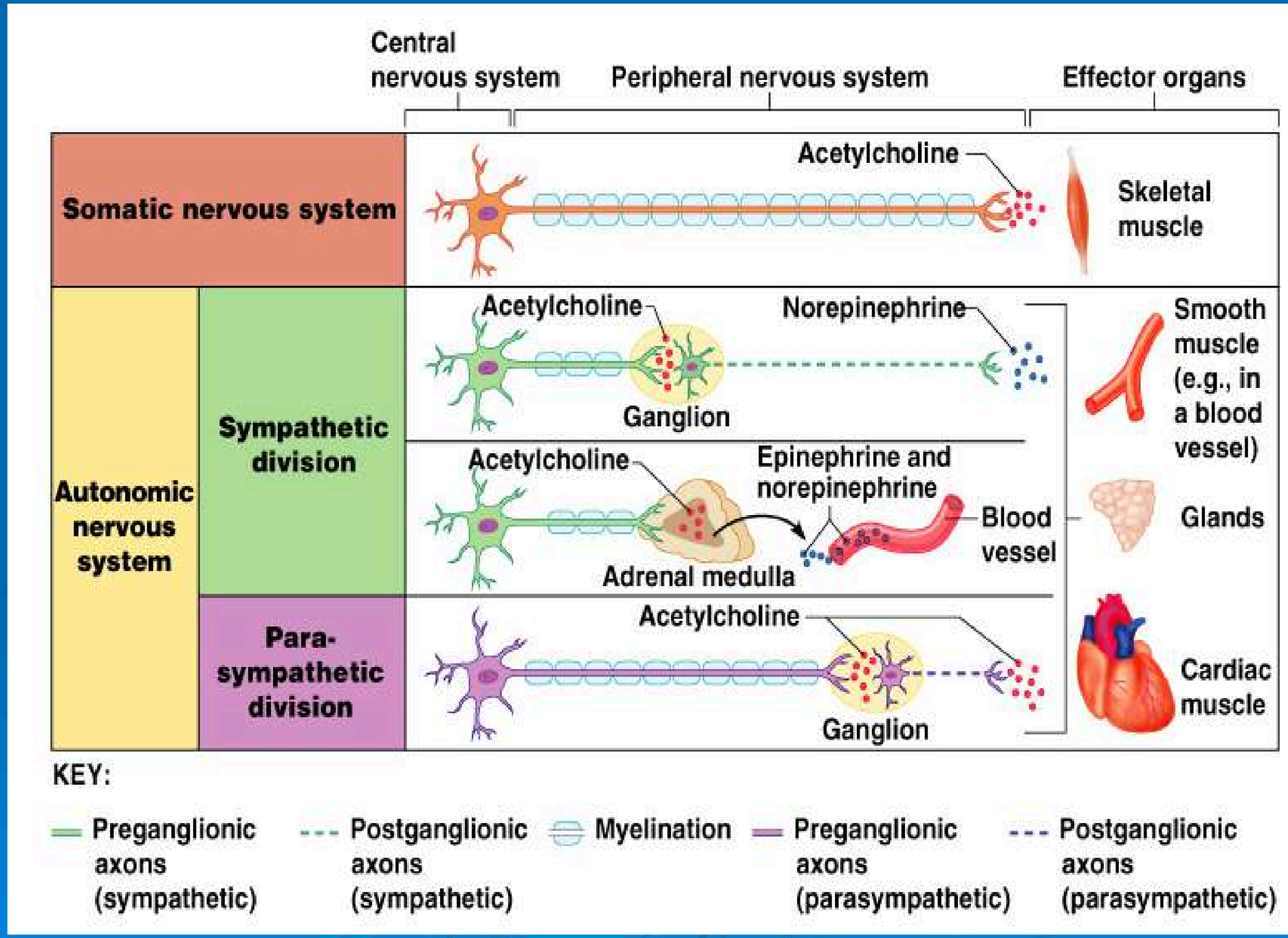
- Nerve to nerve synapse,
- Nerve to muscle - neuromuscular junction, and
- Nerve to gland - neuroglandular junction

Pre vs Post

Presynaptic neuron- carries impulse towards a synapse “Sender”

Postsynaptic neuron- carries impulse away from a synapse “receiver”




Central nervous system
Peripheral nervous system
Effector organs
Somatic nervous system
Acetylcholine
Skeletal muscle
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Sympathetic division
Acetylcholine
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Ganglion
Smooth muscle (e.g., in a blood vessel)
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Epinephrine and norepinephrine
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Para-sympathetic division
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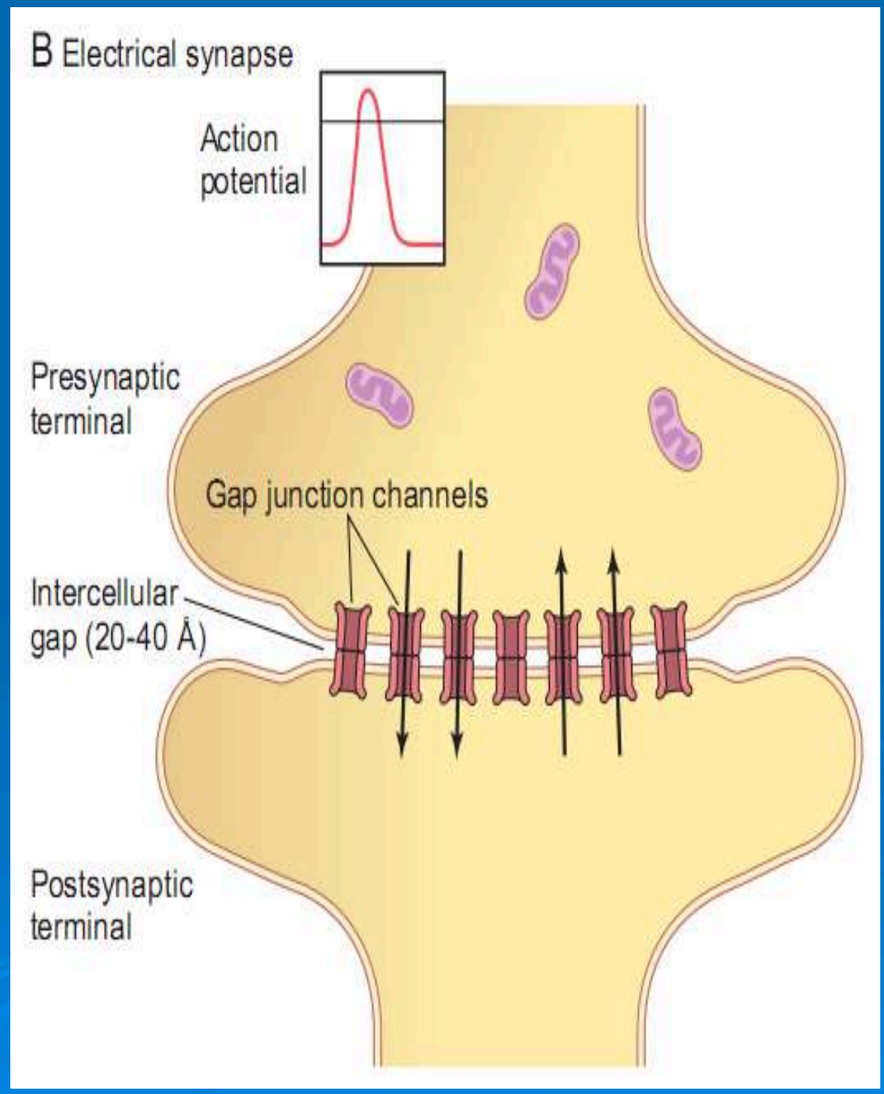
KEY:
Preganglionic axons (sympathetic)
Postganglionic axons (sympathetic)
Myelination
Preganglionic axons (parasympathetic)
Postganglionic axons (parasympathetic)

Types of synapse

- There are two general types of synapses
  - Electrical Synapses (Gap Junctions)
  - Chemical Synapses (Neurological)

Electrical Synapse

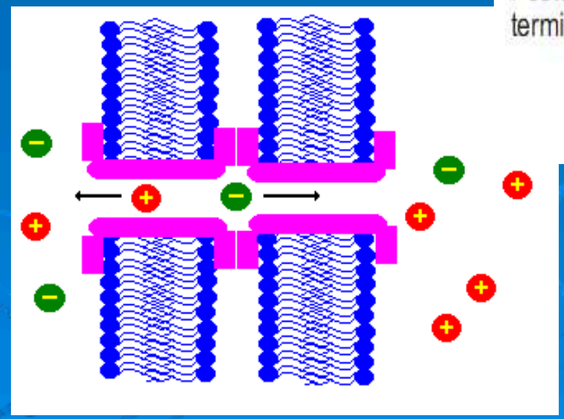
- Electrical Synapses -
- 1. Characteristics of electrical synapses
  - a. Gap junctions
  - b. Cytoplasmic continuity - direct ionic pathway cell to cell
  - c. No delay in transmission of the AP
  - d. Can be unidirectional or bidirectional
  - e. Locations - cell membrane to cell membrane protein interconnection

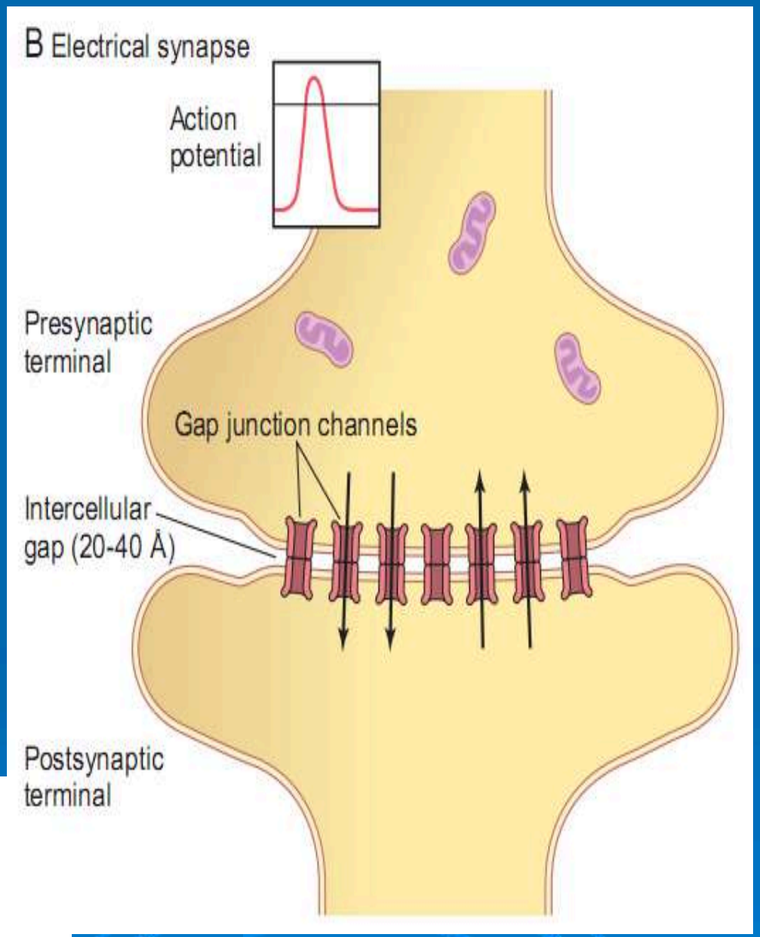


Electrical Synapse

- Allow current carrying ions to flow directly from one neuron to the next

- Found in the brain, limited in adulthood
- Most are replaced by **chemical synapses**

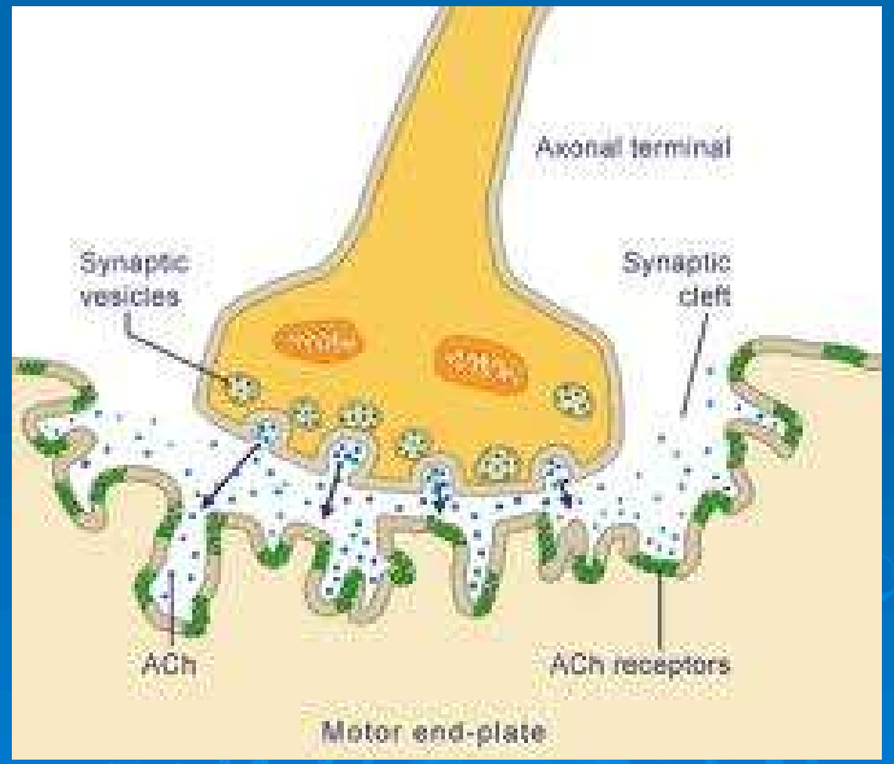




Chemical Synapses

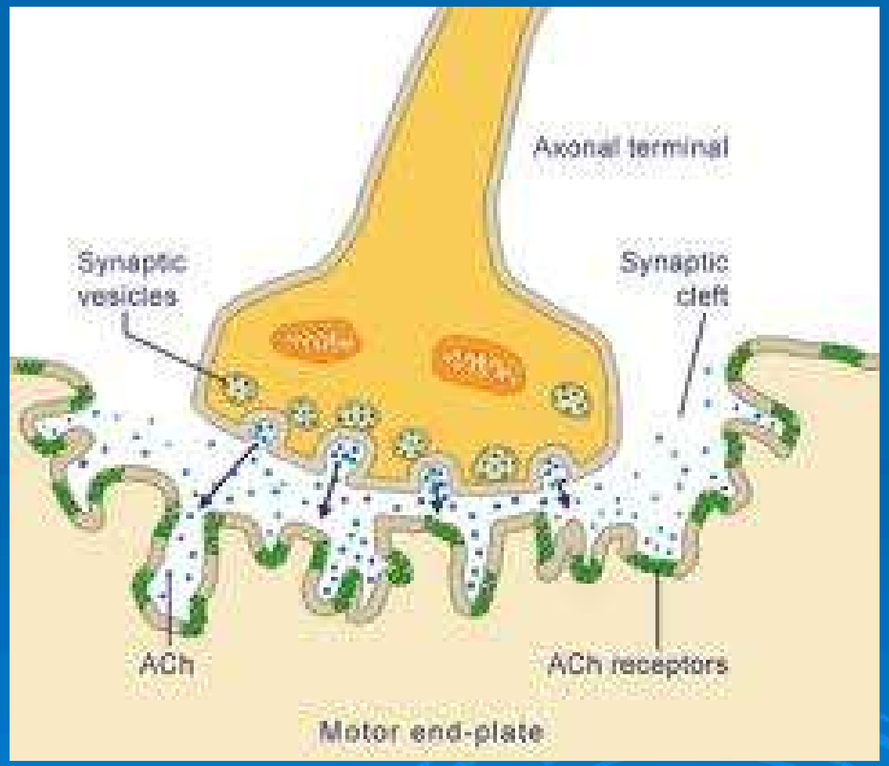
B. Chemical Synapses

- Important characteristics
- 1. one way transmission
- 2. time delay
- 3. exocytosis
- 4. diffusion
- 5. receptor activation



Chemical Synapses

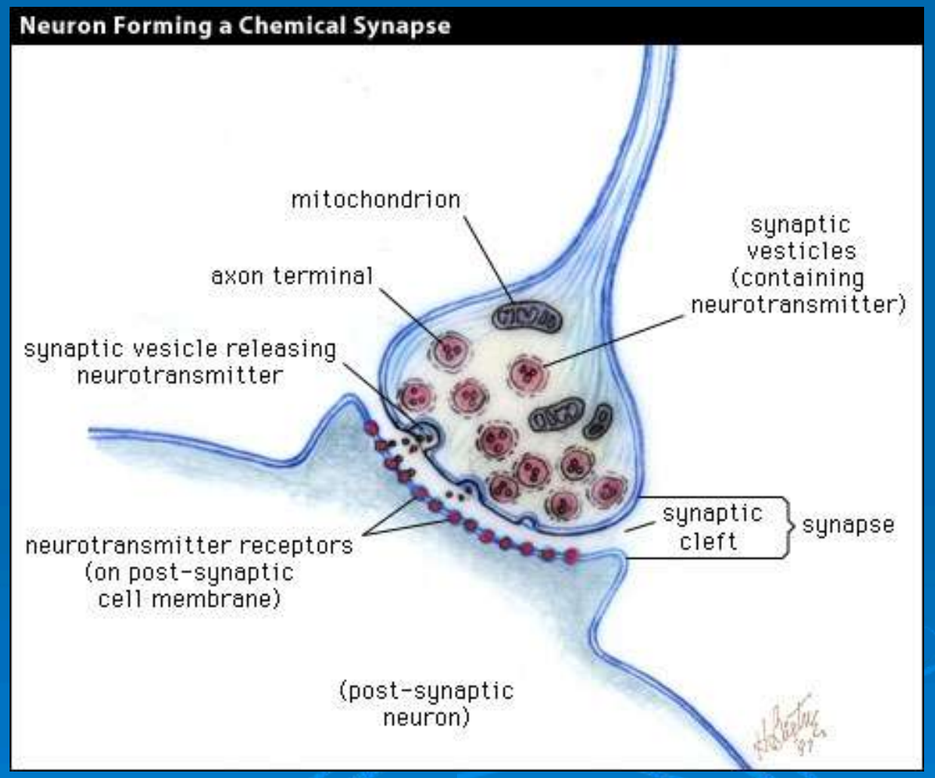
- Release/Reception of neurotransmitters
- Neurotransmitters act to open/close ion channels



Anatomy of the chemical synapse

- 1. Neuron structures - dendrites, soma (body), axon, terminal end or bouton, and axon hillock

- 2. synapse
- axonal terminal
- synaptic vesicles
- receptor region
- synaptic cleft



Information Transfer Across Chemical Synapses

- Synaptic Transmission
  - Presynaptic action potential.

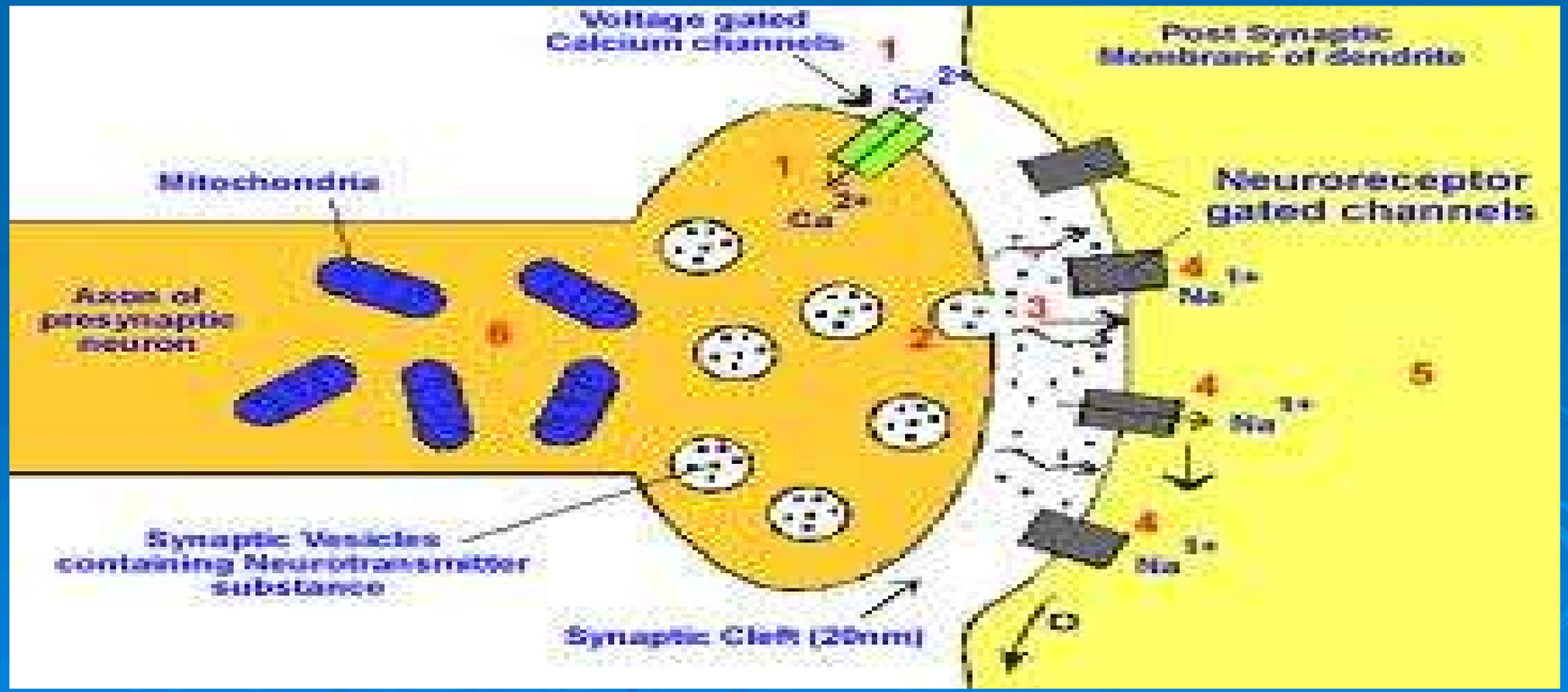
- 1. Calcium gates open in the presynaptic axonal terminal

- Depolarization causes voltage-gated Ca2+ channels to open

- 2. Neurotransmitter is released

Direct result of calcium being present Exocytosis

Transmitters diffuse from the presynaptic membrane to the postsynaptic membrane passing through the basement membrane.



- 3. Neurotransmitter binds to post-synaptic receptors
- Postsynaptic membrane
  - a. Contains receptors for the neurotransmitters
  - b. Binding of the neurotransmitter causes a change in the postsynaptic membrane potential (excitatory postsynaptic potential (EPSP) or inhibitory postsynaptic potential (IPSP)
  - c. No single excitatory or inhibitory input can bring the soma membrane to threshold

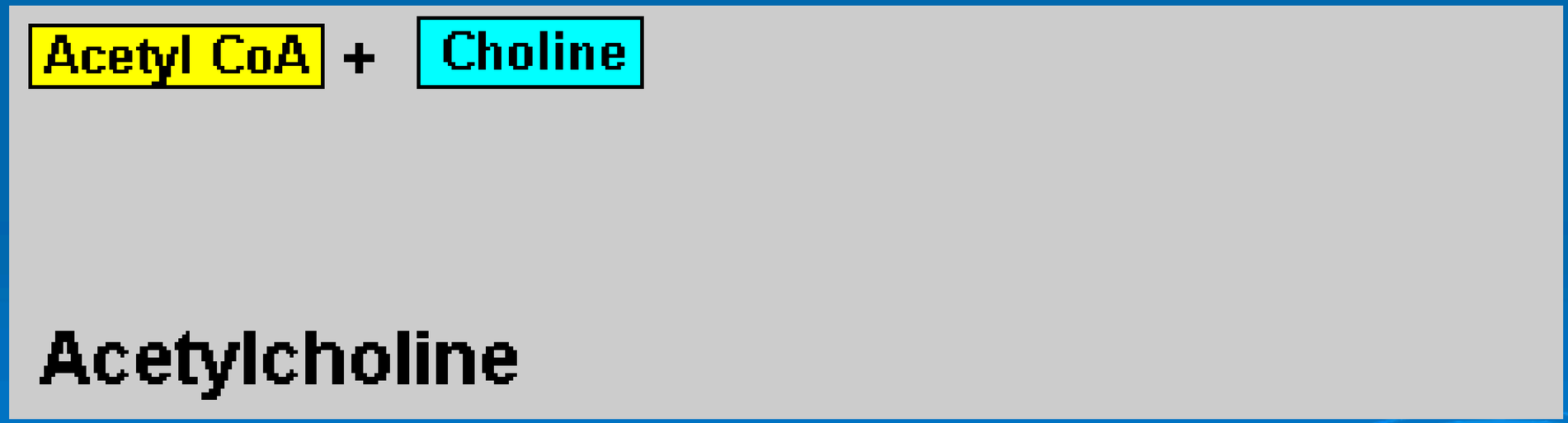
- 4. Ion channels open in the post-synaptic membrane
- Receptors
  - a. Excitation
    - 1) opening of Na+ channels
    - 2) depressed conduction through CL- or K+ channels
  - b. Inhibition
    - 1) opening Cl- channels
    - 2) Increased conduction through K+ channels

- 5. Summation
  - a. If the momentary sum of all of the EPSP bring the axon hillock membrane to threshold it will fire an action potential
  - b. Summation is the nerve process of integrating various inputs (decision making process - To fire an AP or not to fire an AP)
  - c. Special summation
    - 1) Occurs when two or more inputs arrive simultaneously
    - 2) Two inputs are added and two EPSP inputs will depolarize the membrane twice as much as a single input
    - 3) one IPSP + one EPSP = zero postsynaptic membrane change

Neurotransmitters

-language of the nervous system

-50 known NT



Synaptic Transmitters

I. Small-Molecule, Rapidly Acting Transmitters

* Synthesized in cytosol of presynaptic terminal and absorbed by active transport into transmitter vesicles.

* Transmitter vesicles release their transmitter into synaptic cleft in response to action potential within a millisecond or less.

* The subsequent action of small molecule trans mitter on postsynaptic receptors also occurs within another millisecond or less.

* Transmitter vesicles are continually recycled. After fusion of vesicle with presynaptic membrane and release transmitter, the vesicle portion of the membrane invaginates back to inside of presynaptic terminal and pinches of to form a new vesicle.

* Characteristics of Some Important Small-Molecule Transmitters

1. Acetylcholine:

* Synthesized in presynaptic terminal from acetyl coenzyme A and choline in the presence of choline acetyltransferase enzyme and it is then transported into its specific vesicles.

* Vesicles release acetylcholine into synaptic cleft.

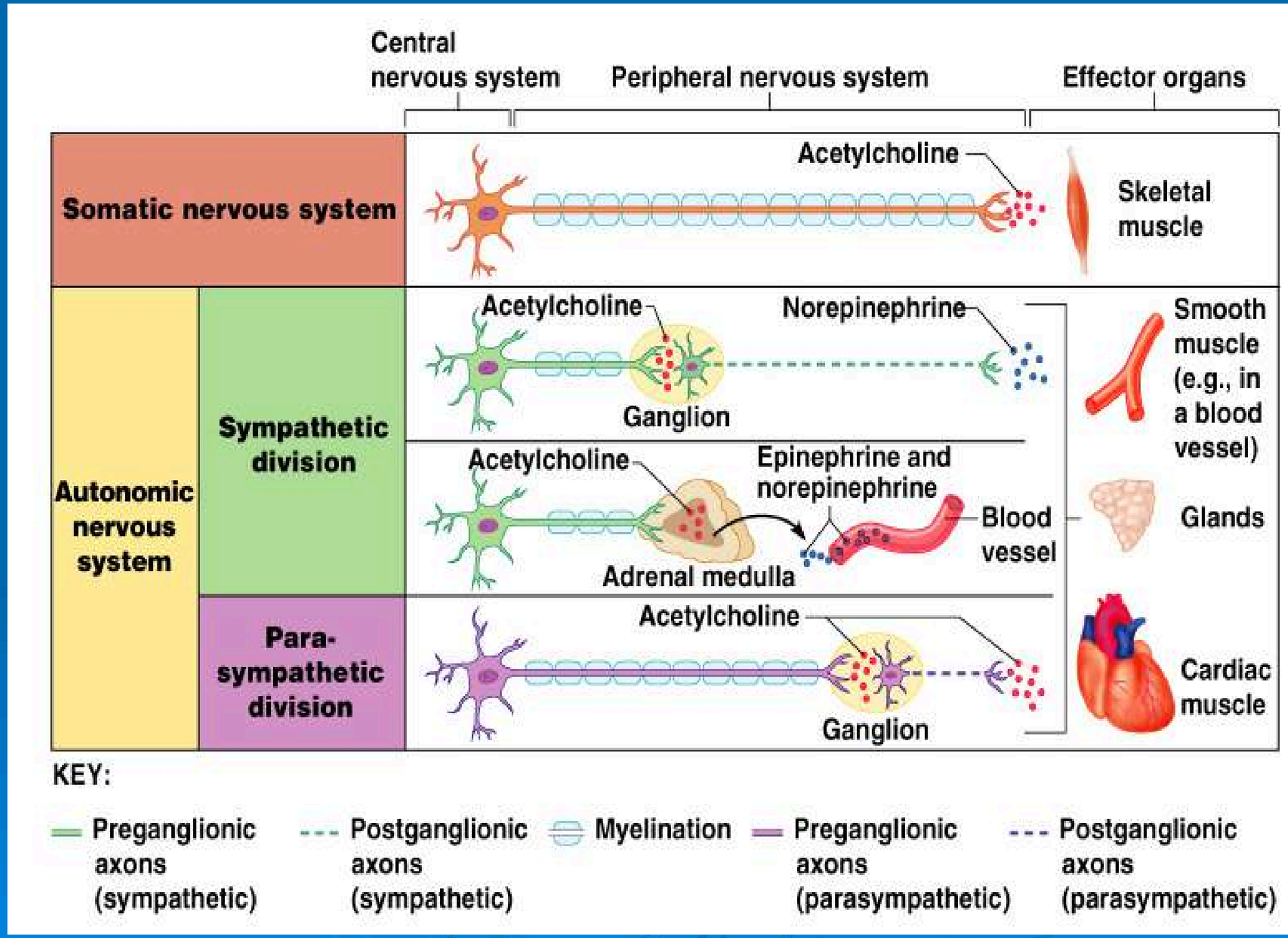
* Once finish its action on postsynaptic receptors, acetylcholine is rapidly split again to acetate and choline by cholinesterase enzyme.

* Vesicles are recycled and choline is actively transported back into presynaptic terminal to be used again for synthe sis of new acetylcholine.

* **Acetylcholine is secreted by:**

- Terminals of the large pyramidal cells from motor cortex
- Neurons in basal ganglia
- Motor neurons that innervate skeletal muscles
- Preganglionic neurons of autonomic nervous system
- Postganglionic neurons of parasympathetic nervous system
- Some of postganglionic neurons of sympathetic nervous system.

* Acetylcholine has an excitatory effect on small intestine and inhibitory effect on heart by vagus nerve.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KEY:
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Preganglionic axons (parasympathetic)
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2. Norepinephrine:

* Secreted by terminals of many neurons in brain stem and hypothalamus to help control overall activity and mood of the mind, such as increasing the level of wakefulness.

- Also secreted by most postganglionic neurons of sympathetic nervous system, where it excites some organs e.g. the heart but inhibits others e.g. the intestine.

3. Dopamine:

* Secreted by neurons that originate in the substantia nigra and terminate in basal ganglia.

* The effect of dopamine is usually inhibition.

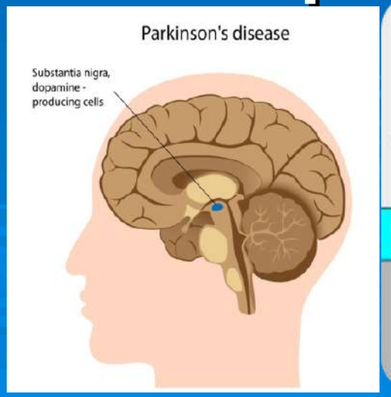
4. Glycine

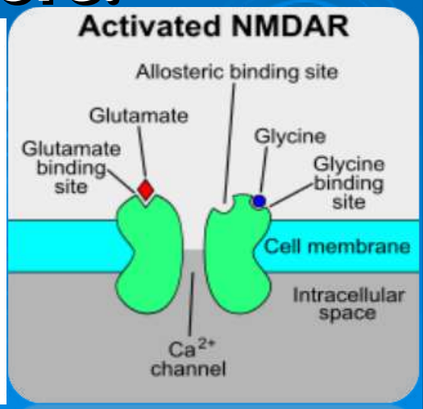
* Secreted at synapses in spinal cord and act as an inhibitory transmitter. However glycine can act as an excitatory transmitter on NMDA receptor which is believed to be involved in memory.

5. Gamma-aminobutyric acid (GABA):

The N-methyl-D-aspartate receptor is a glutamate receptor and ion channel found in neurons

* Secreted by nerve terminals in spinal cord, cerebellum, basal ganglia and many areas of the cortex.
* The effect of GABA is usually inhibition through GABA receptors:
- $GABA_A$ receptors: allow chloride ions influx.
- $GABA_B$ receptors: allow potassium ions efflux.





6. Glutamate:

* Secreted by presynaptic terminals in many sensory pathways entering CNS, as well as in many areas of cerebral cortex.

* The effect of glutamate is usually excitation through glutamate receptors:

- Ionotropic receptors: allow sodium ions influx.

- Metabotropic receptors: act through second messenger system.

- N-methyl D- aspartate (NMDA) receptors: In addition to sodium ions influx and potassium ions efflux, NMDA receptors allow calcium ions influx which are believed to be involved in memory.

7. Serotonin:

* Secreted by nuclei that originate in brain stem and project to many brain and spinal cord areas, especially to dorsal horns of spinal cord and to hypothalamus.

* Serotonin acts as an inhibitor of pain pathways in spinal cord and its inhibitor action in higher regions is believed to control the mood, perhaps even to cause sleep.

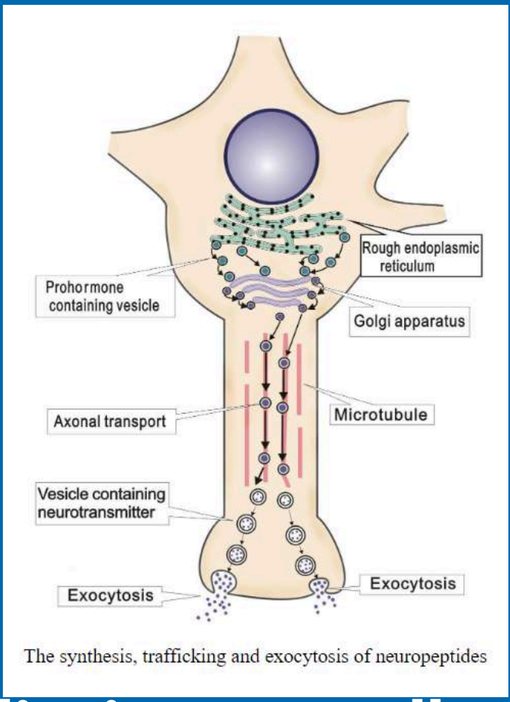
Nitric oxide:

* is especially secreted by nerve terminals in areas of the brain responsible for memory.

* is not preformed and stored in vesicles in presynaptic ter minal. Instead, it is synthesized instantly as needed and then diffuses out of presynaptic terminals to nearby postsynaptic neurons to change intracellular metabolic functions that modify neuronal excitability for seconds, minutes, or perhaps even longer.

II. Large-Molecule, Delayed Acting Neuropeptides

* Synthesized as integral parts of large protein molecules by ribosomes in **neuronal cell body** which enter spaces inside ER and subsequently inside Golgi apparatus, where two changes occur:



The synthesis, trafficking and exocytosis of neuropeptides

1. Neuropeptide forming protein is enzymatically split into smaller fragments, some of which are either the neuropeptide itself or a precursor of it.
2. Second, Golgi apparatus packages the neuropeptide into minute trans mitter vesicles that are released into the cytoplasm and then transported all the way to axonal terminals by axonal streaming and finally release their neuropeptides in response to action potentials. However, the vesicle is autolyzed and is not reused.

* Neuropeptides are released in much smaller amounts than small molecule transmitters. However, this difference is compensated for by the more potent action of neuropeptides.

* Neuropeptides cause much more prolonged actions (Last for days, months or years) which include:

- Prolonged closure of calcium channels
- Prolonged changes in the metabolism
- prolonged change in activation or deactivation of specific genes in the cell nucleus, and/or
- Prolonged alterations in numbers of excitatory or inhibitory receptors.

- Example oxytocin and vasopressin

Effect of drugs on Synaptic Transmission

* **Cafeine, theophylline and theobromine**, which are found in coffee, tea and cocoa, respectively, all **increase neuro nal excitability**, presumably by reducing threshold for excitation of neurons.

* **Strychnine (pesticide)** increases excitability of neurons by **inhibiting the action of some inhibitory transmitter substances**, especially the inhibitory effect of glycine in the spinal cord resulting in **severe tonic muscle spasms**.

* **Anesthetics (Painkillers)** increase neuronal membrane **threshold for excitation** and thereby decrease synaptic transmission. Because many anesthetics are lipid soluble, it has been reasoned that some of them might change physical characteristics of the neuronal membranes, making them **less responsive to excitatory agents**.

Effect of Alkalosis or Acidosis on Synaptic Transmission

* Alkalosis greatly increases neuronal excitability e.g. a rise in arterial blood pH from 7.4 to 7.8 to 8.0 causes cerebral epileptic seizures. In a person who is predisposed to epileptic seizures, hyperventilation may cause an epileptic attack??.

* Acidosis greatly depresses neuronal activity; a fall in pH from 7.4 to below 7.0 causes a comatose state e.g. in very severe diabetic or uremic acidosis, coma develops.

Effect of Hypoxia on Synaptic Transmission

* Cessation of oxygen for only a few seconds can cause complete inexcitability of neurons. This effect is observed when brain's blood flow is temporarily interrupted because within 3-7 sec, the person becomes unconscious.

Thank you