Madenat Alelem University College
Medical physics dept.
Second Stage / 2nd Semester

BIOPHYSICS

DR. RUAA ALMUSA

LEC. 1 / CHAPTER ONE

OUTLINES

- **Introduction to biophysics**
- **Physics of hearing and vision**
- **Fluid mechanics and human circulatory system**
- **Viscosity and viscoelasticity in biological fluids**
- **Thermodynamics of biochemical reactions and metabolism**
- **Random molecular motion in gases and solution**

- **Electrolytes molecular and ionic interactions in solutions**
- **Membrane's structures and properties**
- **Diffusion and osmosis in biological organisms**
- **Electrochemistry of cells**
- **Action potential and electrical activity of neurons**

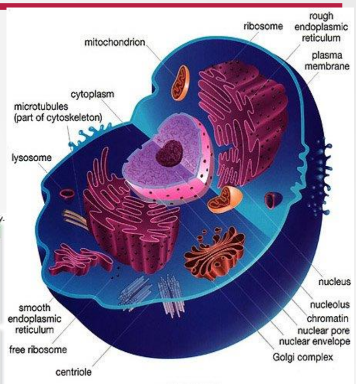
INTRODUCTION TO BIOPHYSICS

Biophysics is the field that applies the theories and methods of physics to understand how biological systems work. And explained the mechanics of how different parts of a cell move and function, and how complex systems in our bodies(the brain, circulation, immune system, hear, vision and others) work.

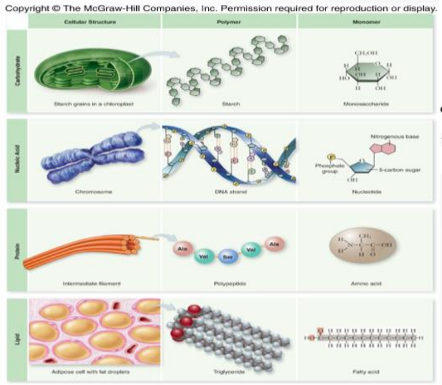
Biophysics explains biological function in terms of the physical properties of specific molecules. The size of these molecules varies from small fatty acids and sugars (~1 nm), to macromolecules like proteins (5–10 nm), starches (>1000 nm), and the DNA molecules (10,000,000 nm). These building blocks of living organisms, assemble into cells, tissues, and whole organisms by forming structures with dimensions of 10, 100, 1000, 10,000 nm and larger.

LEVELS OF BIOPHYSICS

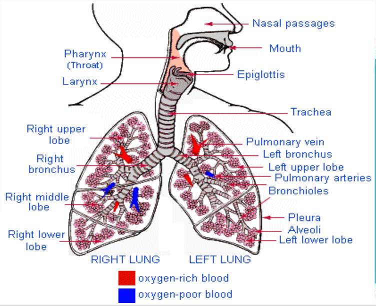
- Biophysics at the cellular level

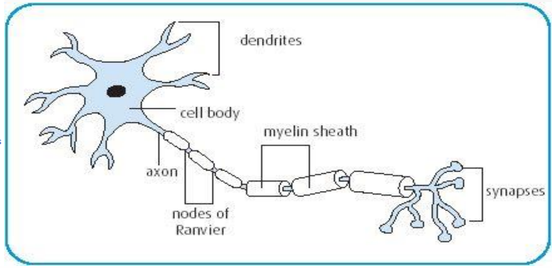


- Biophysics at the molecular level



- Biophysics at the multicellular level





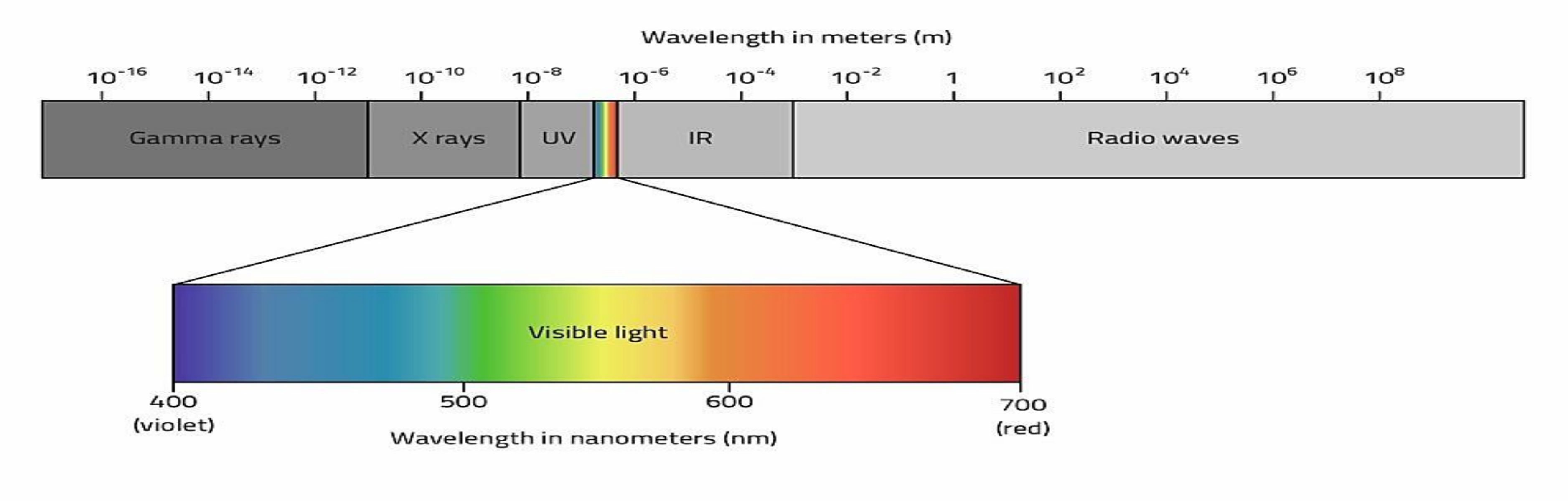
PHYSICS OF VISION

The sense of vision consists of three major components:

1. The eyes that focus an image from outside world on the light sensitive retina.
2. The system of millions of nerves that carries the information deep into the brain.
3. The visual cortex-that part of the brain where, it is all put together.

- Blindness results if any one of the parts does not function.

The eye is an optical instrument that can focus automatically on objects over a wide range of distances, adjust automatically to a wide range of light intensities and is sensitive to a continuous range of electromagnetic waves from less than 400 nm to about 650 nm in wavelength.



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LEC. 2 / CHAPTER ONE

THE HUMAN EYE

STRUCTURE AND FUNCTION

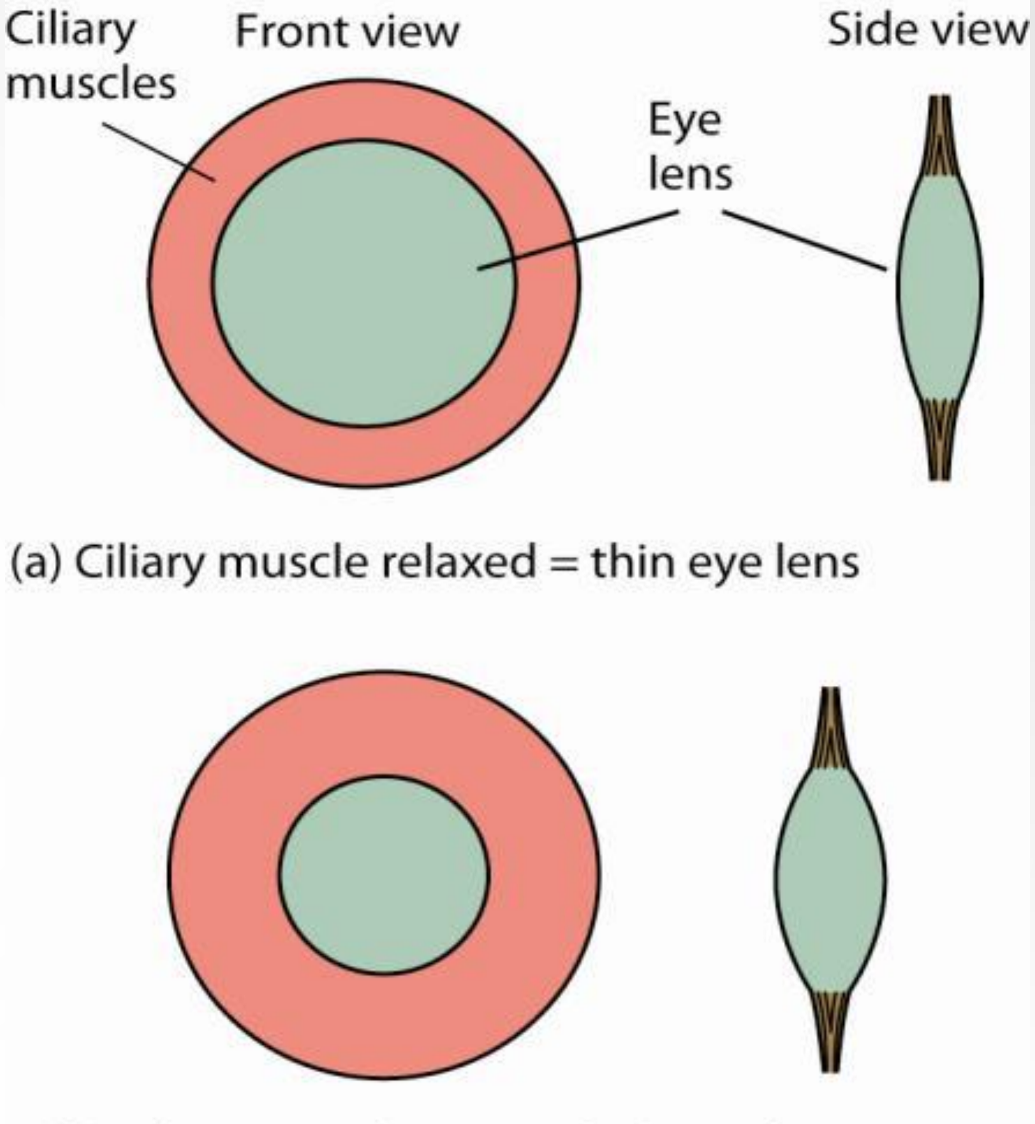
The main optical parts of the eye:

1. **The pupil** is the black hole in iris where light enters
2. **The sclera** is white of the eye that provides attachment for muscles
3. **The retina** is internal membrane contain light receptive cells (rods and cones) and convert light to electrical signals.
4. **The optic nerve** is transmit electrical impulses from retina to the brain for processing so we can see.

The main optical parts of the eye:

5. **The cornea** is a protective transparent layer at the front of the eye. It has a fixed convex curvature.
6. **The eye lens** is flexible and attached to the ciliary muscles. These muscles change the thickness of the eye lens which alters its optical power. This enables it to form an image on the retina of the eye of any object within a range of distances.

- To view a distant object, the eye muscles must relax so that the muscle fibres lengthen, allowing the eye lens to become thin and less powerful.
- To view a near object, the eye muscles must become taut so that the muscle fibres shorten and make the eye lens thicker and more powerful.

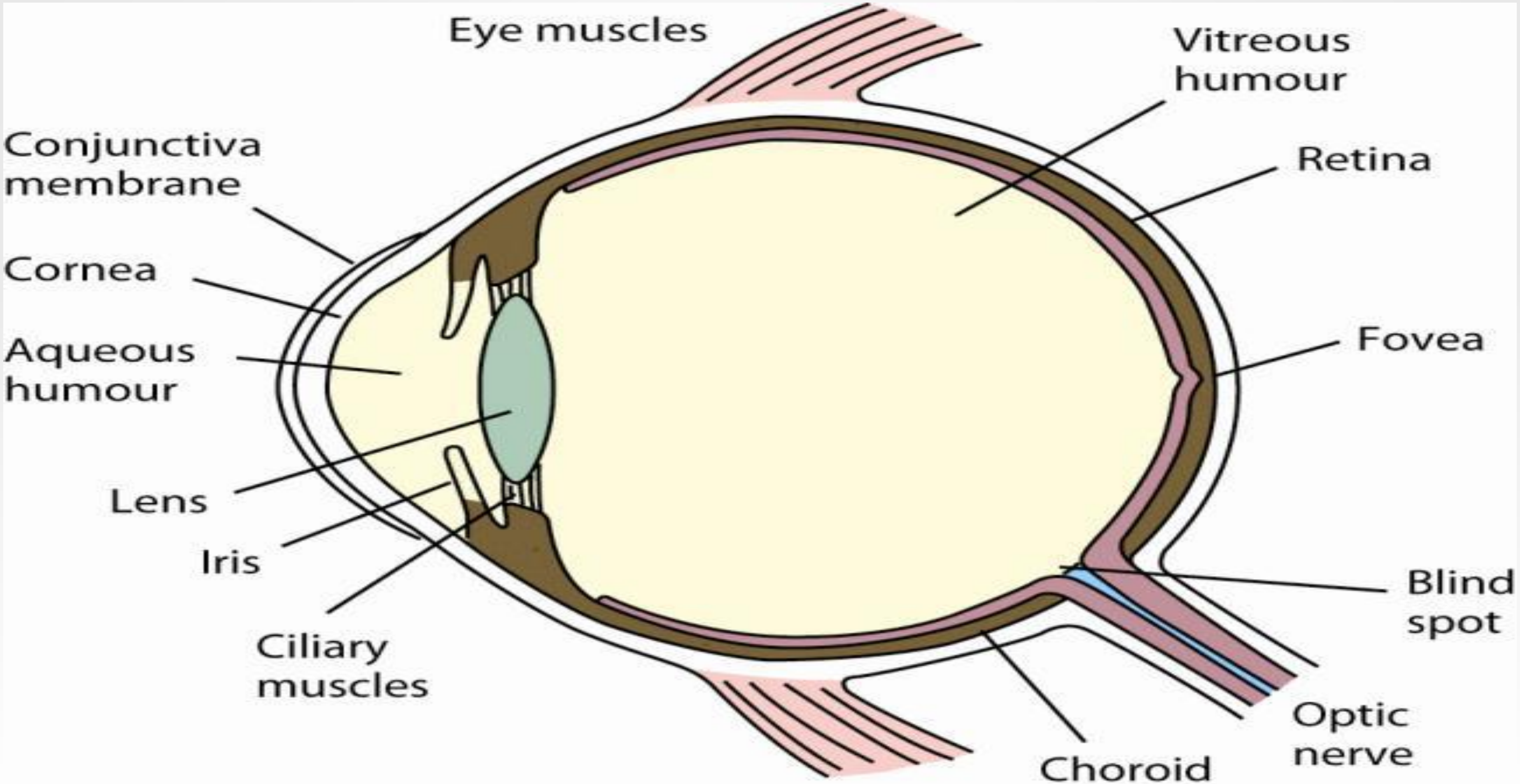


(a) Ciliary muscle relaxed = thin eye lens

(b) Ciliary muscle taut = thick eye lens

7. The iris controls the amount of light entering the eye. It consists of muscle fibres.

- In bright light, the concentric fibres contract and the radial fibres relax so the iris expands, making the eye pupil narrower so less light passes through it.
- In dim light, the concentric fibres relax and the radial fibres contract so the iris contracts, dilating (i.e. widening) the eye pupil so more light passes into the eye.



Eye muscles
Vitreous humour
Conjunctiva membrane
Retina
Cornea
Fovea
Aqueous humour
Lens
Iris
Blind spot
Ciliary muscles
Optic nerve
Choroid

FOCUSING ELEMENTS OF THE EYE

The cornea is refracting the light rays. The amount of refracting depends on the:

1. Curvatures of its surfaces
2. The speed of light in the lens compared with that in the surrounding material.

VISUAL DEFECTS

The index of refraction is nearly constant for all corneas, but the curvature varies from one person to another and is responsible for most our defective vision.

1. If the cornea is curved too much the eye is **near sighted**.
2. Not enough curvature results in **far sighted**.
3. Uneven curvature produces **astigmatism**.

THE LIGHT DETECTOR OF THE EYE

The **retina** is the light sensitive part of the eye, converts the light photons into electrical nerve impulses that are sent to the brain. The photon must be above a minimum energy to cause the reaction.

1. Infrared photons have insufficient energy and thus **are not seen**.
2. Ultraviolet photons have sufficient energy, but absorbed before they reach the retina and also **are not seen**.

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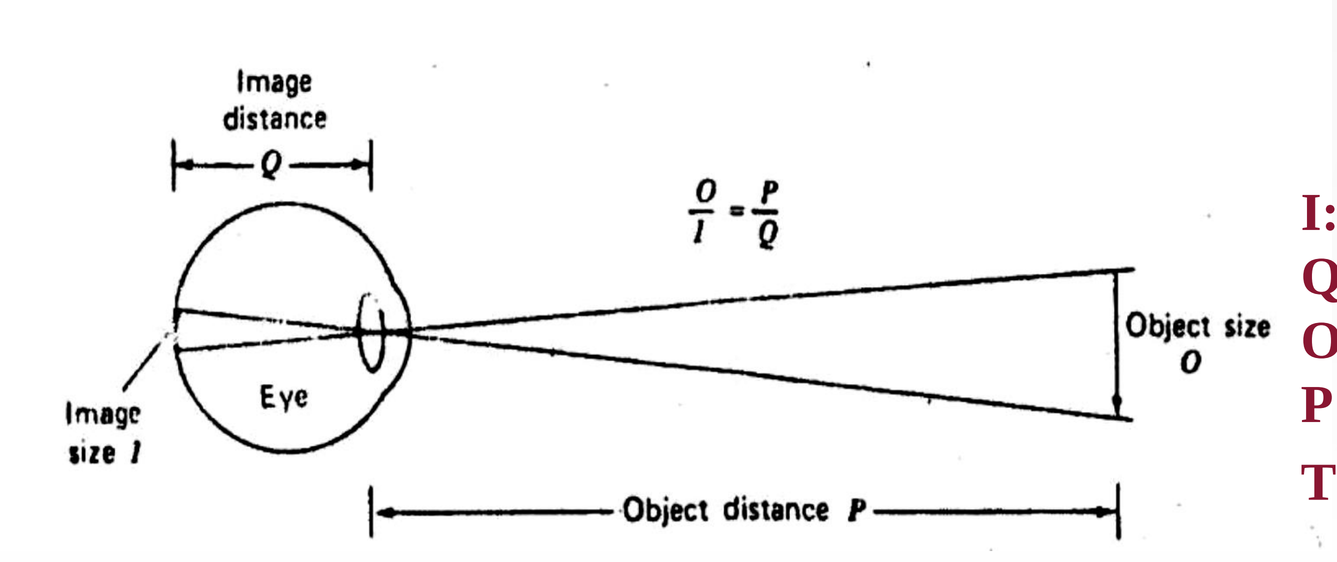
LEC. 3 / CHAPTER ONE

IMAGE SIZE ON THE RETINA

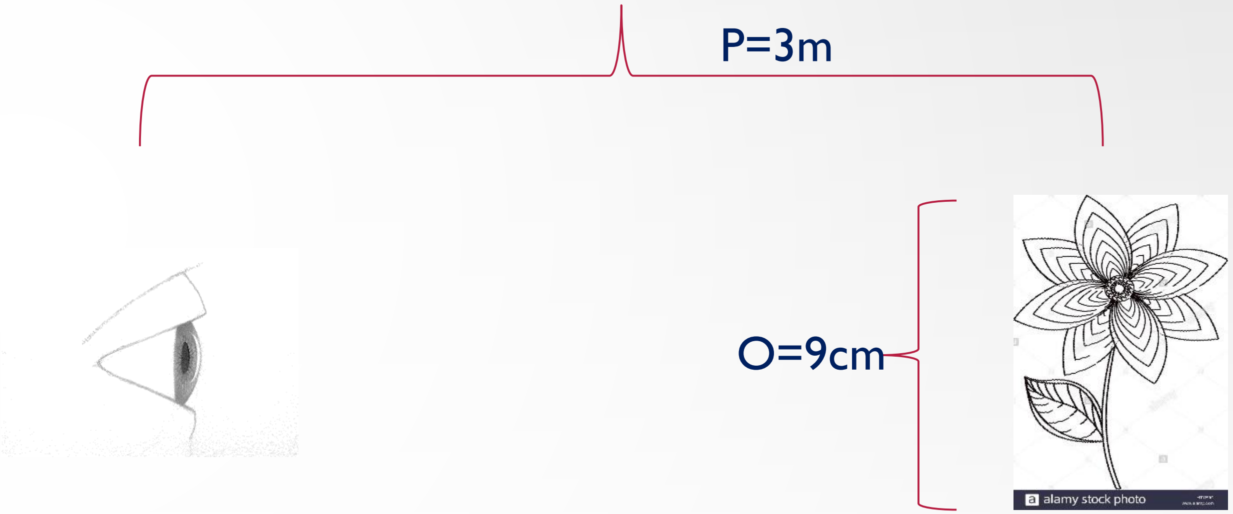
An equation for determining the size of image on the retina comes from the ratios of the lengths of the sides of similar triangles.



I: is image size
Q: is image distance
O: is object size
P: is object distance
Thus we can write $\frac{O}{I} = \frac{P}{Q}$

EXAMPLE:

How big is the image on the retina of a flower in the garden 3m away, (Assume the flower size is 9mm and Q=0.05m)?



Solution:

$$I = \frac{OQ}{P}$$

$$I = \frac{9x10^{-2} x\ 5x10^{-2}}{3}$$

$$I = 15 \text{ x } 10^{-4} \text{ m}$$

$$I = 0.15\ \mu\text{m}$$

PHYSICS OF HEARING/ CHARACTERISTICS OF SOUND

- Sound can travel through any kind of matter, but not through a vacuum.
- The speed of sound is different in different materials.
- The speed depends on temperature, especially for gases.

TABLE 12–1 Speed of Sound in Various Materials (20°C and 1 atm)

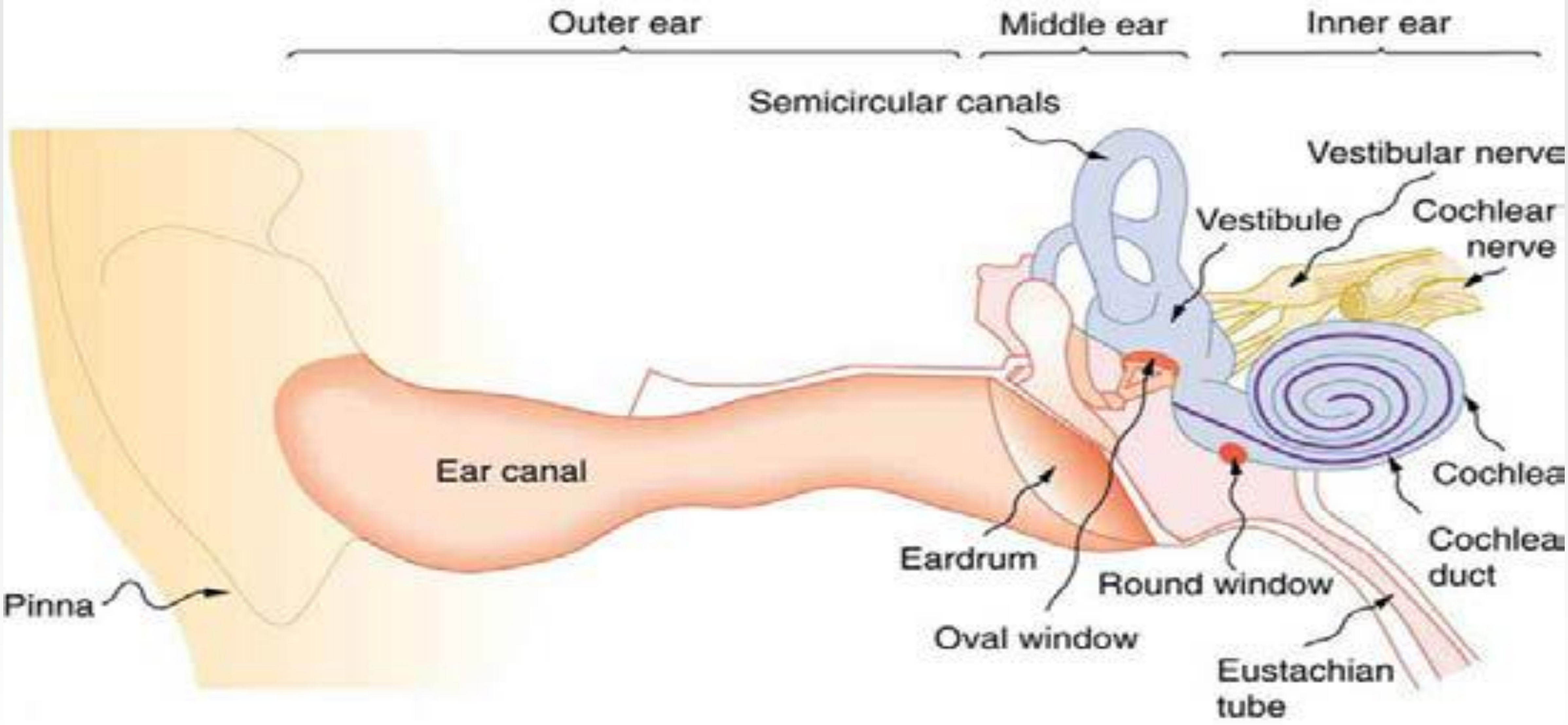
Material	Speed (m/s)
Air	343
Air (0°C)	331
Helium	1005
Hydrogen	1300
Water	1440
Sea water	1560
Iron and steel	≈5000
Glass	≈4500
Aluminum	≈5100
Hardwood	≈4000
Concrete	≈3000

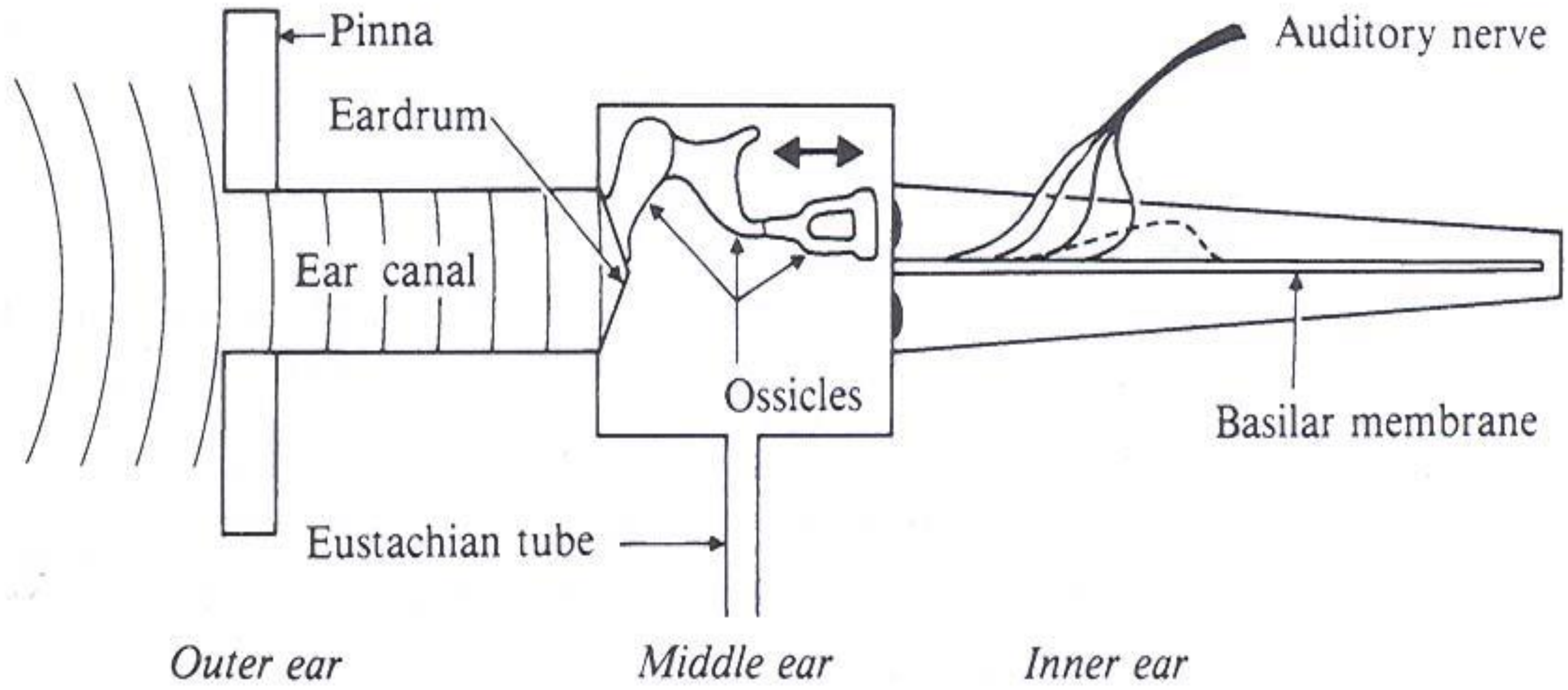
Hearing is the awareness of sound. Normal human hearing frequencies from 20 to 20000 Hz. Sounds below 20 Hz are called infrasound, whereas those above 20000 Hz are ultrasound. Neither is heard by the ear. Other animals have hearing ranges different from that of humans. Dogs can hear sounds as high as 30000 Hz, whereas bats and dolphins can hear up to 100000 Hz sounds. Elephants are known to respond to frequencies below 20 Hz.

PHYSICS OF HEARING

- The sound conducting mechanism is divided into three parts:

1. **The outer ear:** which picks up the sound.
2. **The middle ear:** which transforms pressure variations into mechanical displacements.
3. **The inner ear:** which convert pressure signals into neural signals, send them to the brain for processing via auditory nerves.


Outer ear
Middle ear
Inner ear
Semicircular canals
Vestibular nerve
Vestibule
Cochlear
nerve
Ear canal
Cochlea
Eardrum
Cochlea
duct
Round window
Pinna
Oval window
Eustachian
tube


Pinna
Auditory nerve
Eardrum
Ear canal
Ossicles
Basilar membrane
Eustachian tube
Outer ear
Middle ear
Inner ear

THE HEARING MECHANISM

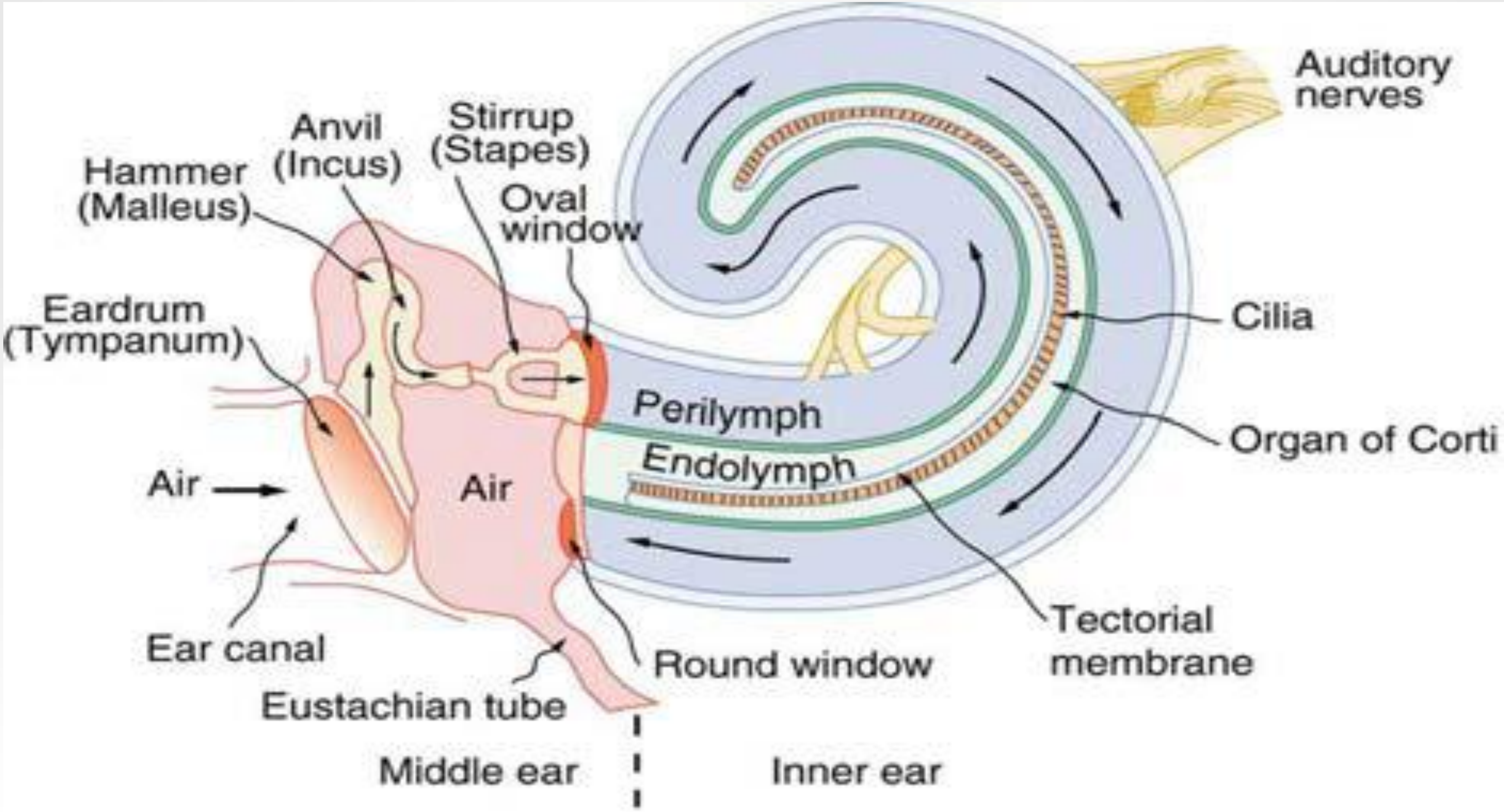
The sound wave that impinges upon our ear is a mechanical pressure wave. The ear is a transducer that converts sound waves into electrical nerve impulses.

The outer ear, carries sound to the eardrum. The air column in the ear canal resonates and is partially responsible for the sensitivity of the ear to sounds in the 2000 to 5000 Hz range.

The middle ear converts sound into mechanical vibrations and applies these vibrations to the cochlea. The middle ear takes the force exerted on the eardrum by sound pressure variations, amplifies it and transmits it to the **inner ear** via the oval window, creating pressure waves in the cochlea approximately 40 times greater than those impinging on the eardrum.

HEARING PROBLEMS

Hearing losses can occur because of problems in the middle or inner ear. Damage to the nerves in the cochlea is not repairable, but amplification can partially solve this problem. There is a risk that amplification will produce further damage. Another common failure in the cochlea is damage or loss of the cilia but with nerves remaining functional.


Auditory nerves
Anvil (Incus)
Stirrup (Stapes)
Hammer (Malleus)
Oval window
Eardrum (Tympanum)
Cilia
Perilymph
Organ of Corti
Endolymph
Air
Air
Ear canal
Eustachian tube
Round window
Tectorial membrane
Middle ear
Inner ear

COCHLEA IMPLANT

The cochlear implant consists of three external components and two internal components:

a) The external components

1. microphone for picking up sound and converting it into an electrical signal.
2. speech processor to select certain frequencies.
3. transmitter to transfer the signal to the internal components through electromagnetic induction.

b) The internal components

- receiver/transmitter implanted in the bone beneath the skin, which converts the signals into electric impulses and sends them through an internal cable to the cochlea an array of about 24 electrodes wound through the cochlea send the impulses directly into the brain.
- The electrodes basically emulate the cilia.

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BIOPHYSICS

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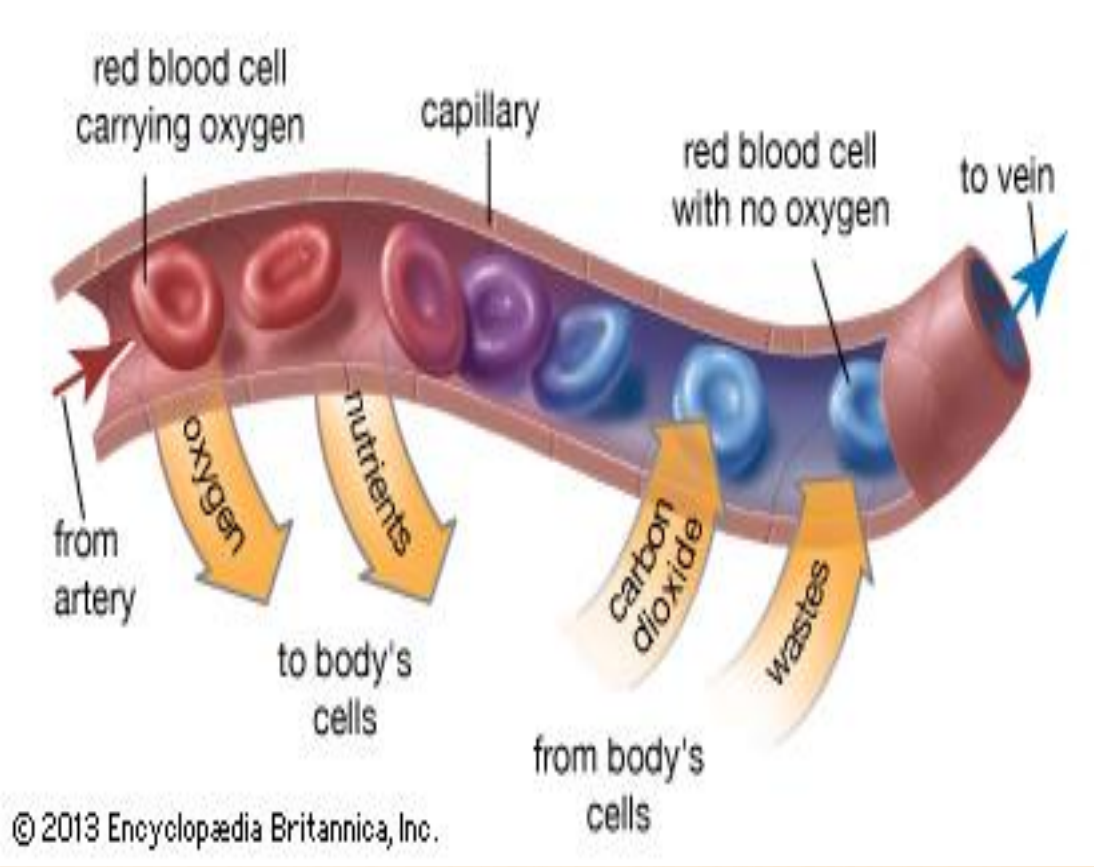
LEC. 4 / CHAPTER TWO

HUMAN CIRCULATORY SYSTEM AND FLUID MECHANICS

Cardiovascular System

- The cardiovascular system consists of the heart, blood vessels that is responsible for the movement of the approximately 5 Litres of blood in the body.
- The systems primary role is for the transportation of oxygen, nutrients, hormones, and cellular waste throughout the body.



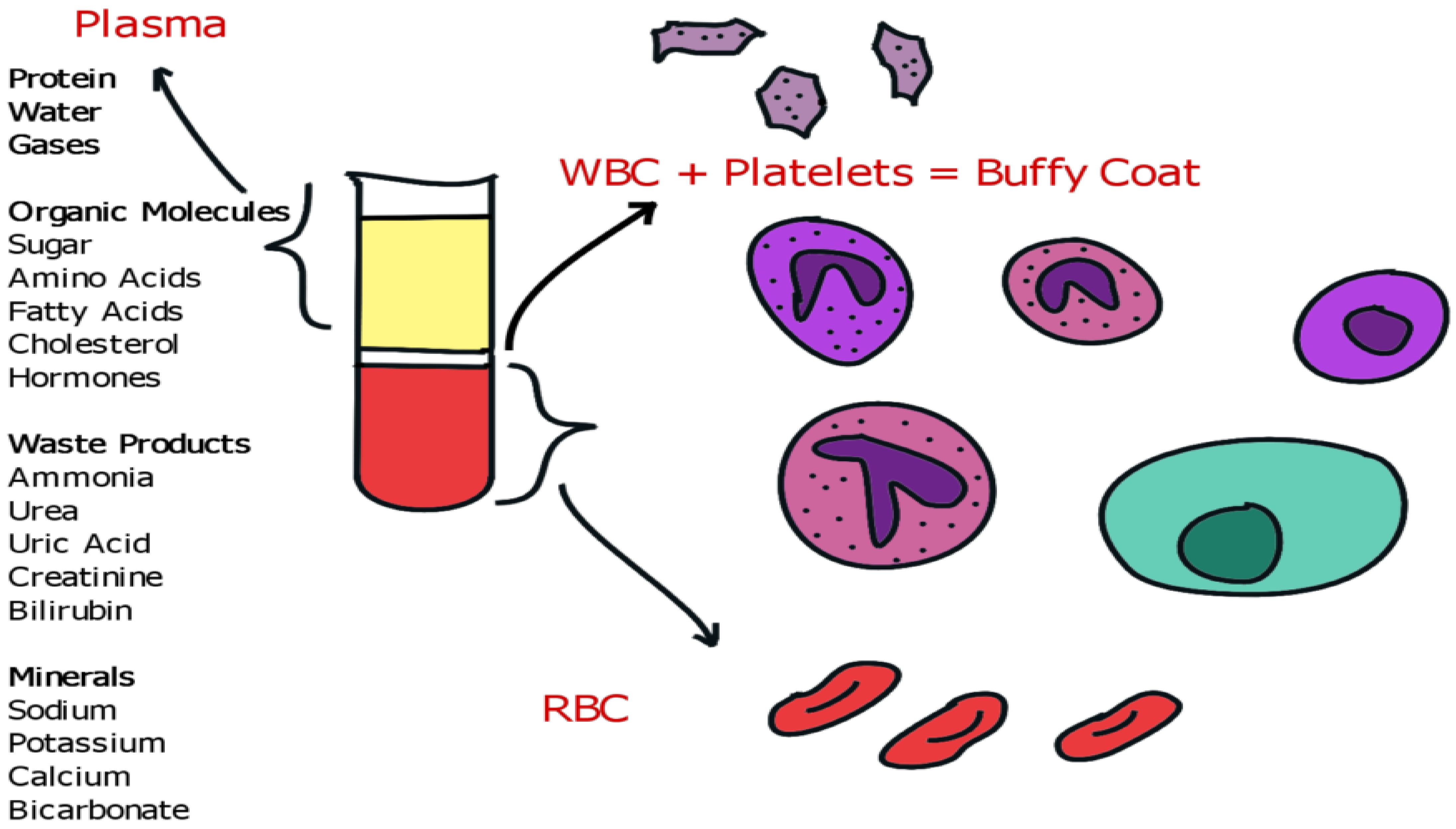
COMPONENTS OF CARDIOVASCULAR SYSTEM

1. BLOOD

Blood is a complex mixture involving:

- Plasma (liquid component) –55-60% of the blood’s volume
- Red blood cells –40% of the blood’s volume, carries oxygen from the lungs and delivers it to all body tissues.
- White blood cells – important for the immune system
- Platelets – important for blood clotting

Constituents of Blood

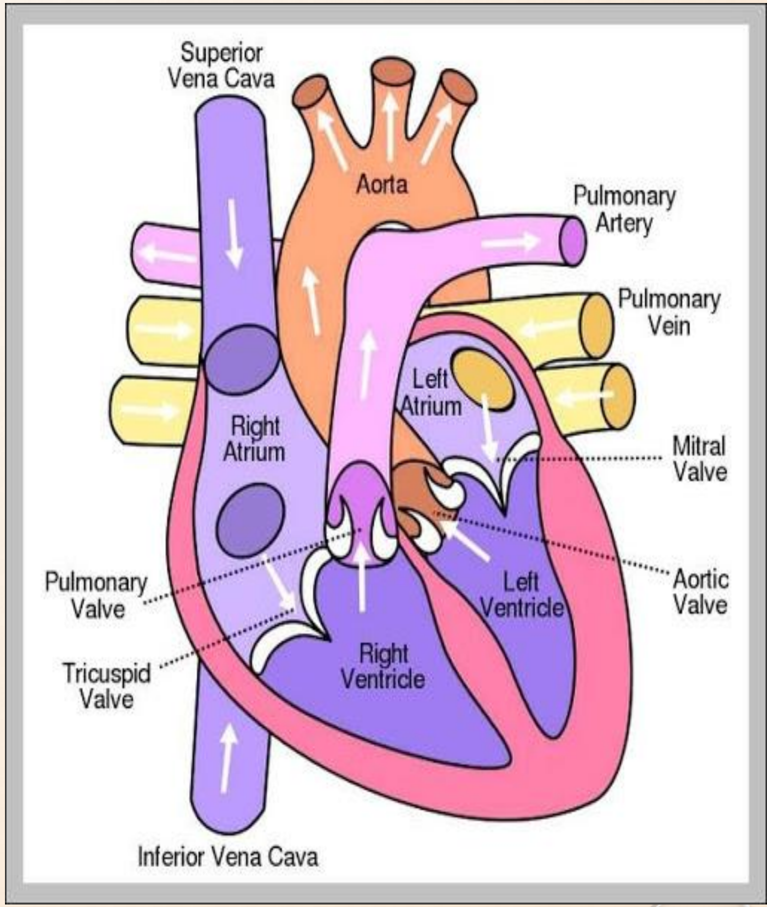


2. HEART

- The heart is an organ that is in the centre of the chest. The only function is to pump blood.

The heart has **four** chambers:

- Right and Left atrium, which is used for collecting blood.
- Right and Left ventricles, which is used for pumping out blood

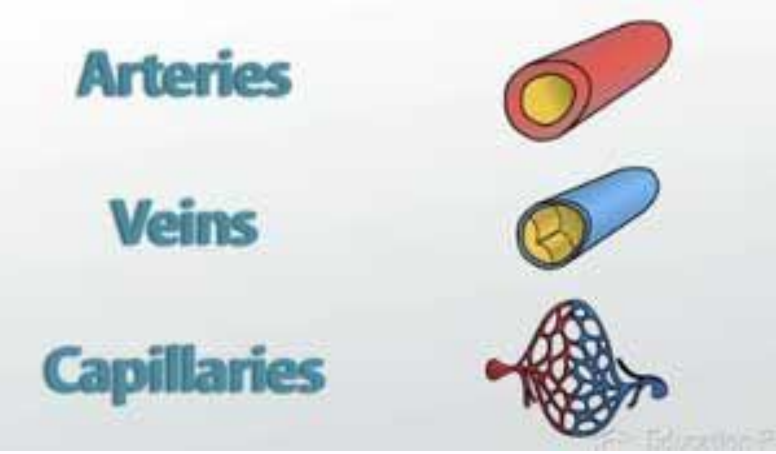


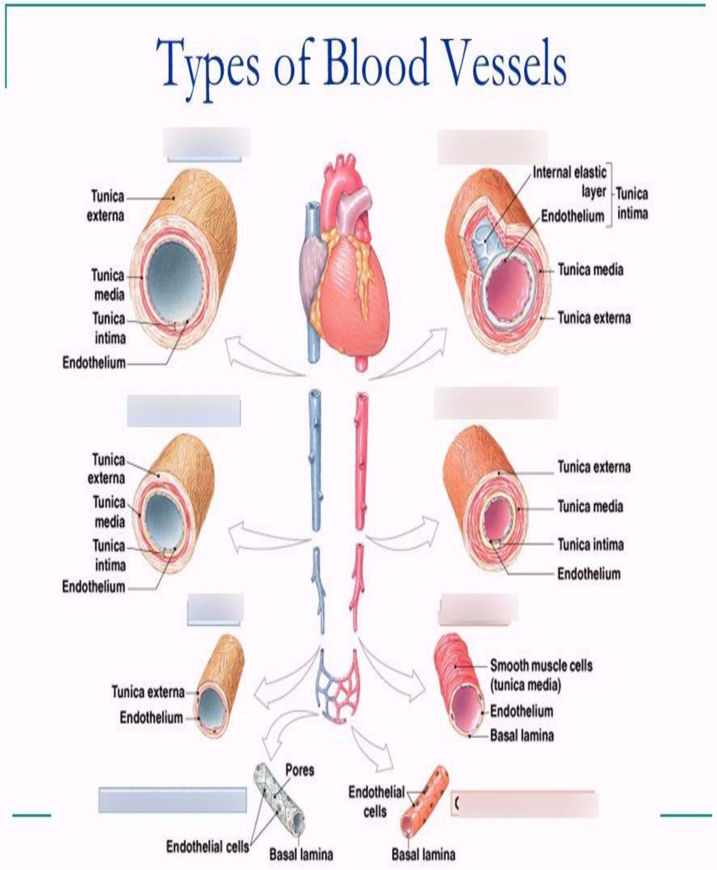
The left side three times thicker than right side

- Four valves are present within the heart to ensure the blood flows in only one direction: the ventricles has inlet and outlet valves.
- The heart allows blood to be oxygenated after it returns to the heart and remove deoxygenated and carbon dioxide via lungs.

2. BLOOD VESSELS

- The blood vessels are closed network of tubes that delivered the blood to the body, consist of arteries, veins, and capillaries.
- The diameter of the blood vessels changes from the moment it leaves the heart (arteries) to when it returns to the heart (veins).
- Blood vessels are muscular vessels that can increase or decrease blood flow.





TYPES OF CERCULATION

1. Coronary circulation – The circulation of blood within the heart.
2. Pulmonary circulation – the flow of blood between the heart and lungs.
3. Systemic circulation – the flow of blood between the heart and the cells of the body.
4. Fetal Circulation

FLUIDS MECHANICS

- There is an important concept is that kinetic energy and potential energy must remain unchanged throughout circulatory system.
- This concept is called the **Conservation of Continuity**, where the energy of fluid in a vessel is constant:

$$mass\ flowing\ in = mass\ flowing\ out$$

$$A_1 v_1 = A_2 v_2$$

$$Q = \frac{Volume}{time}$$

Work = PV

A= Area

υ = velocity

Q= flow rate

P= Pressure

- Typical adult has about 4.5 liters of blood and each section of the heart pumps about 80 ml on each contraction, about 1 min is needed for the average red blood cell to make one complete cycle of the body.

- EX: Estimate the volume of blood your heart pumps to your systemic circulation each day?

$$(80\mathrm{cm}^3/\mathrm{beat})\times(72\mathrm{beats/min})\times(1440\mathrm{min/day}) = 8.3\times10^6\mathrm{cm}^3/\mathrm{day}$$

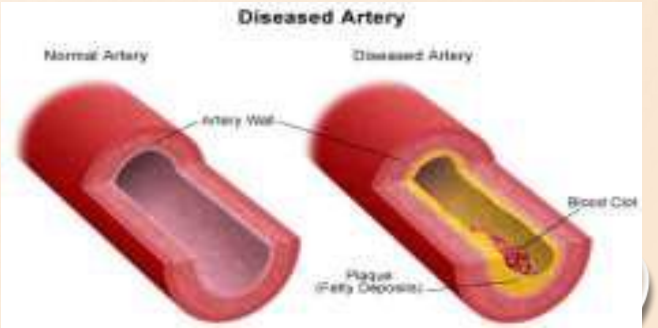
- ➢The Conservation of Energy is the basis of **Bernoulli's Principle or Equation**, this equation is stated that the work done on a fluid as it flows from one place to another is equal to the change in its mechanical energy. and an **increase in the speed** of a fluid flow will result in a **decrease in the pressure**

$$P_1 + \frac{1}{2}\rho v_1^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g h_2$$

pressure

Kinetic Energy

Potential Energy

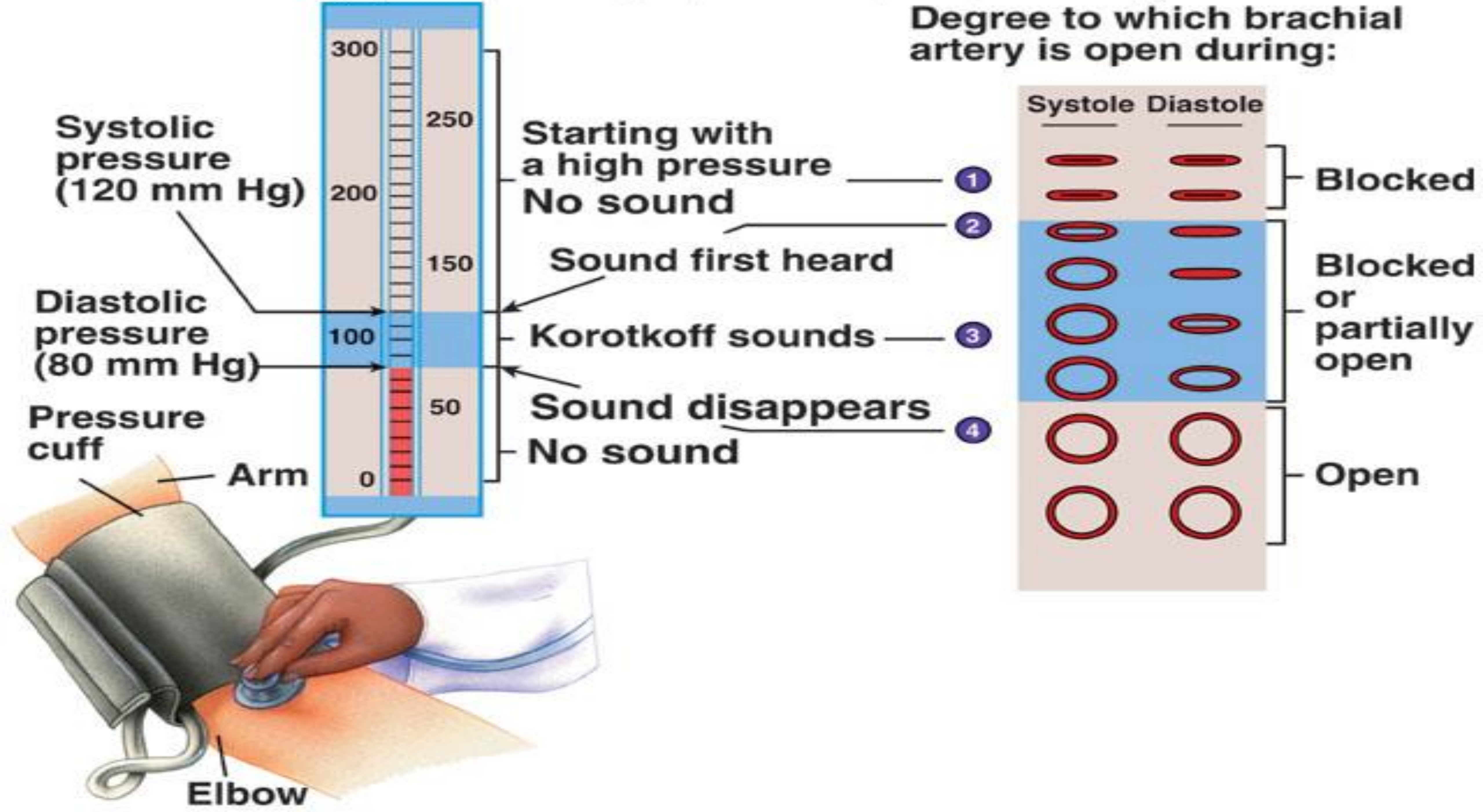


BLOOD PRESSURE

- The blood pressure in the circulation is principally due to the pumping action of the heart, Expressed in millimeters of mercury (mm Hg).
- During each heartbeat, systemic arterial blood pressure varies between a maximum (systolic) and a minimum (diastolic) pressure.
- These are often simplified into one value:

$$MAP \approx 2/3(BPdia) + 1/3(BPsys)$$

MAP = Mean Arterial Pressure, BPdia = Diastolic blood pressure, BPsys = Systolic blood pressure



Degree to which brachial artery is open during:
Systole
Diastole
300
250
200
150
100
50
0
Systolic pressure (120 mm Hg)
Diastolic pressure (80 mm Hg)
Pressure cuff
Arm
Elbow
Starting with a high pressure
No sound
Sound first heard
Korotkoff sounds
Sound disappears
No sound
1
2
3
4
Blocked
Blocked or partially open
Open

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Lec. 5 / Chapter Two

Viscosity and Viscoelasticity In Biological Fluids

Viscosity and fluids

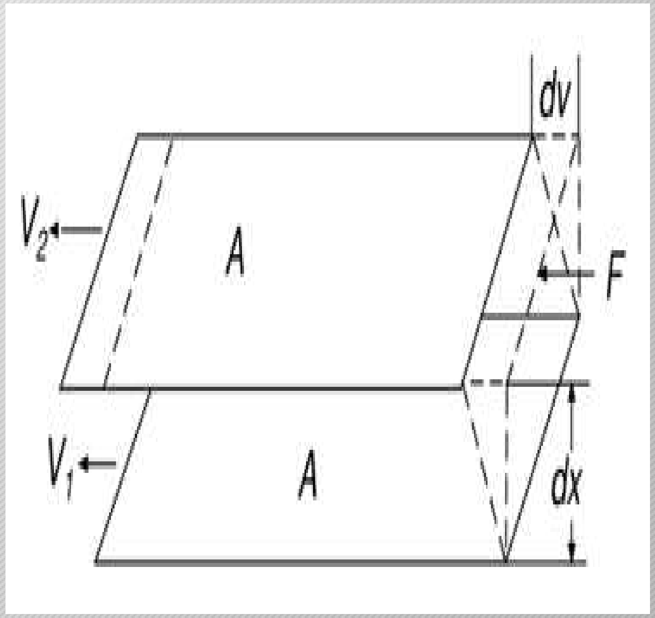
- The viscosity is a measure of a fluid's resistance to flow or it is defined as the internal friction of fluid.
- A fluid is a substance that deforms continuously under the action of a shearing force.
- Rheology: The study of the change in form and the flow of matter, embracing elasticity, viscosity, and plasticity.

- Internal friction becomes apparent when a layer of fluid is made to move in relation to another layer.
- The greater the friction, the greater the amount of force required to cause this movement, which is called shear.
- Viscous fluids require more force to move than less viscous materials.

- Whole blood 5 times as viscous as water, due mainly to RBCs
- Plasma 2 times as viscous as water, due to its proteins.
- Viscosity is important to circulatory function because it partially governs the flow of blood through the vessels.
- RBC or protein deficiency = flows easily
- RBC or protein excess of above = flows sluggishly

Newton's Law of Viscosity

- Two parallel planes of fluid of equal area A are separated by a distance dx and are moving in the same direction at different velocities V1 and V2.
- Newton assumed that the force applied on these planes was proportional to the difference in speed through the liquid:



$$\frac{F}{A} = \eta \frac{dv}{dx}$$

$where\ \eta\ is\ a\ viscosity$ and its constant for materials

$\frac{dv}{dx}$ shear rate γ

$\frac{F}{A}$ shear stress τ

So the law can written as

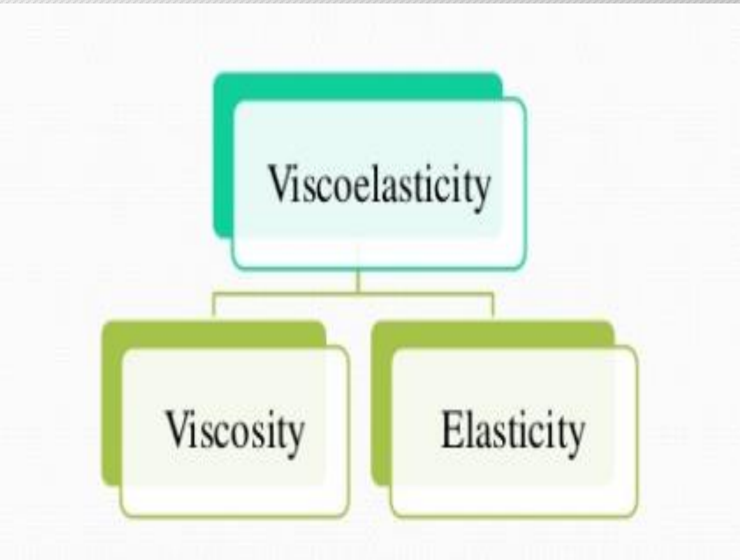
$$\eta = \frac{\tau}{\gamma}$$ (kg / m . sec) or (Pascal . Sec)

Newtonian and Non-newtonian Fluids

- Newtonian fluids have a constant viscosity that doesn't change, no matter the pressure being applied to the fluid. This also means they don't compress, like water.
- Non-Newtonian fluids are just the opposite — if enough force is applied to these fluids, their viscosity will change. These fluids have two types **dilatants**, which get thicker when force is applied, and **pseudo plastics**, which get thinner under the force, like complex fluids (blood).

Viscoelasticity in Biology

- Viscoelasticity is the property of materials that exhibit both viscous and elastic characteristics when undergoing deformation.
- Viscous materials, resist shear and strain linearly with time when a stress is applied. Elastic materials strain when stretched and immediately return to their original state once the stress is removed.



Polymer Viscoelasticity

- Living cells behave both as an elastic solid and as a viscous fluid, and so are considered viscoelastic.
- Cellular viscoelasticity arises from the combination of high water content and structural cellular matrix, the biopolymers support cell shape provide strong enough mechanical properties to resist environmental pressures, but on the other hand their organization is highly dynamic and linked to metabolic conditions.

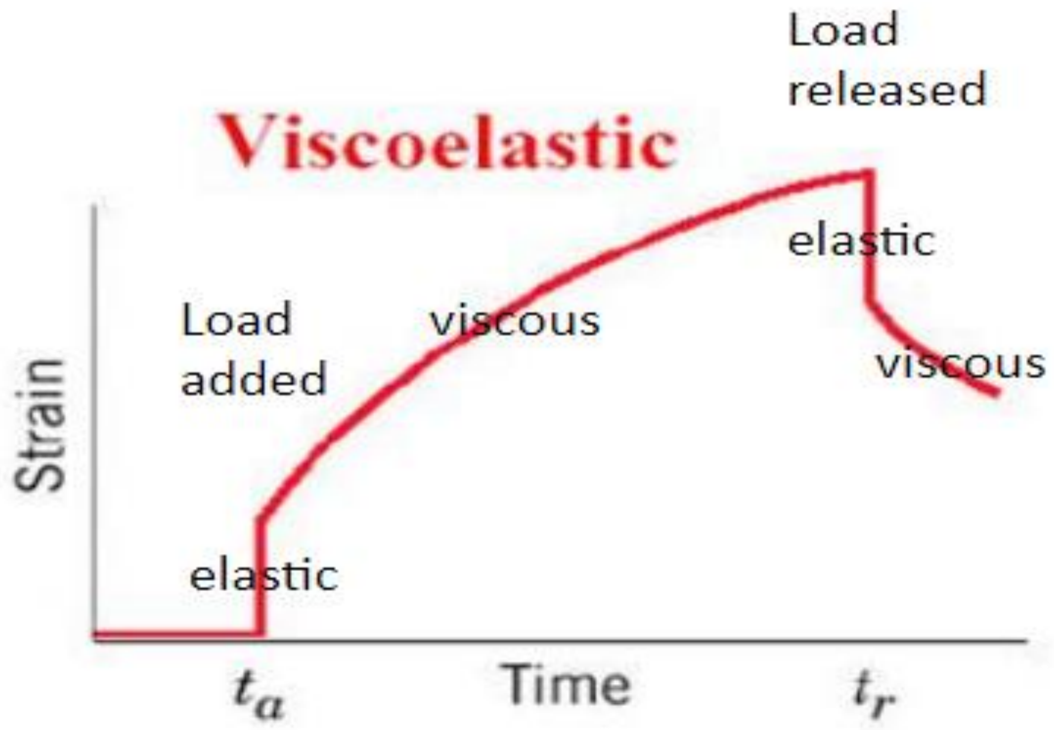
Viscoelastic behavior

- Behaviour of most polymer is in between behaviour of elastic and viscous materials.

1. At low temperature & high strain rate,
   - ✓ Polymer demonstrate **elastic behaviour**,
2. At high temperature & low strain rate,
   - ✓ Polymer demonstrate **viscous behaviour**
3. At intermediate temperatures & rate of strain
   - ✓ Polymer demonstrate **visco-elastic behaviour**

Biopolymer called viscoelastic because :

- Showing both behaviour **elastic & viscous behaviour**
- Instantaneously elastic strain followed by viscous time dependent strain



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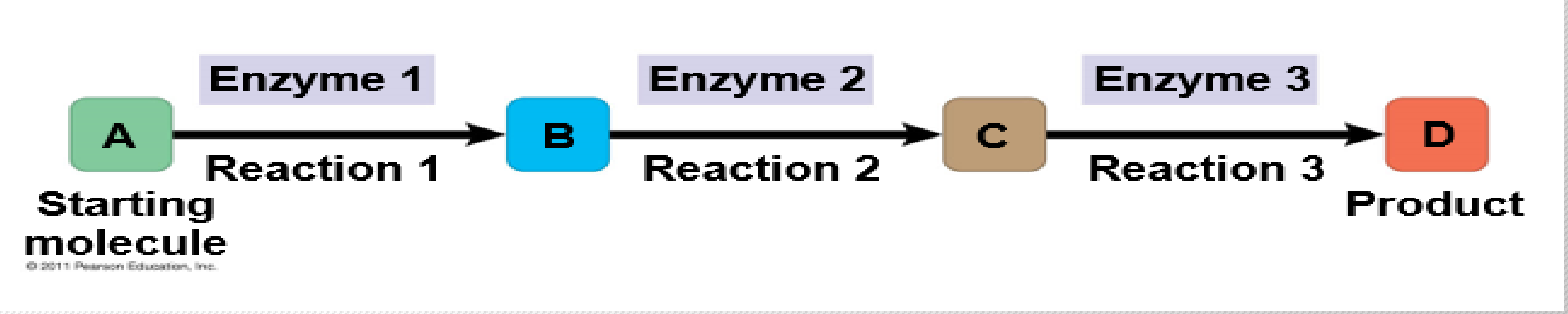
Lec. 6

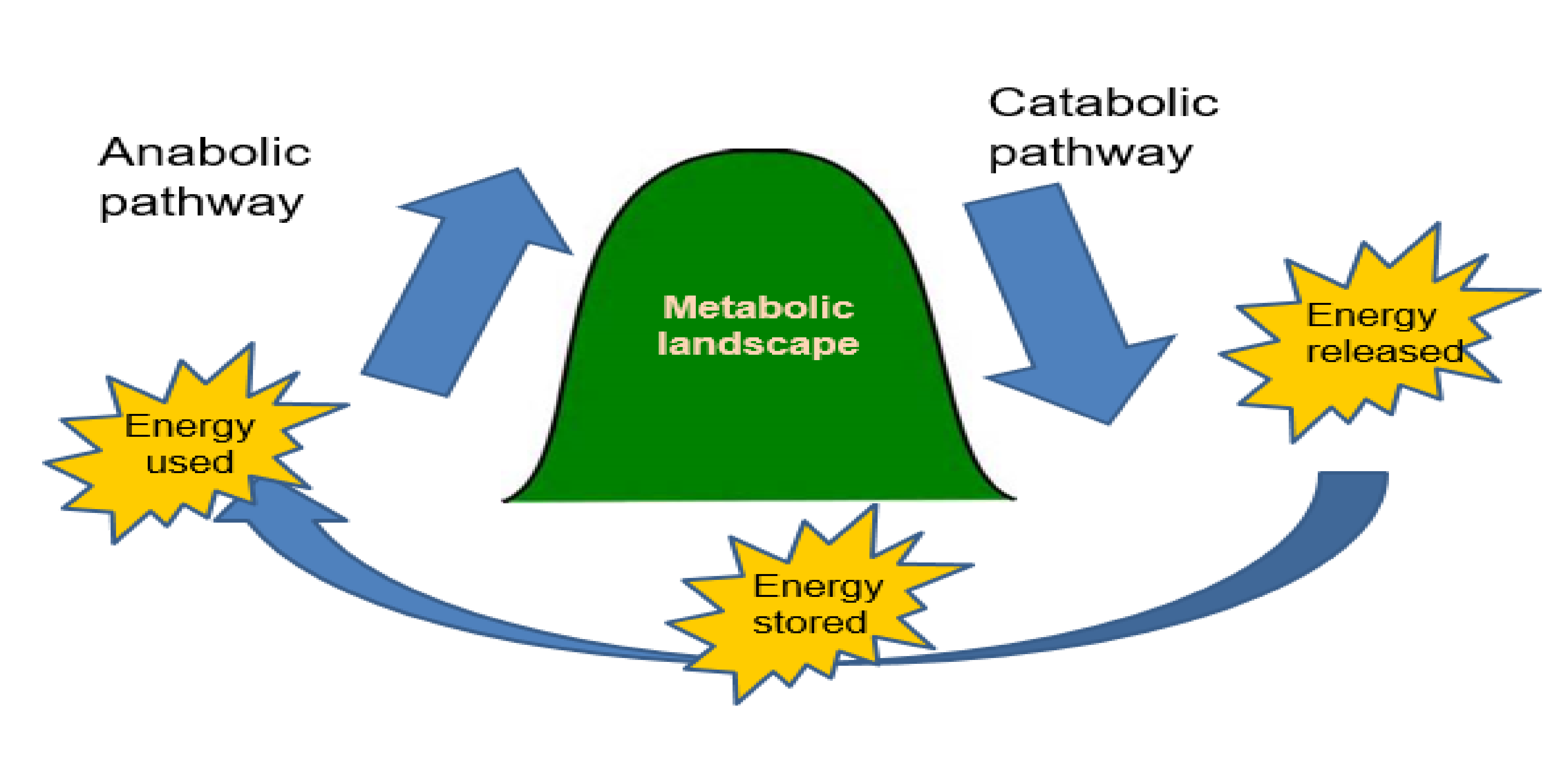
Thermodynamics of Biochemical Reactions and Metabolism

The Energy of Life

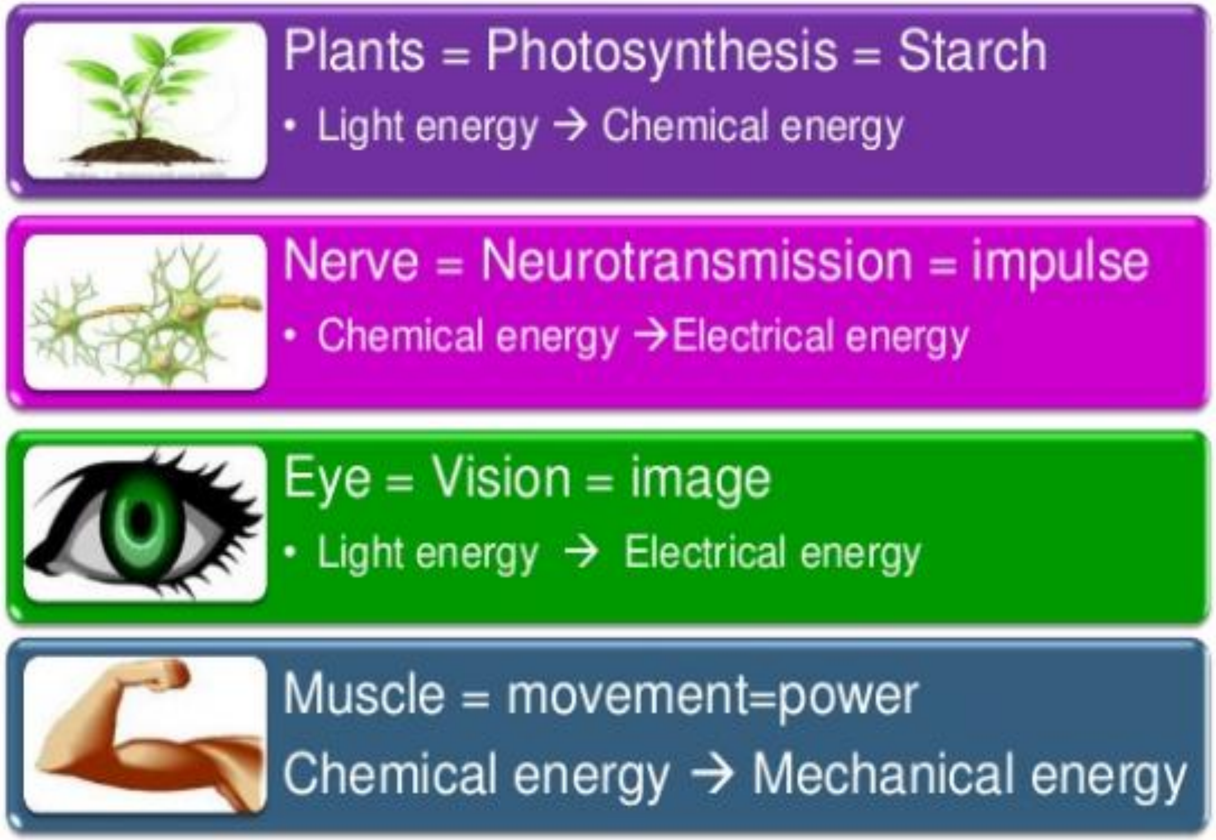
- The living cell is a small chemical factory where thousands of reactions occur
- The cell extracts energy and applies energy to perform work, some organisms even convert energy to light, as in bioluminescence
- Metabolism is the totality of an organism's chemical reactions

- A metabolic pathway begins with a specific molecule and ends with a product. Each step is catalysed by a specific enzyme.
- A Catabolic pathways release energy by breaking down complex molecules into simpler compounds like cellular respiration (the breakdown of glucose in the presence of oxygen).
- An Anabolism is the set of metabolic pathways that construct molecules from smaller units. These reactions require energy.




Anabolic pathway
Catabolic pathway
Metabolic landscape
Energy used
Energy released
Energy stored

- In living cells, thermodynamic changes are essential for biological functions such as growth, reproduction photosynthesis and respiration.
  - Light →Chemical : photosynthesis.
  - Chemical →Chemical : cellular respiration.
  - Chemical→ Electrical : Nervous system.
  - Chemical→ Mechanical : Muscles.



Energy

Energy is the capacity to cause change. Energy exists in various forms

1. Kinetic energy is energy associated with motion
2. Heat (thermal energy) is kinetic energy associated with random movement of atoms or molecules
3. Potential energy is energy that matter possesses because of its location or structure
4. Chemical energy is potential energy available for release in a chemical reaction
5. Energy can be converted from one form to another

The measurement of work

• In bioenergetics, the most useful outcome of the breakdown of nutrients during metabolism is work: W=mgh (Joul) Where m= the mass (the gravitational attraction of the Earth), g = the acceleration of free fall (9.81 m $/S^2$), h = height of the surface from the Earth	• Example: Find the work of moving 10g of nutrients through a 20m trunk of tree? W=mgh = (10x10^{-3}) (9.8) (20) = 2 J

The Laws of Energy Transformation

Thermodynamics is the study of energy transformations,

- According to the first law of thermodynamics, the energy of the universe is constant and energy can be transferred and transformed, but it cannot be created or destroyed
- The first law is also called the principle of conservation of energy

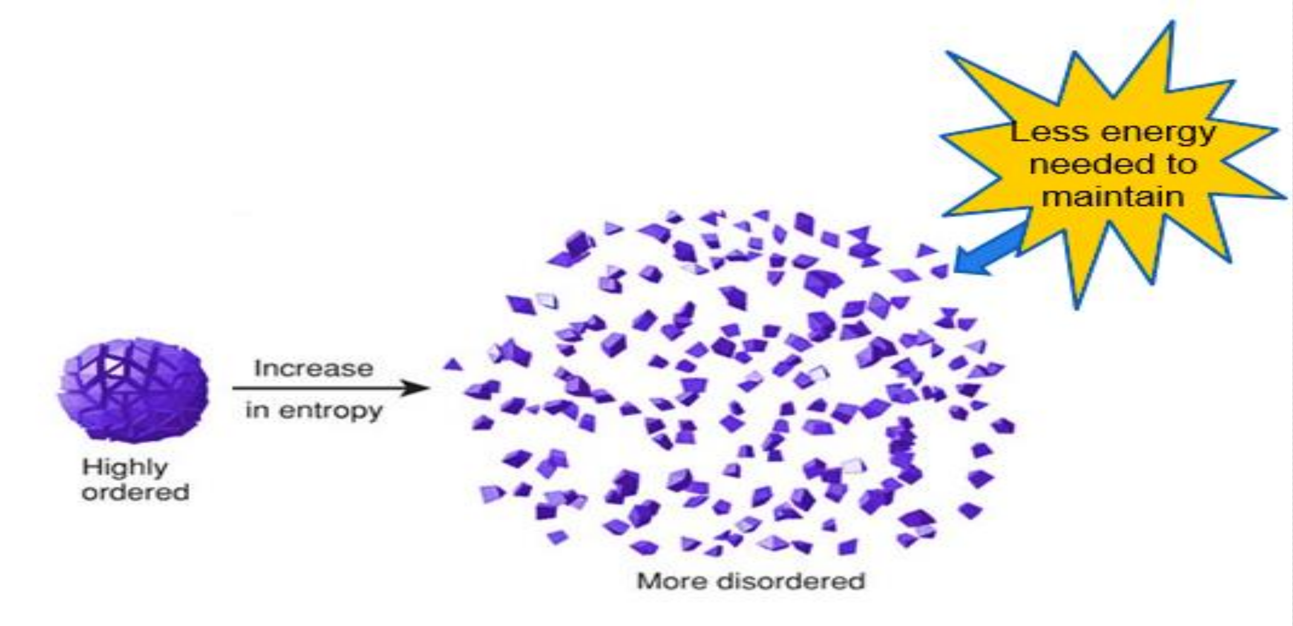
Thermodynamics system

- Based on the differentiation between flows of energy and flow of matter across the system boundary, thermodynamics distinguishes 3 types of systems:
  - 1.An open system exchanges matter and energy with its environment.
  - 2.A closed system exchanges only energy with its environment.
  - 3.An isolated system exchanges neither matter nor energy with its environment.

LAWS OF THERMODYNAMICS

1st Law: Energy can be transferred and transformed but it can’t be created or destroyed. (conservation of energy)

2nd Law: Every energy transfer or transformation increases the entropy (disorder) of the universe.



Entropy(ΔS), Enthalpy(ΔH) and Free Energy (ΔG)

Entropy measures the amount of heat dispersed or transferred during a chemical process.

Enthalpy is the amount of heat energy transferred (heat absorbed or emitted) in a chemical process under constant pressure.

Free Energy is also known as Gibbs energy available to initiate a chemical process and is determined under constant pressure and temperature.

$$\Delta G = \Delta H - T \cdot \Delta S$$

ΔG = Gibbs free energy

ΔH = Change in enthalpy

ΔS = Change in entropy

T = Temperature in K

Exergonic reaction (catabolic reactions)	Endergonic reaction (Anabolic reactions)
ΔG is negative	ΔG is positive
ΔH is less than zero	ΔH is greater than zero
Increase in stability	Decrease in stability
Spontaneous	Non-spontaneous
Movement towards equilibrium	Movement away from equilibrium
Coupled to ATP formation	Coupled to ATP utilization
Catabolism	Anabolism

Example/ For the following biochemical reaction:

$$H_2(g) + I_2(g) \longrightarrow 2HI(g)$$

$$(\Delta S = 82.4\ J/K\ mol,\ \Delta H = 25.9\ kJ/mol)$$

Find 1) ΔG at 25⁰ C

2) ΔG at 200⁰ C and what is the type of the reaction

1) $\Delta G = \Delta H - T\Delta S$

$\Delta G = (25.9 \times 10^3\ J/mol) - (298\ K \times 82.4\ J/K)$

$\Delta G = 1344.8\ J/mol$

$\Delta G = 1.34\ kJ/mol$

Non- Spontaneous

2) $\Delta G = \Delta H - T\Delta S$

$\Delta G = (25.9 \times 10^3\ J/mol) - (473\ K \times 82.4\ J/K)$

$\Delta G = -13075.2\ J/mol$

$\Delta G = -13.1\ kJ/mol$

Spontaneous

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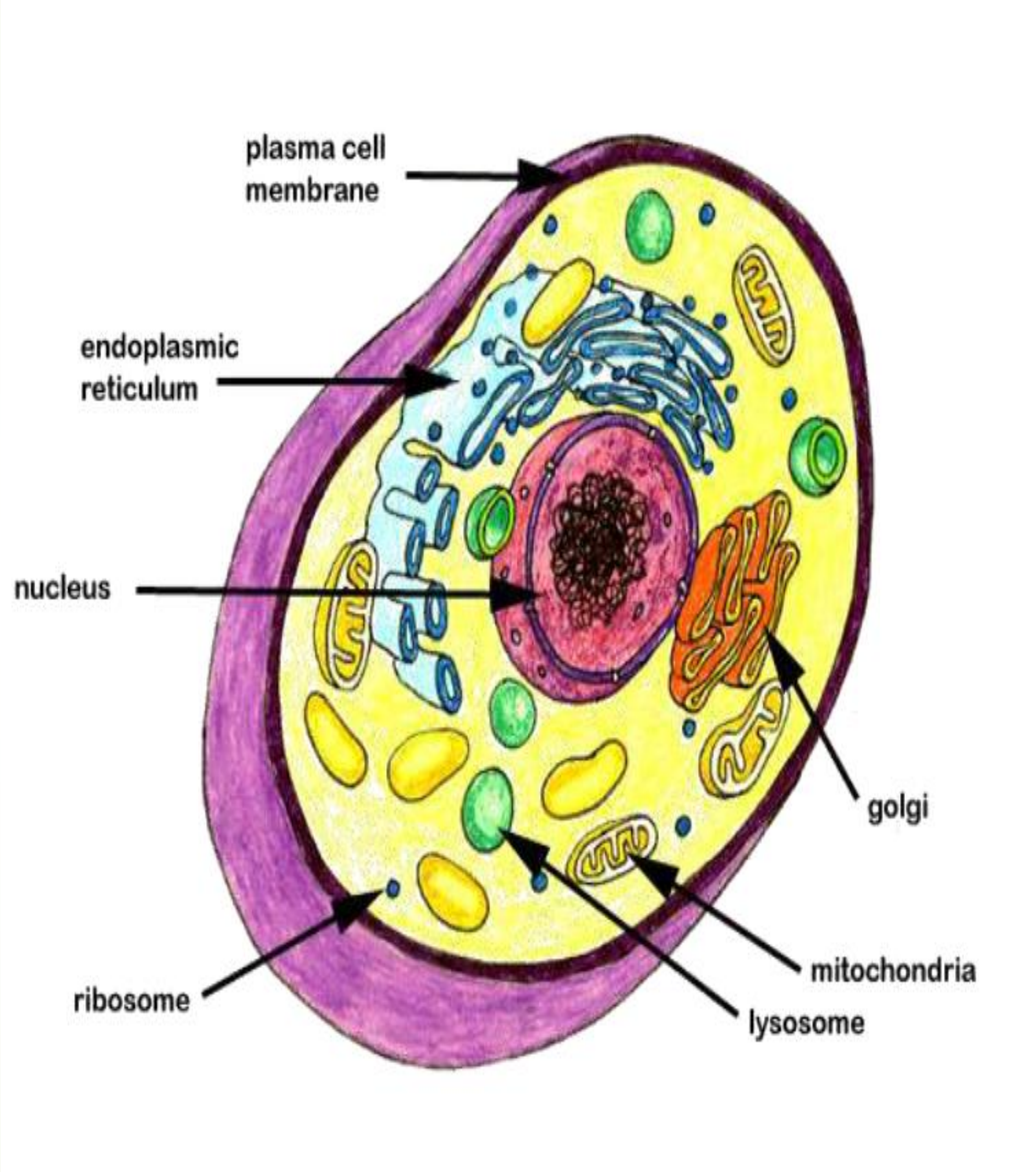
Cell Membrane Structures and Properties

What is a cell?

Cells are the structural and functional units of all living organisms. Some organisms, such as bacteria, are unicellular, consisting of a single cell. Other organisms, such as humans, are multicellular, or have many cells.

Cell parts

- Nucleus
- Cell Membrane
- Mitochondria
- Ribosomes
- Lysosome
- Golgi Apparatus
- Endoplasmic Reticulum

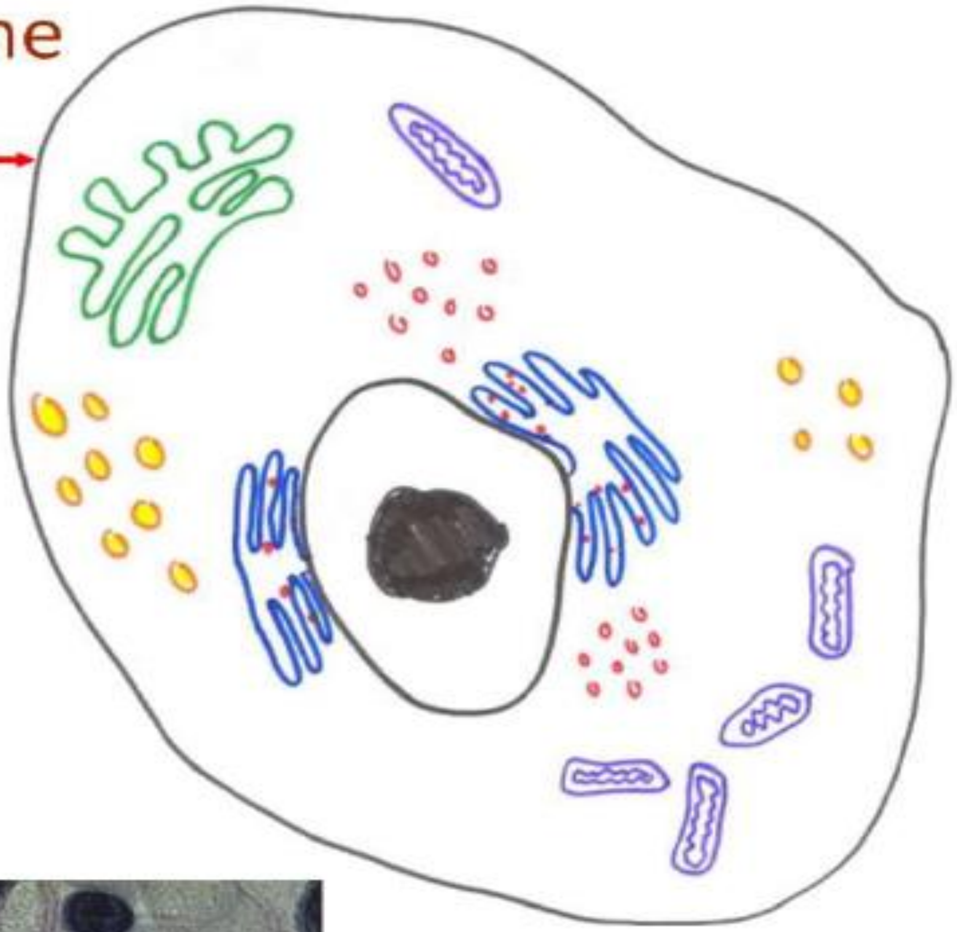


CELL MEMBRANE

Biological membrane that separates the interior of all cells from the outside environment (the extracellular space) which protects the cell from its environment.

Also known as the plasma membrane (PM) or cytoplasmic membrane, and historically referred to as the plasmalemma

Functions of a plasma membrane



1. Hold the cell together

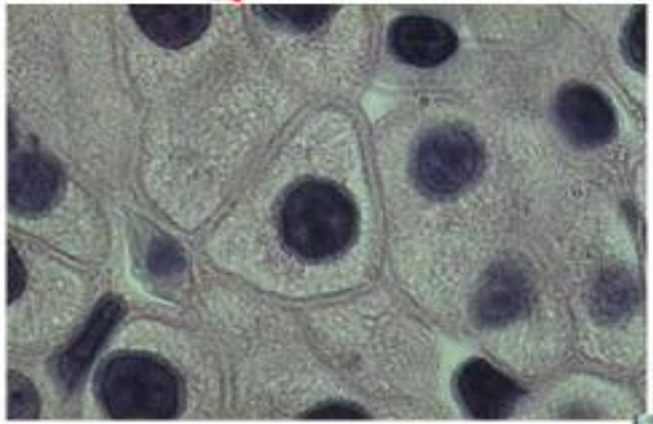
2. Control what goes in and out
   (diffusion, osmosis, active transport)

3. Protect the cell

4. Allow the cell to recognise and be recognised
   (cell signalling and immunity)

5. Bind to other cells and molecules

6. A site for biochemical reactions
   (enzymes, areas for reactions)



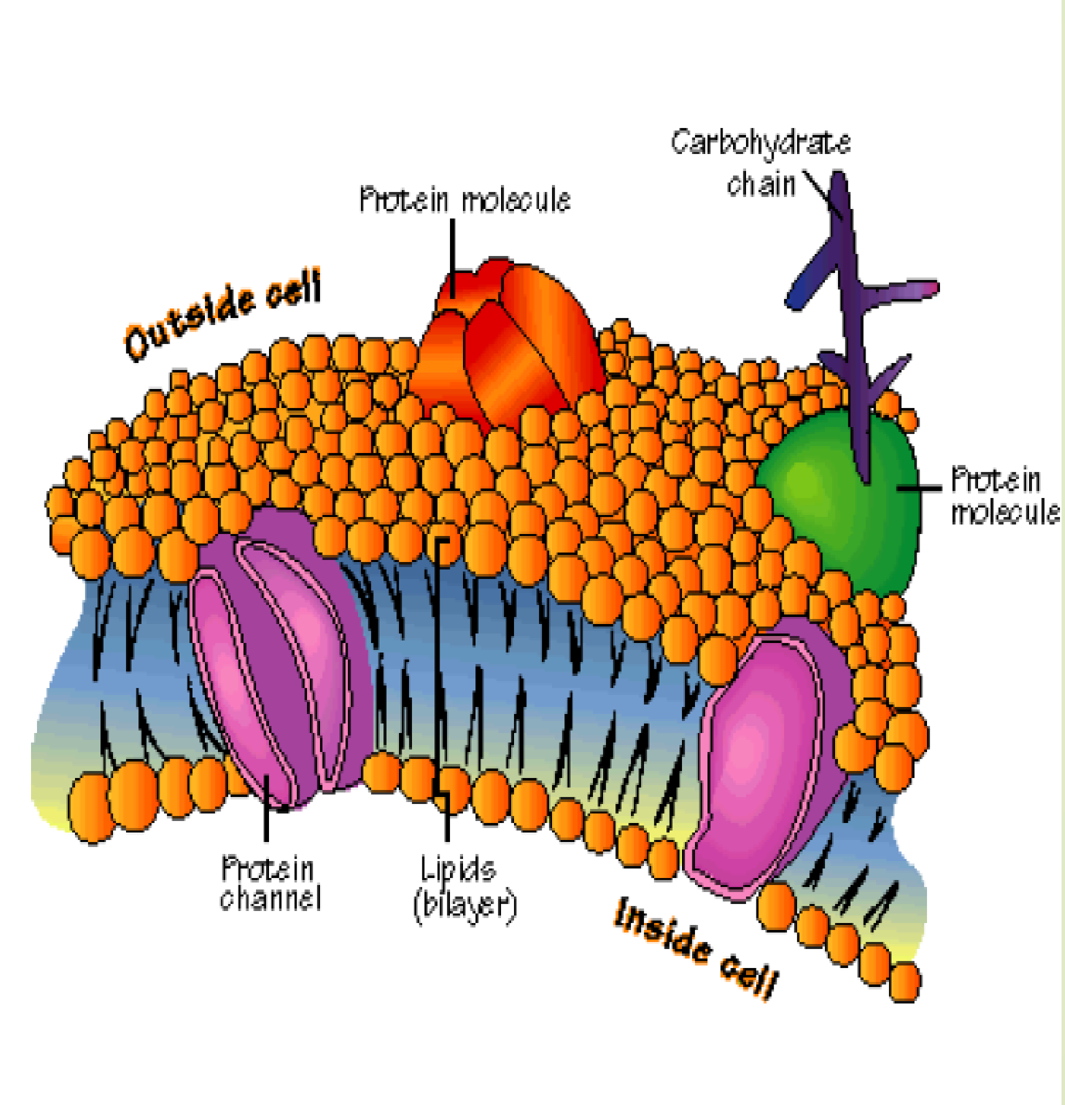
Liver cells binding to one another
http://hplusclub.com/hblog/files/2008/04/liver-cells.JPG

CELL MEMBRANE PROPERTIES

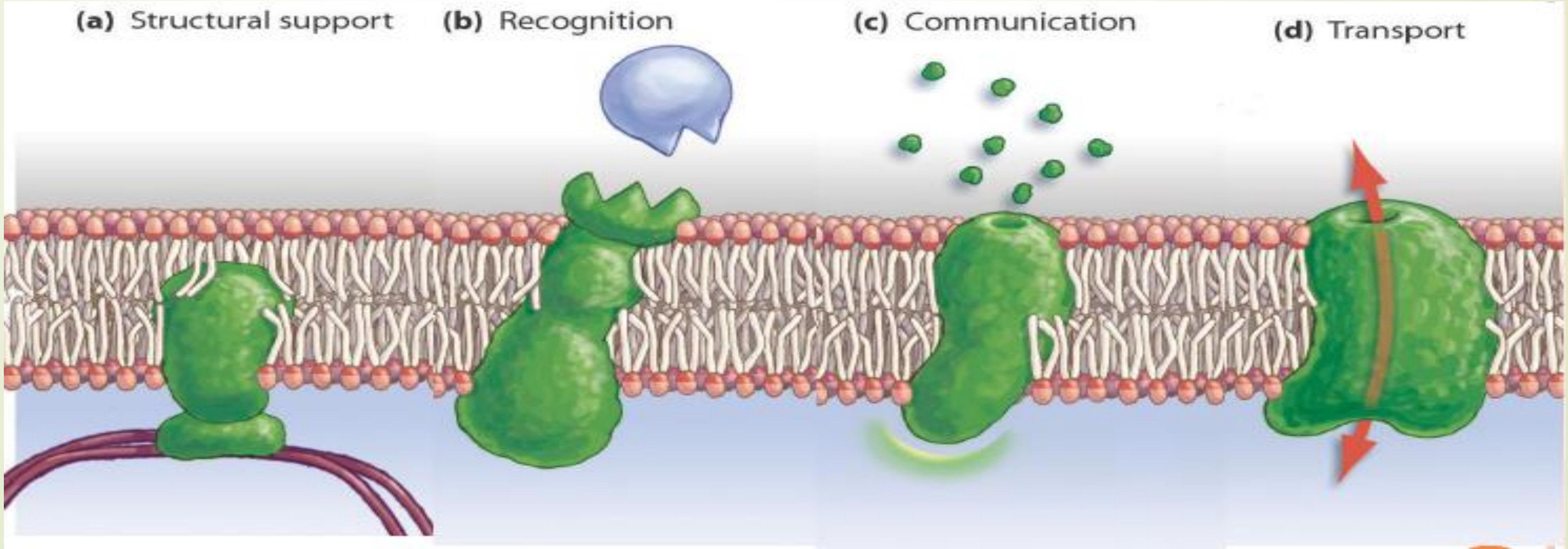
- Thickness is 5-8 nm
- Selectively permeable
- Serve as outer boundary
- Allows some substances to cross more easily than others
- Made of Phospholipids, proteins & conjugated molecules

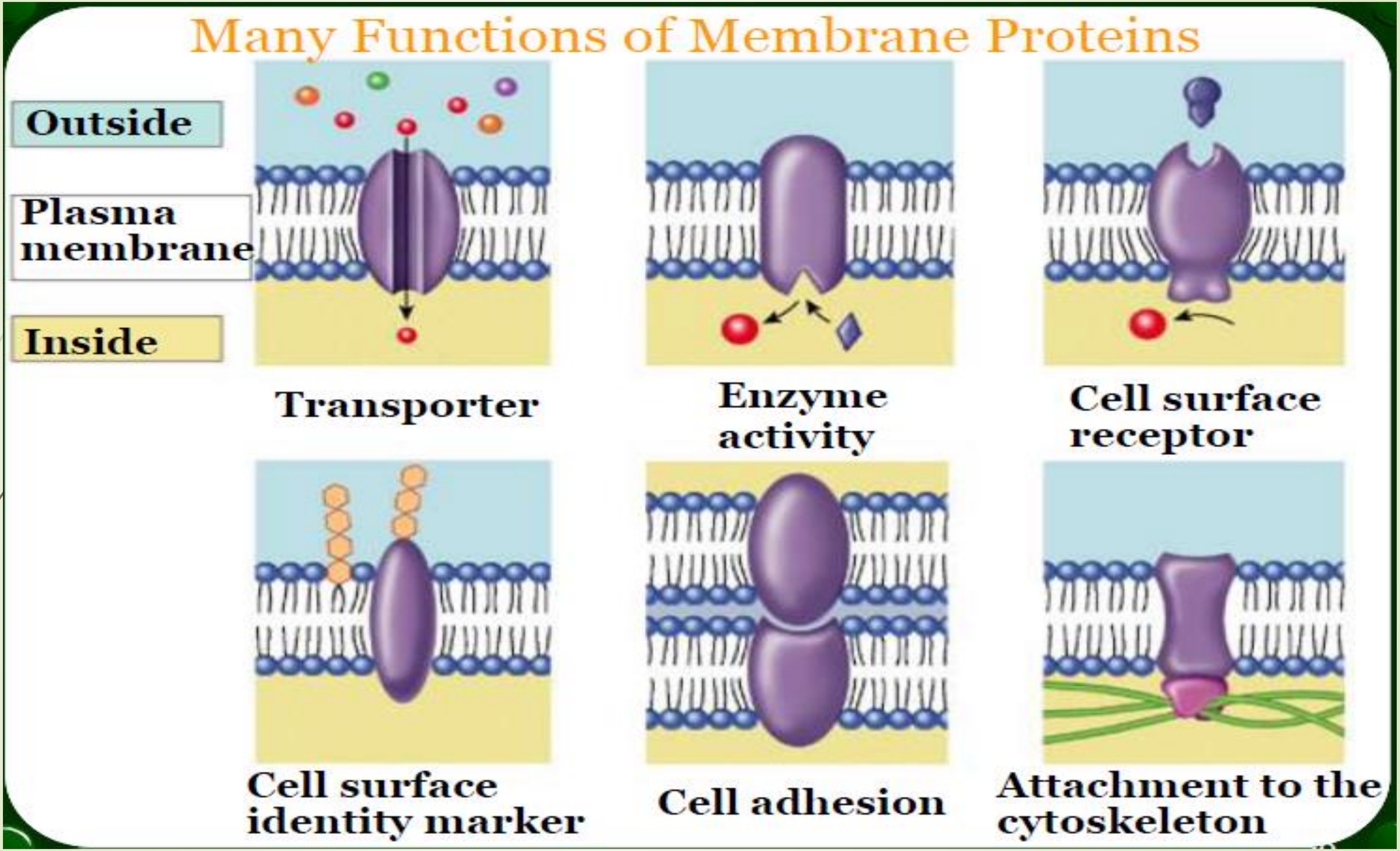
CHEMICAL COMPOSITION

- **Lipids** -four major classes of lipids are commonly present in the plasma membrane: phospholipids, spingolipids, glycolipids and sterols (e.g. cholesterol). All of them are amphipathic. Cholesterol is abundant in mammalian cell and is absent in prokaryotic cells.

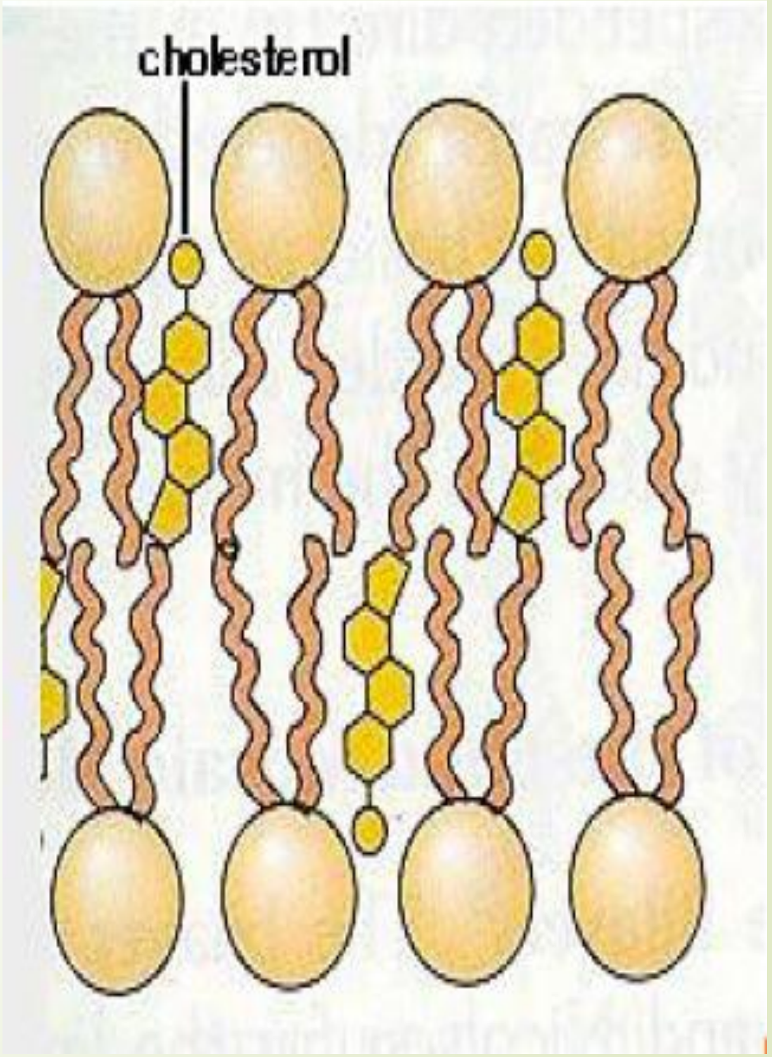


- **Proteins**-plasma membrane contains about 50% protein. Proteins of plasma membranes are of two types ectoproteins and endoproteins. Plasma membranes contains structural proteins, transport proteins and enzymes. Some of them acts as receptors.




Many Functions of Membrane Proteins
Outside
Plasma membrane
Inside
Transporter
Enzyme activity
Cell surface receptor
Cell surface identity marker
Cell adhesion
Attachment to the cytoskeleton

- **Carbohydrates**- they are present only in the plasma membrane and are present exterior (glycoproteins) or polar end of phospholipids at the external surface of plasma membrane.

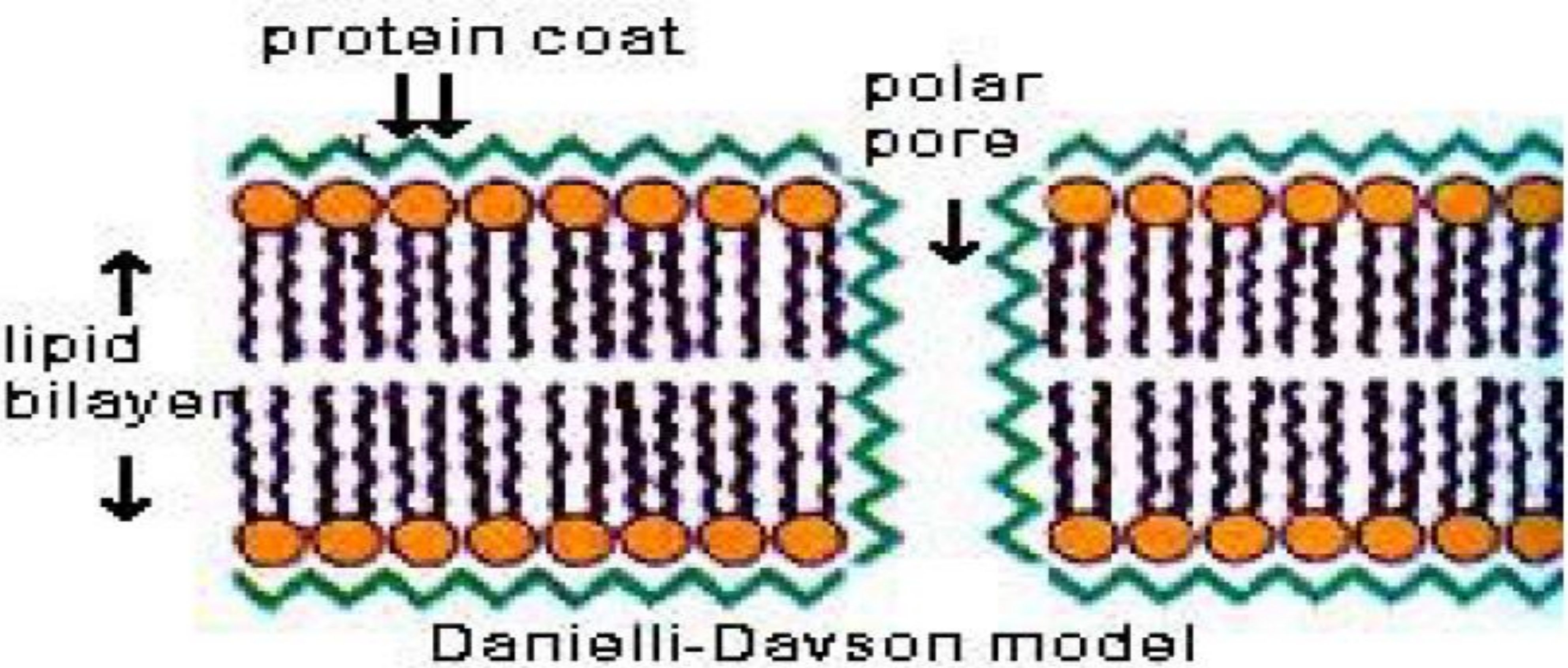


MODELS OF PLASMA MEMBRANE

1. DANIELLI AND DAVSON MODEL

- In 1935, Danielli and Davson studied triglyceride lipid bilayers over a water surface
- They found that they arranged themselves with the polar heads facing outward
- It always formed droplets (oil in water) and the surface tension was much higher than that of cells
- Called as Sandwich model

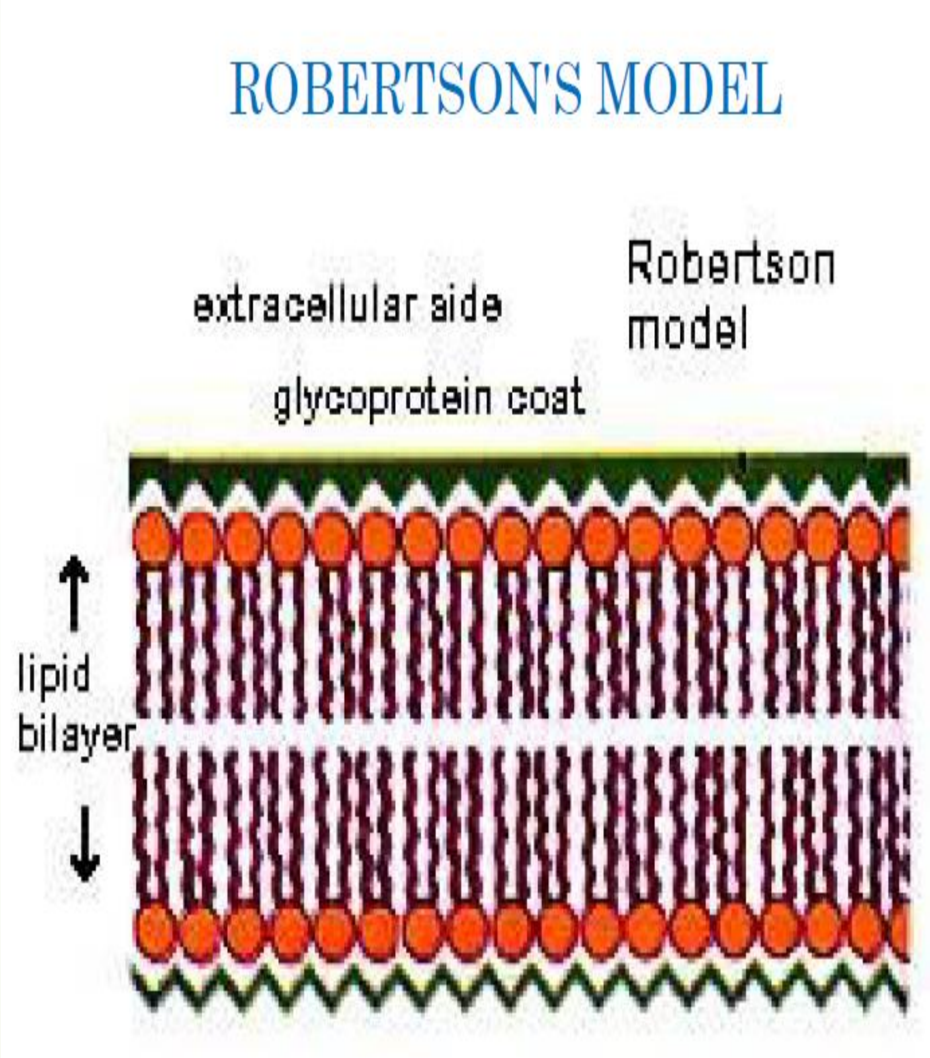
DANIELLI AND DAVSON MODEL



MODELS OF PLASMA MEMBRANE

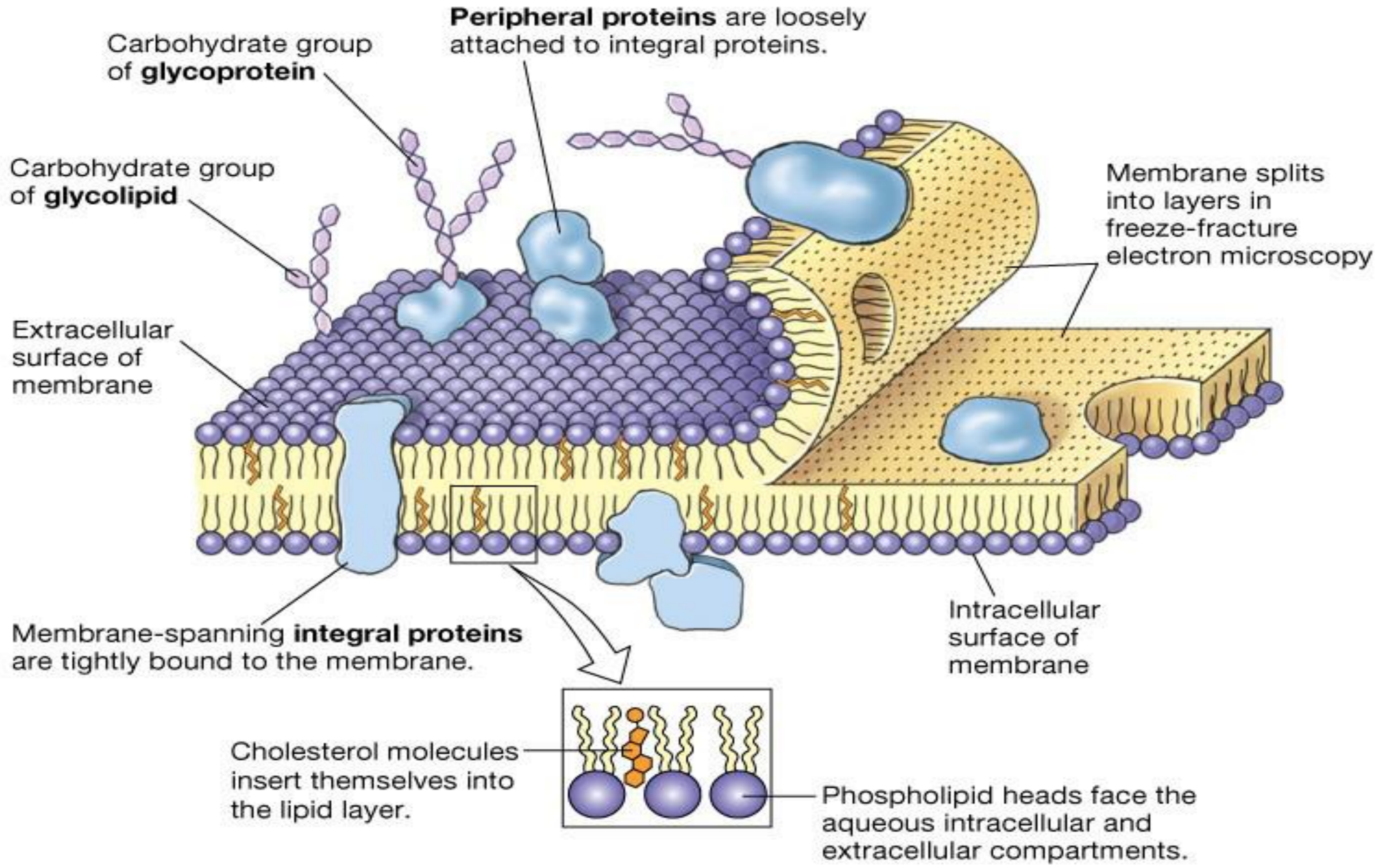
2. ROBERTSON'S MODEL

- In 1965, Robertson noted the structure of membranes seen in the electron micrographs
- He saw no spaces for pores in the electron micrograph
- Proposed unit membrane hypothesis



3. FLUID MOSAIC MODEL

- According to Singer and Nicolson 1972, the biological membranes can be considered as a 2D liquid where all lipid and protein molecules diffuse freely.
- Singer studied phospholipid bilayers and found that they can form a flattened surface on water, with no requirement for a protein coat
- It occurs in form of globular protein
- Widely accepted model


Peripheral proteins are loosely attached to integral proteins.
Carbohydrate group of glycoprotein
Carbohydrate group of glycolipid
Membrane splits into layers in freeze-fracture electron microscopy
Extracellular surface of membrane
Membrane-spanning integral proteins are tightly bound to the membrane.
Intracellular surface of membrane
Cholesterol molecules insert themselves into the lipid layer.
Phospholipid heads face the aqueous intracellular and extracellular compartments.

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Lec. 8

Diffusion and Osmosis in Biological Organisms

Body Fluids

- Two compartments
  - Intracellular (~67% of body's H_20)
  - Extracellular (~33% of body's H_20)
    - Blood plasma: about 20% of this
    - Tissue fluid (or interstitial fluid)
      - Includes extracellular matrix
    - Lymph

Transport across cell membrane

- Plasma (cell) membrane
  - Is selectively permeable
    - Generally not permeable to
      - Proteins
      - Nucleic acids
    - Selectively permeable to
      - Ions
      - Nutrients
      - Waste
  - It is a biological interface between the two compartments

- Plasma (cell) membrane
  - Site of chemical reactions
    - Enzymes located in it
    - Receptors: can bond to molecular signals
    - Transporter molecules
  - Recognition factors: allow for cellular adhesion

TRANSPORT ACROSS CELL MEMBRANE

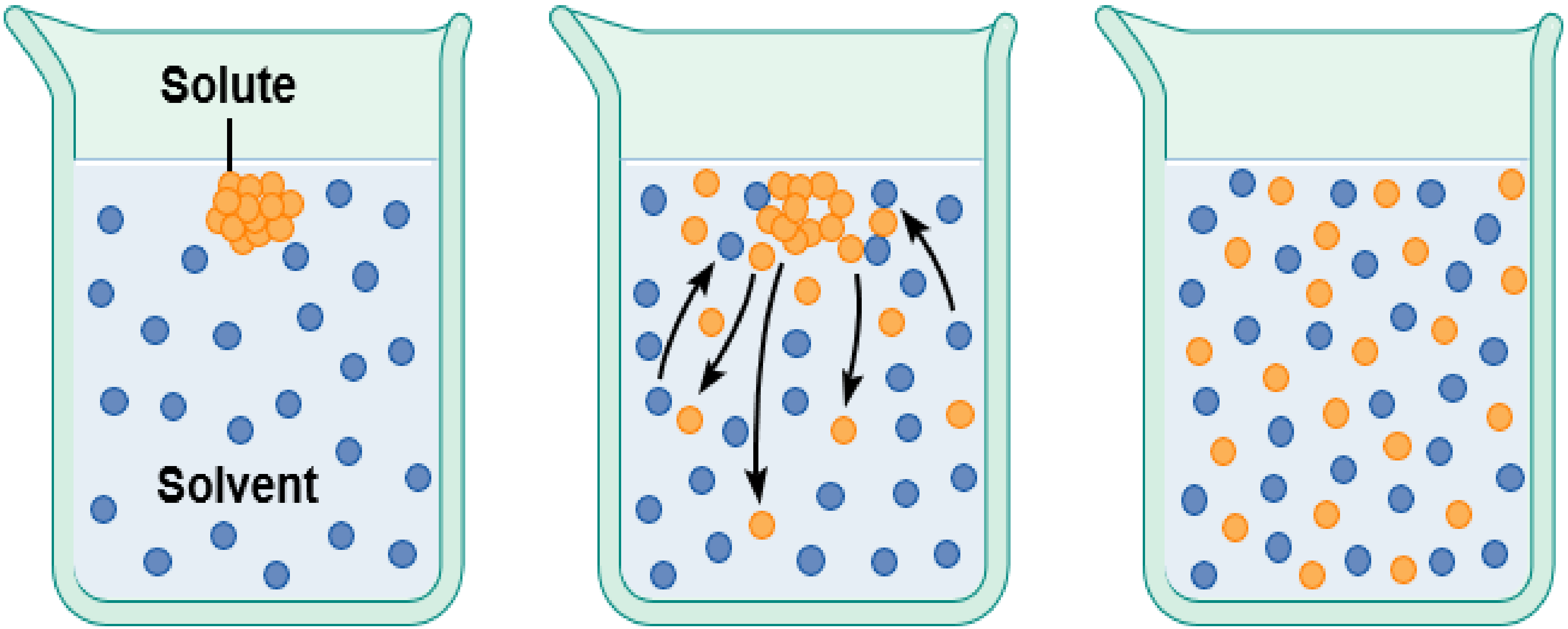
- Transport categories
  - Based on structure
    - Carrier-mediated
      - Facilitated diffusion
      - Active transport
    - Non-carrier mediated
      - Diffusion
      - Osmosis
      - Bulk flow (pressure gradients)
    - Vesicle mediated
      - Exocytosis
      - Endocytosis
        - Pinocytosis
        - phagocytosis

TRANSPORT ACROSS CELL MEMBRANE

- Based on energy requirements
  - Passive transport
    - Based on concentration gradient
    - Does not use metabolic energy
  - Active transport
    - Against a gradient
    - Uses metabolic energy
    - Involves specific carriers

DIFFUSION

- Physical process that occurs:
  - **Concentration difference** across the membrane
  - **Membrane is permeable** to the diffusing substance.
- Molecules/ions are in constant state of random motion due to their thermal energy.
  - Eliminates a concentration gradient and distributes the molecules uniformly.


Solute
Solvent

DIFFUSION THROUGH CELL MEMBRANE

- Cell membrane permeable to:
  - Non-polar molecules (0_2)
  - Lipid soluble molecules (steroids)
  - Small polar covalent bonds ($C0_2$)
  - H_20 (small size, lack charge)
- Cell membrane impermeable to:
  - Large polar molecules (glucose)
  - Charged inorganic ions (Na^+)

RATE OF DIFFUSION

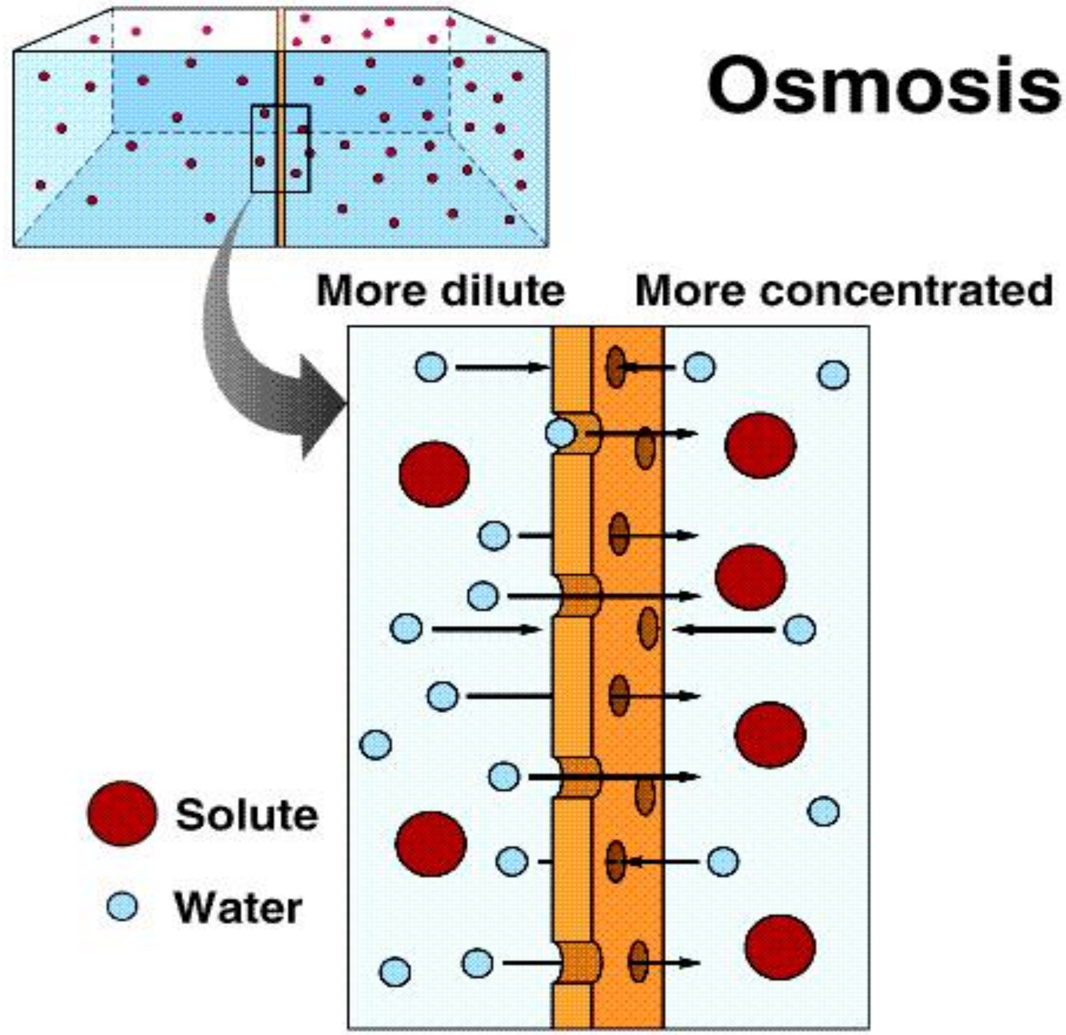
- Dependent upon:
  - The magnitude of concentration gradient.
    - Driving force of diffusion.
  - Permeability of the membrane.
    - Neuronal cell membrane 20 x more permeable to K^+ than Na^+.
  - Temperature.
    - Higher temperature, faster diffusion rate.
  - Surface area of the membrane.
    - Microvilli increase surface area.

OSMOSIS

- Net diffusion of H_20 across a selectively permeable membrane.
- 2 requirements for osmosis:
  - Must be difference in solute concentration on the 2 sides of the membrane.
  - Membrane must be impermeable to the
  - solute.
  - **Osmotically active solutes**: solutes that cannot pass freely through the membrane.

EFFECTS OF OSMOSIS

- Movement of $H_2 0$ form high concentration of $H_2 0$ to lower concentration of $H_2 0$.

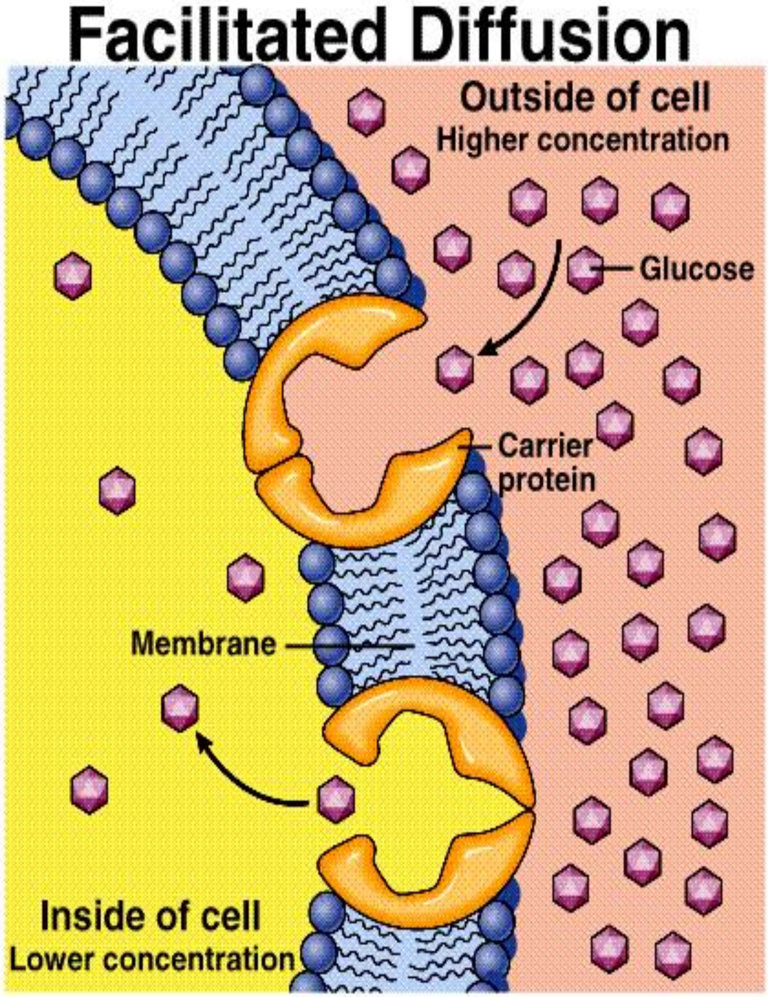


CARRIER-MEDIATED TRANSPORT

- Transport across cell membrane by protein carriers.
- Characteristics of protein carriers:
  - Specificity:
    - Interact with specific molecule only.
  - Competition:
    - Molecules with similar chemical structures compete for carrier site.
  - Saturation:
    - Carrier sites filled.

FACILITATED DIFFUSION

- Facilitated diffusion:
- Passive:
  - ATP not needed. Powered by thermal energy.
  - Involves transport of substance through cell membrane from higher to lower concentration.

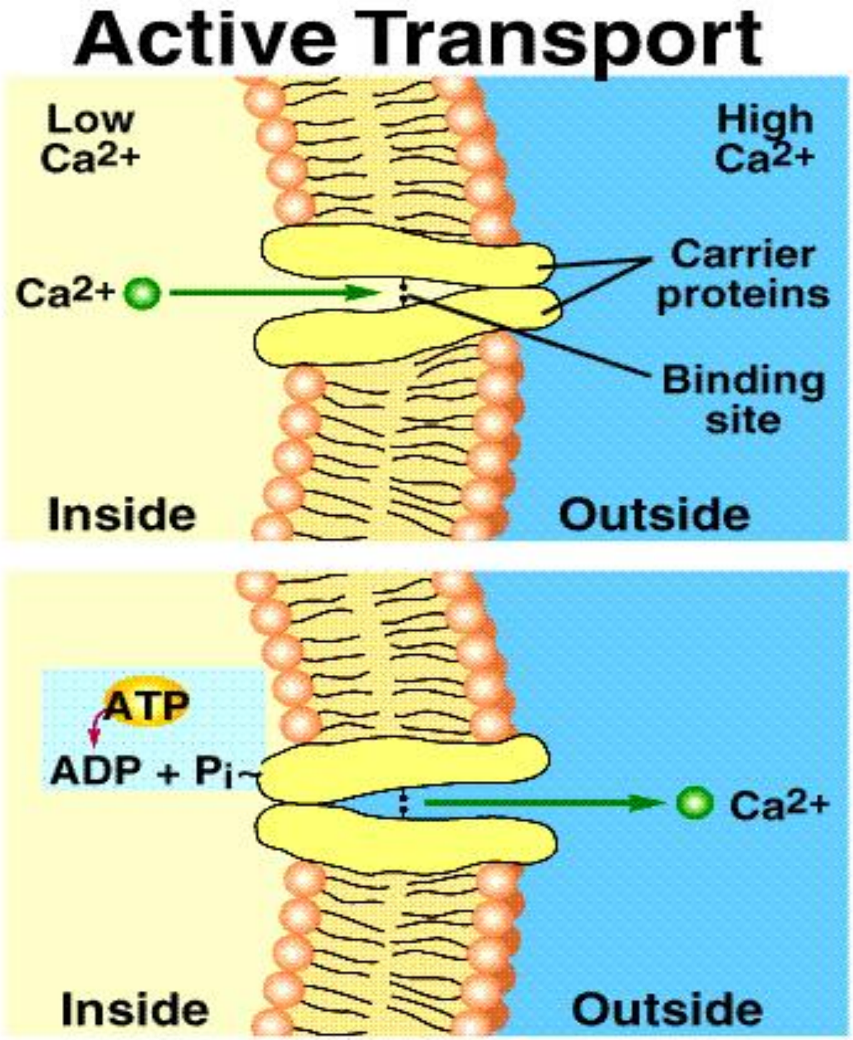


ACTIVE TRANSPORT

- Movement of molecules and ions against their concentration gradients.
  - From lower to higher concentrations.
- Requires ATP.
- 2 Types of Active Transport:
  - Primary
  - Secondary

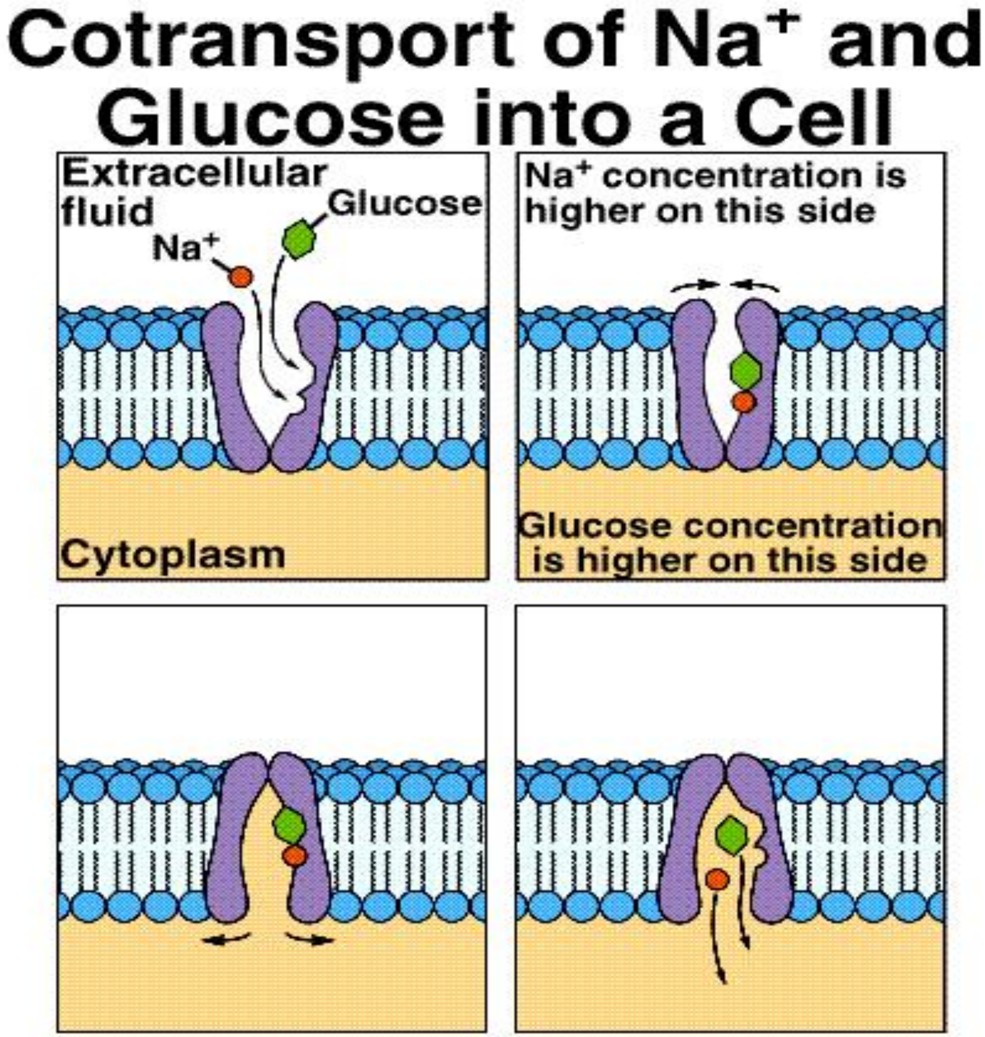
PRIMARY ACTIVE TRANSPORT

- ATP directly required for the function of the carriers.
- Molecule or ion binds to carrier site.
- Binding stimulates phosphorylation (breakdown of ATP).
- Conformational change moves molecule to other side of membrane.



SECONDARY ACTIVE TRANSPORT

- Coupled transport.
- Energy needed for uphill movement obtained from downhill transport of Na^+.



SECONDARY ACTIVE TRANSPORT

- Cotransport (symport):
  - Molecule or ion moving in the same direction.
- Countertransport (antiport):
  - Molecule or ion is moved in the opposite direction.

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Second Stage / 2nd Semester

BIOPHYSICS

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Lec. 9

Electrochemistry

of cells

MEMBRANE POTENTIAL

- The body cells are surrounding by fluids which are ionic and which provide a conductive medium for electric potentials.
- The principal ions are Sodium(Na^+), Potassium (K^+) and Chloride (Cl^-).

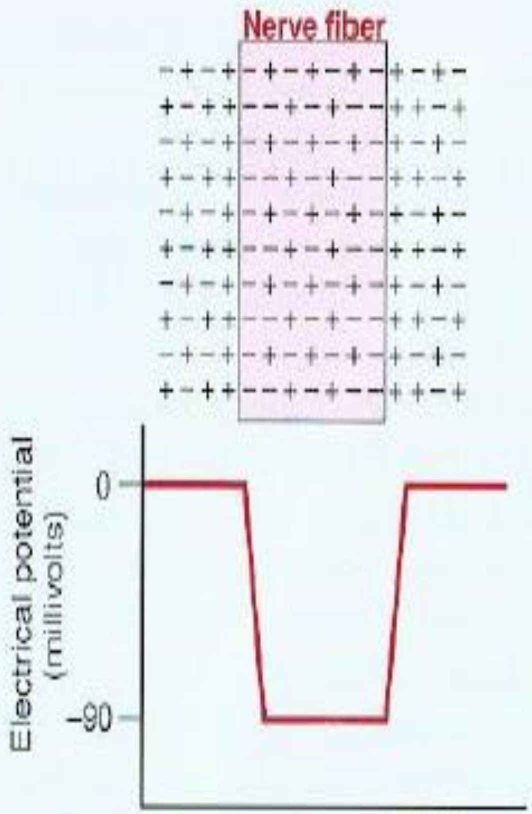
The membrane of normal state readily permits entry of Potassium and Chloride ions but blocks the entry of Sodium ions even though there may be a very high concentration gradient of Sodium across the cell membrane. This results in the concentration of sodium ion more on the outside of the cell membrane than on the inside.

- Since Sodium is a positive ion, in its resting state, a cell has negative charge along the inner surface of its membrane and a positive charge along the outer portion.
- The membrane potential is called the **resting potential** of the cell and is maintained until some kind of disturbance upsets the equilibrium.

Measurements indicate that the majority of cells are polarized, i.e., that their interior is at a negative potential, usually in the range of -30 to -90 mV, depending on the function. Although the voltage of this biological cells is not large, the corresponding electric field is enormous

$$E = U_m/d$$

because the d=the thickness of the cell membrane (very small)



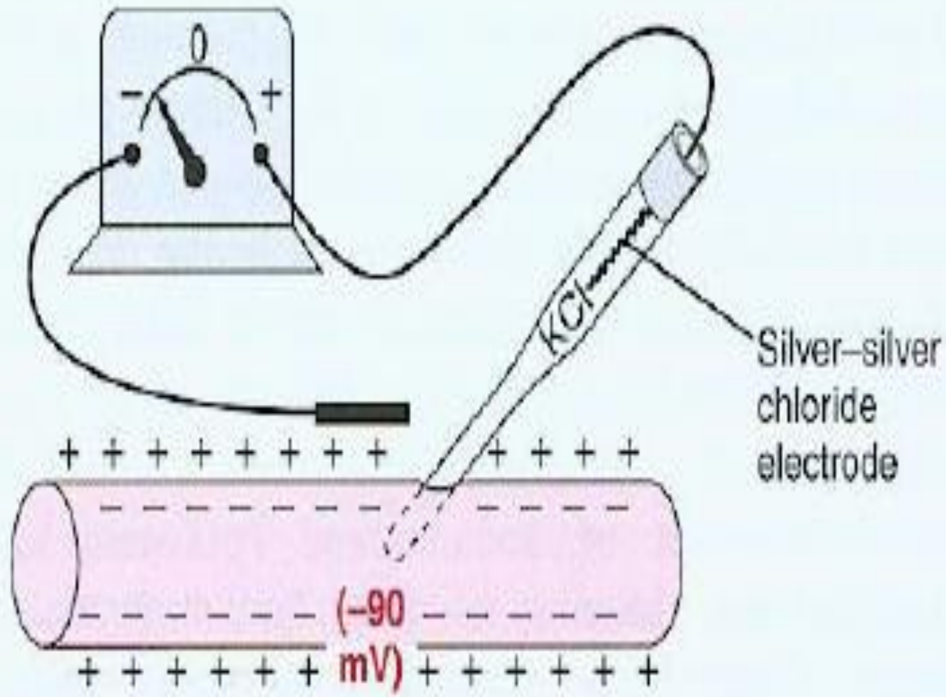


FIGURE 5–2

Measurement of the membrane potential of the nerve fiber using a microelectrode.

When a section of the cell membrane is excited by the follow of ionic current or by some form of externally applied energy, the membrane changes its characteristics and begins to allow some of the Sodium ions to enter.

This movement of Sodium ions into the cell creates an ionic current flow, at the same time Potassium ions which were in higher concentration inside the cell during the resting state, try to leave the cell but are unable to move as rapidly as the Sodium ions.

- As a result, the cell has a slightly positive potential on the inside due to the imbalance of potassium ions (**action potential**) ≈+20 mV. And this cell said to be **depolarized**.
- When Sodium ions movement through the cell stopped, a new state of equilibrium is reached.

- The cell membrane reverts back to its original (selectively permeable condition), where in the passage of Sodium from outside to inside the cell is again blocked.
- It would take a long time for resting potential to develop again. By an active process called “Sodium pump” the Sodium are quickly transported again from inside to outside the cell and the cell become polarized and assume its rest potential, this process is called “**repolarization**”

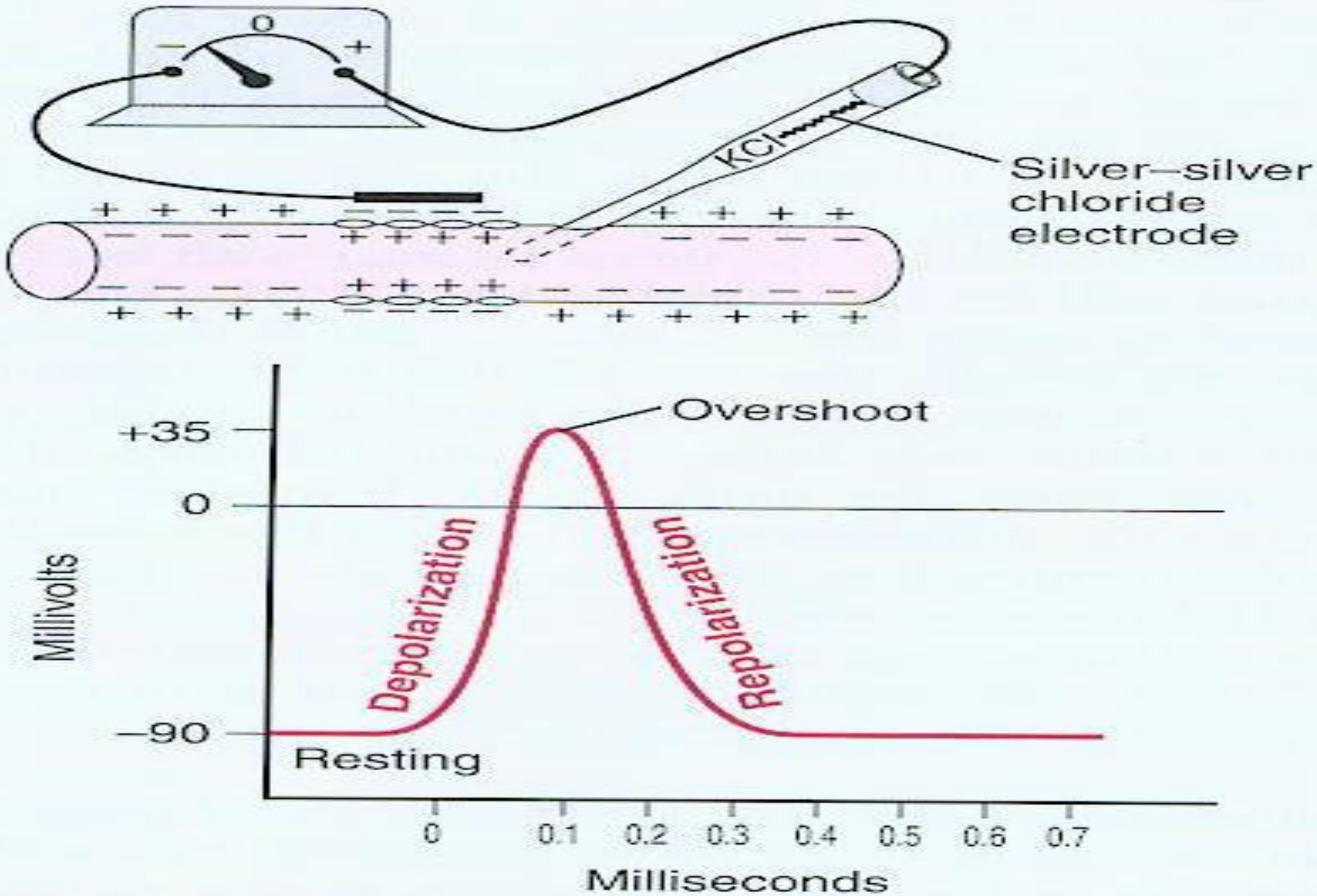


FIGURE 5 – 6

Typical action potential recorded by the method shown in the upper panel of the figure.

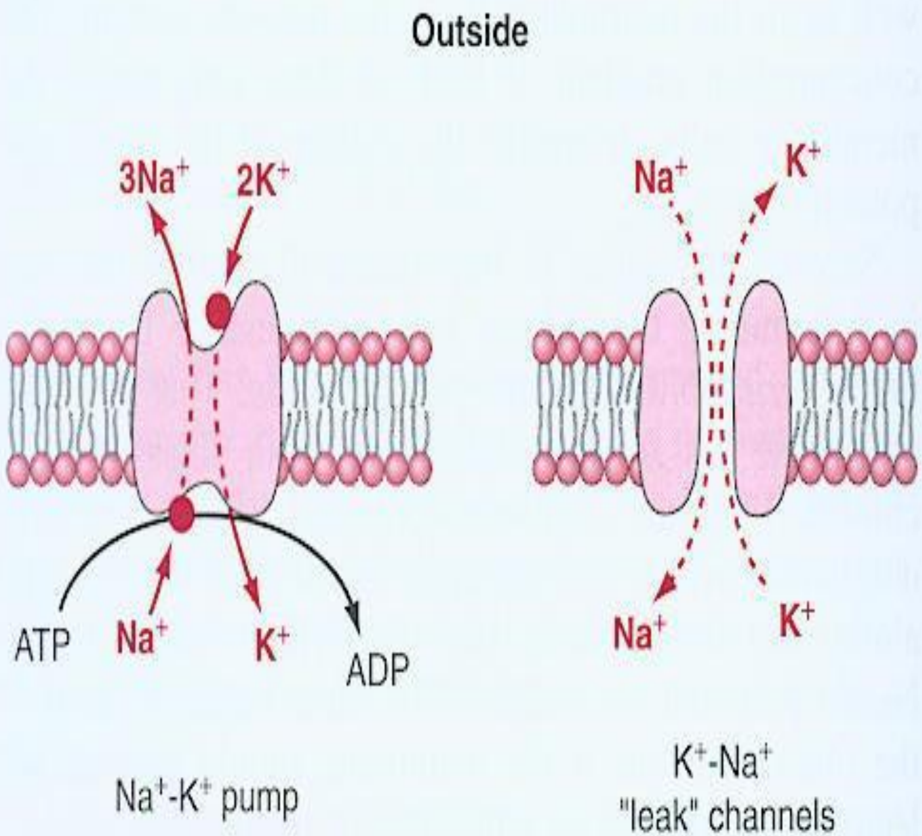
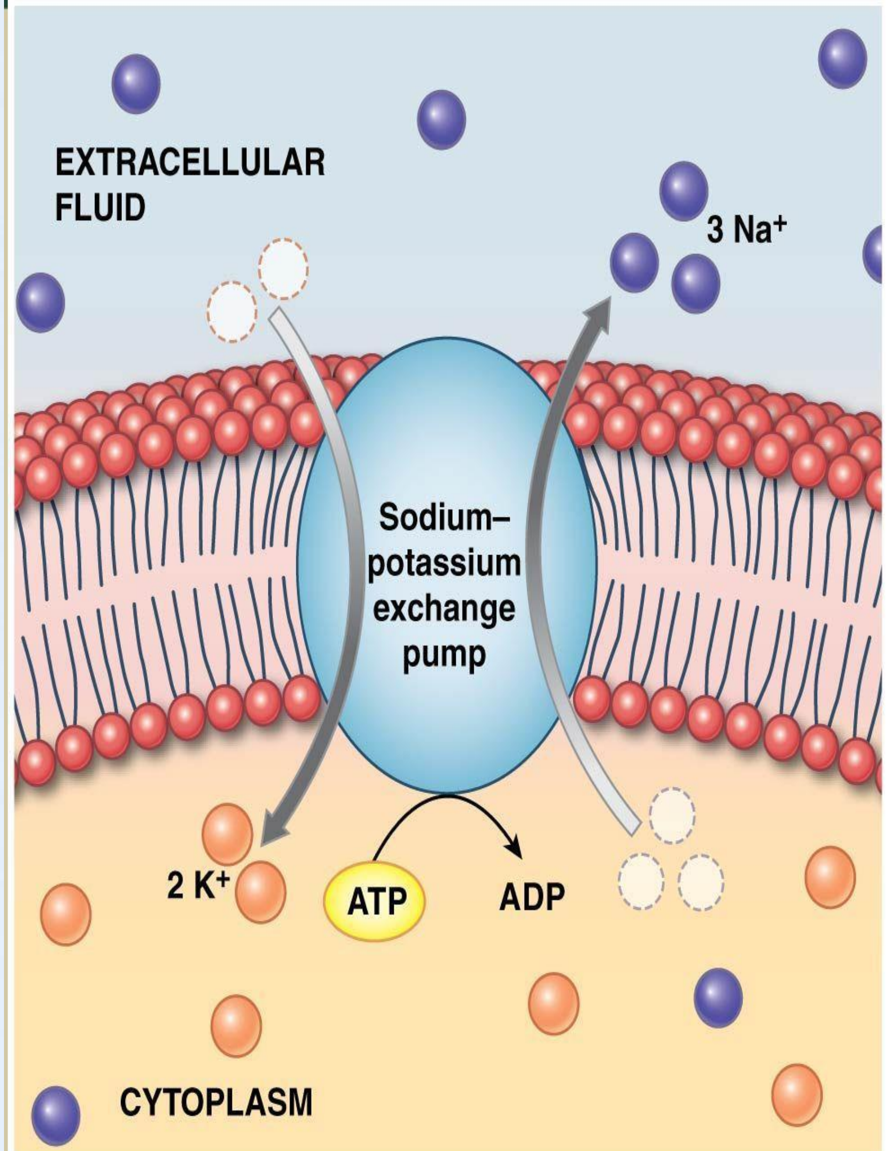


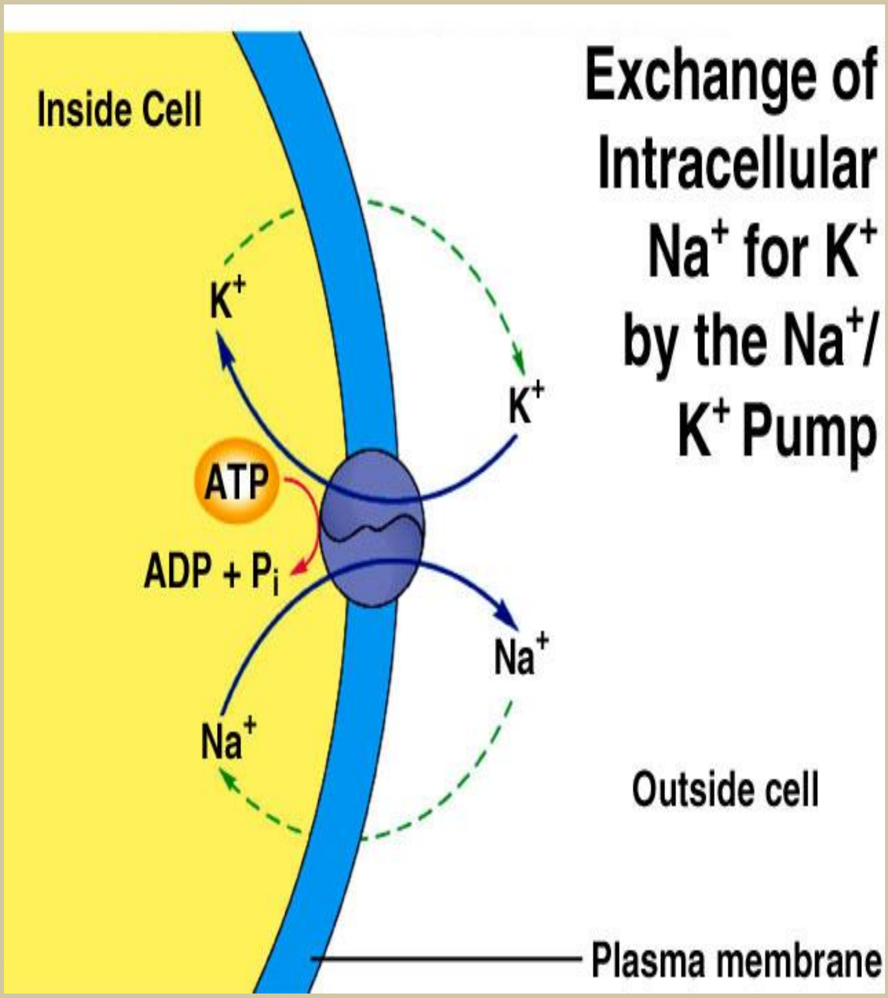
FIGURE 5 – 4

Functional characteristics of the Na^+-K^+ pump and of the potassium-sodium "leak" channels.

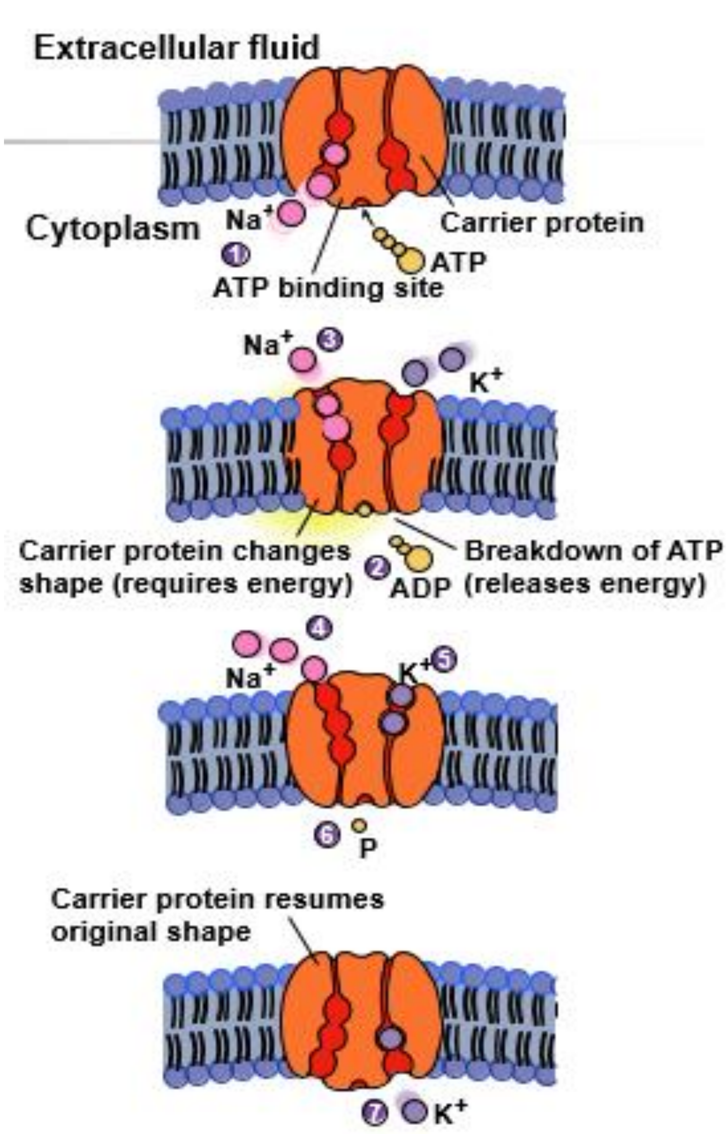


Na^+ - K^+ PUMP

- Primary active transport.
- Carrier protein is also an ATP enzyme that converts ATP to ADP and P_i.



1. Three sodium ions (Na+) and adenosine triphosphate (ATP) bind to the carrier protein.
2. The ATP breaks down to adenosine diphosphate (ADP) and a phosphate (P) and releases energy.
3. The carrier protein changes shape, and the Na+ are transported across the membrane. The Na+ diffuse away from the carrier protein.
4. Two potassium ions (K+) bind to the carrier protein.
5. The carrier protein changes shape, transporting K+ across the membrane, and the K+ diffuse away from the carrier protein. The carrier protein can again bind to Na+ and ATP.



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Biophysics

Dr. Ruaa Almusa

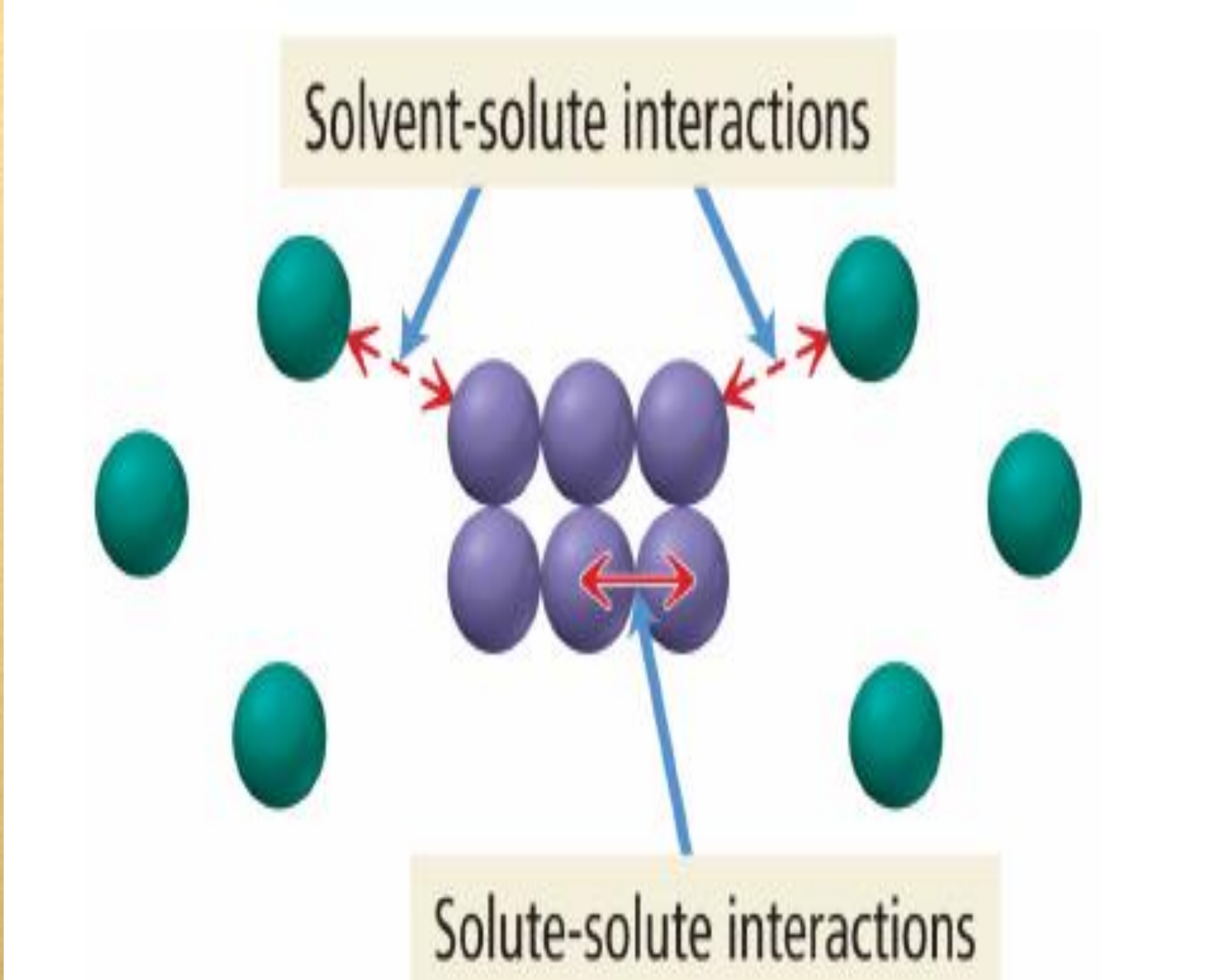
Lec. 10

Molecular and Ionic Interactions in Electrolytes Solutions

- Much of the reactions (both biological and non-biological) that takes place on Earth involve water:
- Almost 75% of the Earth's surface is covered by water or ice.
- About 66% of the human body consists of water.
- A lot of important chemistry takes place in aqueous solutions, in which the solvent is water.

Solute and Solvent Interactions

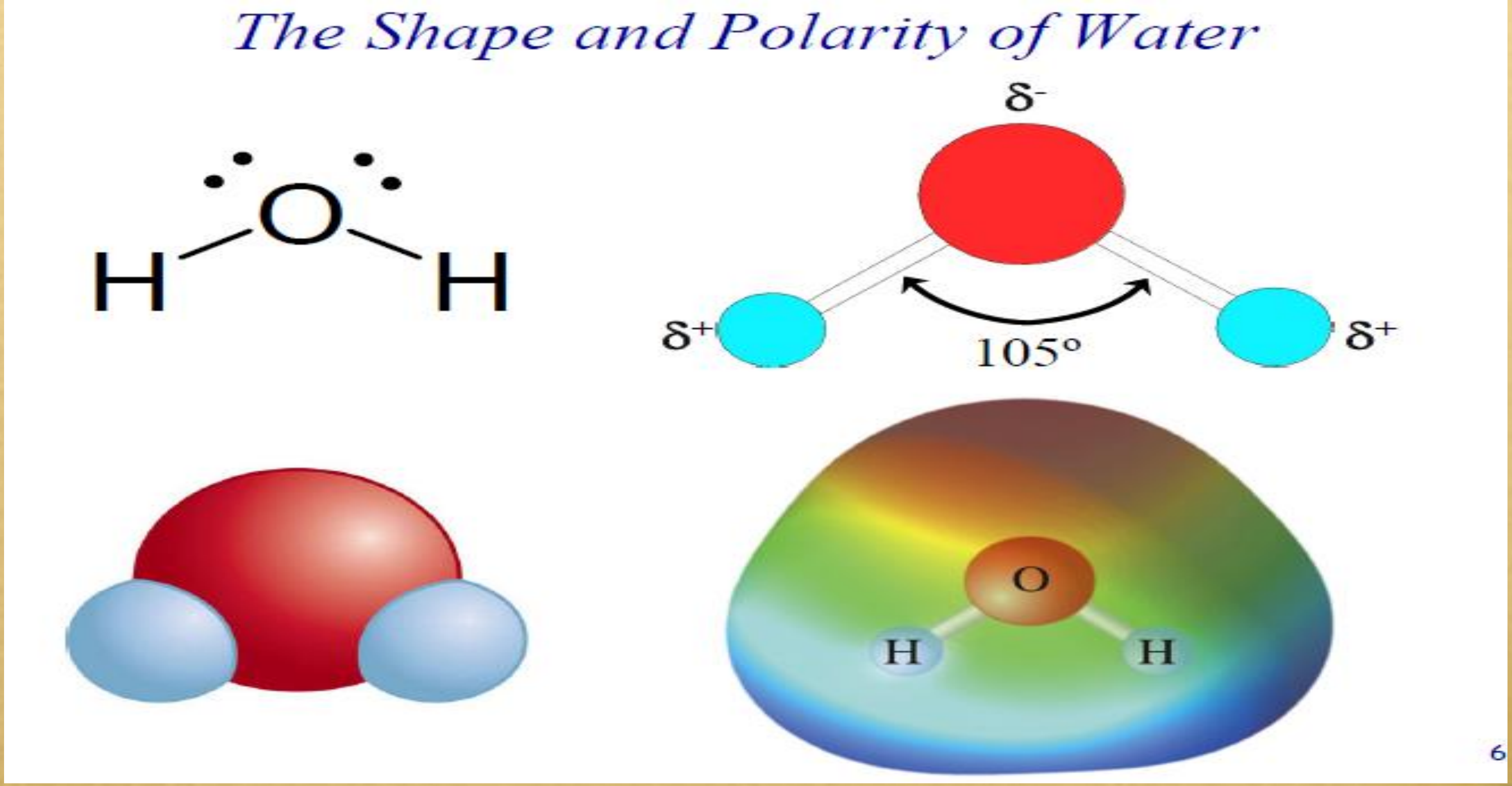
When a solid is put into a liquid solvent such as water, there is a competition between the forces of attraction among the particles of the solute (solute-solute interactions) and the forces of attraction between the solvent molecules and the particles in the solute (solvent-solute interactions). Which interactions are stronger determines whether the solute dissolves.


Solvent-solute interactions
Solute-solute interactions

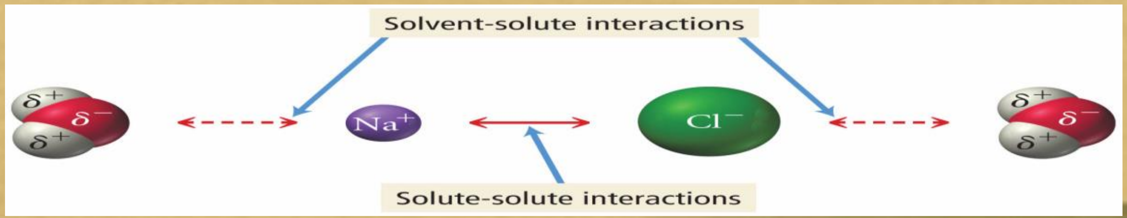
The Role of Water as a Solvent

- Many reactions take place in aqueous solution
- Many ionic substances dissolve in water; water is very good at solvating (dissolving) cations and anions.
- The O end of a water molecule has a negative charge (δ^{-}) while the H ends have positive charges (δ^{+}).

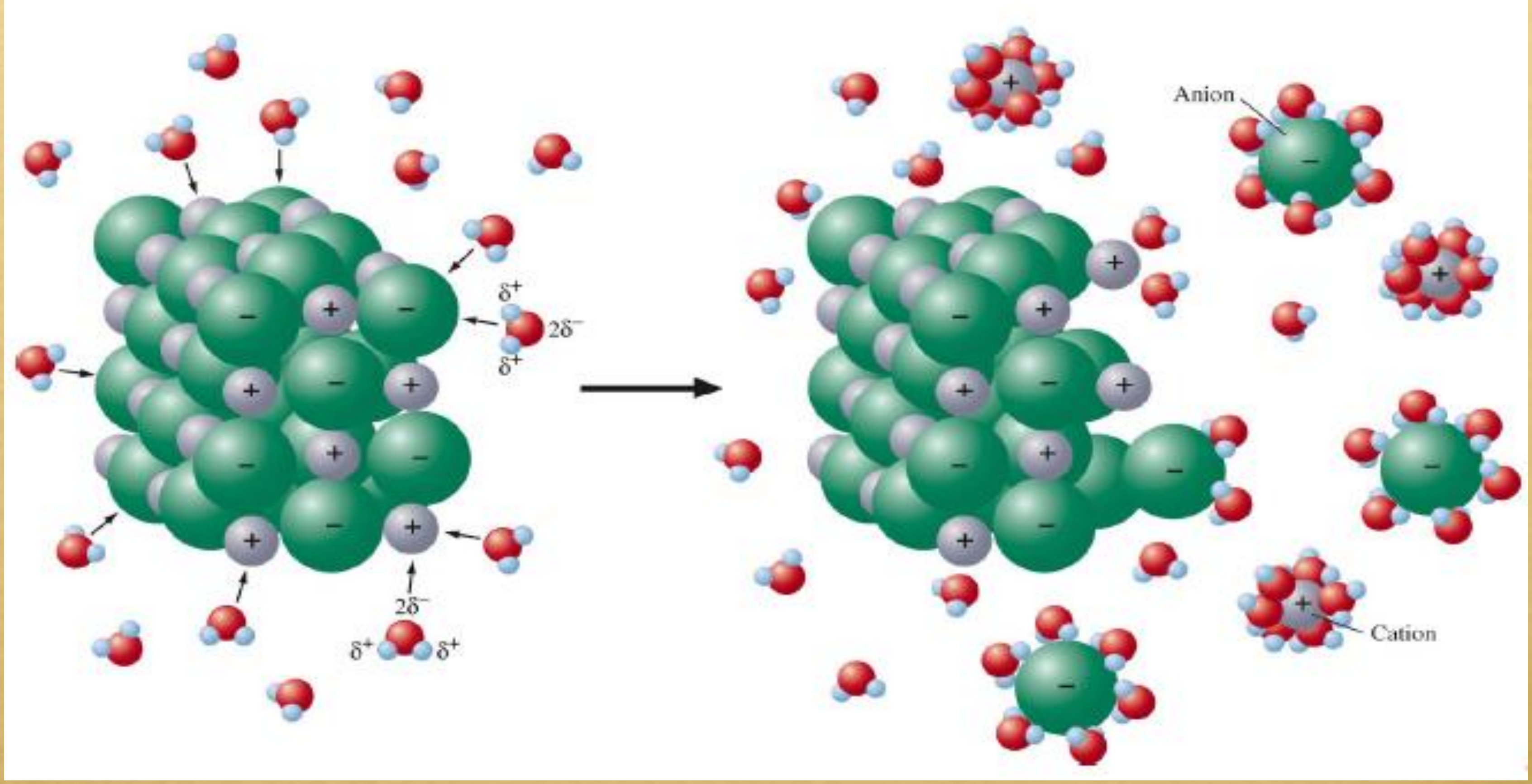
- Water also has an overall bent shape.
- The combined effects of polar bonds in a bent shape make water a polar molecule, having an uneven distribution of electrons.



- When sodium chloride is dissolved in water, the Na^+ and Cl^- ions are attracted to each other, and both are also attracted to water molecules.
- The Na^+ ions are attracted to the partially negative oxygen atom.
- The Cl^- ions are attracted to the partially positive hydrogen atoms.
- The attraction between the water and the ions is greater than that of the ions for each other, and the sodium chloride dissolves.



- The ions are separated from each other, and are free to move randomly through the solution, surrounded by a crowd of water molecules.

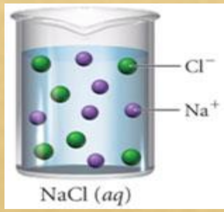


Electrolytes in Aqueous Solution

Substances that dissolve in water can be classified as electrolytes or nonelectrolytes:

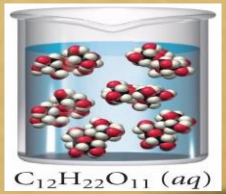
1. **Electrolytes** dissolve in water to form solutions which conduct electricity, because they dissociate to form mobile, solvated cations and anions:

$$NaCl(s) \xrightarrow{H_2O} Na^+(aq) + Cl^-(aq)$$



2. **Nonelectrolytes** do not conduct electricity when dissolved in water, (water itself is a nonelectrolyte):

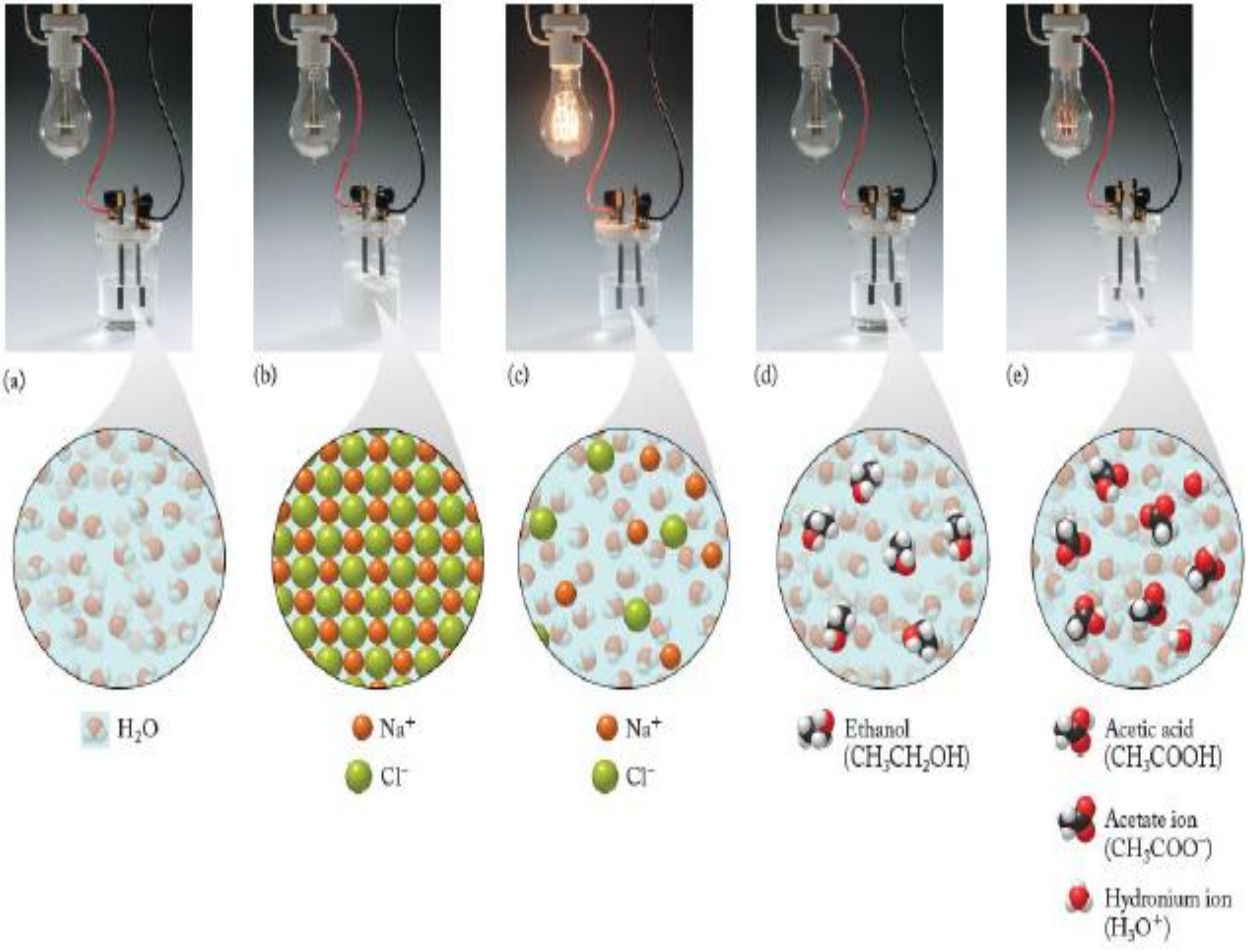
$$C_{12}H_{22}O_{11}(s) \xrightarrow{H_2O} C_{12}H_{22}O_{11}(aq)$$



Strong and Weak Electrolytes

Electrolytes are divided into two categories:

1. Strong electrolytes are dissociated to a very large extent (70-100%) — virtually all of the units of the original substance are separated into ions.
2. Weak electrolytes are dissociated to a very small extent — only a small percentage of the substance is dissociated into ions at any one time. weak electrolytes are conduct electricity, but not very well.


(a)
(b)
(c)
(d)
(e)
H_2O
Na^+
Cl^-
Na^+
Cl^-
Ethanol
(CH_3CH_2OH)
Acetic acid
(CH_3COOH)
Acetate ion
(CH_3COO^-)
Hydronium ion
(H_3O^+)

Biological Electrolytes

- Some minerals (minerals the body needs in relatively large amounts) are important as electrolytes.
- biological Electrolytes are minerals that carry an electric charge when they are dissolved in blood. The blood electrolytes (sodium, potassium, chloride, and bicarbonate) help regulate nerve and muscle function and maintain acid-base balance and water balance.

- The kidneys help maintain electrolyte concentrations by filtering electrolytes and water from blood, returning some to the blood, and excreting any excess into the urine.
- If the balance of electrolytes is disturbed, disorders can develop:

1. Becoming dehydrated or overhydrated
2. Having certain heart, kidney, or liver disorders
3. Severe electrolyte imbalances can cause serious problems such as coma, seizures.