Chapter 1

# Introduction cell biology,

BY

***DR BHAUSAHEB R GHORPADE***

**SHRI ANAND COLLEGE PATHARDI**

**DIST AHMEDNAGAR**

1.1 Introduction cell biology,

1.2 Cell as basic unit of life.

1.3 Introduction to Prokaryotic and Eukaryotic cells.

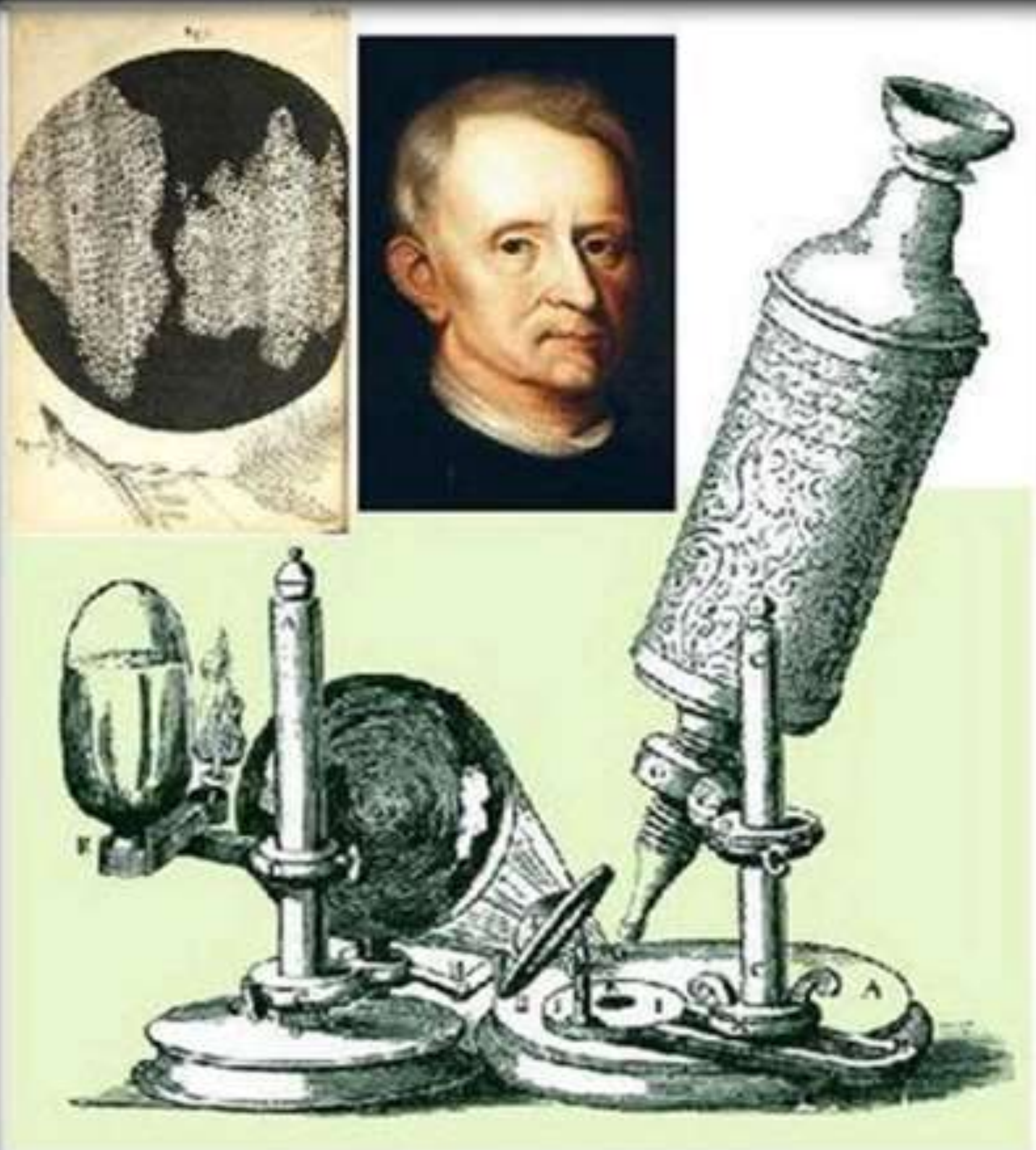
1.4 Structure and function of Prokaryotic (E. coli)

1.5 Structure and function of Eukaryotic cells (Animal and Plant Cell)

# Cell History

- *Cytology-* study of cells
- 1665 English Scientist Robert Hooke
- Used a microscope to examine cork (plant)
- "Hooke called what he saw "Cells"


Robert Hooke
(1635-1703)



Robert Hooke (1665)

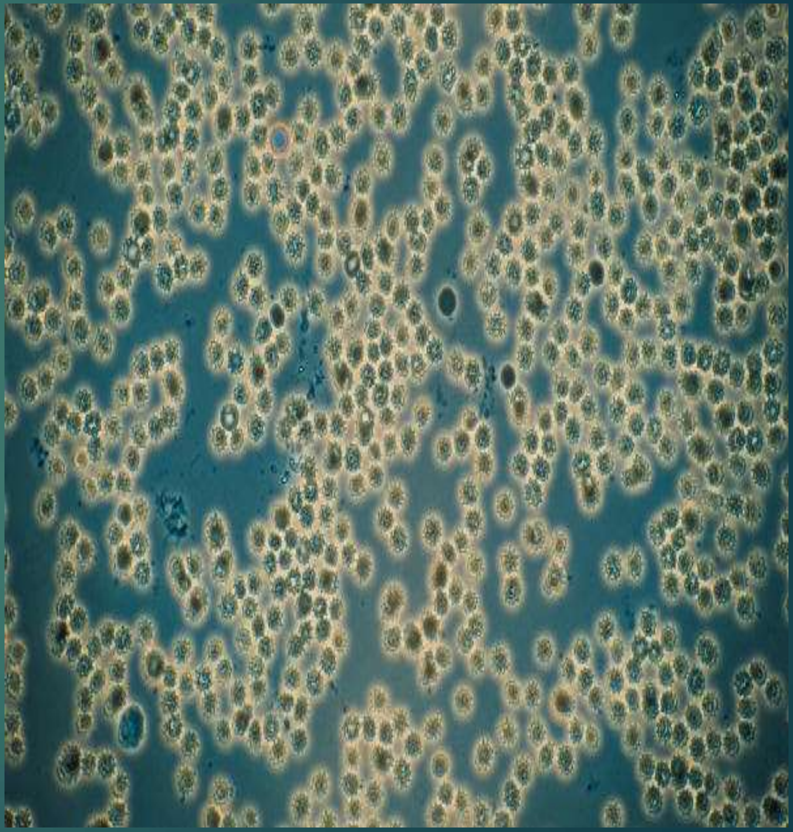
# Cell History

- Robert Brown
  - discovered the nucleus in 1833.
  - German Botanist Matthias Schleiden
  - 1838
  - ALL PLANTS "ARE COMPOSED OF CELLS".
- Theodor Schwann
  - Also in 1838,
  - discovered that animals were made of cells

- **Rudolf Virchow**
  - **1855, German Physician**
  - **" THAT CELLS ONLY COME FROM OTHER CELLS".**
- **His statement debunked "Theory of Spontaneous Generation"**

# Cell Theory

- The COMBINED work of **Schleiden**, Schwann, and Virchow make up the modern <u>CELL THEORY</u>.



## The Cell Theory states that:

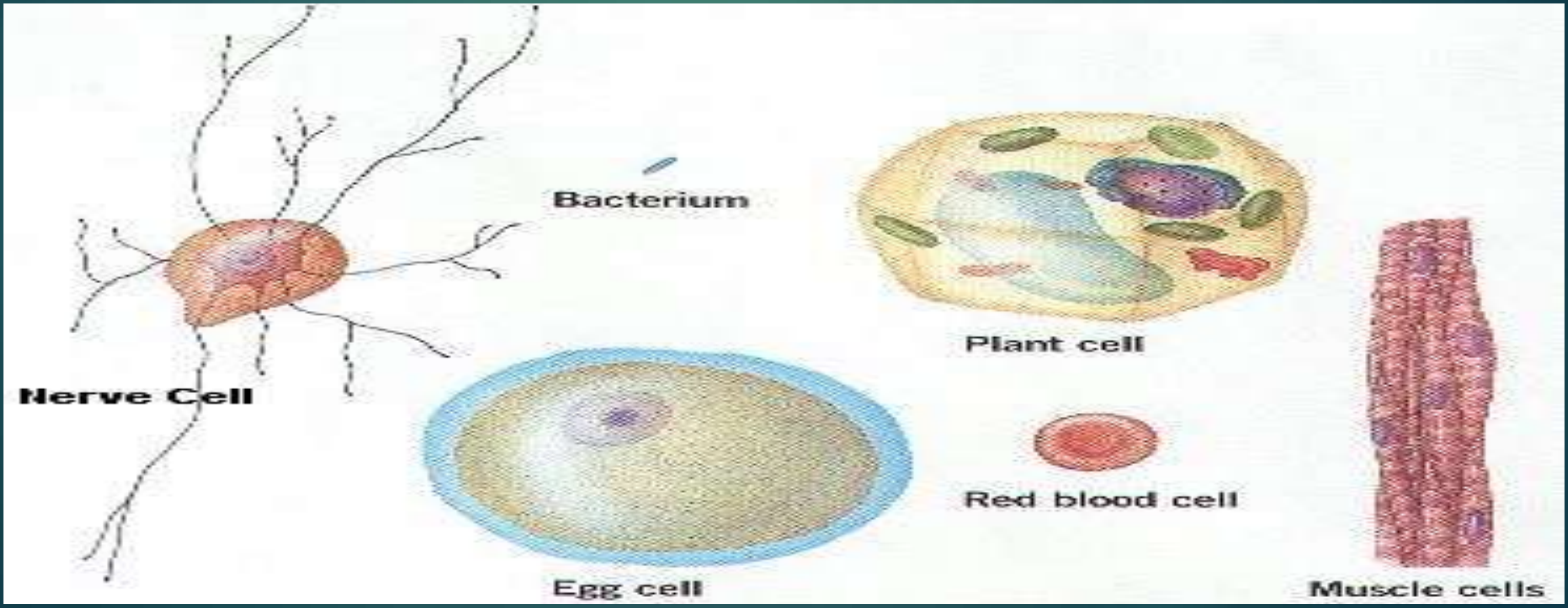
1. All living things are composed of a cell or cells.

2. Cells are the basic unit of life.

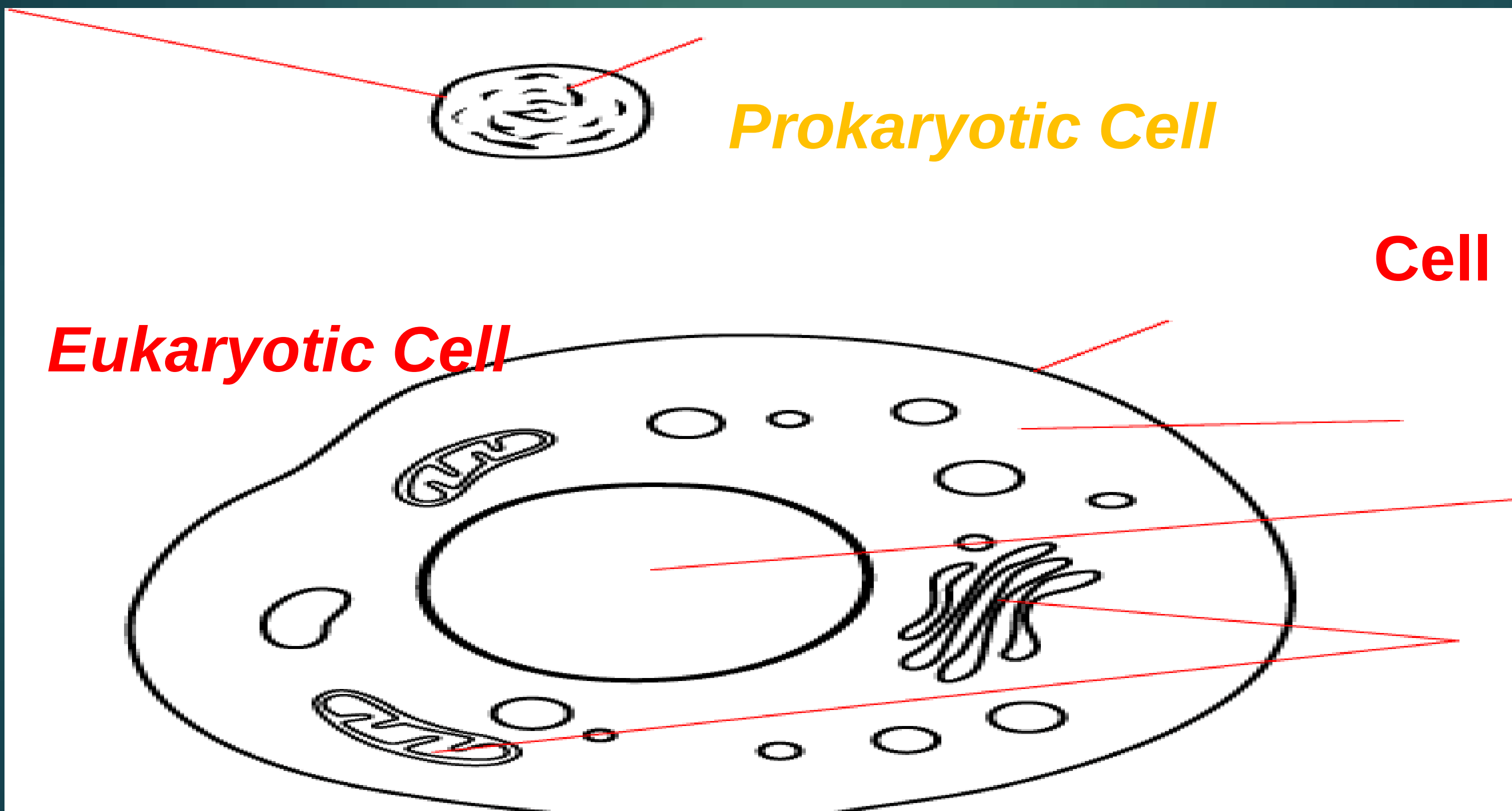
3. All cells come from preexisting cells.

- **1. Cell Size**
- **Female Egg - largest cell in the human body; seen without the aid of a microscope**
- **Most cells are visible only with a microscope.**

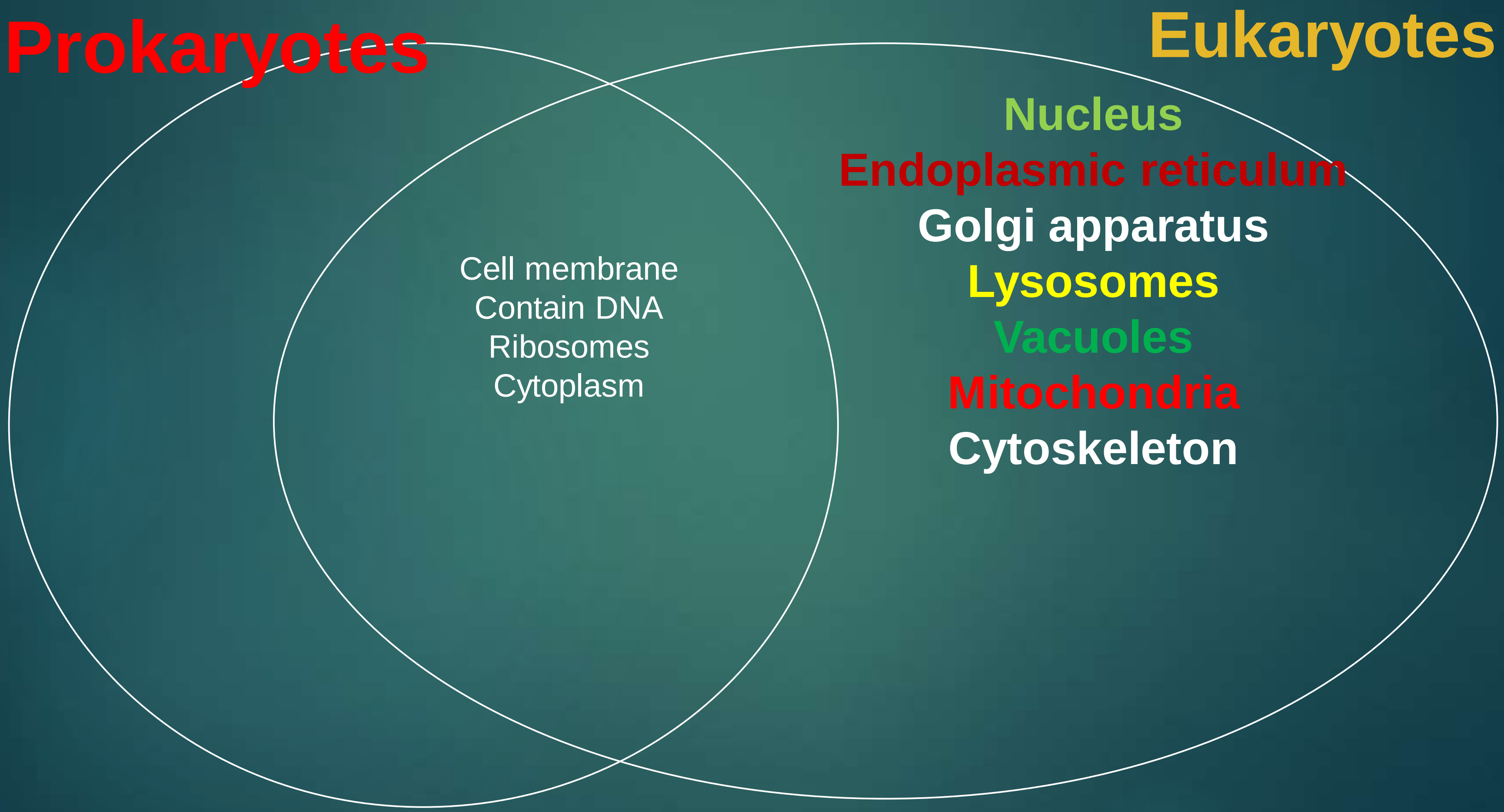
- **Cell Shape**
- **Diversity of form reflects a diversity of function.**
- **THE SHAPE OF A CELL DEPENDS ON ITS FUNCTION**.



# Internal Organization



# Compare and Contrast



# Prokaryotic

Examples

**Bacteria, blue green algae and protozoa**

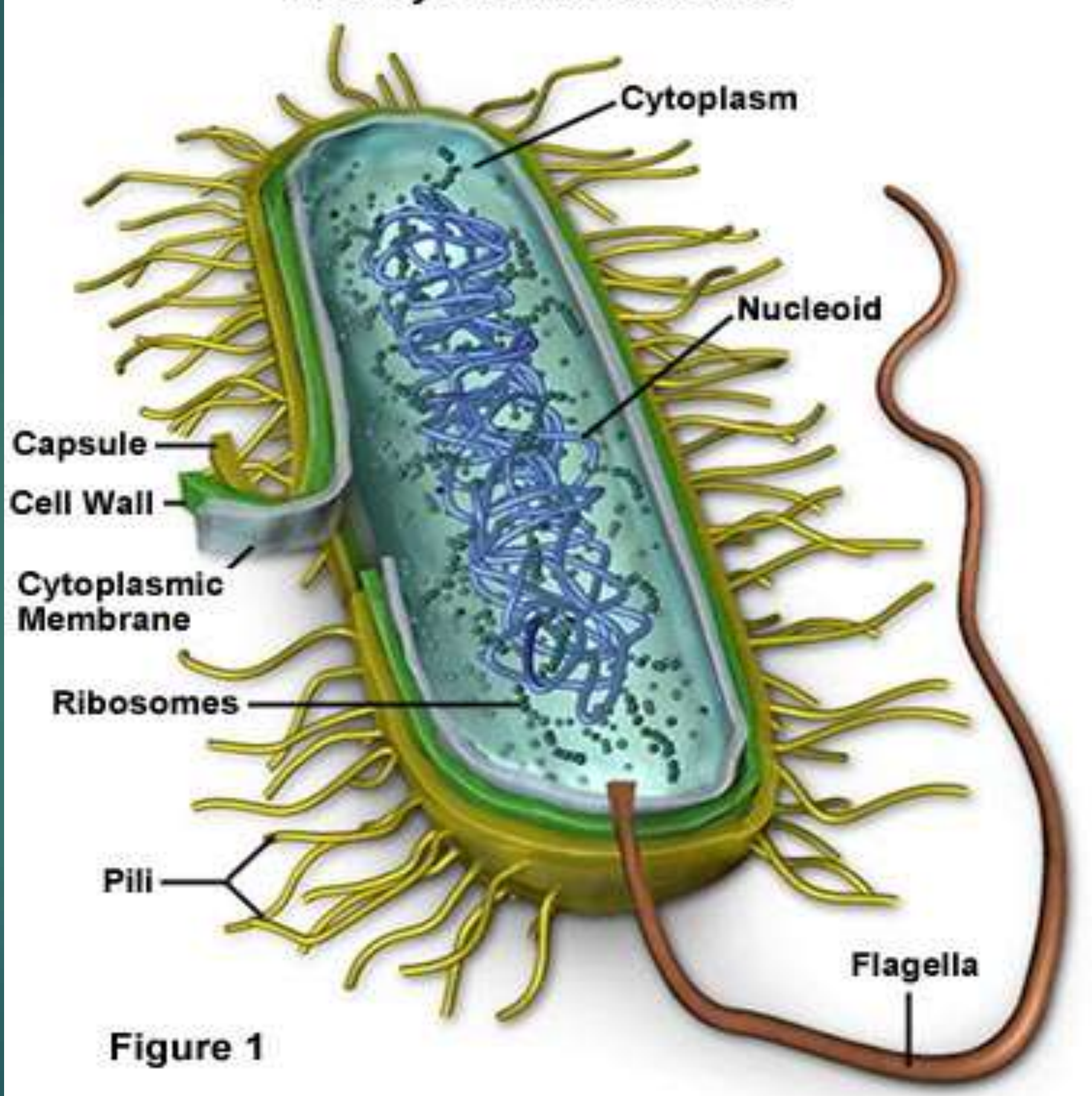



Figure 1

**F Y B Sc Zoology Paper II**
**Course Title: Cell Biology**
**Course Code: ZO – 122**
**Semester - II (2 credits – 30 Hours)**

**Chapter No. 1**

# 1.4 Prokaryotic cell & Eukaryotic cell
# 1.6 Animal & Plant cell

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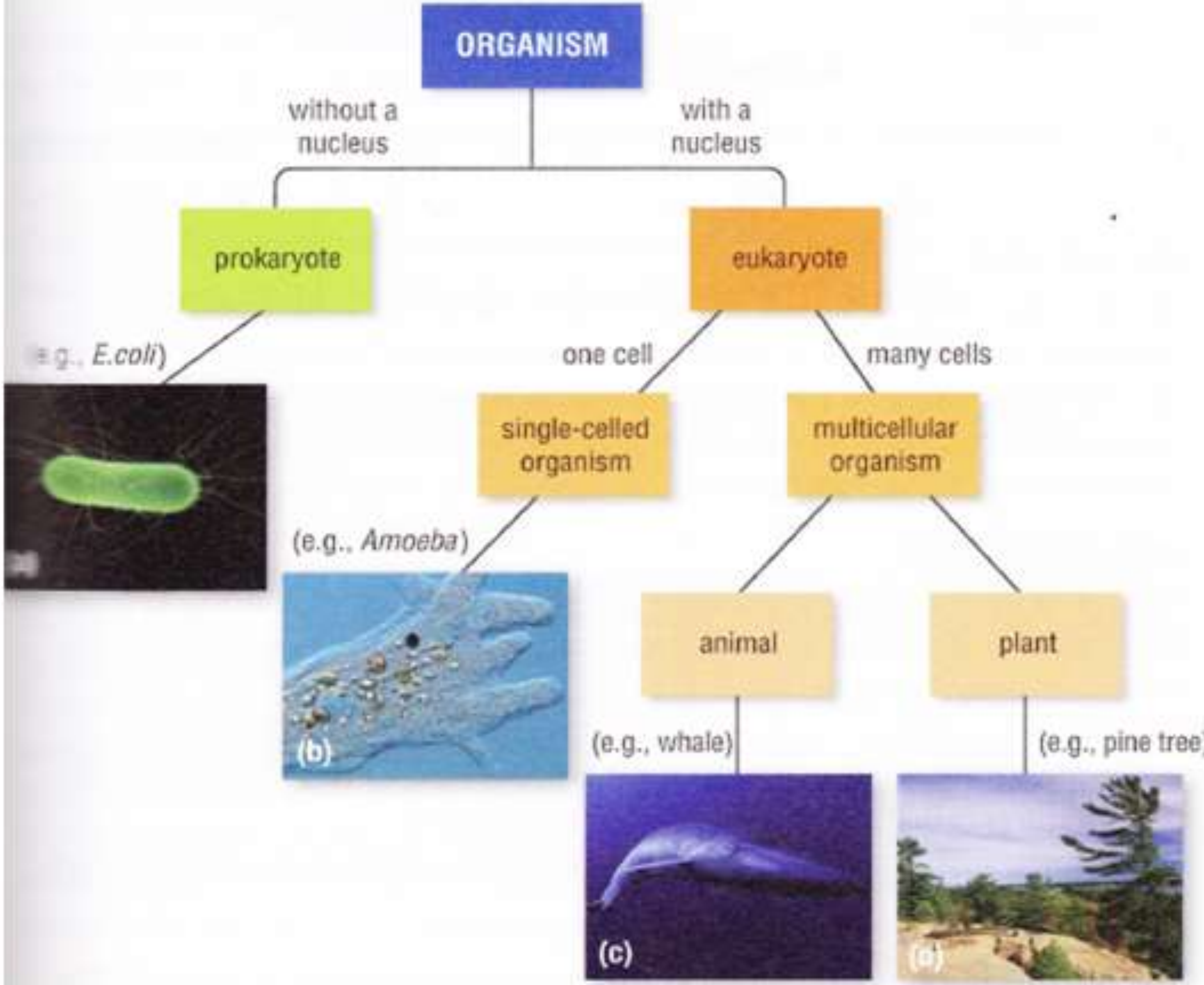
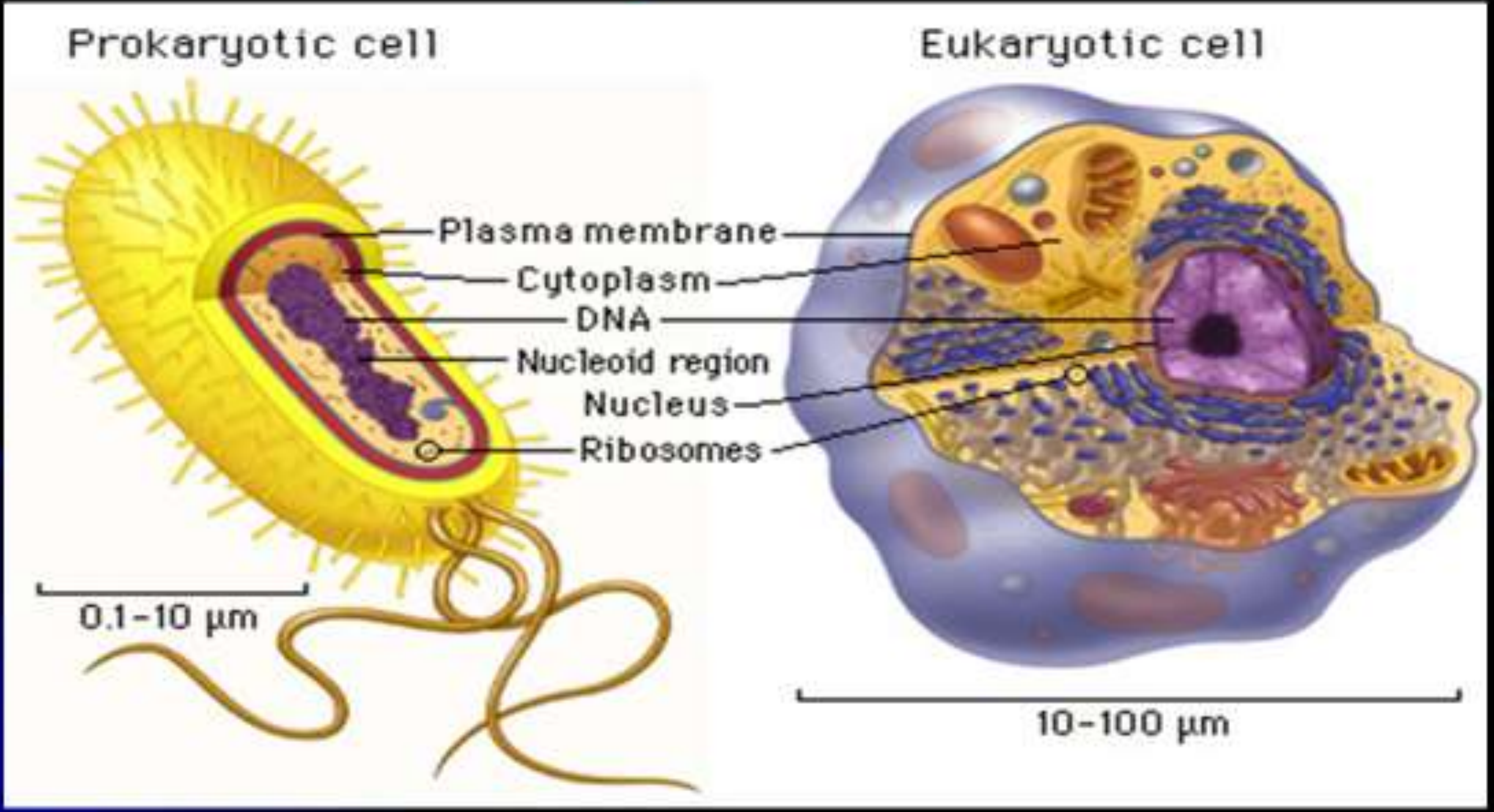
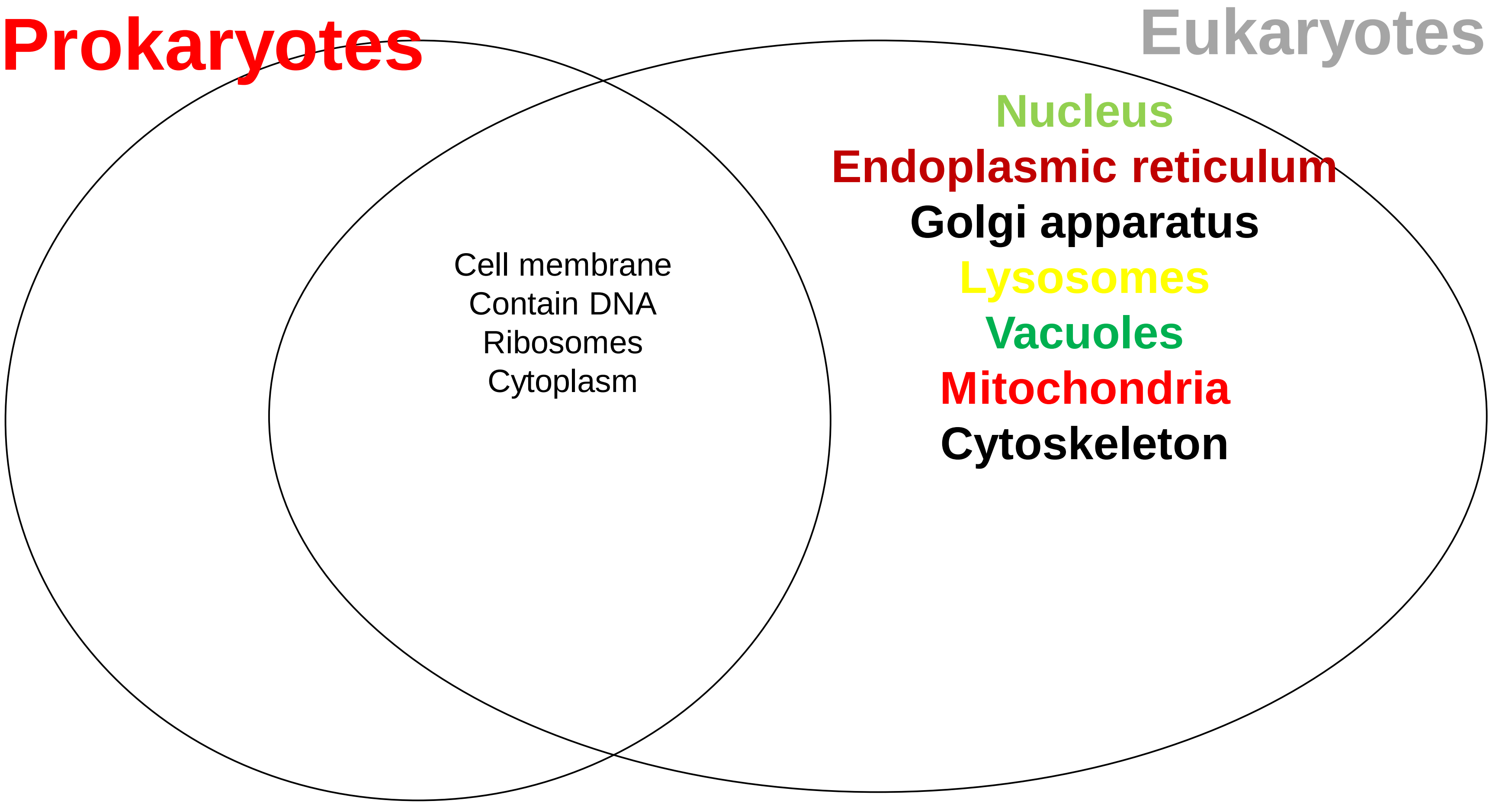
**Note:** ***This material is only for educational purpose and is non - commercial***


ORGANISM
without a nucleus
with a nucleus
prokaryote
eukaryote
(e.g., E.coli)
one cell
many cells
single-celled organism
multicellular organism
(e.g., Amoeba)
(b)
animal
plant
(e.g., whale)
(e.g., pine tree)
(c)

# Prokaryotic Cells Vs. Eukaryotic Cells



# Compare and Contrast



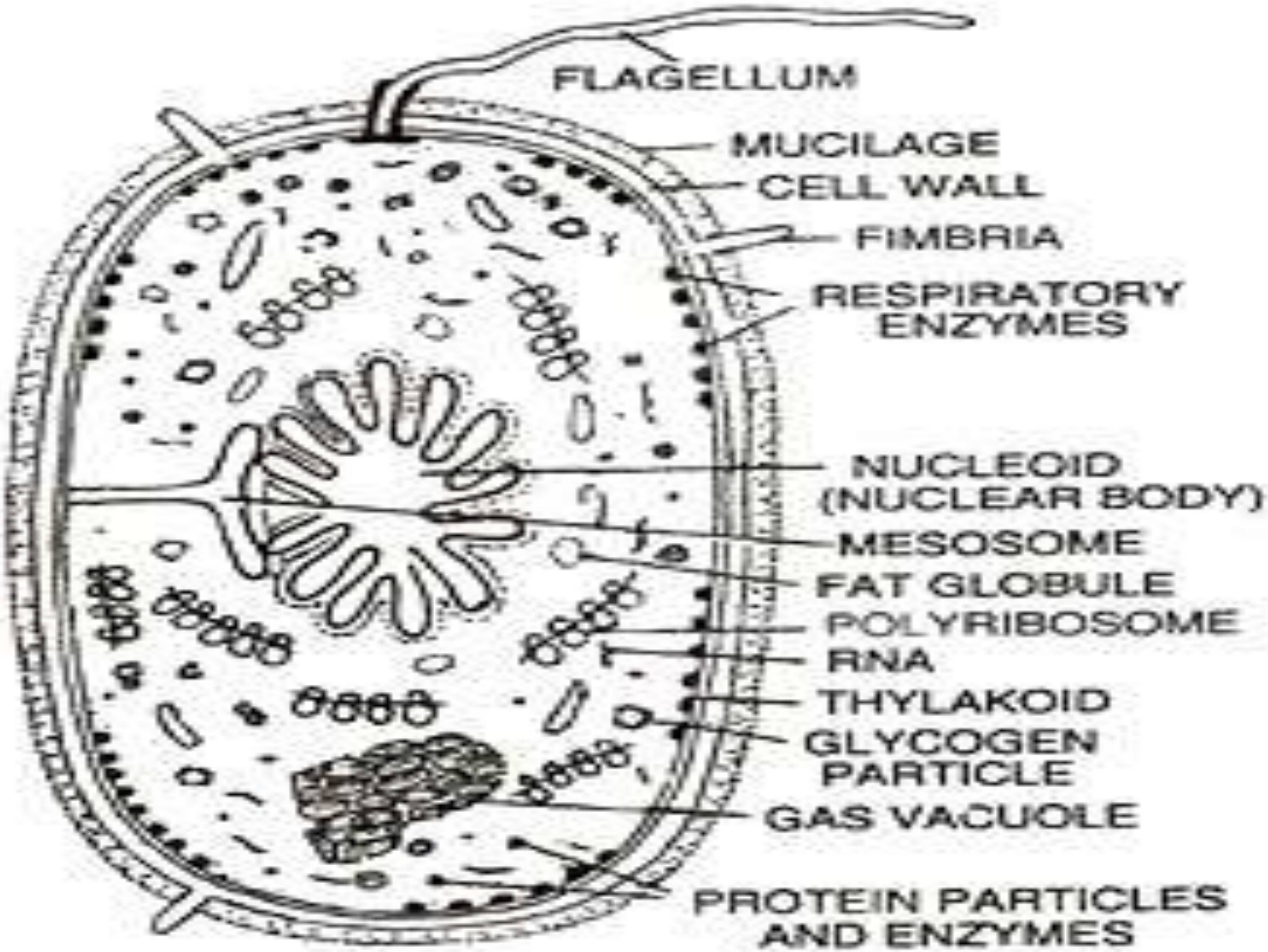
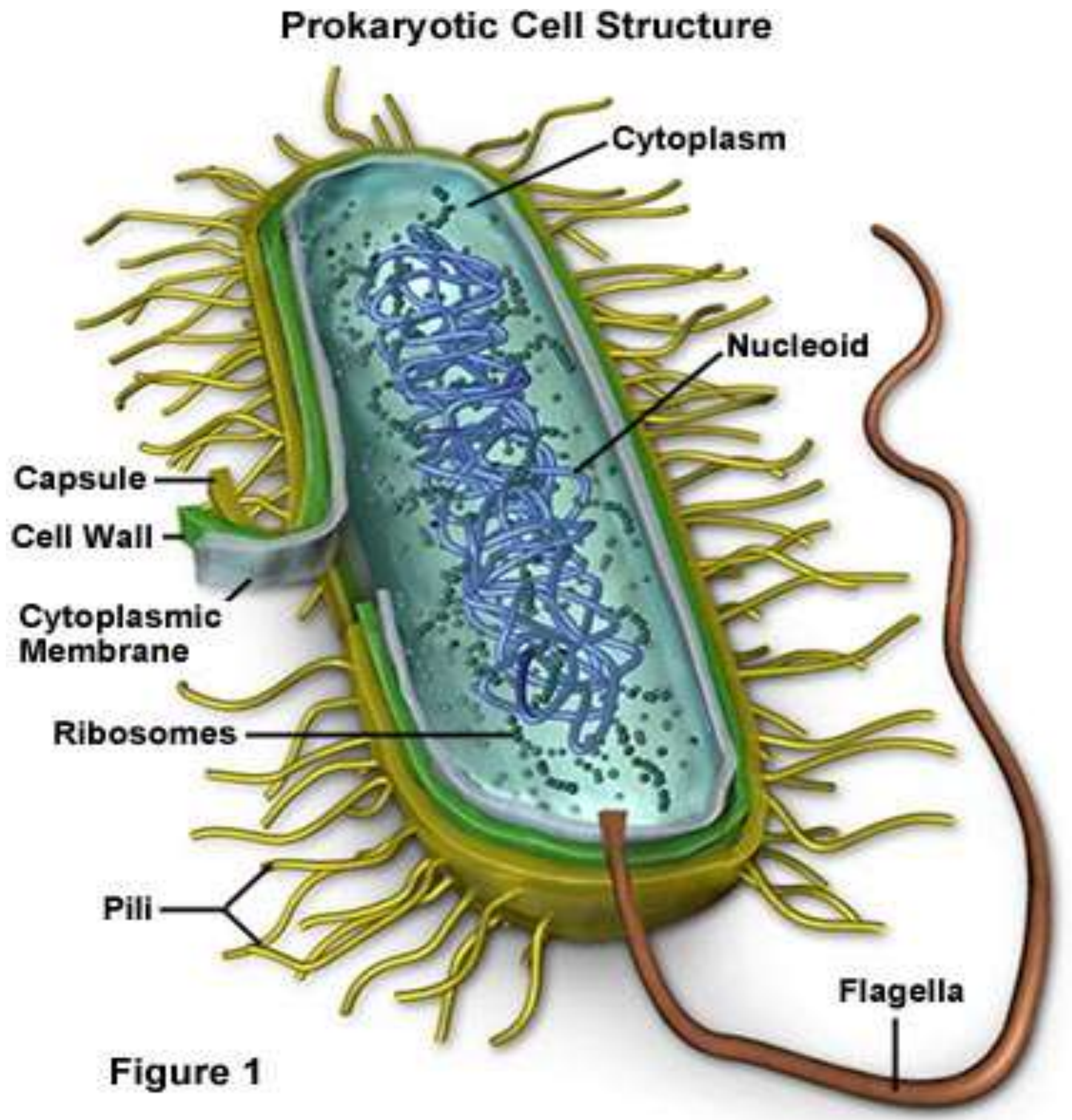



Fig. 8.6. Ultrastructure of a bacterial cell.

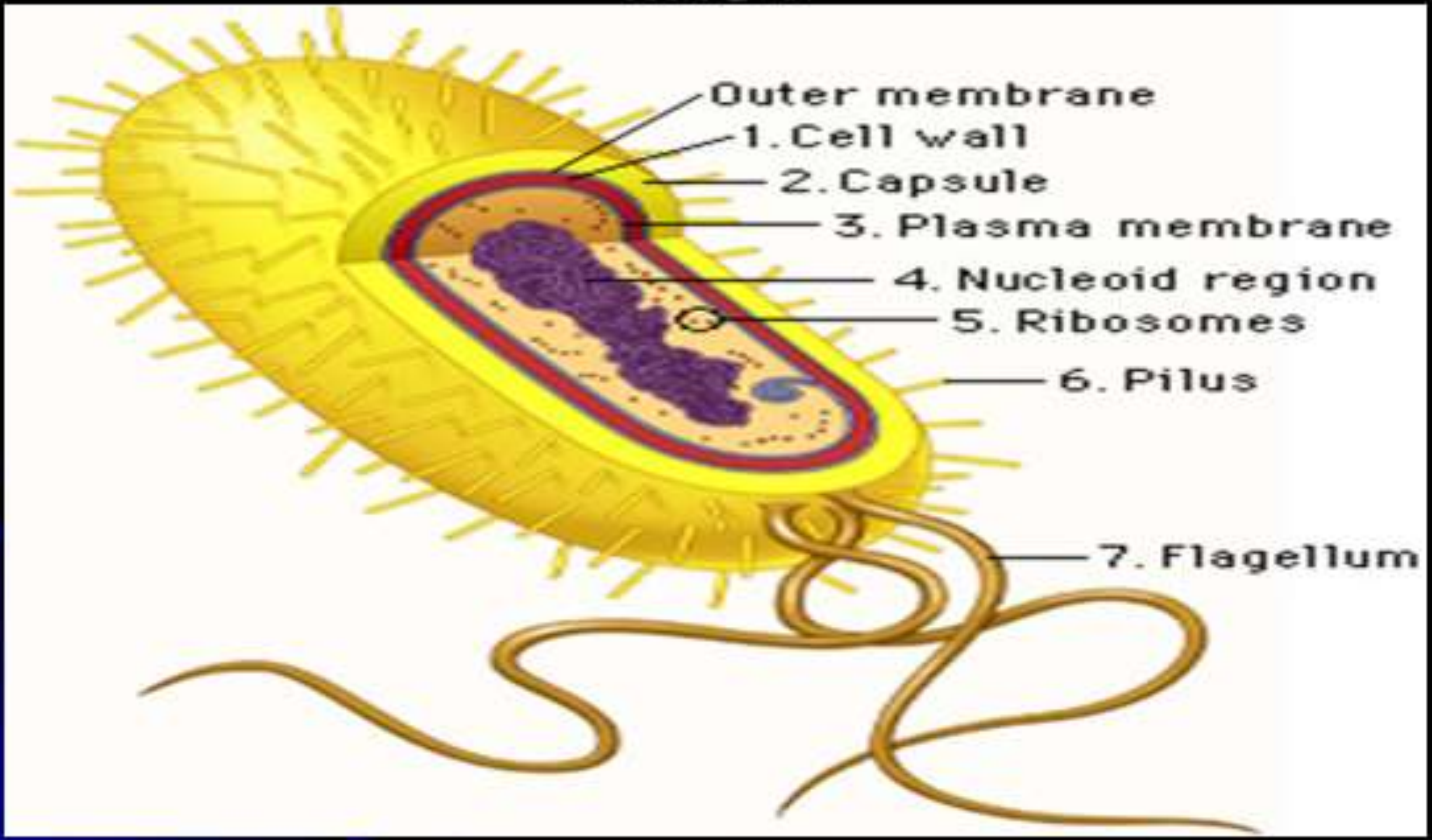
# Prokaryotic

**Examples**

**Bacteria, blue green algae and protozoa**



# What do prokaryotic cell look like?



## 1. Nuclear Material:

- **DNA is naked and lies variously coiled in the cytoplasm.**
- **It is often called gonophore, nuclear body or nucleoid.**
- **It is equivalent to a single naked chromosome and is, therefore, also called prochromosome.**
- **Many prokaryotes also have additional small circular DNA entities called plasmids.**
- **Plasmids carry additional specific factors like nitrogen fixation, resistance, fertility, etc.**

## 2. Nuclear Components:

- Nuclear envelope, nucleoplasm, nucleolus and histone covering of chromatin are absent.
- In eukaryote (= eukaryotic) cells, a typical nucleus is found.

- 3. Types:

- Prokaryote contains organisms like blue-green algae (BGA = cyanobacteria, e.g., Nostoc), bacteria, pleuropneumonia-like organisms or PPLO (e.g., Mycoplasma), archaebacteria, spirochaetes, rickettsiae and chlamydiae. PPLOs are the smallest free living organisms.

- **4. Cell wall:**
- **It is present in bacteria and cyanobacteria. A cell wall is absent in mycoplasma or PPLO.**
- **5. Flagella and Fimbriae:**
- **Flagella are present in some bacteria only (Fig. slide 3).**
- **The bacterial flagella are single-stranded as compared to 11-stranded flagella of eukaryotes.**
- **In some bacteria, non-motile appendages called pili or fimbriae also occur.**
- **They take part in attachment (e.g., Neisseria gonorrhoeae) and conjugation (e.g. Escherichia coli).**

- **6. Photosynthetic Thylakoids:**

- **Blue – green algae and some bacteria are photo-autotrophic.**
- **Their photosynthetic thylakoids lie freely in the cytoplasm.**
- **They are not organised into chloroplasts.**

- **7. Membrane-lined Cell Organelles:**

- **The prokaryotic (= prokaryotic) cells lack mitochondria, endoplasmic reticulum, Golgi apparatus, lysosomes, microtubules, microfilaments and centrioles.**

- **8. Vacuoles:**
- **Typical vacuoles are doubtful. Instead complex gas vacuoles are found.**
- **9. Ribosomes:**
- **Ribosomes are 70S as compared to 80S. Similar 70S ribosomes occur inside chloroplasts and mitochondria of eukaryotes.**

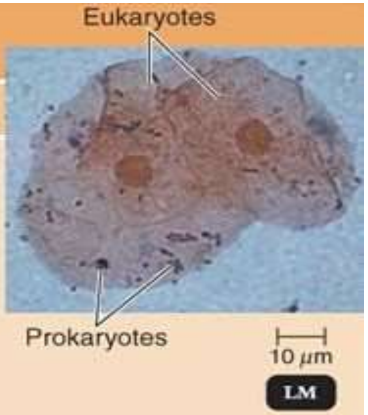
- **10. One-Envelope System:**

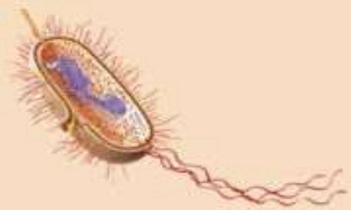
- **In prokaryotic cells, membrane bound cell organelles are absent so that there is a single membrane that surrounds the cell.**
- **Hence, prokaryotes have a single membrane or one-envelope system.**
- **In eukaryotes many organelles are surrounded by their own covering membranes in addition to the cell membrane that covers the whole cell.**
- **Therefore, eukaryotes have a double membrane or two-envelope system of organisation.**

- **12. Spindle:**
- **Mitotic spindle is not formed during cell division.**
- **13. Sexual Reproduction:**
- **It is absent. Therefore, meiosis and gamete formation are unknown.**
- **They multiply very rapidly by asexual means like binary fission, sporulation etc.**
- **14. DNA Content: It is low.**
- **15. Transcription and Translation:**
- **Transcription and Translation occur in the cytoplasm.**

- **16. Respiratory Enzymes:**
- **They usually lie in contact with cell membrane.**
- **17. Endocytosis and Exocytosis:**
- **They seen to be absent in prokaryotes.**
- **18. Nitrogen Fixation:**
- **It occurs only in some prokaryotes, bacteria and cyanobacteria.**

## Table 4.2 Principal Differences between Prokaryotic and Eukaryotic Cells




| Characteristic | Prokaryotic | Eukaryotic |
|---|---|---|
| |  |  |
| **Size of Cell** | Typically 0.2–2.0 µm in diameter | Typically 10–100 µm in diameter |
| **Nucleus** | No nuclear membrane or nucleoli | True nucleus, consisting of nuclear membrane and nucleoli |
| **Membrane-Enclosed Organelles** | Absent | Present; examples include lysosomes, Golgi complex, endoplasmic reticulum, mitochondria, and chloroplasts |
| **Flagella** | Consist of two protein building blocks | Complex; consist of multiple microtubules |
| **Glycocalyx** | Present as a capsule or slime layer | Present in some cells that lack a cell wall |
| **Cell Wall** | Usually present; chemically complex (typical bacterial cell wall includes peptidoglycan) | When present, chemically simple (includes cellulose and chitin) |
| **Plasma Membrane** | No carbohydrates and generally lacks sterols | Sterols and carbohydrates that serve as receptors |
| **Cytoplasm** | No cytoskeleton or cytoplasmic streaming | Cytoskeleton; cytoplasmic streaming |
| **Ribosomes** | Smaller size (70S) | Larger size (80S); smaller size (70S) in organelles |
| **Chromosome (DNA)** | Usually single circular chromosome; typically lacks histones | Multiple linear chromosomes with histones |
| **Cell Division** | Binary fission | Involves mitosis |
| **Sexual Recombination** | None; transfer of DNA only | Involves meiosis |

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# Eukaryotic cells

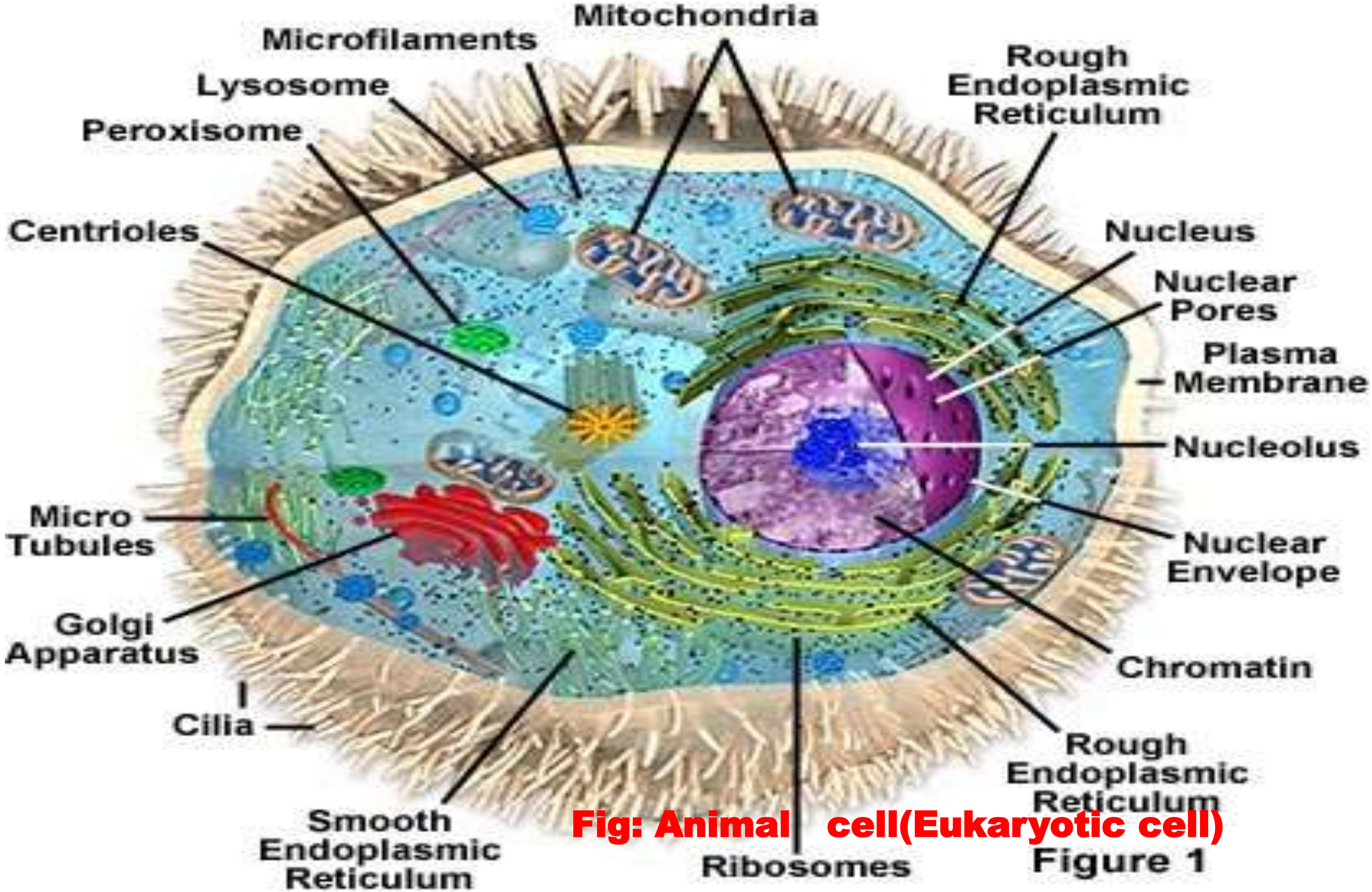



Fig: Animal cell(Eukaryotic cell)

| S. No | Plant cell | Animal Cell |
| --- | --- | --- |
| 1 | Usually they are larger than animal cells | Usually smaller than plant cells |
| 2 | Cell wall present in addition to plasma membrane and consists of middle lamellae, primary and secondary walls | Cell wall absent |
| 3 | Plasmodesmata present | Plasmodesmata absent |
| 4 | Chloroplast present | Chloroplast absent |
| 5 | Vacuole large and permanent | Vacuole small and temporary |
| 6 | Tonoplast present around vacuole | Tonoplast absent |
| 7 | Centrioles absent except motile cells of lower plants | Centrioles present |
| 8 | Nucleus present along the periphery of the cell | Nucleus at the centre of the cell |
| 9 | Lysosomes are rare | Lysosomes present |
| 10 | Storage material is starch grains | Storage material is a glycogen granules |

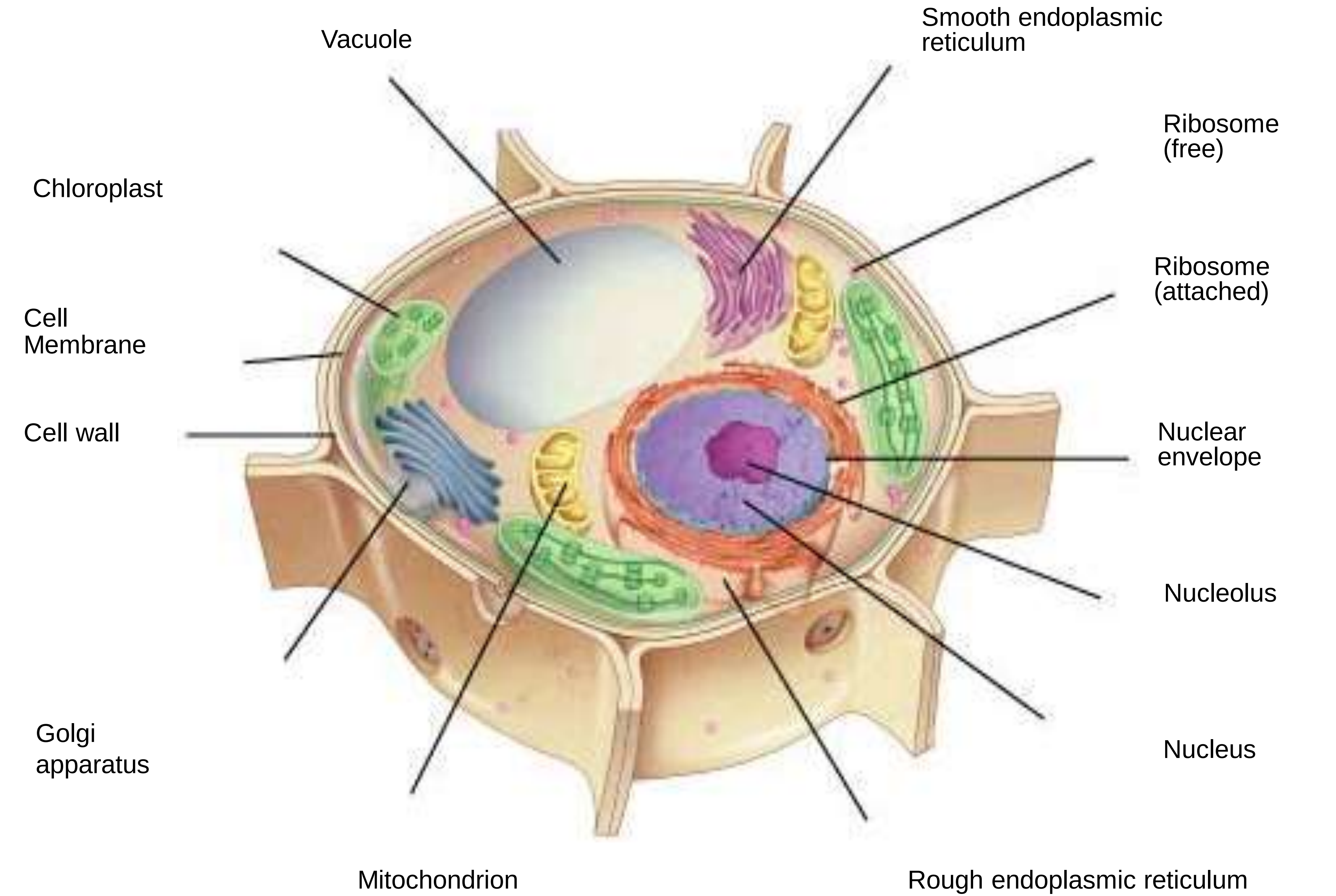
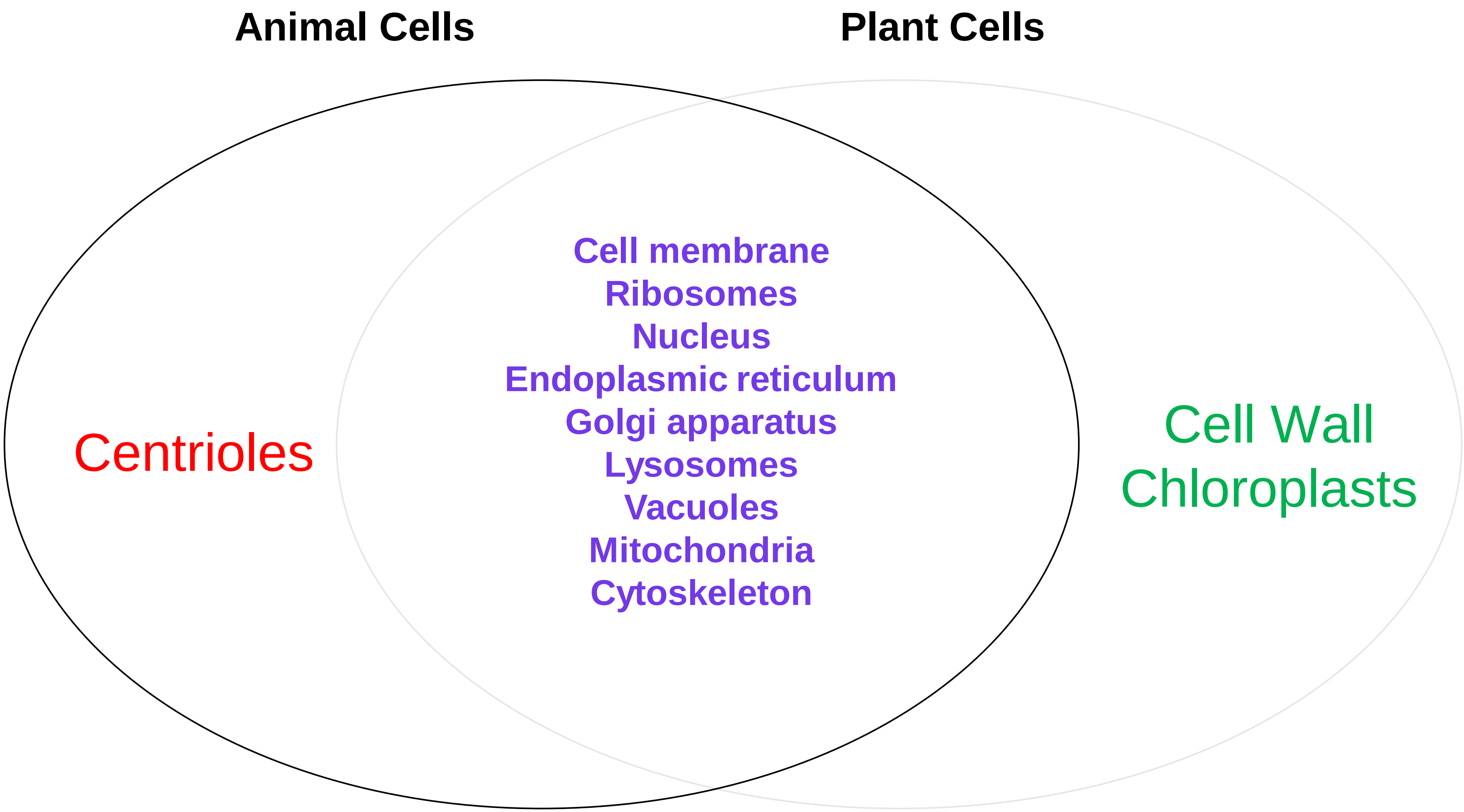
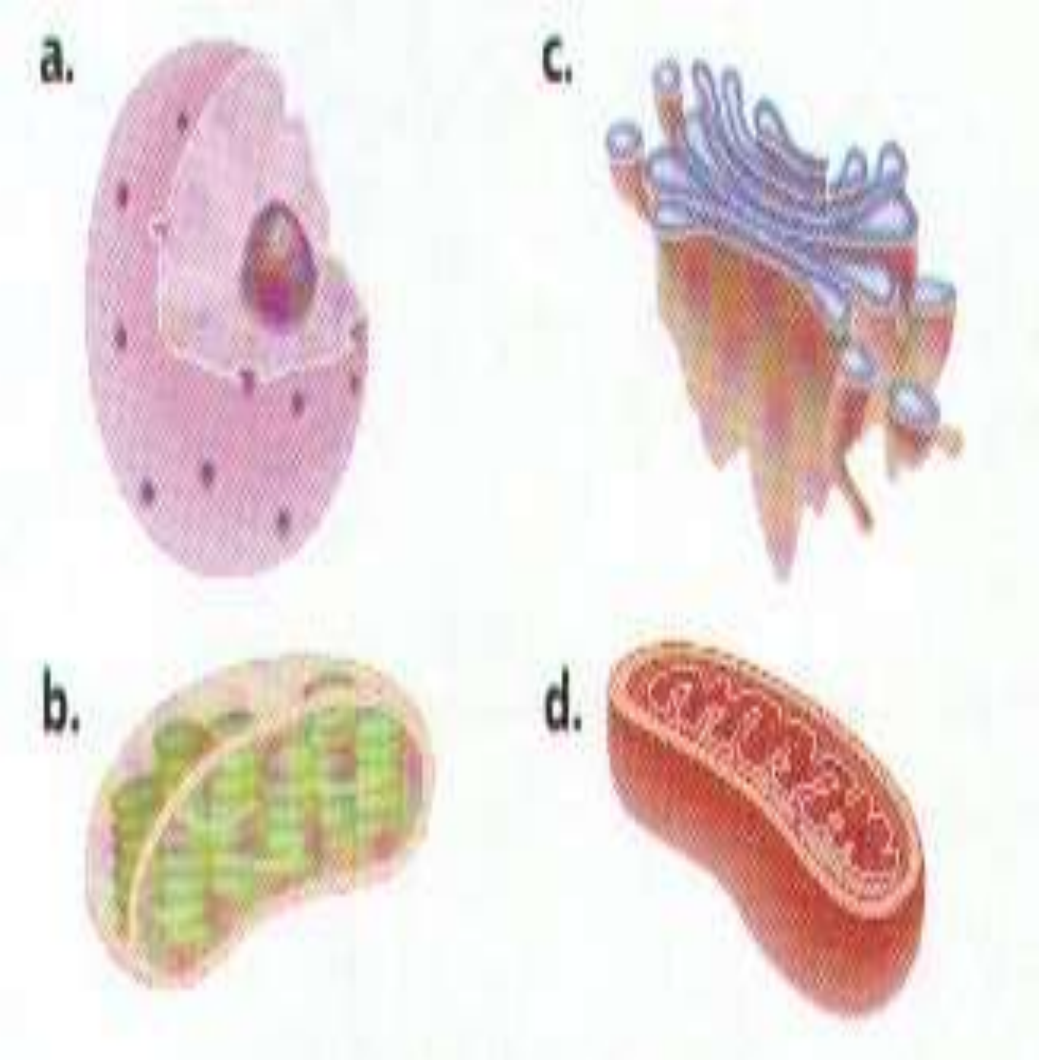



**Fig: Plant cell(Eukaryotic cell)**

# Compare and Contrast



# Internal Organization




- Cells contain **ORGANELLES**.
- **Cell Components that PERFORMS SPECIFIC FUNCTIONS FOR THE CELL.**

# Cellular Organelles

- **The Plasma membrane**
  - **The boundary of the cell.**
  - **Composed of three distinct layers.**
  - **Two layers of fat and one layer of protein.**

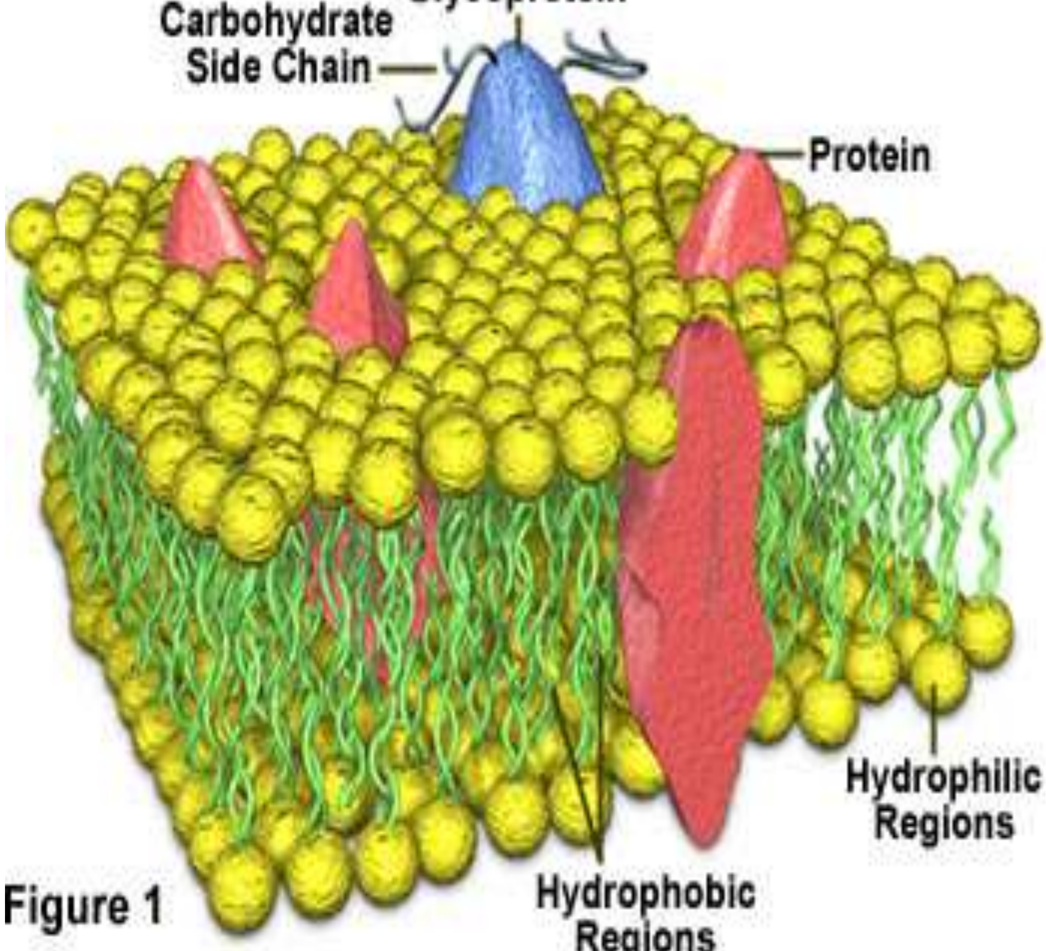
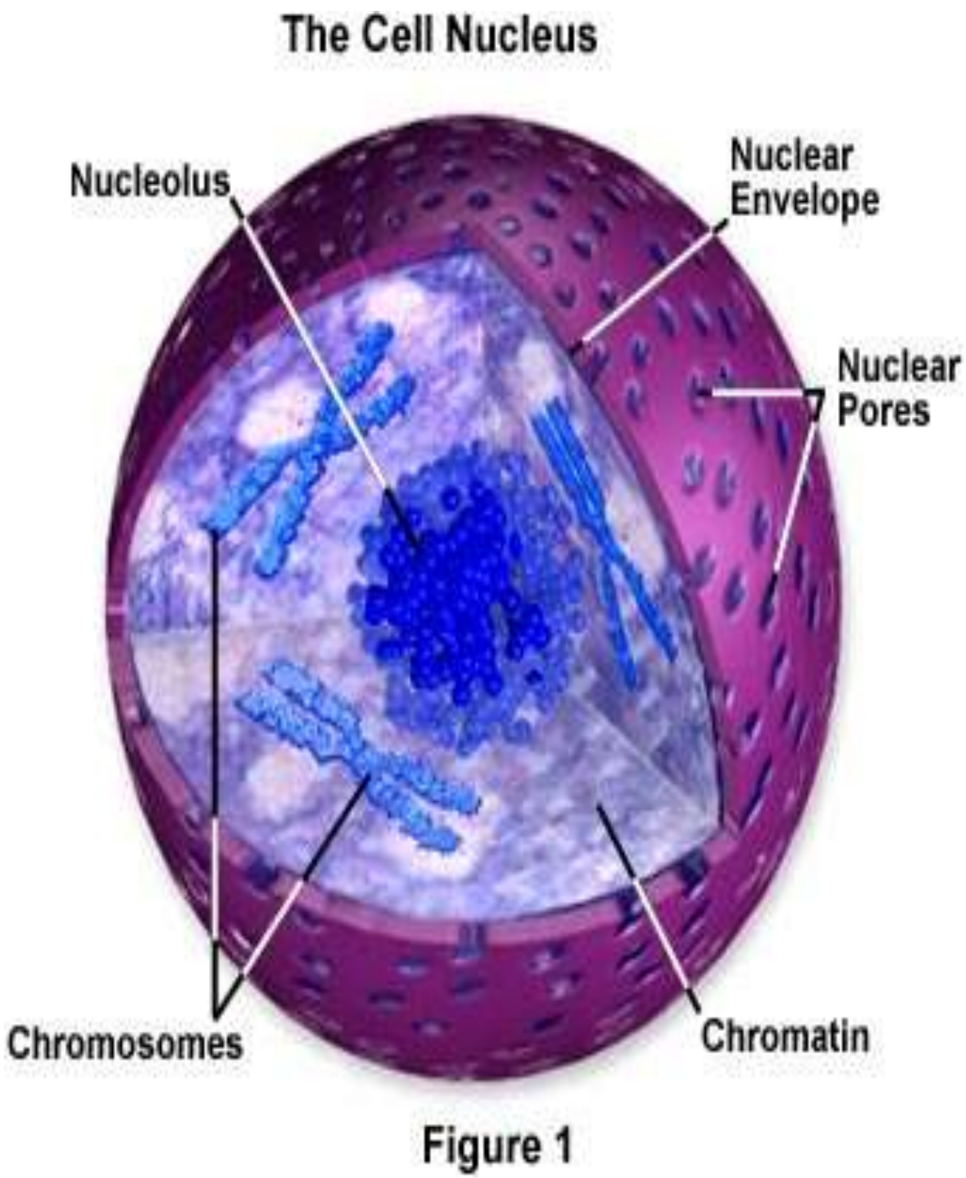


Figure 1

# The Nucleus




- Brain of Cell
- Bordered by a porous membrane - nuclear envelope.
- Contains thin fibers of DNA and protein called Chromatin.
- Rod Shaped Chromosomes
- Contains a small round nucleolus
  - produces ribosomal RNA which makes ribosomes.

# Ribosomes

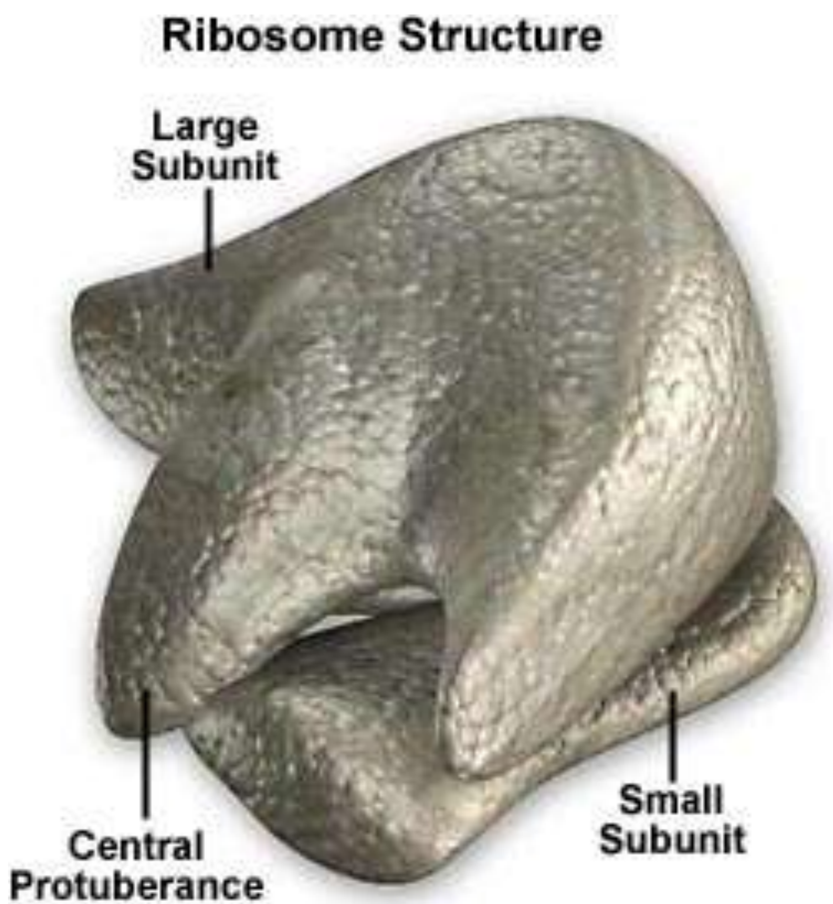
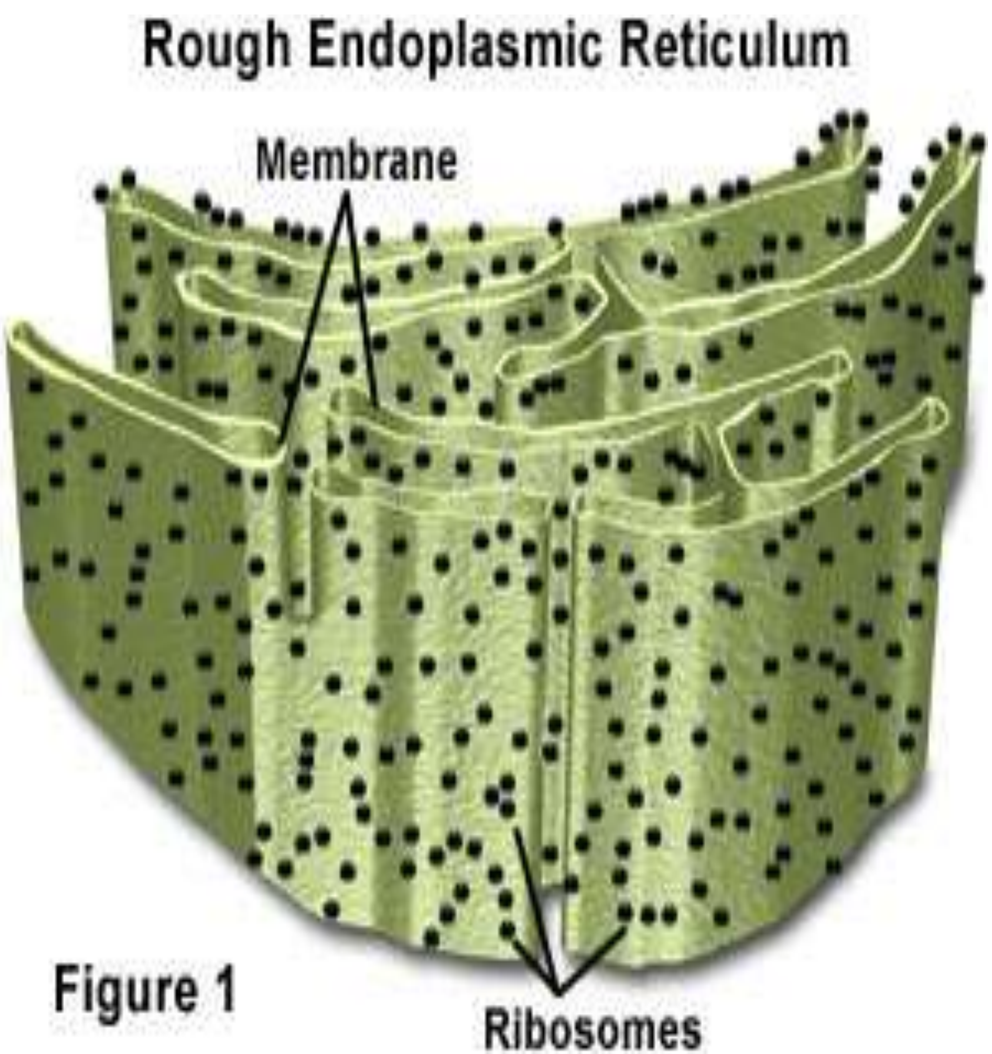



Figure 1

- Small non-membrane bound organelles.
- Contain two sub units
- Site of protein synthesis.
- Protein factory of the cell
- Either free floating or attached to the Endoplasmic Reticulum.

# Endoplasmic Reticulum

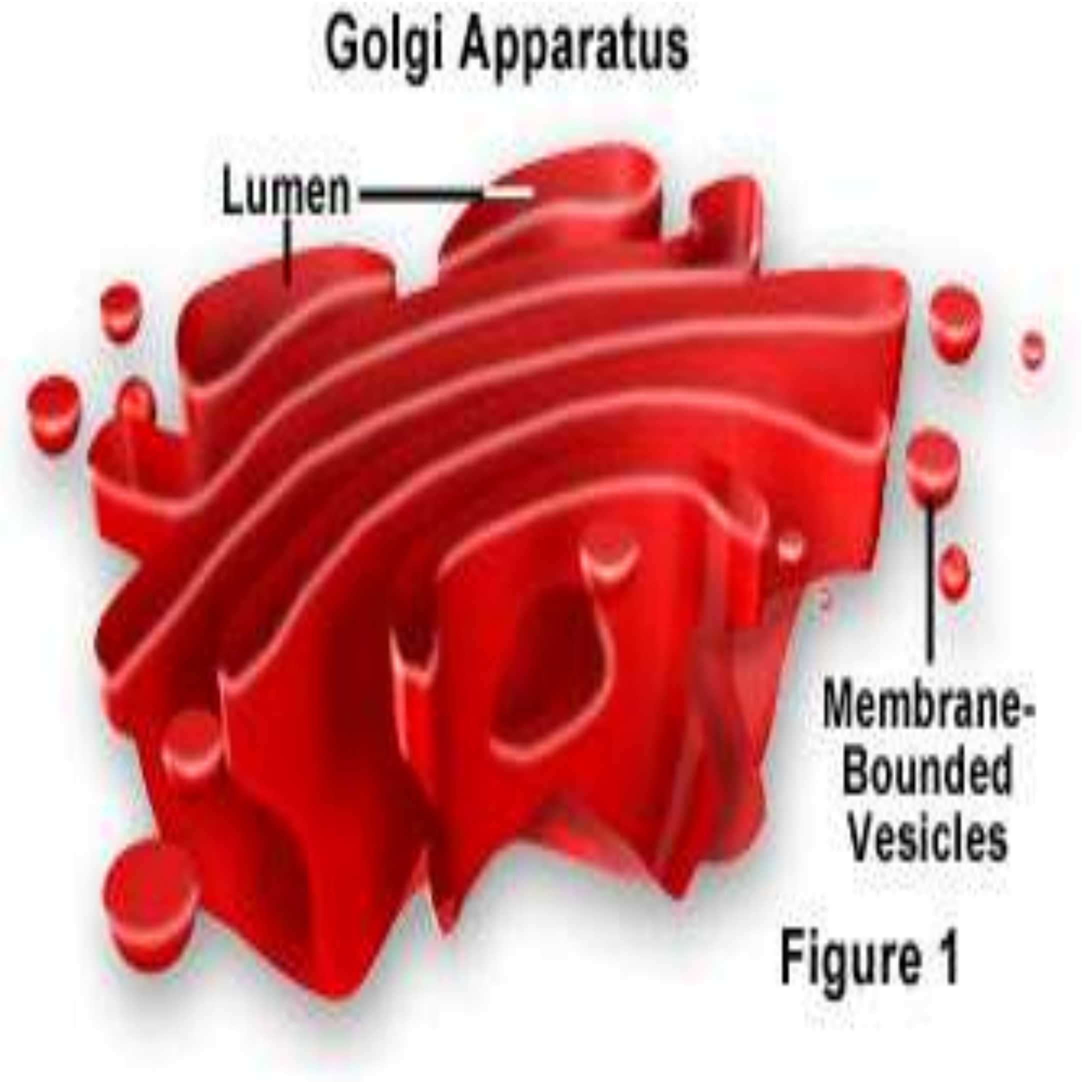



- Complex network of transport channels.
- Two types:

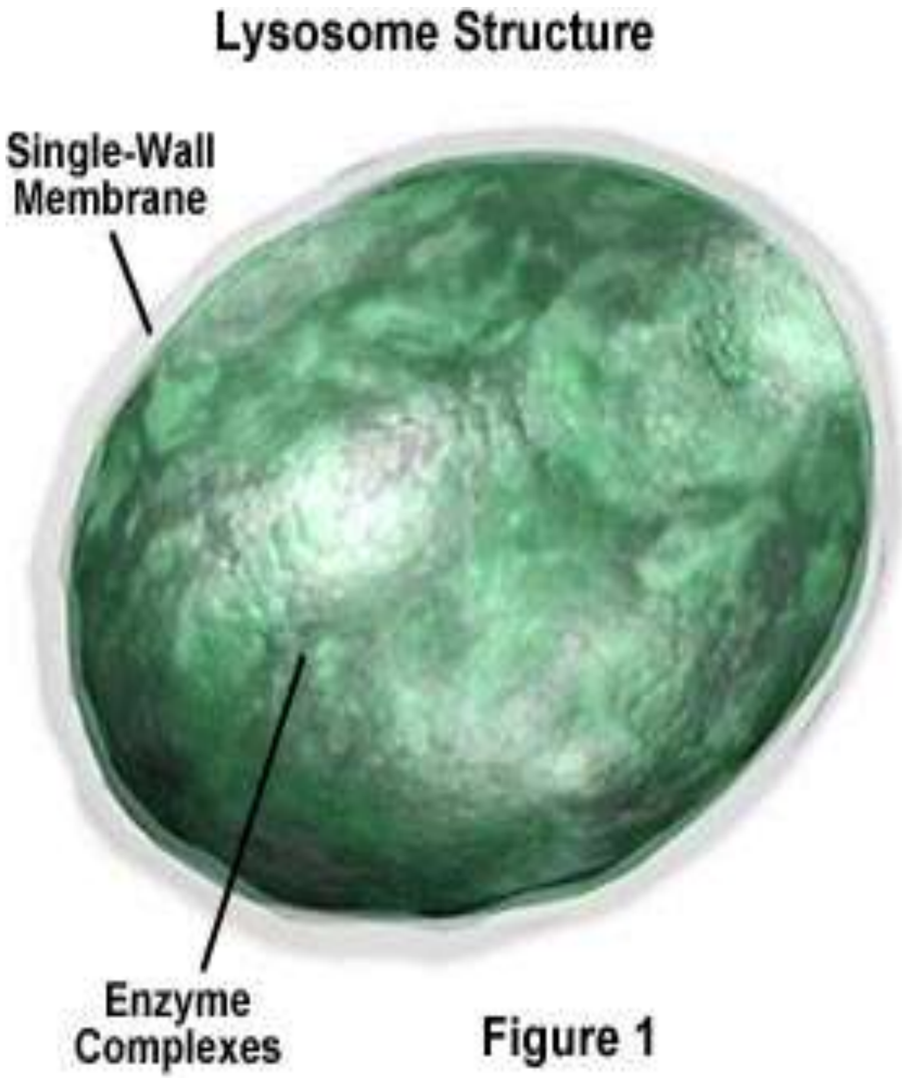
1. Smooth- ribosome free and functions in poison detoxification.
2. Rough - contains ribosomes and releases newly made protein from the cell.

# Golgi Apparatus

- A series of flattened sacs that modifies, packages, stores and transports materials out of the cell.
- Works with the ribosomes and Endoplasmic Reticulum.



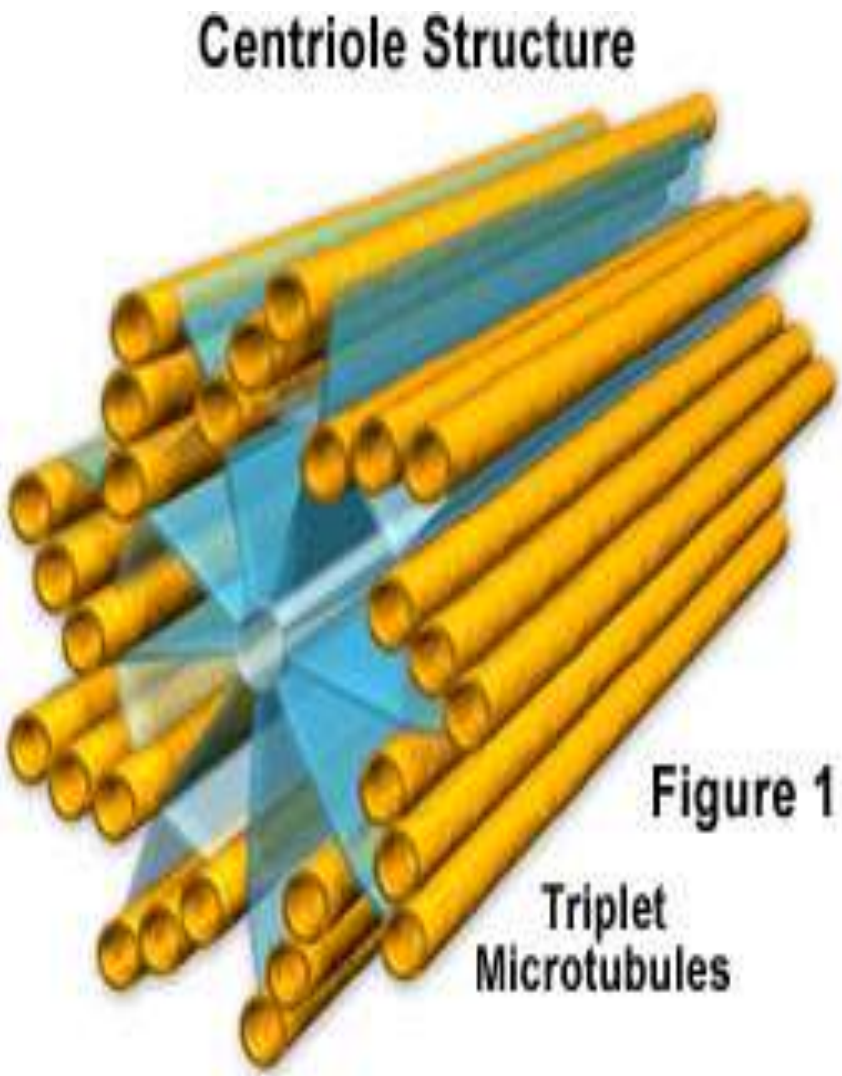
# Lysosomes



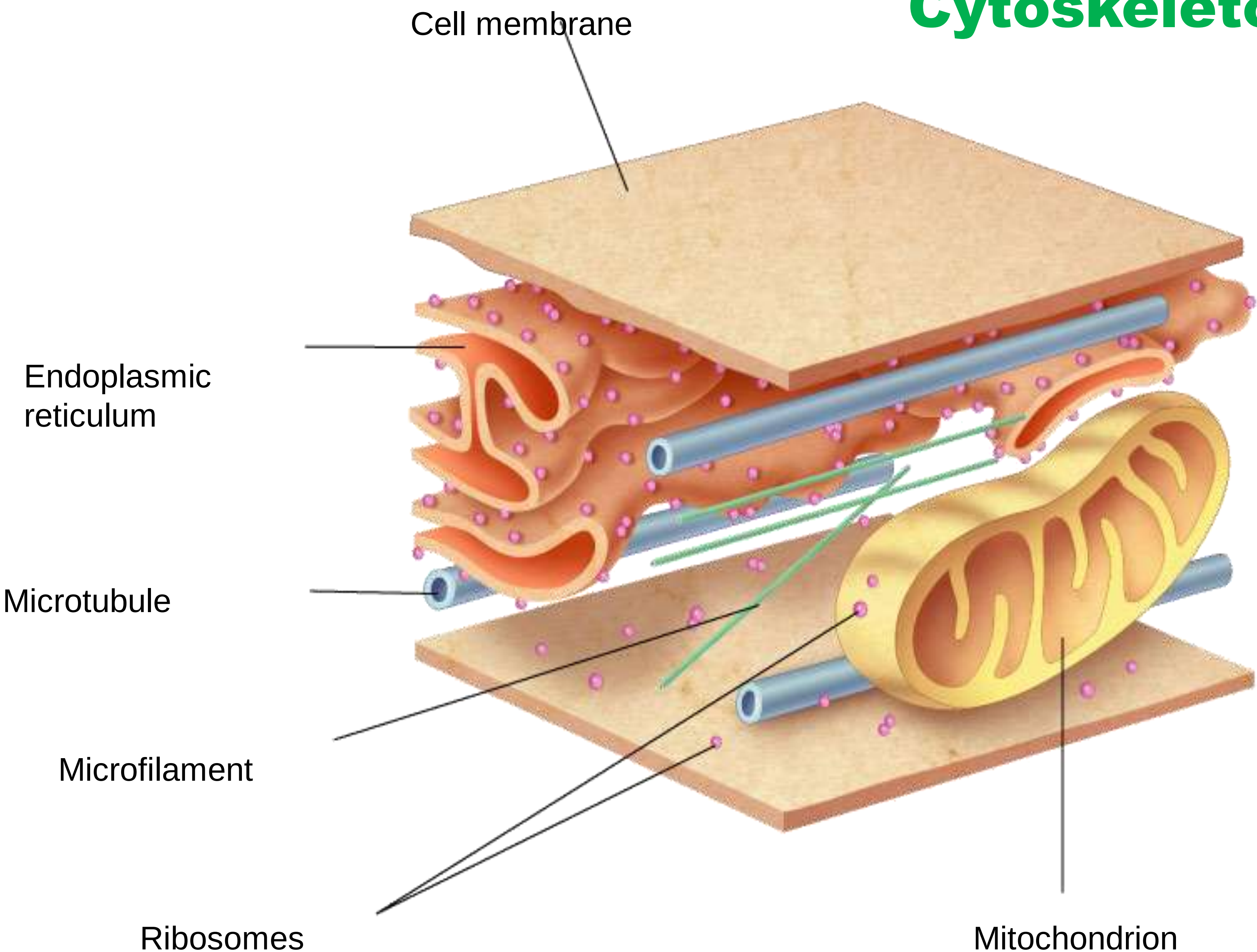

- Recycling Center
  - Recycle cellular debris
- Membrane bound organelle containing a variety of enzymes.
- Internal pH is 5.
- Help digest food particles inside or out side the cell.

# Centrioles

- Found only in animal cells
- Paired organelles found together near the nucleus, at right angles to each other.
- Role in building cilia and flagella
- Play a role in cellular reproduction



# Cytoskeleton

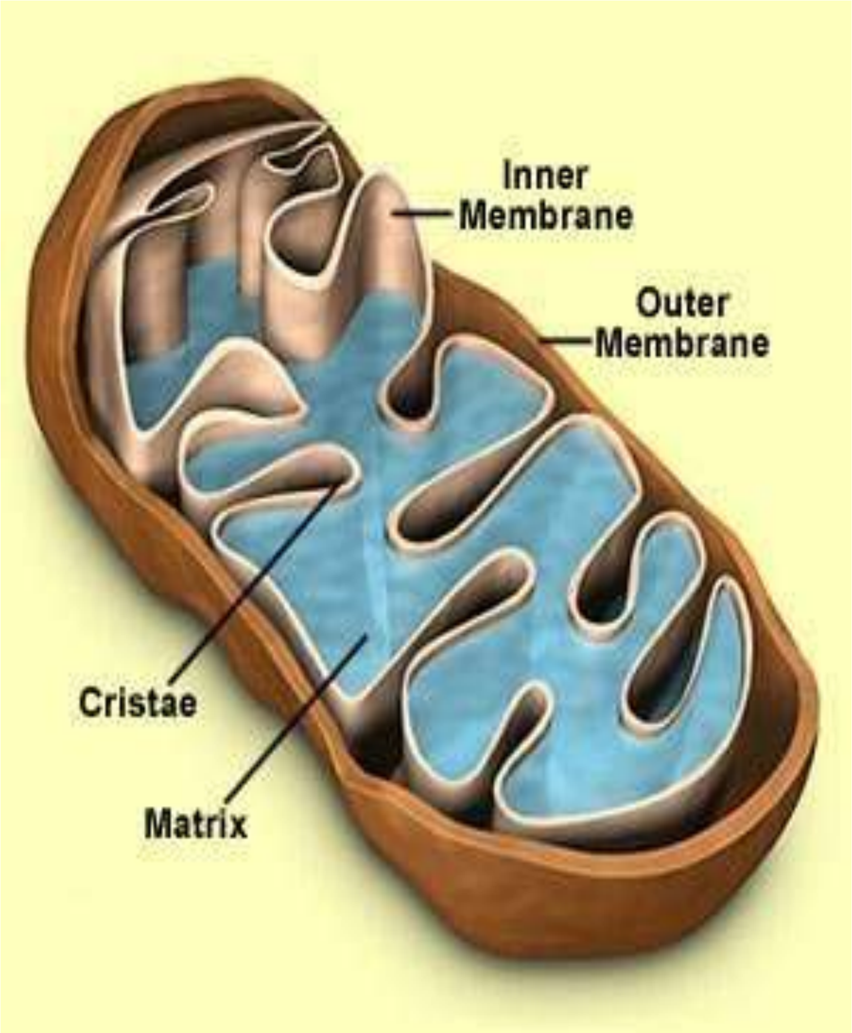


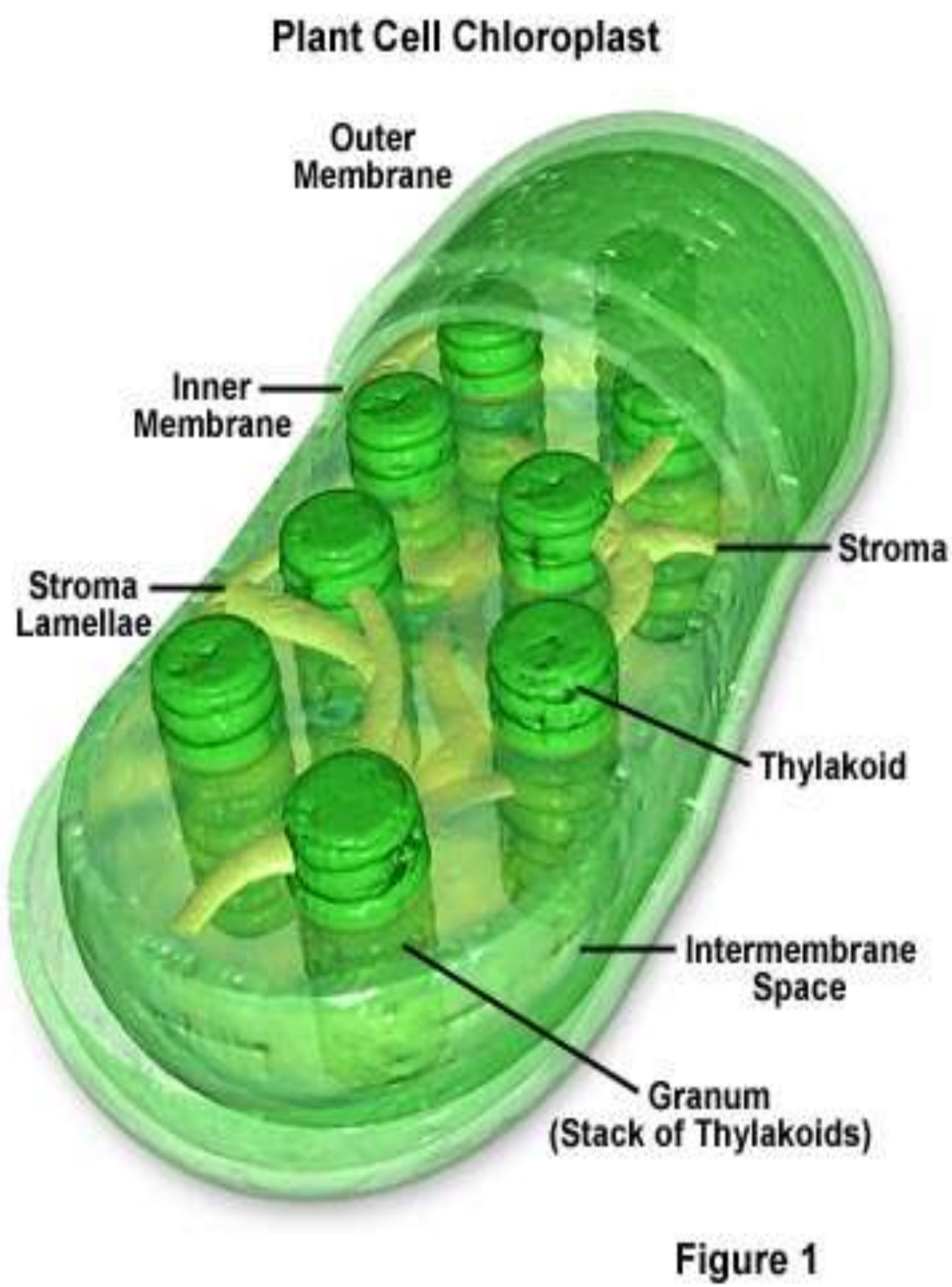
# Cytoskeleton

- Framework of the cell
- Contains small microfilaments and larger microtubules.
- They support the cell, giving it its shape and help with the movement of its organelles.

# Mitochondrion

- Double Membranous
- It's the size of a bacterium
- Contains its own DNA; mDNA
- Produces high energy compound ATP



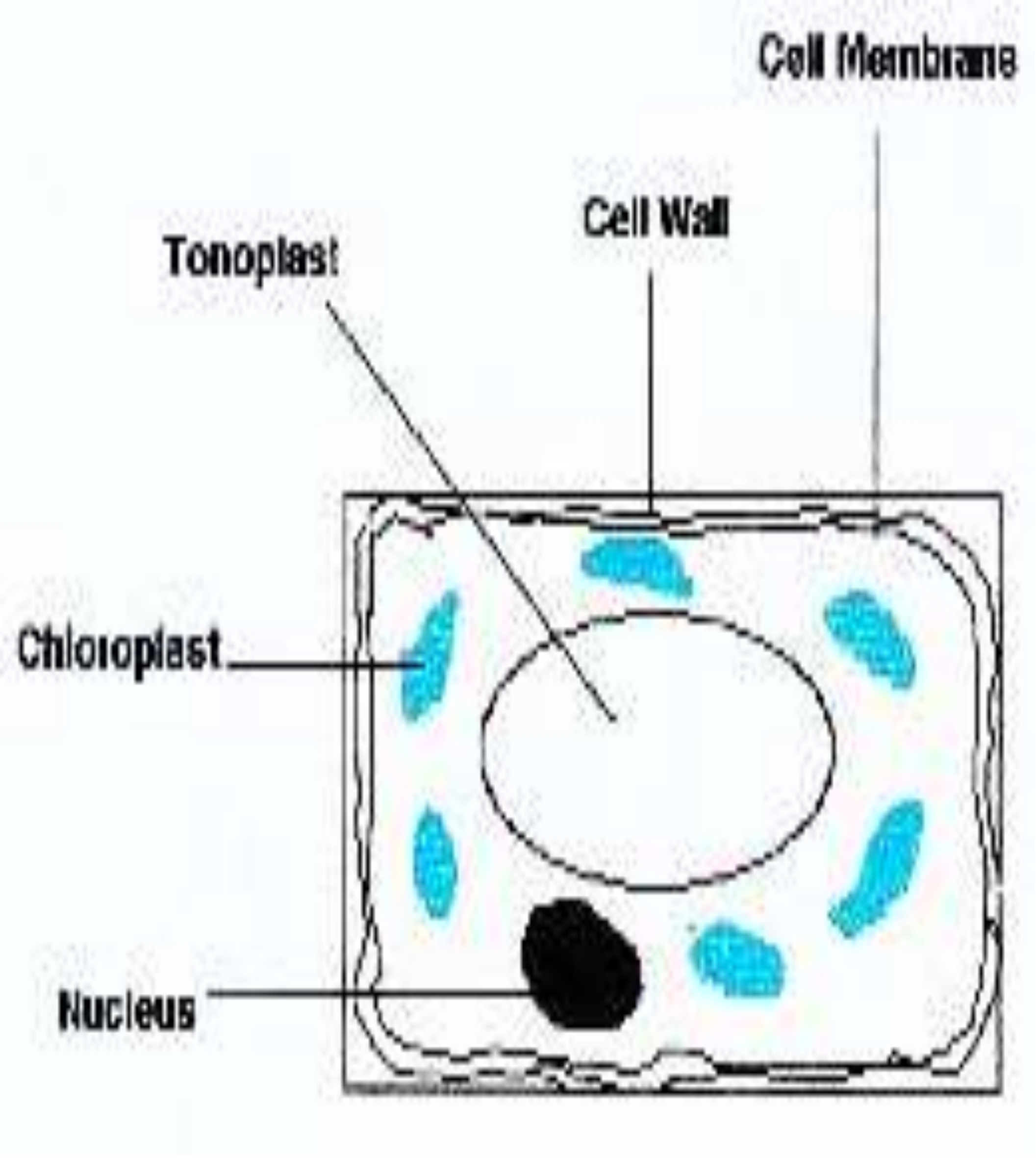



# The Chloroplast

- Double membrane
- Center section contains grana
- Thylakoid (coins) make up the grana.
- Stroma - gel-like material surrounding grana
- Found in plants and algae.

# The Vacuole

- Sacs that help in food digestion or helping the cell maintain its water balance.
- Found mostly in plants and protists.



# Cell Wall

- Extra structure surrounding its plasma membrane in plants, algae, fungi, and bacteria.
- Cellulose – Plants
- Chitin – Fungi
- Peptidoglycan – Bacteria

Thanks…

F Y B Sc Zoology Paper III

Course Title: Practical Zoology

Course Code: ZO – 123

**Semester - II (Sec II Cell Biology)**

Practical 1

# Study of Microscopes


By

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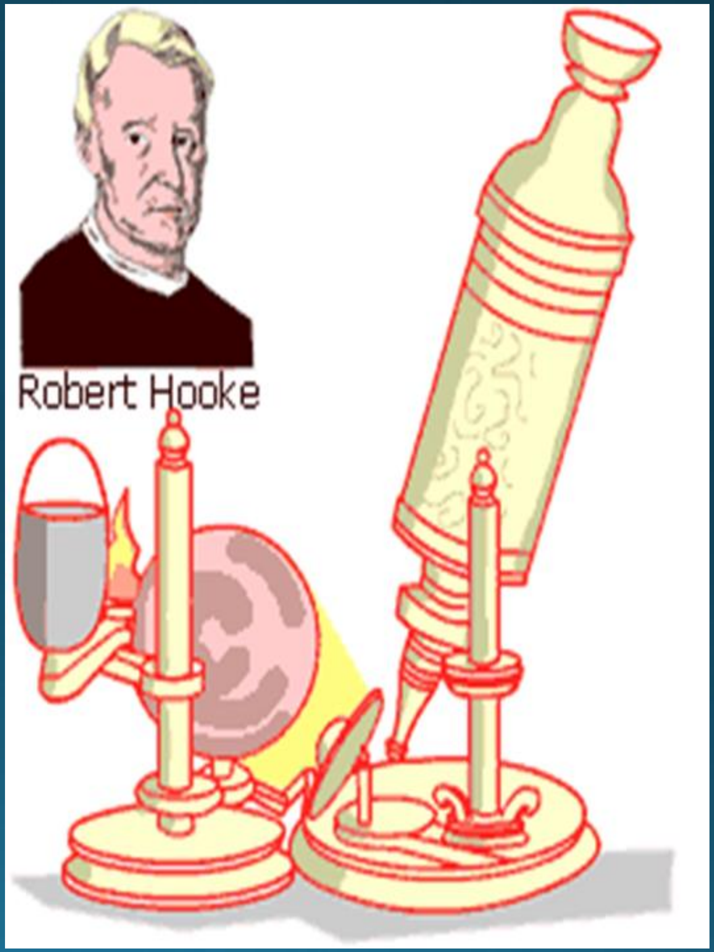
**Note:** This material is only for educational purpose and is non -commercial

# Microscope History

**1665 – English physicist, Robert Hooke looked at a sliver of cork through a microscope lens and noticed some "pores" or "cells" in it.**



# 1) Simple Microscope

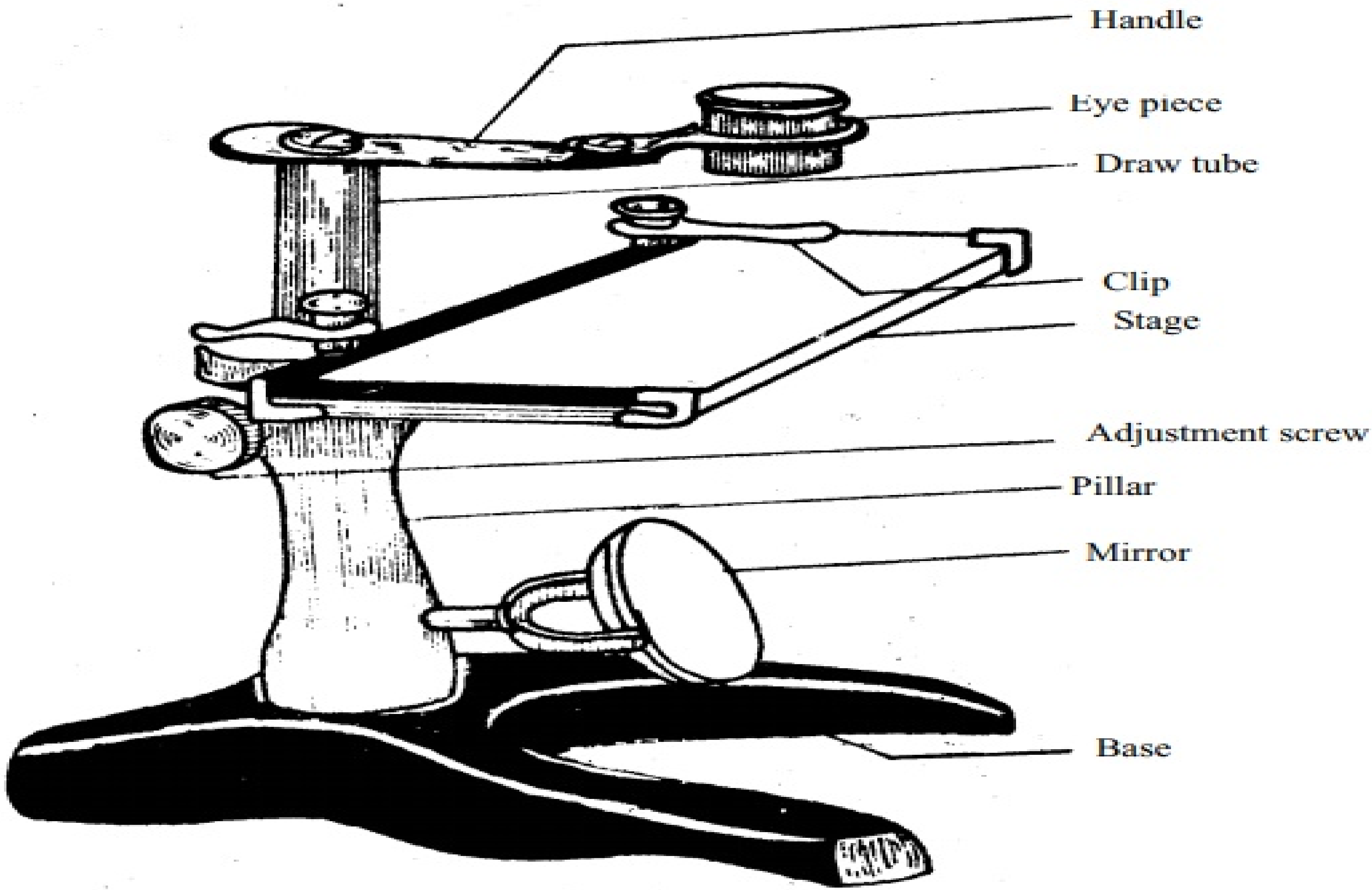



**Fig. P.2A Simple Microscope**

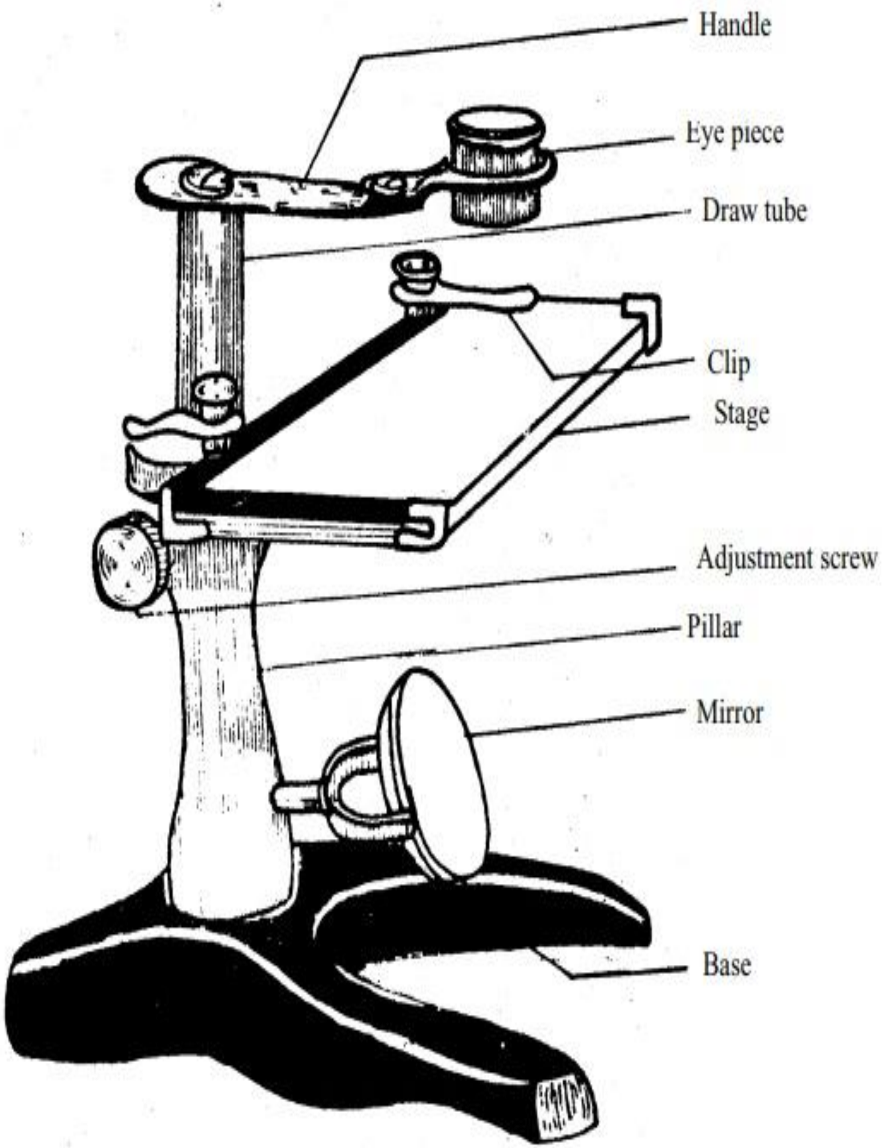



**Fig. P.2A Simple Microscope**

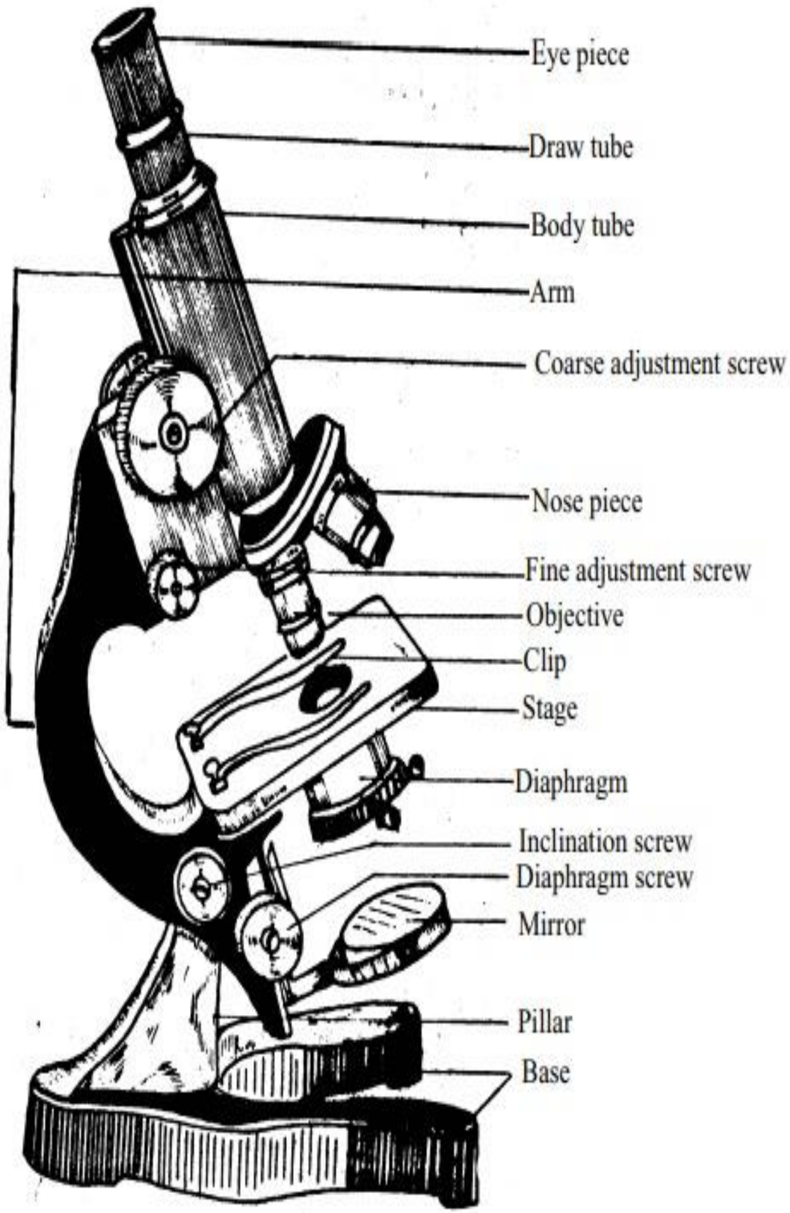
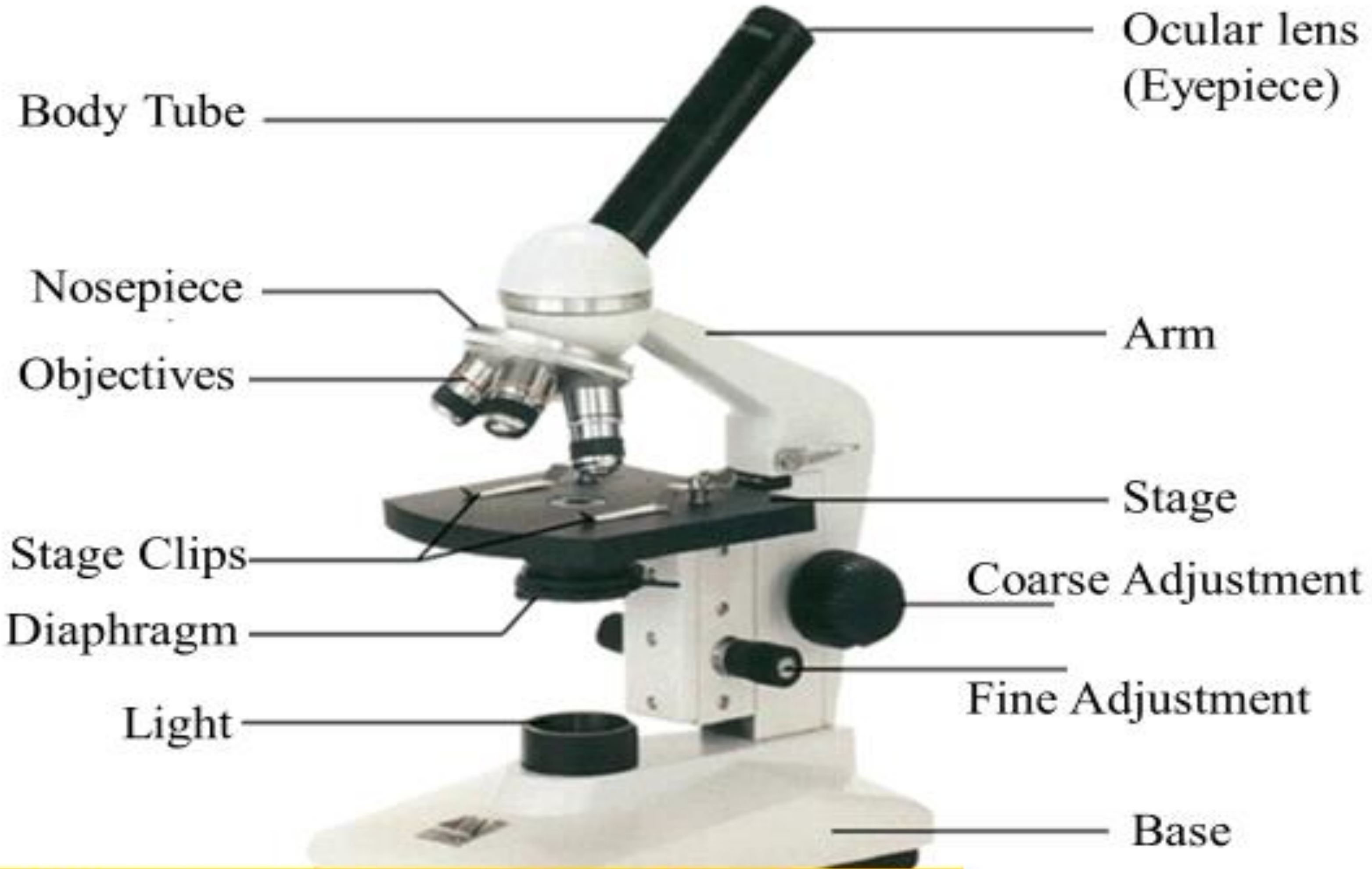



**Fig.P.3A Compound Microscope**

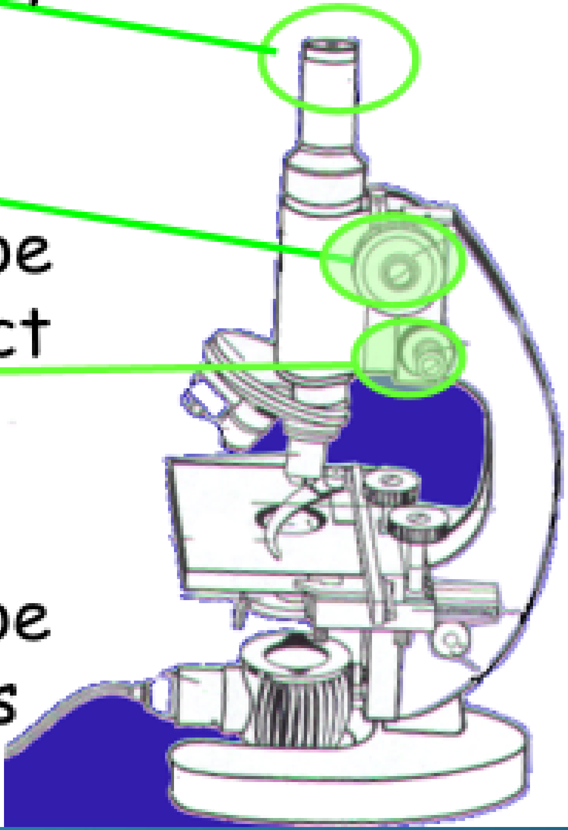
# 2 ) Compound Microscope




Always carry a microscope with one hand holding the **arm** and one hand under the **base**.

# PARTS OF A MICROSCOPE

1. ocular (lens) eyepiece
   - the lens of the microscope that you look through
2. course adjustment
   - the large knob on the microscope that you turn to bring the object into focus
3. fine adjustment
   - the small knob on the microscope that brings the image into focus



# PARTS OF A MICROSCOPE

## 4. arm

- the part of the microscope supporting the body tube

## 5. body tube

- the part that holds the eyepiece and the objective lenses.

## 6. nosepiece

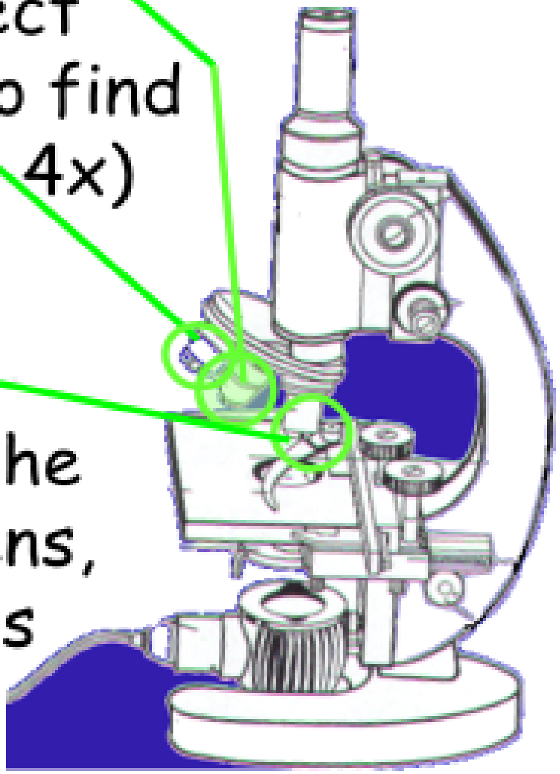
- the part at the bottom of the body tube that holds the objective lenses and allows them to be turned

7. *high power objective lens*

- the lens that magnifies the object the greatest amount. (usually 40x)

8. *Low power (scanner) objective lens*

- the lens that magnifies the object the least amount (usually used to find the object; magnifies only 3x or 4x)



9. *middle power objective lens*

- the lens that usually magnifies the object more than the scanner lens, but less than the high power lens (usually 10x to 20x)

10. *stage*

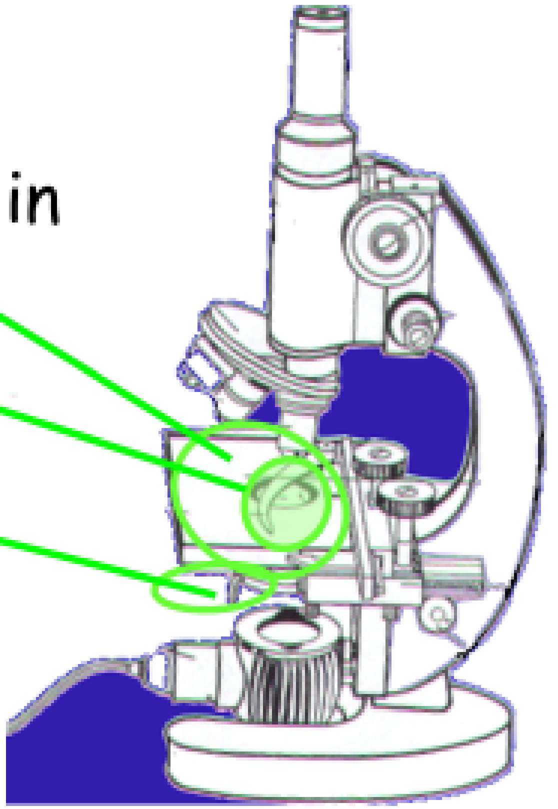
- the flat part below the objectives lens where the slide is placed

11. *clip*

- the part that holds the slide in place so it doesn't move

12. *diaphragm*

- the part that controls the amount of light entering the field of view

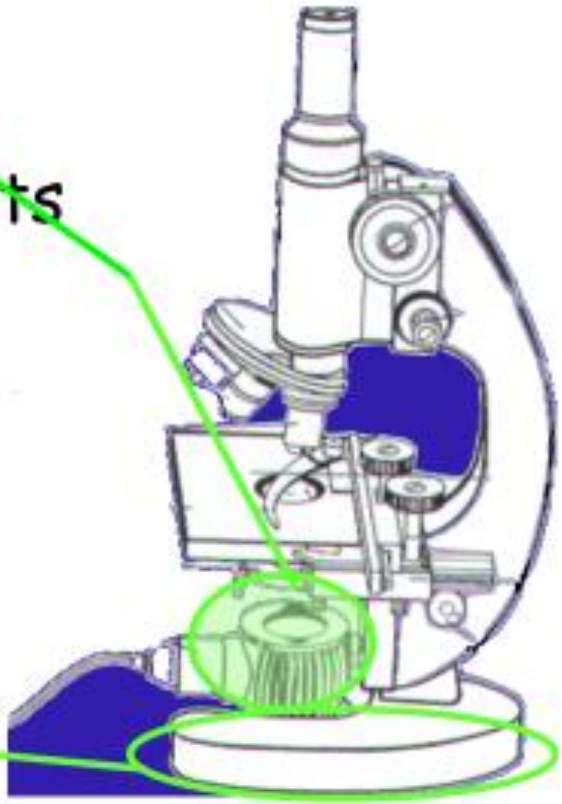


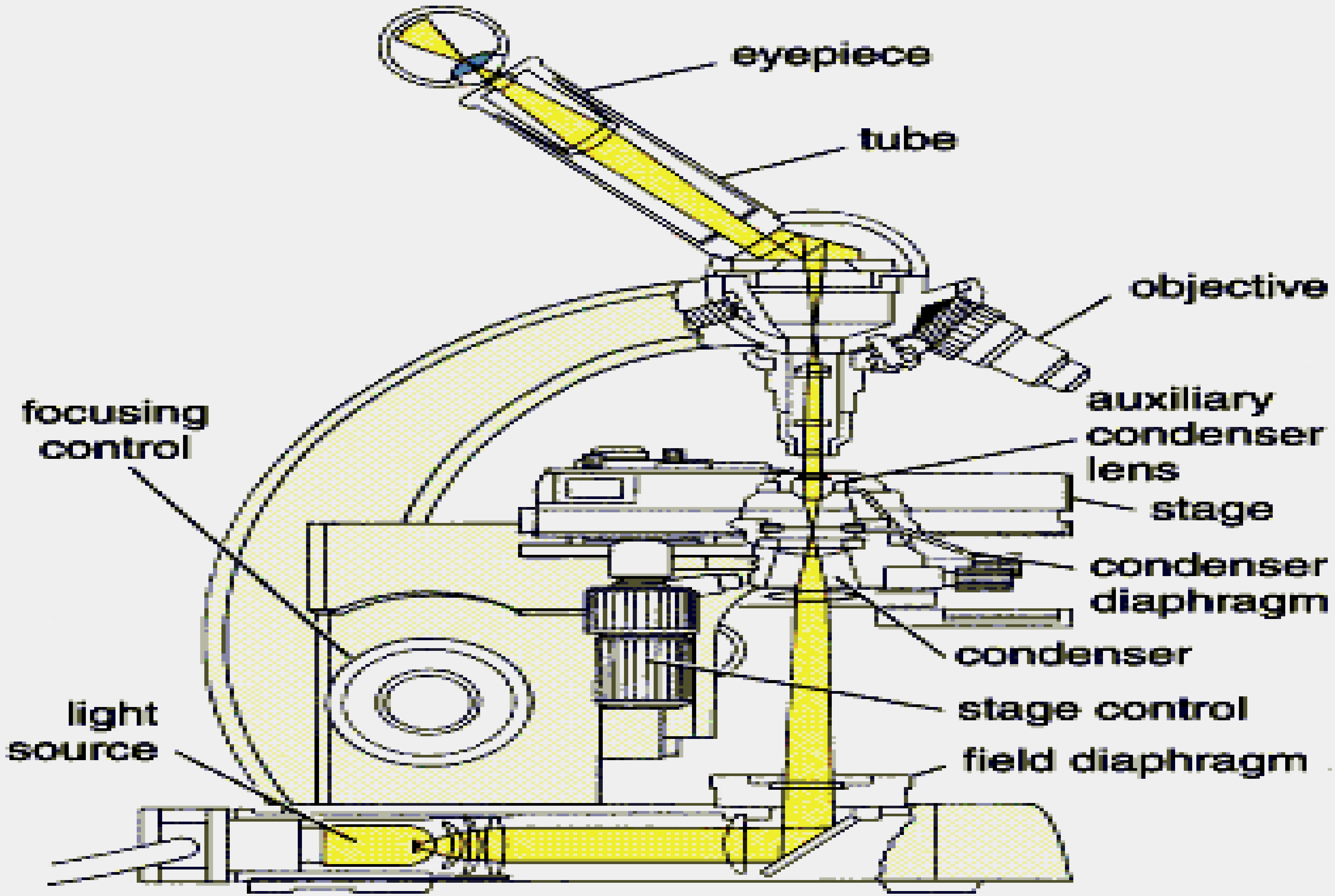
13. *light source*

- the lamp (or mirror) under the stage that sends light through the object being viewed.

14. *base*

- the bottom part that supports the rest of the microscope

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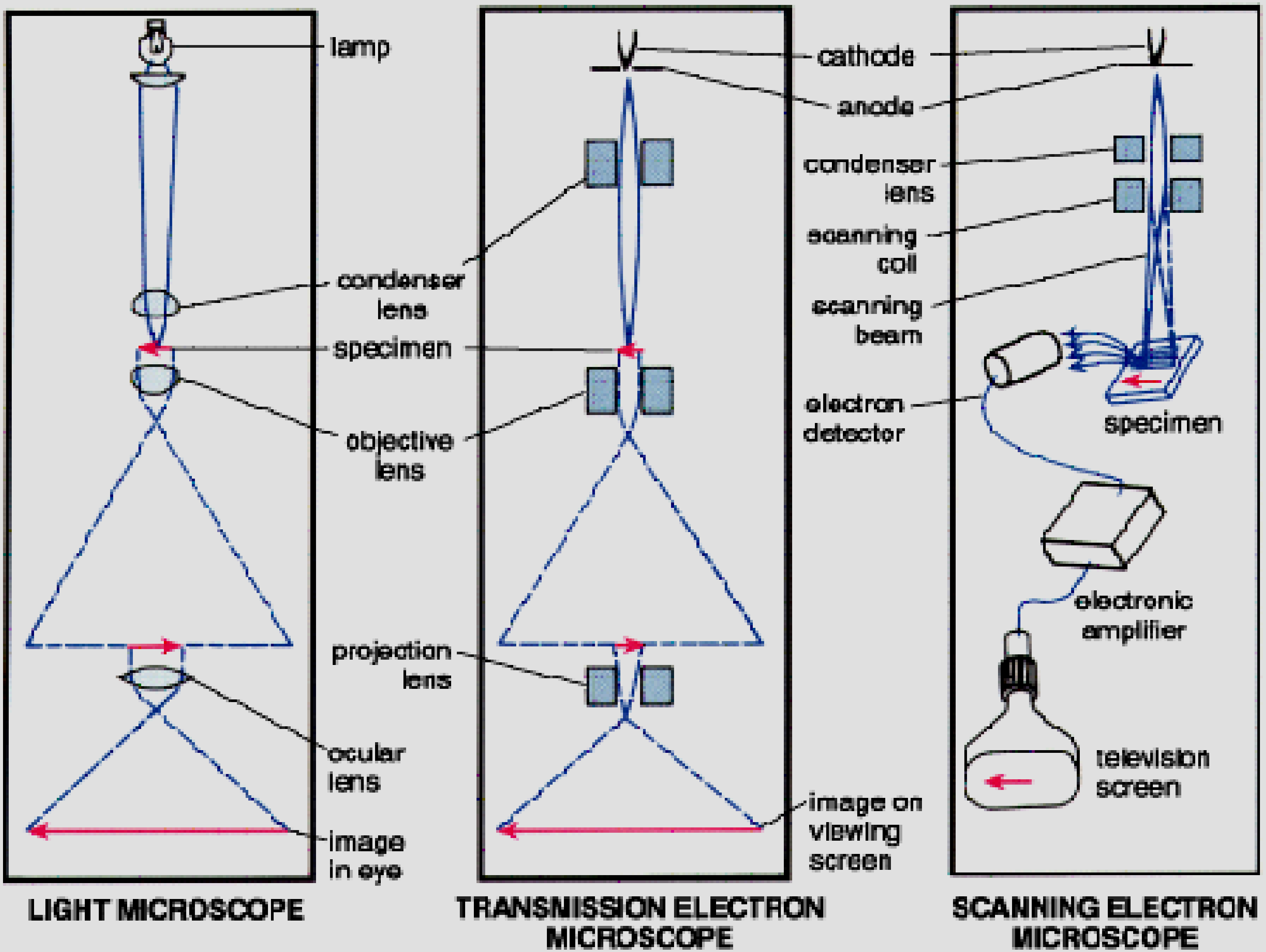
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objective lens
ocular lens
image in eye
LIGHT MICROSCOPE
cathode
anode
projection lens
image on viewing screen
TRANSMISSION ELECTRON MICROSCOPE
condenser lens
scanning coil
scanning beam
electron detector
specimen
electronic amplifier
television screen
SCANNING ELECTRON MICROSCOPE

F Y B Sc Zoology Paper II

# Course Title: Cell Biology

Course Code: ZO – 122

Semester - II (2 credits – 30 Hours)

Chapter No. 3

# Plasma Membrane

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# 3 Plasma Membrane:

**Content:**

**3.1Introduction**

**3.2 Structure of plasma membrane: Fluid mosaic model.**

**3.3Transport across membranes: Active and Passive transport, Facilitated transport, exocytosis, endocytosis, phagocytosis – vesicles and their importance in transport.**

**3.4 Other functions of Cell membrane in brief Protection, cell recognition, shape, storage, cell signalling.**

**3.5 Cell Junctions: Tight junctions, gap junctions, Desmosomes.**

# Cellular Organelles

- **The Plasma membrane**
  - The boundary of the cell.
  - Composed of three distinct layers.
  - Two layers of fat and one layer of protein.

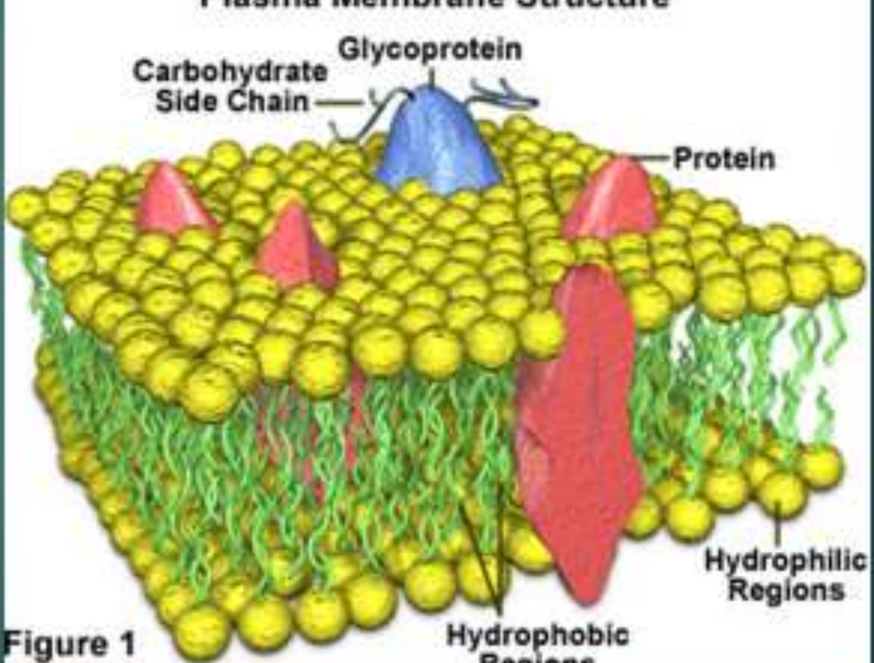


Figure 1

# Chemical composition of cell membrane

**Proteins**

**1 Intrinsic proteins**

**2 extrinsic proteins**

**A) Spectrins**

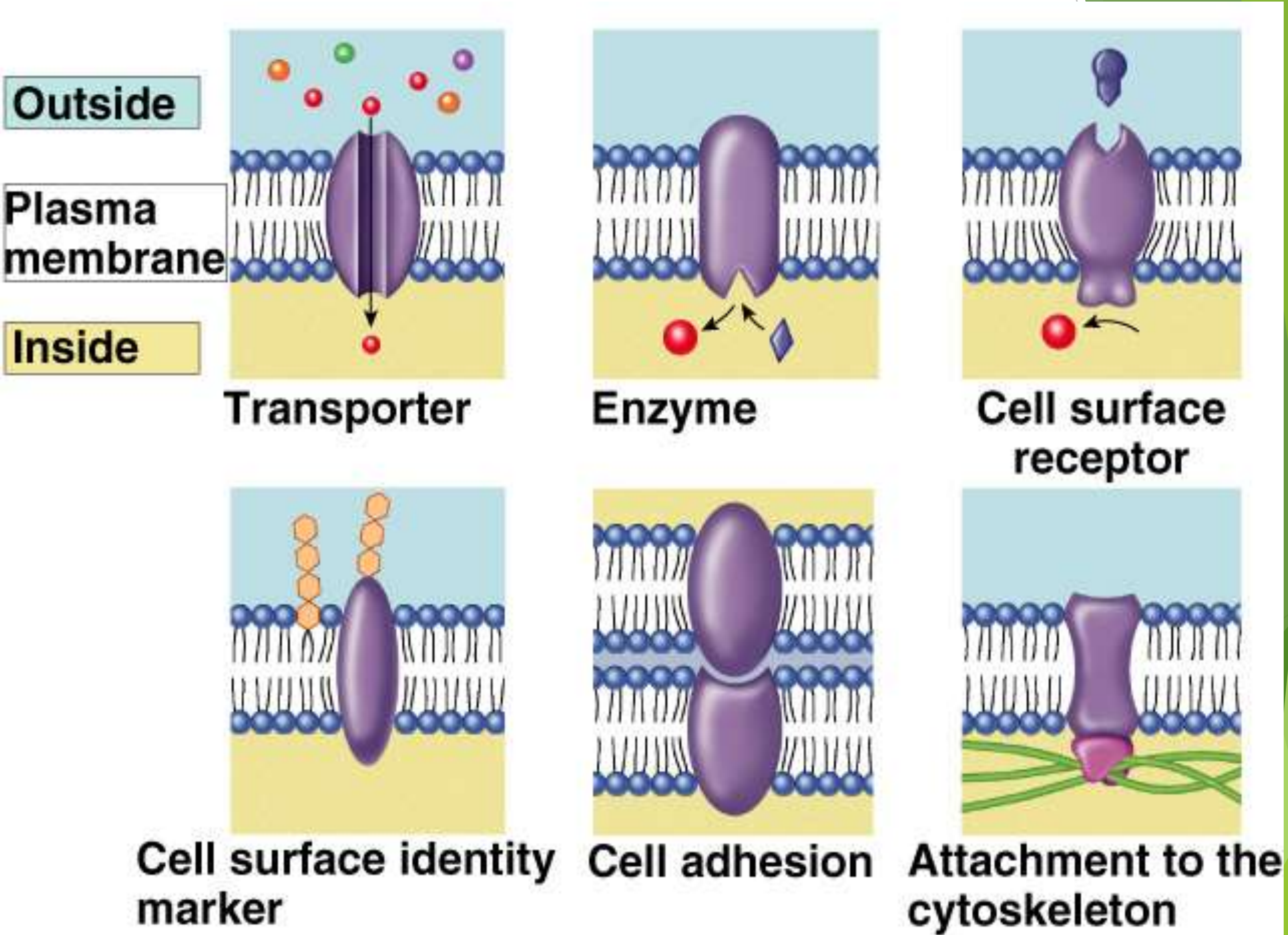
**B) Ankyrin**

**C) Glycoprptein**

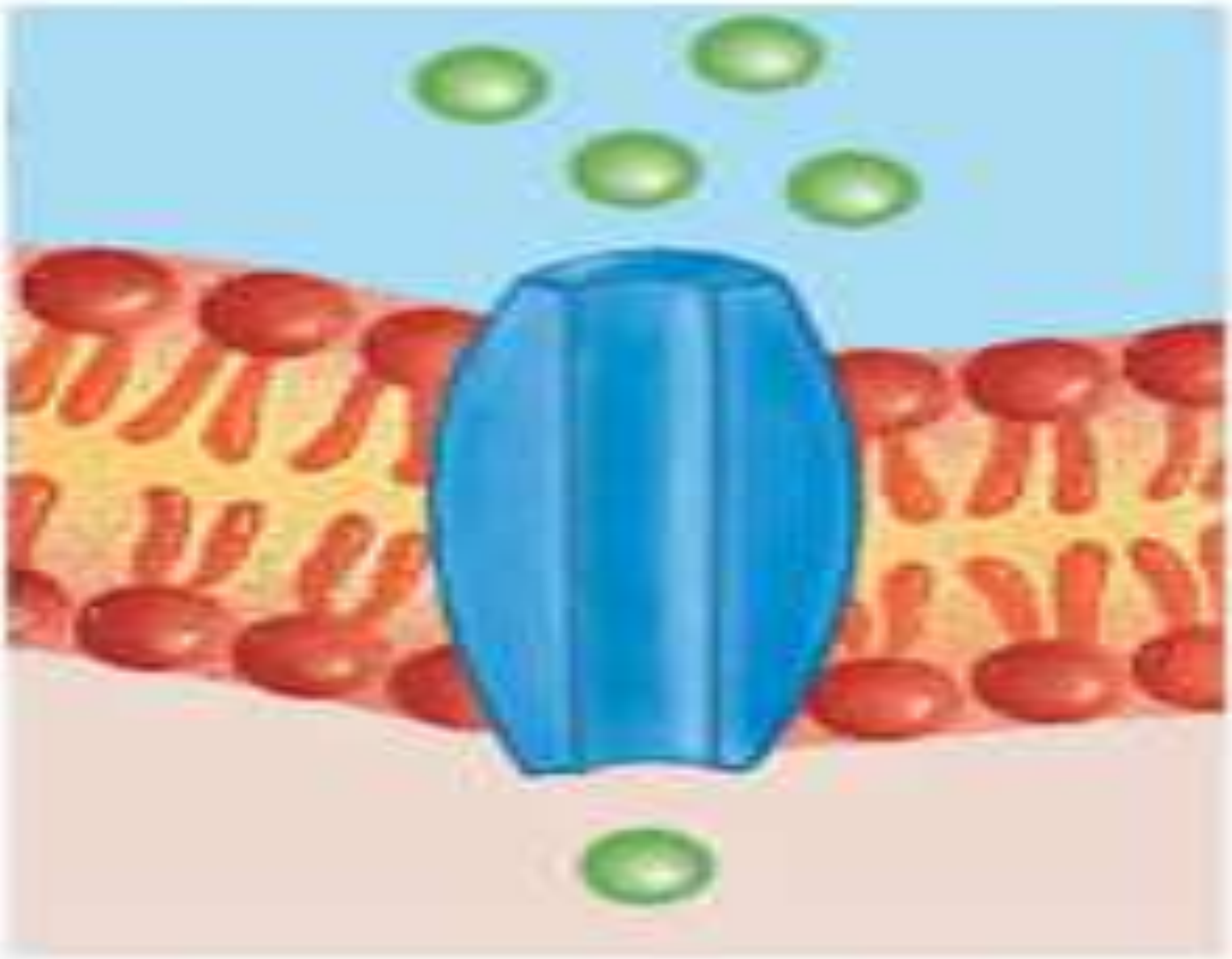
**D) Enzymes**

**E) Glycoproteins**

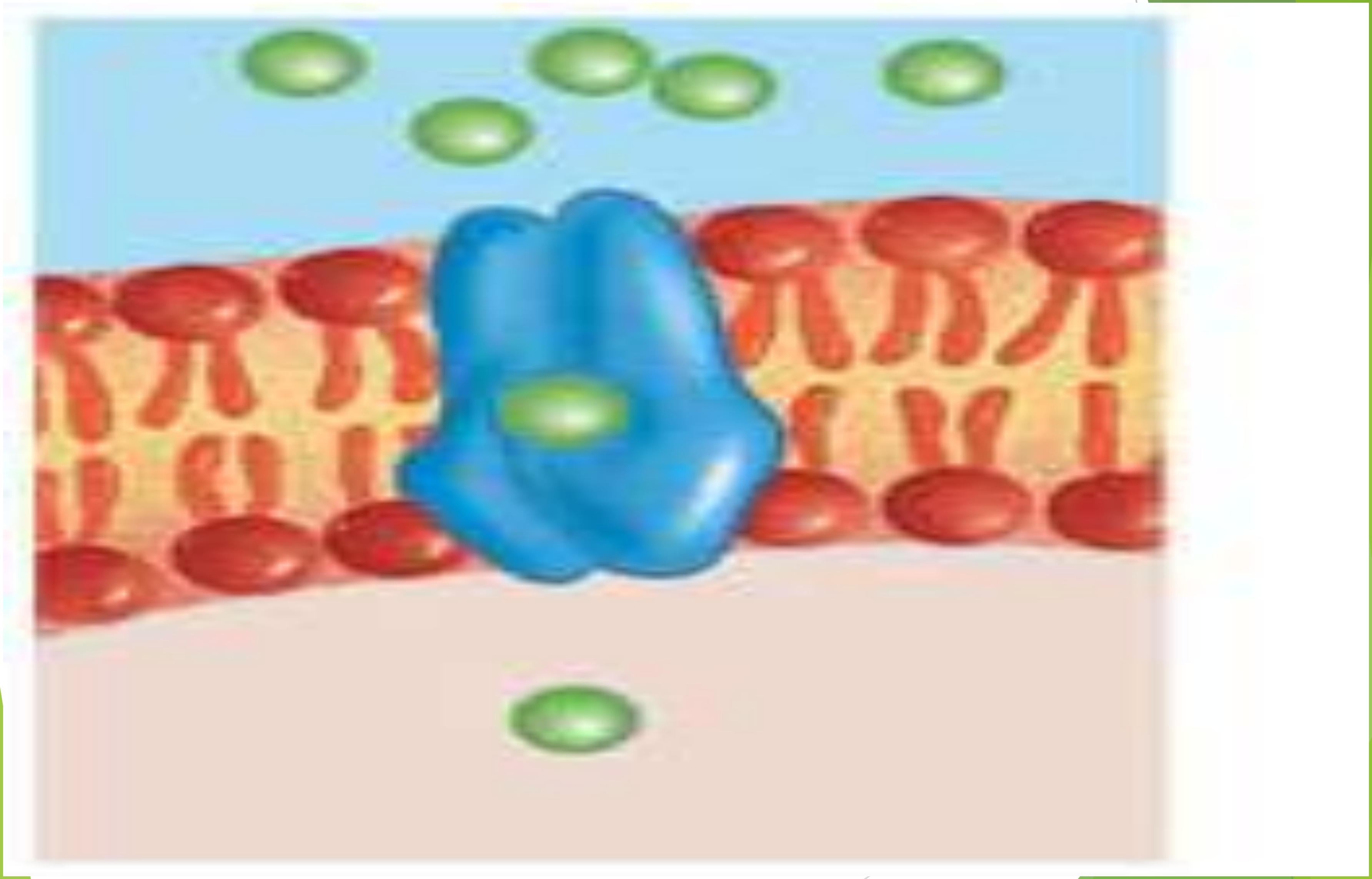
# Plasma Membrane Proteins



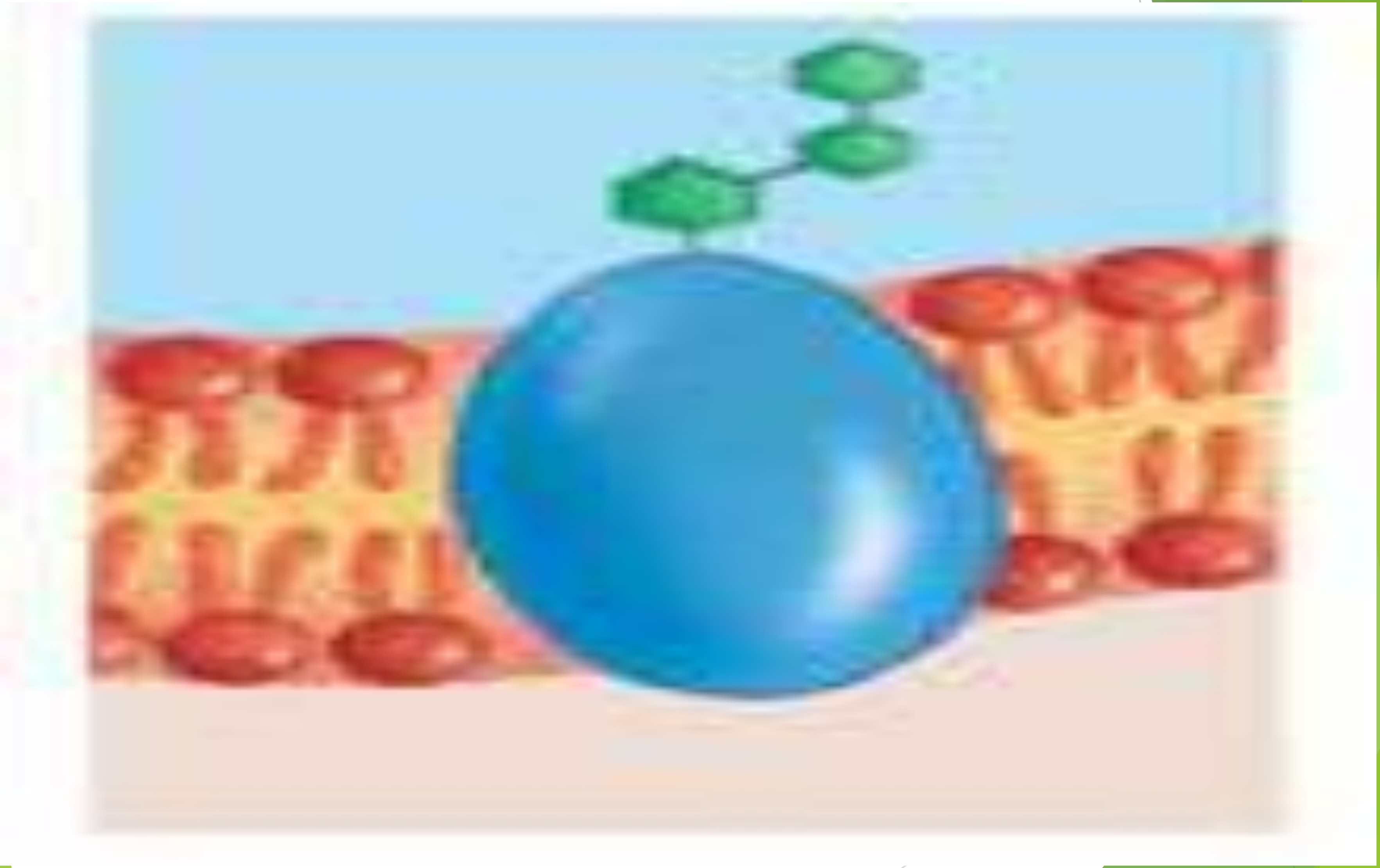
# Channel protein



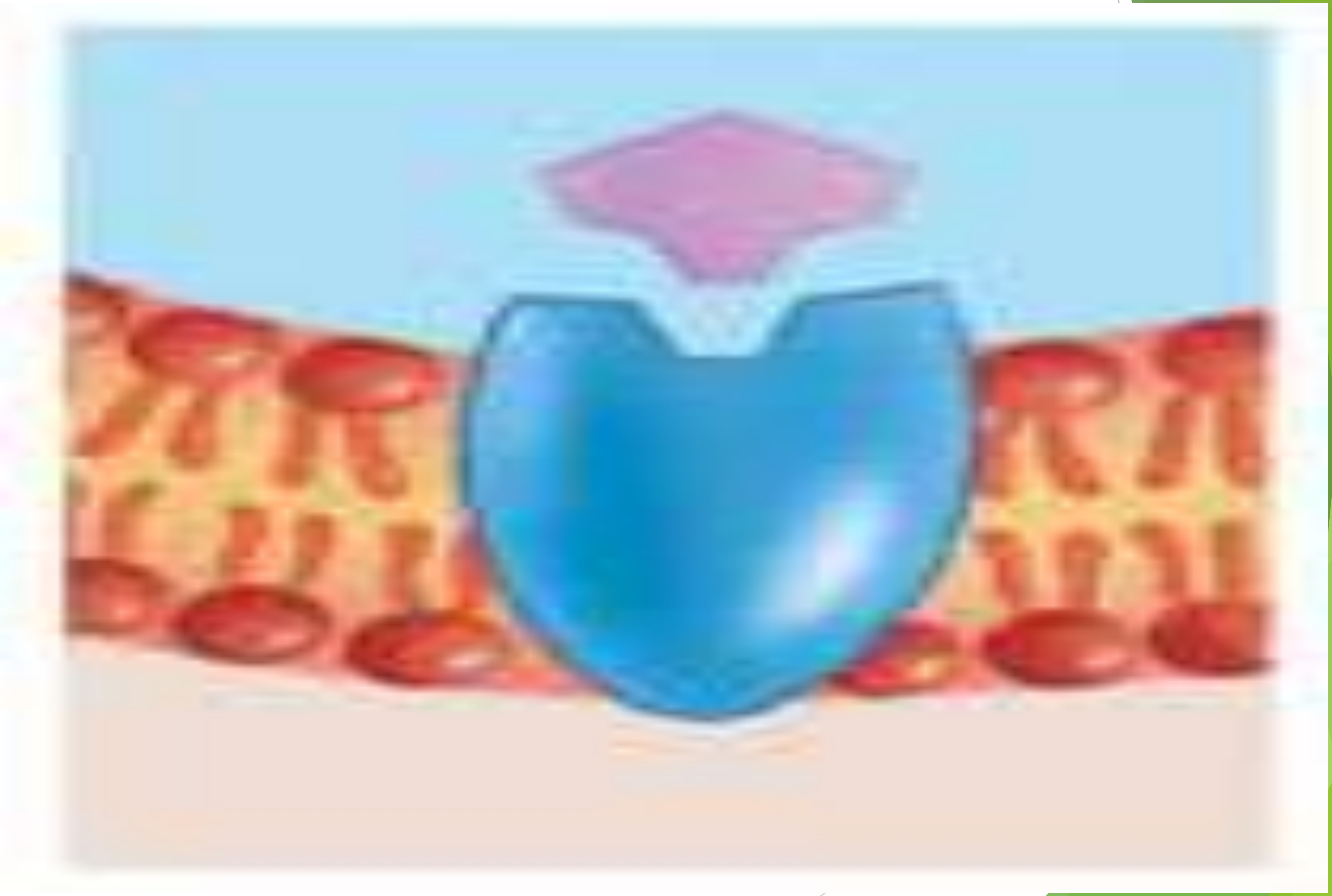
# Carrier protein



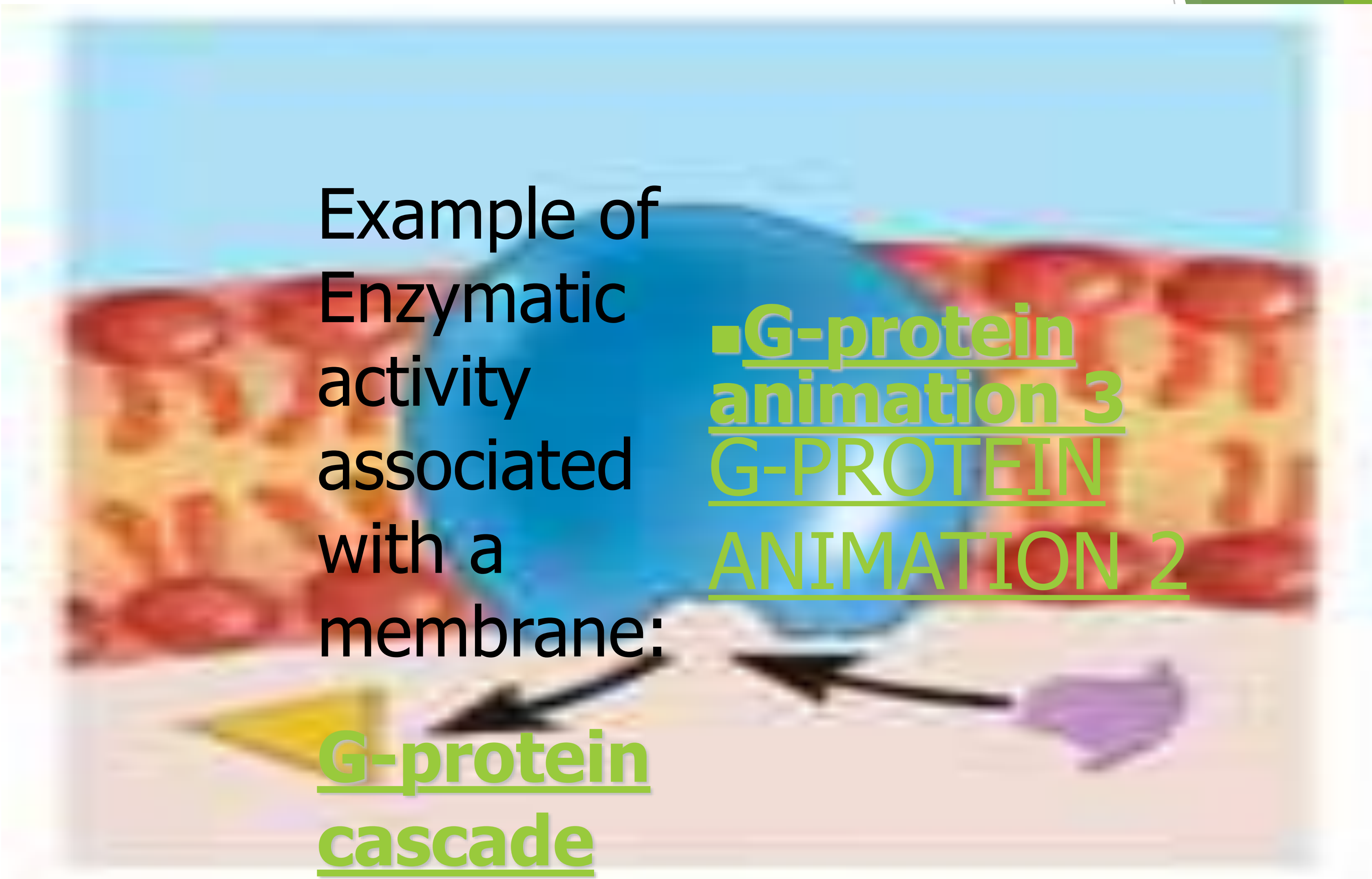
# Cell recognition protein



# Receptor protein



# Enzymatic protein



Example of Enzymatic activity associated with a membrane:

**G-protein cascade**

- **G-protein animation 3**

G-PROTEIN ANIMATION 2

# LIPIDS

1. Phospholipids
2. Cholesterol
3. Glycolipids

## Membrane models

1 Bilayer model
2 Fluid Mosaic model
3 Lipid Bilayer model

- **Phospholipid Bilayer**
- **Fluid Mosaic Model**
- **Membrane Proteins**
- **Diffusion**
- **Osmosis**
- **Passive Transport**
- **Active Transport**
- **Pinocytosis**
- **Phagocytosis**

1 Bilayer model

I Lipid membrane

II Protein lipid protein(Davson and Danielli)

III Proteis penetrating lipid

# Fluid-Mosaic Model

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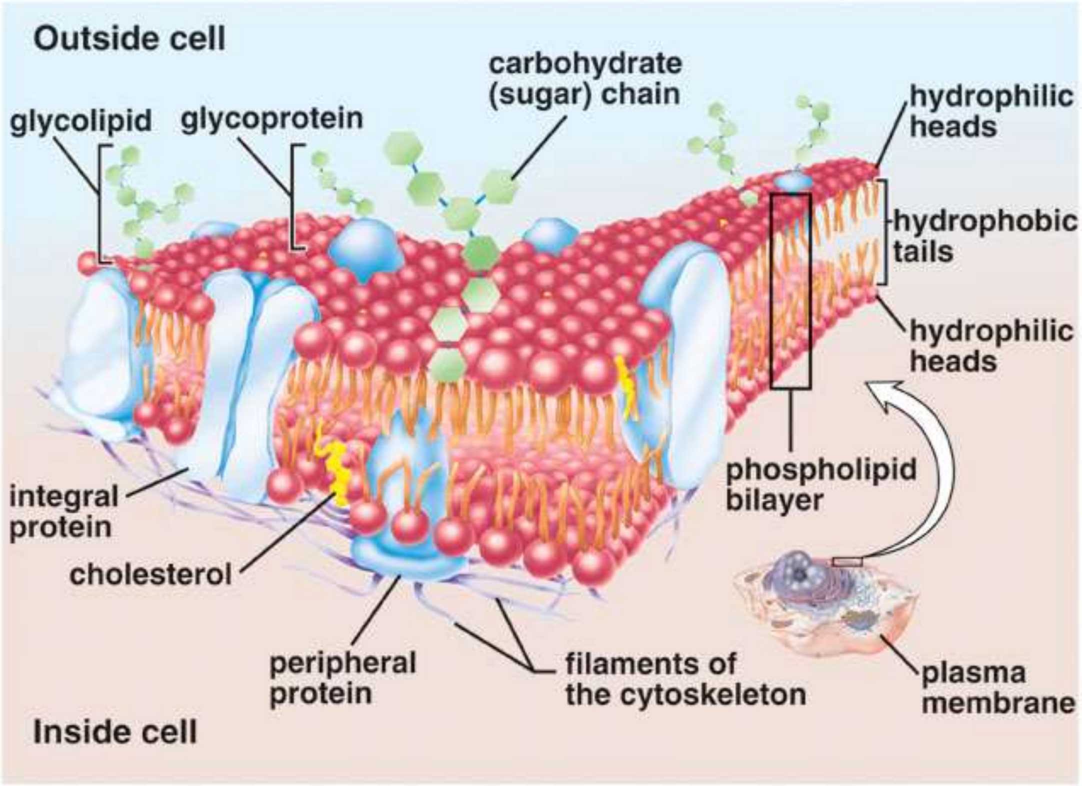


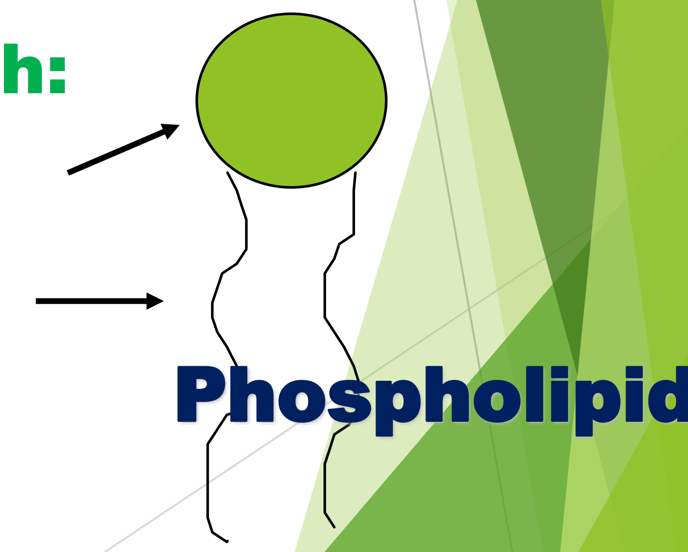
# 3.3Transport across membranes

## Membrane Functions

- Protection
- Communication
- Selectively allow substances in
- Respond to environment
- Recognition

# Plasma Membrane

- Boundary that separates the living cell from it's non-living surroundings.
- Phospholipid bilayer
- Amphipathic - having both:
  - hydrophilic heads
  - hydrophobic tails
- ~8 nm thick
- Is a dynamic structure



# Functions of cell membrane

- Transport
- Cell recognition and adhesion
- Antigen specificity
- Hormone transport
- Oxidative phosphorylation
- Endocytosis and exocytosis
- Chemoreception
- Transmission

# Permeability of the Cell Membrane- **Differentially Permeable**

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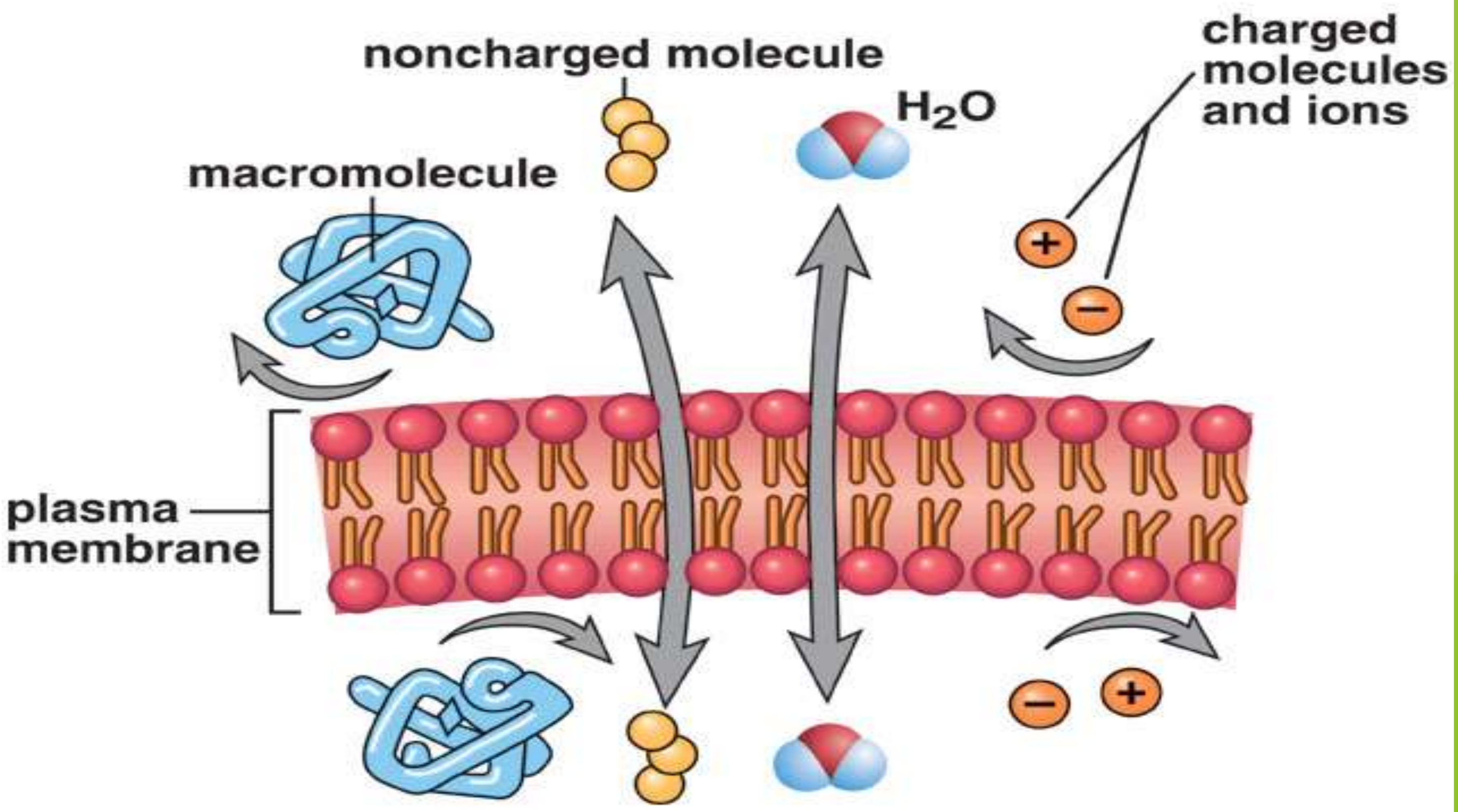
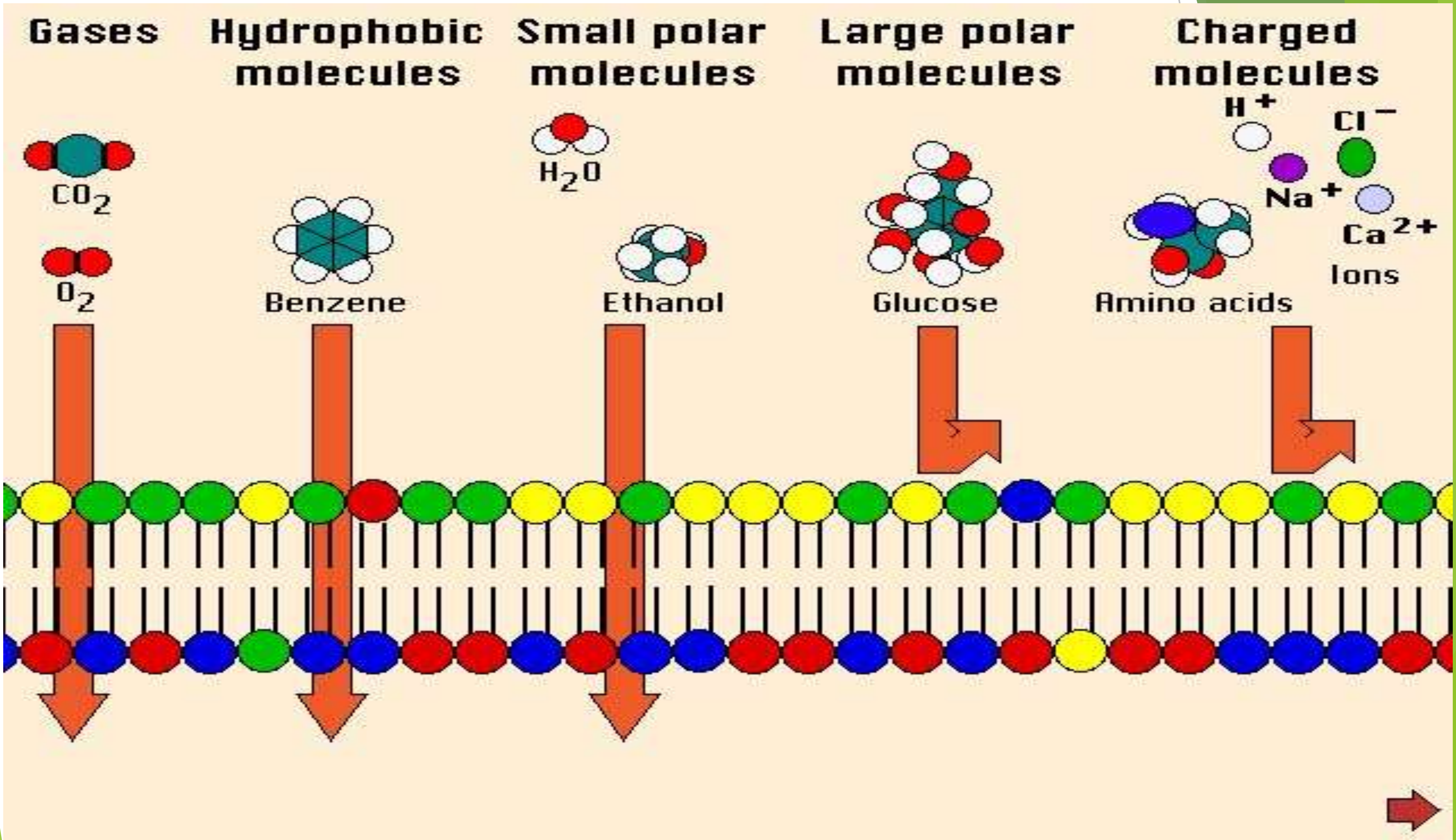
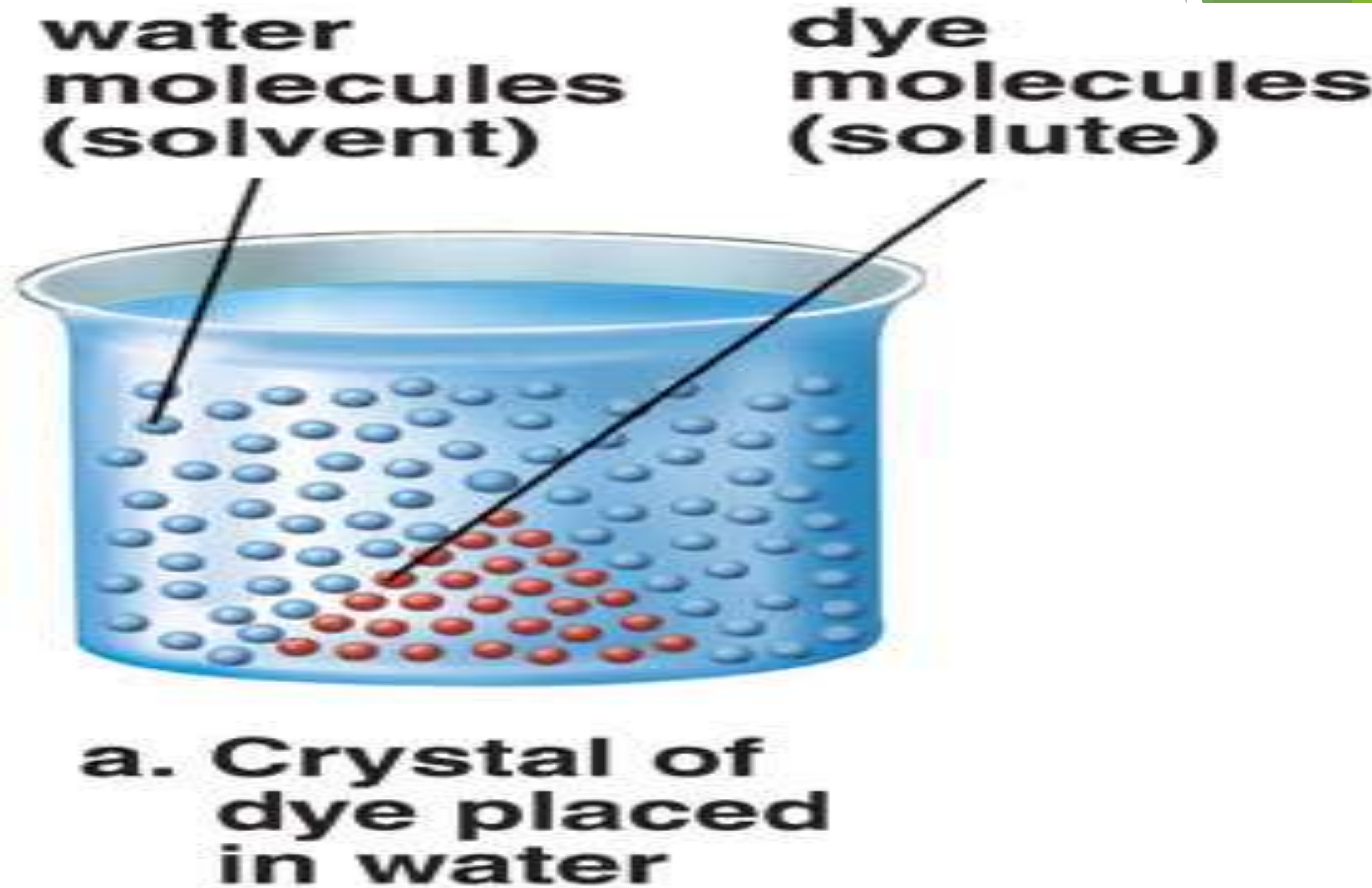


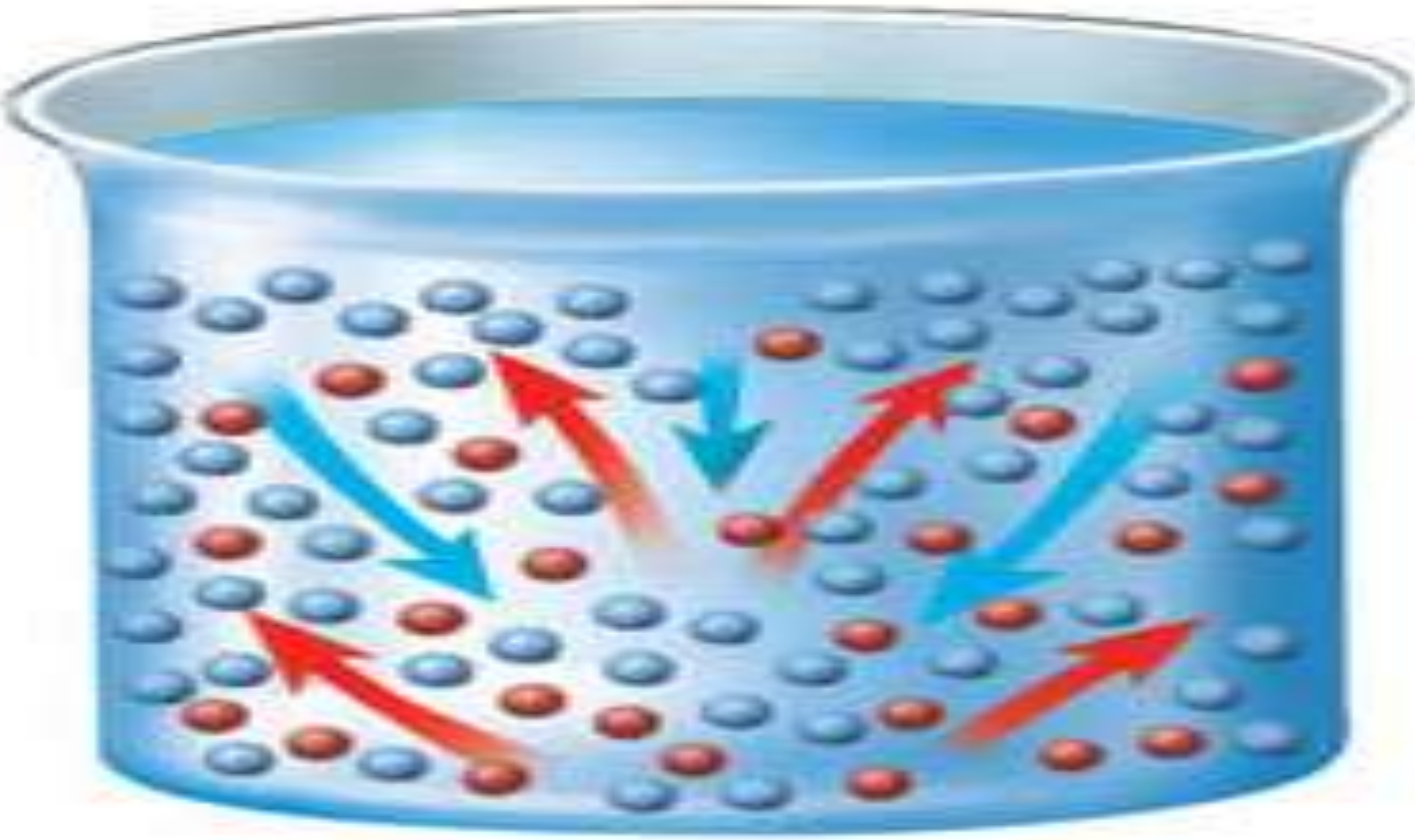
# Permeability of the Cell Membrane



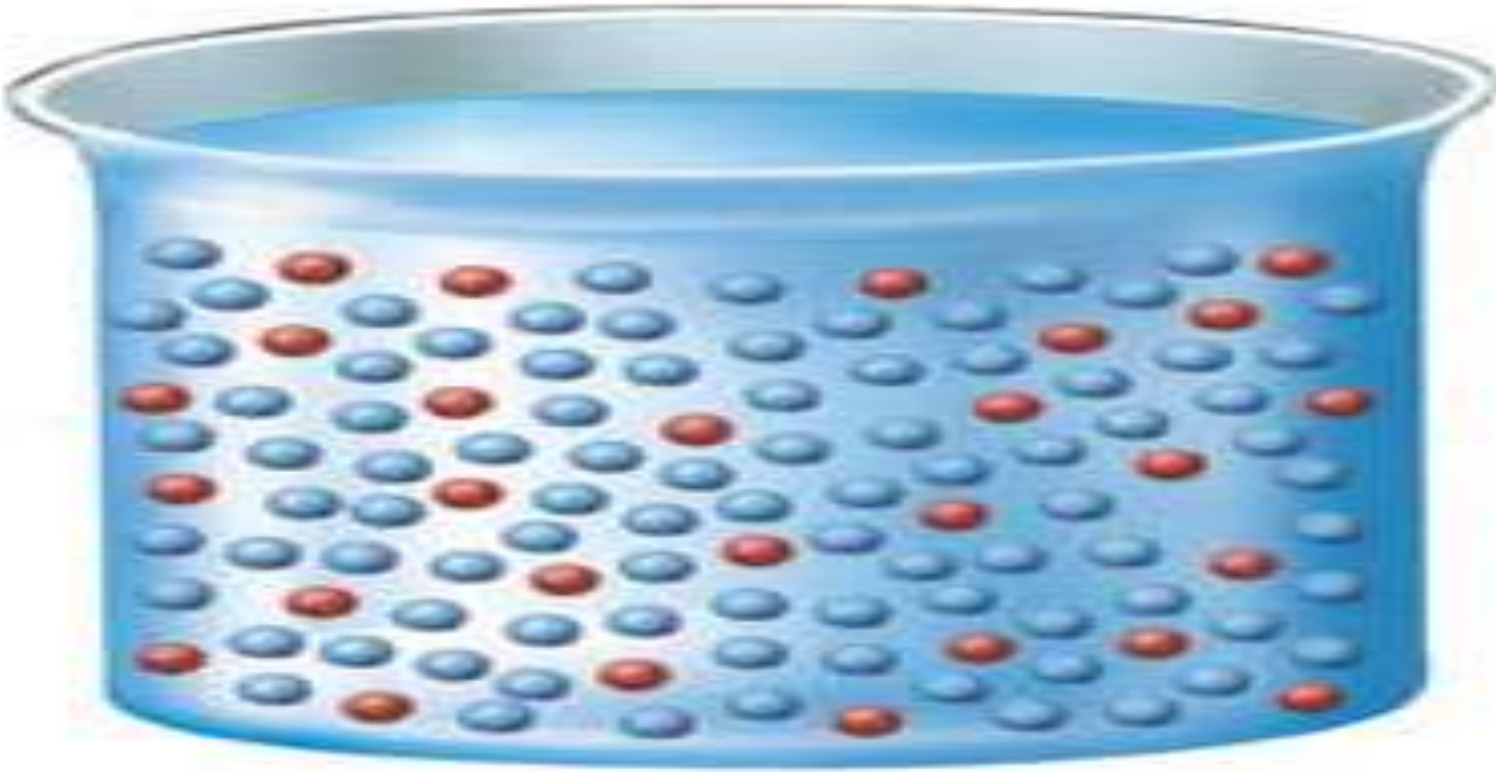
- **Diffusion**
  - the <u>passive</u> movement of molecules from a higher to a lower concentration until *equilibrium* is reached.
  - How can we explain diffusion?
  - Gases move through plasma membranes by diffusion.
- **Osmosis**– A special case of diffusion

# Process of diffusion





b. Diffusion of water and dye molecules



c. Equal distribution of molecules results

# Gas exchange in lungs by diffusion

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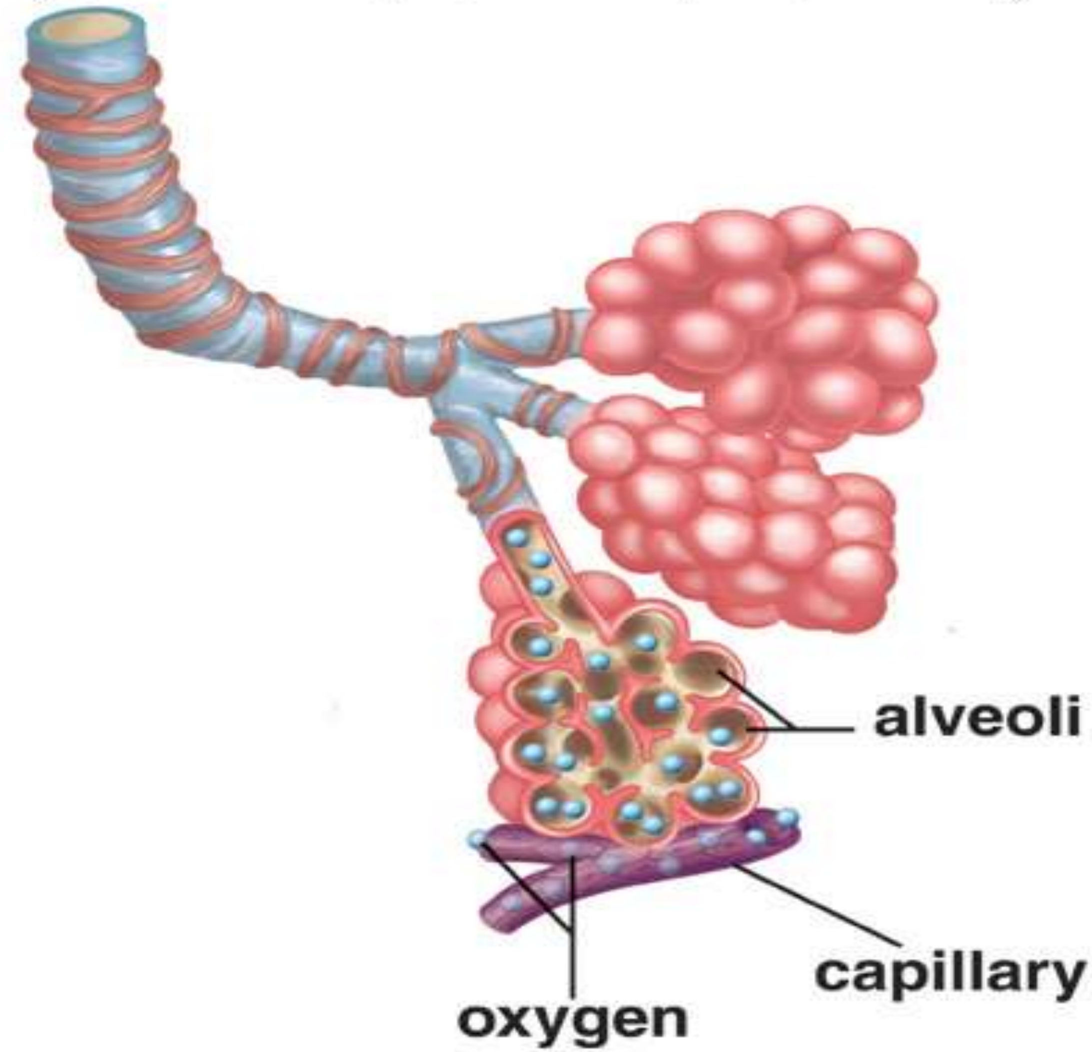


# Osmosis

The diffusion of water across a differentially permeable membrane due to concentration differences

# Question:
# What's in a Solution?

**Answer:**

- solute + solvent → solution
- NaCl + $H_20$ → saltwater

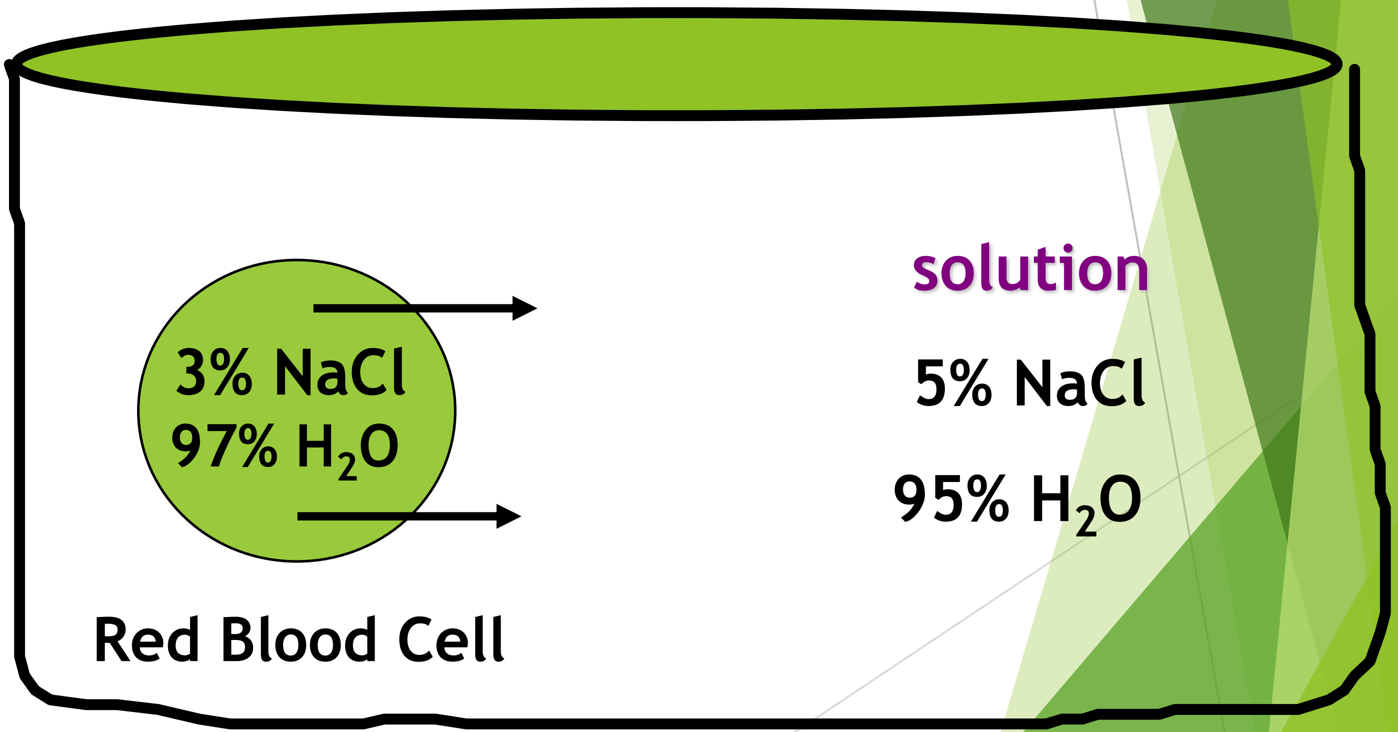
# TONICITY

- Refers to the concentration of <u>**SOLUTES**</u>
- Is a <u>**RELATIVE**</u> term, comparing two different solutions
- Hypertonic
- Hypotonic
- Isotonic

# Hypertonic

- A **solution** with a greater **solute concentration** compared to another **solution.**

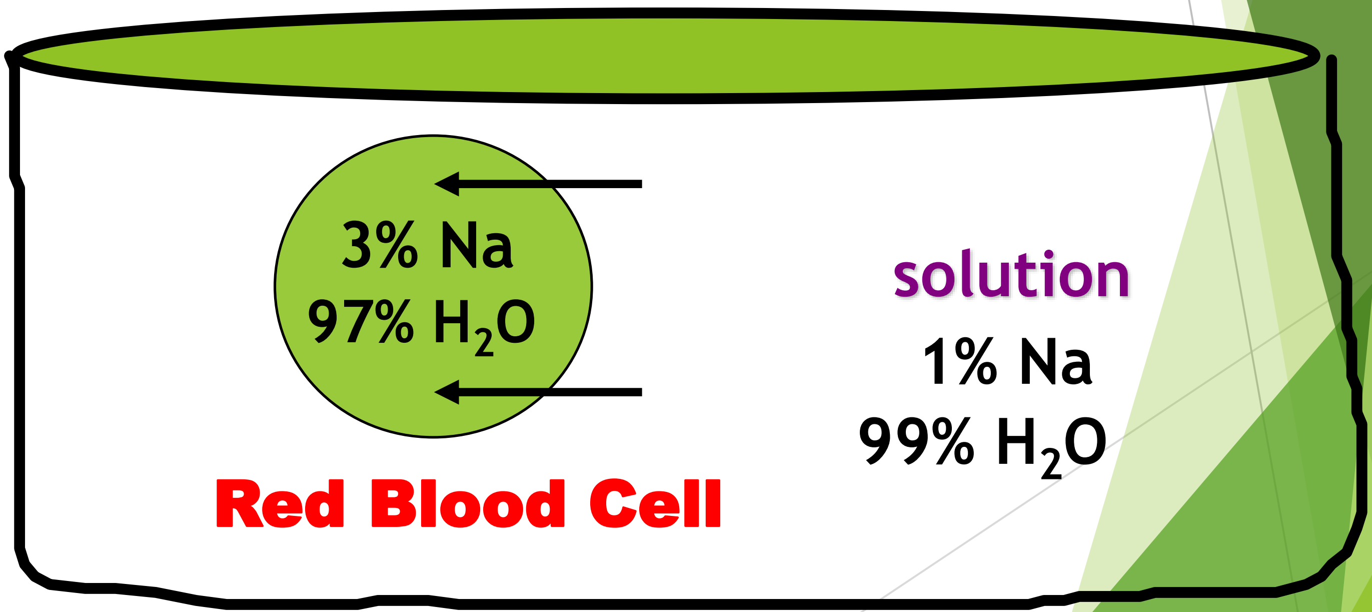
**Which way will the water move?**



# Hypotonic

- A **solution** with a **lower solute concentration** compared to another **solution**.

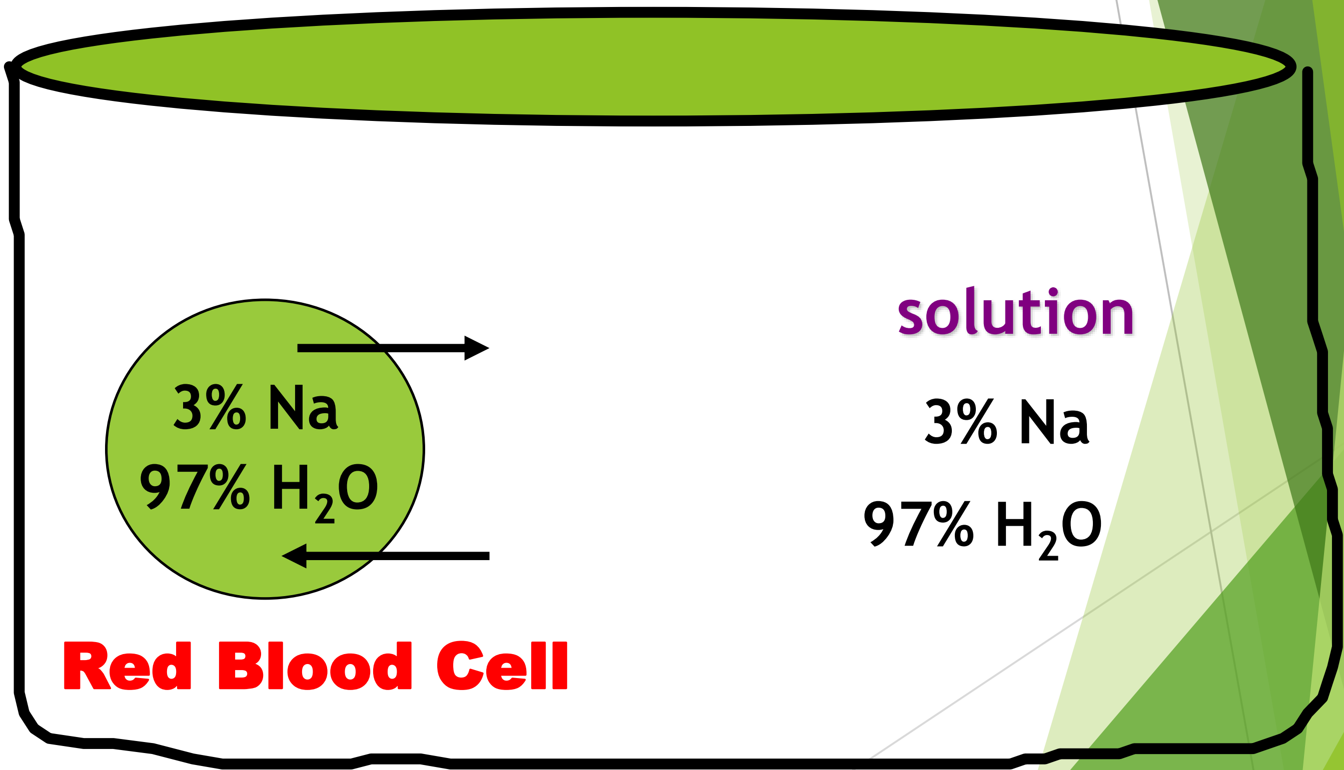
**Which way will the water move?**



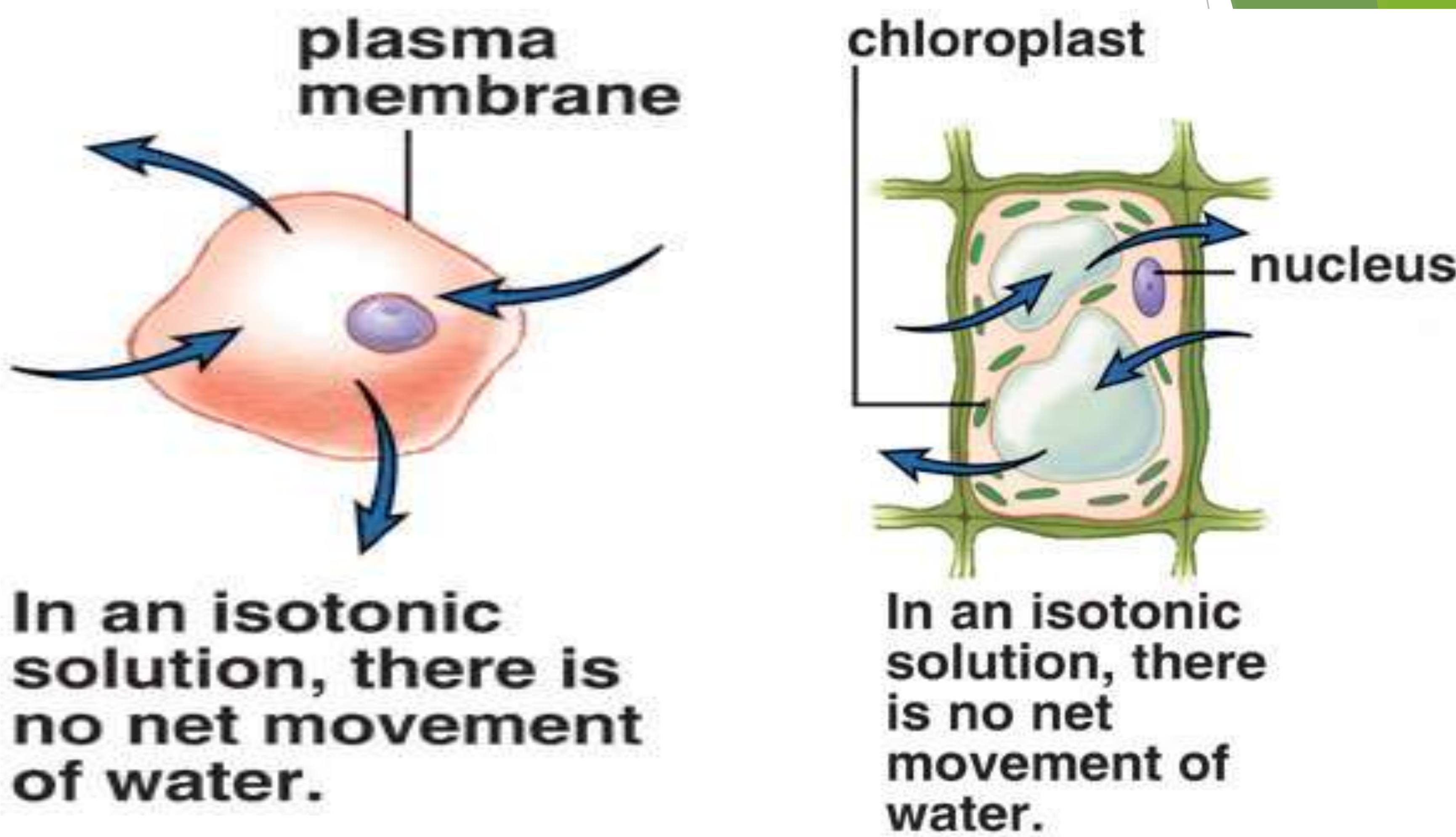
# Isotonic

- A **solution** with an **equal solute concentration** compared to another **solution.**

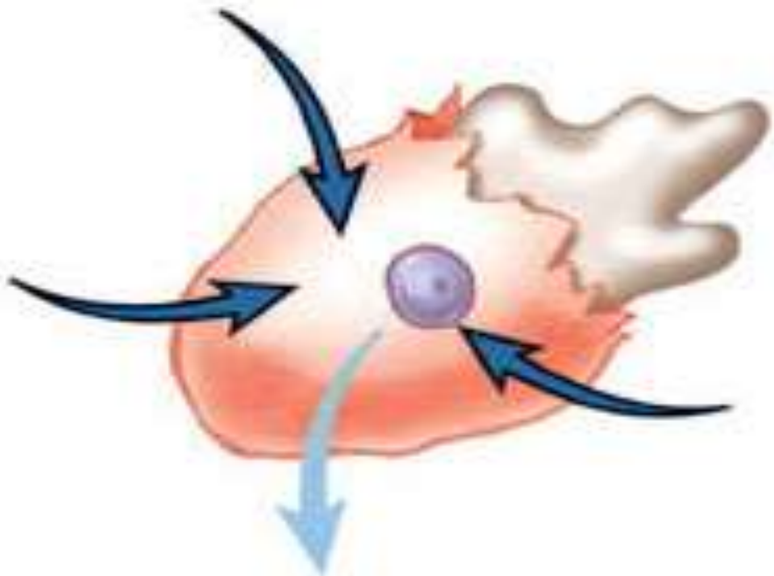
**Which way will the water move?**



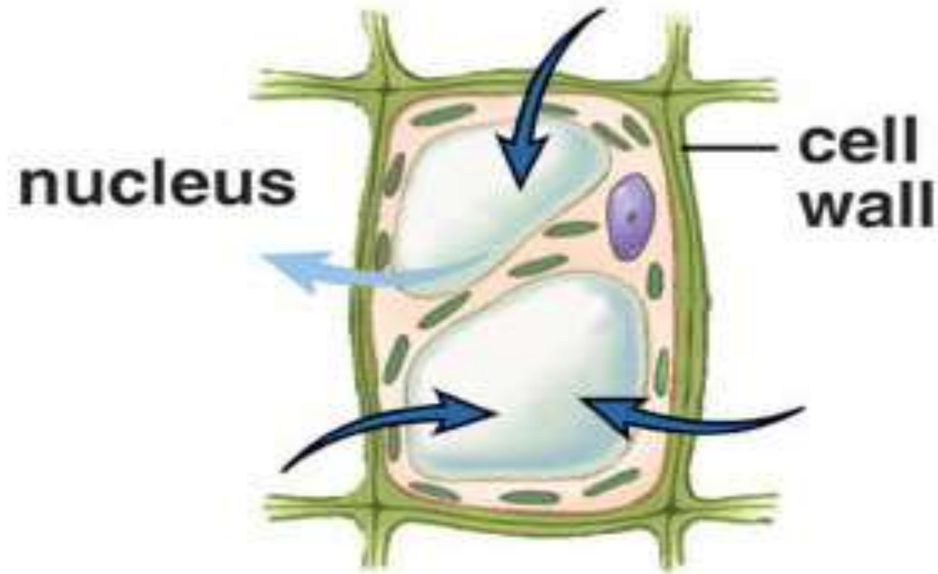
# ISOTONIC SOLUTION



# HYPOTONIC SOLUTION

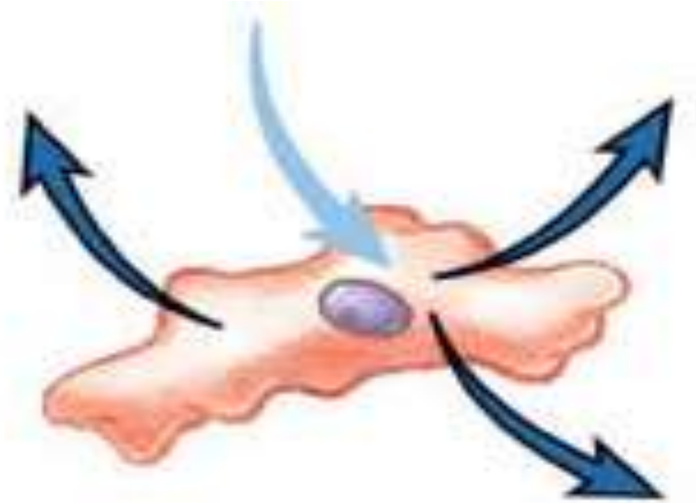


In a hypotonic solution, water enters the cell, which may burst (lysis).

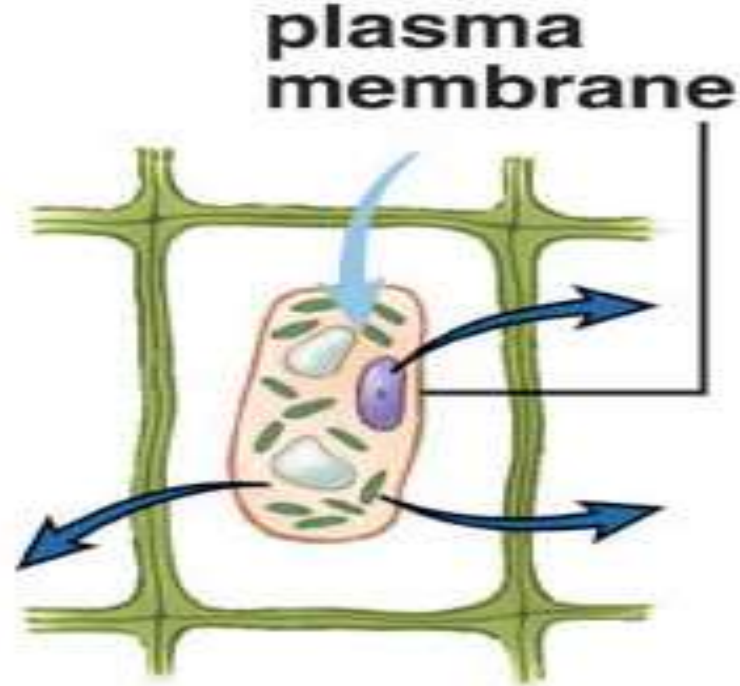



In a hypotonic solution, vacuoles fill with water, turgor pressure develops, and chloroplasts are seen next to the cell wall.

# HYPERTONIC SOLUTION



In a hypertonic solution, water leaves the cell, which shrivels (crenation).




In a hypertonic solution, vacuoles lose water, the cytoplasm shrinks (plasmolysis), and chloroplasts are seen in the center of the cell.

# Carrier Proteins

- **Function—Transport. Are specific, combine with only a certain type of molecule.**
- **Types**
  - **Facilitated transport--passive**
  - **Active transport—requires energy**

# Facilitated Transport

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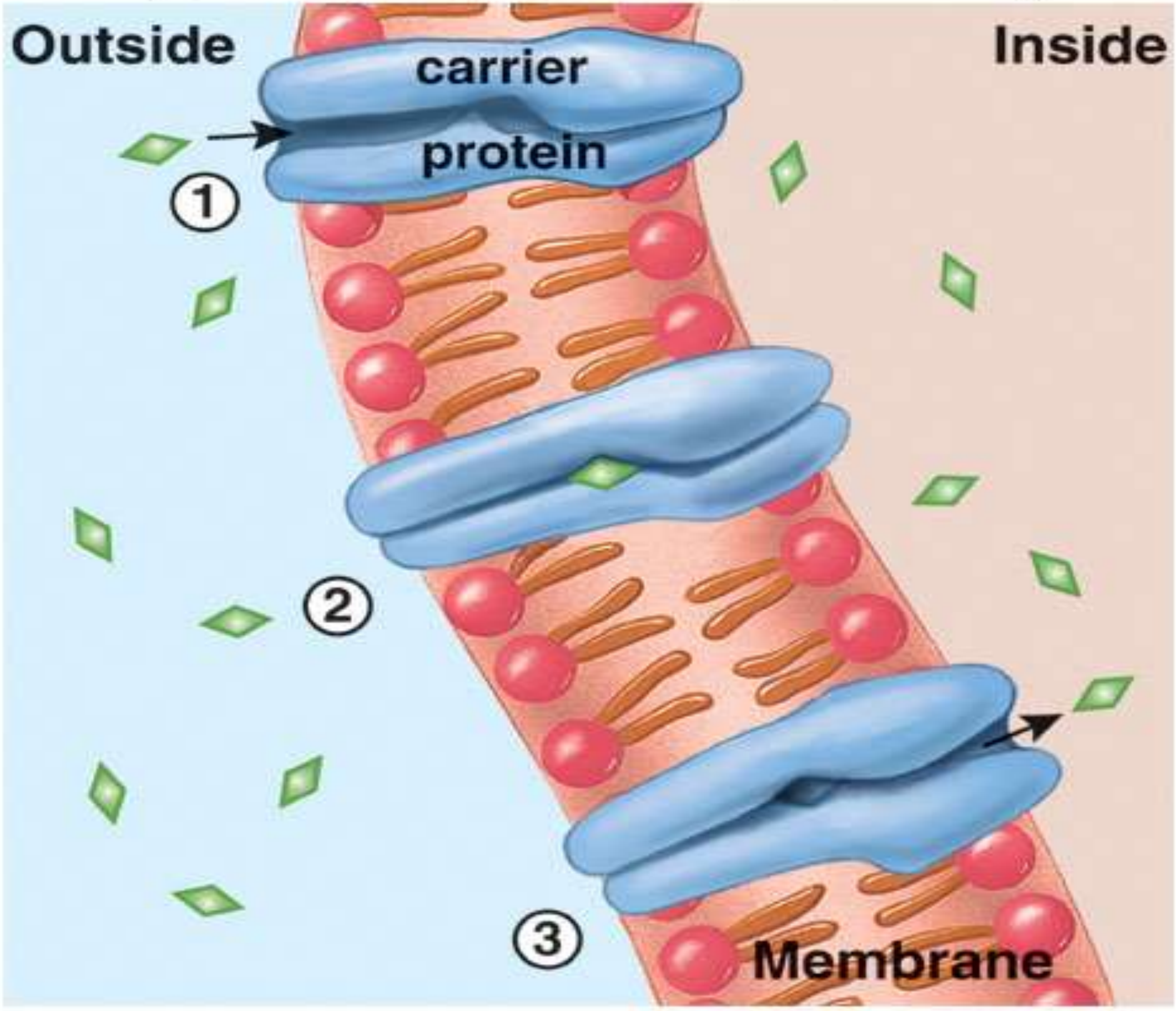

# Active Transport

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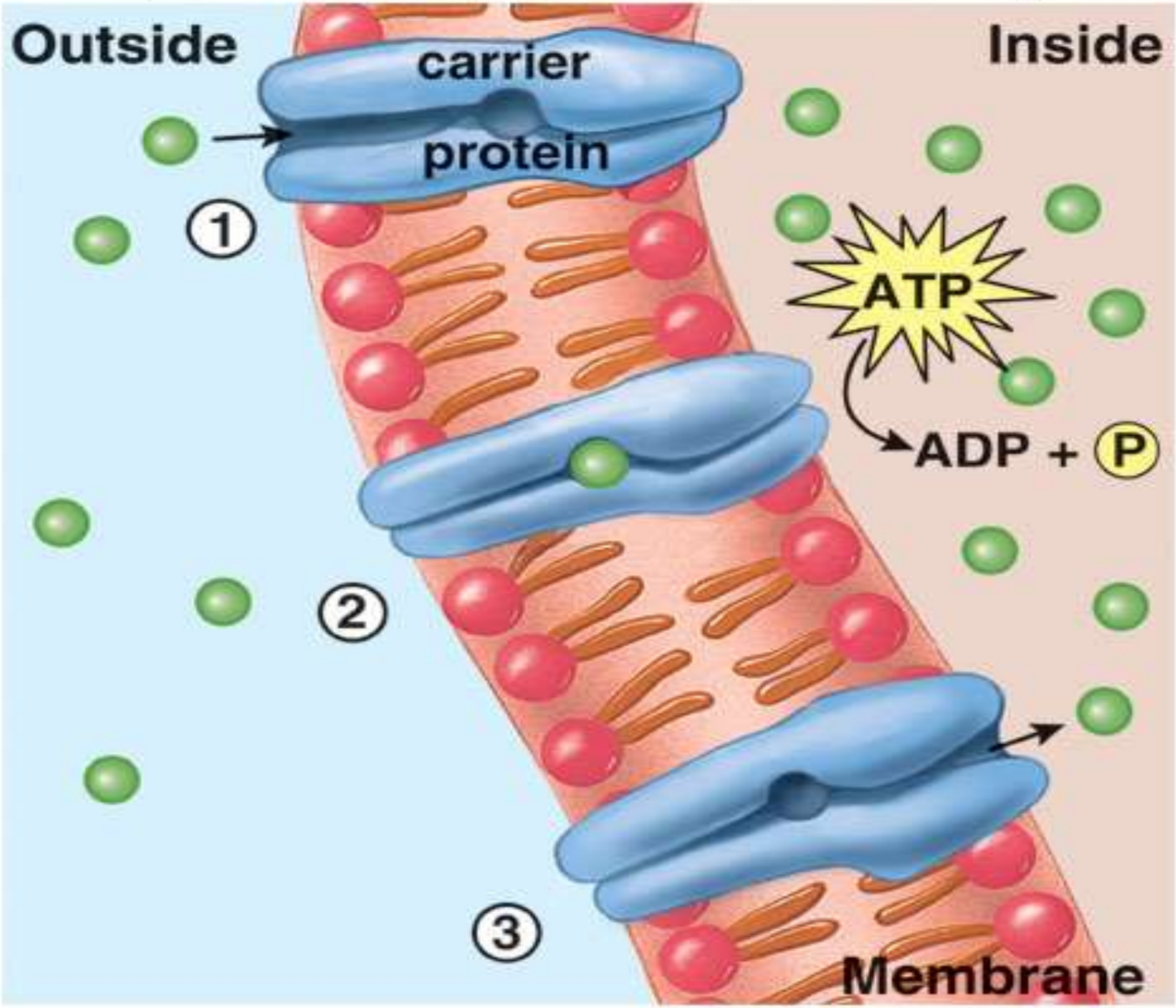
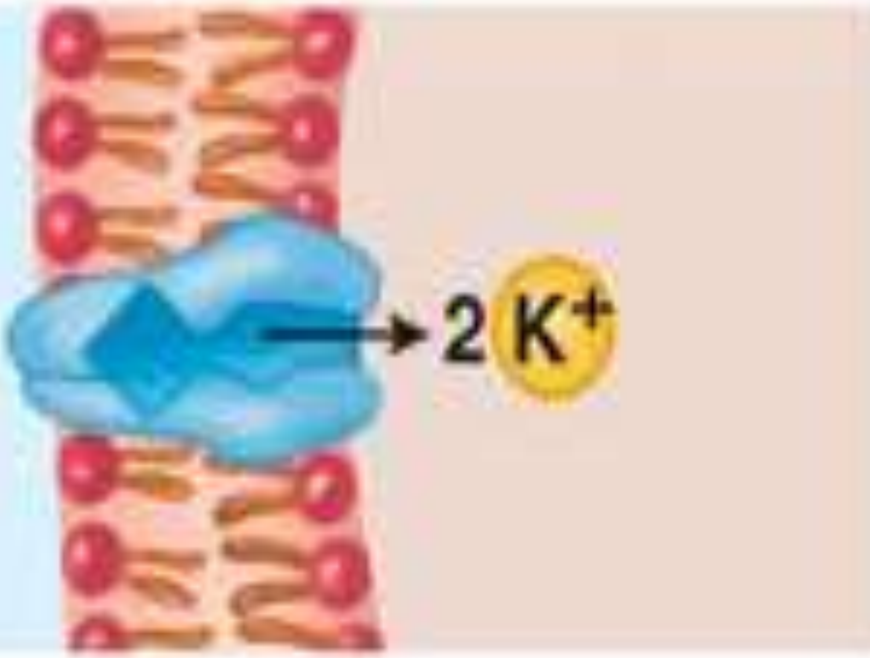


# The sodium-potassium pump

Change in shape results that causes carrier to release potassium ions ($K^+$) inside the cell. New shape is suitable to take up three sodium ions ($Na^+$) once again.



# Exocytosis and Endocytosis

- **Exocytosis---Cellular secretion**
- **Endocytosis—**
  - **Phagocytosis— "Cell eating"**
  - **Pinocytosis– "Cell drinking"**
  - **Receptor-mediated endocytosis-specific particles, recognition.**

# Exocytosis

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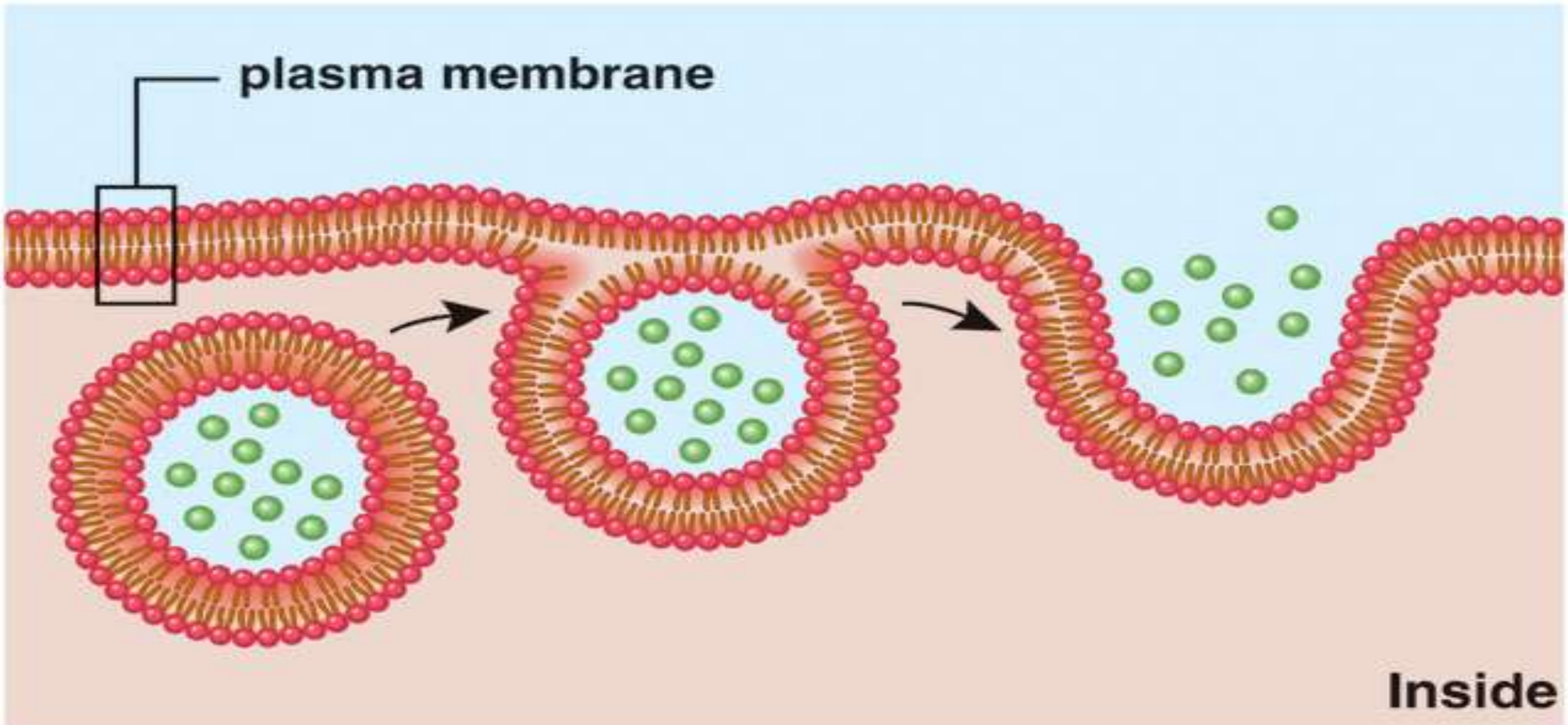

# Phagocytosis

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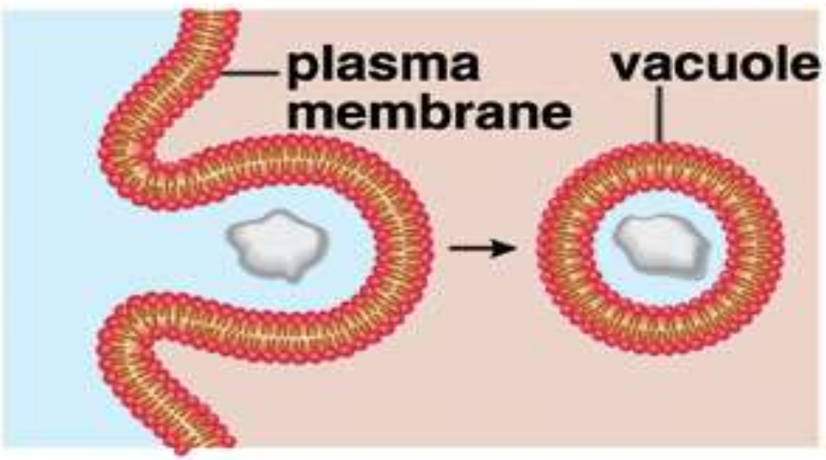


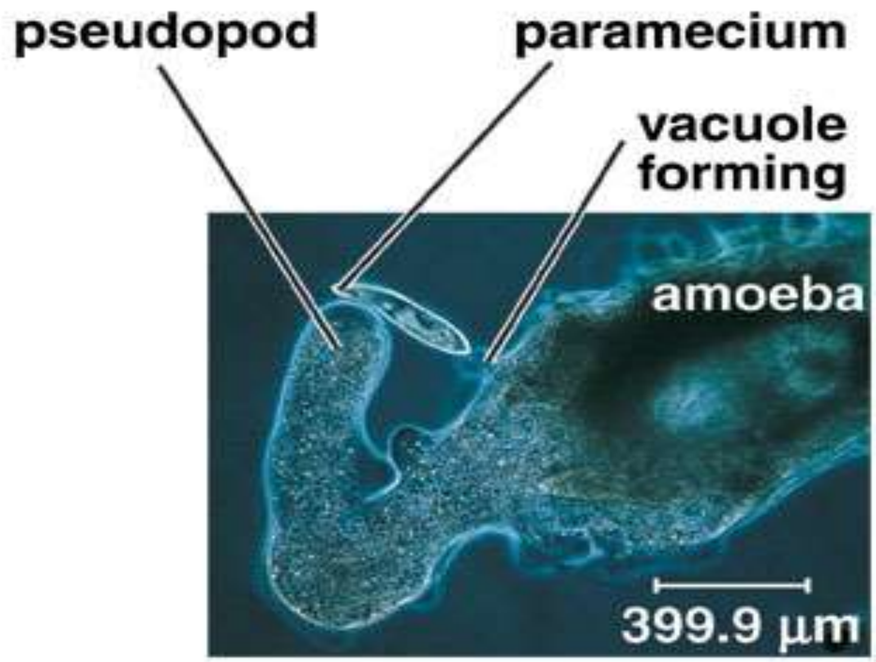


a. Phagocytosis

Phagocytosis 1

Phagocytosis 2

# Pinocytosis

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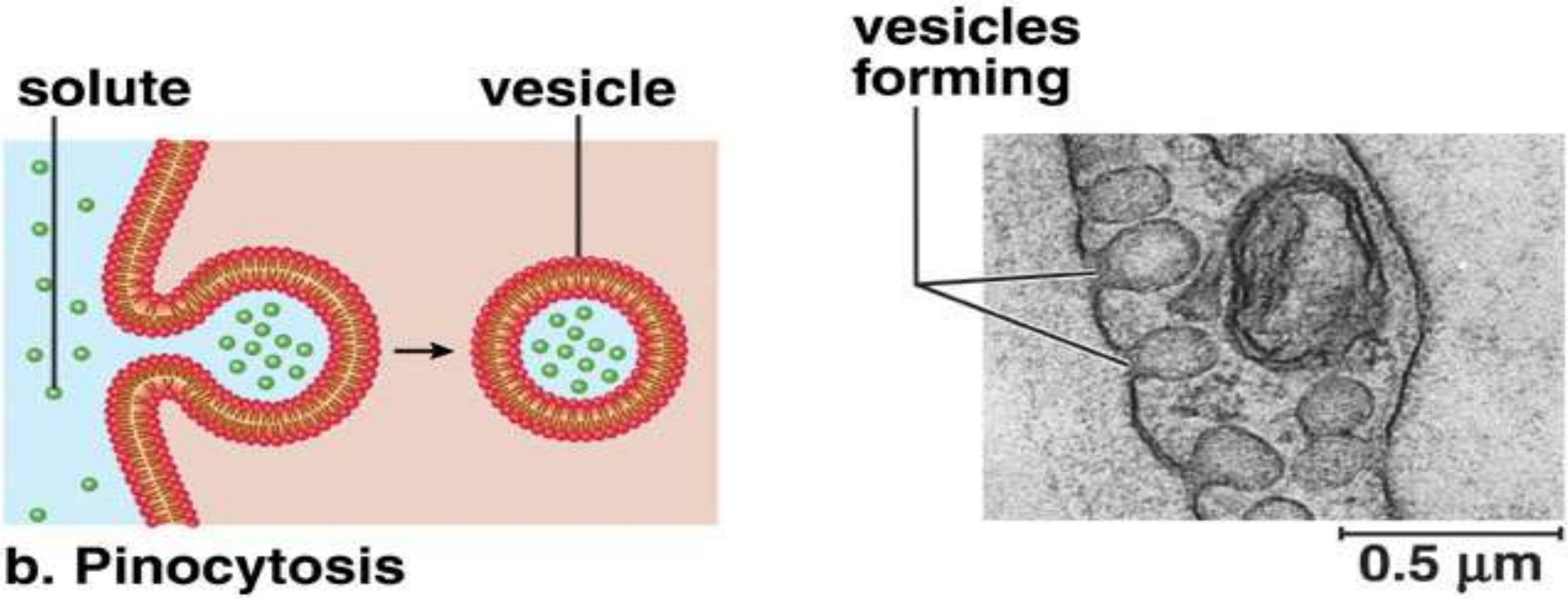

# Receptor-mediated Endocytosis

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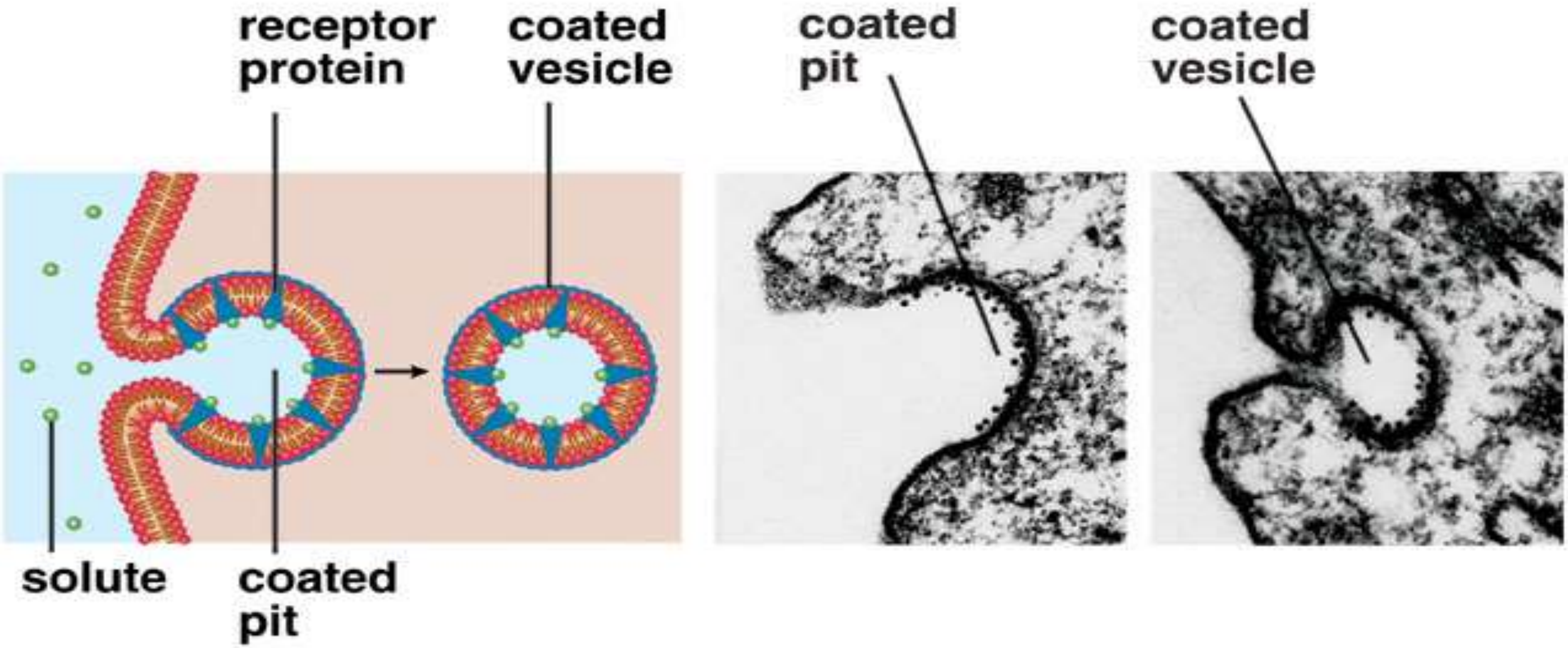


c. Receptor-mediated endocytosis

# SUMMARY

- Phospholipid Bilayer
- Fluid Mosaic Model
- Membrane Proteins
- Diffusion
- Facilitated Diffusion
- Osmosis
- Bulk Transport
- Active Transport

**Thanks...**

**F Y B Sc Zoology Paper II**

**Course Title: Cell Biology**

**Course Code: ZO – 122**

**Semester - II (2 credits – 30 Hours)**

# Chapter No. 4

# Nucleus

## 4.1 Introduction 4.2 Structure

**By**

**Dr. Bhausaheb R Ghorpade**

*bhaughorpade@shrianandcollege.com*

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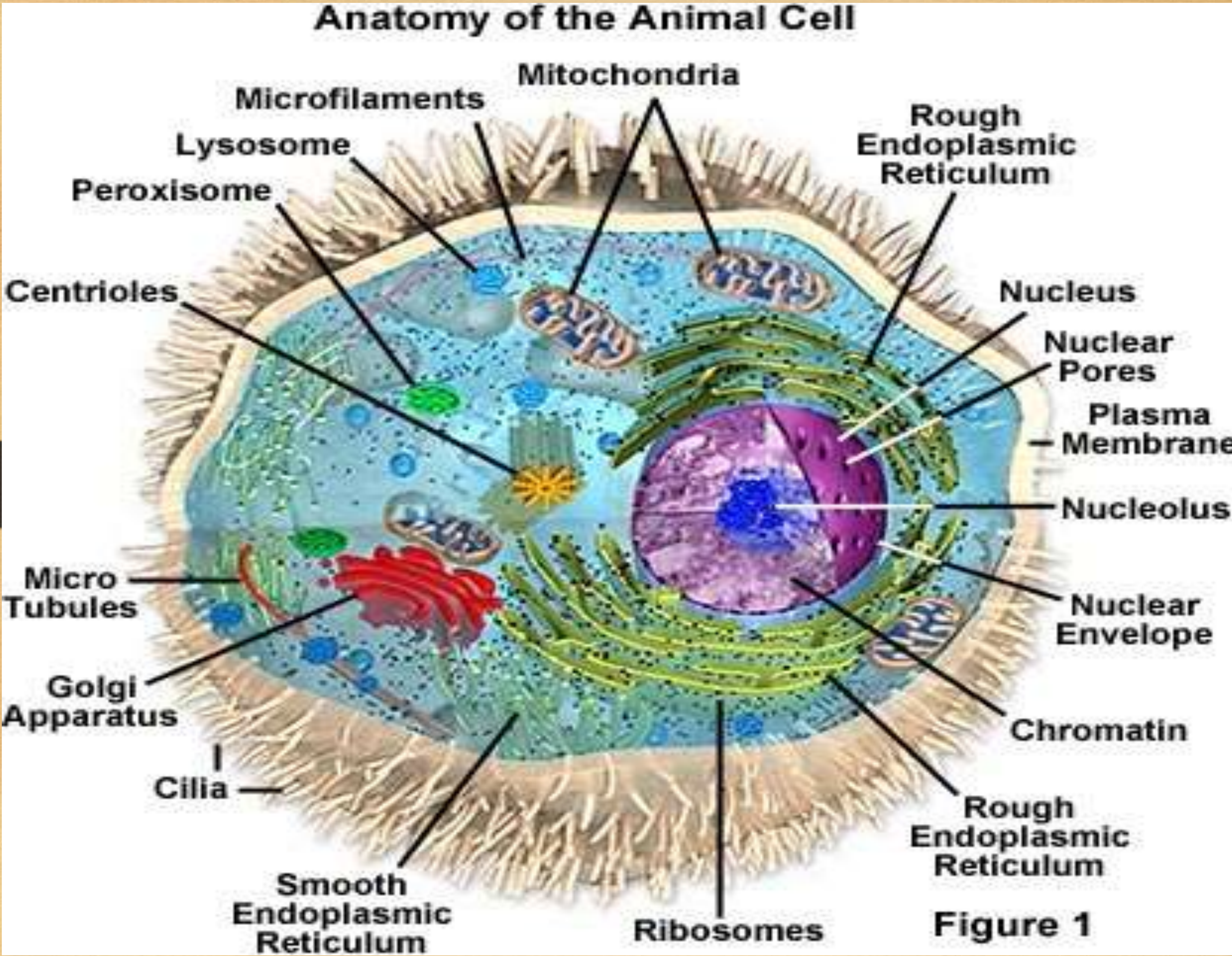
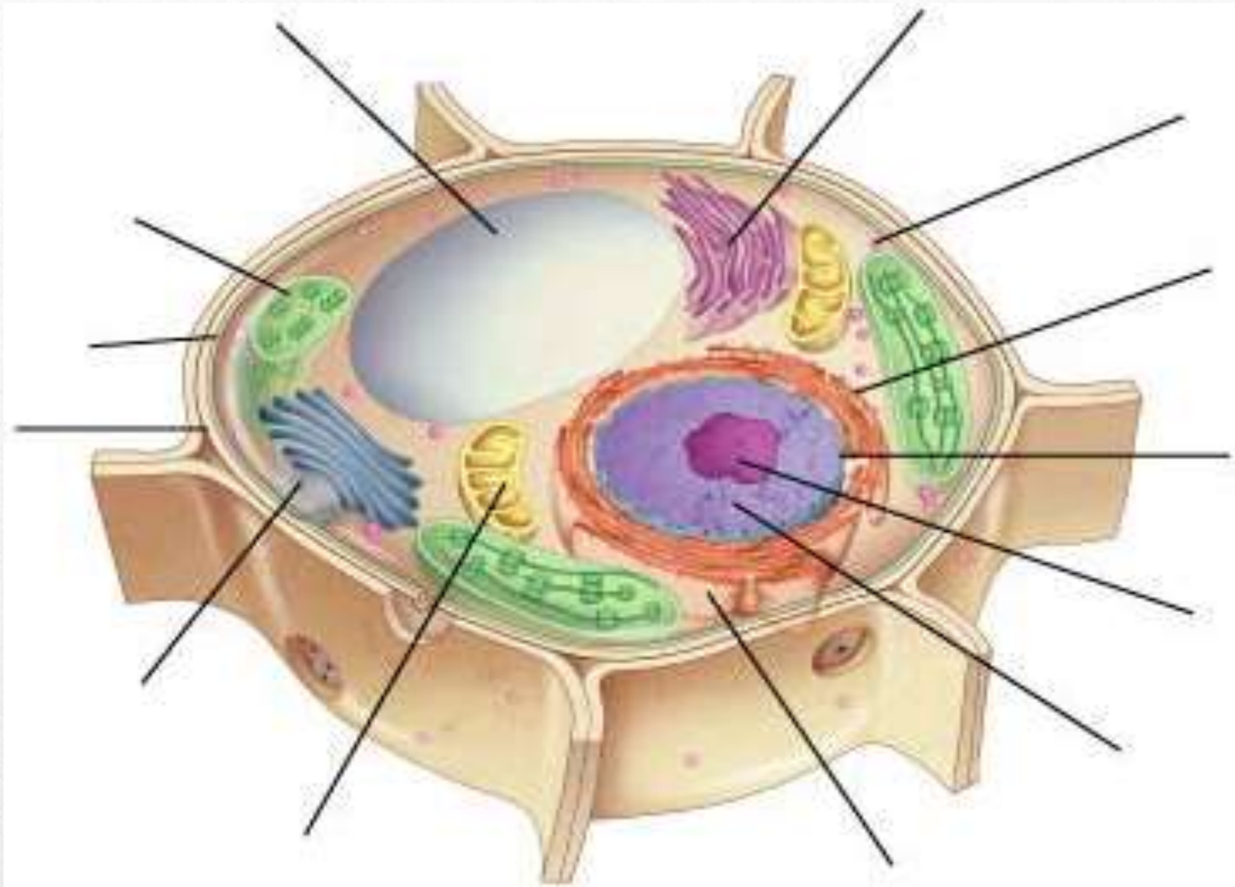

Anatomy of the Animal Cell
Mitochondria
Microfilaments
Lysosome
Peroxisome
Rough Endoplasmic Reticulum
Centrioles
Nucleus
Nuclear Pores
Plasma Membrane
Nucleolus
Micro Tubules
Nuclear Envelope
Golgi Apparatus
Chromatin
Cilia
Rough Endoplasmic Reticulum
Smooth Endoplasmic Reticulum
Ribosomes
Figure 1


Vacuole
Smooth endoplasmic reticulum
Ribosome (free)
Chloroplast
Ribosome (attached)
Cell Membrane
Nuclear envelope
Cell wall
Nucleolus
Nucleus
Golgi apparatus
Mitochondrion
Rough endoplasmic reticulum

# Plant Cell

# The Nucleus- Introduction

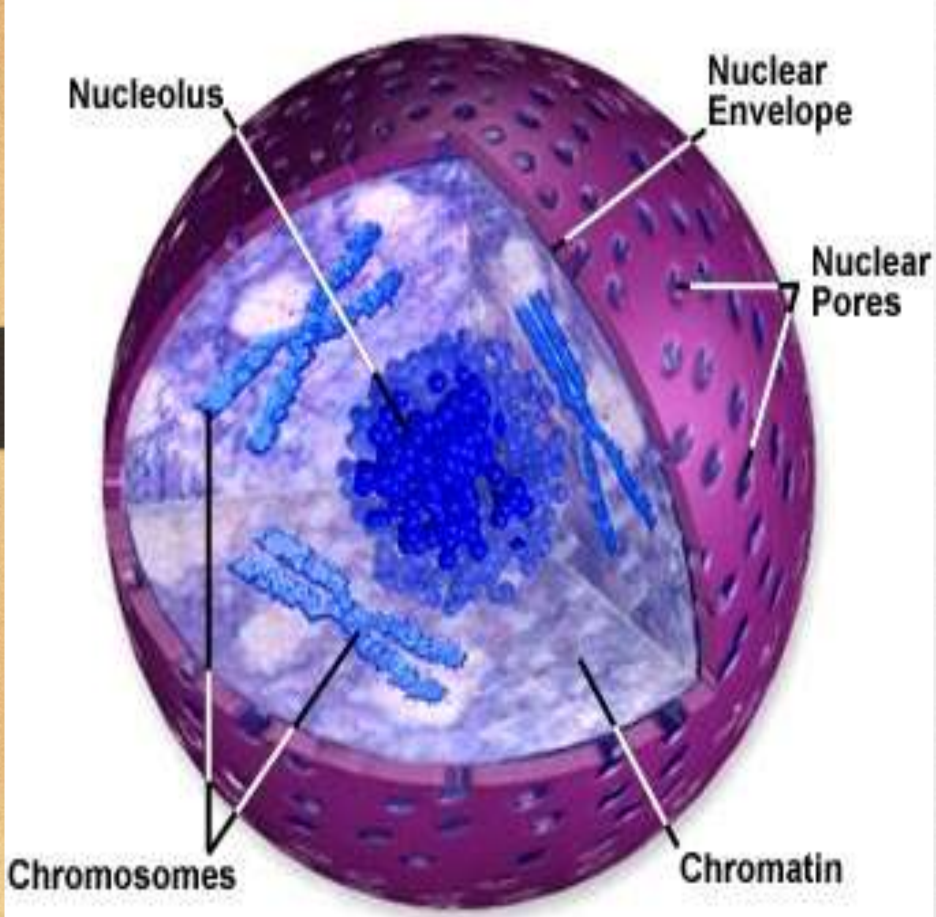


Figure 1

- Brain of Cell
- Bordered by a porous membrane - nuclear envelope.
- Contains thin fibers of DNA and protein called Chromatin.
- Rod Shaped Chromosomes
- Contains a small round nucleolus
  - produces ribosomal RNA which makes ribosomes.

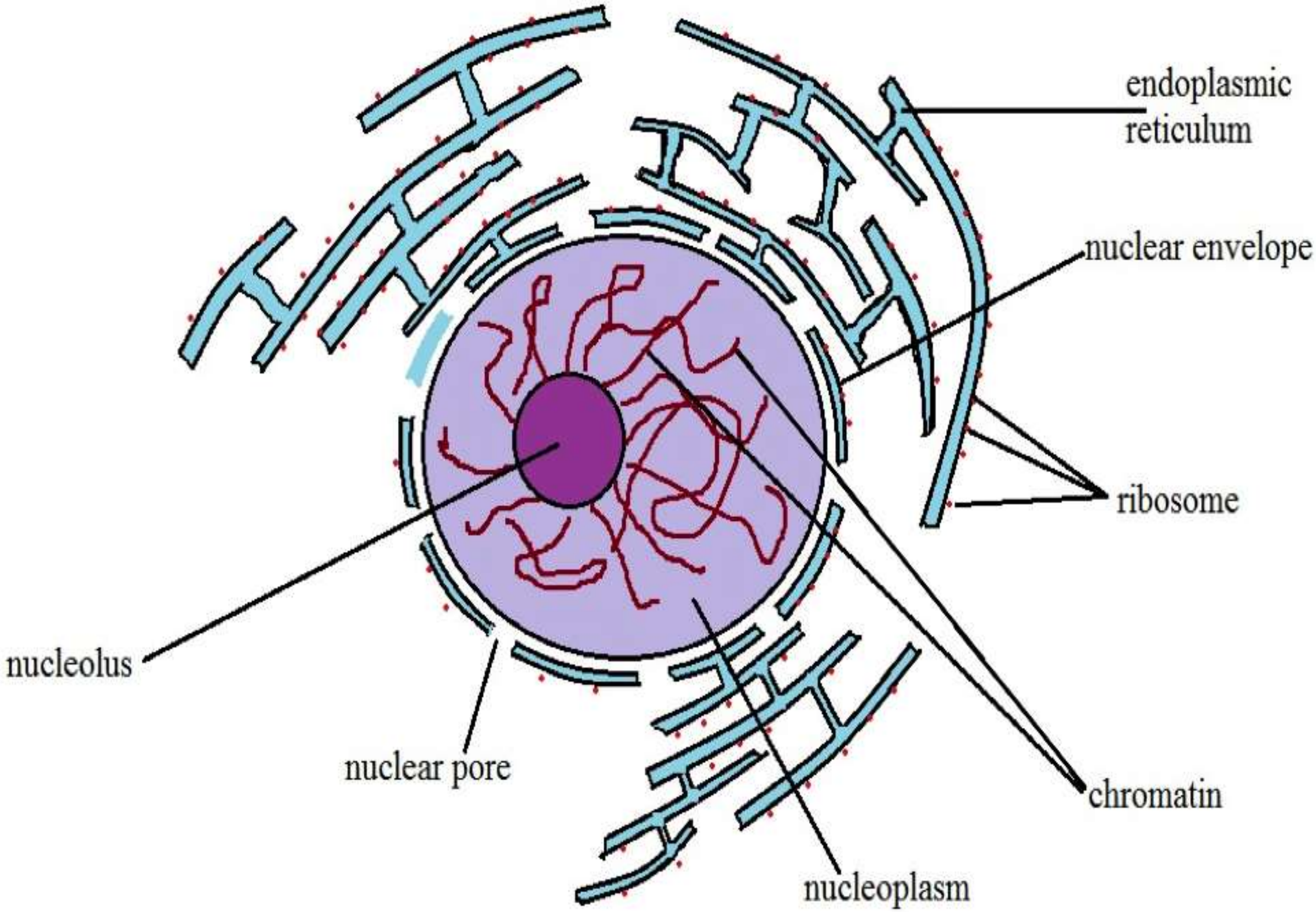
- A cell normally contains only one nucleus.
- Under some conditions, however, the nucleus divides but the cytoplasm does not.
- This produces a multinucleate cell (syncytium) such as occurs in skeletal muscle fibres. Some cells—e.g., the human red blood cell—lose their nuclei upon maturation.

- A nucleus is defined as a double-membraned eukaryotic cell organelle that contains the genetic material.

# Structure Of Nucleus

- Typically, it is the most evident organelle in the cell.
- The nucleus is completely bound by membranes.
- It is engirdled by a structure referred to as the nuclear envelope.
- Nucleus, in biology, a specialized structure occurring in most cells (except bacteria and blue-green algae) and separated from the rest of the cell by a double layer, the nuclear membrane.
- This membrane seems to be continuous with the endoplasmic reticulum (a membranous network) of the cell and has pores, which probably permit the entrance of large molecules.

- The nucleus controls and regulates the activities of the cell (e.g., growth and metabolism) and carries the genes, structures that contain the hereditary information.
- Nucleoli are small bodies often seen within the nucleus.
- The gel-like matrix in which the nuclear components are suspended is the nucleoplasm.
- Because the nucleus houses an organism's genetic code, which determines the amino acid sequence of proteins critical for day-to-day function, it primarily serves as the information centre of the cell.


endoplasmic reticulum
nuclear envelope
ribosome
nucleolus
nuclear pore
chromatin
nucleoplasm

## Nuclear envelope

- The nucleus is completely surrounded by double-layered nuclear envelope.
- The outer layer of the membrane is connected to the endoplasmic reticulum.
- It consists of both an inner and outer membrane,run parallel to each other.
- Like the cell membrane, the nuclear envelope consists of phospholipids that form a lipid bilayer.
- The envelope is perforated by small gaps known as the nuclear pores, having iameter around 100nm .
- The small pore size controls the passage of molecules into and out of the nucleus.

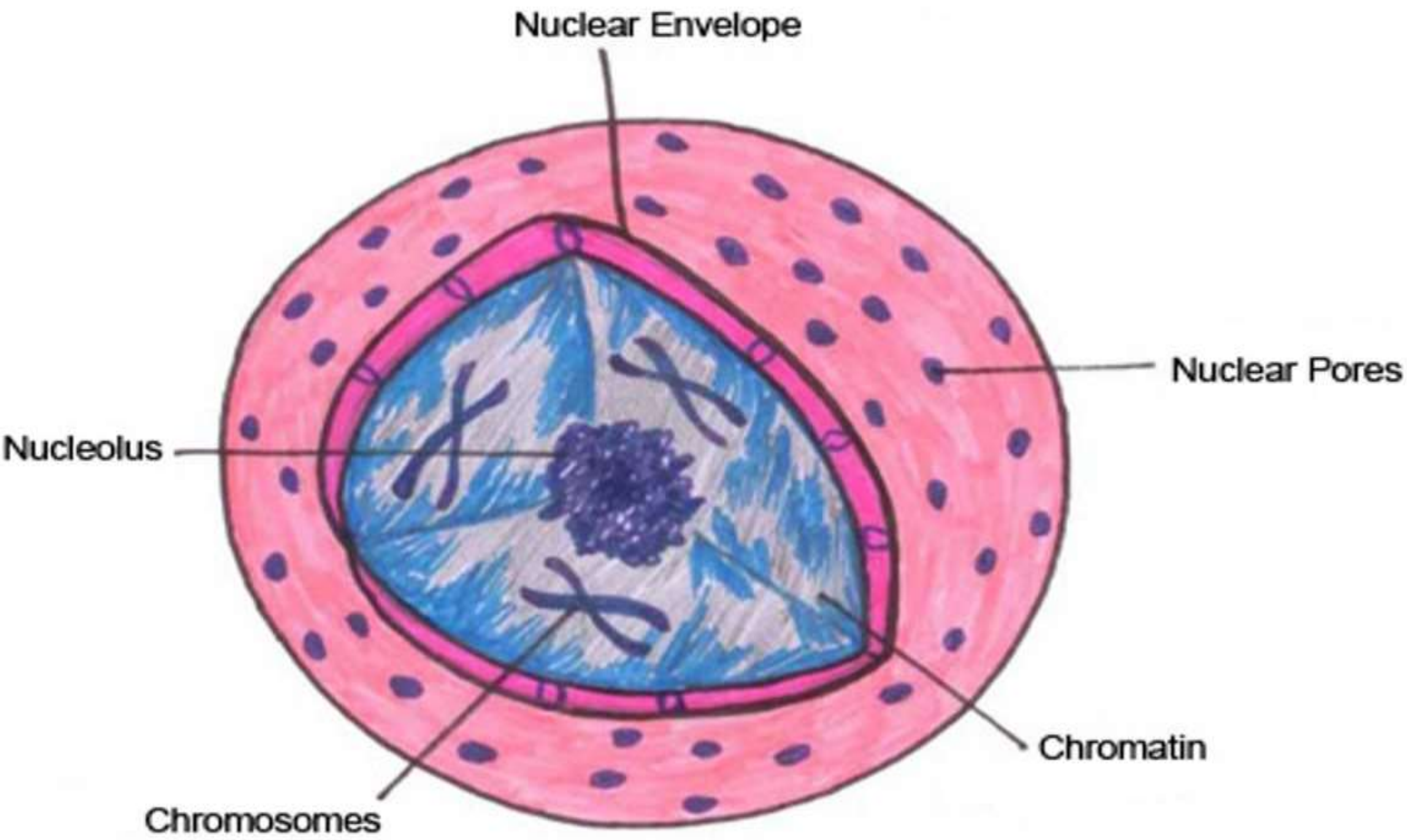
- **Larger molecules such as larger proteins and nucleic acid are unable to pass through these pores, i.e. nuclear envelope is to selectively separate the contents of the nucleus from that of the cytoplasm.**

- **The nuclear membrane is one of the aspects that distinguish eukaryotic cells from prokaryotic cells.**

**Nucleoplasm**

- **Nucleoplasm is the gelatinous substance within the nuclear envelope.**

.




Cell Nucleus Diagram

*Sketch by Saptakee Sengupta*

- **Nucleoplasm is semi-aqueous material is similar to the cytoplasm and also called karyoplasm.**
- **It is mainly composed of water with dissolved salts, enzymes, and organic molecules suspended within.**
- **The nucleolus and chromosomes are surrounded by nucleoplasm, which functions to cushion and protect the contents of the nucleus.**
- **Nucleoplasm also supports the nucleus by helping to maintain its shape.**
- **The nucleoplasm provides a medium for transport of enzymes and nucleotides (DNA and RNA subunits), throughout the nucleus.**

# Nucleolus

- The nucleolus is the most prominent structure of the nucleus but lacks its own membrane.
- The nucleolus is a dense, membrane-less structure composed of RNA and proteins.
- Some of the eukaryotic organisms have a nucleus that contains up to four nucleoli.
- The nucleolus contains nucleolar organizers, which are parts of chromosomes with the genes for ribosome synthesis by transcribing and assembling ribosomal RNA subunits.
- These subunits join together to form a ribosome during protein synthesis.
- The nucleolus disappears when a cell undergoes division and is reformed after the completion of cell division.

- During cell division (mitosis), the nucleolus breaks up only to reform from specific sections of the chromosomes after mitosis.
- Although the nucleolus is the most prominent (and thus visible) structures of the nucleus, its size is largely dependent on the level of ribosome production as well as the different types of molecular processes that occur in the nucleus.
- The nucleolus is the site of transcription and processing of the ribosomal gene.
- In some organisms, the nucleus contains as many as four nucleoli.

## Chromatin

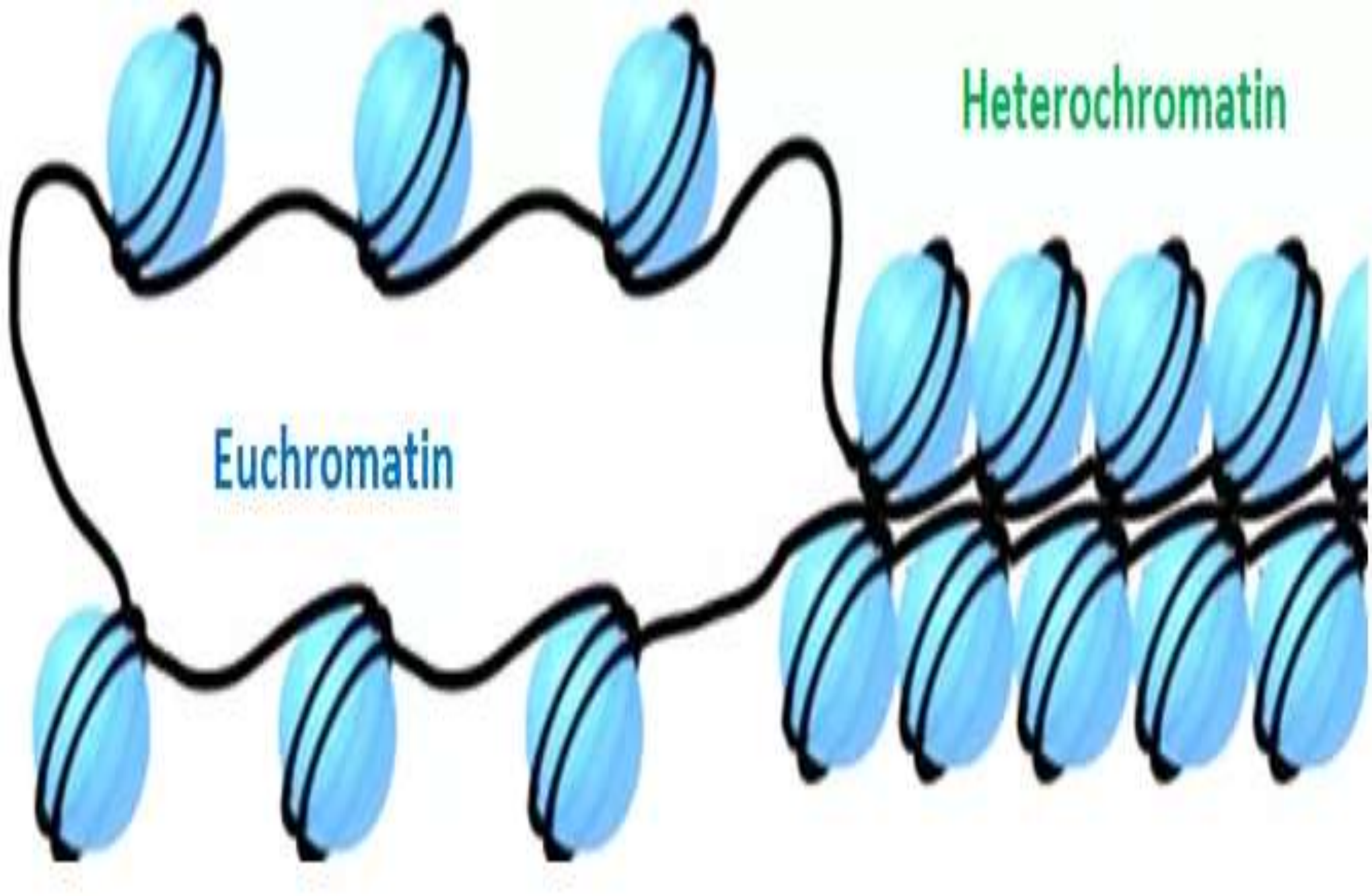
- Chromatin is a complex of DNA and proteins that forms chromosomes within the nucleus of eukaryotic cells.
- Nuclear DNA does not appear in free linear strands; it is highly condensed and wrapped around nuclear proteins in order to fit inside the nucleus.
- Chromatin exists in two forms.
- One form, called euchromatin, is less condensed and can be transcribed.
- The second form, called heterochromatin, is highly condensed and is typically not transcribed.

- **In eukaryotic cells, chromatin contains DNA, RNA, basic proteins called histones, and nonhistone (more acidic) proteins.**
- **The content of RNA and nonhistone protein is variable between different chromatin preparations, but histone and DNA are always present in a fixed ratio of about one to one by weight.**
- **Histones are only of five types, each one present in large amounts.**
- **Histones are small proteins which are basic because they have a high content (10 to 20 per cent) of the basic amino acids arginine and lysine.**
- **Being basic, histones bind tightly to DNA, which is an acid.**
- **The four main histones, H2A, H2B, H3 and H4 are very similar in different species.**

## Euchromatin

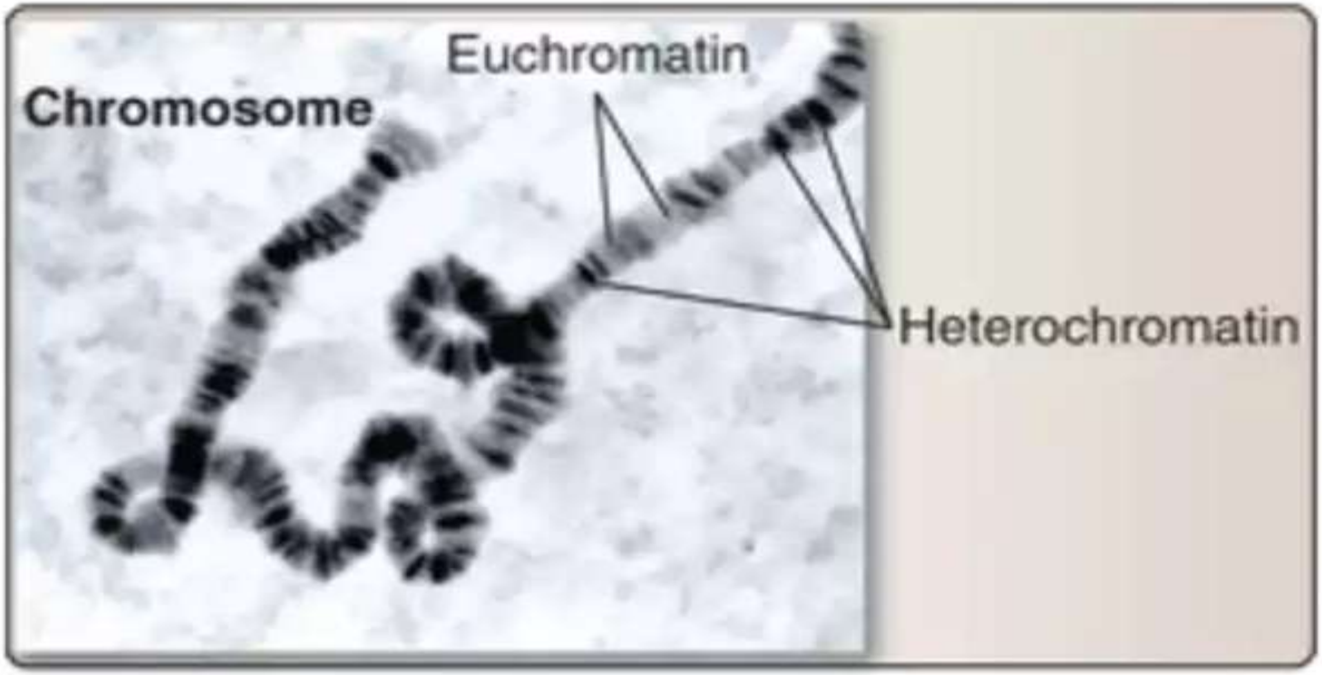
- Euchromatin is present towards the center of the nucleus and accounts for about 90% of the genome in an organism.
- It is a more lightly packed DNA that is characterized by less intense staining and DNA sequences that are transcriptionally active or might become transcriptionally-active at some point during growth.
- Under an optical microscope, it appears as light-colored bands after staining.
- The structure of euchromatin can be represented as an unfolded set of beads in a string where the beads are the nucleosomes.

- **In euchromatin, the wrapping around by histone proteins is loose, and thus the individual DNA sequences might be accessible.**
- **The conformation of euchromatin is said to be controlled by a methylated part in the chromosome called histone tail.**
- **Euchromatin is the only confirmation of chromosomes in the case of the prokaryotic genome, which suggests that this form evolved earlier than heterochromatin.**
- **Unlike heterochromatin, euchromatin doesn’t exist in two forms.**
- **It only exists as constitutive euchromatin.**



Heterochromatin
Euchromatin

unacademy



## Heterochromatin

- It is a tightly packed or condensed DNA that is characterized by intense stains when stained with nuclear stains, containing transcriptionally inactive sequences.
- It exists in multiple variations, up to four to five state, each of which is marked with combinations of epigenetic markers.
- The staining of heterochromatin might result in heteropycnosis; heteropycnosis is the differential staining of parts of chromosomes.

- **This chromosome is different from euchromatin in that the genes in these chromosomes are usually inactivated and are not expressed.**
- **Heterochromatin is present in the nucleus towards the periphery. It is also not present in prokaryotic cells, indicating this form appeared later during evolution.**
- **However, the two most common heterochromatin include; constitutive heterochromatin and facultative heterochromatin.**

- Constitutive heterochromatin usually packages the same sequences of DNA in all cells of the same species. It is usually repetitive and is present in structural forms like telomeres and centromeres.
- In humans, genes 1, 9, 16, and the Y chromosomes in men contain larger quantities of this heterochromatin.
- Facultative heterochromatin packages genes that are usually silenced through various mechanisms; however, unlike constitutive heterochromatin, facultative chromatin packages different genes in different organisms within the same species.
- The facultative chromosome is not repetitive but has the same structural components as the constitutive heterochromatin.

- The formation of facultative heterochromatin is regulated by the process of morphogenesis or differentiation.
- In humans, one of the two X chromosomes in women is inactivated as facultative heterochromatin while the other is expressed as euchromatin.
- Heterochromatin has multiple functions. Some of which include gene regulation and chromosomes integrity.
- The tightly packaged DNA in heterochromatin prevents the chromosomes from various protein factors that might lead to the binding of DNA or the inaccurate destruction of chromosomes by endonucleases.

## Function of Nucleus

- Protein synthesis, cell division, and differentiation
- Control the synthesis of enzymes involved in cellular metabolism
- Controlling hereditary traits of the organism
- Store DNA strands, proteins, and RNA
- Site of RNA transcription - e.g. mRNA required for protein synthesis

- Storage of proteins and RNA (ribonucleic acid) in the nucleolus.
- The nucleus is a site for transcription in which messenger RNA (mRNA) are produced for protein synthesis.
- During the cell division, chromatins are arranged into chromosomes in the nucleus.
- Production of ribosomes (protein factories) in the nucleolus.
- Selective transportation of regulatory factors and energy molecules through nuclear pores.

- **The nucleus provides a site for genetic transcription that is segregated from the location of translation in the cytoplasm, allowing levels of gene regulation that are not available to prokaryotes.**
- **The main function of the cell nucleus is to control gene expression and mediate the replication of DNA during the cell cycle.**

- It controls the hereditary characteristics of an organism.
- The organelle is also responsible for protein synthesis, cell division, growth, and differentiation.
- Storage of hereditary material, the genes in the form of long and thin DNA (deoxyribonucleic acid) strands, referred to as chromatin.

***Thanks...***

**F Y B Sc Zoology Paper II**

**Course Title: Cell Biology**

**Course Code: ZO – 122**

**Semester - II (2 credits – 30 Hours)**

# 5 Endomembrane system

# 6 Mitochondria & Perioxisomes


**By**

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**Note: This material is only for educational purpose and is non - commercial**

## Anatomy of the Animal Cell

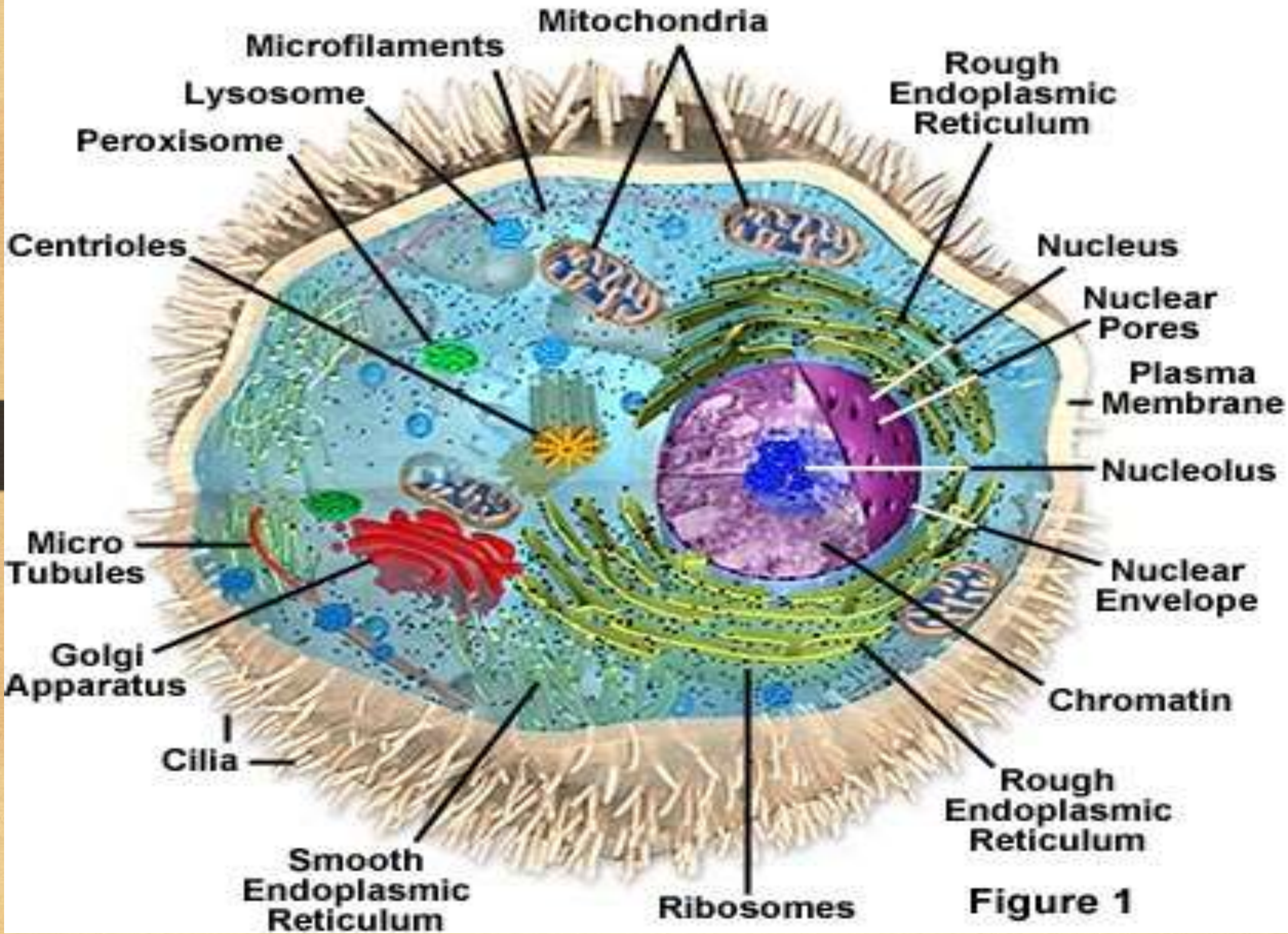
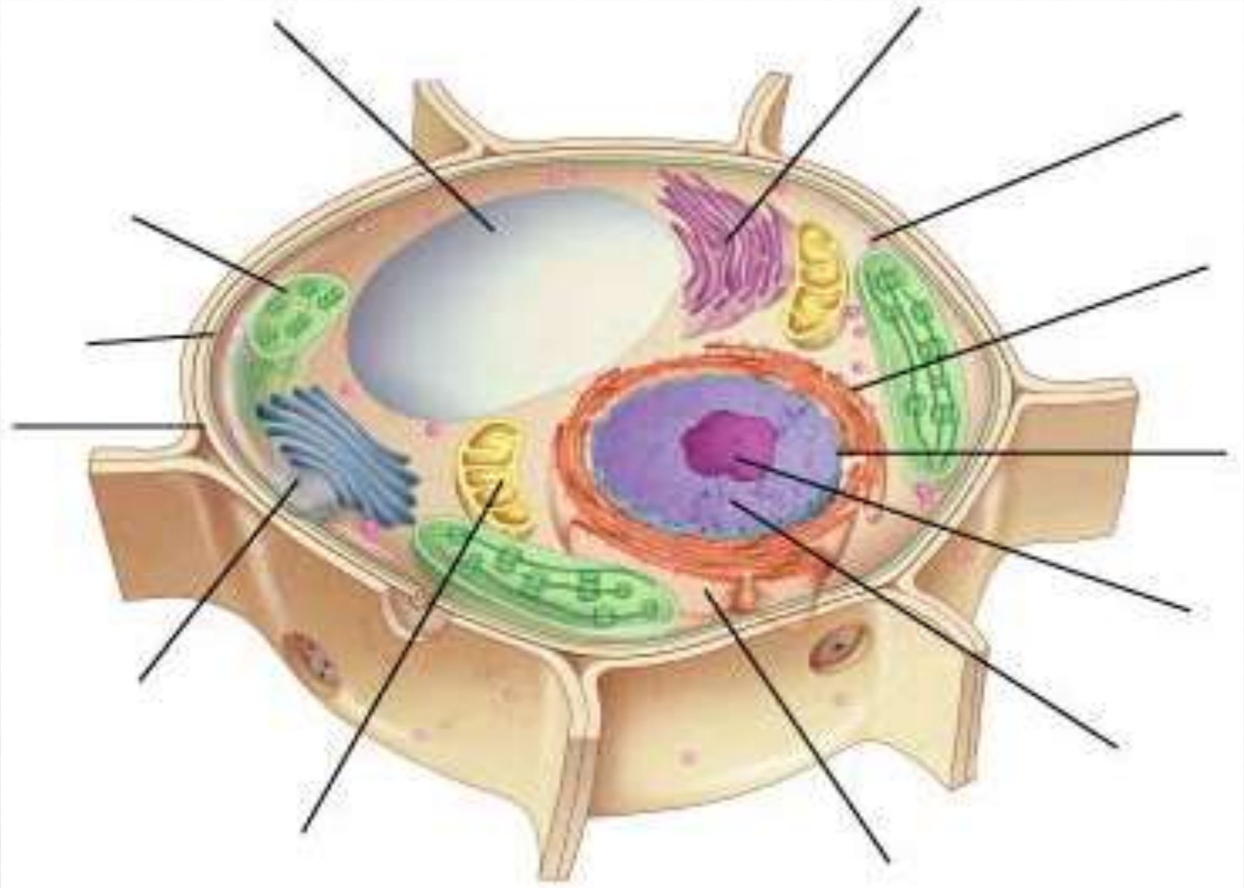
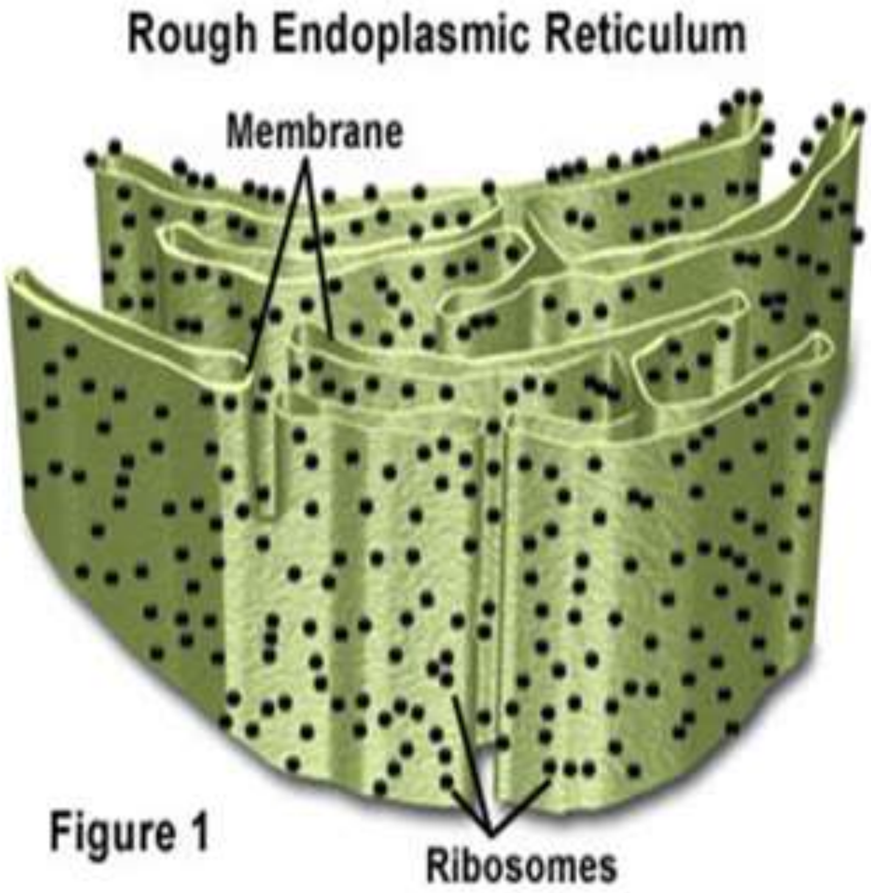



Figure 1


Vacuole
Smooth endoplasmic reticulum
Ribosome (free)
Chloroplast
Ribosome (attached)
Cell Membrane
Nuclear envelope
Cell wall
Nucleolus
Nucleus
Golgi apparatus
Mitochondrion
Rough endoplasmic reticulum

# Plant Cell

# Endoplasmic Reticulum




- Complex network of transport channels.
- Two types:

1. Smooth- ribosome free and functions in poison detoxification.
2. Rough - contains ribosomes and releases newly made protein from the cell.

## Endoplasmic Reticulum

- “Endoplasmic Reticulum is a complex network of tubular membranes exclusively present in the cytoplasm of the eukaryotic cell.”
- It is in two forms:
- rough endoplasmic reticulum is a type with ribosome-studded surface
- another with a smooth surface is called the smooth endoplasmic reticulum.
- These membranes form continuous folds, eventually joining the outer layer the nuclear membrane of the nuclear membrane.
- The endoplasmic reticulum is observed in every other type of eukaryotic cell except for sperm cells and red blood cells.

- **Rough endoplasmic reticulum has ribosomes embedded within its structure, giving a "rough" appearance.**
- **Smooth endoplasmic reticulum does not have these ribosomes, hence appear "smooth."**

## Structure of Rough Endoplasmic Reticulum

- **The rough endoplasmic reticulum is named so because of its appearance.**
- **It is a series of connected flattened sacs having several ribosomes on its outer surface, hence the name.**
- **It synthesizes and secretes proteins in the liver, hormones and other substances in the glands.**

- **Rough ER is prominent in cells where protein synthesis occurs (such as hepatocytes)**

## ***Structure of Smooth Endoplasmic Reticulum***

- **The smooth endoplasmic reticulum, does not have ribosomes.**
- **The smooth endoplasmic reticulum has a tubular form.**
- **It participates in the production of phospholipids, the chief lipids in cell membranes and are essential in the process of metabolism.**
- **It (SER)transports the products of the rough ER to other cellular organelles, especially the Golgi apparatus.**

## ***Functions of Smooth Endoplasmic Reticulum :***

- **It is responsible for the synthesis of essential lipids like phospholipids and cholesterol.**
- **It is also responsible for the production and secretion of steroid hormones.**
- **It is also involved in the metabolism of carbohydrates.**
- **It stores and release calcium ions, important for the nervous system and muscular system.**

## ***Functions Rough Endoplasmic Reticulum :***

- **It is mainly associated with protein synthesis.**
- **It also plays a important role in protein folding.**
- **It also ensures quality control (regarding correct protein folding).**
- **It is also involved in protein sorting.**

# Golgi apparatus

- It has multiple names such as Golgi complex or Golgi body.
- The name is given on the name of the scientist, who discovered the organelle, i.e. Camillo Golgi.
- It is found in all the eukaryotic cells, plants as well as animals.
- They are membrane-bound organelle present in the cytosol of the cell.

# Golgi Apparatus

- A series of flattened sacs that modifies, packages, stores and transports materials out of the cell.
- Works with the ribosomes and Endoplasmic Reticulum.

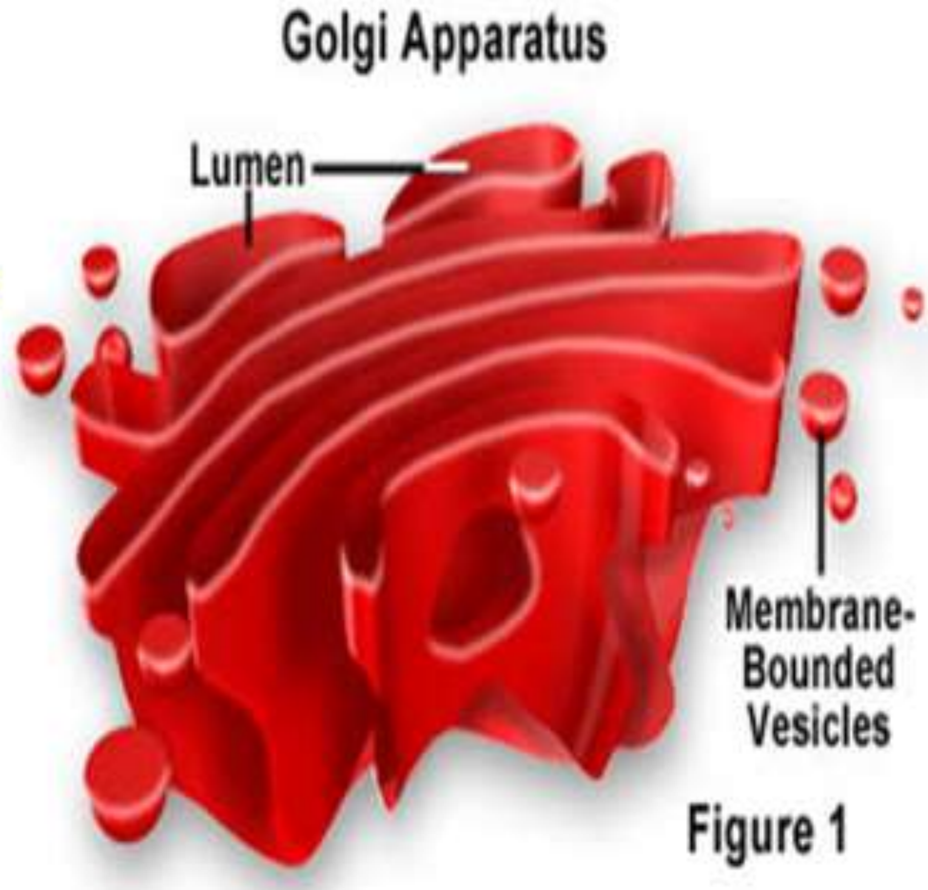



Figure 1

# Golgi Apparatus Structure

- The Golgi body comprises 5 to 8 cup-shaped, series of compartments known as cisternae.
- Cisternae is a flattened, disk-shaped, stacked pouches that make up the Golgi apparatus.
- A Golgi stack mostly contains 4 to 8 cisternae.
- However, ~60 cisternae are found in some protists.
- A mammalian cell contains ~40 to 100 stacks of cisternae.
- Animal cells generally contain around 10 to 20 Golgi stacks per cell, which are connected by tubular connections.

- **Golgi complex is mostly found near the nucleus.**

- **Creation, or evolution, whichever one, you hold a belief in has worked in wondrous ways to evolve or design the various living beings in this world in the most optimum ways.**
- **For example, take the Golgi complex, it has been designed in such a way, to ensure a sufficient number of Golgi bodies are present in the cell as per the requirement.**

# Functions of Golgi Bodies

- Its main function is the packaging and secretion of proteins.
- It receives proteins from Endoplasmic Reticulum.
- It packages it into membrane-bound vesicles, which are then transported to various destinations, such as lysosomes, plasma membrane or secretion.
- They also take part in the transport of lipids and the formation of lysosomes.

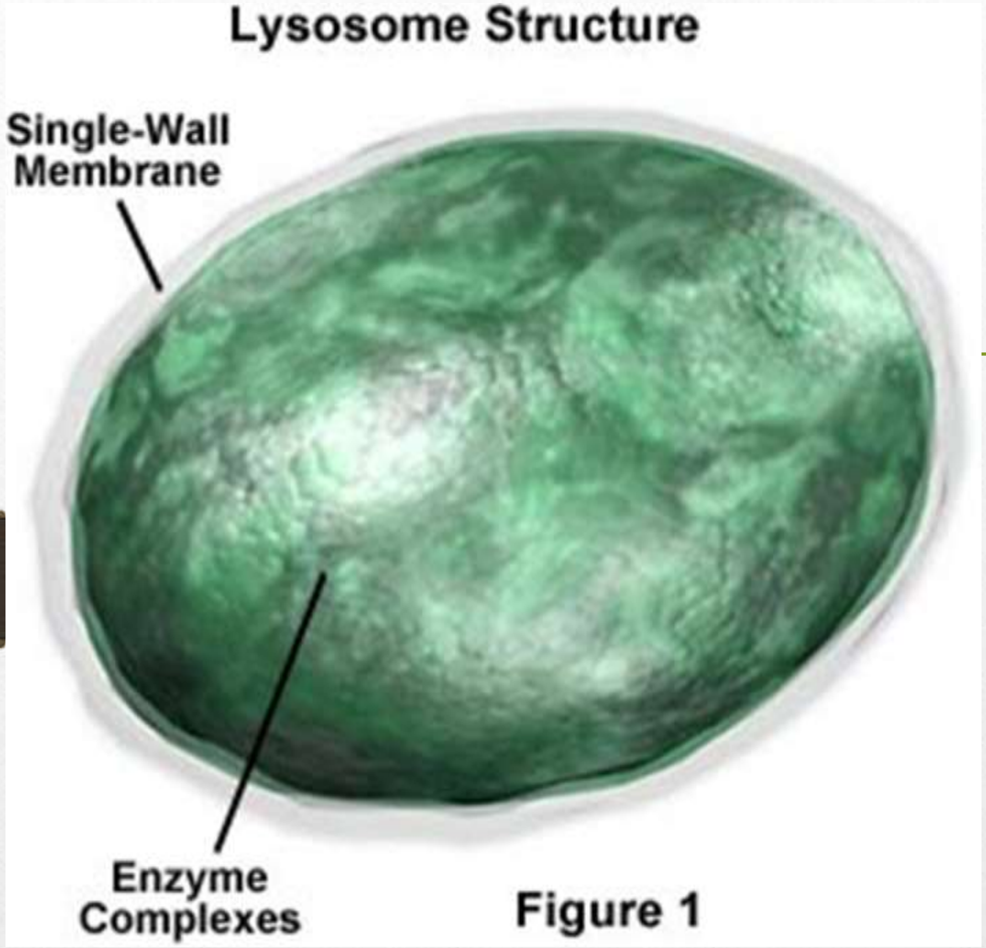
- Post-translational modification and enzymatic processing occur near the membrane surface in Golgi bodies, e.g. phosphorylation, glycosylation, etc.

- Golgi apparatus is the site for the synthesis of various glycolipids, sphingomyelin, etc.

- In the plant cells, complex polysaccharides of the cell wall are synthesised in the Golgi apparatus.

# Lysosomes

- **These are sphere-shaped sacs filled with hydrolytic enzymes that have the capability to break down many types of biomolecules."**
- **Lysosomes are an important cell organelle found within eukaryotic animal cells.**
- **Due to their peculiar function, they are also known as the "*suicide bags*" of the cell.**
- **The term was coined by Christian de Duve, a Belgian biologist, who discovered it and ultimately got a Nobel Prize in Medicine or Physiology in the year 1974.**
- **In other words, lysosomes are membranous organelles whose specific function is to breakdown cellular wastes and debris by engulfing it with hydrolytic enzymes.**




## Structure of Lysosomes :

Lysosomes are membrane-bound organelles and the area within the membrane is called the lumen, which contains the hydrolytic enzymes and other cellular debris.

- **The pH level of the lumen lies between 4.5 and 5.0, which makes it quite acidic.**
- **It is almost comparable to the function of acids found in the stomach.**
- **Besides breaking down biological polymers, lysosomes are also involved in various other cell processes such as counting discharged materials, energy metabolism, cell signalling, and restoration of the plasma membrane.**
- **The sizes of lysosomes vary, with the largest ones measuring in more at than 1.2 µm.**
- **But they typically range from 0.1 µm to 0.6 µm.**

## Why are Lysosomes called as Suicidal Bags?

- As stated before, lysosomes work as the waste discarding structures of the cell by processing undesirable materials and degrading them, both from the exterior of the cell and waste constituents inside the cell.
- But sometimes, the digestive enzymes may end up damaging the lysosomes themselves, and this can cause the cell to die.
- This is termed as autolysis, where "auto" means "self" and "lysis" means "the disintegration of the cell by the destruction of its cell membrane".
- Therefore, the lysosomes are known as "Suicidal Bags" of the cell.

# Lysosome functions:

- The key function of lysosomes is digestion and removal of waste.
- Cellular debris or foreign particles are pulled in to the cell through the process of endocytosis.
- The process of endocytosis happens when the cell membrane falls in on itself (invagination), creating a vacuole or a pouch around the external contents and then bringing those contents into the cell.
- On the other hand, discarded wastes and other substances originating from within the cell is digested by the process of autophagocytosis or autophagy.

**Lysosomal Enzymes:**

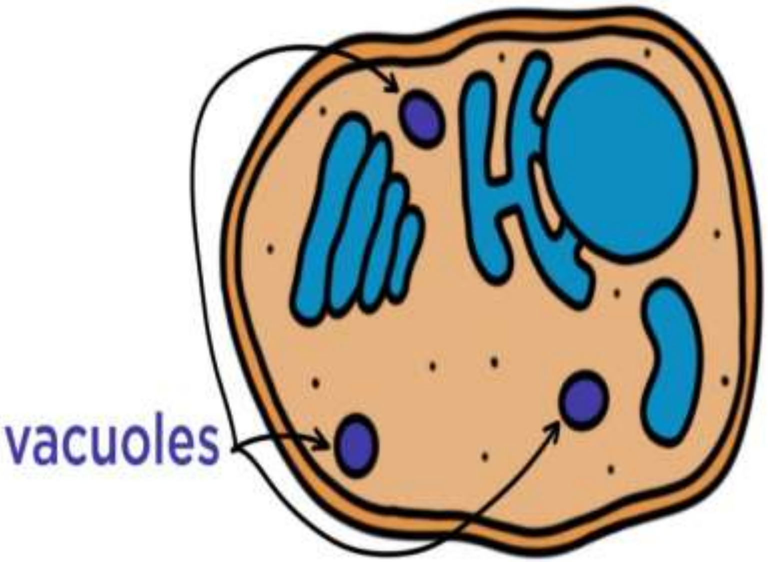
- Lysosomes comprise of over 50 different enzymes. They are synthesized in the rough endoplasmic reticulum.
- Once synthesized, the enzymes are brought in from the Golgi apparatus in tiny vesicles or sacs, which then merges with bigger acidic vesicles.
- The enzymes produced especially for lysosomes are mixed with the molecule mannose 6-phosphate making them get fixed appropriately up into acidified vesicles.
- The process of autophagy involves disassembly or degradation of the cellular components through a natural, regulated mechanism.

# Vacuoles

- The term "vacuole" means "empty space".
- "Vacuoles are membrane-bound cell organelles present in the cytoplasm and filled with a watery fluid containing various substances."
- They help in the storage and disposal of various substances.
- They can store food or other nutrients required by a cell to survive.
- They also store waste products and prevent the entire cell from contamination.
- The vacuoles in plant cells are larger than those in the animal cells.
- The plant vacuoles occupy more than 80% of the volume of the cell.
- The vacuoles may be one or more in number.

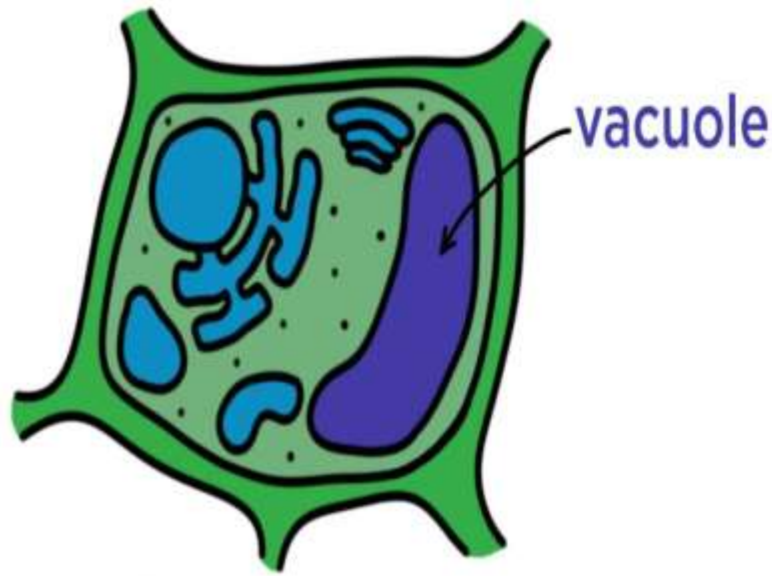
# ORGANELLES: VACUOLE

## ANIMAL CELL




- several small vacuoles
- used for storage
- can contain nutrients, water, or waste

## PLANT CELL




- one large vacuole
- used to store water and push against the cell wall
- keeps the plant rigid

# Structure of Vacuole

- A vacuole is a membrane bound structure found in the cytoplasmic matrix of a cell.
- The membrane surrounding the vacuole is known as tonoplast.
- The components of the vacuole, known as the cell sap, differ from that of the surrounding cytoplasm.
- The membranes are composed of phospholipids.
- The membranes are embedded with proteins that help in transporting molecules across the membrane.
- Different combinations of these proteins help the vacuoles to hold different materials.

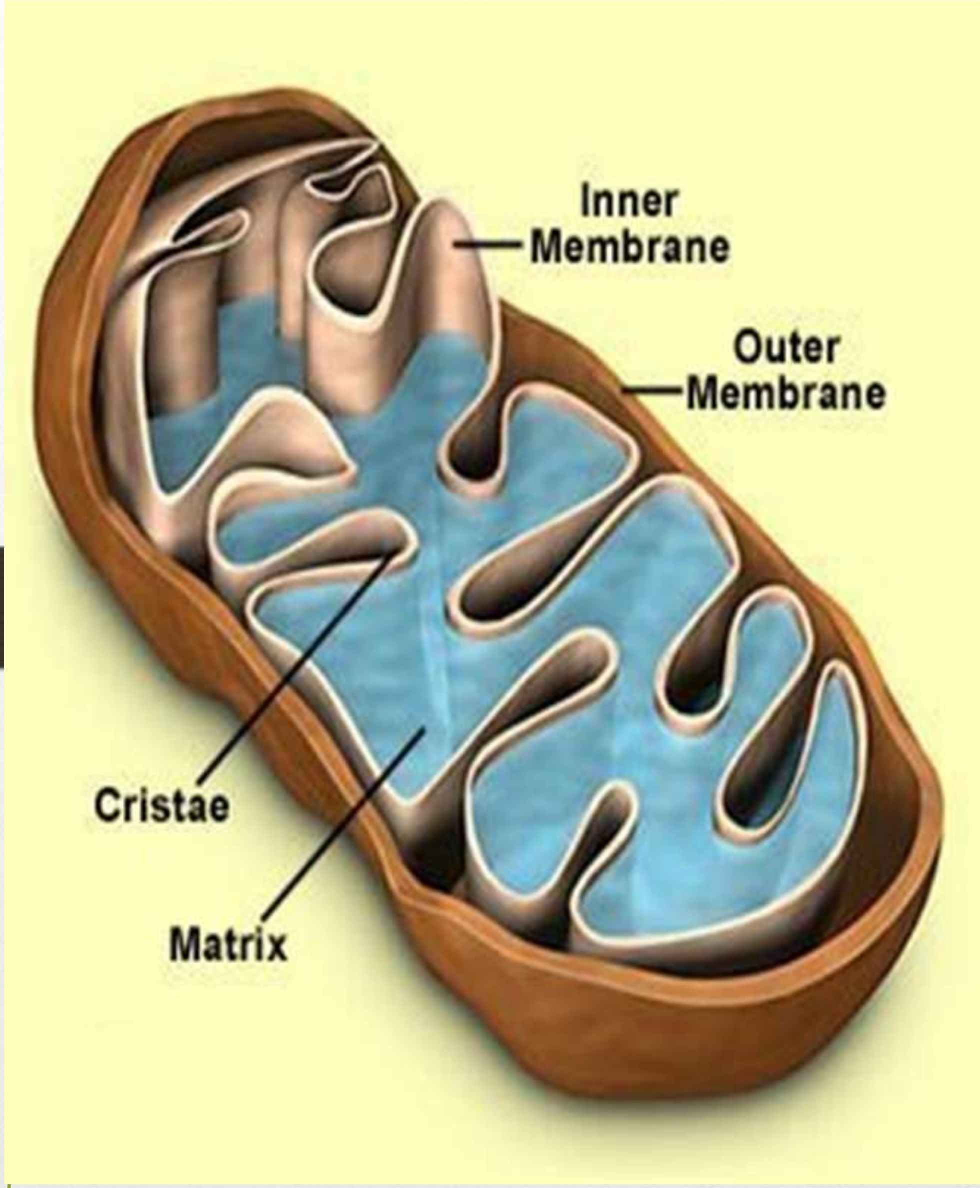
## Functions of Vacuole

- **The important functions of vacuole include Storage**
- **A vacuole stores salts, minerals, pigments and proteins within the cell.**
- **The solution that fills a vacuole is known as the cell sap.**
- **The vacuole is also filled with protons from the cytosol that helps in maintaining an acidic environment within the cell.**
- **A large number of lipids are also stored within the vacuoles.**
- **Turgor Pressure**
- **The vacuoles are completely filled with water and exert force on the cell wall.**

- It provides shape to the cell and helps it to withstand extreme conditions.

## Endocytosis and Exocytosis

- The substances are taken in by a vacuole through endocytosis and excreted through exocytosis.
- These substances are stored in the cells, separated from the cytosol.
- Lysosomes are vesicles that intake food and digest it.
- This is endocytosis and it varies in different cells.




# Mitochondria

**"Mitochondria are membrane-bound organelles present in the cytoplasm of all eukaryotic cells, that produces adinosine triphosphate (ATP), the main energy molecule used by the cell."**

- **Popularly known as the "Powerhouse of the cell,"**
- **The term 'mitochondrion' is derived from the Greek words "*mitos*" and "*chondrion*" which means "thread" and "granules-like" respectively.**
- **It was first described by a German pathologist named Richard Altmann in the year 1890.**
- **mitochondria are a double membrane-bound organelle found in most eukaryotic organisms.**
- **They are found inside the cytoplasm and essentially functions as the cell's "digestive system."**

- They play a major role in breaking down nutrients and generating energy-rich molecules for the cell.
- Many of the biochemical reactions involved in cellular respiration take place within the mitochondria.

## Structure of Mitochondria

- The mitochondrion is a double-membraned, rod-shaped structure found in both plant and animal cell.
- Its size ranges from 0.5 to 1.0 micrometre in diameter.
- The structure comprises an outer membrane, an inner membrane, and a gel-like material called the matrix.

- The outer membrane and the inner membrane are made of proteins and phospholipid layers separated by the intermembrane space.
- The outer membrane covers the surface of the mitochondrion and has a large number of special proteins known as porins.
- It is freely permeable to ions, nutrient molecules, energy molecules like the ADP and ATP molecules.

# Cristae

- The inner membrane of mitochondria is rather complex in structure.
- It has many folds that form a layered structure called cristae, and this helps in increasing the surface area inside the organelle.

- The cristae and the proteins of the inner membrane aids in the production of ATP molecules.
- The inner membrane is strictly permeable only to oxygen and to ATP molecules.
- A number of chemical reactions take place within the inner membrane of mitochondria.
- Mitochondrial Matrix
- The mitochondrial matrix is a viscous fluid that contains a mixture of enzymes and proteins.
- It also comprises ribosomes, inorganic ions, mitochondrial DNA, nucleotide cofactors, and organic molecules.
- The enzymes present in the matrix play an important role in the synthesis of ATP molecules.

## Functions of Mitochondria

- The most important function of mitochondria is to produce energy through the process of oxidative phosphorylation.
- It regulates the metabolic activity of the cell
- It promotes the growth of new cells and cell multiplication
- It helps in detoxifying ammonia in the liver cells
- It plays an important role in apoptosis or programmed cell death
- It is responsible for building certain parts of the blood and various hormones like testosterone and oestrogen

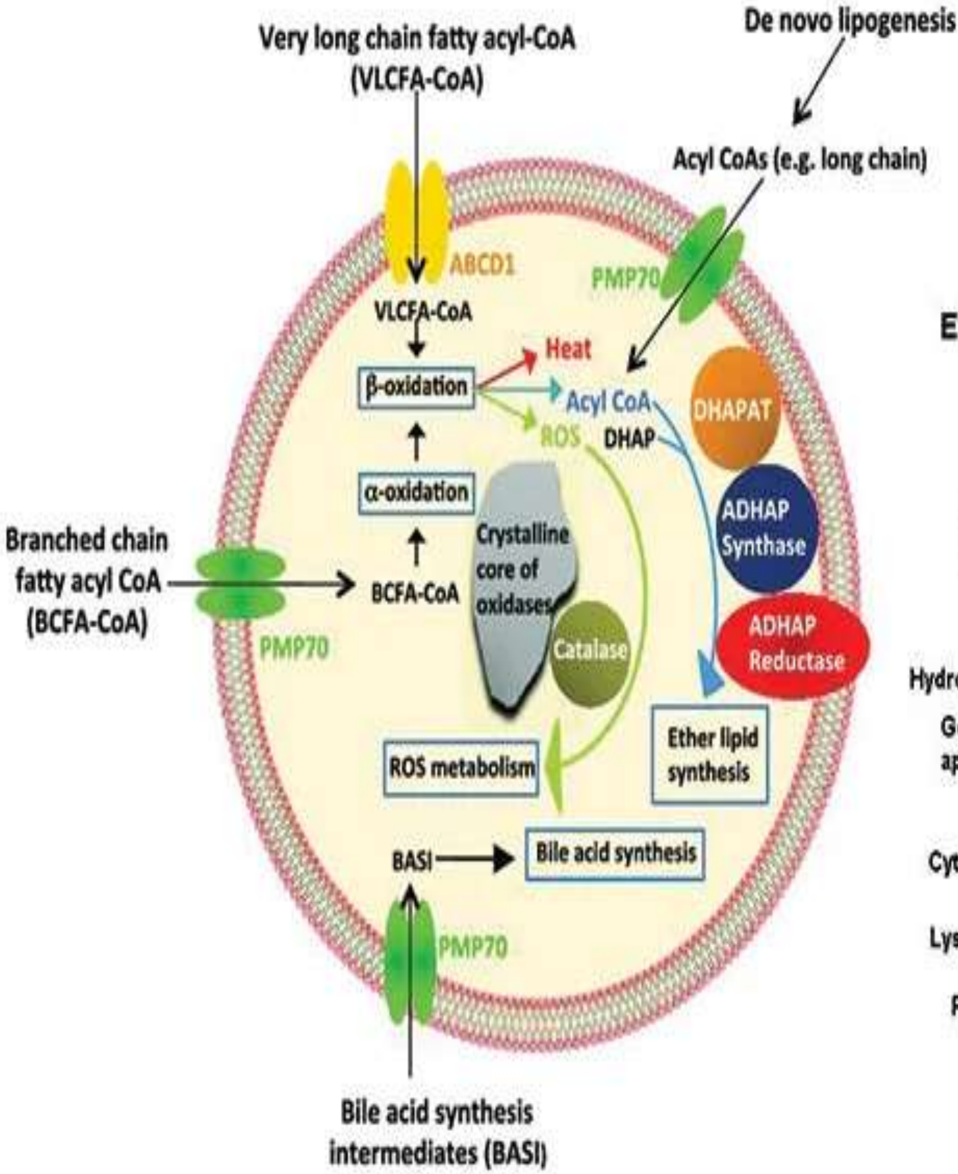
- **It helps in maintaining an adequate concentration of calcium ions within the compartments of the cell**
- **It is also involved in various cellular activities like**

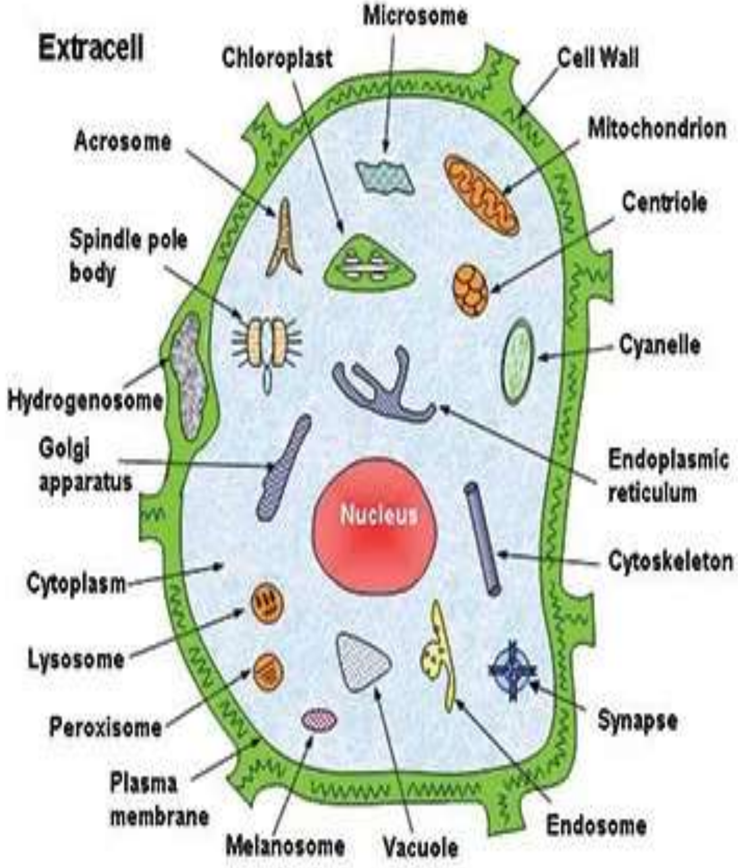
- **cellular differentiation,**
- **cell signalling,**
- **cell senescence,**
- **controlling the cell cycle and also in cell growth.**

# Peroxisomes

- Peroxisomes are small vesicles, single membrane-bound organelles found in the eukaryotic cells.
- They contain digestive enzymes for breaking down toxic materials in the cell and oxidative enzymes for metabolic activity.
- They are a heterogeneous group of organelles and the presence of the marker enzymes distinguished them from other cell organelles.
- Peroxisomes play an important role in lipid production and are also involved in the conversion of reactive oxygen species such as hydrogen peroxide into safer molecules like water and oxygen by the enzyme catalase.

# Peroxisomes



- Mostly peroxisomes occur as an individual organelle, e.g. in fibroblasts.
- They also exist in the form of interconnected tubules in liver cells known as peroxisome reticulum.

**Peroxisome Structure**

- Peroxisomes vary in shape, size and number depending upon the energy requirements of the cell.
- These are made of a phospholipid bilayer with many membrane-bound proteins.
- The enzymes involved in lipid metabolism are synthesised on free ribosomes and selectively imported to peroxisomes.

- These enzymes include one of the two signalling sequences-
- Peroxisome Target Sequence 1 being the most common one.
- The phospholipids of peroxisomes are usually synthesised in smooth Endoplasmic reticulum.
- Due to the ingress of proteins and lipids, the peroxisome grows in size and divides into two organelles.
- Peroxisomes do not have their own DNA. Proteins are transported from the cytosol after translation.

# Functions of Peroxisome

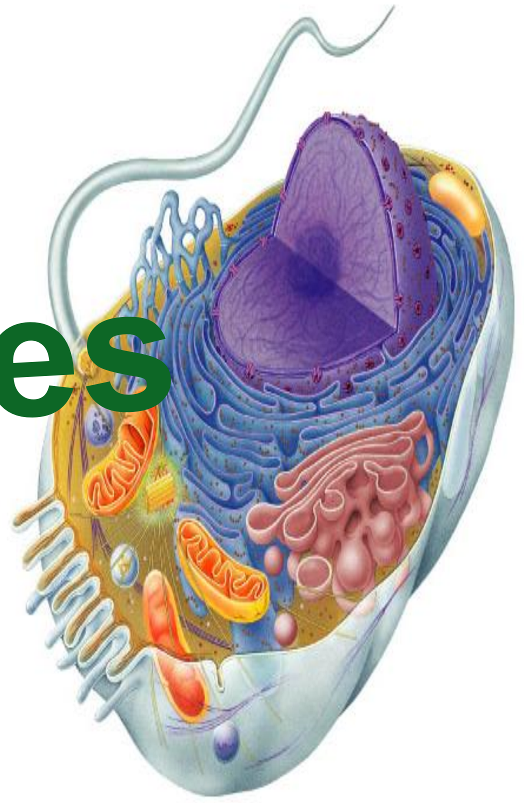
- The main function of peroxisome is the lipid metabolism and the processing of reactive oxygen species.
- They take part in various oxidative processes.
- They take part in lipid metabolism and catabolism of D-amino acids, polyamines and bile acids.
- The reactive oxygen species such as peroxides produced in the process is converted to water by various enzymes like peroxidase and catalase.
- In plants, peroxisomes facilitate photosynthesis and seed germination.
- They prevent loss of energy during photosynthesis carbon fixation.

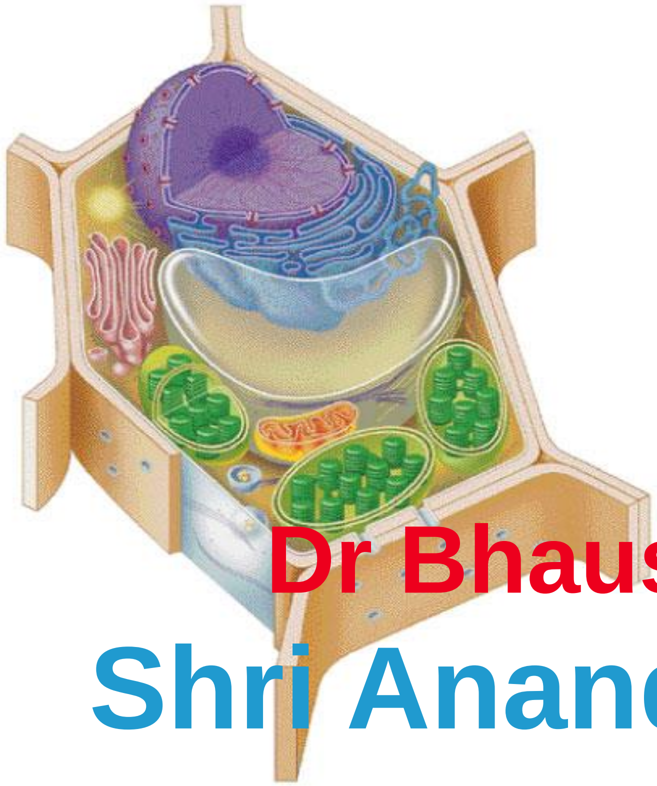
**Metabolism of Peroxisomes**

- Isolated peroxisomes are permeable to small molecules such as sucrose.
- During the isolation process, they often lose proteins that are normally confined to the peroxisomal matrix.
- In all living cells, peroxisomes are the sealed vesicles surrounded by a single membrane.

**Thanks…**

# Cell Organelles





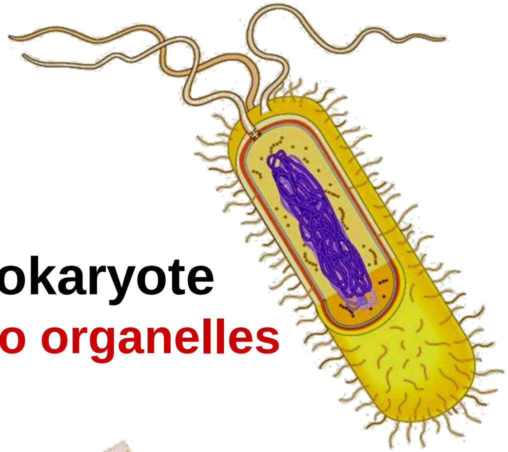
By

**Dr Bhausaheb R Ghorpade**

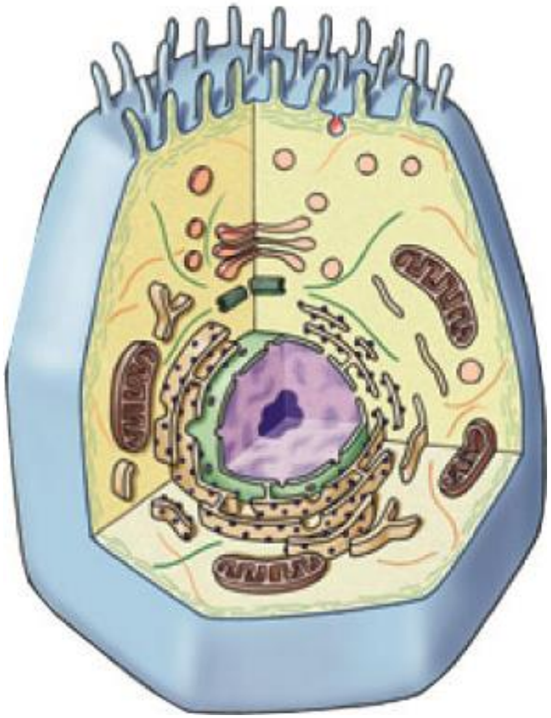
**Shri Anand College Pathardi**

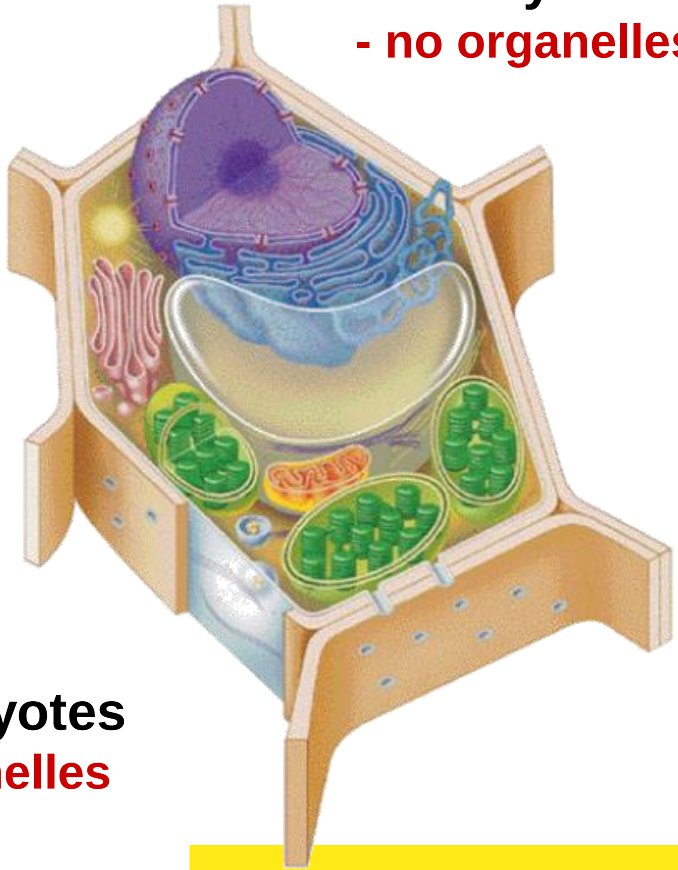
# Types of cells

**bacteria cells**



**Prokaryote**
**- no organelles**



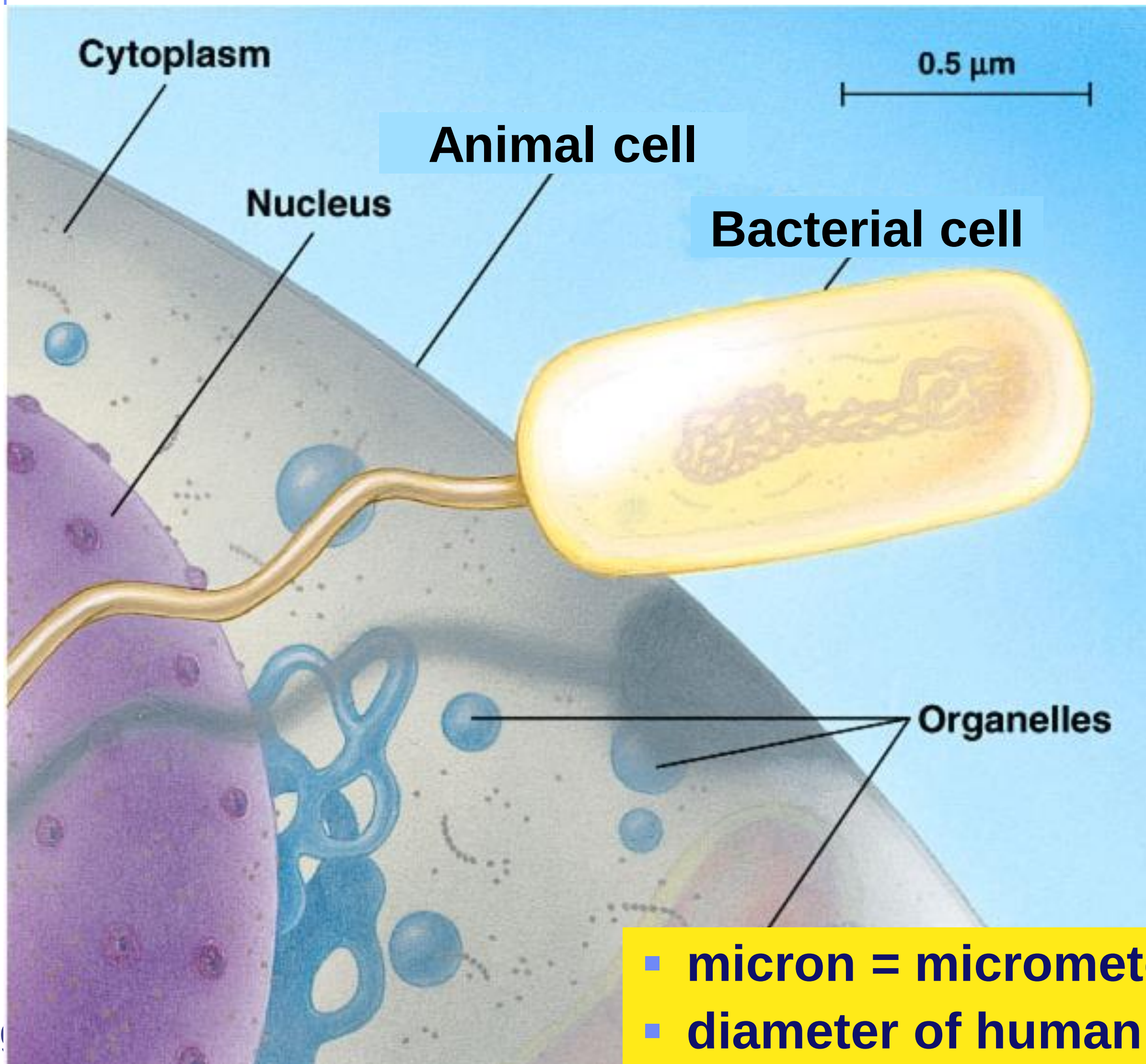


**Eukaryotes**
**- organelles**

**animal cells**

**plant cells**

# Cell size comparison

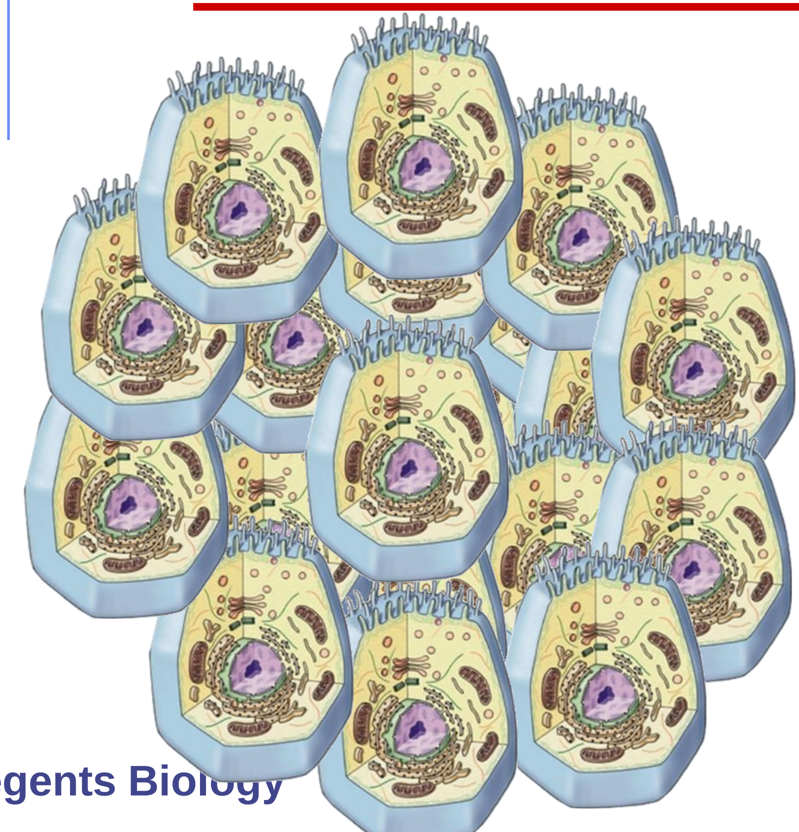



- most bacteria
  - 1-10 microns
- eukaryotic cells
  - 10-100 microns

- micron = micrometer = 1/1,000,000 meter
- diameter of human hair = ~20 microns

# Why study cells?

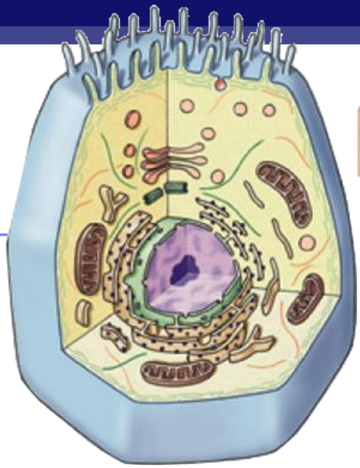
- Cells → Tissues → Organs → Bodies
  - bodies are made up of cells
  - cells do all the work of life!

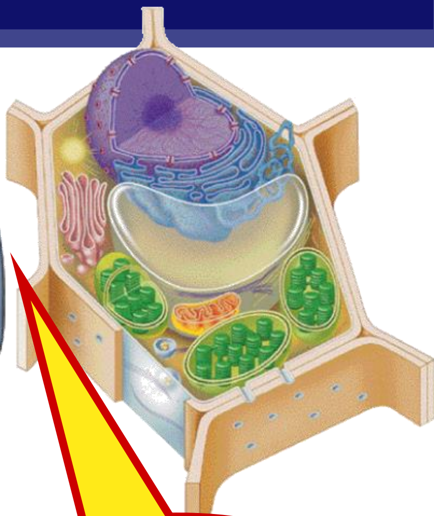


# The Work of Life

- What jobs do cells have to do for an organism to live…
  - "breathe"
    - gas exchange: $O_2$ in vs. $CO_2$ out
  - eat
    - take in & digest food
  - make energy
    - ATP
  - build molecules
    - proteins, carbohydrates, fats, nucleic acids
  - remove wastes
  - control internal conditions
    - homeostasis
  - respond to external environment
  - build more cells
    - growth, repair, reproduction & development


# The Jobs of Cells



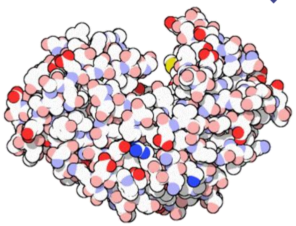


- Cells have 3 main jobs
  - **make energy**

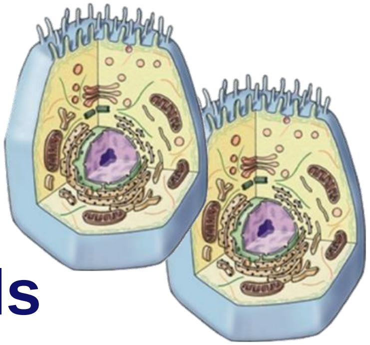

    - need energy for all activities
    - need to clean up waste produced while making energy

Our organelles do all these jobs!

  - **make proteins**

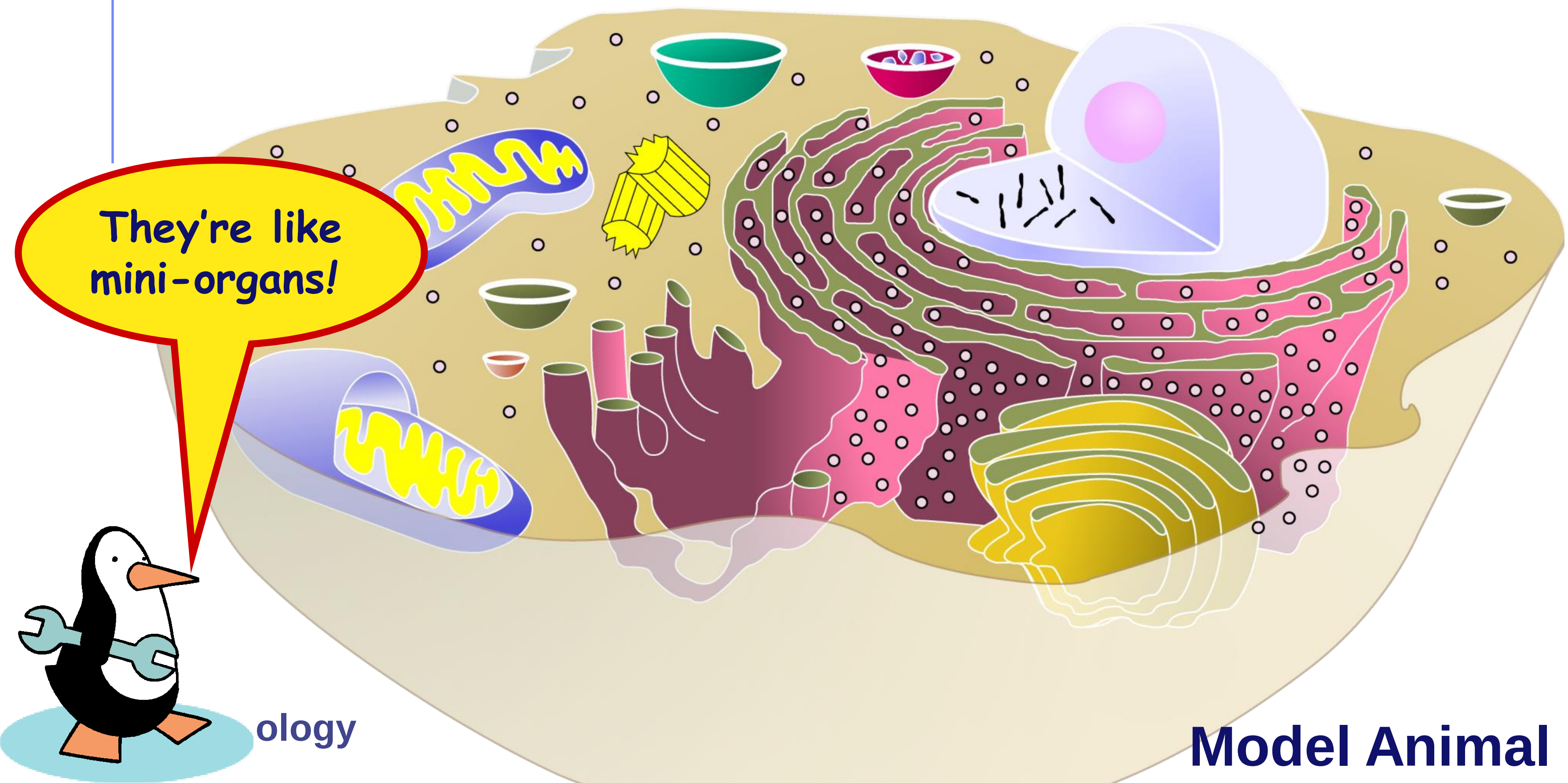


    - proteins do all the work in a cell, so we need lots of them
  - **make more cells**
    - for growth
    - to replace damaged or diseased cells



# Organelles

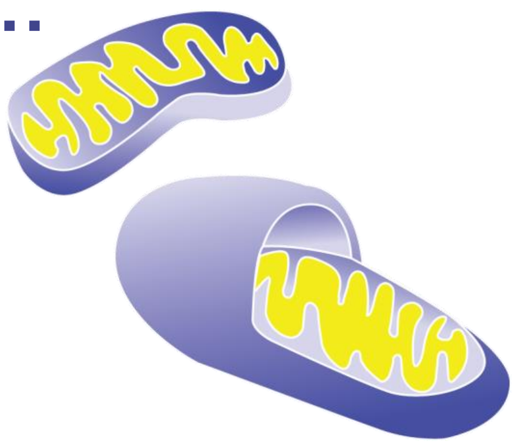
- **Organelles do the work of cells**
  - each structure has a job to do
    - **keeps the cell alive; keeps you alive**




**Model Animal Cell**

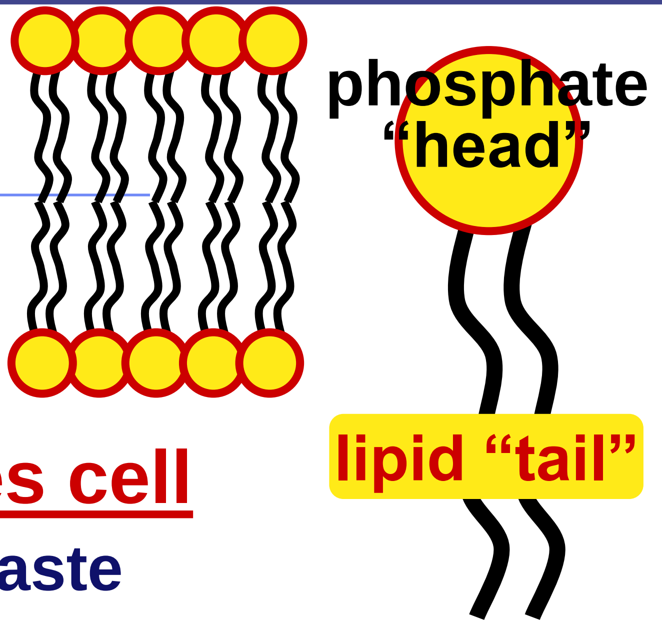
# 1. Cells need power!

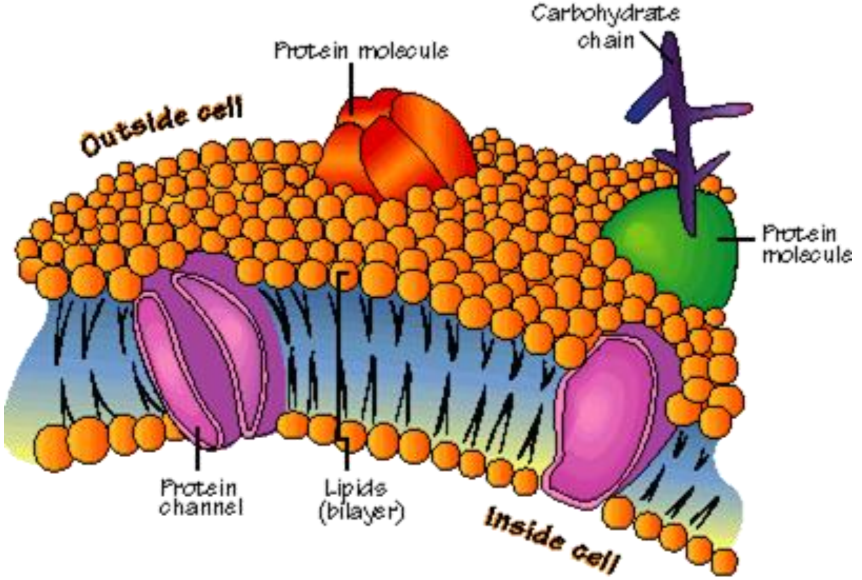
- **Making energy**
  - to fuel daily life & growth, the cell must…
    - take in food & digest it
    - take in oxygen ($O_2$)
    - make ATP
    - remove waste
  - organelles that do this work…
    - cell membrane
    - lysosomes
    - vacuoles & vesicles
    - mitochondria

# Cell membrane

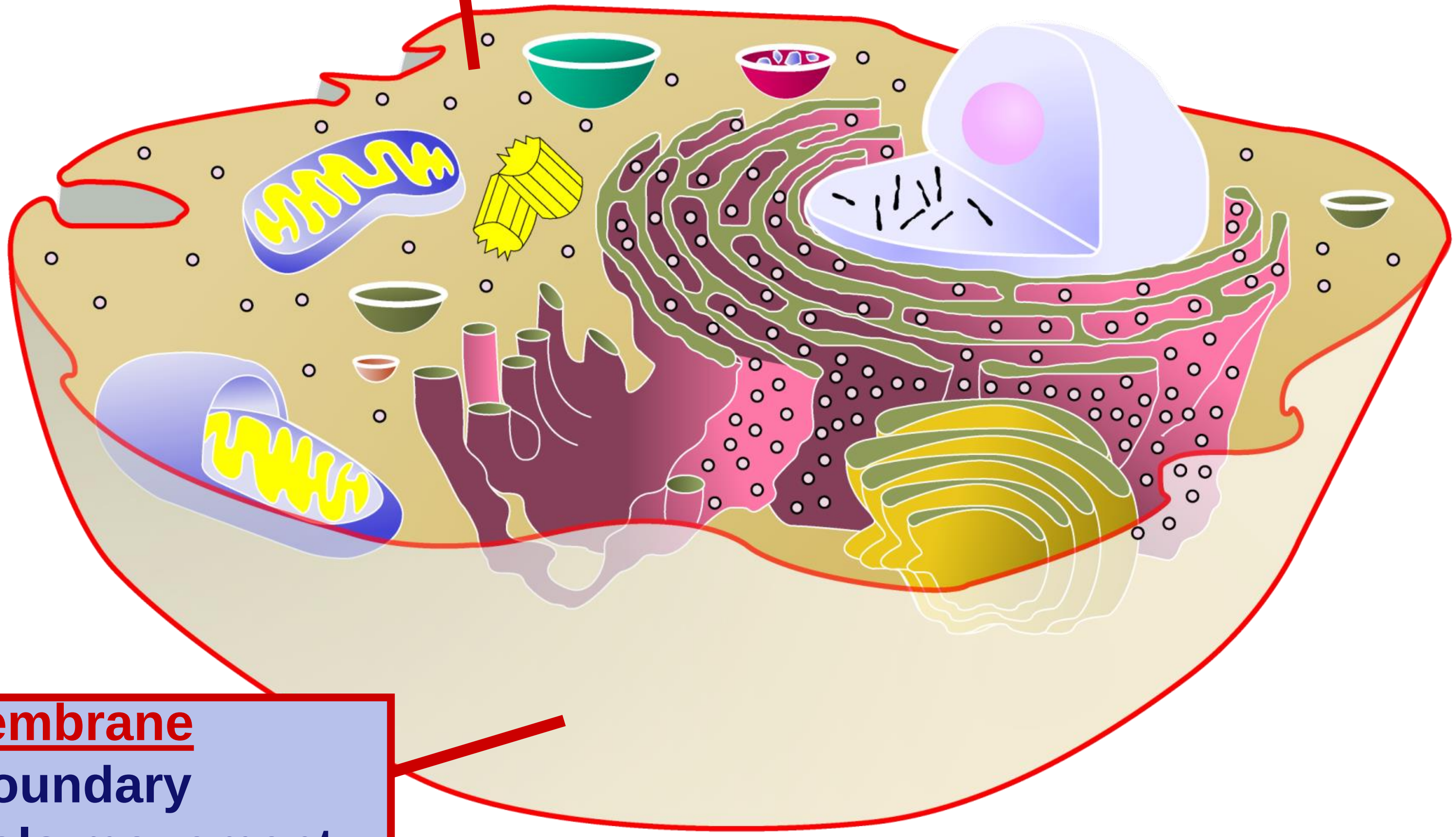
- **Function**
  - separates cell from outside
  - controls what enters or leaves cell
    - $O_2$, $CO_2$, food, $H_2O$, nutrients, waste
  - recognizes signals from other cells
    - allows communication between cells
- **Structure**
  - double layer of fat
    - phospholipid bilayer
  - receptor molecules
    - proteins that receive signals



## cytoplasm

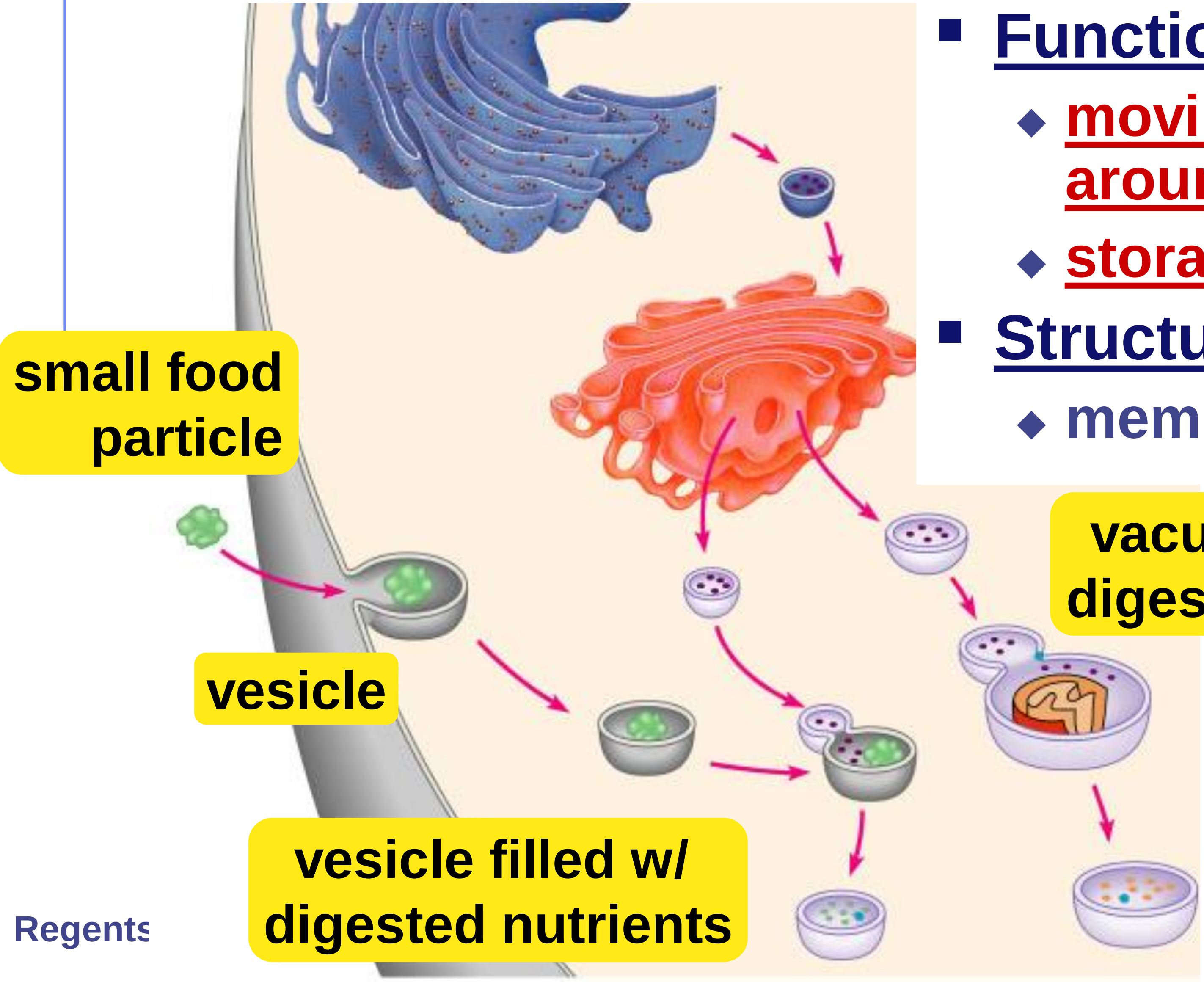
- jelly-like material holding organelles in place



## cell membrane

- cell boundary
- controls movement of materials in & out
- recognizes signals

# Vacuoles & vesicles

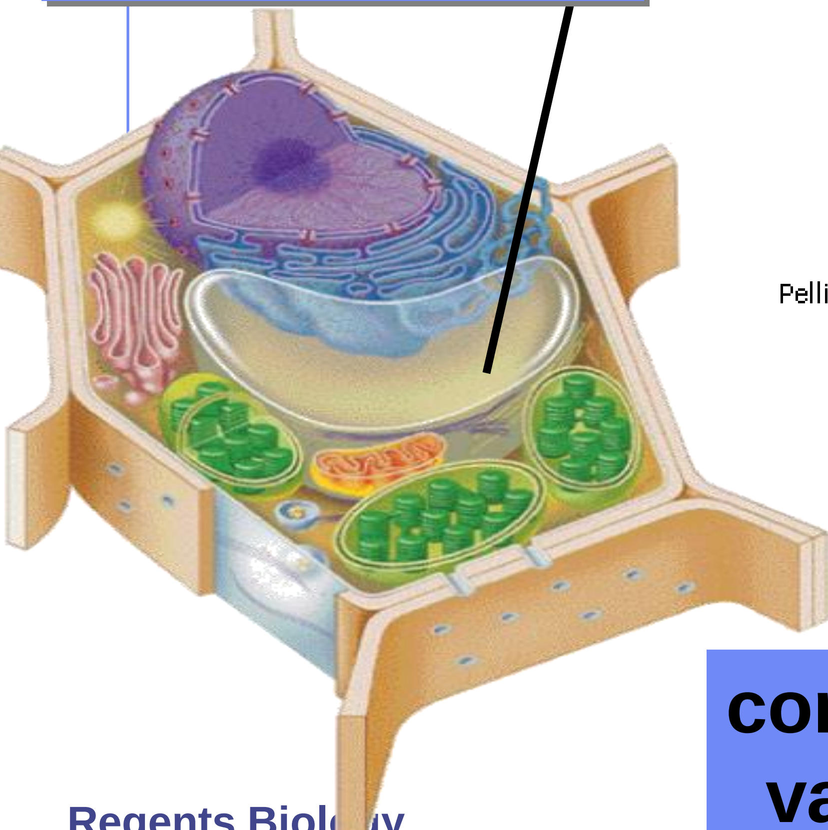



- Function
  - moving material around cell
  - storage
- Structure
  - membrane sac

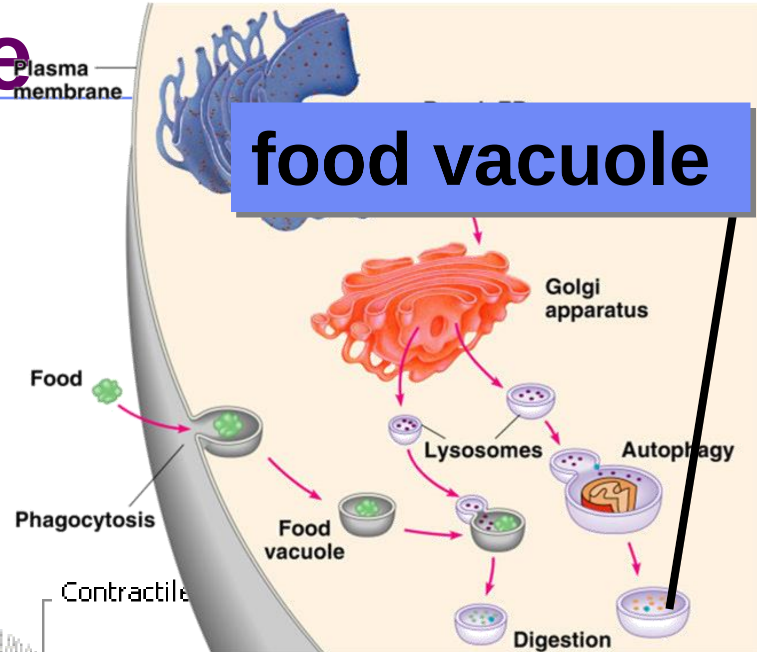
# Food & water storage

plant cells

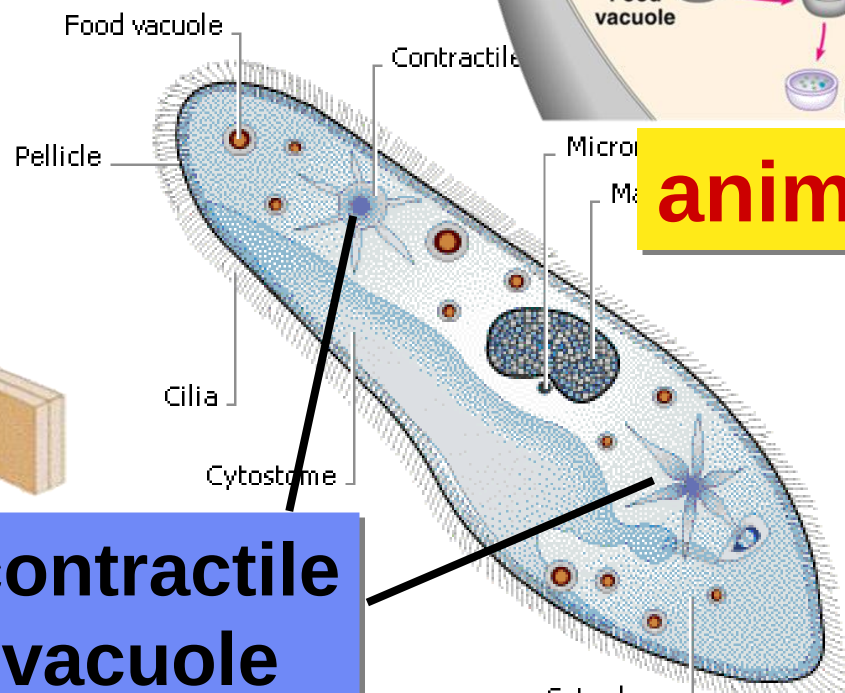
central vacuole



food vacuole




animal cells



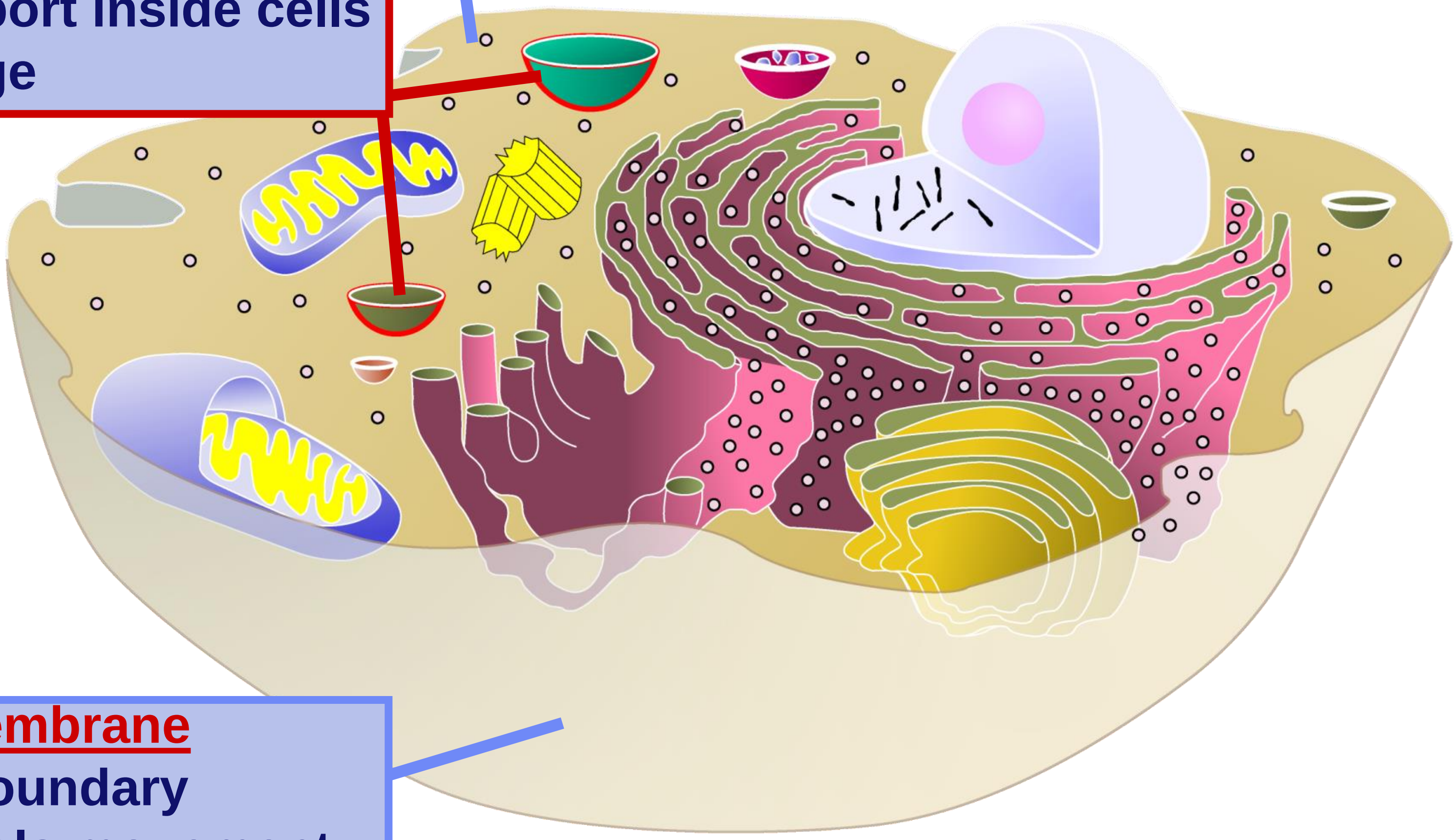

contractile vacuole

**cytoplasm**

- jelly-like material holding organelles in place

**vacuole & vesicles**

- transport inside cells
- storage

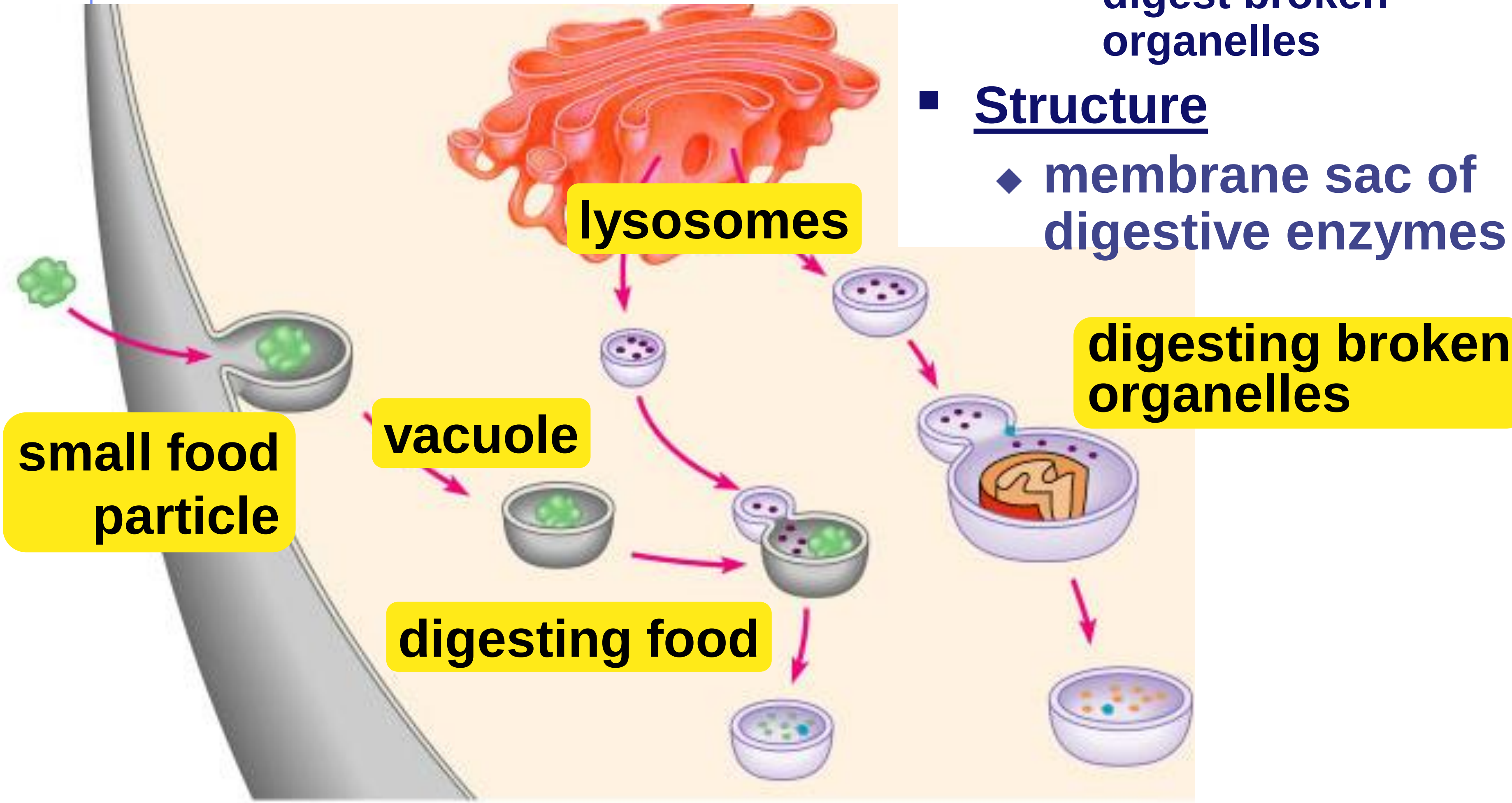


**cell membrane**

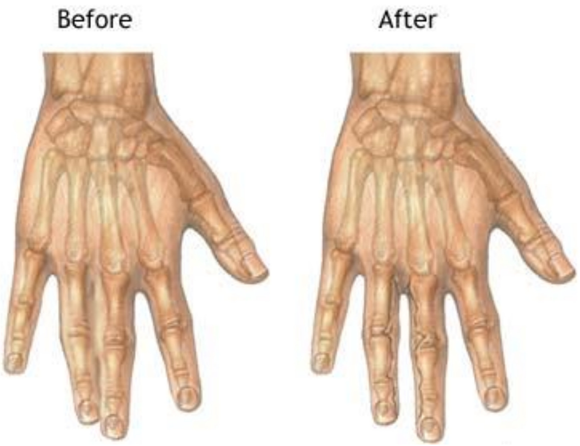
- cell boundary
- controls movement of materials in & out
- recognizes signals

# Lysosomes

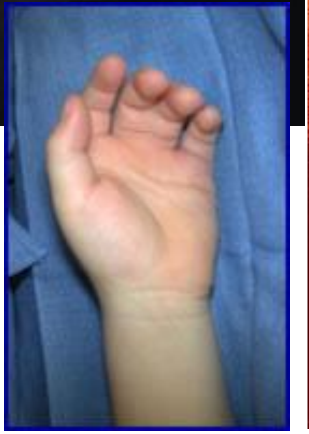
- **Function**
  - digest food
    - used to make energy
  - clean up & recycle
    - digest broken organelles
- **Structure**
  - membrane sac of digestive enzymes

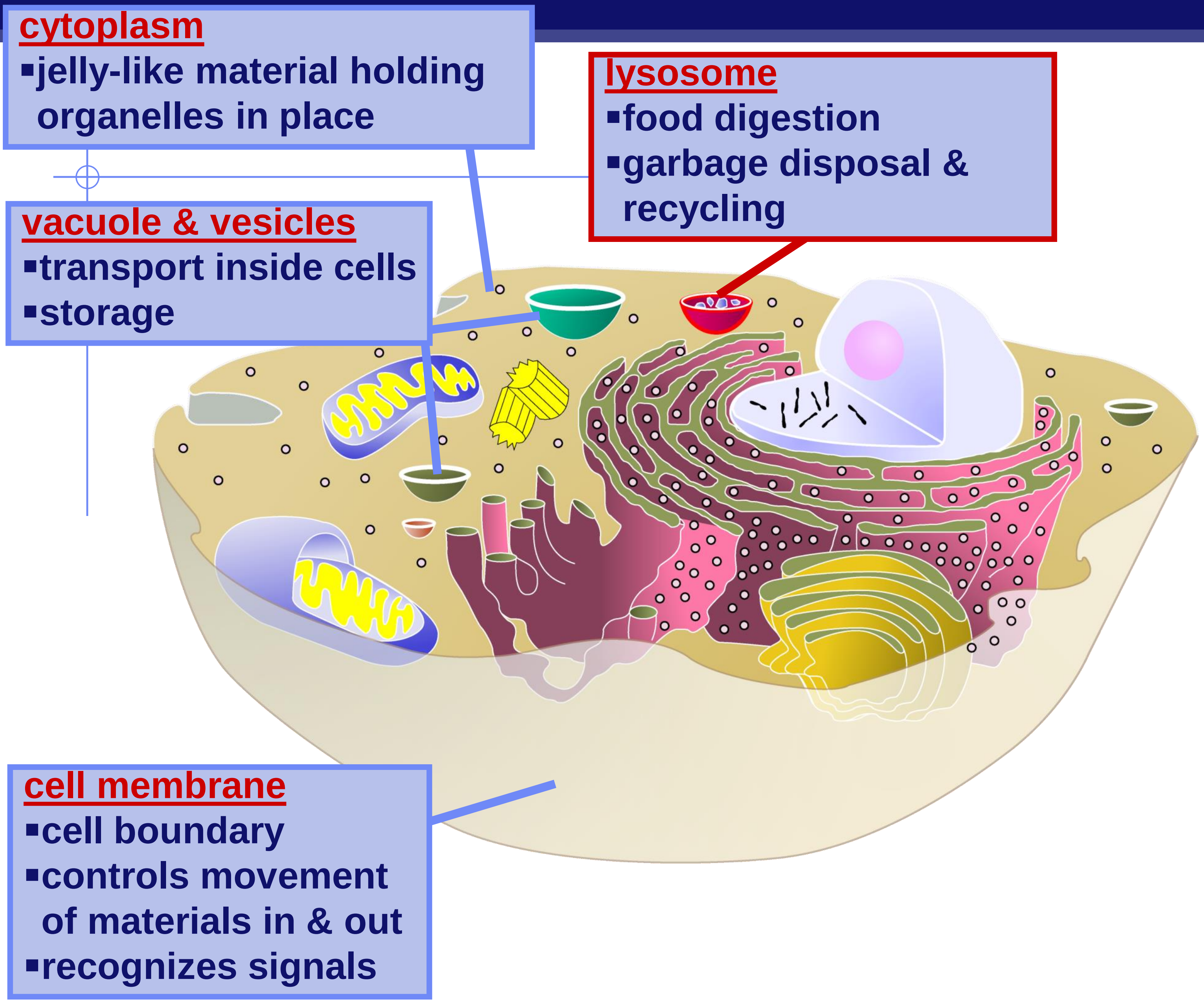


# A Job for Lysosomes

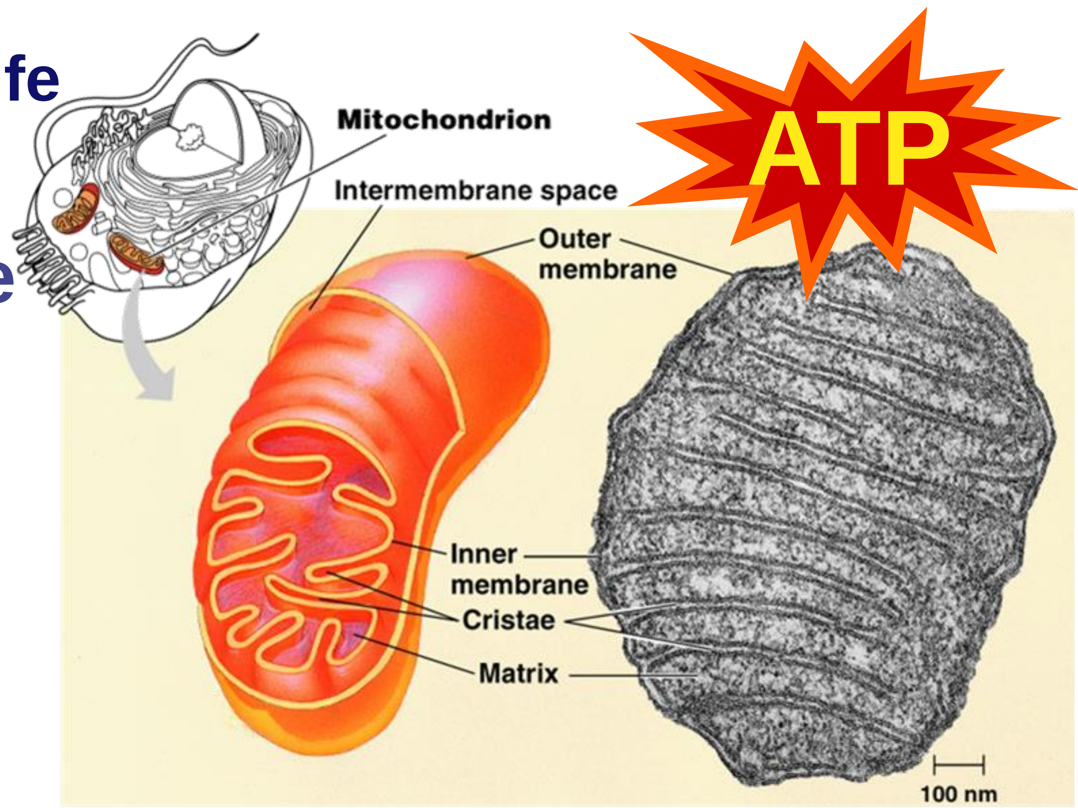





cytoplasm
▪jelly-like material holding organelles in place
lysosome
▪food digestion
▪garbage disposal & recycling
vacuole & vesicles
▪transport inside cells
▪storage
cell membrane
▪cell boundary
▪controls movement of materials in & out
▪recognizes signals

# Mitochondria

- Function
  - <u>**make ATP energy from cellular respiration**</u>
    - sugar + $O_2 \rightarrow$ ATP
    - fuels the work of life
- Structure
  - double membrane

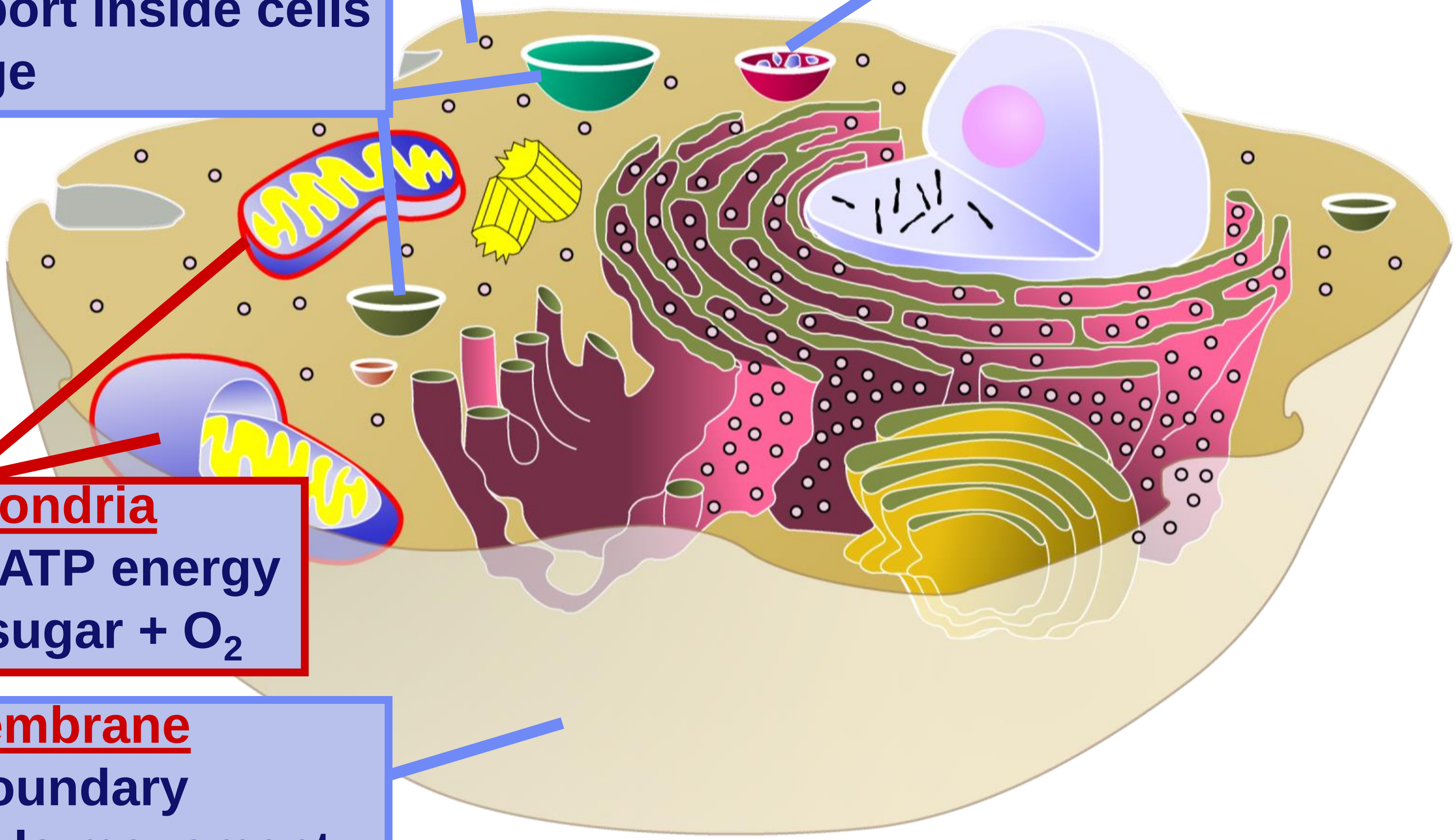



in <u>both</u> animal & plant cells

**cytoplasm**
- jelly-like material holding organelles in place

**lysosome**
- food digestion
- garbage disposal & recycling

**vacuole & vesicles**
- transport inside cells
- storage

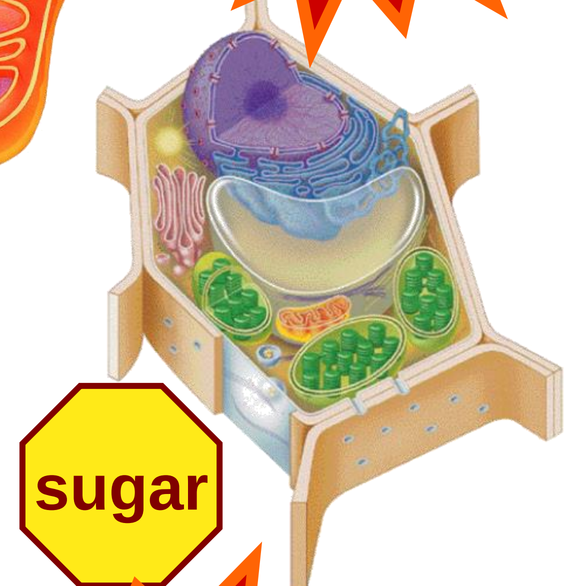


**mitochondria**
- make ATP energy from sugar + $O_2$

**cell membrane**
- cell boundary
- controls movement of materials in & out
- recognizes signals

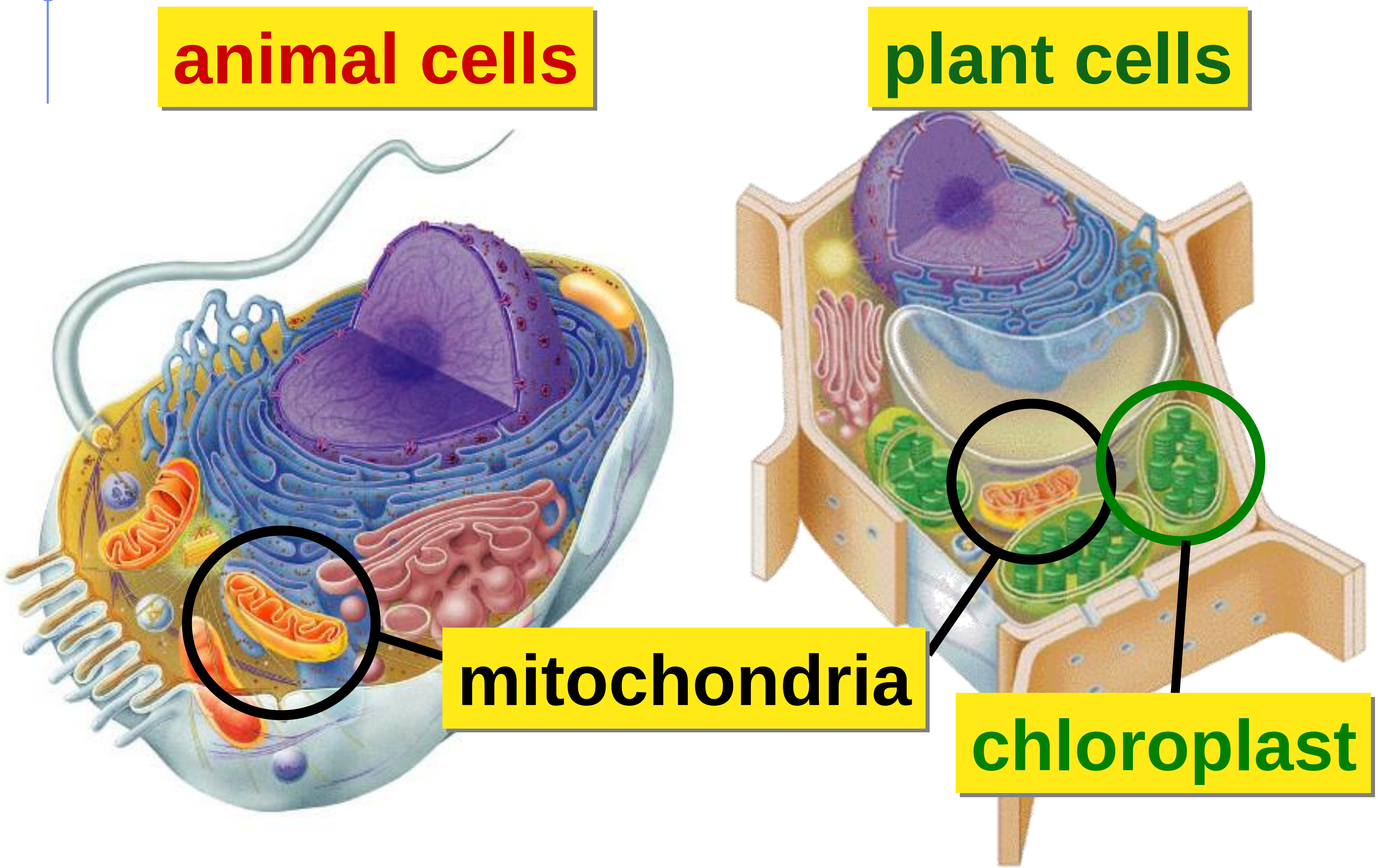
# Plants make energy two ways!

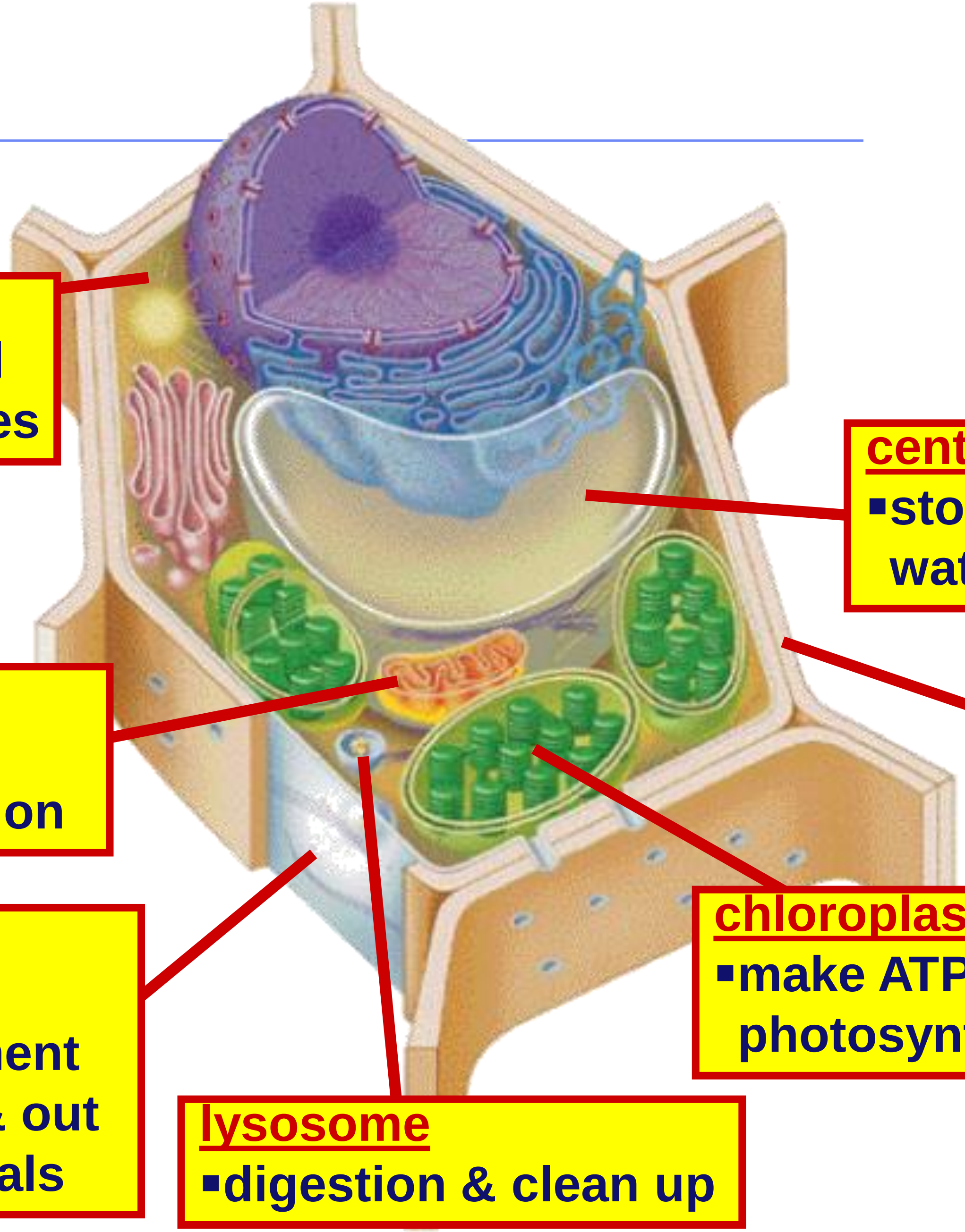
- **Mitochondria**
  - make energy from sugar + $O_2$
    - **cellular respiration**
    - sugar + $O_2$ ⟶ ATP
- **Chloroplasts**
  - make energy + sugar from sunlight
    - **photosynthesis**
    - sunlight + $CO_2$ ⟶ ATP & sugar
      - ATP = active energy
      - sugar = stored energy
        - build leaves & roots & fruit out of the sugars



# Mitochondria are in both cells!!




cytoplasm
▪jelly-like material around organelles
central vacuole
▪storage: food, water or waste
cell wall
▪support
mitochondria
▪make ATP in cellular respiration
cell membrane
▪cell boundary
▪controls movement of materials in & out
▪recognizes signals
lysosome
▪digestion & clean up
chloroplast
▪make ATP & sugars in photosynthesis

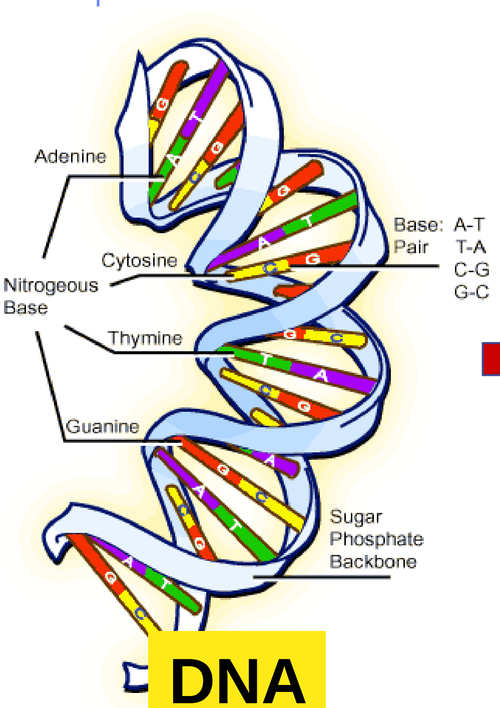
# 2. Cells need workers = proteins!

- **Making proteins**
  - to run daily life & growth, the cell must…
    - read genes (DNA)
    - build proteins
      - structural proteins (muscle fibers, hair, skin, claws)
      - enzymes (speed up chemical reactions)
      - signals (hormones) & receptors
  - organelles that do this work…
    - nucleus
    - ribosomes
    - endoplasmic reticulum (ER)
    - Golgi apparatus

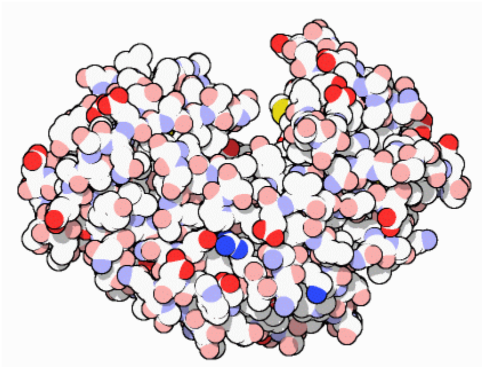
# Proteins do all the work!

**one of the major job of cells is to make proteins, because…**

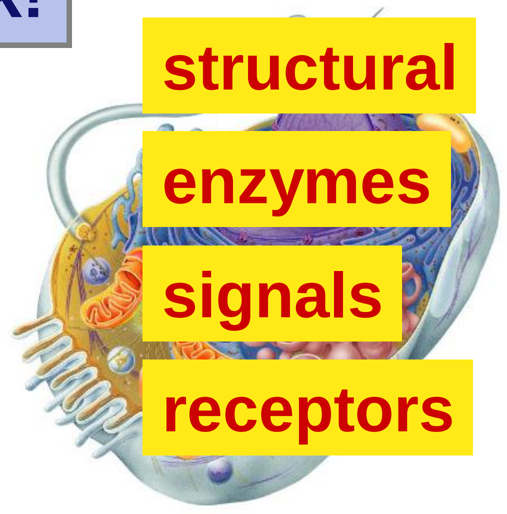
**proteins do all the work!**




**DNA**



**proteins**



**structural**

**enzymes**

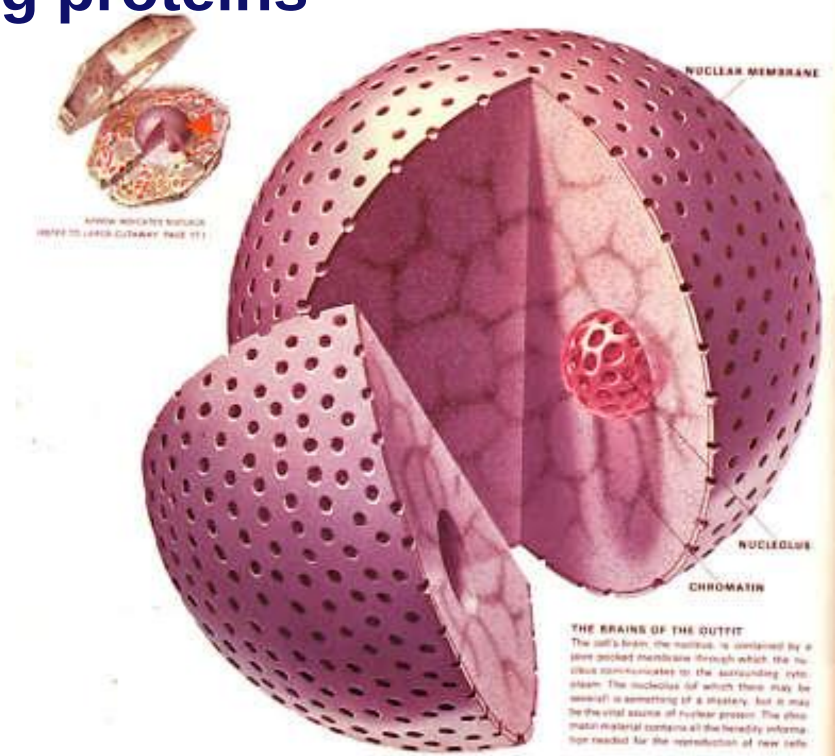
**signals**

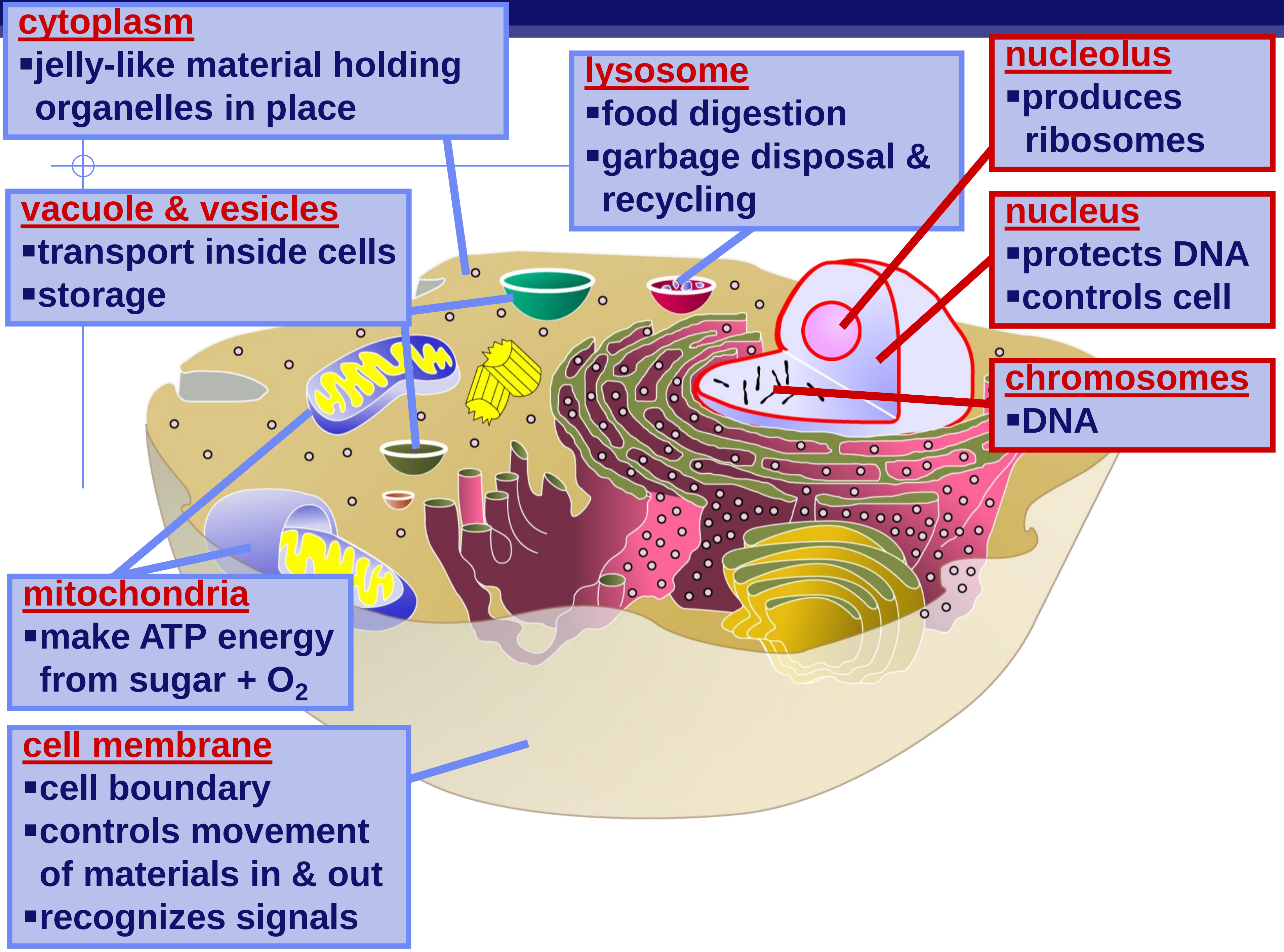
**receptors**

**cells**

# Nucleus

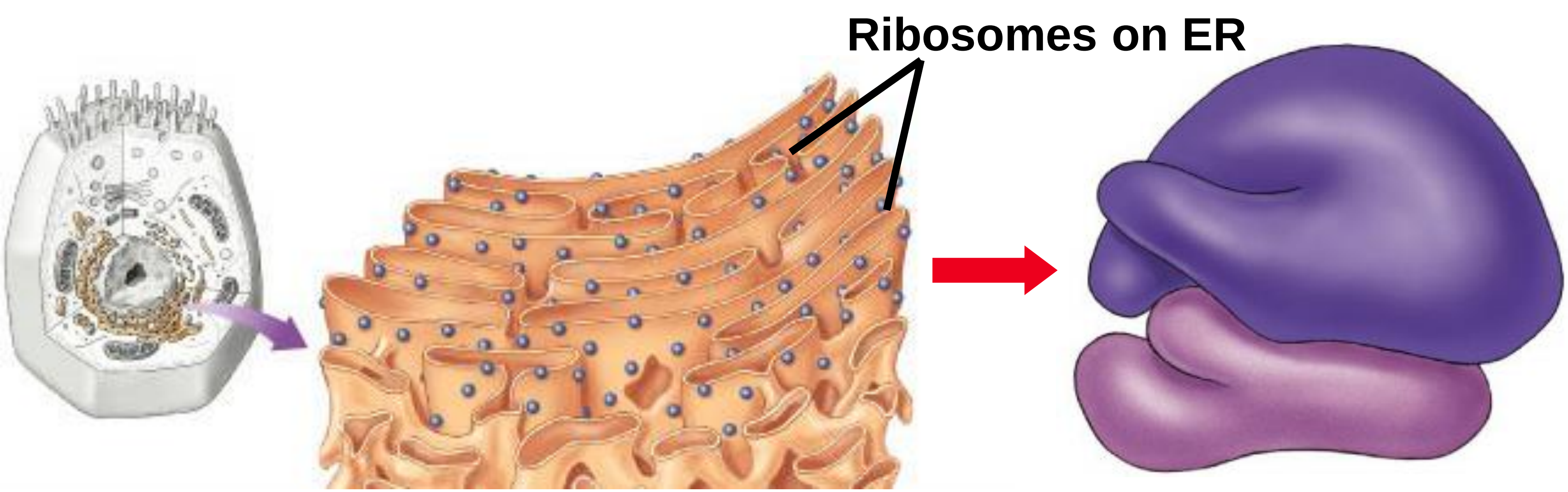
- **Function**
  - control center of cell
  - **protects DNA**
    - instructions for building proteins
- **Structure**
  - **nuclear membrane**
  - **nucleolus**
    - ribosome factory
  - **chromosomes**
    - DNA

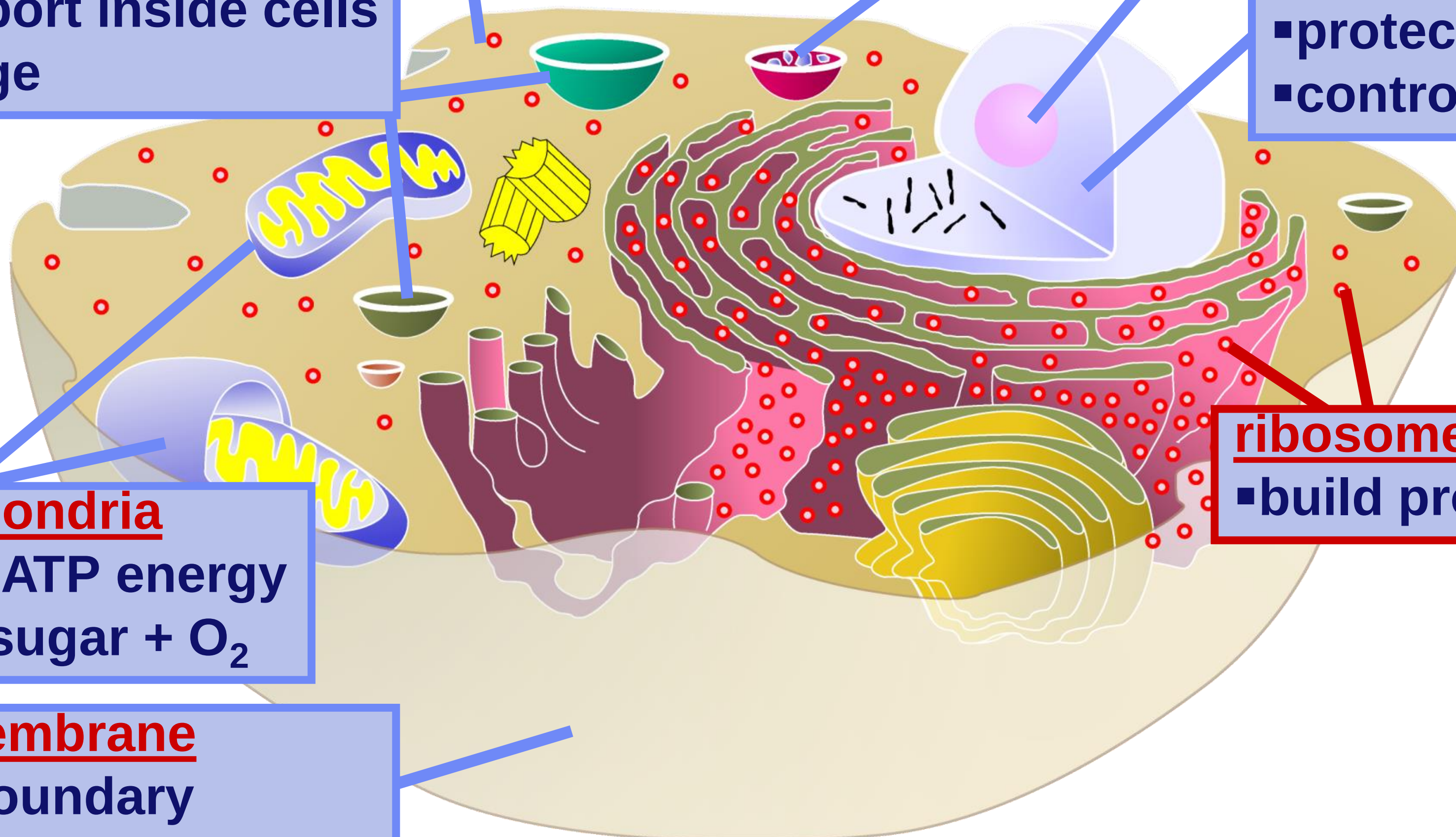



cytoplasm
▪jelly-like material holding organelles in place
lysosome
▪food digestion
▪garbage disposal & recycling
nucleolus
▪produces ribosomes
vacuole & vesicles
▪transport inside cells
▪storage
nucleus
▪protects DNA
▪controls cell
chromosomes
▪DNA
mitochondria
▪make ATP energy from sugar + $O_2$
cell membrane
▪cell boundary
▪controls movement of materials in & out
▪recognizes signals

# Ribosomes

- <u>Function</u>
  - <u>protein factories</u>
  - read instructions to build proteins from DNA
- <u>Structure</u>
  - some <u>free</u> in cytoplasm
  - some <u>attached</u> to ER





**cytoplasm**
- jelly-like material holding organelles in place

**lysosome**
- food digestion
- garbage disposal & recycling

**nucleolus**
- produces ribosomes

**vacuole & vesicles**
- transport inside cells
- storage

**nucleus**
- protects DNA
- controls cell

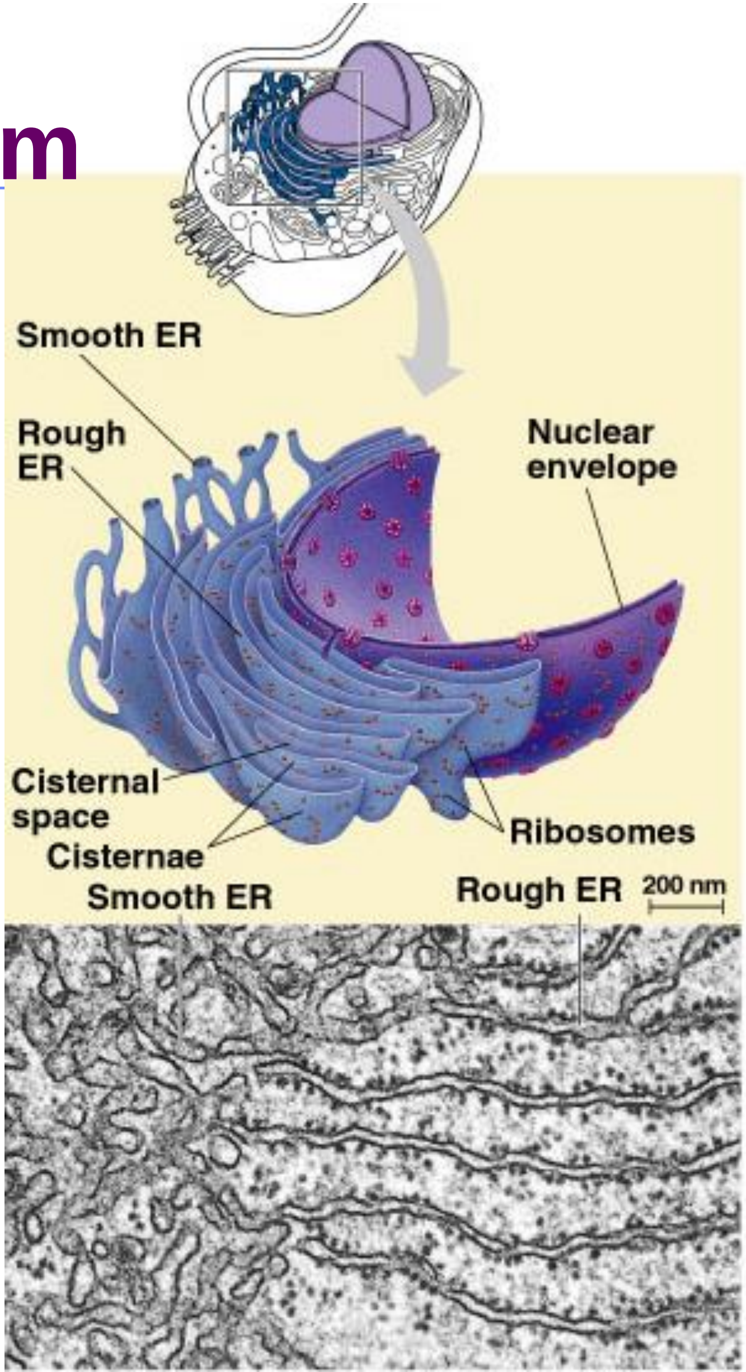
**ribosomes**
- build proteins

**mitochondria**
- make ATP energy from sugar + $O_2$

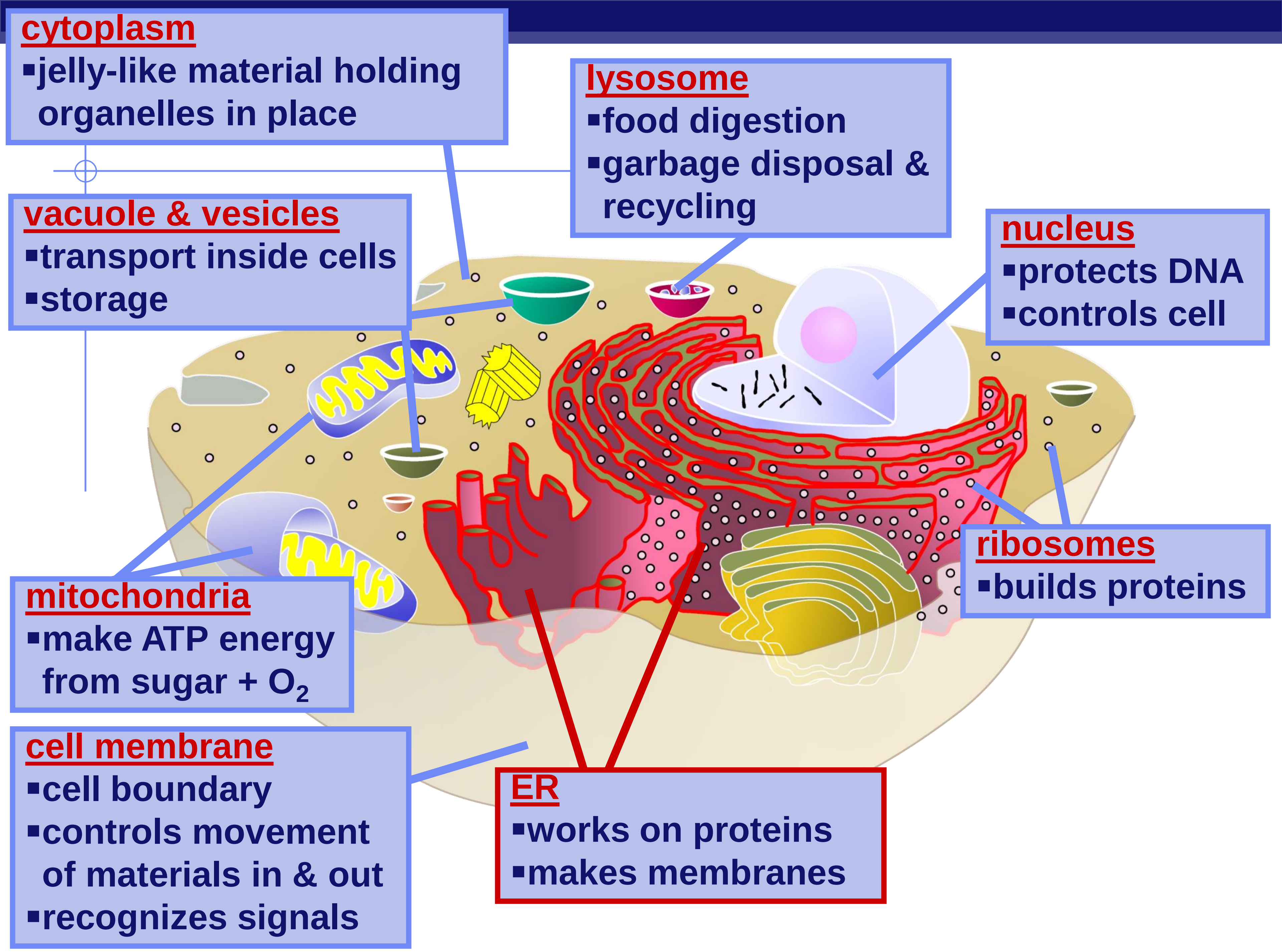
**cell membrane**
- cell boundary
- controls movement of materials in & out
- recognizes signals

# Endoplasmic Reticulum

- **Function**
  - **works on proteins**
    - helps complete the proteins after ribosome builds them
  - **makes membranes**
- **Structure**
  - **rough ER**
    - ribosomes attached
    - works on proteins
  - **smooth ER**
    - makes membranes




Reg


cytoplasm
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▪food digestion
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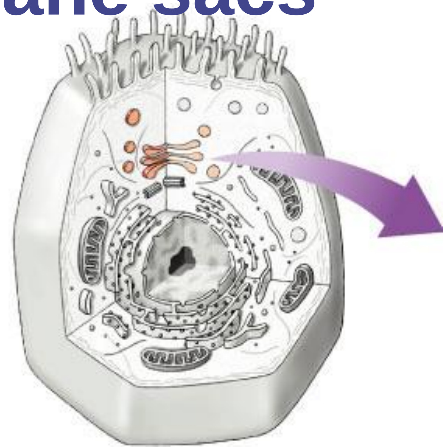
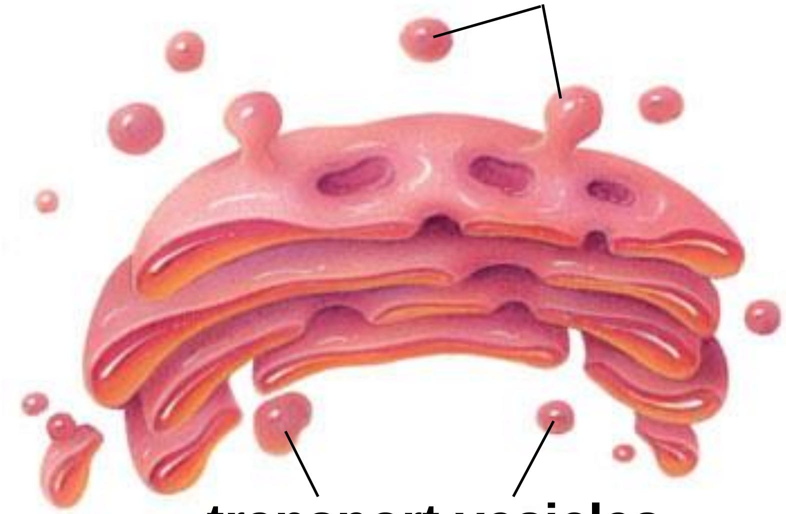
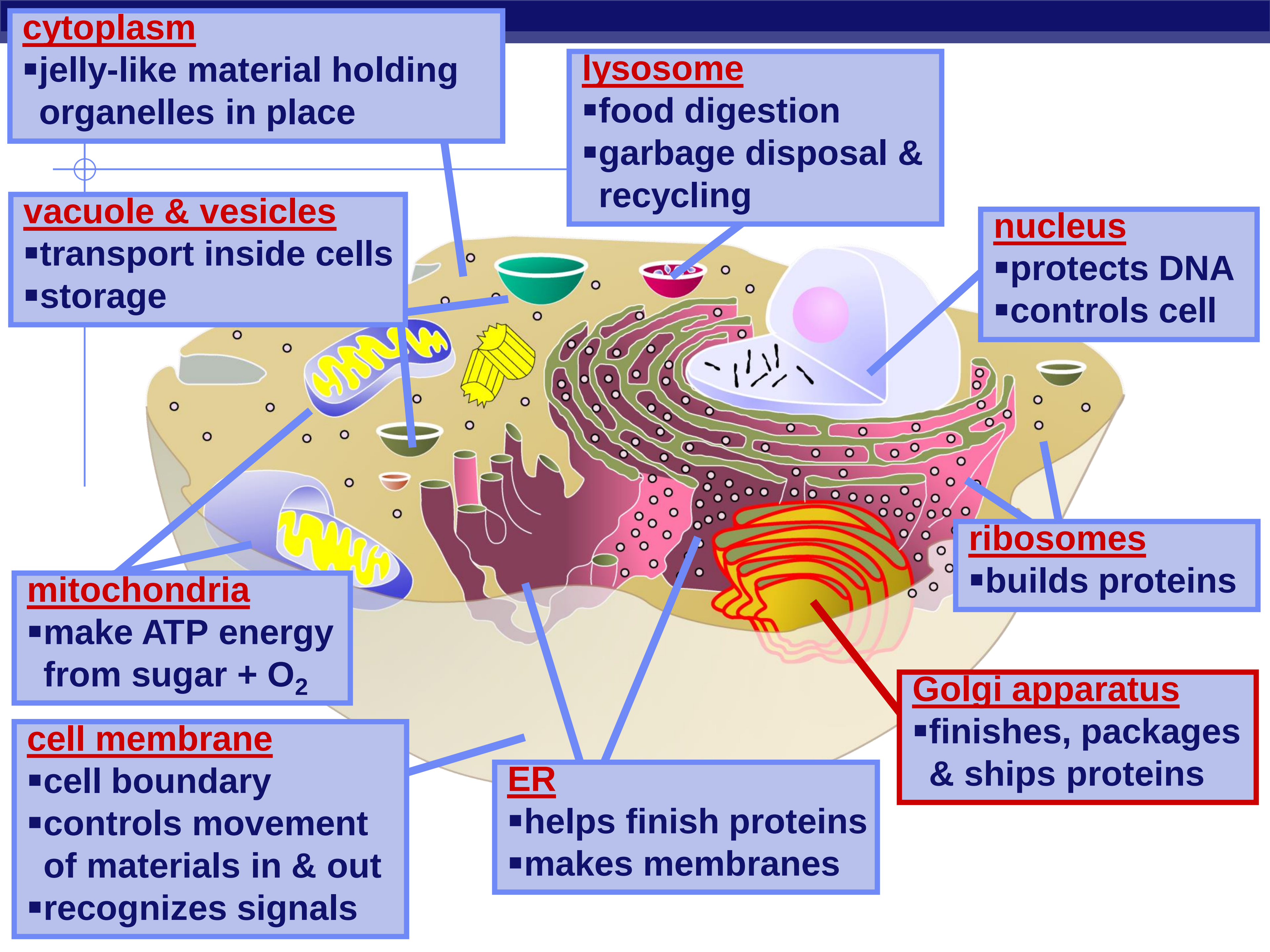
▪storage
nucleus
▪protects DNA
▪controls cell
ribosomes
▪builds proteins
mitochondria
▪make ATP energy from sugar + $O_2$
cell membrane
▪cell boundary
▪controls movement of materials in & out
▪recognizes signals
ER
▪works on proteins
▪makes membranes

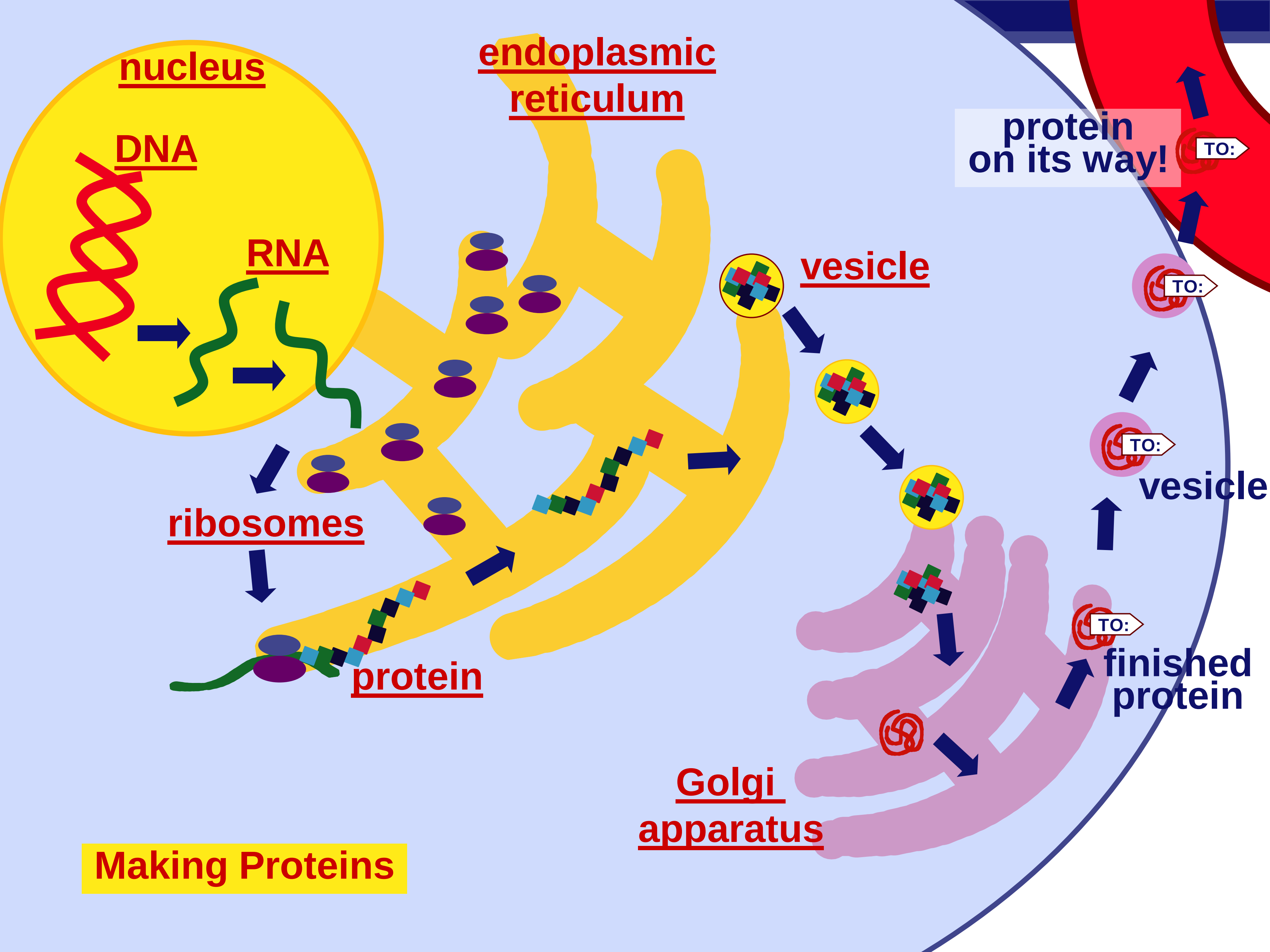
# Golgi Apparatus

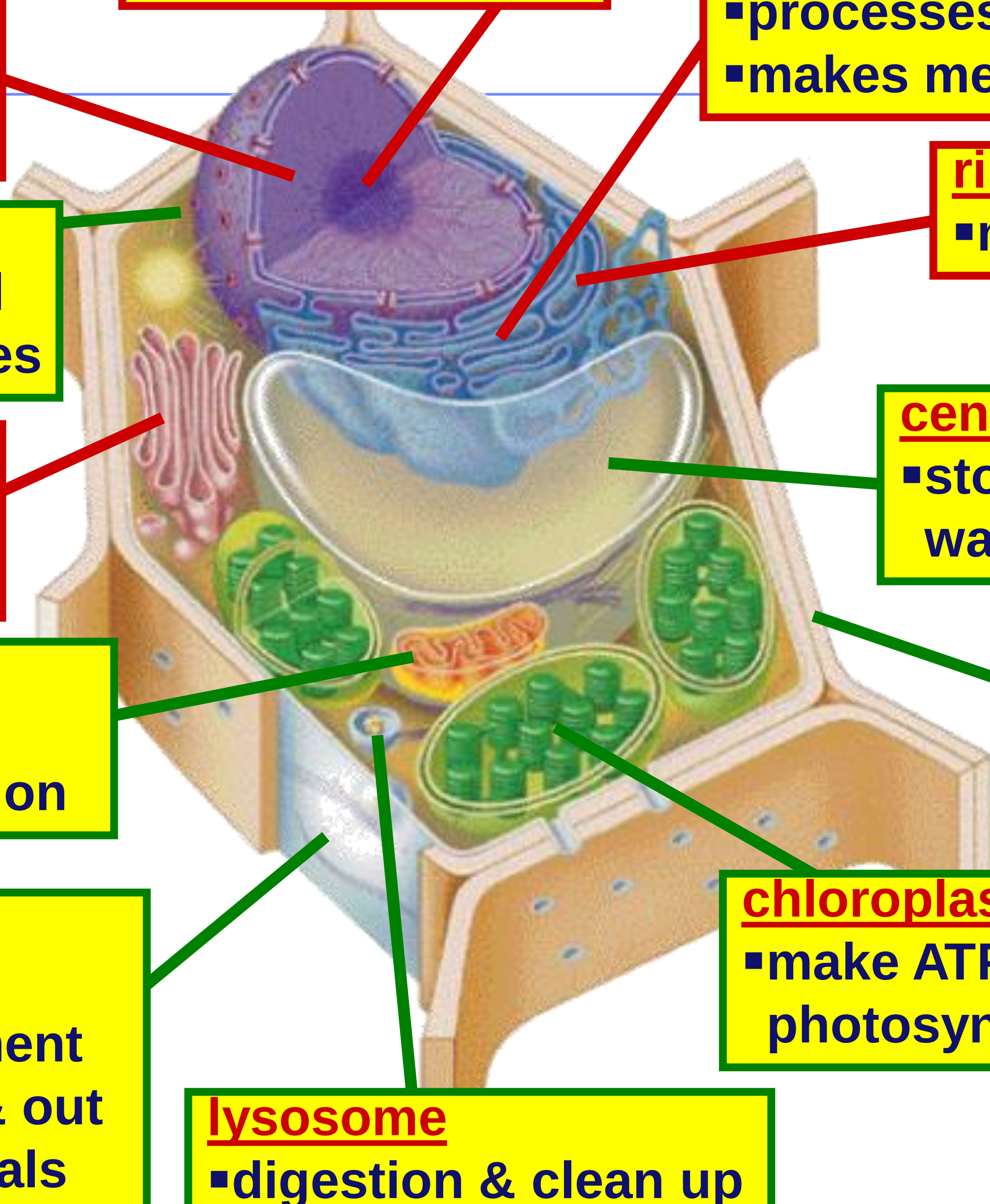
- **Function**
  - finishes, sorts, labels & ships proteins
    - like UPS headquarters
      - shipping & receiving department
  - ships proteins in vesicles
    - "UPS trucks"
- **Structure**
  - membrane sacs






cytoplasm
▪jelly-like material holding organelles in place
lysosome
▪food digestion
▪garbage disposal & recycling
vacuole & vesicles
▪transport inside cells
▪storage
nucleus
▪protects DNA
▪controls cell
ribosomes
▪builds proteins
mitochondria
▪make ATP energy from sugar + $O_2$
Golgi apparatus
▪finishes, packages & ships proteins
cell membrane
▪cell boundary
▪controls movement of materials in & out
▪recognizes signals
ER
▪helps finish proteins
▪makes membranes

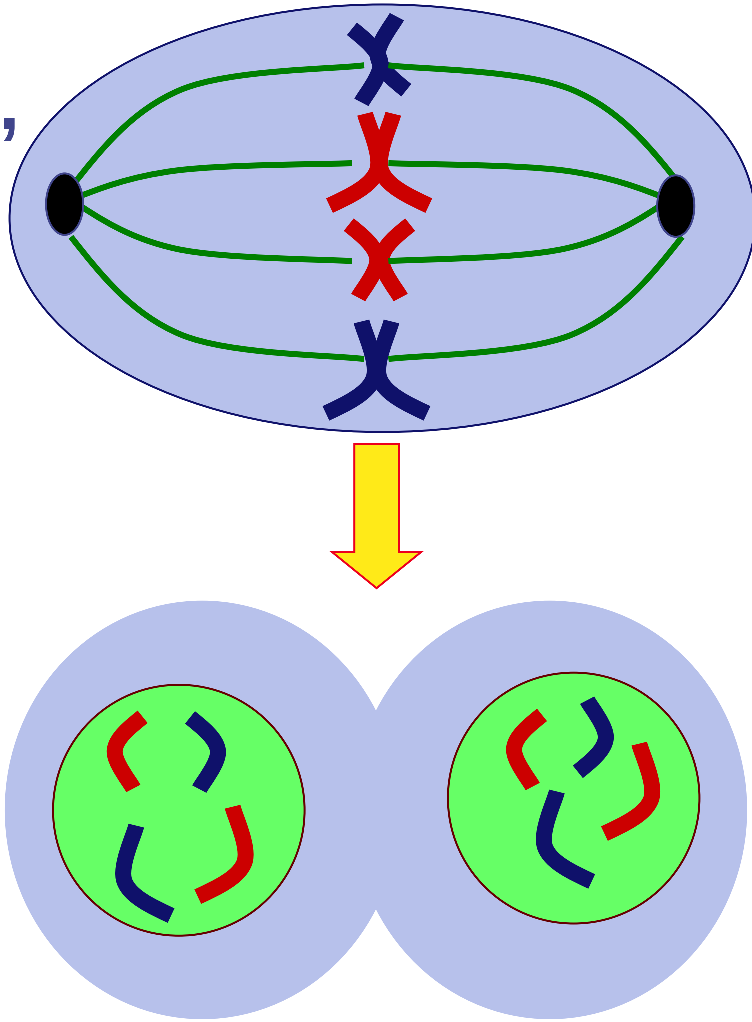

nucleus
DNA
RNA
endoplasmic reticulum
ribosomes
protein
vesicle
protein on its way!
TO:
TO:
TO:
vesicle
TO:
finished protein
Golgi apparatus
Making Proteins



nucleolus
▪make ribosomes
nucleus
▪control cell
▪protects DNA
endoplasmic reticulum
▪processes proteins
▪makes membranes
ribosomes
▪make proteins
cytoplasm
▪jelly-like material around organelles
Golgi apparatus
▪finish & ship proteins
central vacuole
▪storage: food, water or waste
mitochondria
▪make ATP in cellular respiration
cell wall
▪support
cell membrane
▪cell boundary
▪controls movement of materials in & out
▪recognizes signals
chloroplast
▪make ATP & sugars in photosynthesis
lysosome
▪digestion & clean up

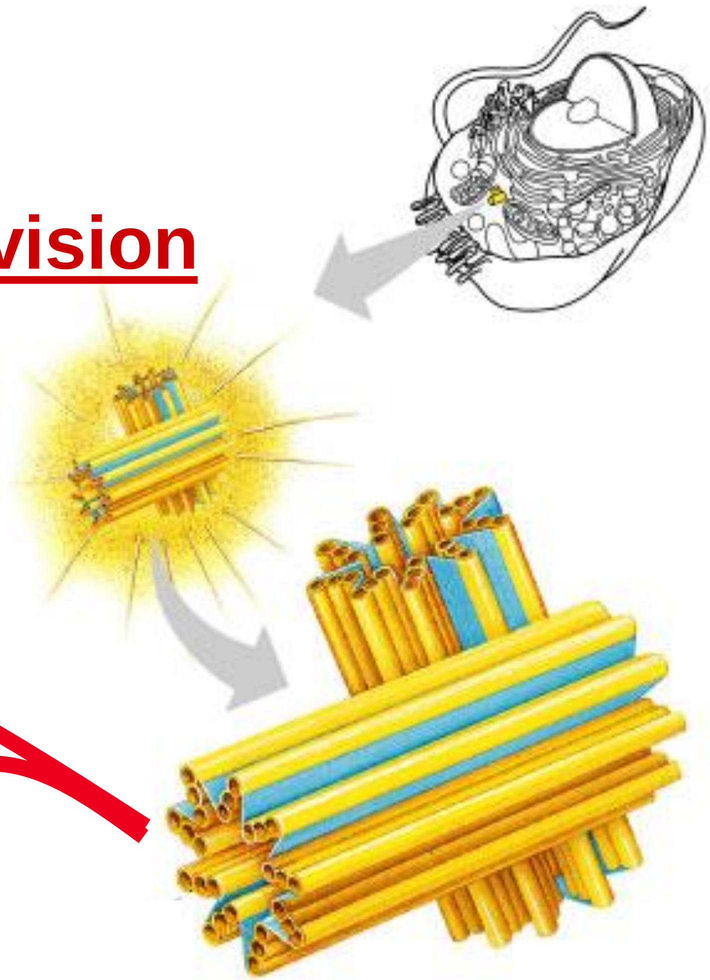
# 3. Cells need to make more cells!

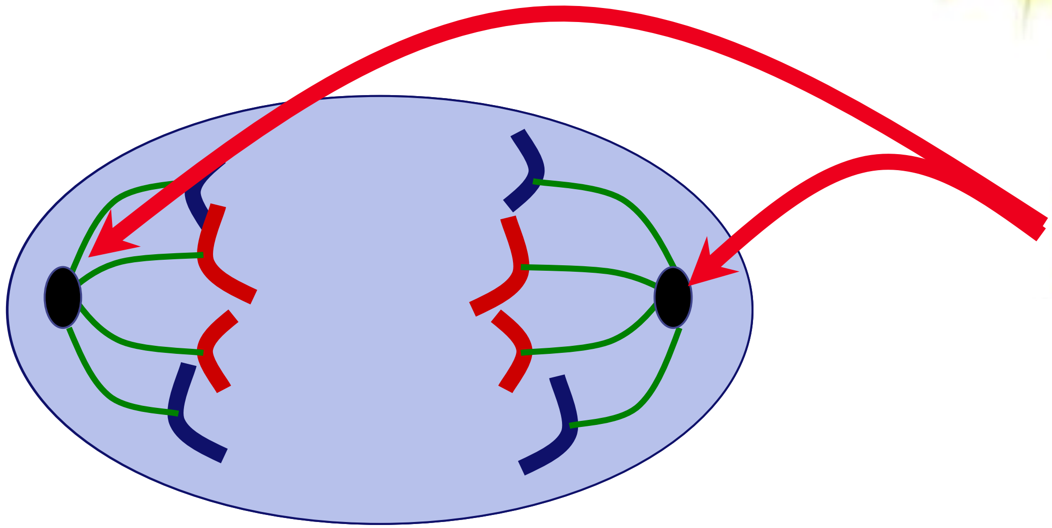
- Making more cells
  - to replace, repair & grow, the cell must…
    - copy their DNA
    - make extra organelles
    - divide the new DNA & new organelles between 2 new "daughter" cells
  - organelles that do this work…
    - nucleus
    - centrioles

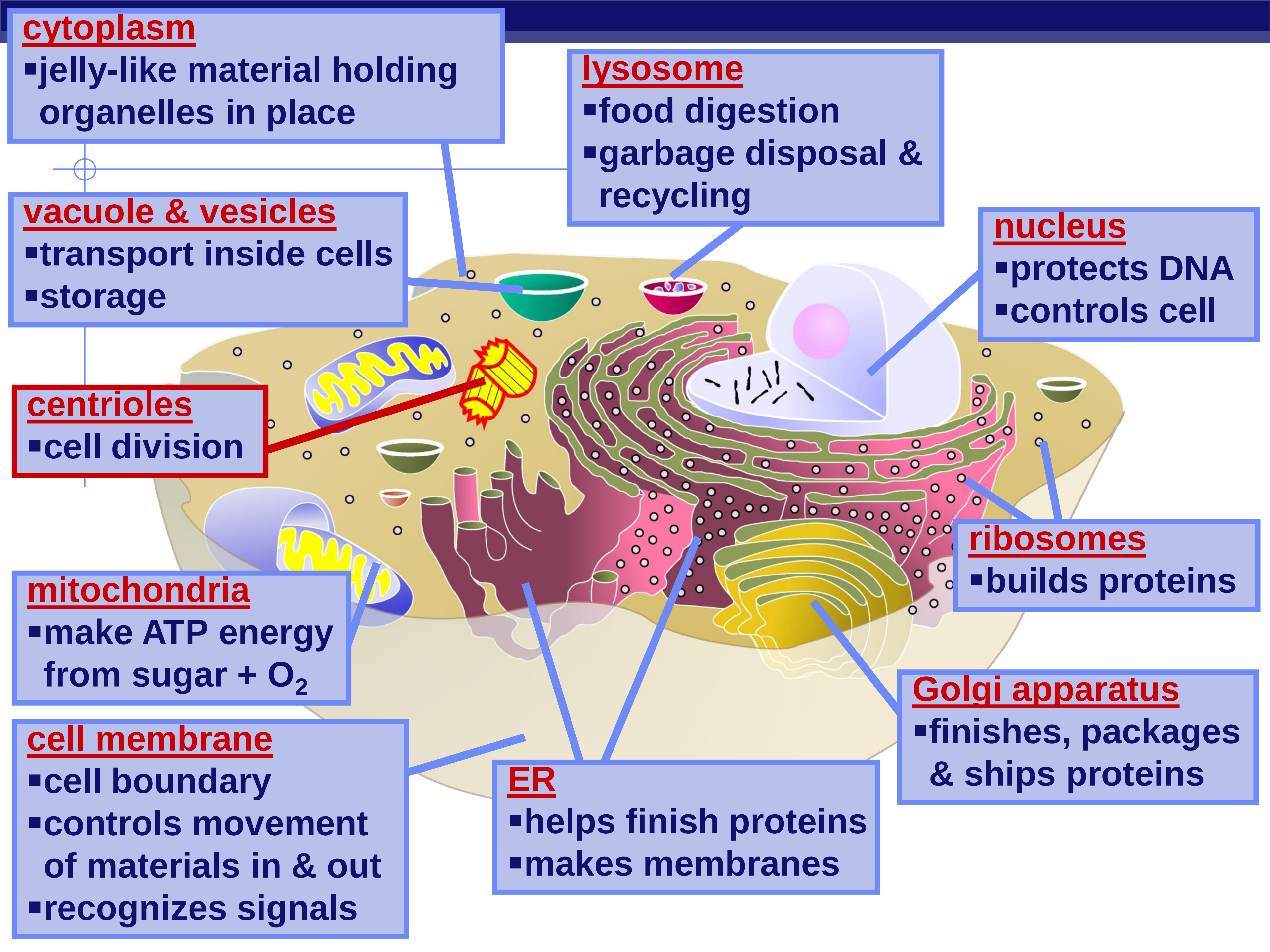


# Centrioles

- <u>Function</u>
  - <u>help coordinate cell division</u>
    - only in animal cells
- <u>Structure</u>
  - one pair in each cell






cytoplasm
▪jelly-like material holding organelles in place
lysosome
▪food digestion
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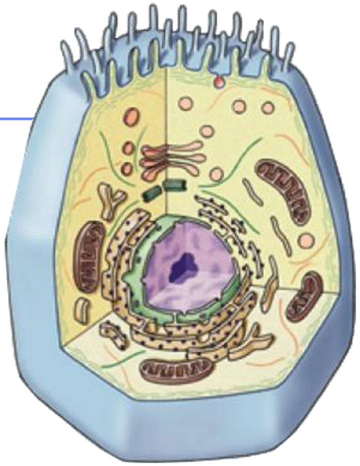
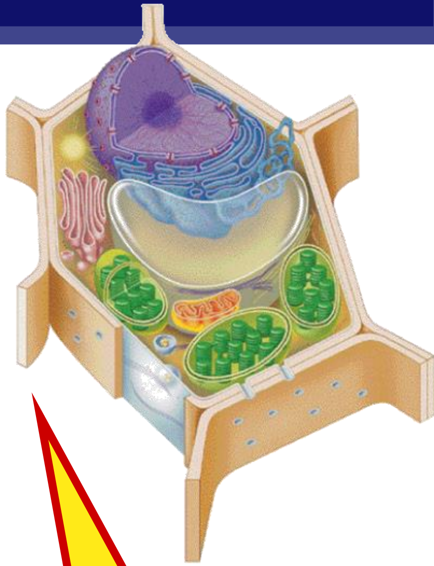
vacuole & vesicles
▪transport inside cells
▪storage
nucleus
▪protects DNA
▪controls cell
centrioles
▪cell division
ribosomes
▪builds proteins
mitochondria
▪make ATP energy from sugar + $O_2$
cell membrane
▪cell boundary
▪controls movement of materials in & out
▪recognizes signals
ER
▪helps finish proteins
▪makes membranes
Golgi apparatus
▪finishes, packages & ships proteins

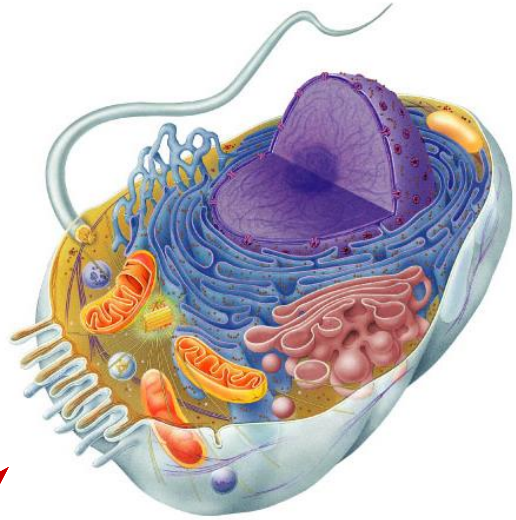
# Cell Summary

- **Cells have 3 main jobs**
  - **make energy**
    - need food + $O_2$
    - cellular respiration & photosynthesis
    - need to remove wastes
  - **make proteins**
    - need instructions from DNA
    - need to chain together amino acids & "finish" & "ship" the protein
  - **make more cells**
    - need to copy DNA & divide it up to daughter cells





Our organelles do all those jobs!



Thanks

That's my
cellular story…

Any Questions?

F Y B Sc Zoology Paper II

# Course Title: Cell Biology

Course Code: ZO – 122

Semester - II (2 credits – 30 Hours)

Chapter No. 7

# Cell Division

By

Dr. Bhausaheb R Ghorpade

*bhaughorpade@shrianandcollege.com*

**Note:** This material is only for educational purpose and is non -commercial

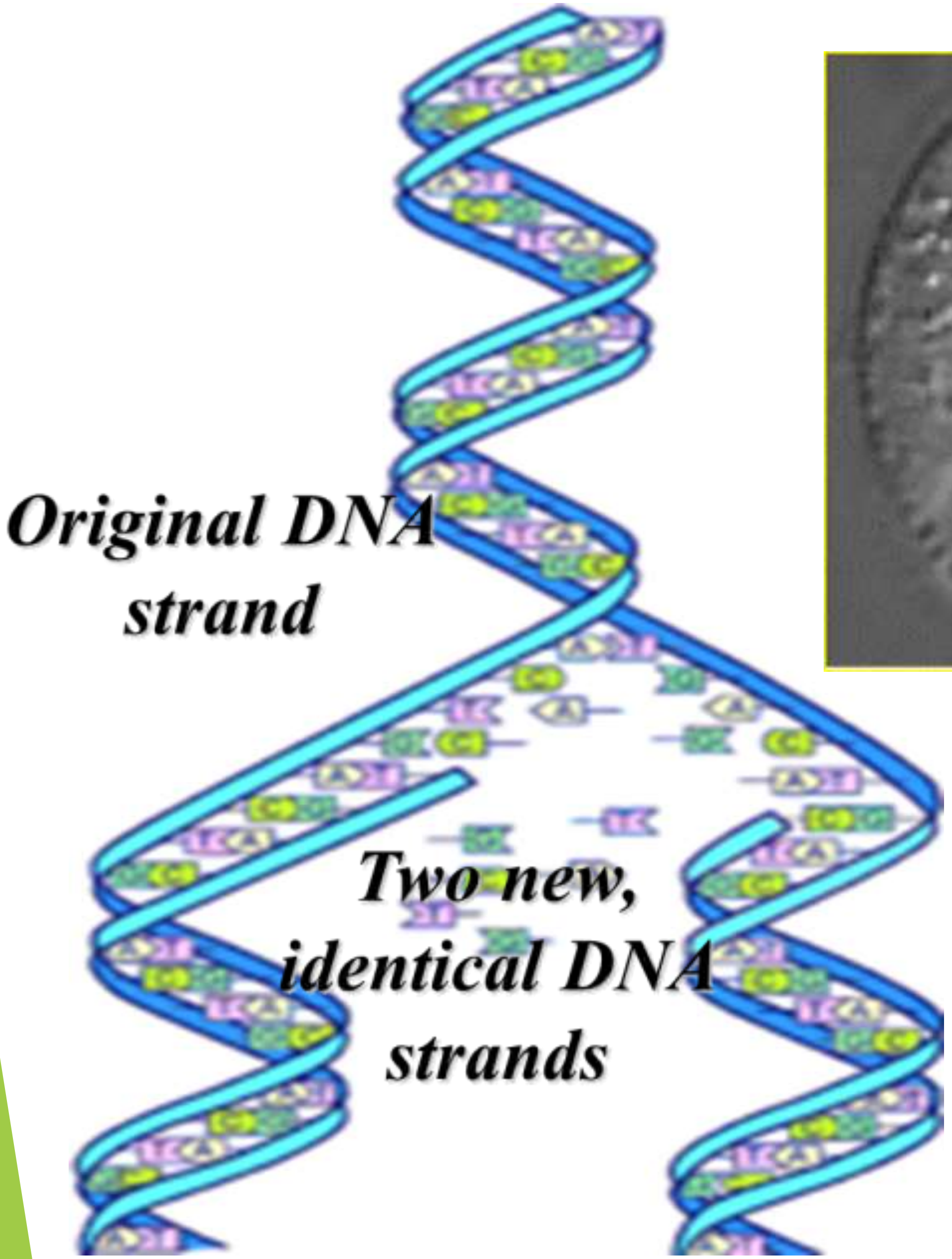
# 7 Cell Division:

**Content: 7.1Introduction ,7.2 Cell cycle, (G1,S,G2,M phases)., 7.3 Mitosis. ,7.4 Meiosis.**

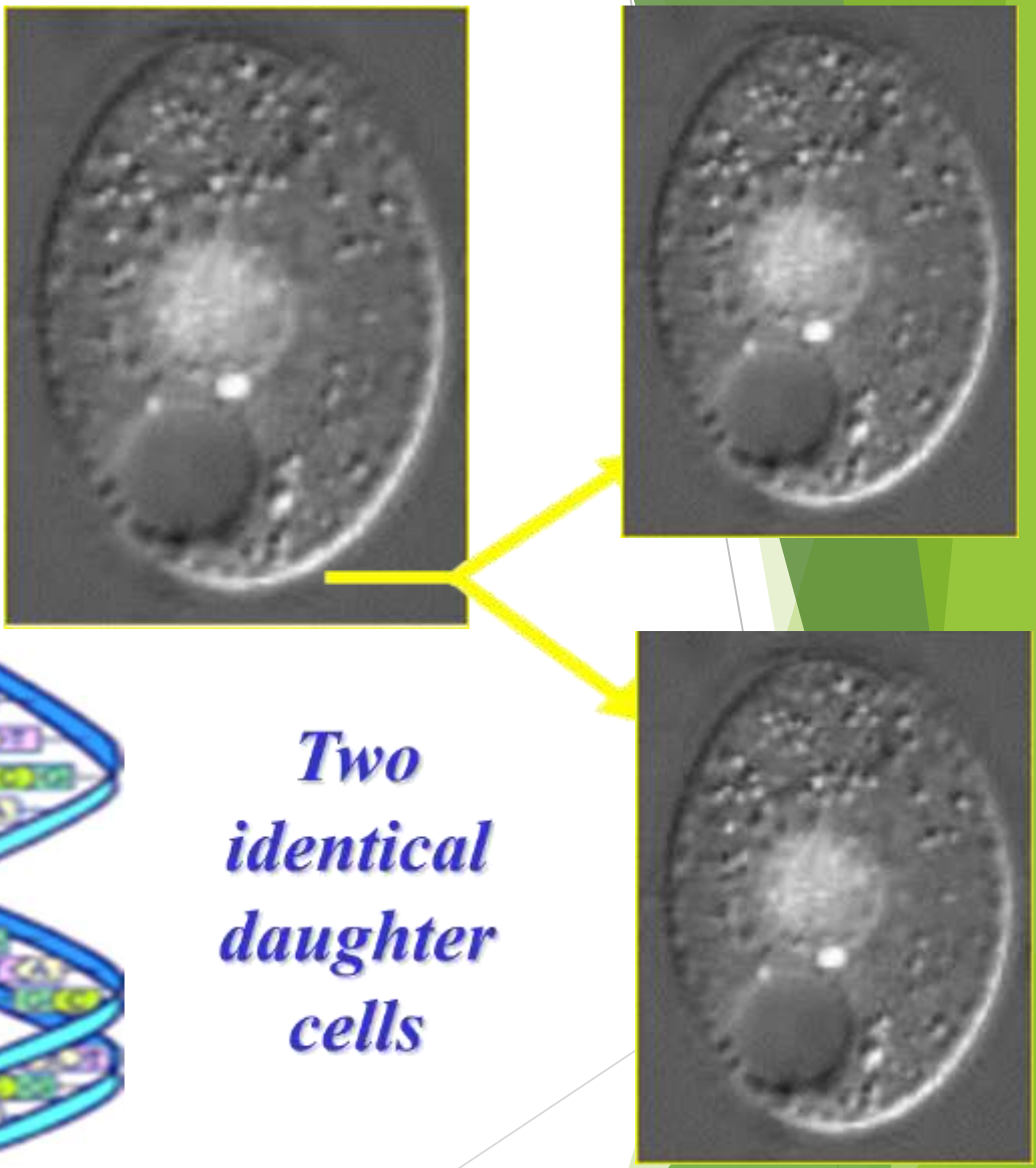
## 7.1Introduction:

- **Cell division is the process by which a parent cell divides and gives rise to two or more daughter cells.**
- **It is a means of reproduction for single-cell organisms.**
- **In multicellular organisms, cell division contributes to growth, development, repair, and the generation of reproductive cells (sperms and eggs).**
- **All cells are derived from pre-existing cells New cells are produced for growth and to replace damaged or old cells**

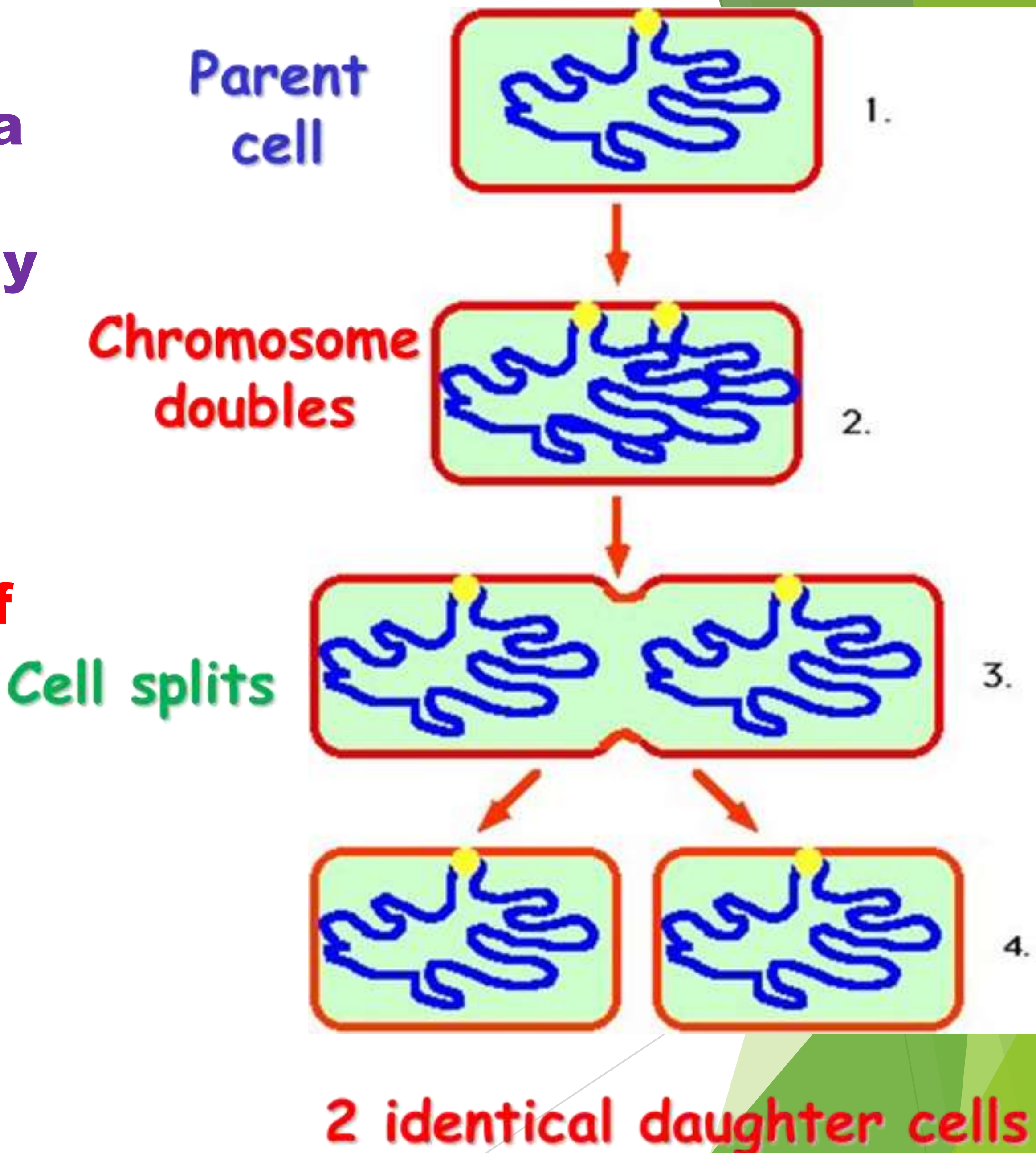
- Differs in prokaryotes (bacteria) and eukaryotes (protists, fungi, plants, & animals)
- The instructions for making cell parts are encoded in the DNA, so each new cell must get a complete set of the DNA molecules
- DNA Replication
- DNA must be copied or replicated before cell division
- Each new cell will then have an identical copy of the DNA




*Two identical daughter cells*



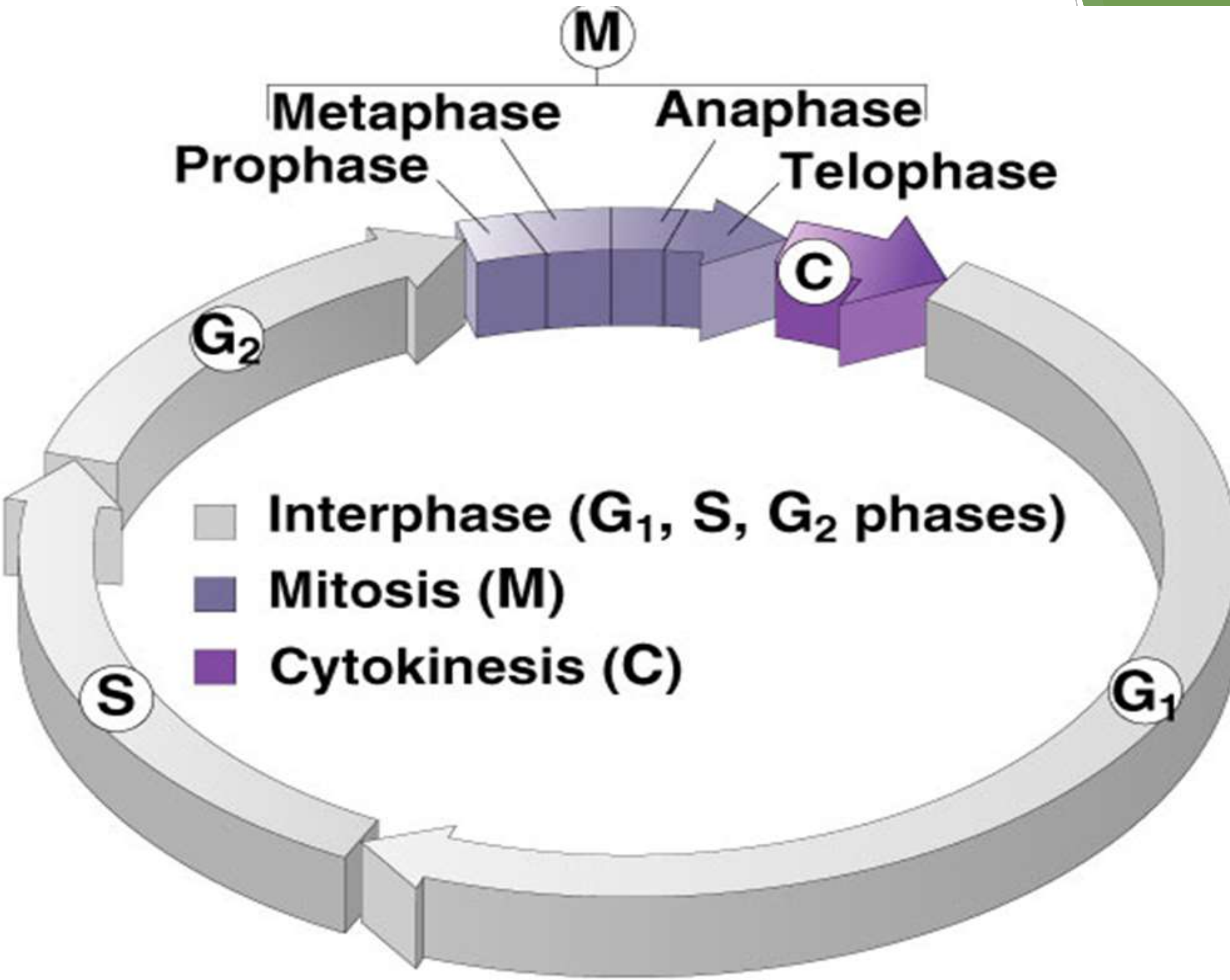
- Prokaryotes such as bacteria divide into 2 identical cells by the process of binary fission
- Single chromosome makes a copy of itself
- Cell wall forms between the chromosomes dividing the cell

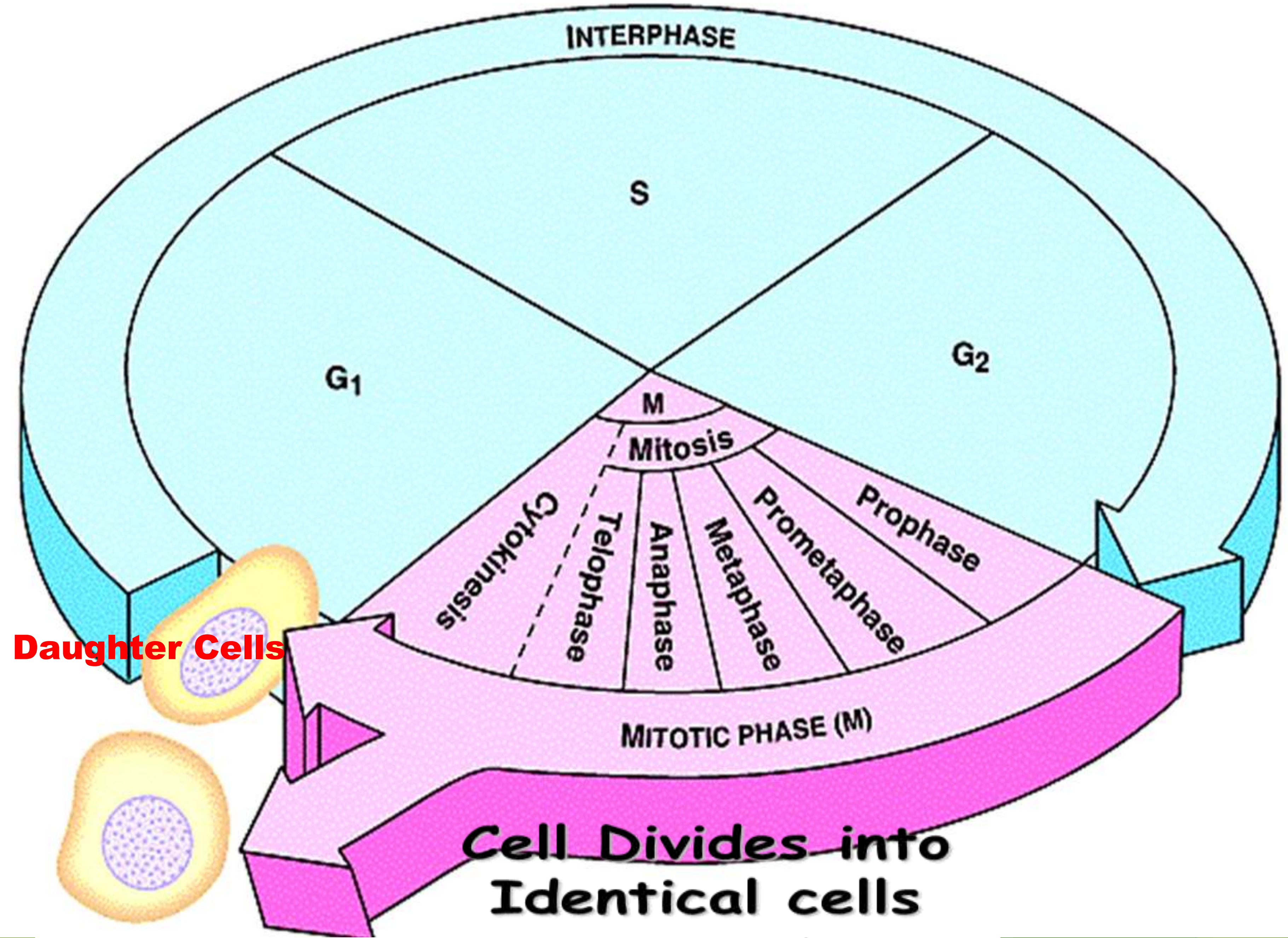


# 7.2 Cell cycle

- **Five Phases of the Cell Cycle**
- **$G_1$ - primary growth phase**
- **S – synthesis; DNA replicated**
- **$G_2$ - secondary growth phase**
  - ***collectively these 3 stages are called interphase***
- **M - mitosis**
- **C - cytokinesis**

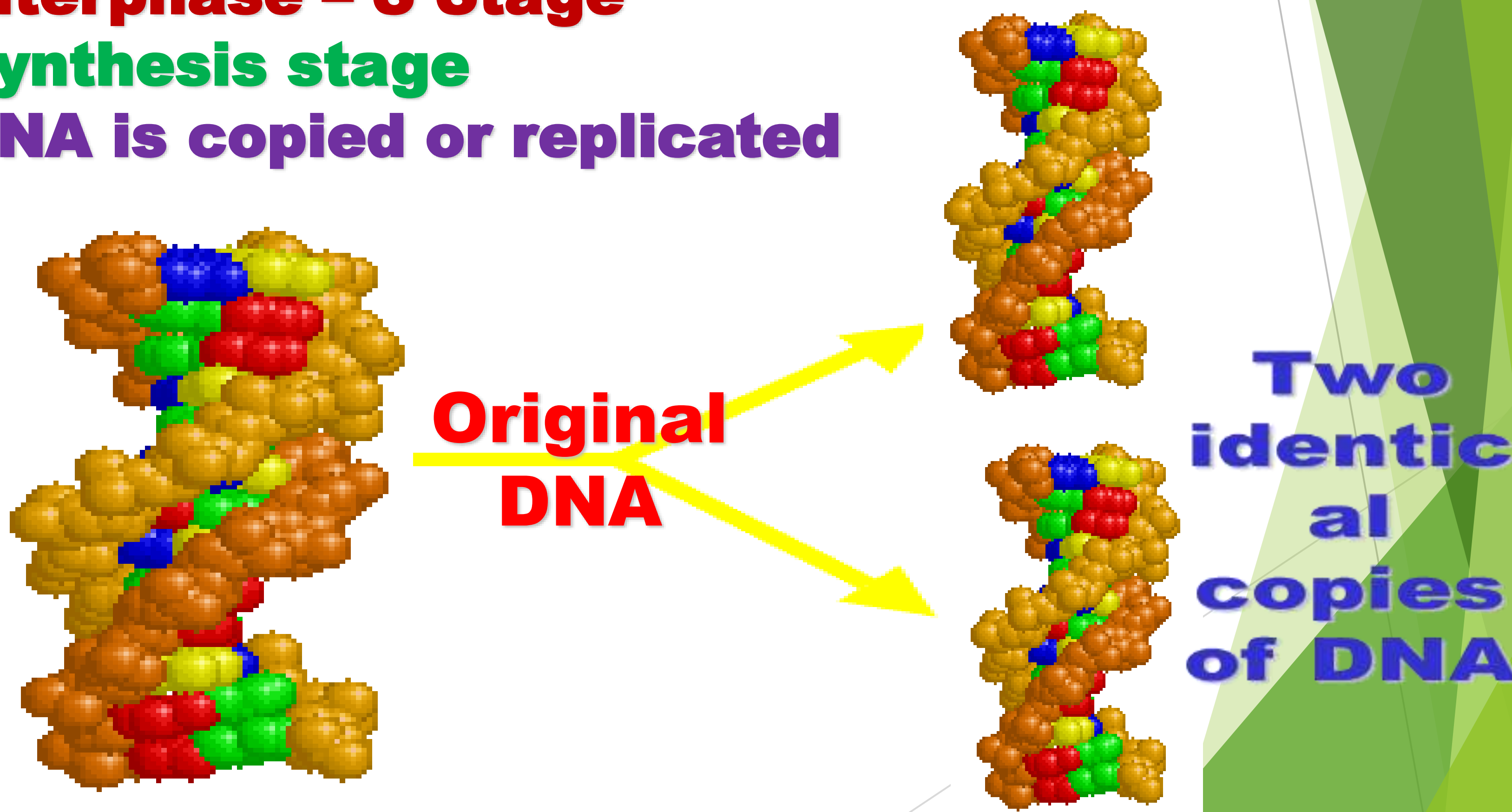
# 7.2 Cell cycle




INTERPHASE
S
G1
G2
M
Mitosis
Cytokinesis
Telophase
Anaphase
Metaphase
Prometaphase
Prophase
MITOTIC PHASE (M)
Daughter Cells
Cell Divides into
Identical cells

## Interphase - G1 Stage

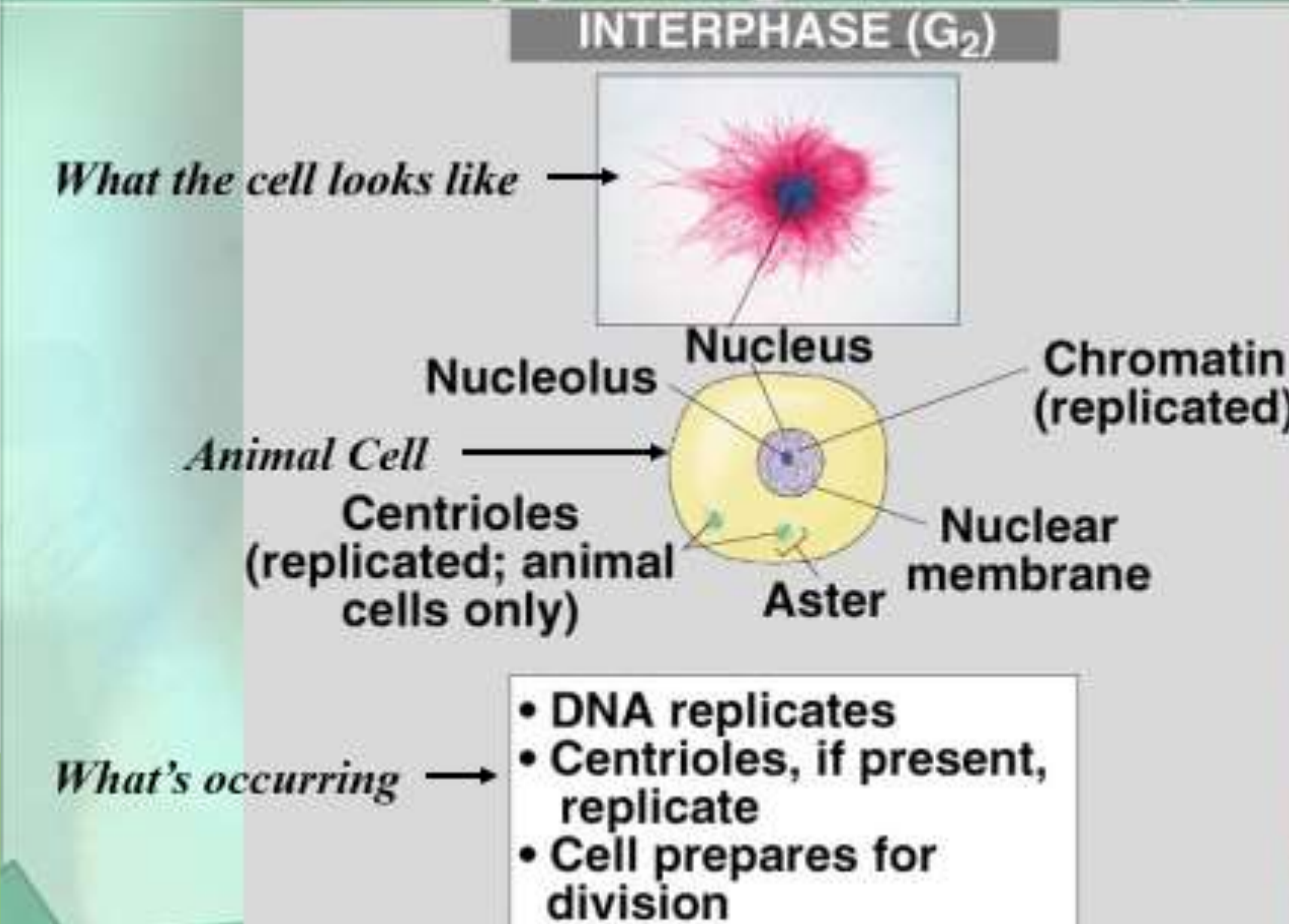
- 1st growth stage after cell division
- Cells mature by making more cytoplasm & organelles
- Cell carries on its normal metabolic activities
- Interphase – S Stage
- Synthesis stage
- DNA is copied or replicated



# Interphase – G2 Stage

- ✓2nd Growth Stage
- ✓Occurs after DNA has been copied
- ✓All cell structures needed for division are made (e.g. centrioles)
- ✓Both organelles & proteins are synthesized

# What's Happening in Interphase?



- 7.3 Mitosis

- Division of the nucleus
- Also called karyokinesis
- Only occurs in eukaryotes
- Has four stages
- Doesn't occur in some cells such as brain cells

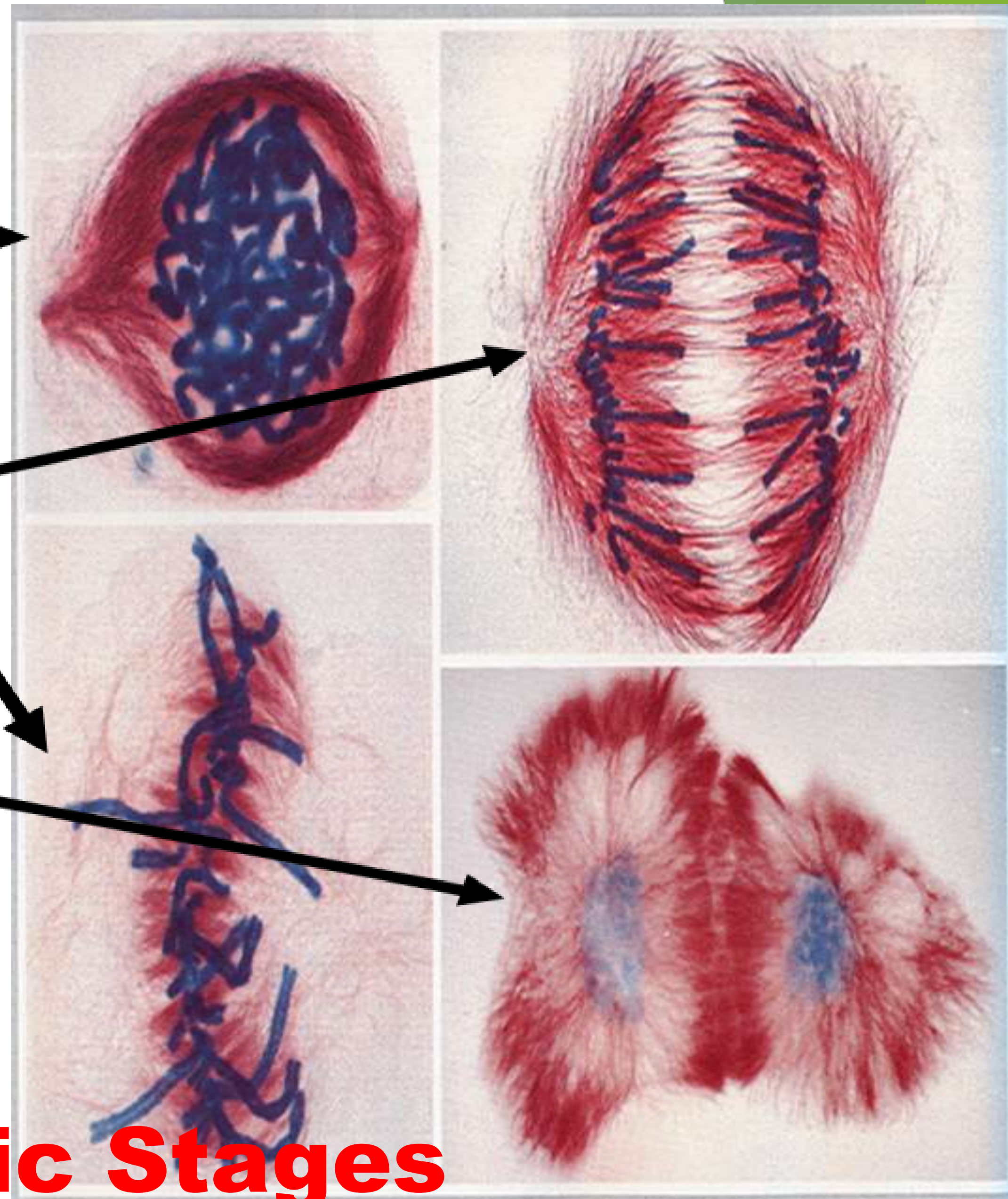
## Mitotic stages

1) Prophase

2)Metaphase

3)Anaphase

4)Telophase

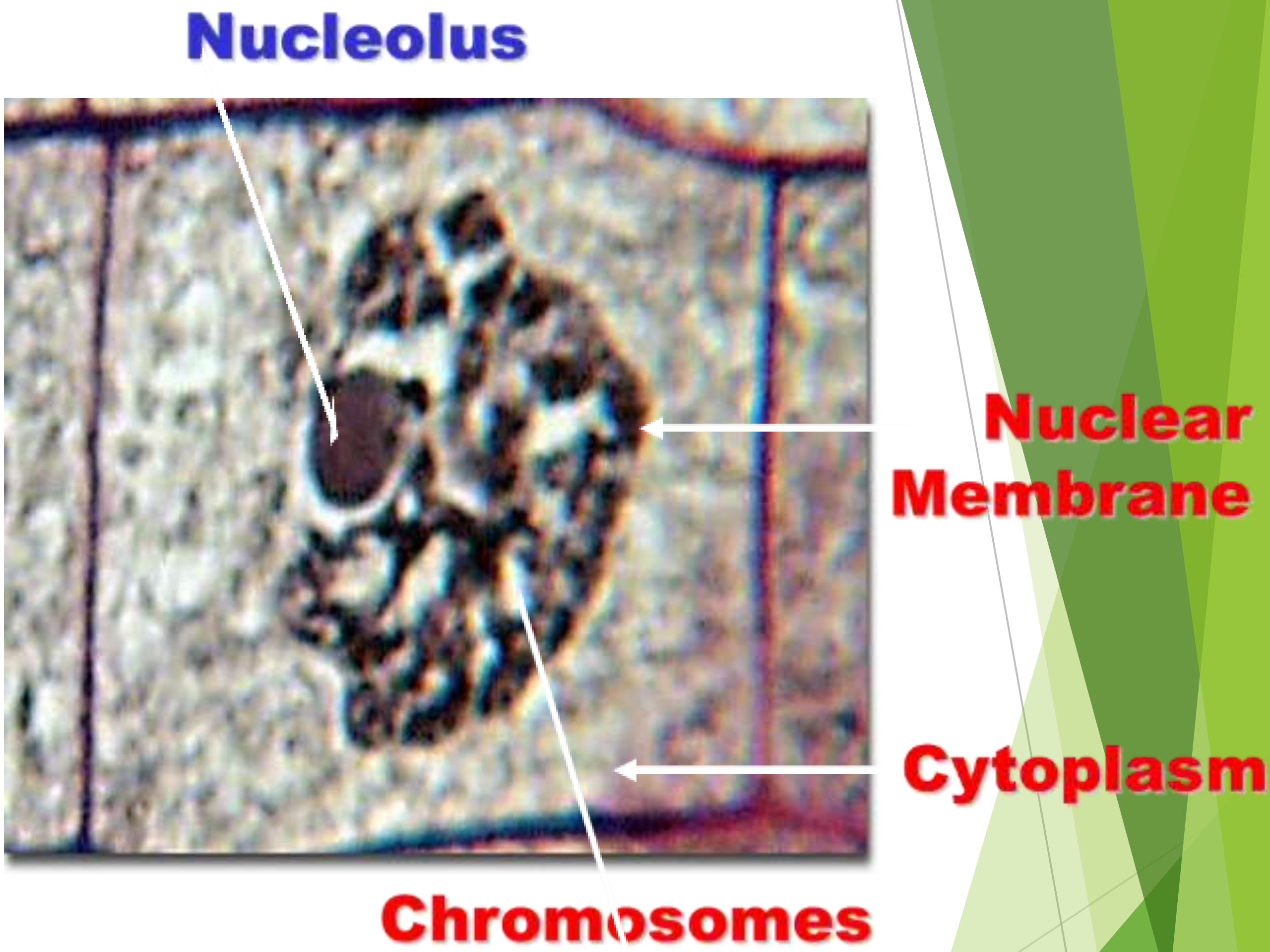


**Four Mitotic Stages**

# 1. Early Prophase

**Chromatin in nucleus condenses to form visible chromosomes**

**Mitotic spindle forms from fibers in cytoskeleton or centrioles (animal)**



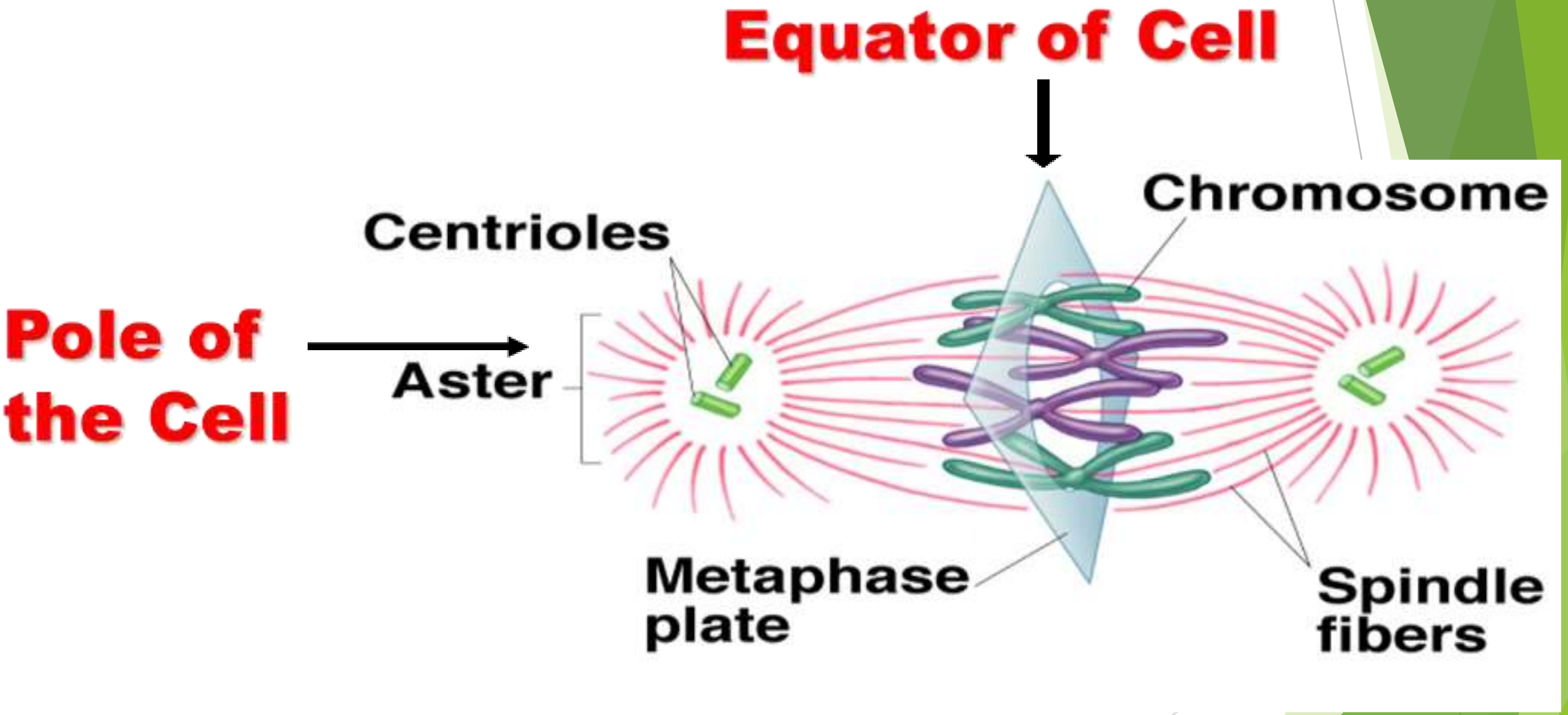
# Late Prophase

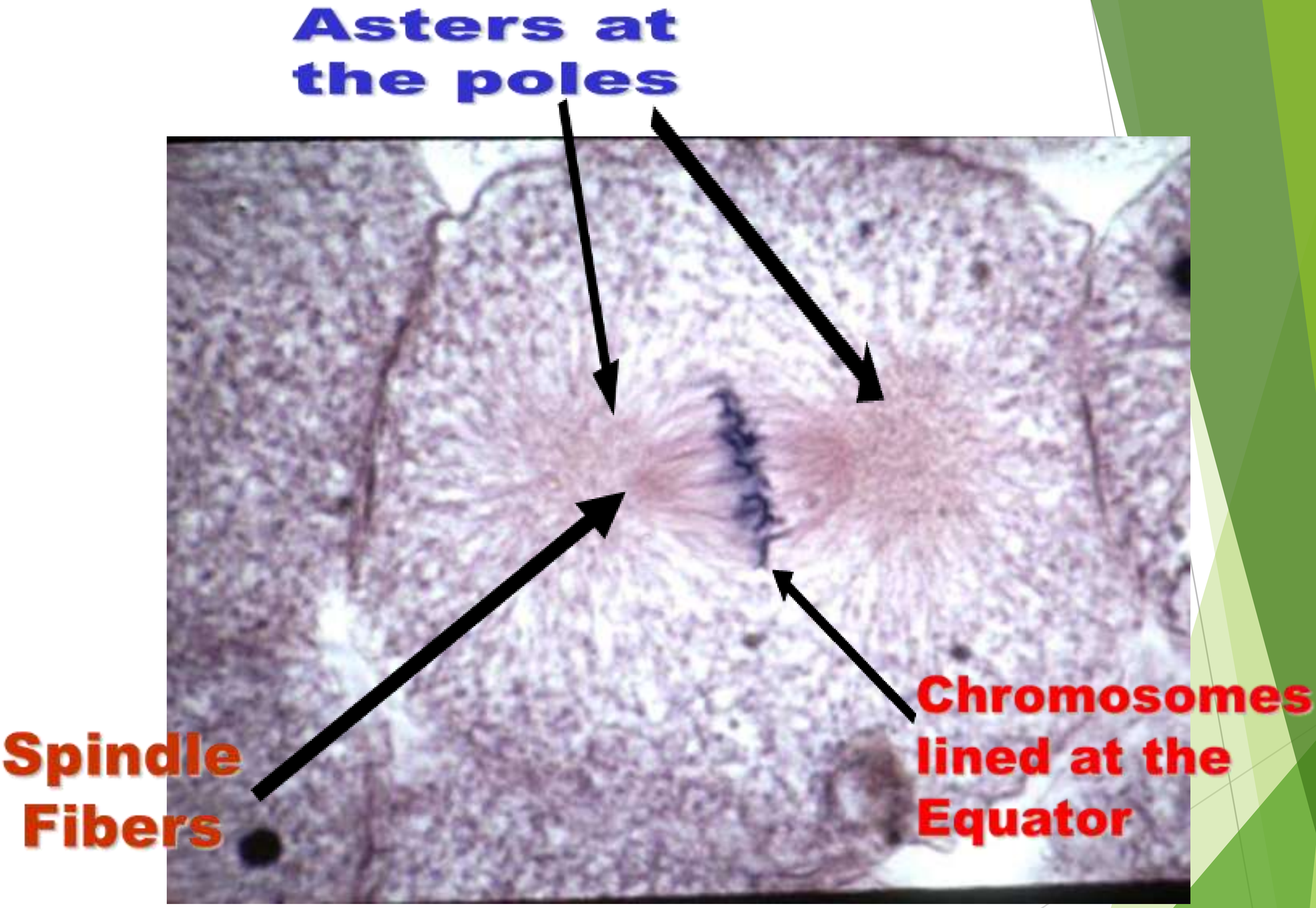

**Nucleus & Nucleolus have disintegrated**

- Nuclear membrane & nucleolus are broken down
- Chromosomes continue condensing & are clearly visible
- Spindle fibers called kinetochores attach to the centromere of each chromosome
- Spindle finishes forming between the poles of the cell

# 2. Metaphase

- Chromosomes, attached to the kinetochore fibers, move to the center of the cell Chromosomes are now lined up at the equator

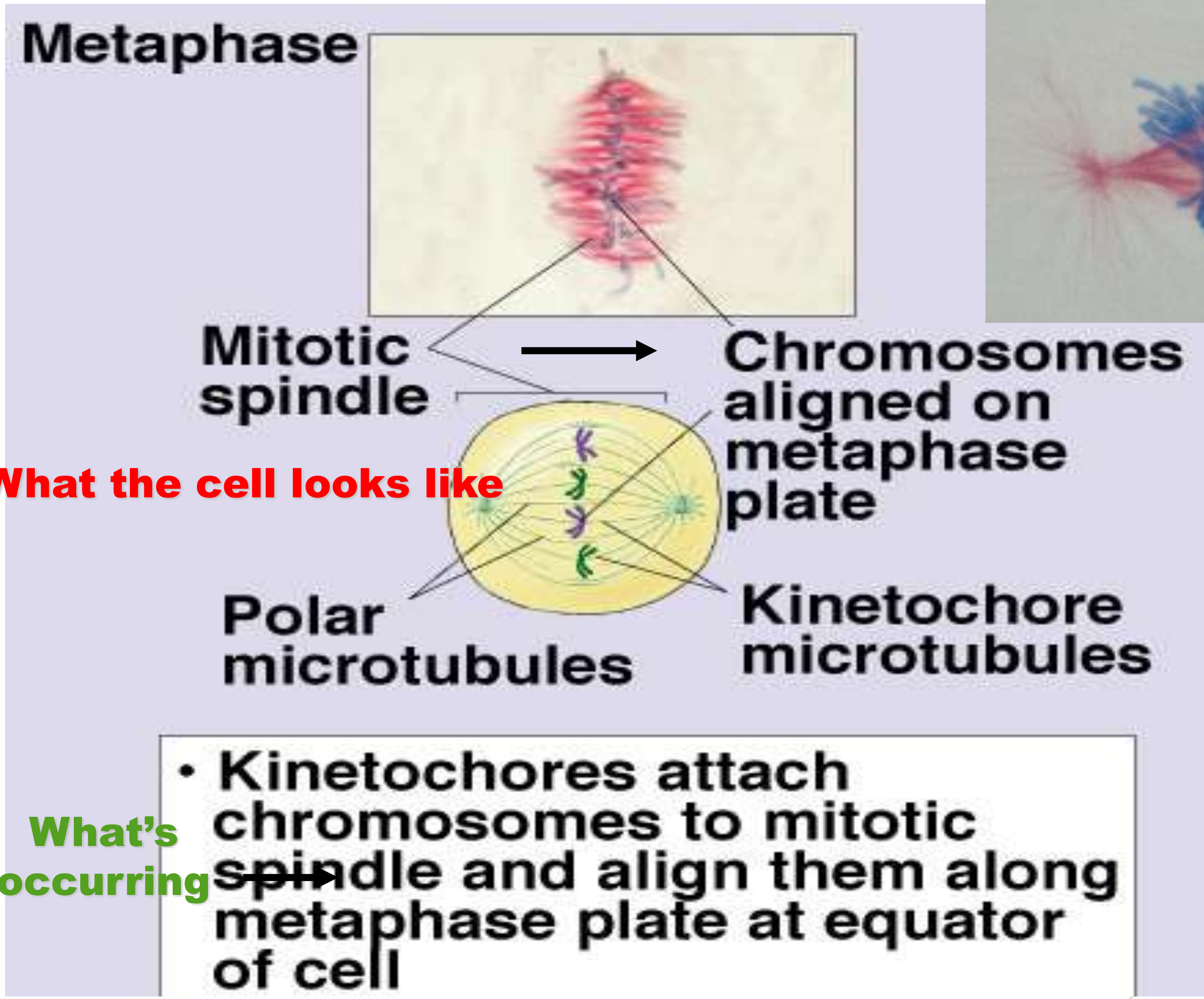


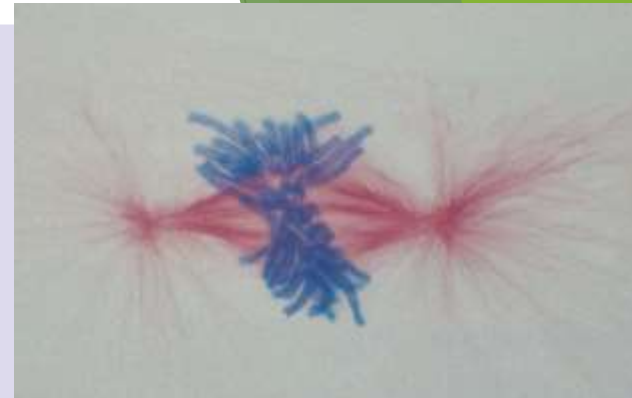

Asters at
the poles
Spindle
Fibers
Chromosomes
lined at the
Equator

# Metaphase

What the cell looks like

What's occurring

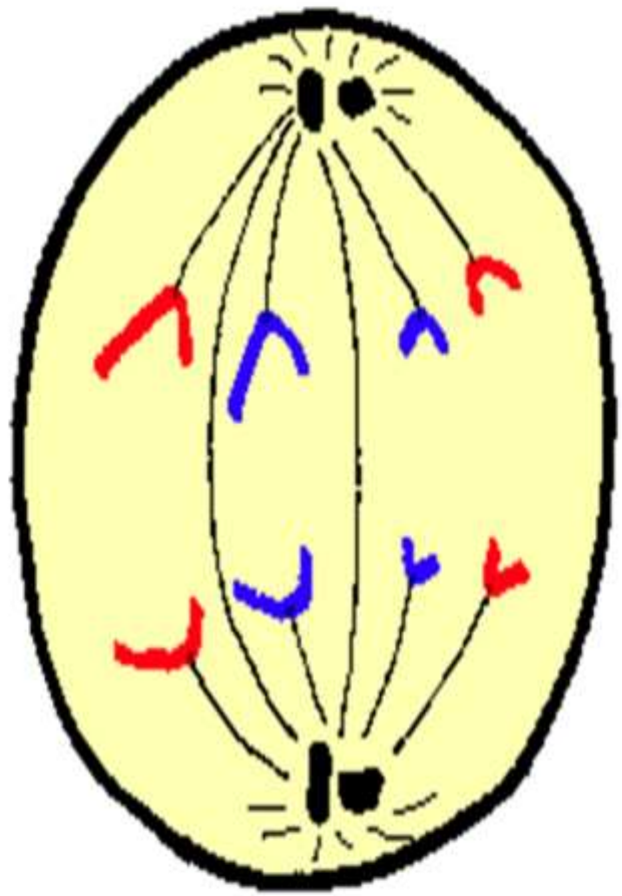


# Review of Metaphase

# 3) Anaphase

**Occurs rapidly Sister chromatids are pulled apart to opposite poles of the cell by kinetochore fibers**

# 4) Telophase

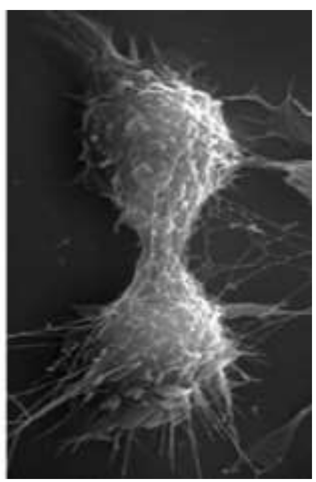
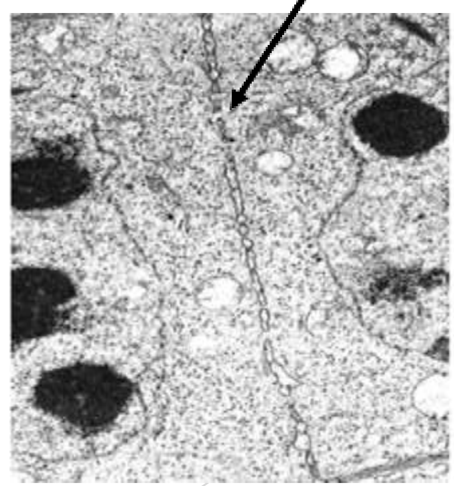
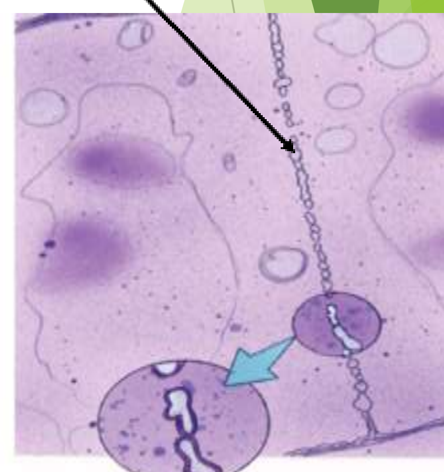
- Sister chromatids at opposite poles
- Spindle disassembles
- Nuclear envelope forms around each set of sister chromatids
- Nucleolus reappears
- CYTOKINESIS occurs
- Chromosomes reappear as chromatin

# Cytokinesis

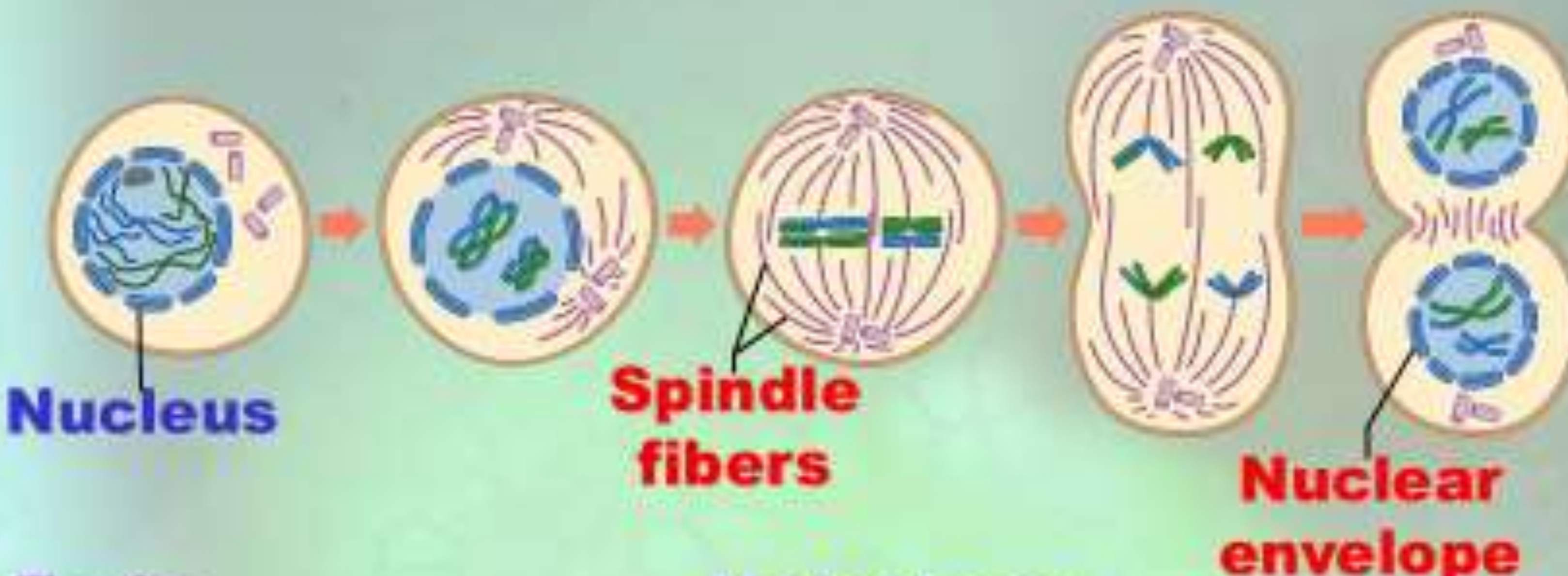
- Means division of the cytoplasm
- Division of cell into two, identical halves called daughter cells
- In plant cells, cell plate forms at the equator to divide cell
- In animal cells, cleavage furrow forms to split cell

Cleavage furrow in animal cell

Cell plate in animal cell

# Meiosis I: Reduction Division



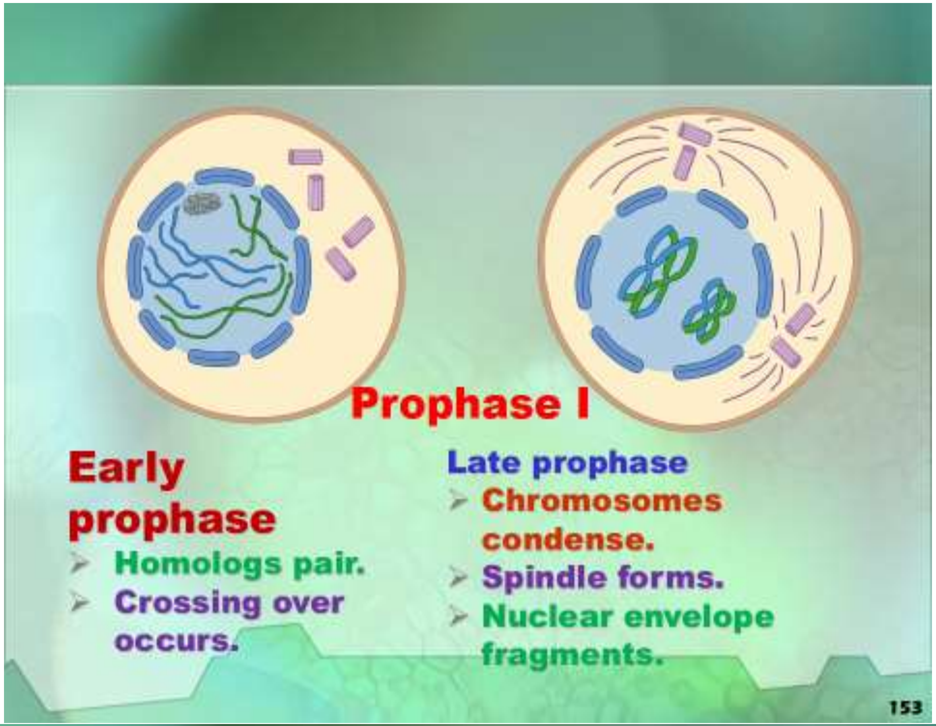

Early Prophase I (Chromosome number doubled)

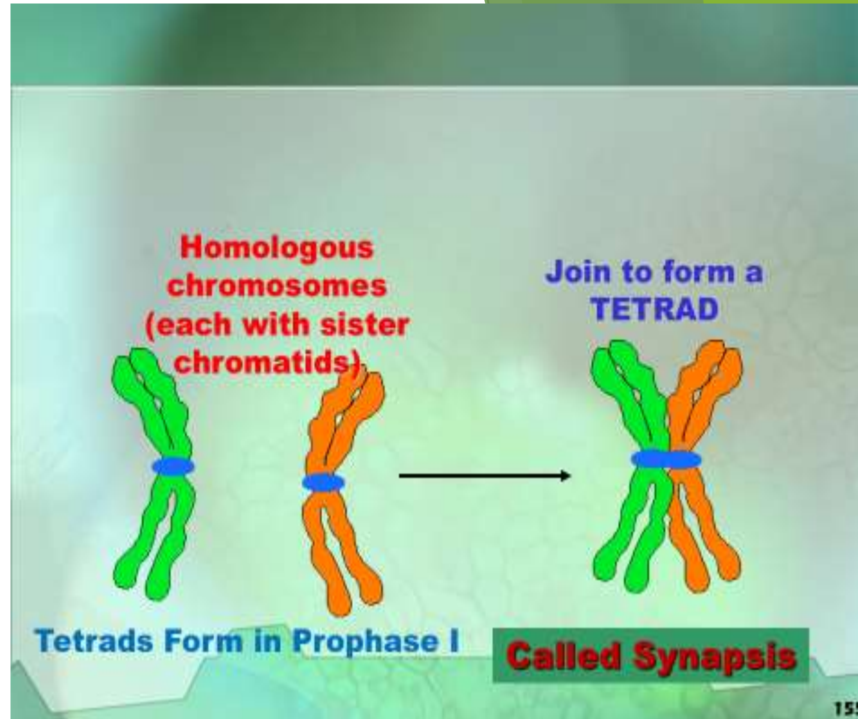
Late Prophase I

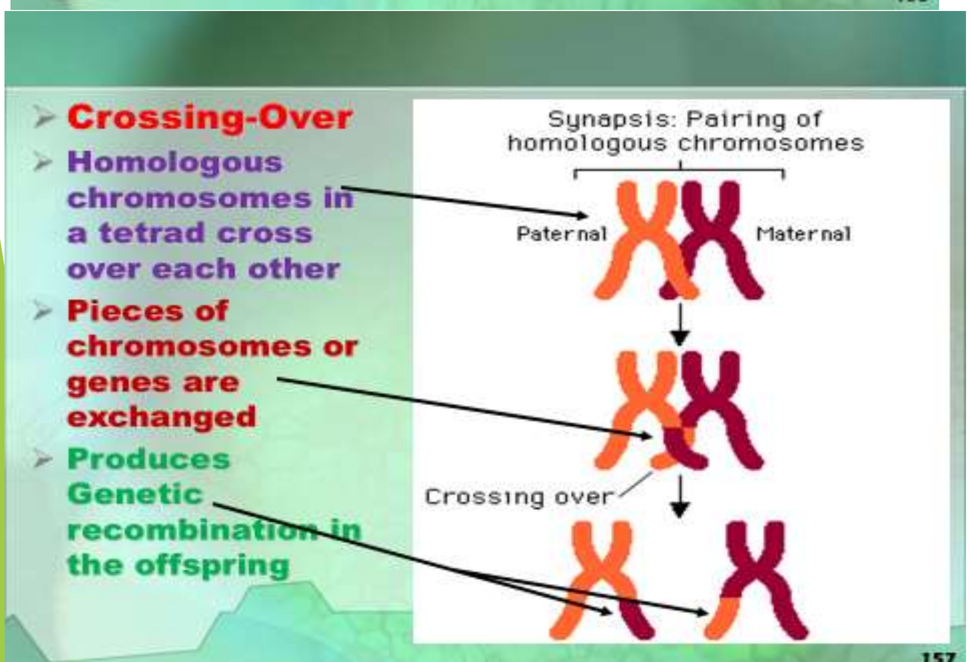
Metaphase I

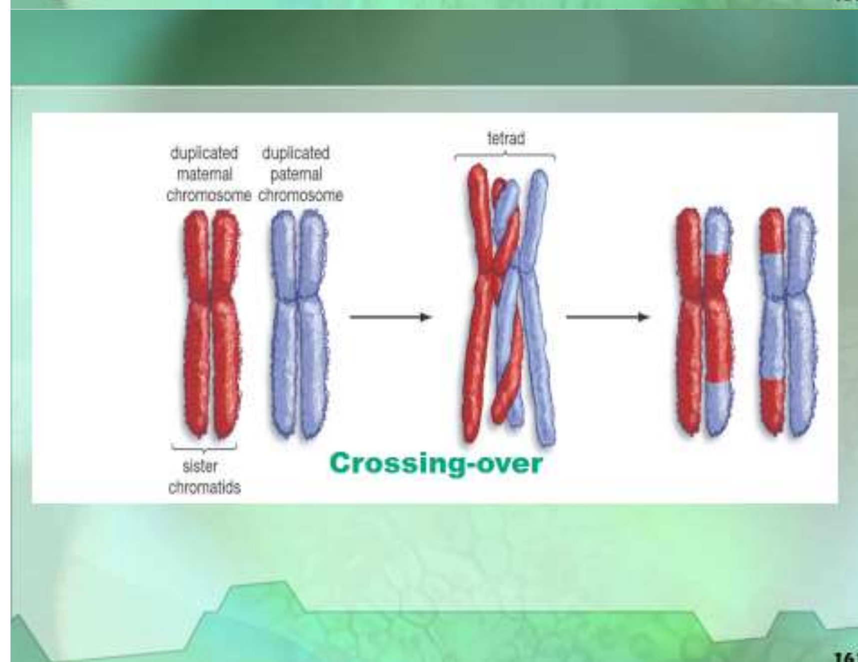
Anaphase I

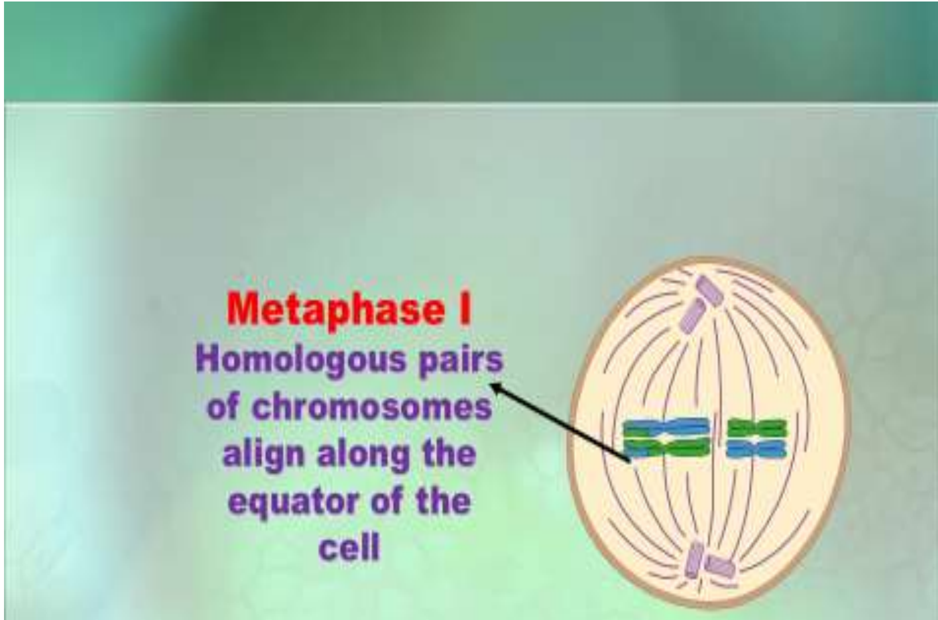
Telophase I (diploid)

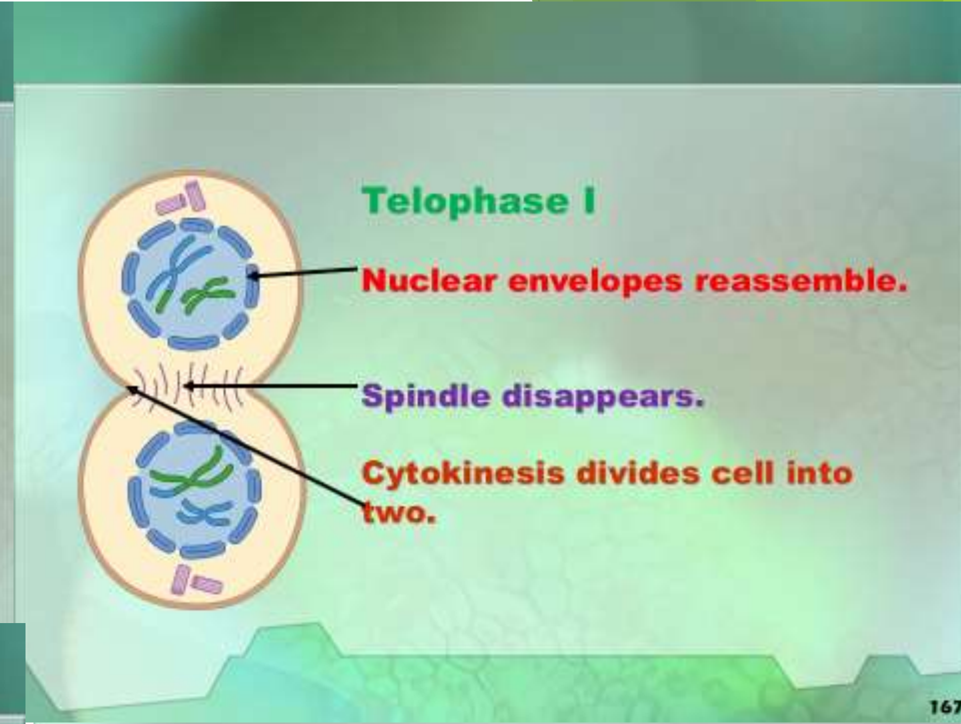

Prophase I
Early prophase
Homologs pair.
Crossing over occurs.
Late prophase
Chromosomes condense.
Spindle forms.
Nuclear envelope fragments.
153

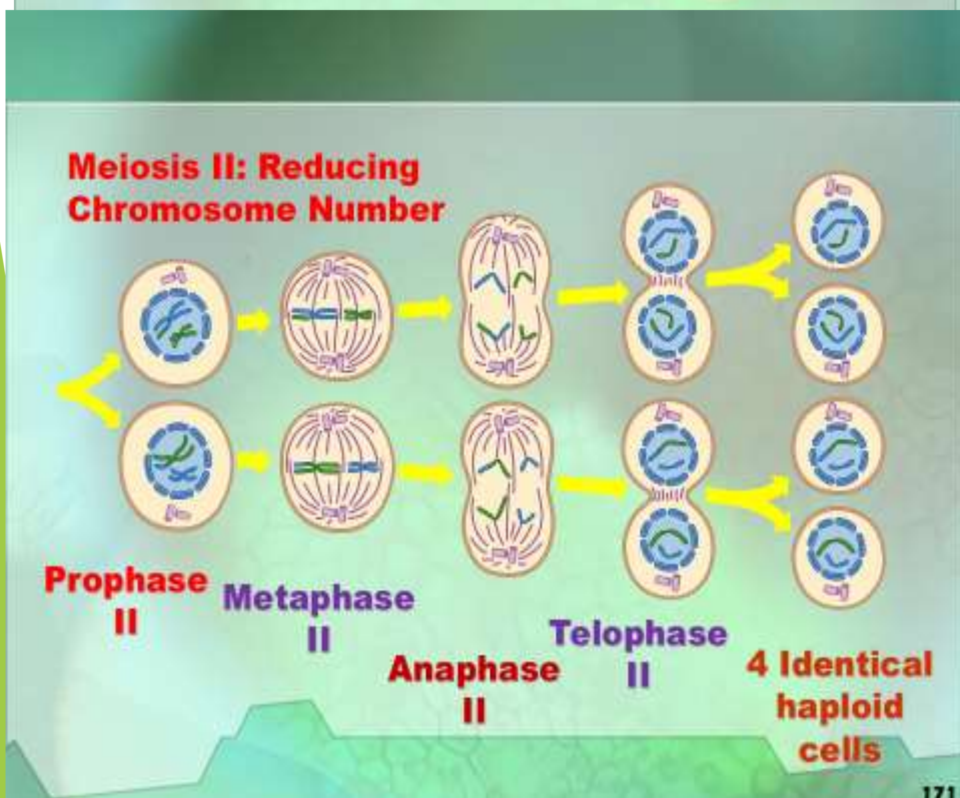

Homologous chromosomes (each with sister chromatids)
Join to form a TETRAD
Tetrads Form in Prophase I
Called Synapsis
155

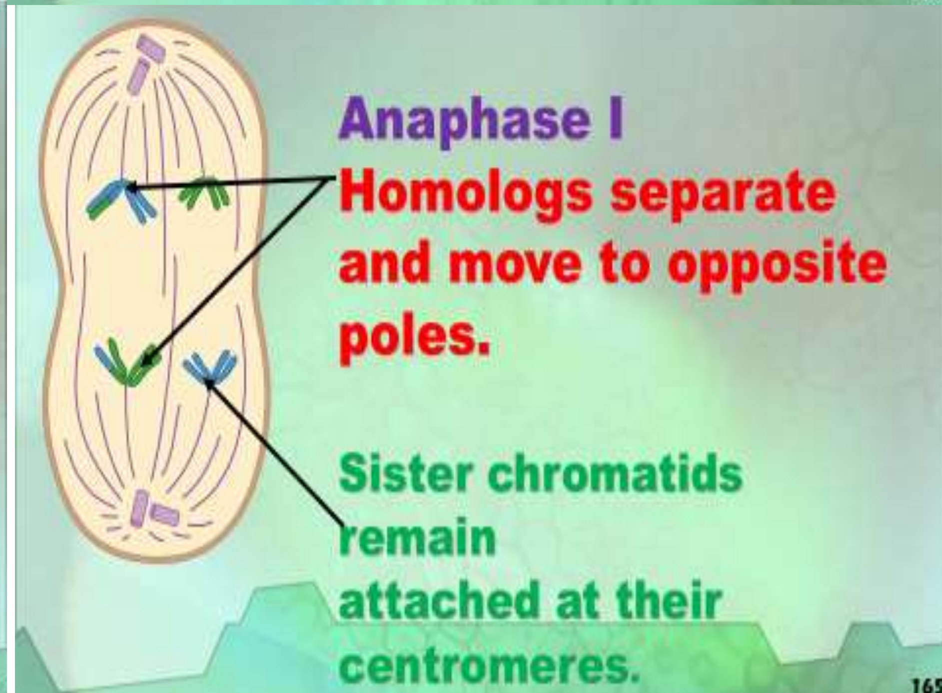

Crossing-Over
Homologous chromosomes in a tetrad cross over each other
Pieces of chromosomes or genes are exchanged
Produces Genetic recombination in the offspring
Synapsis: Pairing of homologous chromosomes
Paternal
Maternal
Crossing over
157

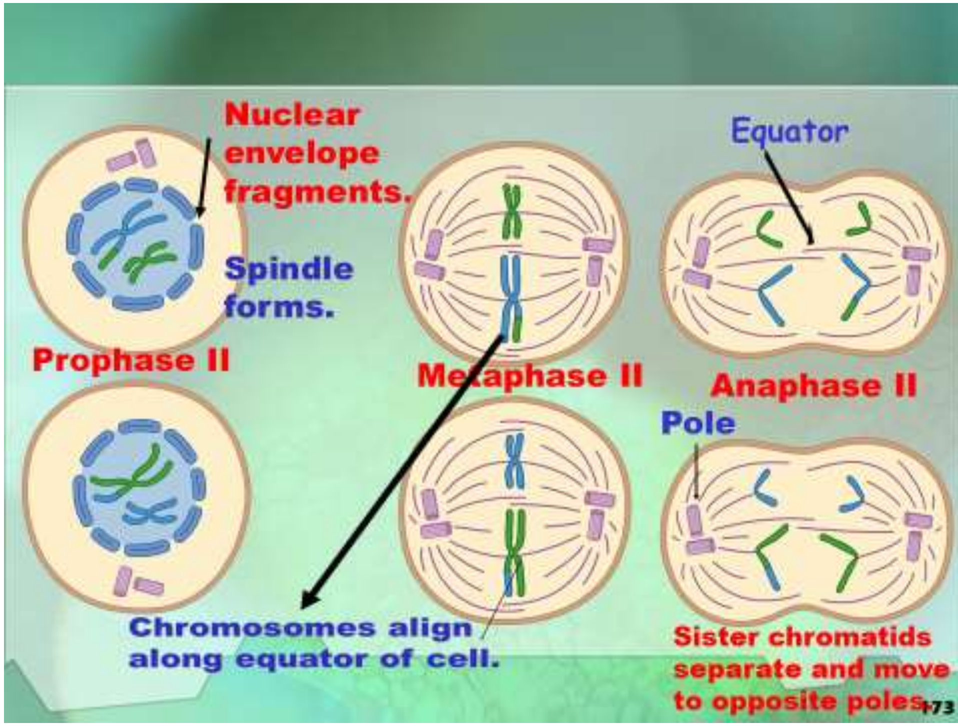

duplicated maternal chromosome
duplicated paternal chromosome
tetrad
sister chromatids
Crossing-over
161

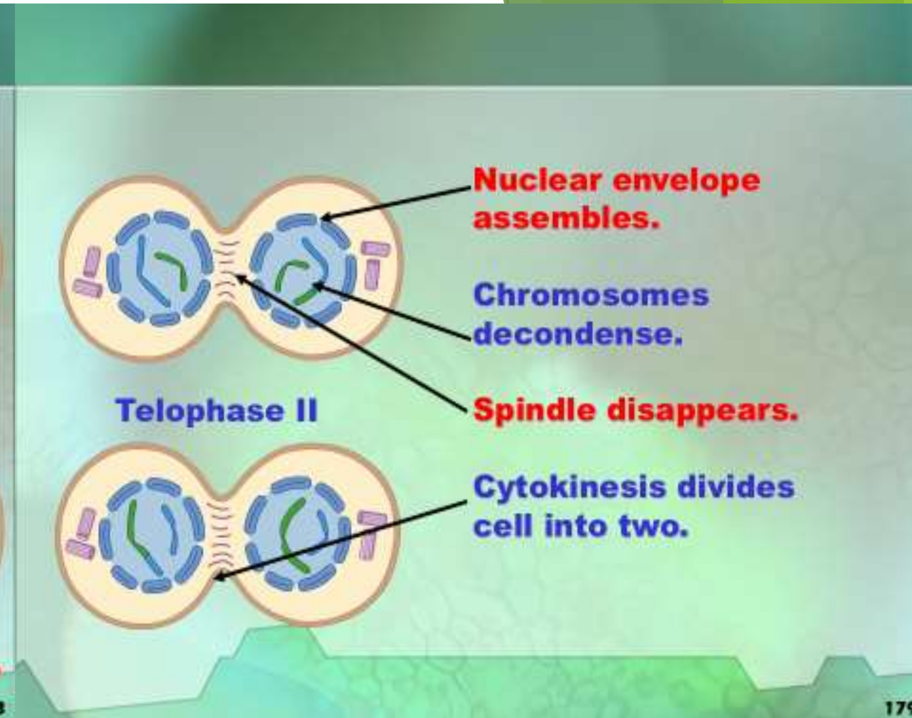

Metaphase I
Homologous pairs of chromosomes align along the equator of the cell

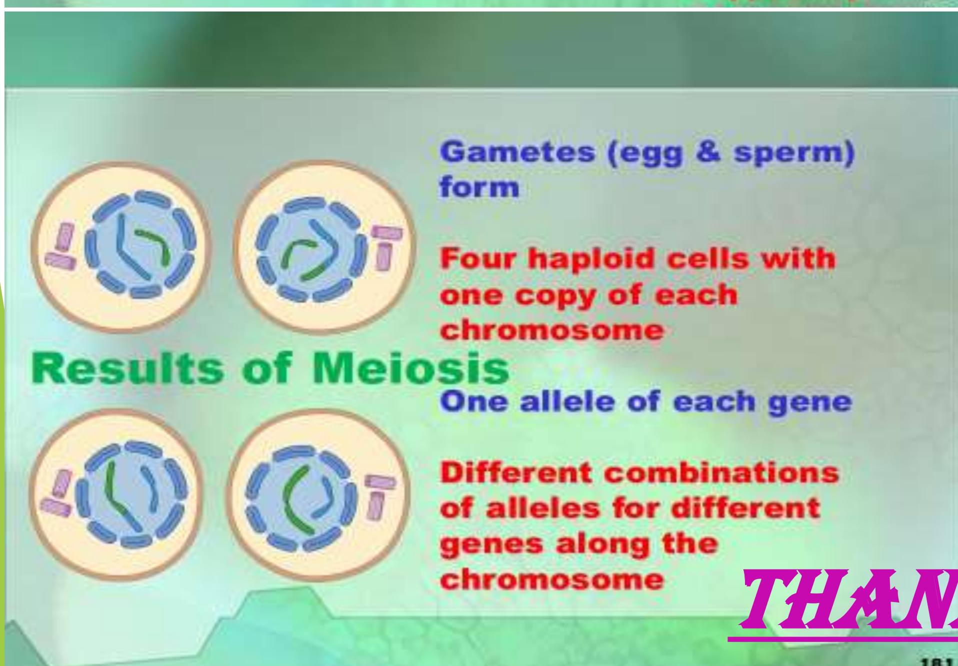

Telophase I
Nuclear envelopes reassemble.
Spindle disappears.
Cytokinesis divides cell into two.
167


Meiosis II: Reducing Chromosome Number
Prophase II
Metaphase II
Anaphase II
Telophase II
4 Identical haploid cells
171


Anaphase I
Homologs separate and move to opposite poles.
Sister chromatids remain attached at their centromeres.
165




| Diff between...... | Mitosis | Meiosis |
|---|---|---|
| Number of divisions | 1 | 2 |
| Number of daughter cells | 2 | 4 |
| Genetically identical? | Yes | No |
| Chromosome # | Same as parent | Half of parent |
| Where | Somatic cells | Germ cells |
| When | Throughout life | At sexual maturity |
| Role | Growth and repair | Sexual reproduction |

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***THANKS...***

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# Chapter 10

# Cell Cycle and Cell Division



Are you aware that all organisms, even the largest, start their life from a single cell? You may wonder how a single cell then goes on to form such large organisms. Growth and reproduction are characteristics of cells, indeed of all living organisms. All cells reproduce by dividing into two, with each parental cell giving rise to two daughter cells each time they divide. These newly formed daughter cells can themselves grow and divide, giving rise to a new cell population that is formed by the growth and division of a single parental cell and its progeny. In other words, such cycles of growth and division allow a single cell to form a structure consisting of millions of cells.

## 10.1 Cell Cycle

Cell division is a very important process in all living organisms. During the division of a cell, DNA replication and cell growth also take place. All these processes, i.e., cell division, DNA replication, and cell growth, hence, have to take place in a coordinated way to ensure correct division and formation of progeny cells containing intact genomes. The sequence of events by which a cell duplicates its genome, synthesises the other constituents of the cell and eventually divides into two daughter cells is termed **cell cycle.** Although cell growth (in terms of cytoplasmic increase) is a continuous process, DNA synthesis occurs only during one specific stage in the cell cycle. The replicated chromosomes (DNA) are then distributed to daughter nuclei by a complex series of events during cell division. These events are themselves under genetic control.

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### 10.1.1 Phases of Cell Cycle

A typical eukaryotic cell cycle is illustrated by human cells in culture. These cells divide once in approximately every 24 hours (Figure 10.1). However, this duration of cell cycle can vary from organism to organism and also from cell type to cell type. Yeast for example, can progress through the cell cycle in only about 90 minutes.

The cell cycle is divided into two basic phases:

- **Interphase**
- **M Phase (Mitosis phase)**

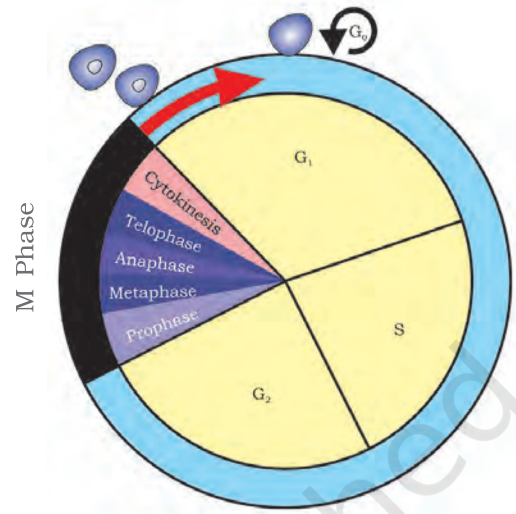


**Figure 10.1** A diagrammatic view of cell cycle indicating formation of two cells from one cell

The M Phase represents the phase when the actual cell division or mitosis occurs and the interphase represents the phase between two successive M phases. It is significant to note that in the 24 hour average duration of cell cycle of a human cell, cell division proper lasts for only about an hour. The interphase lasts more than 95% of the duration of cell cycle.

The M Phase starts with the nuclear division, corresponding to the separation of daughter chromosomes **(karyokinesis)** and usually ends with division of cytoplasm **(cytokinesis).** The interphase, though called the resting phase, is the time during which the cell is preparing for division by undergoing both cell growth and DNA replication in an orderly manner. The interphase is divided into three further phases:

- **$G_1$ phase (Gap 1)**
- **S phase (Synthesis)**
- **$G_2$ phase (Gap 2)**

$G_1$ phase corresponds to the interval between mitosis and initiation of DNA replication. During $G_1$ phase the cell is metabolically active and continuously grows but does not replicate its DNA. S or **synthesis** phase marks the period during which DNA synthesis or replication takes place. During this time the amount of DNA per cell doubles. If the initial amount of DNA is denoted as 2C then it increases to 4C. However, there is no increase in the chromosome number; if the cell had diploid or 2n number of chromosomes at $G_1$, even after S phase the number of chromosomes remains the same, i.e., 2n.

In animal cells, during the S phase, DNA replication begins in the nucleus, and the centriole duplicates in the cytoplasm. During the $G_2$ phase, proteins are synthesised in preparation for mitosis while cell growth continues.

How do plants and animals continue to grow all their lives? Do all cells in a plant divide all the time? Do you think all cells continue to divide in all plants and animals? Can you tell the name and the location of tissues having cells that divide all their life in higher plants? Do animals have similar meristematic tissues?

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You have studied mitosis in onion root tip cells. It has 16 chromosomes in each cell. Can you tell how many chromosomes will the cell have at $G_1$ phase, after S phase, and after M phase? Also, what will be the DNA content of the cells at $G_1$, after S and at $G_2$, if the content after M phase is 2C?

Some cells in the adult animals do not appear to exhibit division (e.g., heart cells) and many other cells divide only occasionally, as needed to replace cells that have been lost because of injury or cell death. These cells that do not divide further exit $G_1$ phase to enter an inactive stage called ***quiescent stage ($G_0$)*** of the cell cycle. Cells in this stage remain metabolically active but no longer proliferate unless called on to do so depending on the requirement of the organism.

In animals, mitotic cell division is only seen in the diploid somatic cells. However, there are few exceptions to this where haploid cells divide by mitosis, for example, male honey bees. Against this, the plants can show mitotic divisions in both haploid and diploid cells. From your recollection of examples of alternation of generations in plants (Chapter 3) identify plant species and stages at which mitosis is seen in haploid cells.

## 10.2 M Phase

This is the most dramatic period of the cell cycle, involving a major reorganisation of virtually all components of the cell. Since the number of chromosomes in the parent and progeny cells is the same, it is also called as ***equational division.*** Though for convenience mitosis has been divided into four stages of nuclear division (karyokinesis), it is very essential to understand that cell division is a progressive process and very clear-cut lines cannot be drawn between various stages. Karyokinesis involves following four stages:

- ***Prophase***
- ***Metaphase***
- ***Anaphase***
- ***Telophase***

### 10.2.1 Prophase

Prophase which is the first stage of karyokinesis of mitosis follows the S and $G_2$ phases of interphase. In the S and $G_2$ phases the new DNA molecules formed are not distinct but intertwined. Prophase is marked by the initiation of condensation of chromosomal material. The chromosomal material becomes untangled during the process of chromatin condensation (Figure 10.2 a). The centrosome, which had undergone duplication during S phase of interphase, now begins to move towards opposite poles of the cell. The completion of prophase can thus be marked by the following characteristic events:

- Chromosomal material condenses to form compact mitotic chromosomes. Chromosomes are seen to be composed of two chromatids attached together at the centromere.
- Centrosome which had undergone duplication during interphase, begins to move towards opposite poles of the cell. Each centrosome radiates out microtubules called asters. The two asters together with spindle fibres forms mitotic apparatus.

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Cells at the end of prophase, when viewed under the microscope, do not show golgi complexes, endoplasmic reticulum, nucleolus and the nuclear envelope.

### 10.2.2 Metaphase

The complete disintegration of the nuclear envelope marks the start of the second phase of mitosis, hence the chromosomes are spread through the cytoplasm of the cell. By this stage, condensation of chromosomes is completed and they can be observed clearly under the microscope. This then, is the stage at which morphology of chromosomes is most easily studied. At this stage, metaphase chromosome is made up of two sister chromatids, which are held together by the centromere (Figure 10.2 b). Small disc-shaped structures at the surface of the centromeres are called kinetochores. These structures serve as the sites of attachment of spindle fibres (formed by the spindle fibres) to the chromosomes that are moved into position at the centre of the cell. Hence, the metaphase is characterised by all the chromosomes coming to lie at the equator with one chromatid of each chromosome connected by its kinetochore to spindle fibres from one pole and its sister chromatid connected by its kinetochore to spindle fibres from the opposite pole (Figure 10.2 b). The plane of alignment of the chromosomes at metaphase is referred to as the **metaphase plate.** The key features of metaphase are:

- Spindle fibres attach to kinetochores of chromosomes.
- Chromosomes are moved to spindle equator and get aligned along metaphase plate through spindle fibres to both poles.

### 10.2.3 Anaphase

At the onset of anaphase, each chromosome arranged at the metaphase plate is split simultaneously and the two daughter chromatids, now referred to as daughter chromosomes of the future daughter nuclei, begin their migration towards the two opposite poles. As each chromosome moves away from the equatorial plate, the centromere of each chromosome remains directed towards the pole and hence at the leading edge, with the arms of the chromosome trailing behind (Figure 10.2 c). Thus, anaphase stage is characterised by

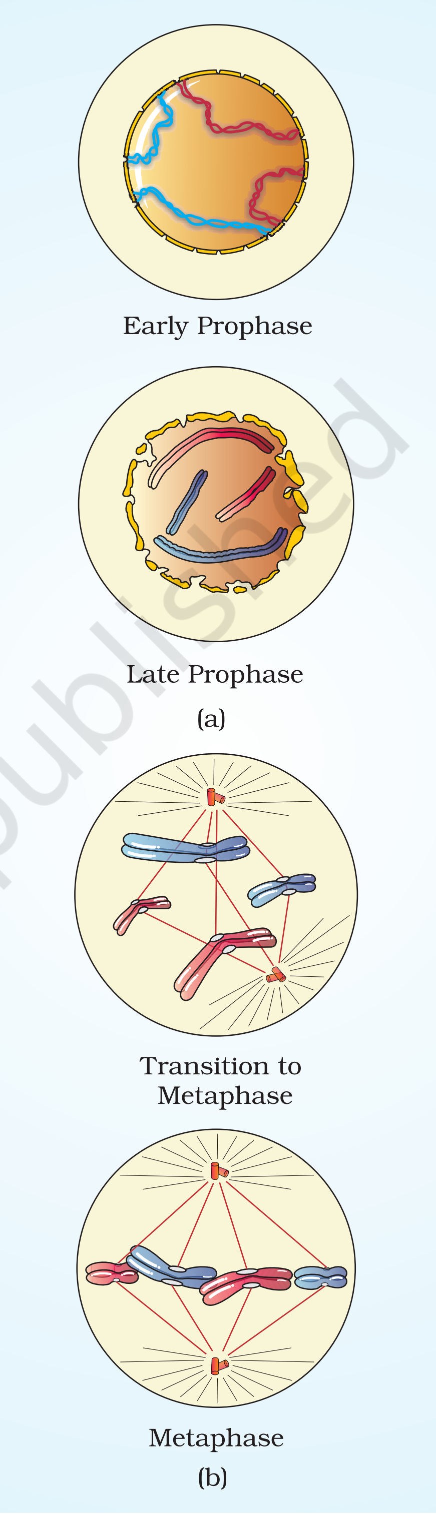


**Figure 10.2 a and b** : A diagrammatic view of stages in mitosis

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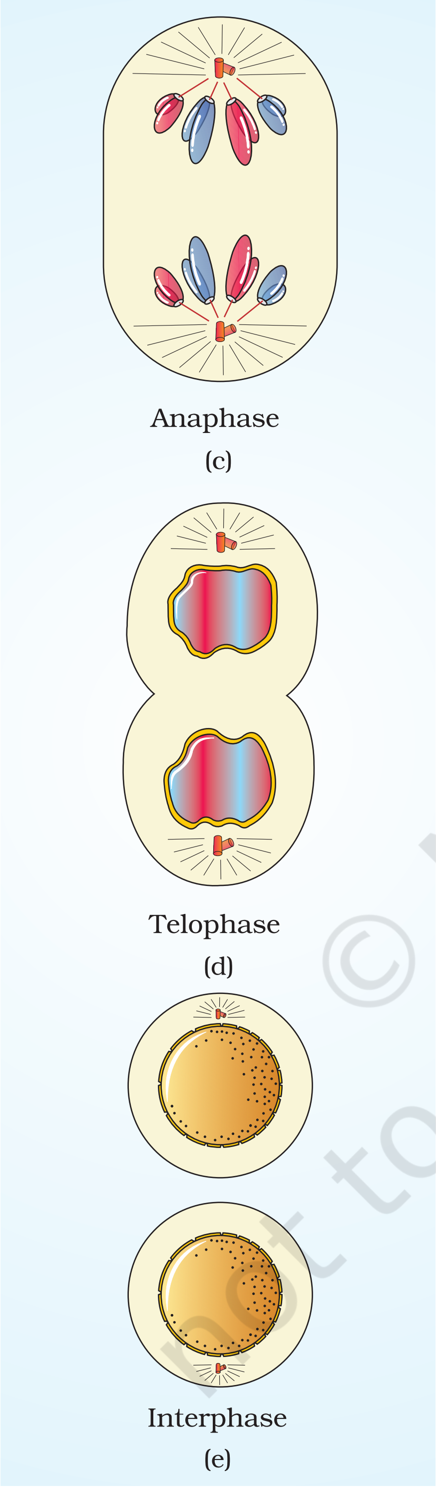


**Figure 10.2 c to e** : A diagrammatic view of stages in Mitosis

the following key events:

- Centromeres split and chromatids separate.
- Chromatids move to opposite poles.

### 10.2.4 Telophase

At the beginning of the final stage of karyokinesis, i.e., telophase, the chromosomes that have reached their respective poles decondense and lose their individuality. The individual chromosomes can no longer be seen and each set of chromatin material tends to collect at each of the two poles (Figure 10.2 d). This is the stage which shows the following key events:

- Chromosomes cluster at opposite spindle poles and their identity is lost as discrete elements.
- Nuclear envelope develops around the chromosome clusters at each pole forming two daughter nuclei.
- Nucleolus, golgi complex and ER reform.

### 10.2.5 Cytokinesis

Mitosis accomplishes not only the segregation of duplicated chromosomes into daughter nuclei (karyokinesis), but the cell itself is divided into two daughter cells by the separation of cytoplasm called cytokinesis at the end of which cell division gets completed (Figure 10.2 e). In an animal cell, this is achieved by the appearance of a furrow in the plasma membrane. The furrow gradually deepens and ultimately joins in the centre dividing the cell cytoplasm into two. Plant cells however, are enclosed by a relatively inextensible cell wall, thererfore they undergo cytokinesis by a different mechanism. In plant cells, wall formation starts in the centre of the cell and grows outward to meet the existing lateral walls. The formation of the new cell wall begins with the formation of a simple precursor, called the **cell-plate** that represents the middle lamella between the walls of two adjacent cells. At the time of cytoplasmic division, organelles like mitochondria and plastids get distributed between the two daughter cells. In some organisms karyokinesis is not followed by cytokinesis as a result of which multinucleate condition arises leading to the formation of syncytium (e.g., liquid endosperm in coconut).

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## 10.3 Significance of Mitosis

Mitosis or the equational division is usually restricted to the diploid cells only. However, in some lower plants and in some social insects haploid cells also divide by mitosis. It is very essential to understand the significance of this division in the life of an organism. Are you aware of some examples where you have studied about haploid and diploid insects?

Mitosis usually results in the production of diploid daughter cells with identical genetic complement. The growth of multicellular organisms is due to mitosis. Cell growth results in disturbing the ratio between the nucleus and the cytoplasm. It therefore becomes essential for the cell to divide to restore the nucleo-cytoplasmic ratio. A very significant contribution of mitosis is cell repair. The cells of the upper layer of the epidermis, cells of the lining of the gut, and blood cells are being constantly replaced. Mitotic divisions in the meristematic tissues – the apical and the lateral cambium, result in a continuous growth of plants throughout their life.

## 10.4 MEIOSIS

The production of offspring by sexual reproduction includes the fusion of two gametes, each with a complete haploid set of chromosomes. Gametes are formed from specialised diploid cells. This specialised kind of cell division that reduces the chromosome number by half results in the production of haploid daughter cells. This kind of division is called **meiosis.** Meiosis ensures the production of haploid phase in the life cycle of sexually reproducing organisms whereas fertilisation restores the diploid phase. We come across meiosis during gametogenesis in plants and animals. This leads to the formation of haploid gametes. The key features of meiosis are as follows:

- Meiosis involves two sequential cycles of nuclear and cell division called **meiosis I** and **meiosis II** but only a single cycle of DNA replication.
- Meiosis I is initiated after the parental chromosomes have replicated to produce identical sister chromatids at the S phase.
- Meiosis involves pairing of homologous chromosomes and recombination between non-sister chromatids of homologous chromosomes.
- Four haploid cells are formed at the end of meiosis II.

Meiotic events can be grouped under the following phases:

| **Meiosis I** | **Meiosis II** |
|---|---|
| Prophase I | Prophase II |
| Metaphase I | Metaphase II |
| Anaphase I | Anaphase II |
| Telophase I | Telophase II |

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### 10.4.1 Meiosis I

**Prophase I:** Prophase of the first meiotic division is typically longer and more complex when compared to prophase of mitosis. It has been further subdivided into the following five phases based on chromosomal behaviour, i.e., Leptotene, Zygotene, Pachytene, Diplotene and Diakinesis.

During **leptotene** stage the chromosomes become gradually visible under the light microscope. The compaction of chromosomes continues throughout leptotene. This is followed by the second stage of prophase I called **zygotene**. During this stage chromosomes start pairing together and this process of association is called synapsis. Such paired chromosomes are called homologous chromosomes. Electron micrographs of this stage indicate that chromosome synapsis is accompanied by the formation of complex structure called **synaptonemal complex.** The complex formed by a pair of synapsed homologous chromosomes is called a **bivalent** or a tetrad. However, these are more clearly visible at the next stage. The first two stages of prophase I are relatively short-lived compared to the next stage that is **pachytene**. During this stage, the four chromatids of each bivalent chromosomes becomes distinct and clearly appears as tetrads. This stage is characterised by the appearance of recombination nodules, the sites at which crossing over occurs between non-sister chromatids of the homologous chromosomes. Crossing over is the exchange of genetic material between two homologous chromosomes. Crossing over is also an enzyme-mediated process and the enzyme involved is called recombinase. Crossing over leads to recombination of genetic material on the two chromosomes. Recombination between homologous chromosomes is completed by the end of pachytene, leaving the chromosomes linked at the sites of crossing over.

The beginning of **diplotene** is recognised by the dissolution of the synaptonemal complex and the tendency of the recombined homologous chromosomes of the bivalents to separate from each other except at the sites of crossovers. These X-shaped structures, are called **chiasmata.** In oocytes of some vertebrates, diplotene can last for months or years.

The final stage of meiotic prophase I is **diakinesis.** This is marked by terminalisation of chiasmata. During this phase the chromosomes are fully condensed and the meiotic spindle is assembled to prepare the homologous chromosomes for separation. By the end of diakinesis, the nucleolus disappears and the nuclear envelope also breaks down. Diakinesis represents transition to metaphase.

**Metaphase I:** The bivalent chromosomes align on the equatorial plate (Figure 10.3). The microtubules from the opposite poles of the spindle attach to the kinetochore of homologous chromosomes.

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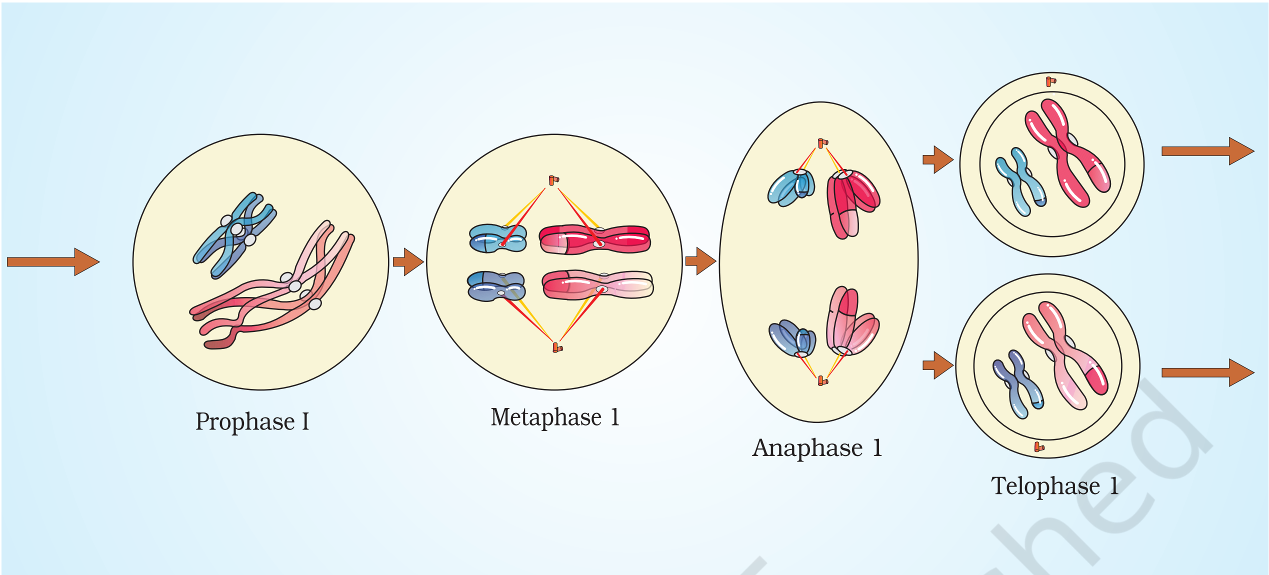


**Figure 10.3** Stages of Meiosis I

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**Anaphase I:** The homologous chromosomes separate, while sister chromatids remain associated at their centromeres (Figure 10.3).

**Telophase I:** The nuclear membrane and nucleolus reappear, cytokinesis follows and this is called as dyad of cells (Figure 10.3). Although in many cases the chromosomes do undergo some dispersion, they do not reach the extremely extended state of the interphase nucleus. The stage between the two meiotic divisions is called interkinesis and is generally short lived. There is no replication of DNA during interkinesis. Interkinesis is followed by prophase II, a much simpler prophase than prophase I.

### 10.4.2 Meiosis II

**Prophase II:** Meiosis II is initiated immediately after cytokinesis, usually before the chromosomes have fully elongated. In contrast to meiosis I, meiosis II resembles a normal mitosis. The nuclear membrane disappears by the end of prophase II (Figure 10.4). The chromosomes again become compact.

**Metaphase II**: At this stage the chromosomes align at the equator and the microtubules from opposite poles of the spindle get attached to the kinetochores (Figure 10.4) of sister chromatids.

**Anaphase II:** It begins with the simultaneous splitting of the centromere of each chromosome (which was holding the sister chromatids together), allowing them to move toward opposite poles of the cell (Figure 10.4) by shortening of microtubules attached to kinetochores.

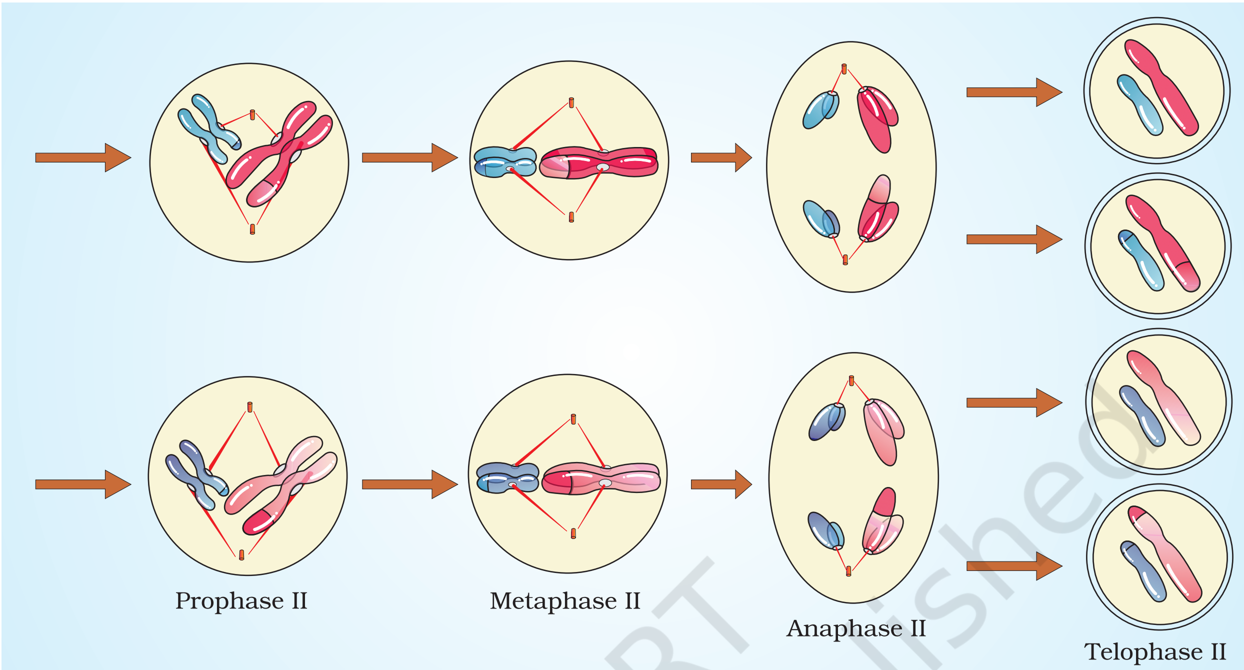


**Figure 10.4** Stages of Meiosis II

**Telophase II:** Meiosis ends with telophase II, in which the two groups of chromosomes once again get enclosed by a nuclear envelope; cytokinesis follows resulting in the formation of tetrad of cells i.e., four haploid daughter cells (Figure 10.4).

## 10.5 Significance of Meiosis

Meiosis is the mechanism by which conservation of specific chromosome number of each species is achieved across generations in sexually reproducing organisms, even though the process, per se, paradoxically, results in reduction of chromosome number by half. It also increases the genetic variability in the population of organisms from one generation to the next. Variations are very important for the process of evolution.

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## Summary

According to the cell theory, cells arise from preexisting cells. The process by which this occurs is called cell division. Any sexually reproducing organism starts its life cycle from a single-celled zygote. Cell division does not stop with the formation of the mature organism but continues throughout its life cycle.

The stages through which a cell passes from one division to the next is called the cell cycle. Cell cycle is divided into two phases called (i) Interphase – a period of preparation for cell division, and (ii) Mitosis (M phase) – the actual period of cell division. Interphase is further subdivided into $G_1$, S and $G_2$. $G_1$ phase is the period when the cell grows and carries out normal metabolism. Most of the organelle duplication also occurs during this phase. S phase marks the phase of DNA replication and chromosome duplication. $G_2$ phase is the period of cytoplasmic growth. Mitosis is also divided into four stages namely prophase, metaphase, anaphase and telophase. Chromosome condensation occurs during prophase. Simultaneously, the centrioles move to the opposite poles. The nuclear envelope and the nucleolus disappear and the spindle fibres start appearing. Metaphase is marked by the alignment of chromosomes at the equatorial plate. During anaphase the centromeres divide and the chromatids start moving towards the two opposite poles. Once the chromatids reach the two poles, the chromosomal elongation starts, nucleolus and the nuclear membrane reappear. This stage is called the telophase. Nuclear division is then followed by the cytoplasmic division and is called cytokinesis. Mitosis thus, is the equational division in which the chromosome number of the parent is conserved in the daughter cell.

In contrast to mitosis, meiosis occurs in the diploid cells, which are destined to form gametes. It is called the reduction division since it reduces the chromosome number by half while making the gametes. In sexual reproduction when the two gametes fuse the chromosome number is restored to the value in the parent. Meiosis is divided into two phases – meiosis I and meiosis II. In the first meiotic division the homologous chromosomes pair to form bivalents, and undergo crossing over. Meiosis I has a long prophase, which is divided further into five phases. These are leptotene, zygotene, pachytene, diplotene and diakinesis. During metaphase I the bivalents arrange on the equatorial plate. This is followed by anaphase I in which homologous chromosomes move to the opposite poles with both their chromatids. Each pole receives half the chromosome number of the parent cell. In telophase I, the nuclear membrane and nucleolus reappear. Meiosis II is similar to mitosis. During anaphase II the sister chromatids separate. Thus at the end of meiosis four haploid cells are formed.

## EXERCISES

1. What is the average cell cycle span for a mammalian cell?
2. Distinguish cytokinesis from karyokinesis.
3. Describe the events taking place during interphase.
4. What is $G_o$ (quiescent phase) of cell cycle?

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5. Why is mitosis called equational division?
6. Name the stage of cell cycle at which one of the following events occur:
   (i) Chromosomes are moved to spindle equator.
   (ii) Centromere splits and chromatids separate.
   (iii) Pairing between homologous chromosomes takes place.
   (iv) Crossing over between homologous chromosomes takes place.
7. Describe the following:
   (a) synapsis (b) bivalent (c) chiasmata
   Draw a diagram to illustrate your answer.
8. How does cytokinesis in plant cells differ from that in animal cells?
9. Find examples where the four daughter cells from meiosis are equal in size and where they are found unequal in size.
10. Distinguish anaphase of mitosis from anaphase I of meiosis.
11. List the main differences between mitosis and meiosis.
12. What is the significance of meiosis?
13. Discuss with your teacher about
    (i) haploid insects and lower plants where cell-division occurs, and
    (ii) some haploid cells in higher plants where cell-division does not occur.
14. Can there be mitosis without DNA replication in 'S' phase?
15. Can there be DNA replication without cell division?
16. Analyse the events during every stage of cell cycle and notice how the following two parameters change
    (i) number of chromosomes (N) per cell
    (ii) amount of DNA content (C) per cell

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