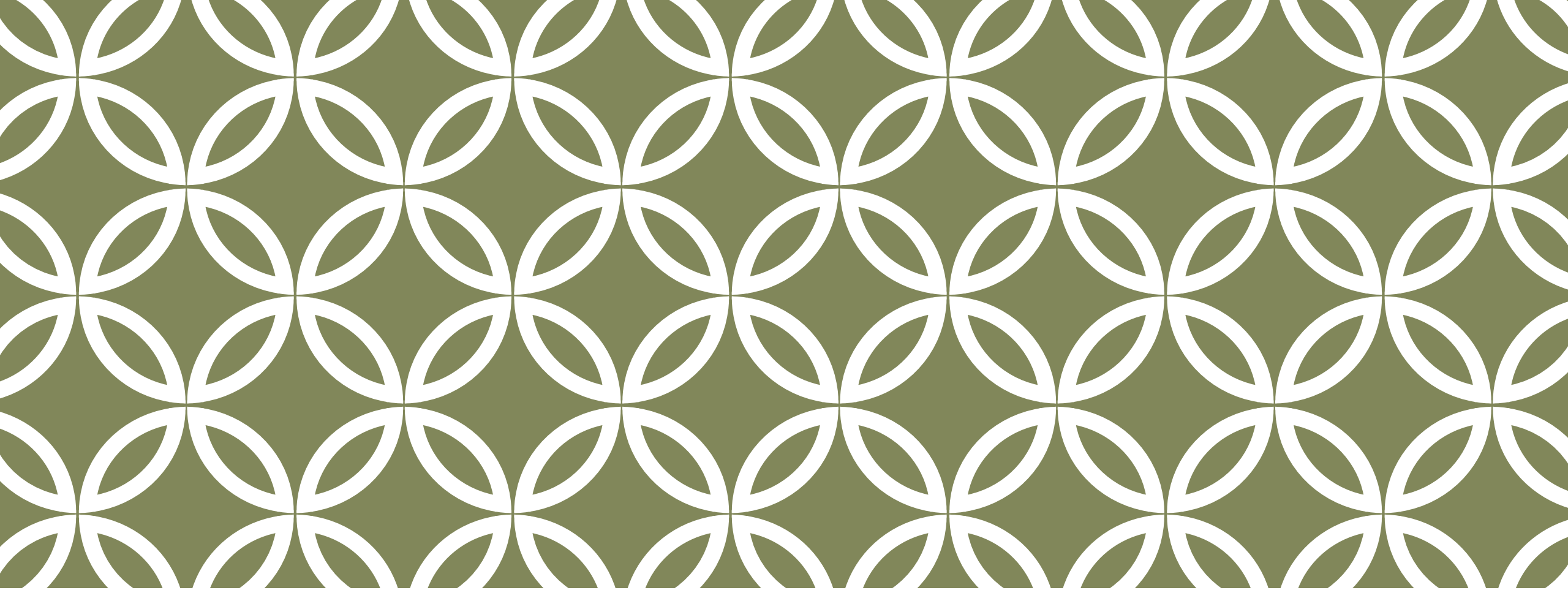
INTRODUCTION IN CELL BIOLOGY

Lecture 1

07-09-2023



THE OUTLINE OF THE CELL STRUCTURE

Topic 1

"LIFE" IS EASY TO RECOGNIZE BUT DIFFICULT TO DEFINE. THE DICTIONARY DEFINES LIFE AS "THE STATE OR QUALITY THAT DISTINGUISHES LIVING BEINGS OR ORGANISMS FROM DEAD ONES AND FROM INORGANIC MATTER, CHARACTERIZED CHIEFLY BY METABOLISM, GROWTH, AND THE ABILITY TO REPRODUCE AND RESPOND TO STIMULI".

According to a popular text, living things:

- are highly organized compared to natural inanimate objects
- display homeostasis, maintaining a relatively constant internal environment
- reproduce themselves
- grow and develop from simple beginnings
- take energy and matter from the environment and transform it
- respond to stimuli
- show adaptation to their environment

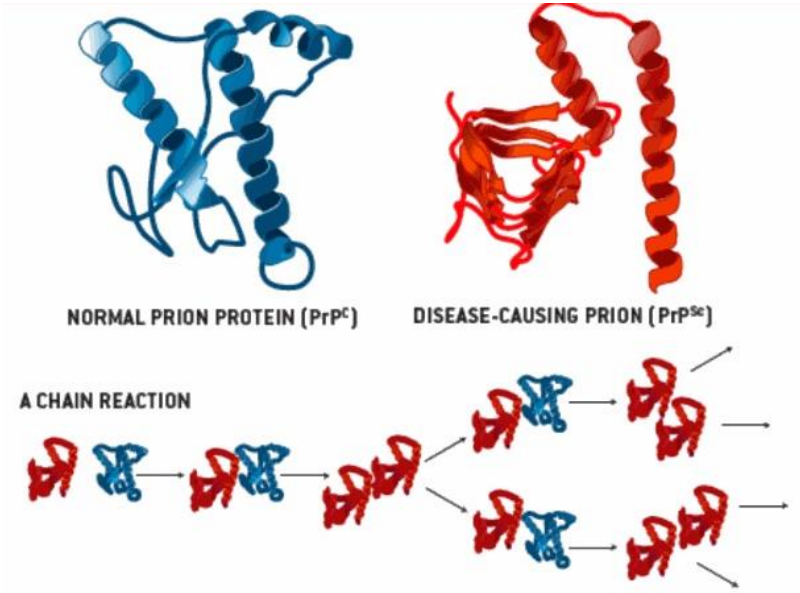
FORMS OF LIFE *thing that is living or alive*

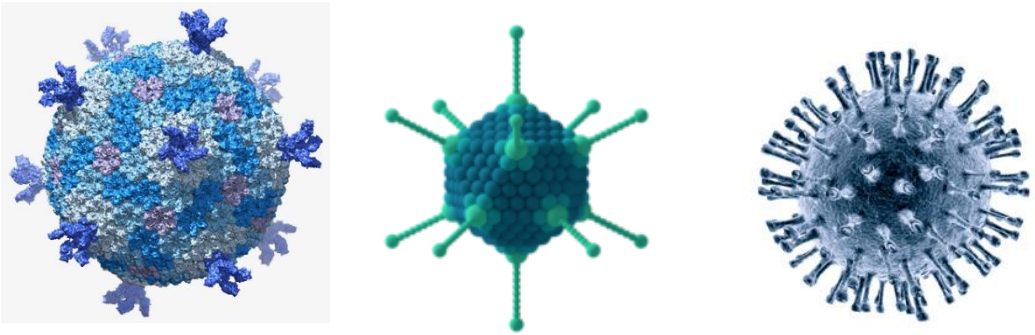
Forms of life below cells

Prions are small molecules of proteins capable to enter a cell and self replicate in this host cell

Mobile DNA elements - a type of DNA that can move around within the genome

Viruses - more complex particles containing nucleic acids and proteins, they use living cells to replicate their genomes and produce proteins to form new virus particles



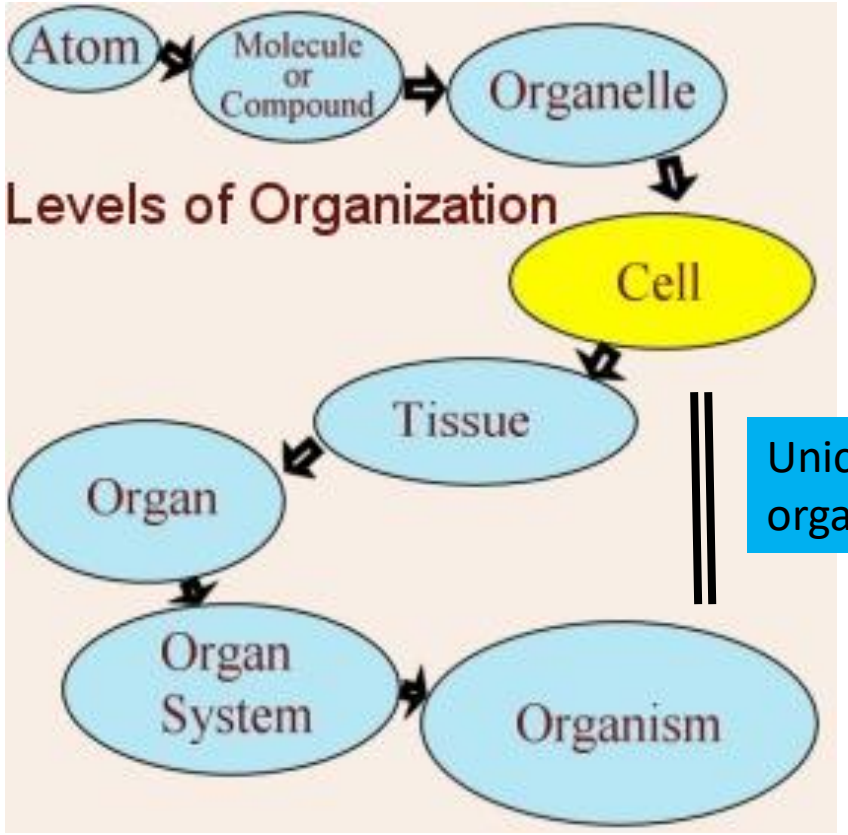


CELL | THE BASIC UNIT OF LIFE

The basic structural, functional, and biological unit of all known living organisms

Cells are the smallest unit of life that can replicate independently, and are often called the "building blocks of life"

The study of cells is called cell biology



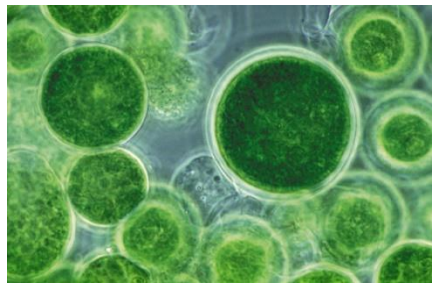
LIFE PROCESSES WITHIN CELL

- Transport of substances and ions through membranes
- Synthesis of RNA and Proteins
- Secretion
- Intracellular transport of substances and movement of a cell
- Production of energy and degradation of particles and polymers
- Intracellular and intercellular signalling
- Cell cycle/division
- Cell differentiation and death

CELLS VARY ENORMOUSLY IN THEIR APPEARANCE AND FUNCTION

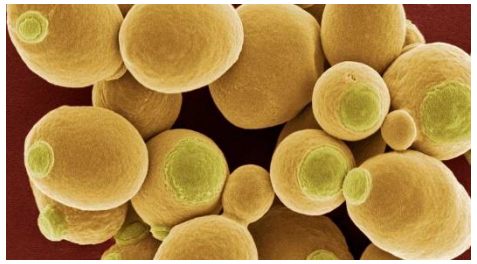
Bacteria

Algae



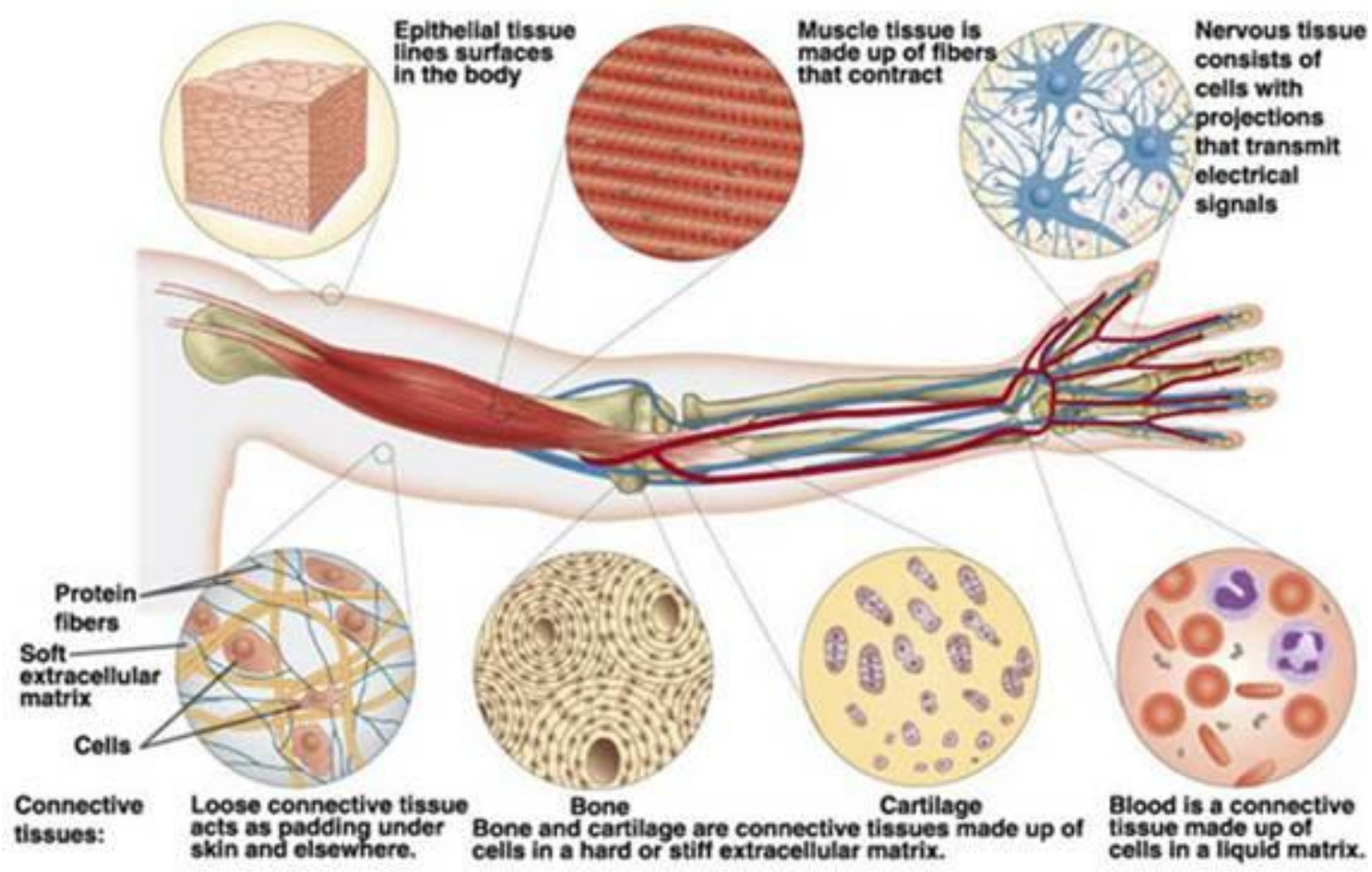
Protists

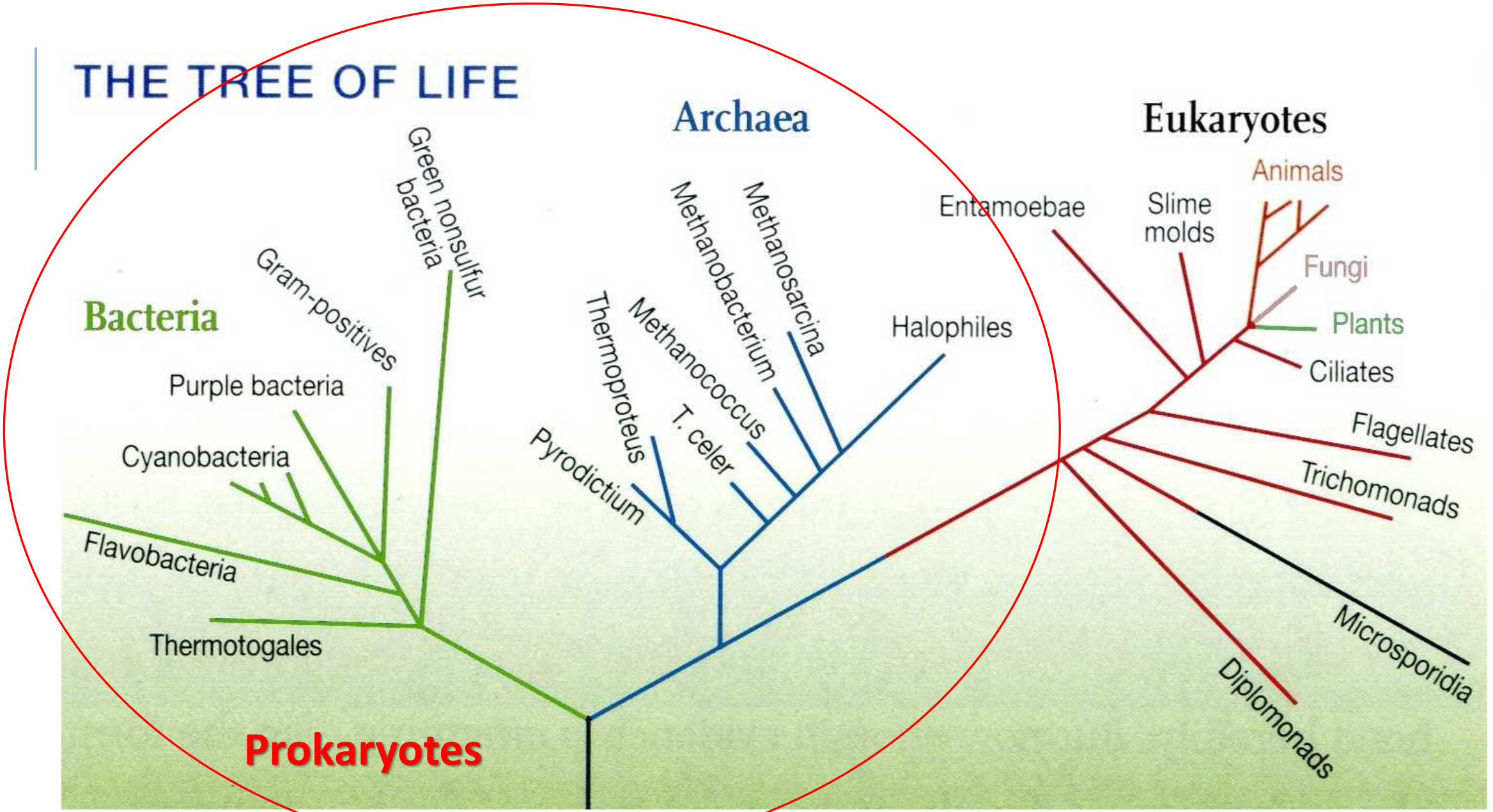
Yeasts



Egg

CELLS IN THE HUMAN BODY

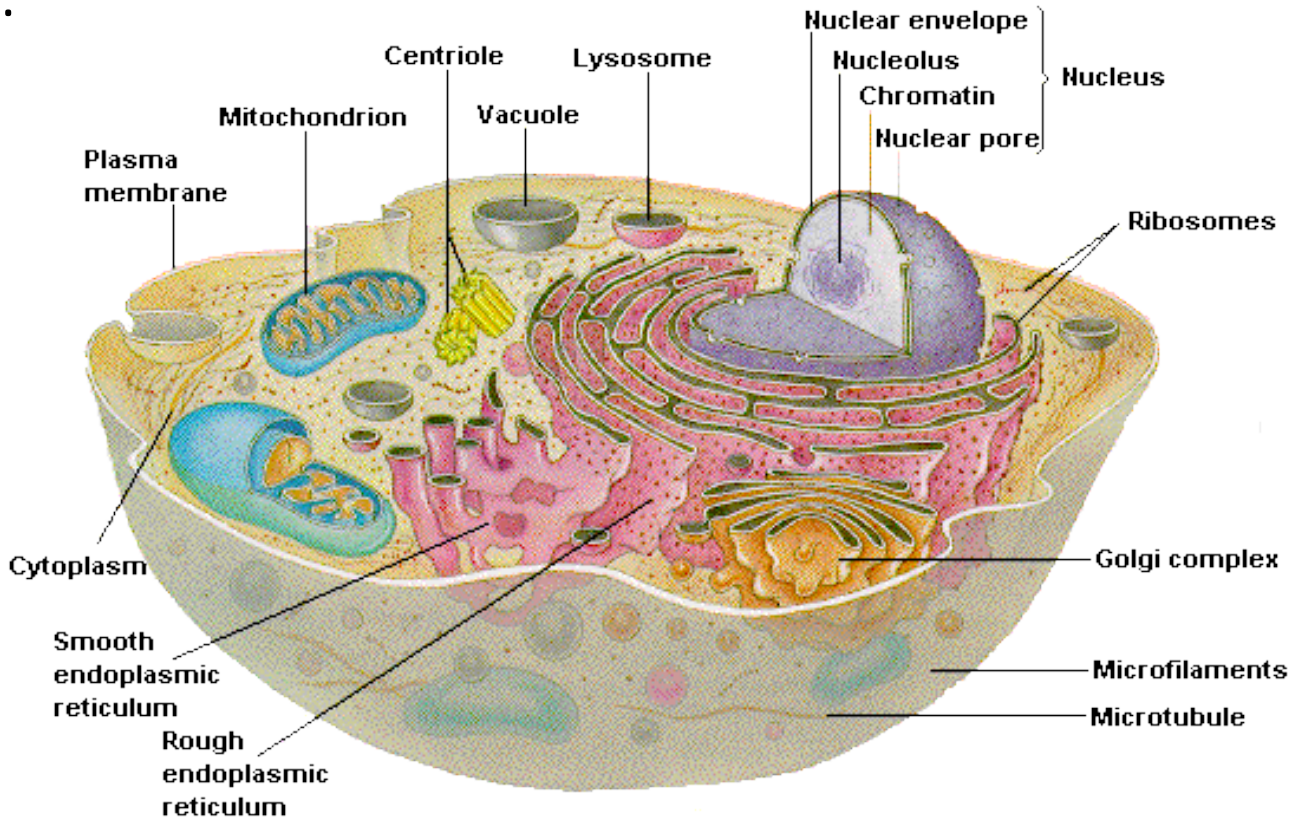



THE TREE OF LIFE
Archaea
Eukaryotes
Green nonsulfur bacteria
Gram-positives
Bacteria
Purple bacteria
Cyanobacteria
Flavobacteria
Thermotogales
Methanobacterium
Methanosarcina
Methanococcus
Thermoproteus
T. celer
Pyrodictium
Halophiles
Entamoebae
Slime molds
Animals
Fungi
Plants
Ciliates
Flagellates
Trichomonads
Microsporidia
Diplomonads
Prokaryotes

CELL STRUCTURE | **OVERVIEW**

Introductory overview on the cell structure:

https://www.youtube.com/watch?v=URUJD5NEXC8



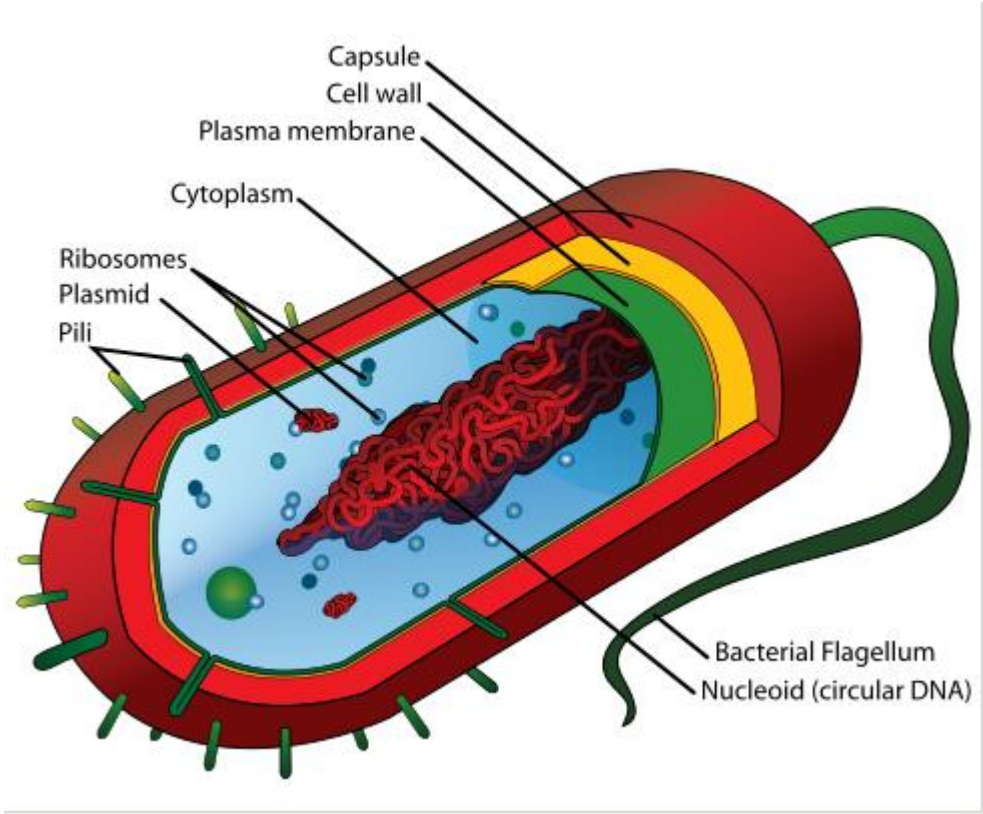
CORNERSTONES IN CELL BIOLOGY

- **1590** Hans and Zaccharias Janssen **constructed first microscope**
- **1655** Robert Hooke described cells
- **1674** Leeuwenhoek **discovered bacteria**
- **1833** Robert Browns described **cell nucleus**
- **1855** Rudolf Virchow postulates that cells arise from preexisting cells
- **1857** Albert Kölliker described **mitochondria** (sarcosomes) 肉瘤
- **1879** Walther Flemming described **chromosomes and mitosis**
- **1883** **Chromosome** theory of inheritance by Edouard Van Beneden
- **1898** Camillo Golgi, described **Golgi complex**

CORNERSTONES IN CELL BIOLOGY

- **1937** Feulgen, Behrens & Mahdihassans used differential centrifugation to separate nuclei from cytoplasm
- **1941** Albert Hewett Coons developed **immunofluorescent techniques** for labeling antibodies
- **1952** George Otto Gey, the **first human cell line development *in vitro*** (HeLa cells)
- **1955** Harry Eagle defined the nutritional needs of animal cells in culture
- **1973** M. D. Eggers used **confocal laser scanning microscope** to study cells
- **1976** Hayashi, I. and Sato, G. publish papers showing that different cell lines require different mixtures of hormones and growth factors in serum-free media
- **1981** **Transgenic mice and fruit flies** are produced
- **1998** Mice are **cloned from somatic cells**

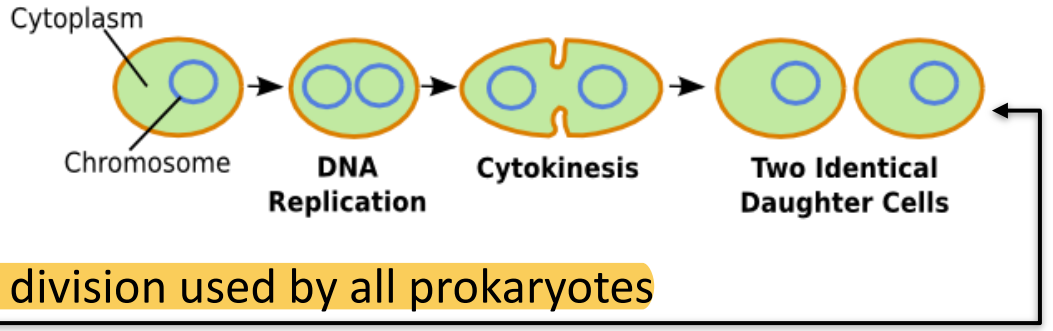
CELL STRUCTURE | **PROKARYOTES**



- Cell capsule
- Cell wall
- Cell membrane (plasma membrane or plasmalemma)
- Genomic DNA – **nucleoid** (circular)
- Plasmid DNA
- Inclusion bodies
- Pilli
- Flagella
- Photosynthetic membranes etc.

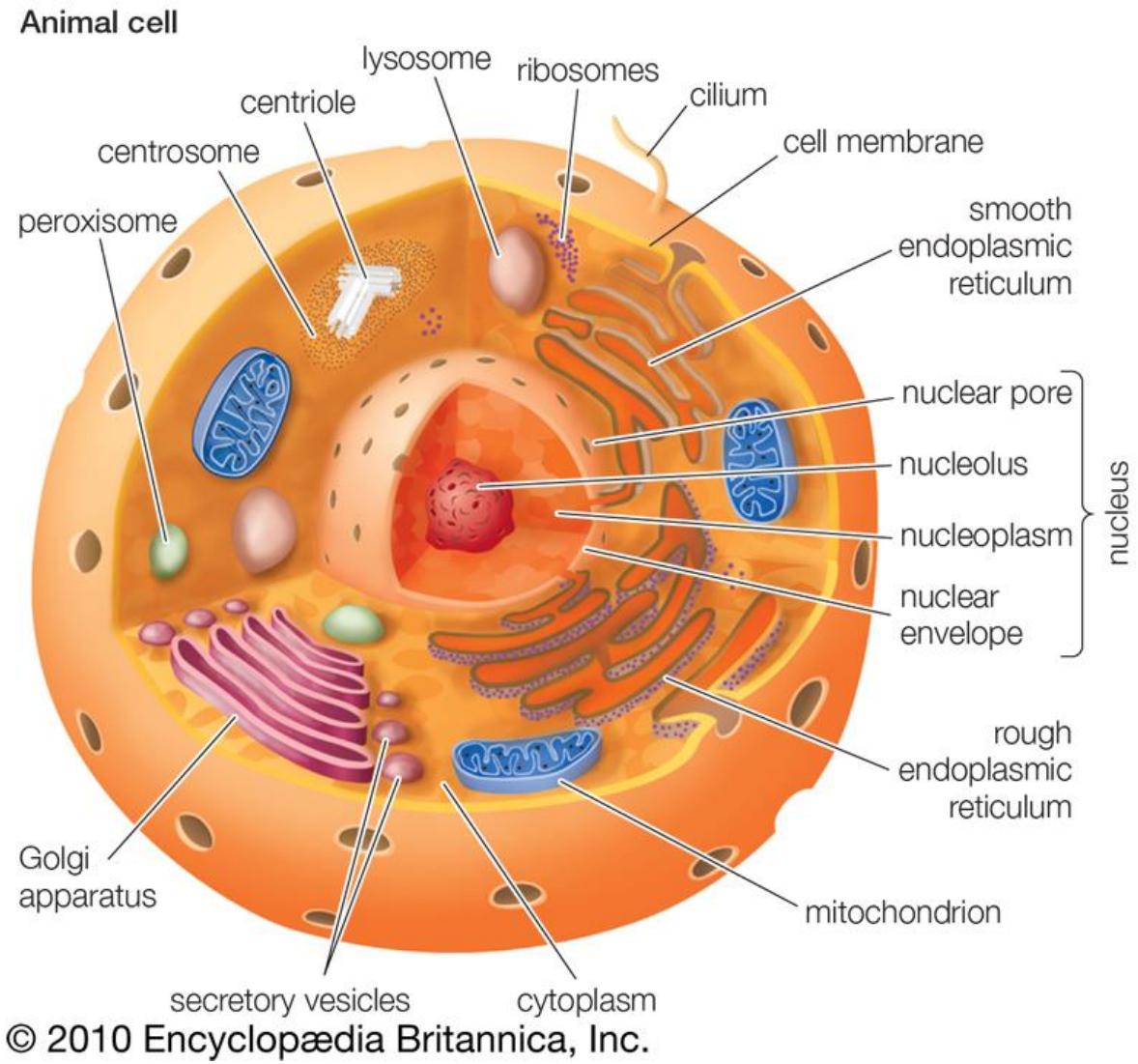
See more at: http://michaeldomingos.hubpages.com/hub/Bacterial-Intracellular-Structures-That-Give-Bacteria-an-Advanatage
http://www.cellsalive.com/cells/bactcell_js.htm

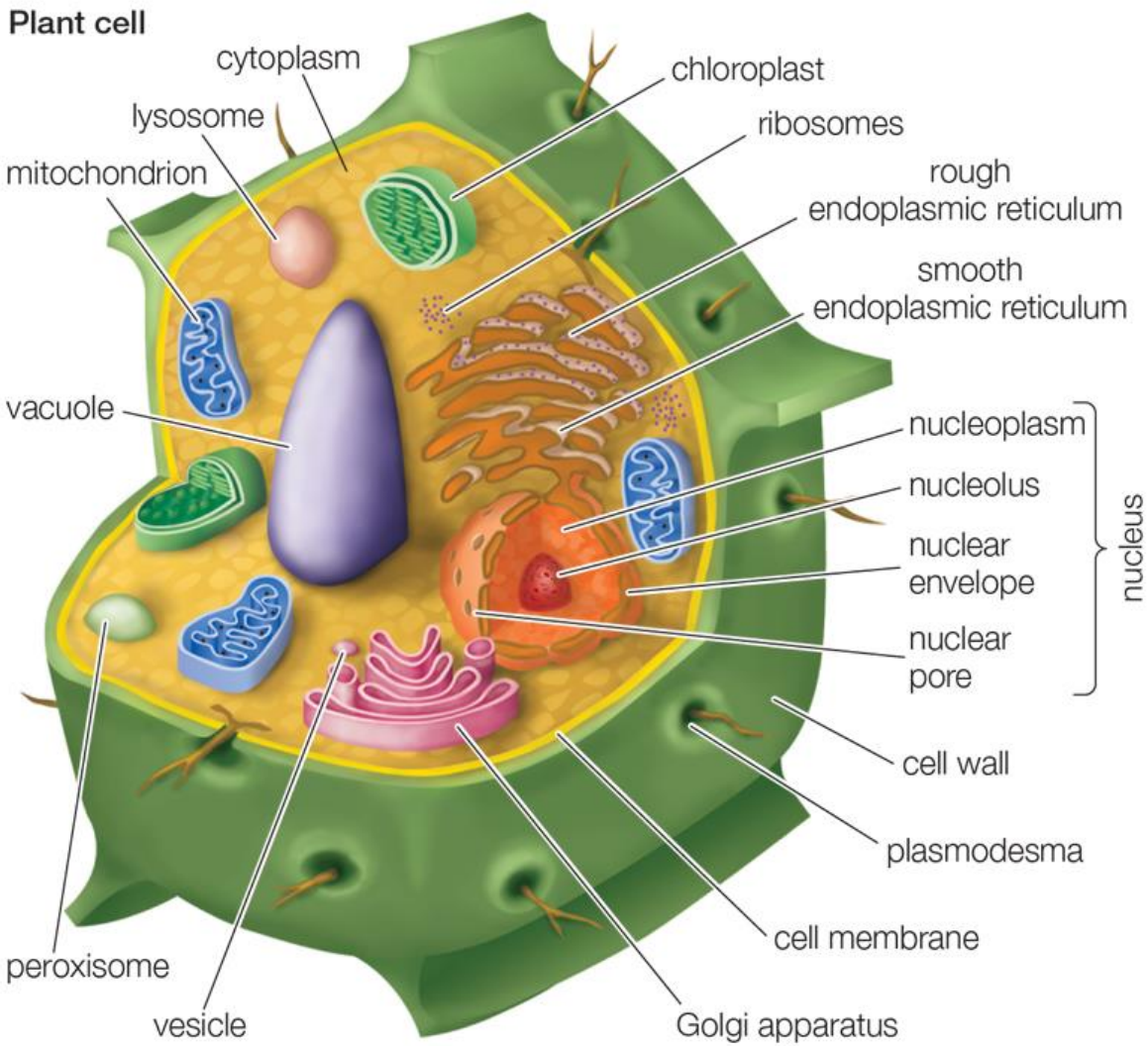
PROKARYOTIC CELL | TYPICAL FEATURES



- Appeared 3.5 billon years ago
- Size 0.5-10 µm
- Unicellular
- **Binary fission** - a form of asexual reproduction and cell division used by all prokaryotes
- **Genome** - circular DNA in the cytoplasm, **do not have nucleus**
- Additional small circular molecules of DNA (plasmids) in the cytoplasm confer growth advantages
- Small number of organoids, **no membrane bounded organelles**
- 70S ribosomes, do not use endoplasmic reticulum and Golgi complex to modify proteins
- **Rigid cell wall** formed from murein, polysaccharides and amino acids
- Often have **flagella** D=20 nm, formed from twisted threads of a single protein (flagellin)
- Anaerobic **respiration** occurs in the cytosol, aerobic in mesosomes

CELL STRUCTURE | **EUKARYOTES**



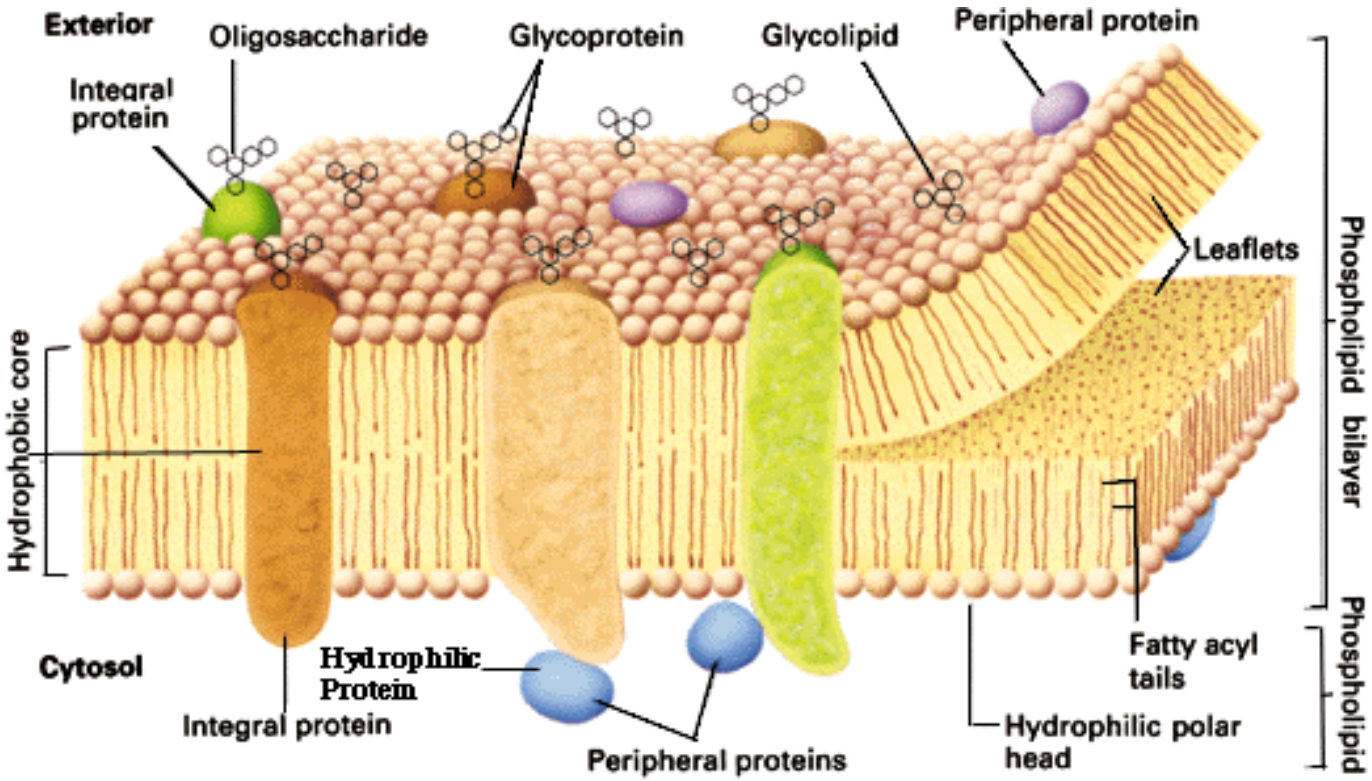


EUKARYOTIC CELL | **TYPICAL FEATURES**

- Appeared 1.2 billon years ago
- Protists, fungi, plants, animals
- Size: 10 - 100 µm
- Unicellular to multicellular organisms
- Divide by **mitosis or meiosis**, form spindle apparatus
- Genomic DNA organised in **chromosomes** & into the **nucleus**
- Lots of different membrane coated **organelles**: nucleus, mitochondria, lysosomes, peroxisomes, Golgi, vesicles etc.
- 80S ribosomes, use **endoplasmic reticulum** (ER) and **Golgi complex** to modify proteins
- Plants and fungi have a **cell wall**, formed mainly from cellulose in plants and chitin in fungi
- In the animal kingdom, cells may have liquid, semi liquid or solid **extracellular matrix**
- **Flagella** D=200 nm, formed from bundles of microtubules
- Anaerobic **respiration** occurs in the cytosol, aerobic in mitochondria

CELL MEMBRANE*

- The semipermeable membrane surrounding the cytoplasm of a cell
- Formed of a **phospholipid bilayer**, in which protein molecules (e.g., receptors) are embedded
- Cell membranes are **involved in a variety of cellular processes** such as cell adhesion, ion conductivity and cell signalling and **serve as the attachment surface** for several extracellular structures, including the cell wall, and intracellular cytoskeleton



** = plasma membrane or plasmalemma*

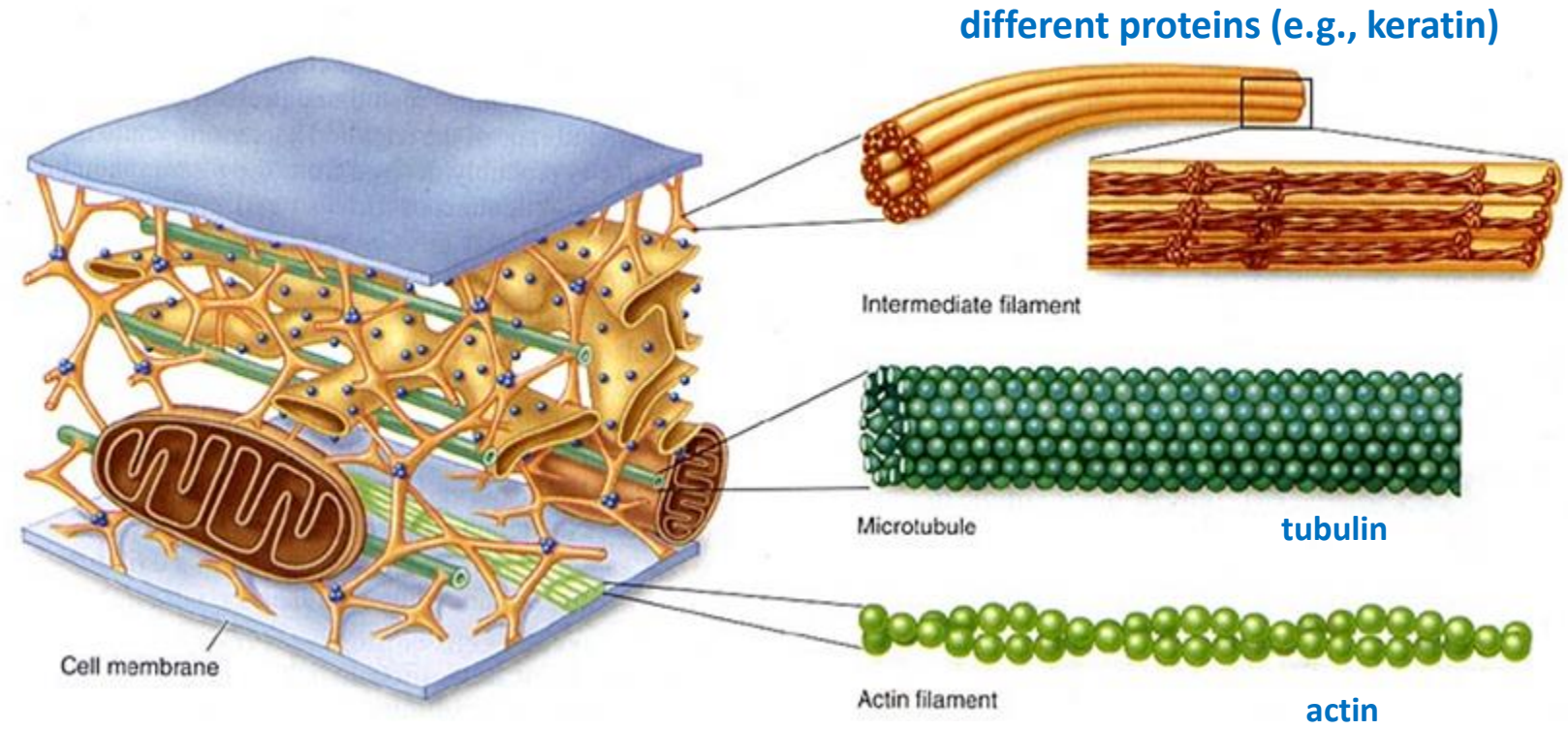
CYTOPLASM

- The cytoplasm comprises **cytosol** (the gel-like substance enclosed within the cell membrane) – and the **organelles** – the cell's internal sub-structures except for nucleus
- The cytoplasm is about 80% water and usually colourless; other components include salts and proteins
- Although cytoplasm may appear to have no form or structure, **it is actually highly organized**
- A framework of protein scaffolds called the **cytoskeleton** provides the cytoplasm and the cell with their structure

CYTOSKELETON

The cytoskeleton is **an intracellular matrix,** a 3D scaffold that supports cell shape and function

In eukaryotes, the matrix is a **dynamic structure** composed of **three main proteins**, which are capable of rapid assembly or disassembly dependent on the cell's requirements



from Johnson, George B. *The Living World.* © 2006 The McGraw-Hill Companies, Inc.

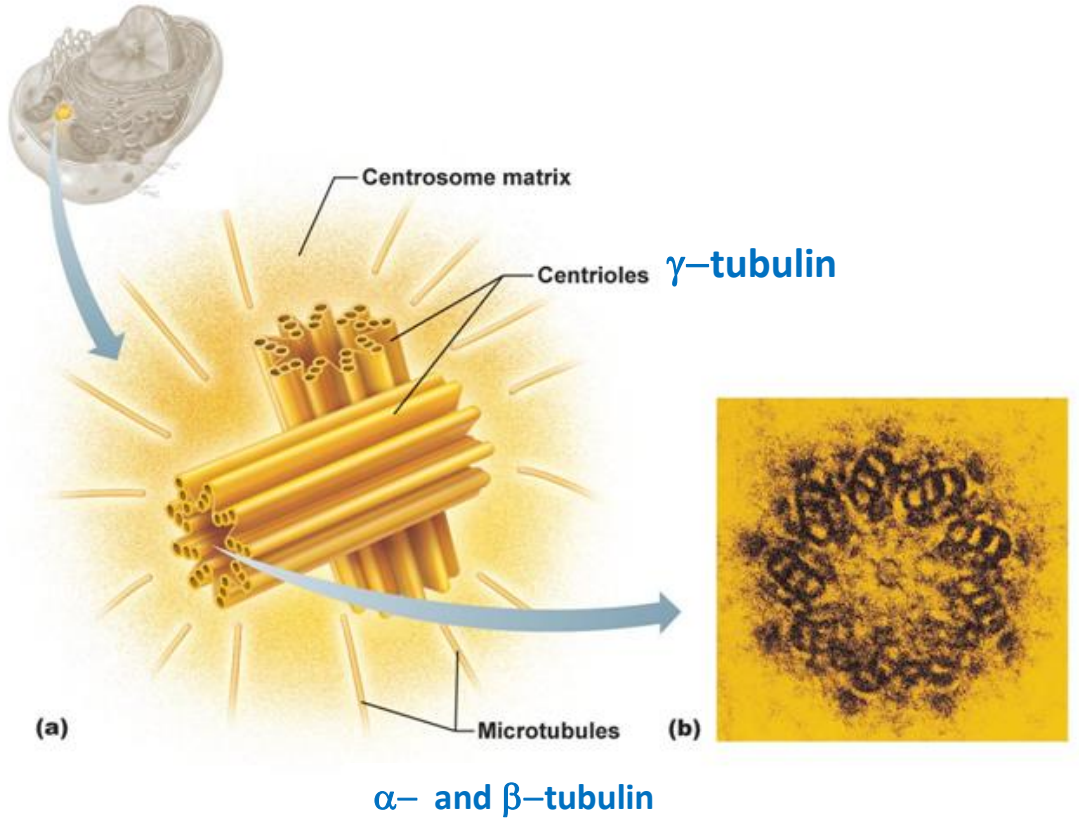
CENTRIOLES | CENTROSOME

Centrosome – the **main centre for organizing microtubules** in animal cells

Centrosome is formed from **two centrioles** that are positioned perpendicular to each other, and they are embraced in amorph protein mass, called **pericentriolar material**

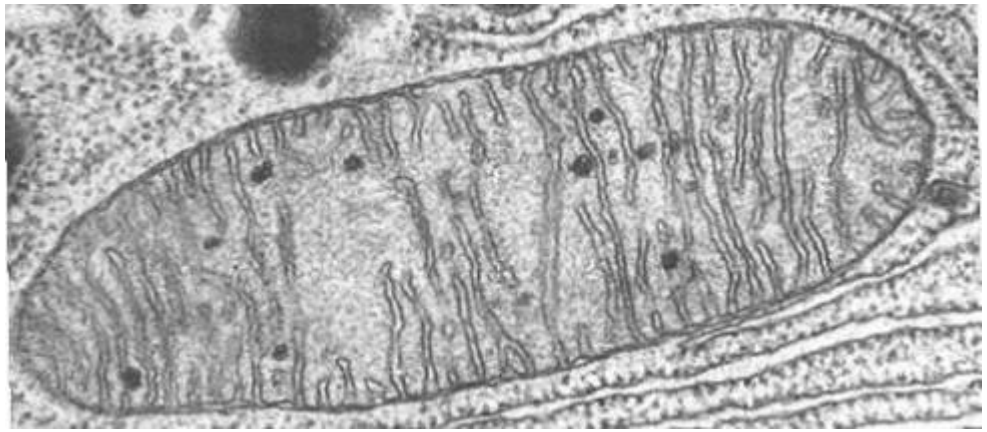
Centrioles are made from tubular structures that are made of gamma(γ)-tubulin

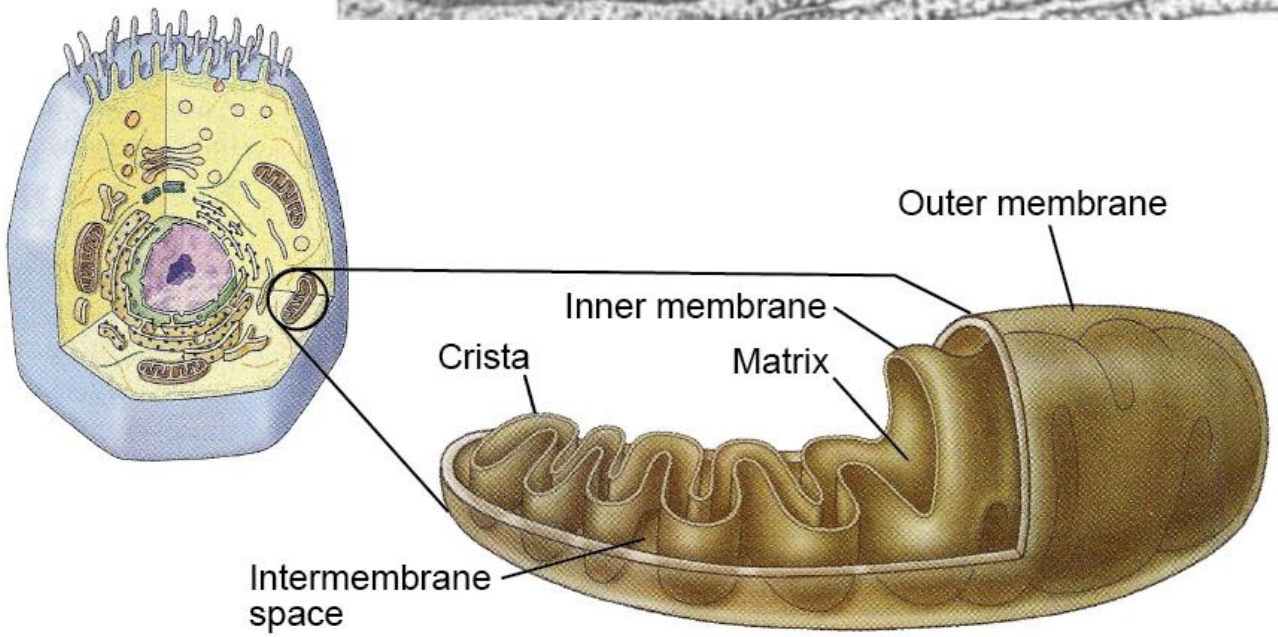
Typically, they are positioned in proximity of nucleus (in the non-dividing cells!)



MITOCHONDRIA

- The **energy-releasing organelles** of the cell, the site of some of the reactions of aerobic cellular respiration
- Surrounded by two membranes, the outer membrane apparently originated from the eukaryotic host cell, whereas the inner membrane appears to be bacterial in origin
- The inner membrane has many folds, called **cristae**, similar to the folds seen in the plasma membrane of some bacteria. The cristae contain the molecules of the **electron transport chain**, which converts chemical bond energy to ATP
- Has its own circular DNA, called mtDNA

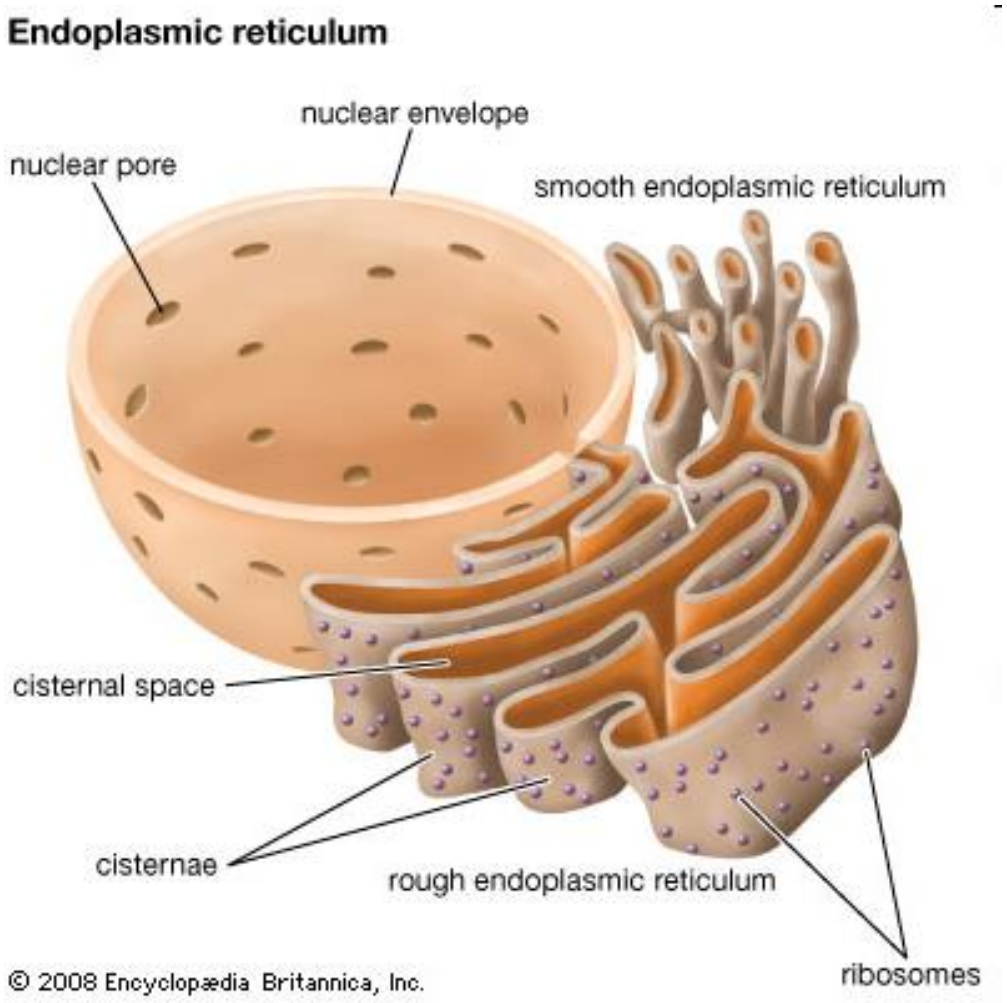




https://online.science.psu.edu/biol011_active002/node/4190

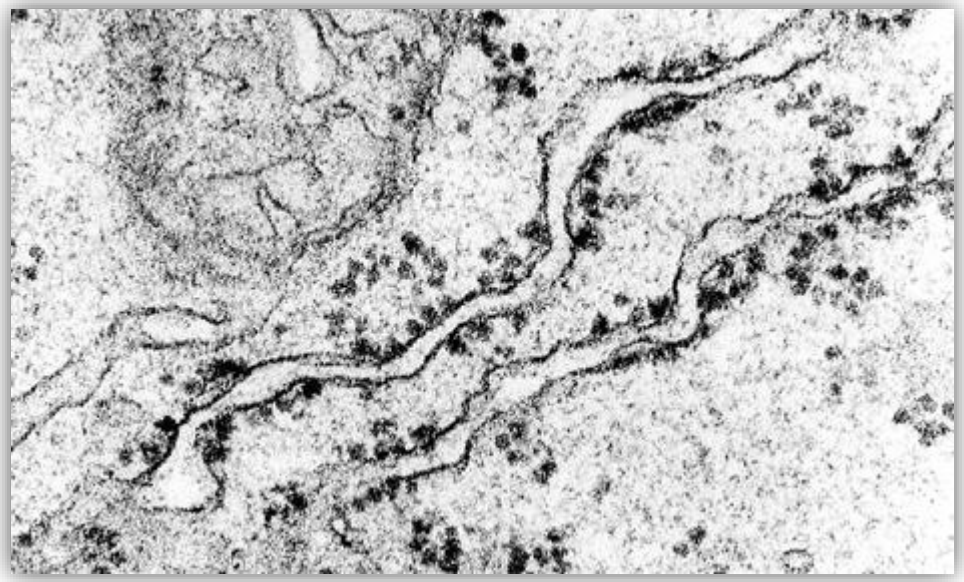
ENDOPLASMIC RETICULUM (ER)

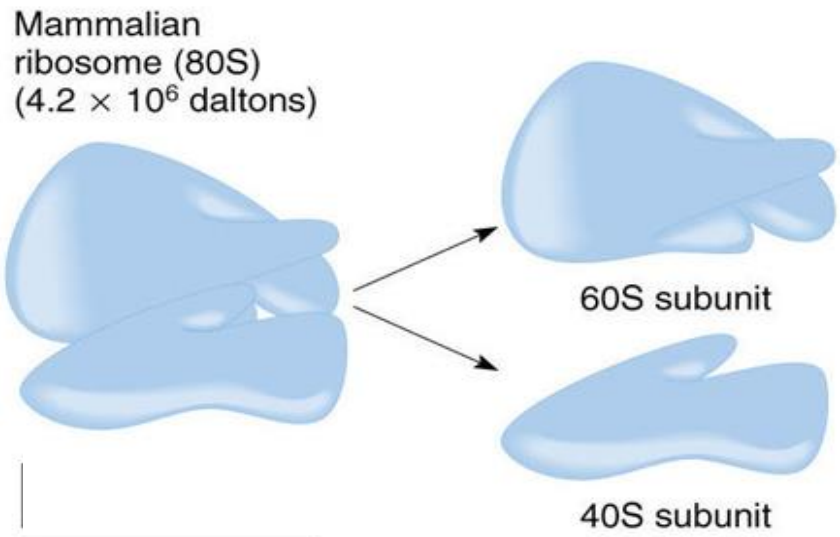
- a network of **membranous tubules** within the cytoplasm of a eukaryotic cell, continuous with the nuclear membrane
- with ribosomes attached – **rough**, no ribosomes - **smooth**
- involved in protein and lipid synthesis and transportation, storage of Ca^{2+} ions
- appears **in most eukaryotic cells**, absent in red blood cells and spermatozoa



RIBOSOMES

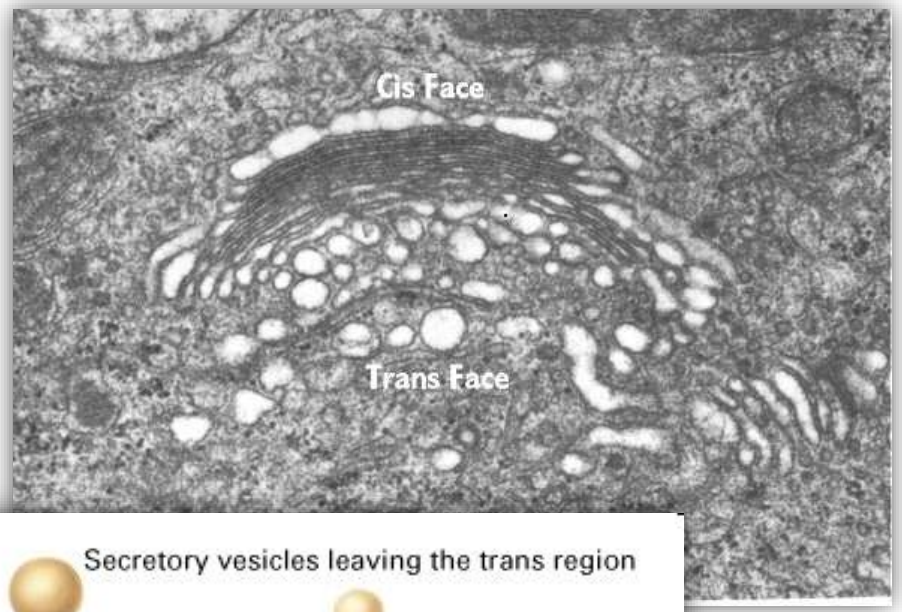
- **Form basis of translational aparatus** - responsible for **protein synthesis** - translation of mRNA into a polypeptide chain
- large and complex molecular machine built from **two subunits** – small and large consistinf of rRNA and ribosomal proteins
- **no membrane** – an organoid (ribonucleoprotein), not an organelle
- found in both prokaryotes and eukaryotes, but differ in their size, sequence, structure, and the ratio of protein to RNA

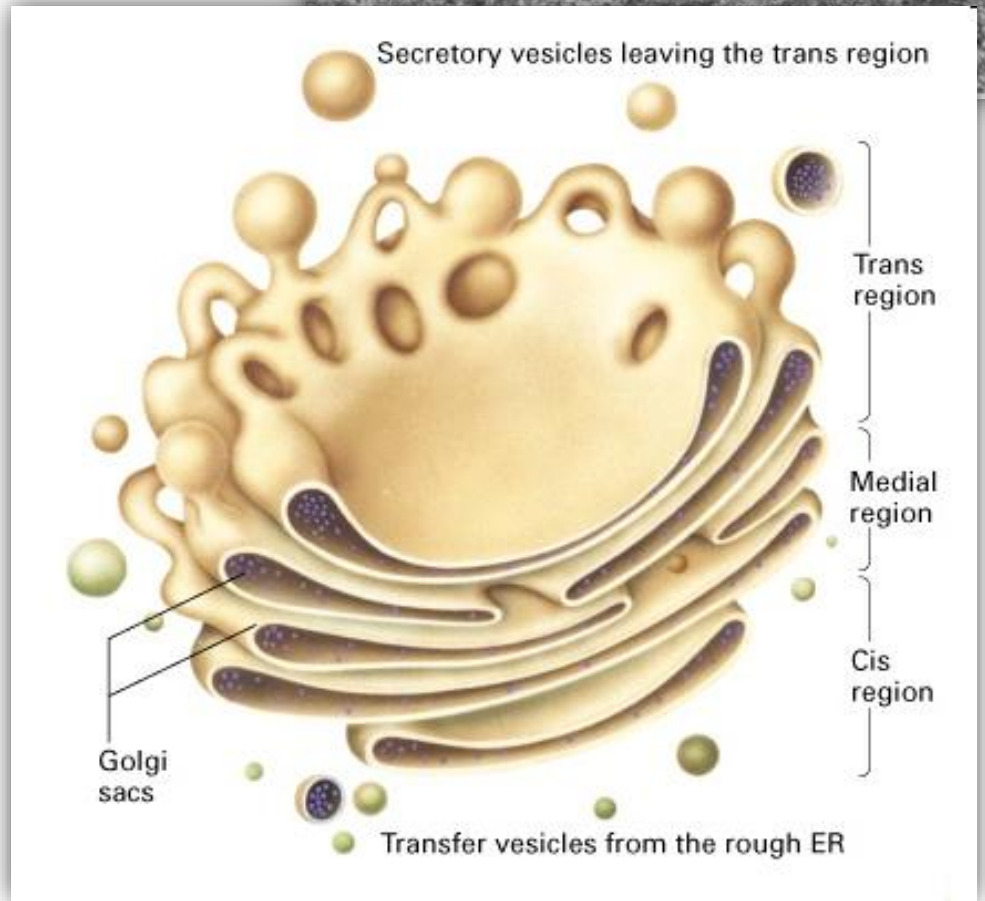




GOLGI APPARATUS*

- made up of a series of flattened, stacked pouches called **cisternae** (n=4-8)
- responsible for **transporting, modifying, and packaging** proteins and lipids into vesicles for **delivery** to targeted destinations
- located in the cytoplasm next to the ER and near the cell nucleus
- while many types of cells contain only one or several Golgi apparatus, plant cells can contain hundreds

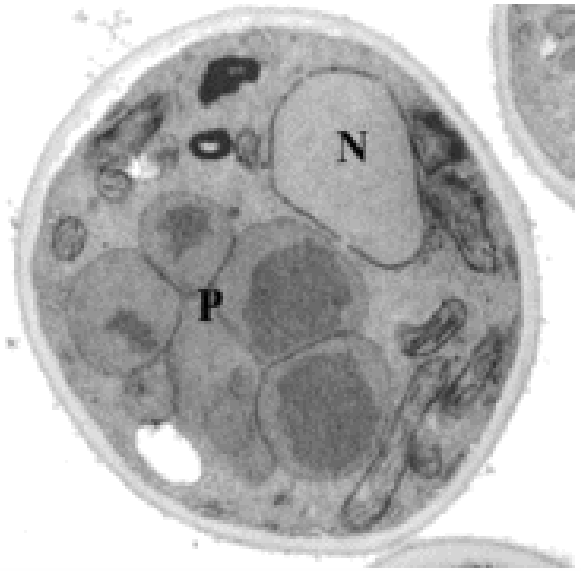


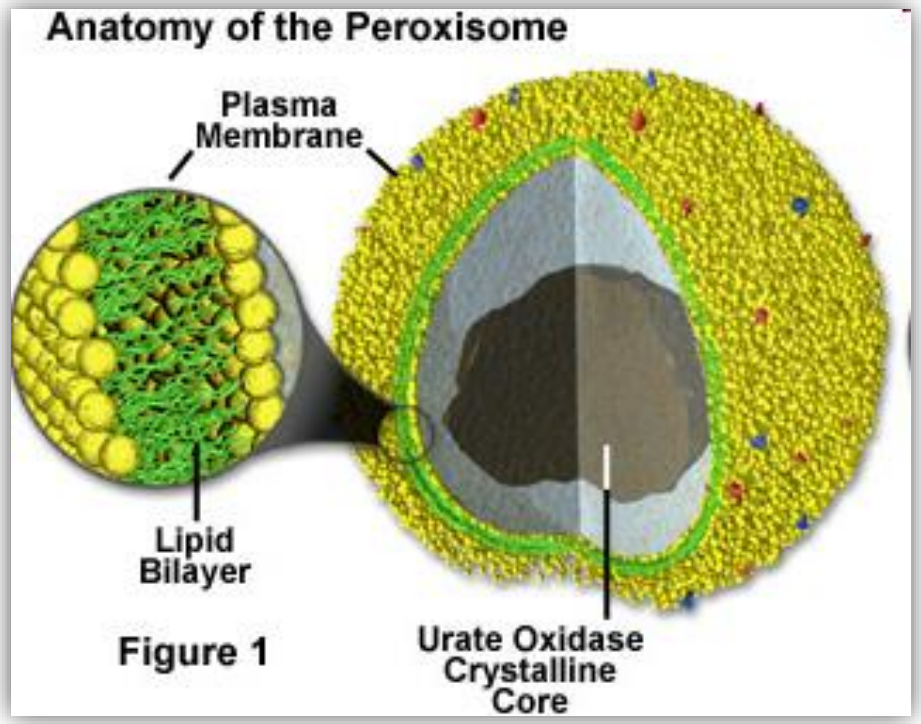


** **Golgi complex**, **Golgi body**, or simply the **Golgi***

PEROXISOMES

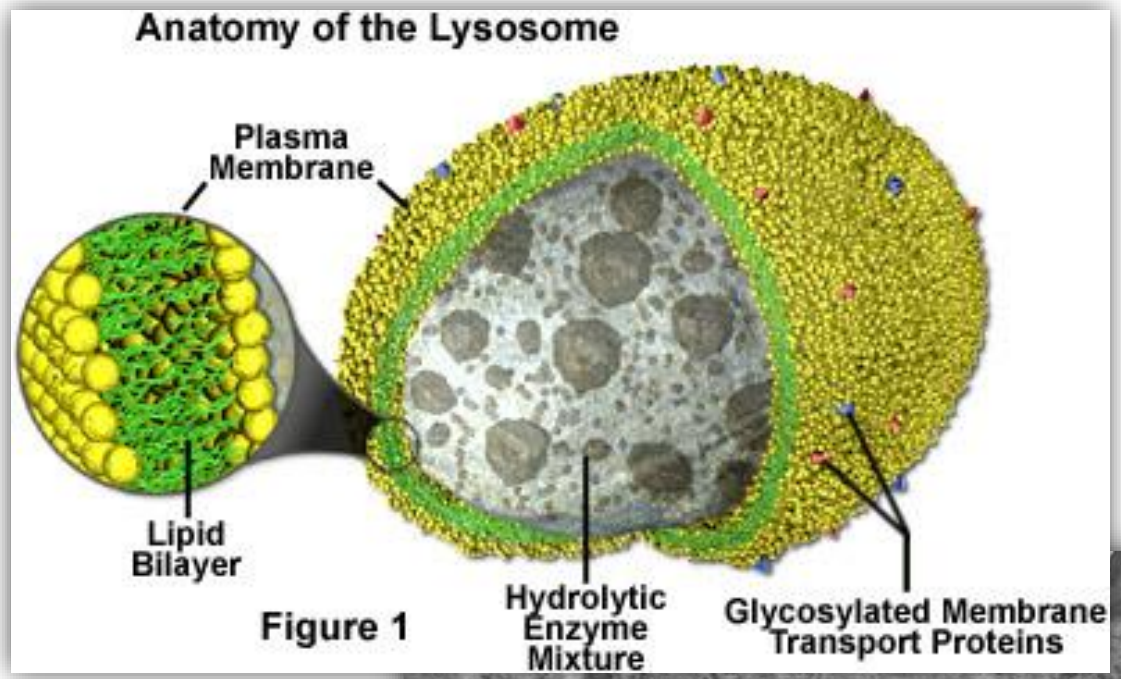
- Peroxisomes are small, membrane-enclosed organelles that contain enzymes involved in a variety of metabolic reactions called **peroxisomal respiration**
- neutralise hydrogen peroxide into water and oxygen
- assembled, like mitochondria and chloroplasts, from proteins that are synthesized on free ribosomes and then imported into peroxisomes as completed polypeptide chains
- Although peroxisomes do not contain their own genomes, they are similar to mitochondria and chloroplasts in that they **replicate by division**

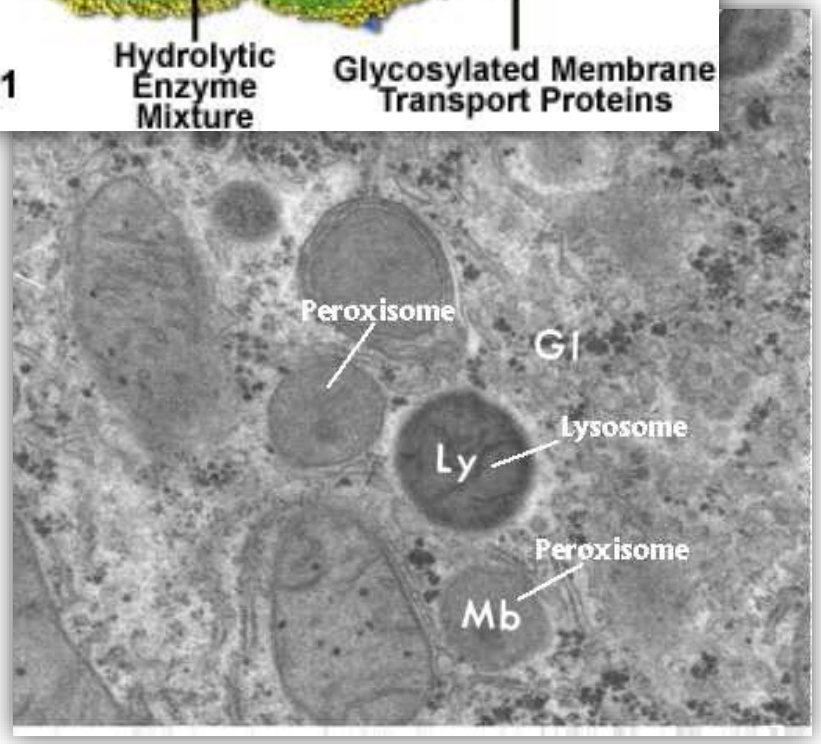




LYSOSOMES

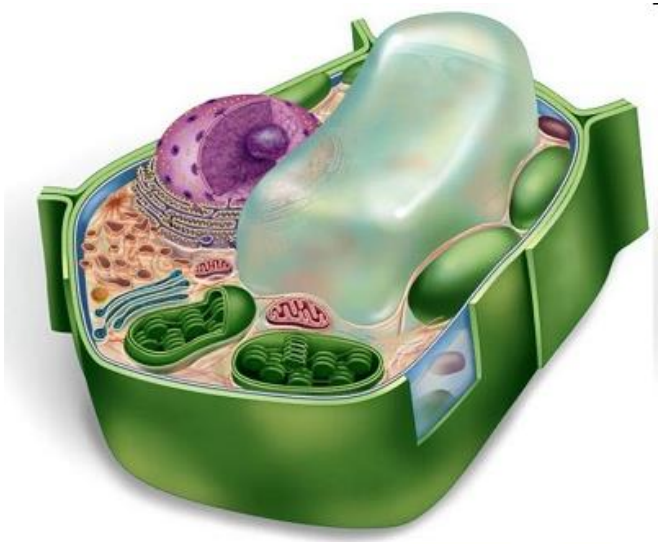
- an organelle in the cytoplasm of eukaryotic cells enclosed in a membrane containing **acid hydrolase enzymes** that break down waste materials and cellular debris
- known to contain more than 50 different enzymes
- responsible for **cellular homeostasis** for their involvements in secretion, plasma membrane repair, cell signalling and energy metabolism

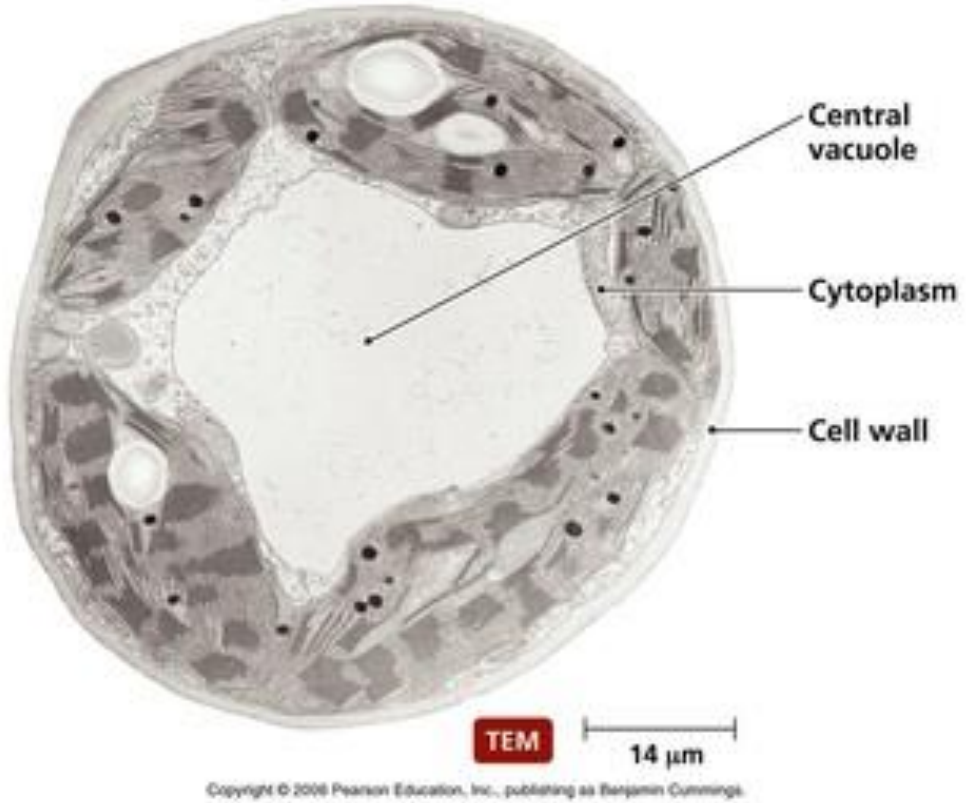


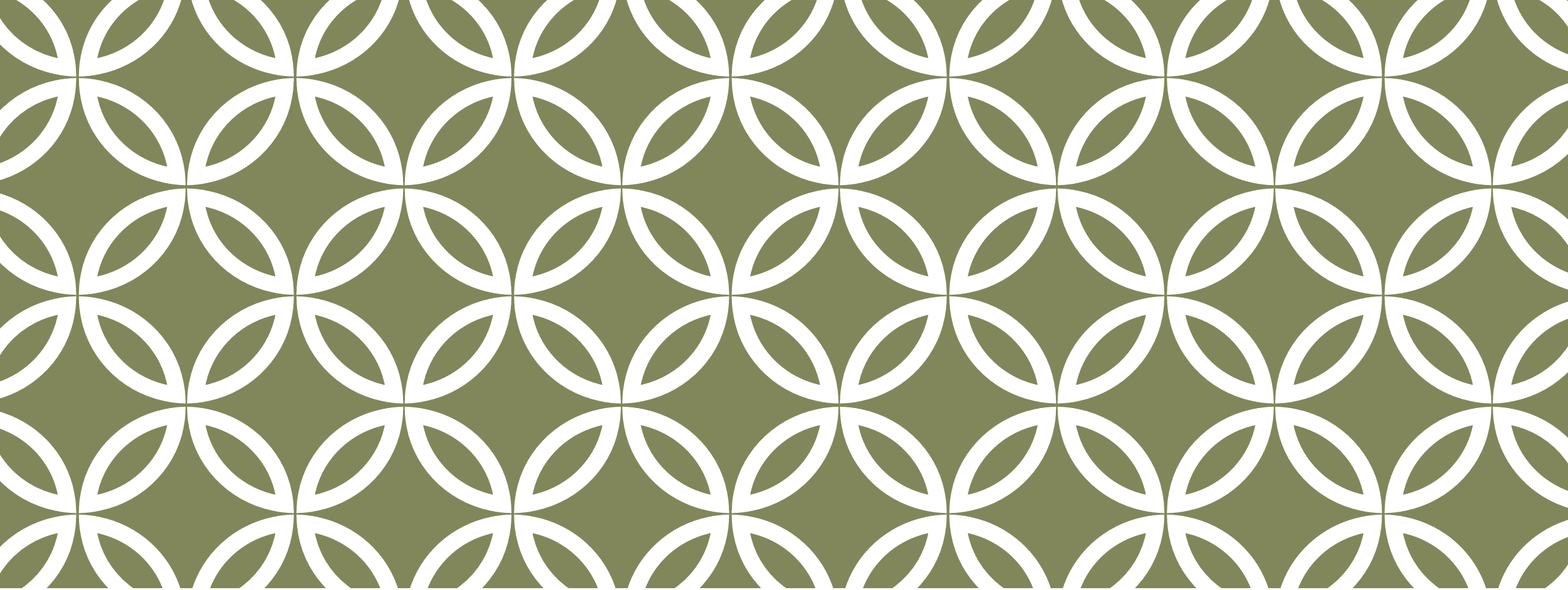


VACUOLES

- storage bubbles found in cells, found in both animal and plant cells (much larger there) with no basic shape or size
- might store food or any variety of nutrients a cell might need to survive; or store waste products so the rest of the cell is protected from contamination
- play a major role in autophagy, maintaining a balance between biogenesis (production) and degradation (or turnover), of many substances and cell structures in certain organisms
- aid in the lysis and recycling of misfolded proteins
- participates in the destruction of invading bacteria (phagocytosis)







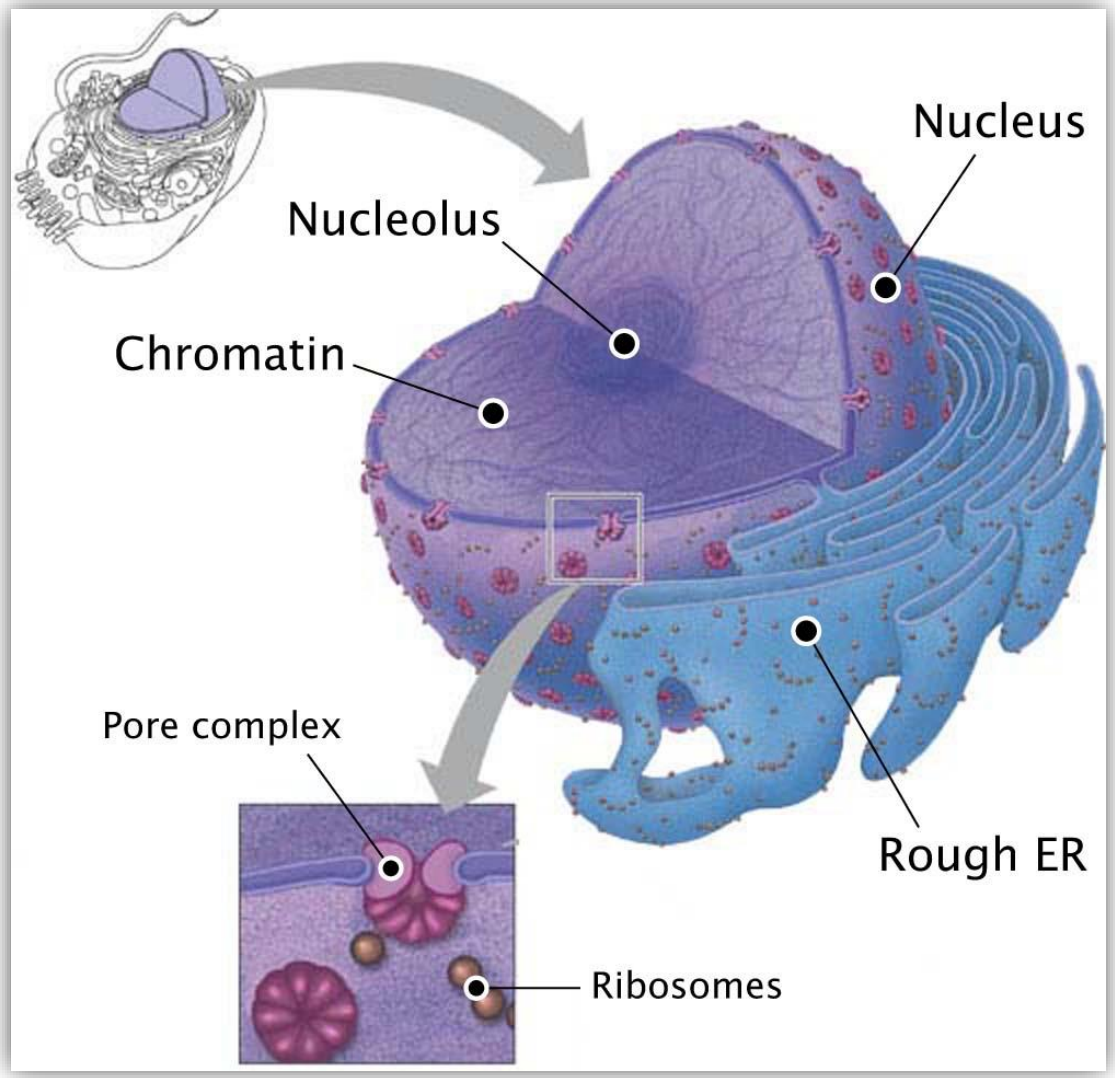
THE NUCLEUS

NUCLEAR STRUCTURE

Contains the genetic information of the cell packaged in the form of chromatin. The **key functions** of the cell nucleus include deoxyribonucleic acid replication and further to control gene expression during the cell cycle

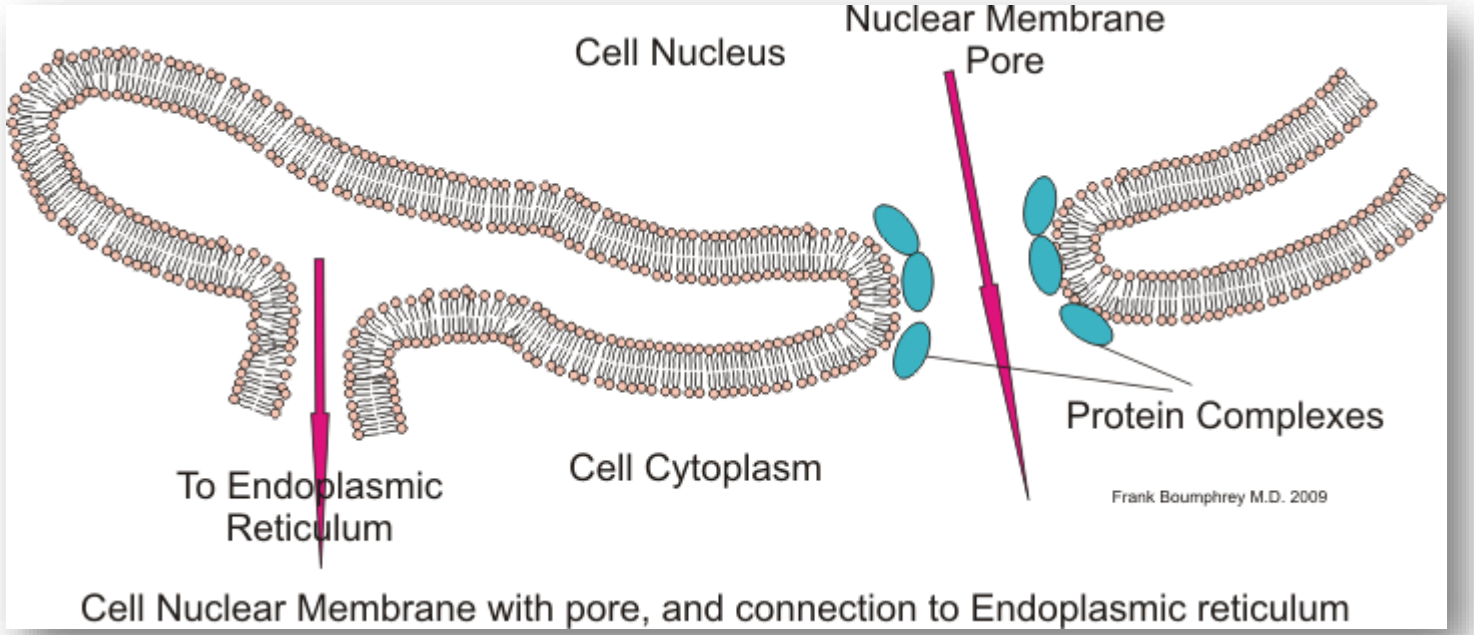
Principal structural components:

- **Nuclear envelope** (double membrane) with nuclear pore complexes
- **Nucleoplasm**
- **Nucleolus** (1 or more) - the clearest substructure in the nucleus in most eukaryotes, primarily serves as the site of ribosome synthesis and assembly
- **Chromatin** – long streatches of gDNA that is highly coiled and folded by proteins



NUCLEAR ENVELOPE

A **highly regulated membrane barrier** that allows the compartmentalisation of the nucleus from the cytoplasm



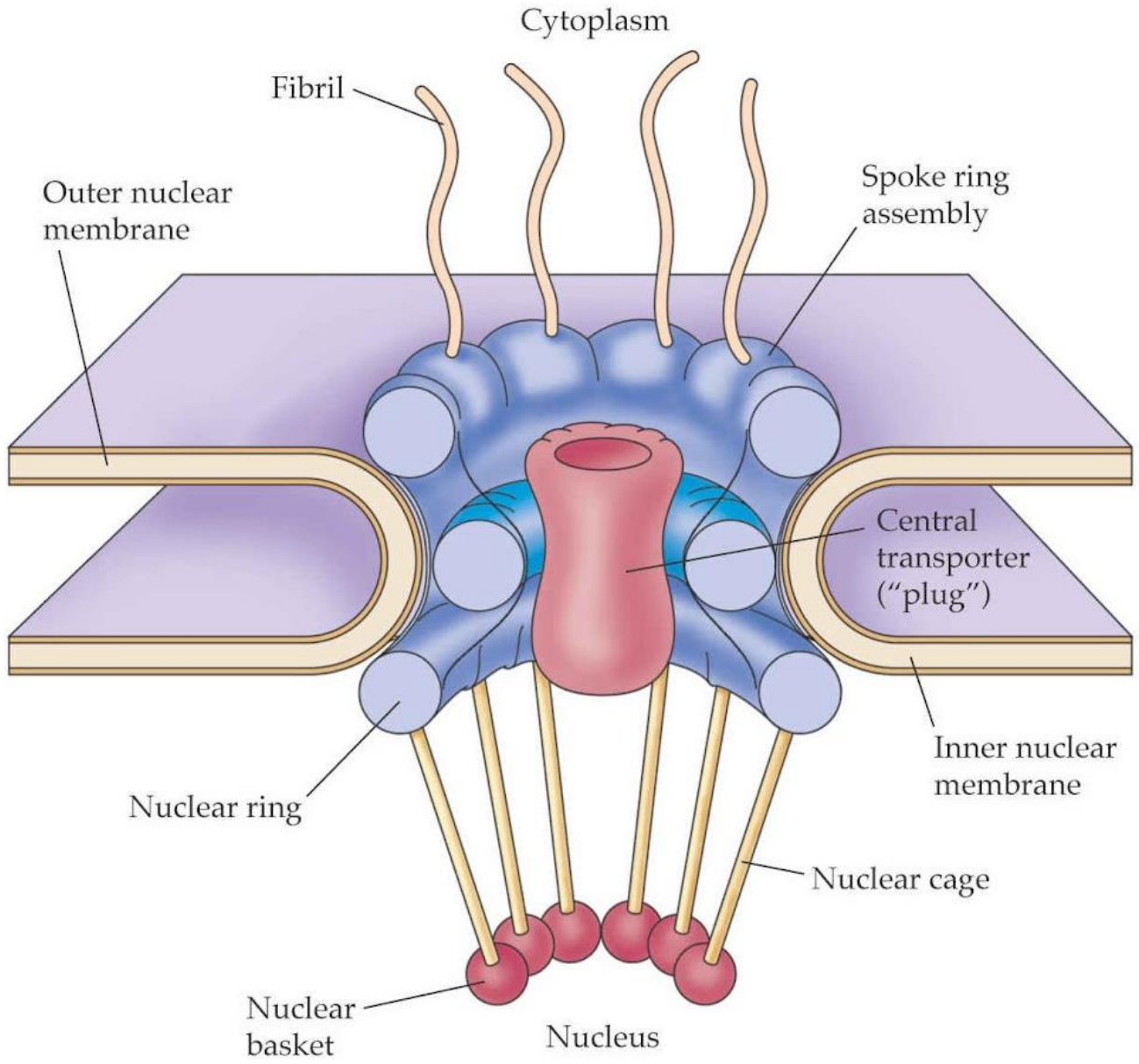
Terminology and definitions:

- A nuclear membrane, also known as the **nuclear envelope, nucleolemma or karyotheca**, is the double lipid bilayer membrane which surrounds the genetic material and nucleolus in eukaryotic cells
- The nuclear membrane consists of **two lipid bilayers**—the inner nuclear membrane, and the outer nuclear membrane, which are permeable only to small nonpolar molecules
- The space between the membranes is called the **perinuclear space**, a region contiguous with the lumen (inside) of the endoplasmic reticulum; it is usually about 20–40 nm wide

NUCLEAR PORE COMPLEXES

The inner and outer nuclear membranes are joined at **nuclear pore complexes**, **NPCs**, the sole channels through which small polar molecules and macromolecules are able to travel through the nuclear envelope

The nuclear pore complex is a complicated structure that is responsible for the selective traffic of proteins and RNAs between the nucleus and the cytoplasm

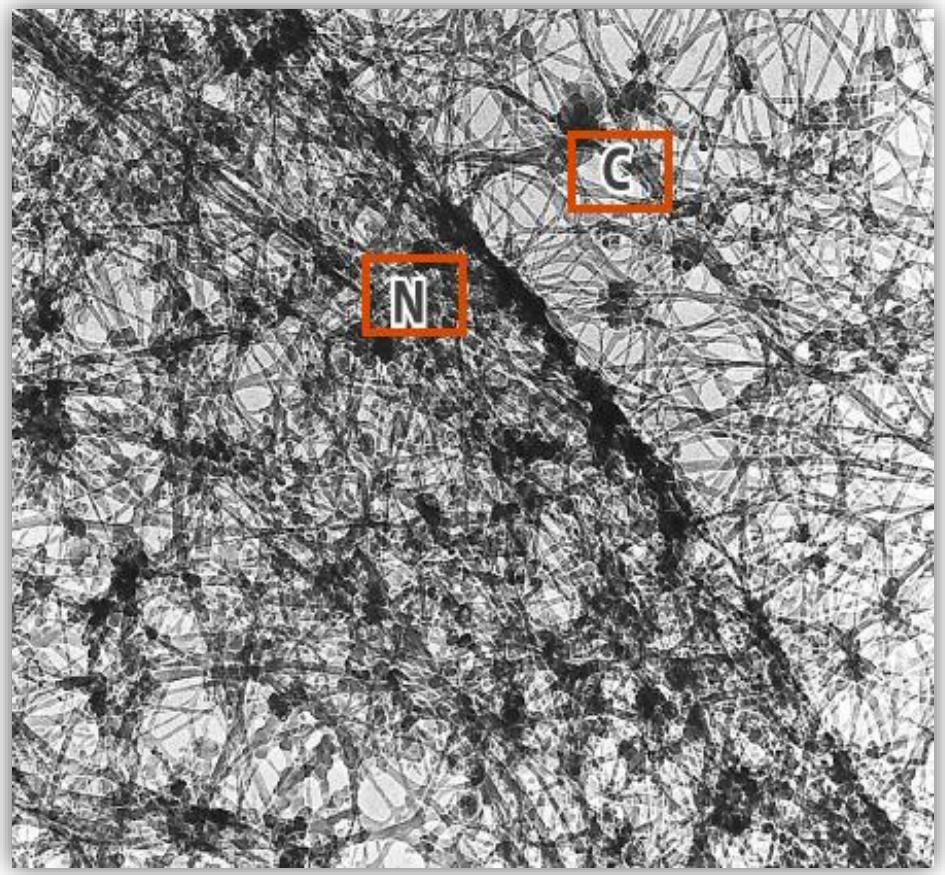


NUCLEOPLASM

- Similar to the cytoplasm of a cell, the nucleus contains **nucleoplasm or karyoplasm**. The nucleoplasm is one of the types of **protoplasm** (the living content of a cell that is surrounded by a plasma membrane), and it is enveloped by the nuclear envelope
- The nucleoplasm is a highly viscous liquid that includes the chromosomes and nucleoli
- Many substances such as nucleotides (necessary for purposes such as the replication of DNA) and enzymes (which direct activities that take place in the nucleus) are located in the nucleoplasm
- The soluble, liquid portion of the nucleoplasm is called the **nucleosol** or **nuclear hyaloplasm**

NUCLEAR MATRIX

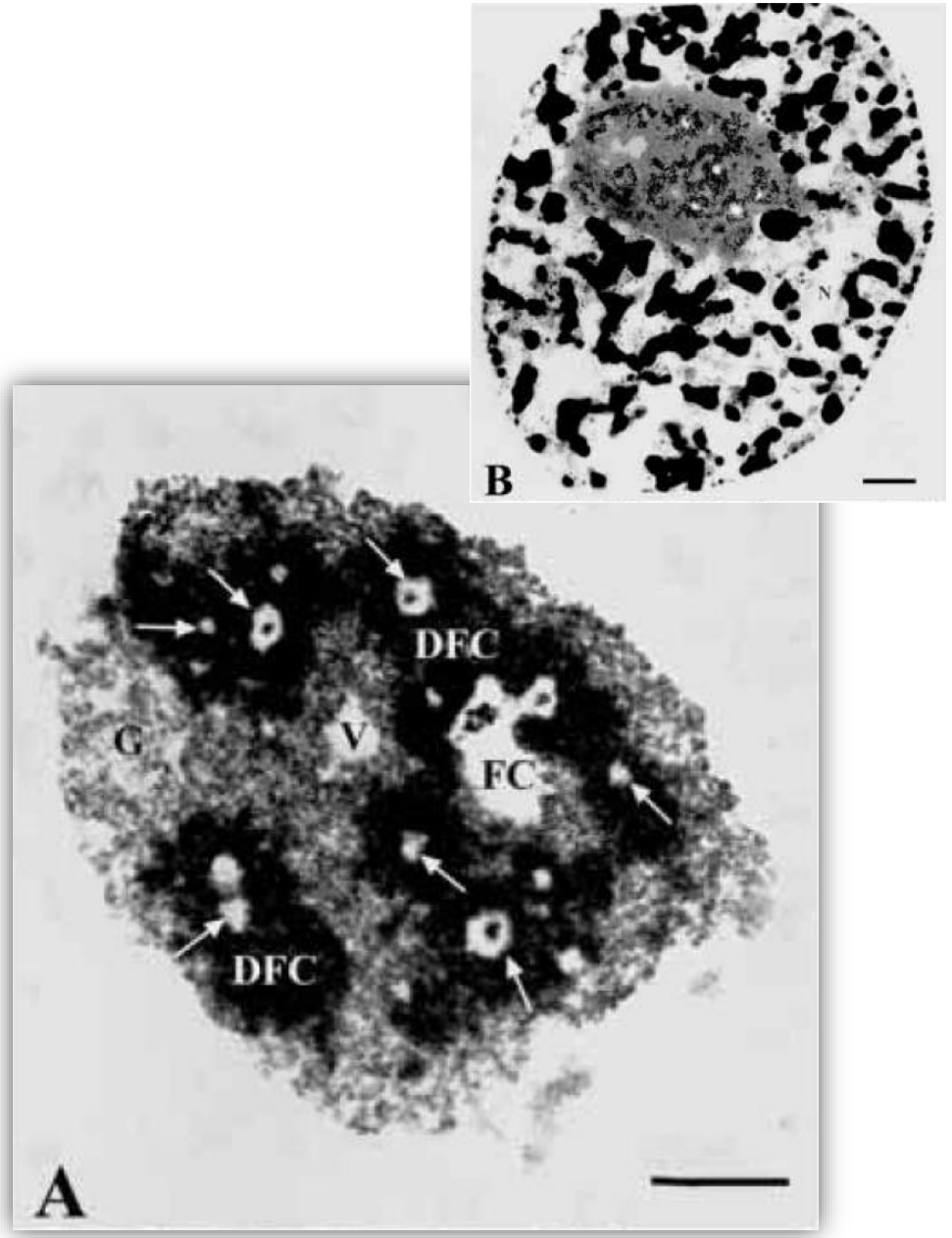
- **A polymer meshwork**, a “nuclear matrix” or “nuclear-scaffold” is an essential component of the in vivo nuclear architecture
- The nuclear matrix is **a network of fibres** found throughout the inside of a cell nucleus and is **somewhat analogous to the cell cytoskeleton**. However, in contrast to the cytoskeleton, the nuclear matrix has been proposed to be a **highly dynamic structure**, perhaps more like a dynamic sponge with open compartments for free diffusion of molecules in the nucleus
- The nuclear matrix, along with the **nuclear lamina** (a structure near the inner **nuclear** membrane and the peripheral chromatin) aid in organizing the genetic information within the cell



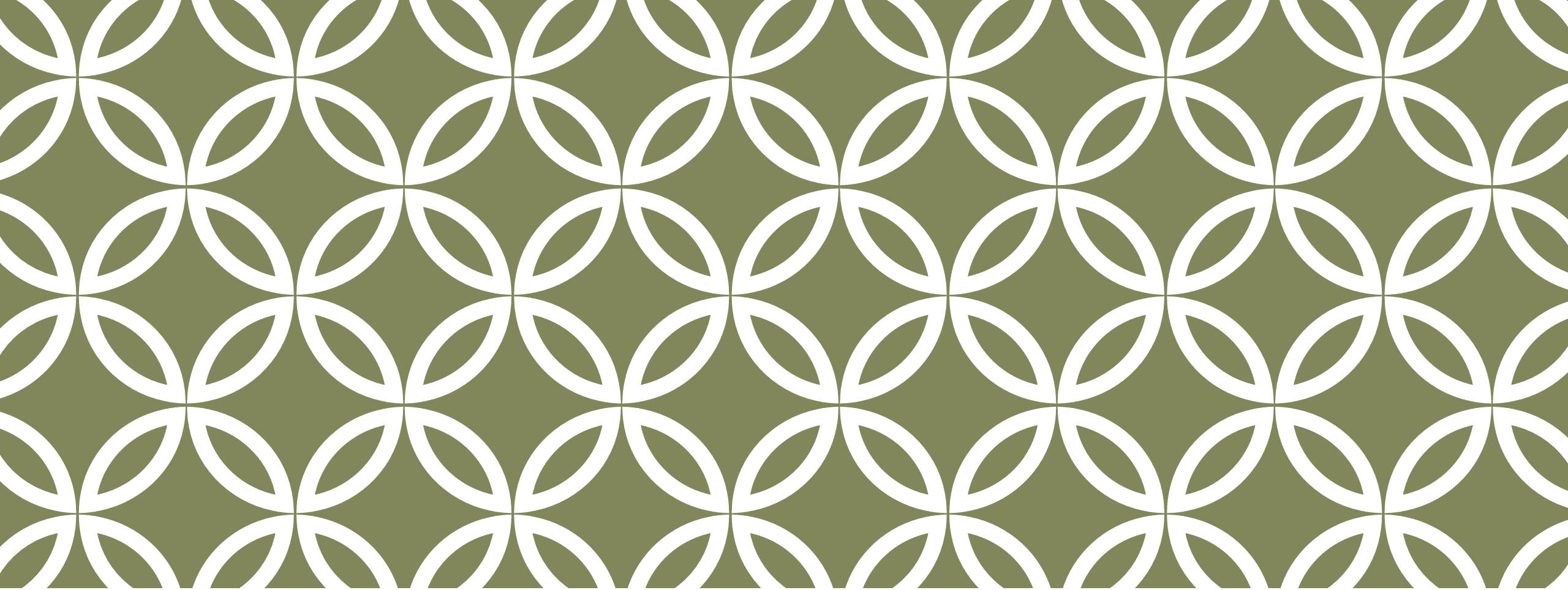
http://quizlet.com/11525634/bio-lecture-4-t3-flash-cards/

NUCLEOLUS

- The most prominent substructure within the nucleus, **the site of rRNA transcription and processing**, and of ribosome assembly
- Cells require large numbers of ribosomes to meet their needs for protein synthesis. Actively growing mammalian cells, for example, contain 5 million to 10 million ribosomes that must be synthesized each time the cell divides.
- Three major components of the nucleolus are recognized: the **fibrillar center** (FC), the **dense fibrillar component** (DFC), and **granular component** (GC). The DFC consists of newly transcribed rRNA bound to ribosomal proteins, while the GC contains RNA bound to ribosomal proteins that are being assembled into immature ribosomes

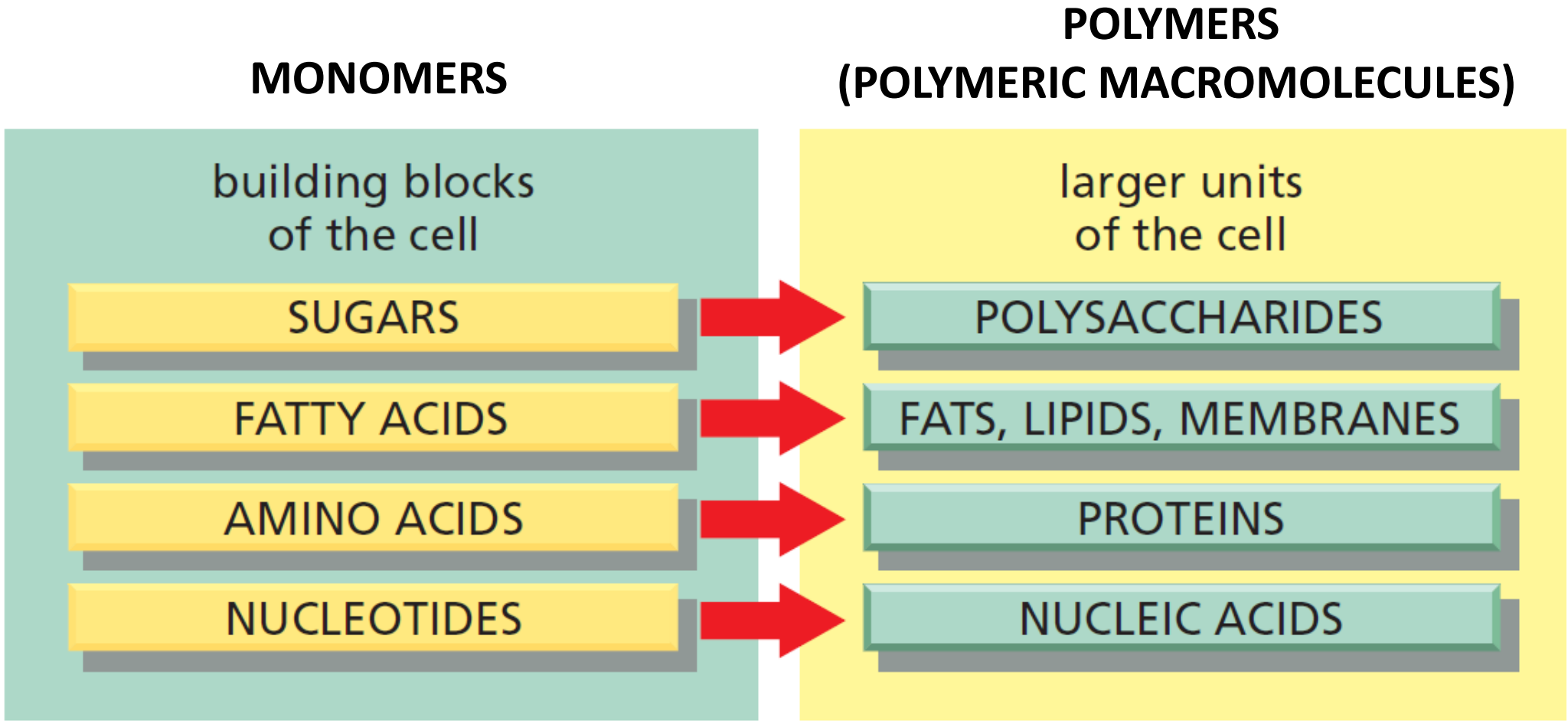


FC, fibrillar center; **DFC**, Dense fibrillar component; **G**, granular component. Bars, **0.5 µm**.

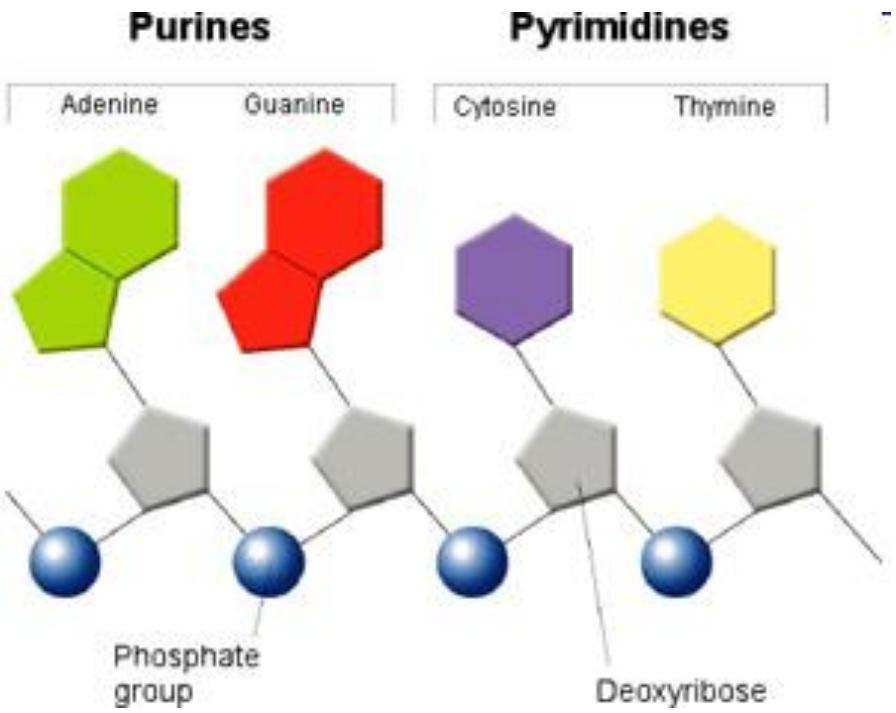


DNA & CHROMATIN

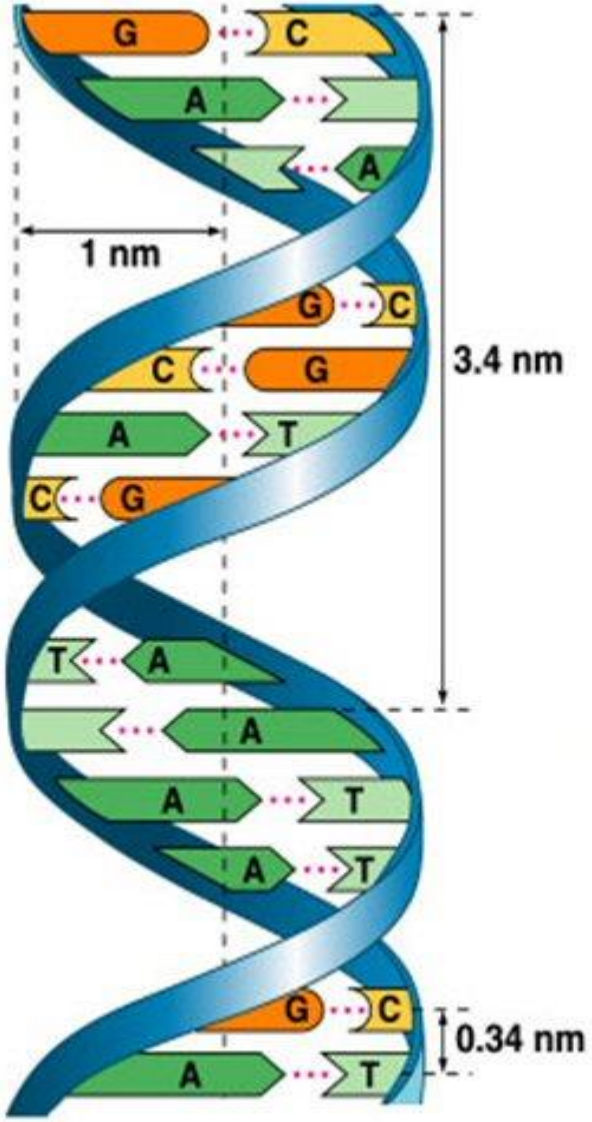
CELLS CONTAIN FOUR MAJOR FAMILIES OF SMALL ORGANIC MOLECULES (*monomers below*)



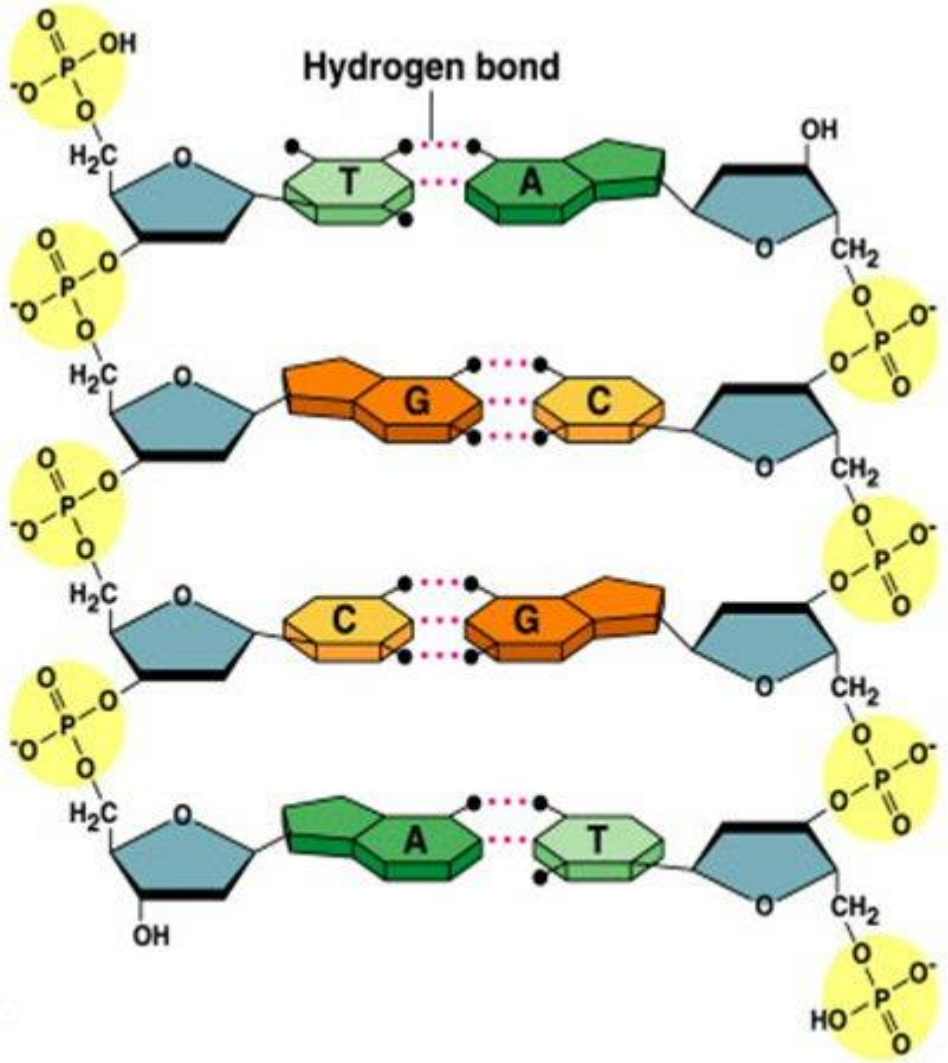
THE DNA MOLECULE



https://www.youtube.com/watch?v=o_-6JXLYS-k



(a) Key features of DNA structure



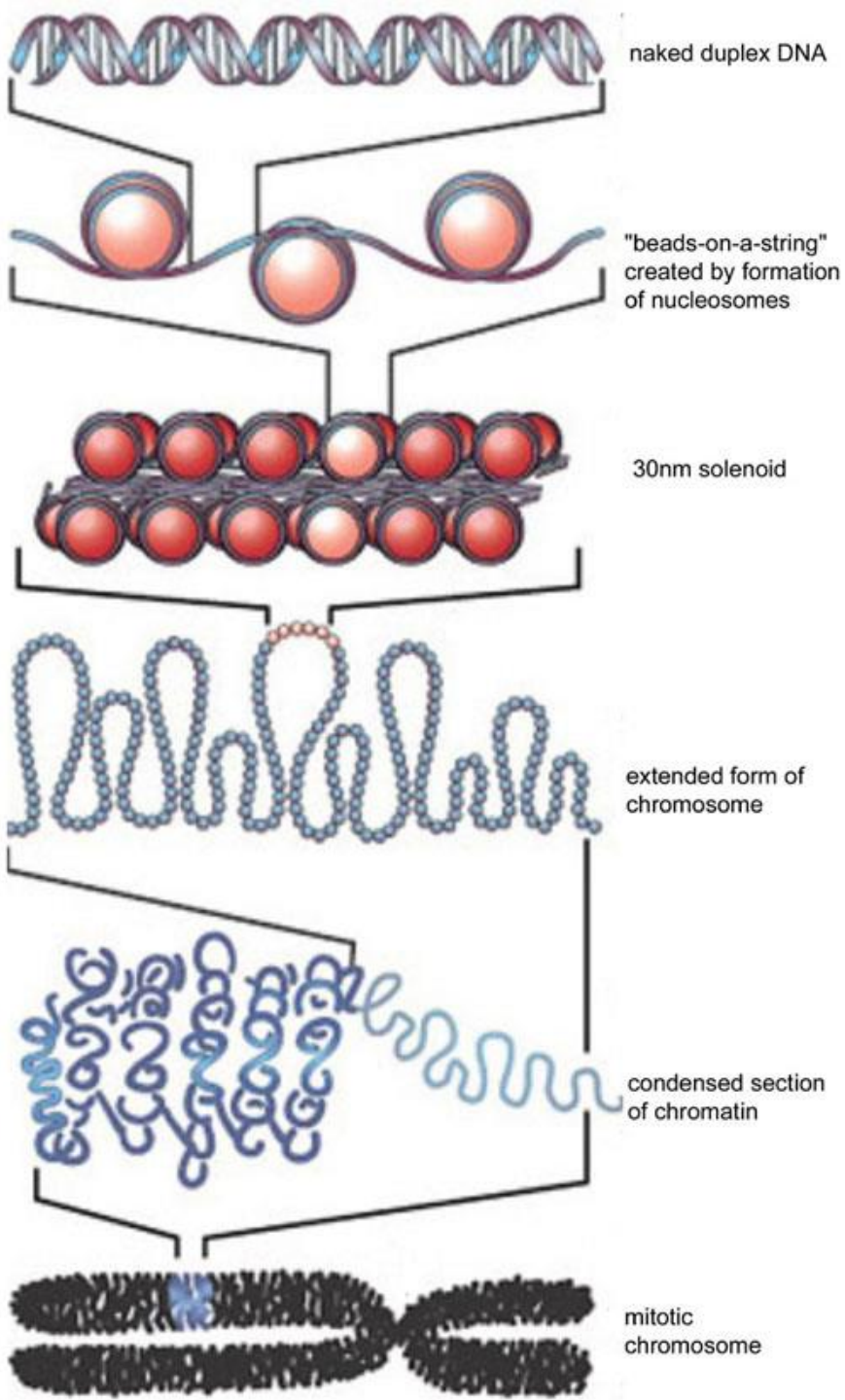
(b) Partial chemical structure

ORGANISATION LEVELS OF DNA

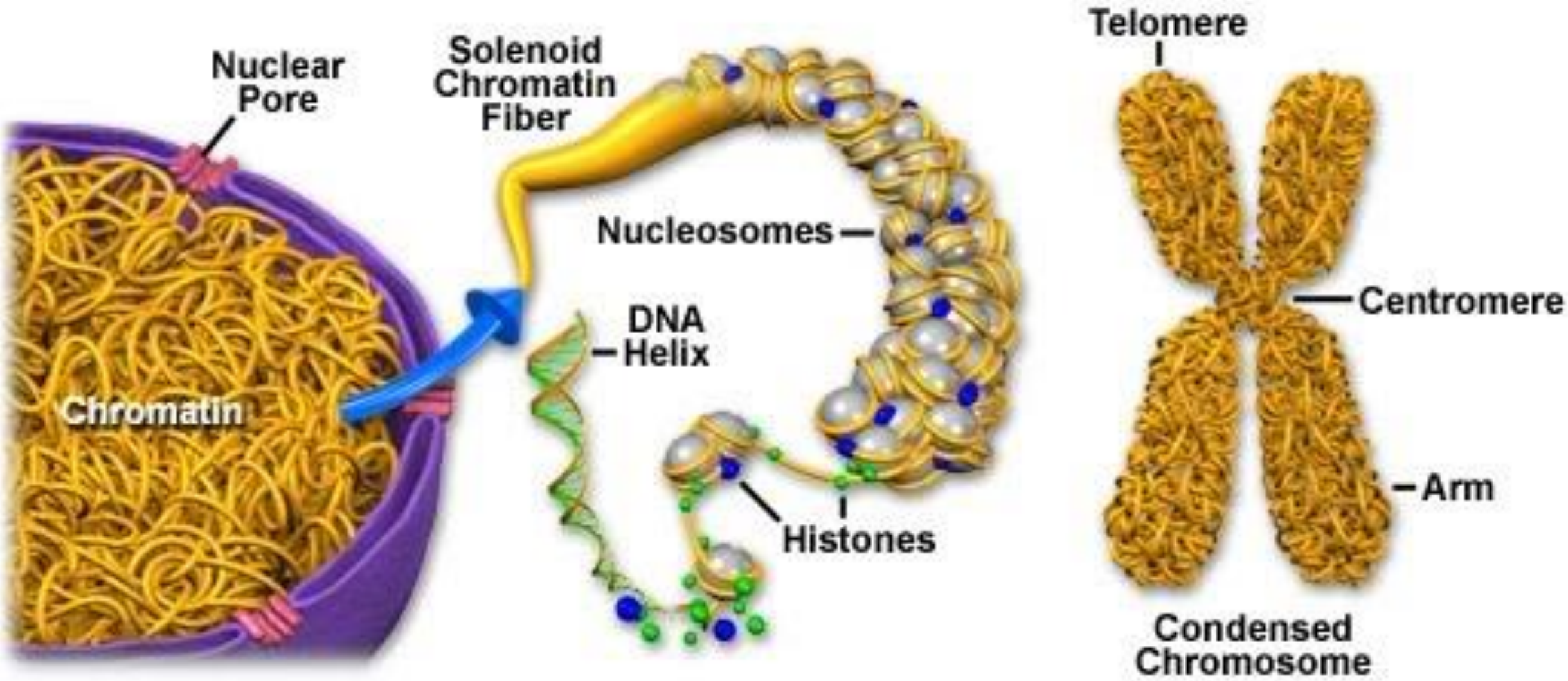
In general terms, there are **three levels of chromatin organization**:

1. DNA wraps around **histone proteins** forming **nucleosomes**; the "beads on a string" structure (**euchromatin**)
2. Multiple histones wrap into a 30 nm fibre consisting of nucleosome arrays in their most compact form (**heterochromatin**).
3. Higher-level DNA packaging of the 30 nm fibre into the **metaphase chromosome** (during mitosis and meiosis).

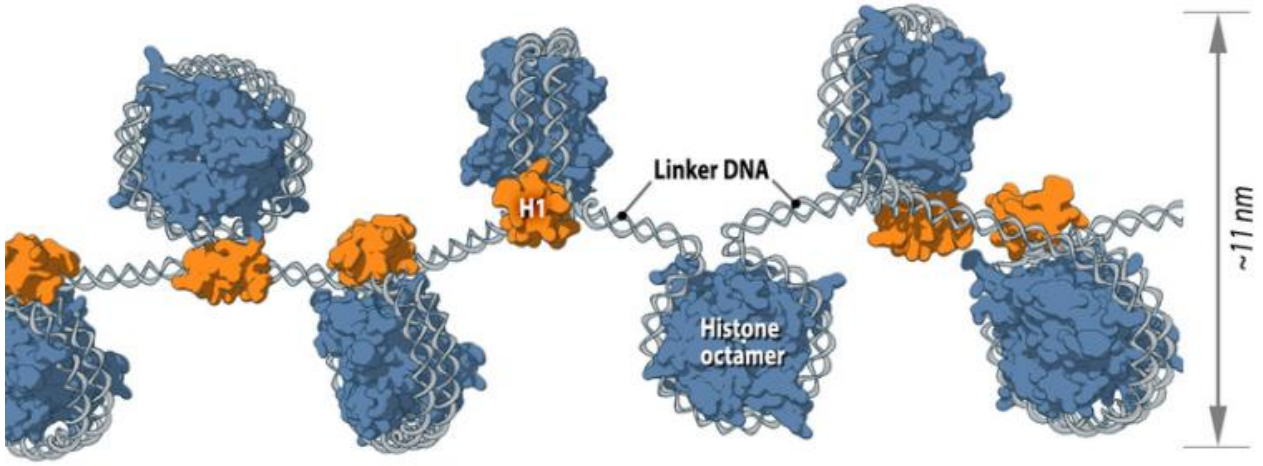
!!! There are **many cells that do not follow this organisation**. Spermatozoa and avian red blood cells have more tightly packed chromatin than most eukaryotic cells.



Chromatin and Condensed Chromosome Structure



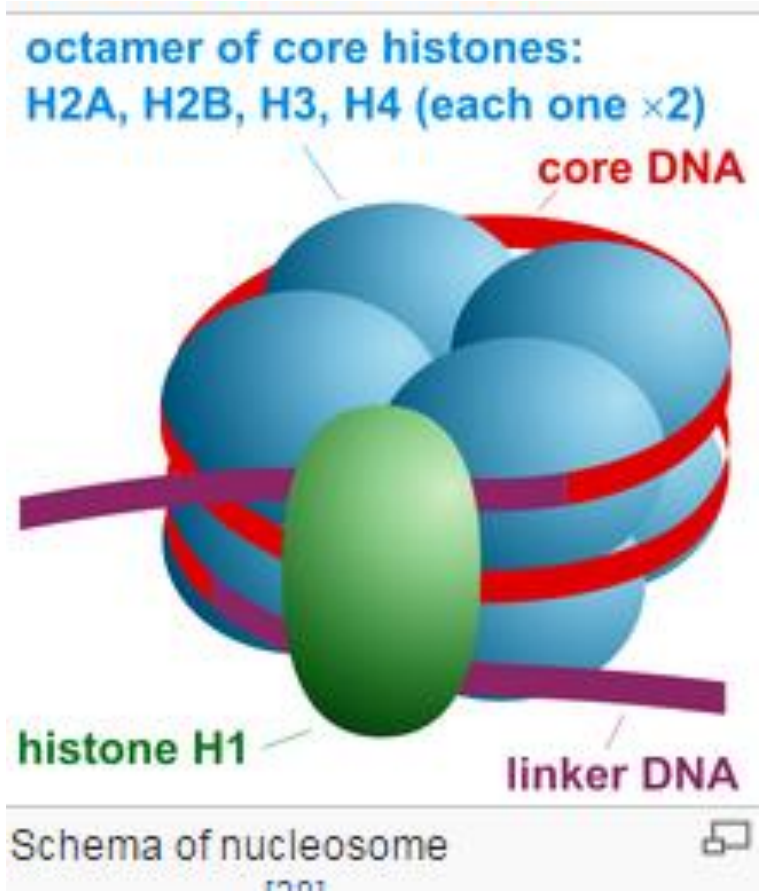
NUCLEOSOME



- Nucleosomes form the **fundamental repeating units of eukaryotic chromatin**, which is used to pack the large eukaryotic genomes into the nucleus while still ensuring appropriate access to it

!!! in mammalian cells approximately 2 m of linear DNA have to be packed into a nucleus of roughly 10 µm diameter

- The nucleosome core particle consists of approximately 147 base pairs of DNA wrapped in 1.67 left-handed superhelical turns around a histone octamer consisting of 2 copies each of the core histones H2A, H2B, H3, and H4.



CHROMATIN

Chromatin is a **complex of macromolecules** found in cells, consisting of DNA, protein and RNA

The **primary functions** of chromatin are:

1) to package DNA into a smaller volume to fit in the cell

2) to reinforce the DNA macromolecule to allow mitosis

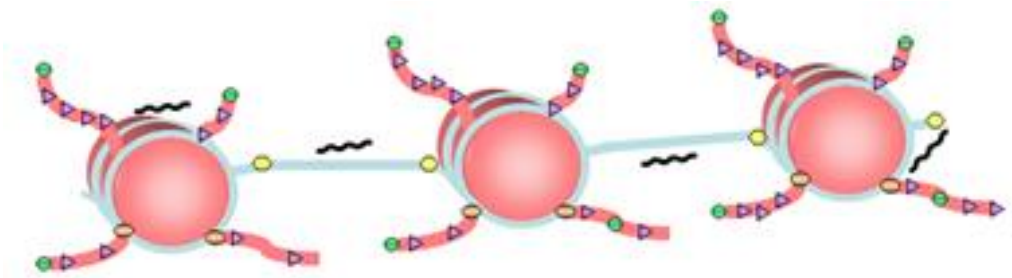
3) to prevent DNA damage,

4) to control gene expression and DNA replication

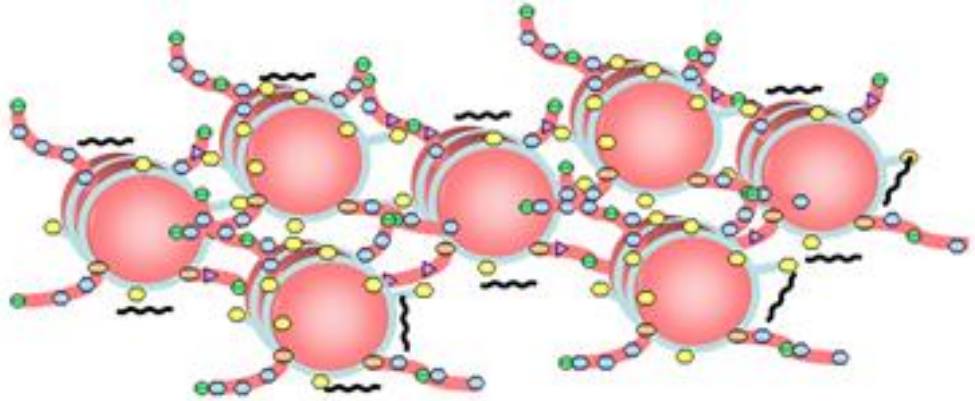
Heterochromatin – non-active regions of gDNA
Euchromatin – transcroptionally active regions of gDNA

ER – endoplasmic reticulum
M – mitochondria
Nu – nucleolus
E - euchromatin
H - heterochromatin

TYPES OF CHROMATIN



Euchromatin
Gene-rich, transcriptionally active
Dispersed appearance
Unique DNA sequences



Heterochromatin
Gene-poor, less transcriptionally active
Condensed appearance
Repetitive DNA sequences