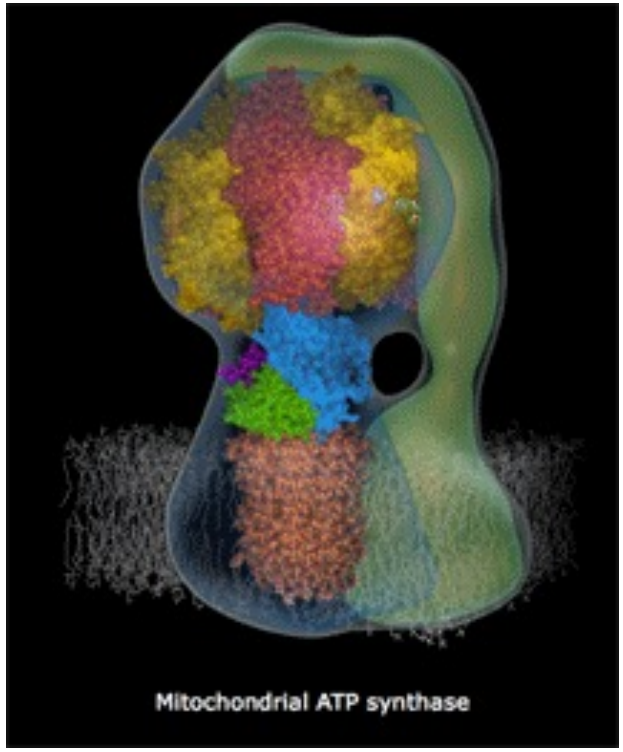
Macromolecular Structures

Sc. in Nanotechnology Engineering
Sapienza University of Rome



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Course Bibliography – Part 1

- 📚 Main Textbook
- Alberts, B. et al. (2023). Essential Cell Biology (6th Ed.).
- W. W. Norton & Company – ISBN: 978-0393884853
- (Use selected chapters as the main reference.)

- 🔬 Biochemistry Reference
- Nelson, D. L., Cox, M. M. (2021). Lehninger Principles of Biochemistry (8th Ed.).
- W.H. Freeman – ISBN: 978-1319381493
- (Use selected chapters: water, weak interactions, bioenergetics.)

Course Bibliography – Part 2

- Macromolecular Structure
- Petsko & Ringe (2003) or Brändén & Tooze (1999)
- (Optional reference for protein structure.)

- Physical / Quantitative Perspective
- Phillips et al. (2012) Physical Biology of the Cell
- or Dill & Bromberg (2010) Molecular Driving Forces (Ch. 1–2)

- Nanobiomedicine (Optional)
- Vo-Dinh, T. (2012). Nanotechnology in Biology and Medicine
- CRC Press – ISBN: 978-1420085351

Instructor:

Prof. Beatrice Vallone

Course Information

Course: Macromolecular Structures – Nanotechnology Engineering (Sapienza)
Semester: Fall 2025
Schedule: Wednesdays (2h), Fridays (3h) — Start: Sept 24, 2025

Learning Objectives

- Understand the molecular basis of cellular structure and function.
- Learn the biochemical and energetic mechanisms sustaining life.
- Acquire technical vocabulary in cell biology and biochemistry.
- Connect macromolecular structures to engineering and nanotechnology applications.

Lecture Plan & Readings

Date	Topic	Reading
Sept 24 (Wed)	Introduction, Course Goals, Evolution as Framework for Biology	Alberts Ch. 1; Nature E&E LUCA paper (rec.)
Sept 27 (Fri)	Chemistry of Life: Water, Bonds, Thermodynamics	Alberts Ch. 2; Lehninger Ch. 2; Dill & Bromberg Ch. 1–2 (opt.)
Oct 1 (Wed)	Macromolecules Overview: Carbohydrates & Lipids	Alberts Ch. 2 (carbs/lipids)
Oct 4 (Fri)	Proteins: Amino Acids, Peptide Bond, Primary Structure	Alberts Ch. 4 (start)
Oct 8 (Wed)	Protein Folding & Higher-Order Structures	Alberts Ch. 4; Petsko & Ringe (opt.)
Oct 11 (Fri)	Enzyme Structure & Catalysis	Alberts Ch. 4; Lehninger Ch. 6
Oct 15 (Wed)	Functional Proteins: Myoglobin & Hemoglobin	Alberts Ch. 4; Lehninger Ch. 7
Oct 18 (Fri)	Antibodies & Immune System Basics	Alberts Ch. 24
Oct 22 (Wed)	Cytoskeleton I: Actin, Myosin	Alberts Ch. 17
Oct 25 (Fri)	Cytoskeleton II: Microtubules	Alberts Ch. 17

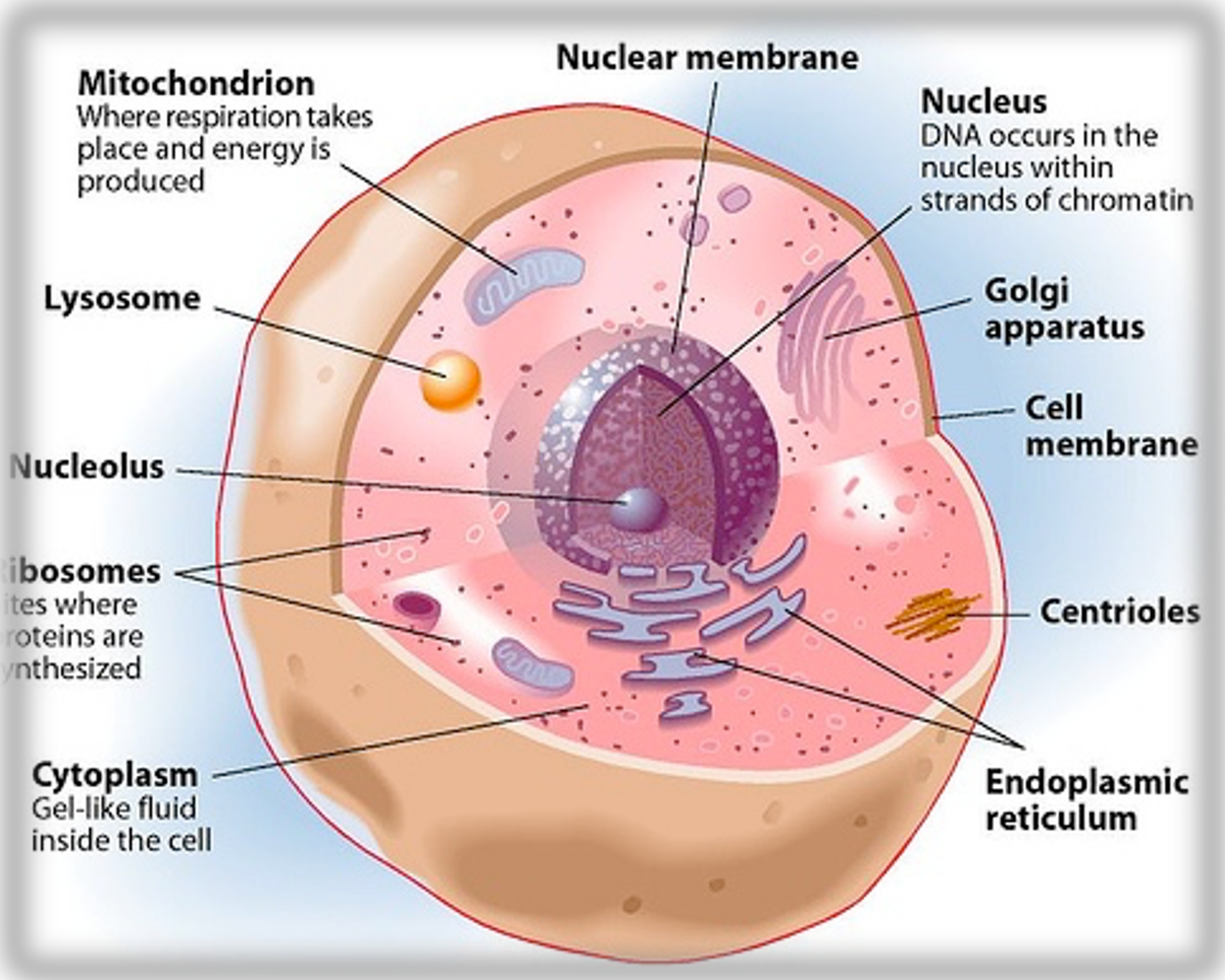
The Cell — A Modern Engineering Perspective

From macro to nano: what is a cell?

We will explore how we visualize and understand cells, and why this knowledge empowers nanotechnology.

Cell – ***basic structural and functional unit***

- The **cell** is the basic structural, functional and biological unit of all known living organisms. It is the smallest unit of life that is classified as a living thing and is often called the "building block of life".
- The cell was discovered by Robert Hooke in 1665.


Mitochondrion
Where respiration takes place and energy is produced
Nuclear membrane
Nucleus
DNA occurs in the nucleus within strands of chromatin
Lysosome
Golgi apparatus
Cell membrane
Nucleolus
ibosomes
tes where
roteins are
nthesized
Centrioles
Cytoplasm
Gel-like fluid inside the cell
Endoplasmic reticulum

- The observations of Hooke, Leeuwenhoek, Schleiden, Schwann, Virchow, and others led to the development of the cell theory.
- The cell theory is a widely accepted explanation of the relationship between cells and living things.

Cell Theory

- All organisms are composed of cells
- All cells come only from preexisting cells (Rudolf Virchow)
- Cells are the smallest structural and functional unit of organisms
- Cells carry genetic information in the form of DNA

Robert Hooke (1665)

Antony van Leeuwenhoek (1673)

Matthias Jacob Schleiden (1838) plant

Theodor Schwann (1839) animal

Prokaryotic and eukaryotic cells

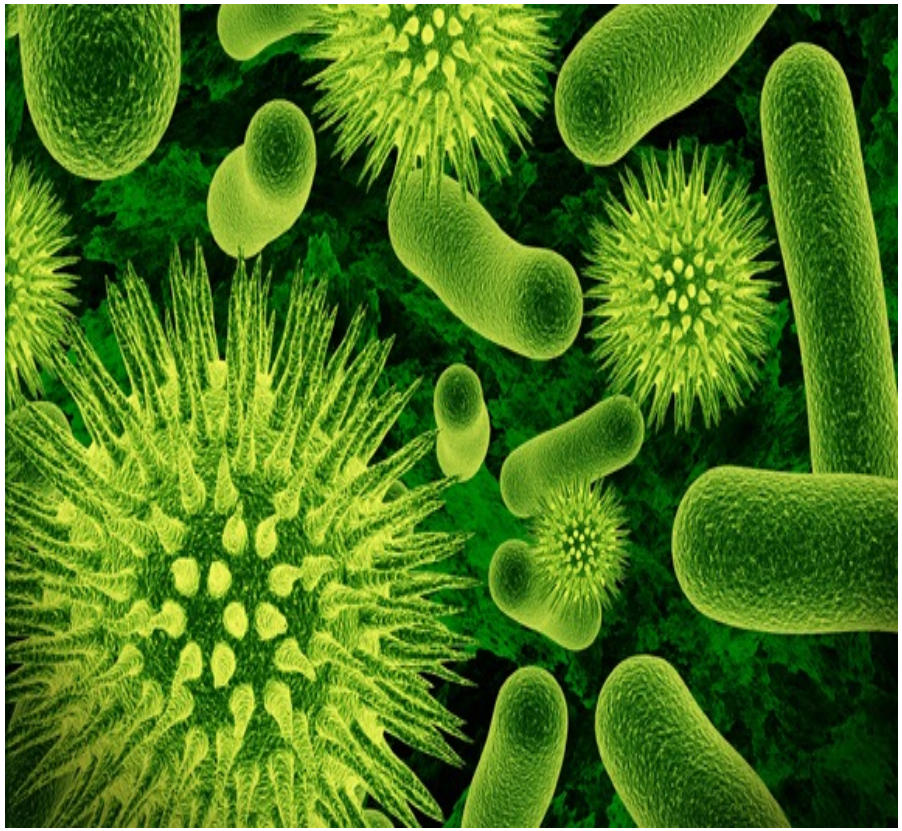
- All cells
  - surrounded by a plasma membrane.
  - have cytosol, containing the organelles.
  - contain chromosomes
  - have ribosomes
- A major difference
  - eukaryotic cell: chromosomes are contained in the nucleus (within a membranous nuclear envelope)
  - prokaryotic cell: the DNA is concentrated in the nucleoid

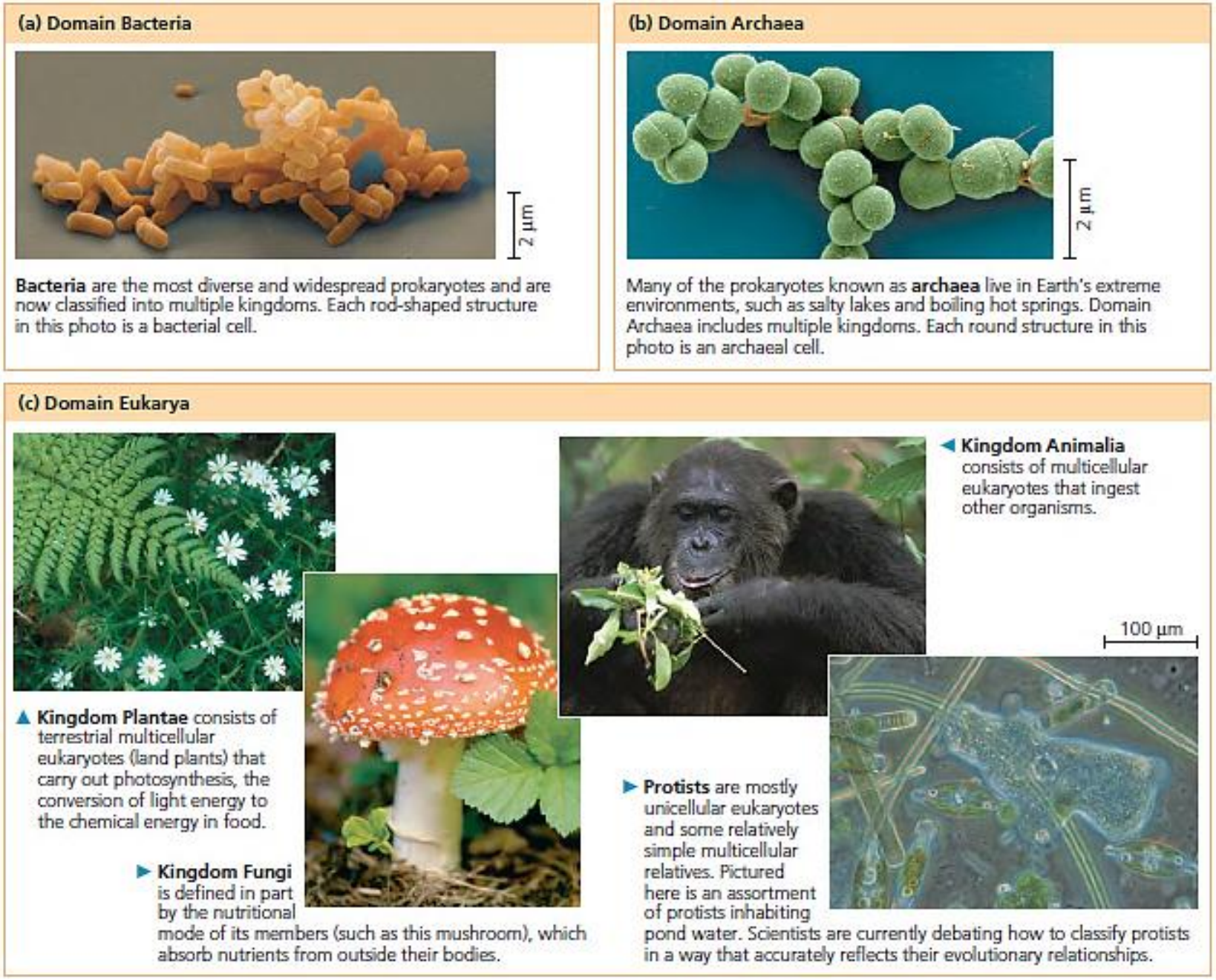
A major difference...

- Cytoplasm
  - All the material within the plasma membrane of a prokaryotic cell is cytoplasm.
  - Within the cytoplasm of a eukaryotic cell is a variety of membrane-bounded organelles of specialized form and function.
- Eukaryotic cells are generally much bigger than prokaryotic cells.
  - smallest bacteria, mycoplasmas, are 0.1 to 1.0 micron. (most bacteria: 1-10 microns)
  - Eukaryotic cells are typically 10-100 microns in diameter

Size of the Cells

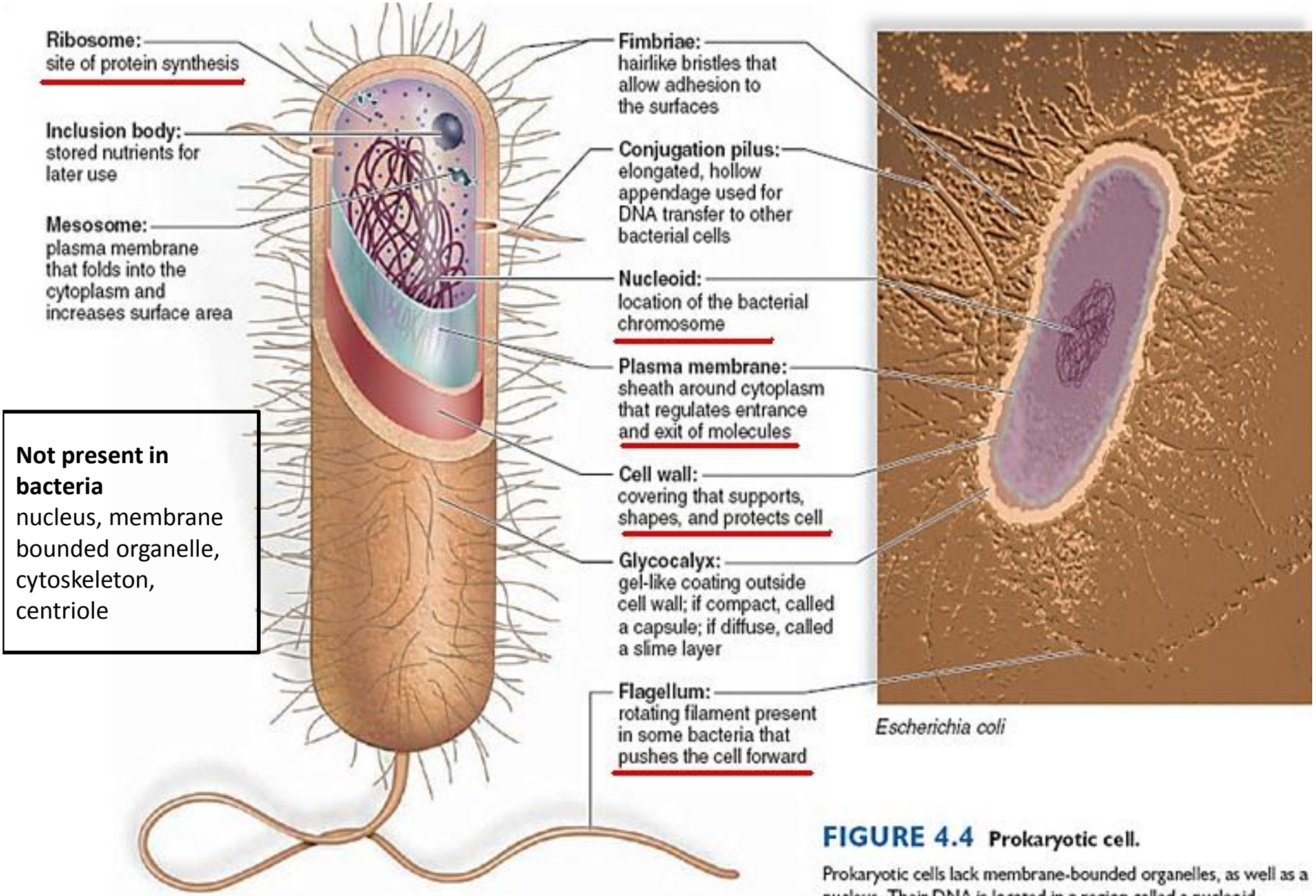
- The smallest cell is 0.1 to 0.5 micrometer in bacteria.
- The largest cell measuring 170mm x 130mm, is the ostrich egg.





Campbell *et al*, Biology; 2009.

Eukaryotic Cells	Prokaryotic Cells
"complex" organisms, including all plants, protists, fungi and animals	"Simple" organisms, including bacteria and cyanobacteria
Contain nucleus and membrane bound organelles Several chromosome	Lack nucleus and other membrane-encased organelles. Single chromosome (DNA + non-histone protein)
Can specialize for certain functions, multicellular organs and organisms	Usually exist as single, virtually identical cells
Cellular respiration occur in mitochondria	Cellular respiration occur in mesosome (extended membrane)
Ribosome: 40s, 60S	Ribosome: 30S, 50S
Photosynthesis occur in chloroplast	Photosynthesis occur in chlorophyll located region
Cell Wall present in Plants & Fungi only	Cell Wall



Not present in bacteria
nucleus, membrane bounded organelle, cytoskeleton, centriole

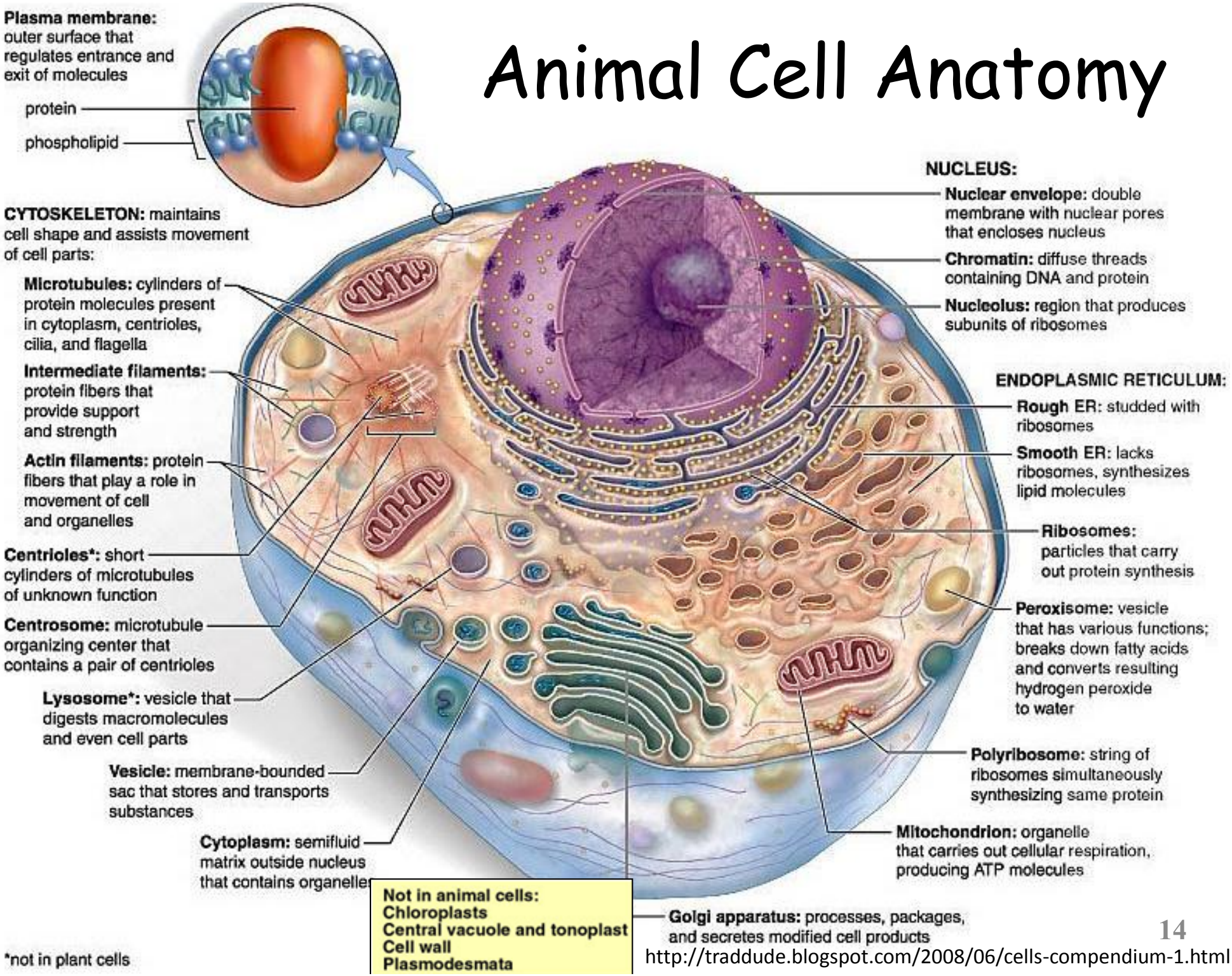
FIGURE 4.4 **Prokaryotic cell.**

Prokaryotic cells lack membrane-bounded organelles, as well as a nucleus. Their DNA is located in a region called a nucleoid.

Cells

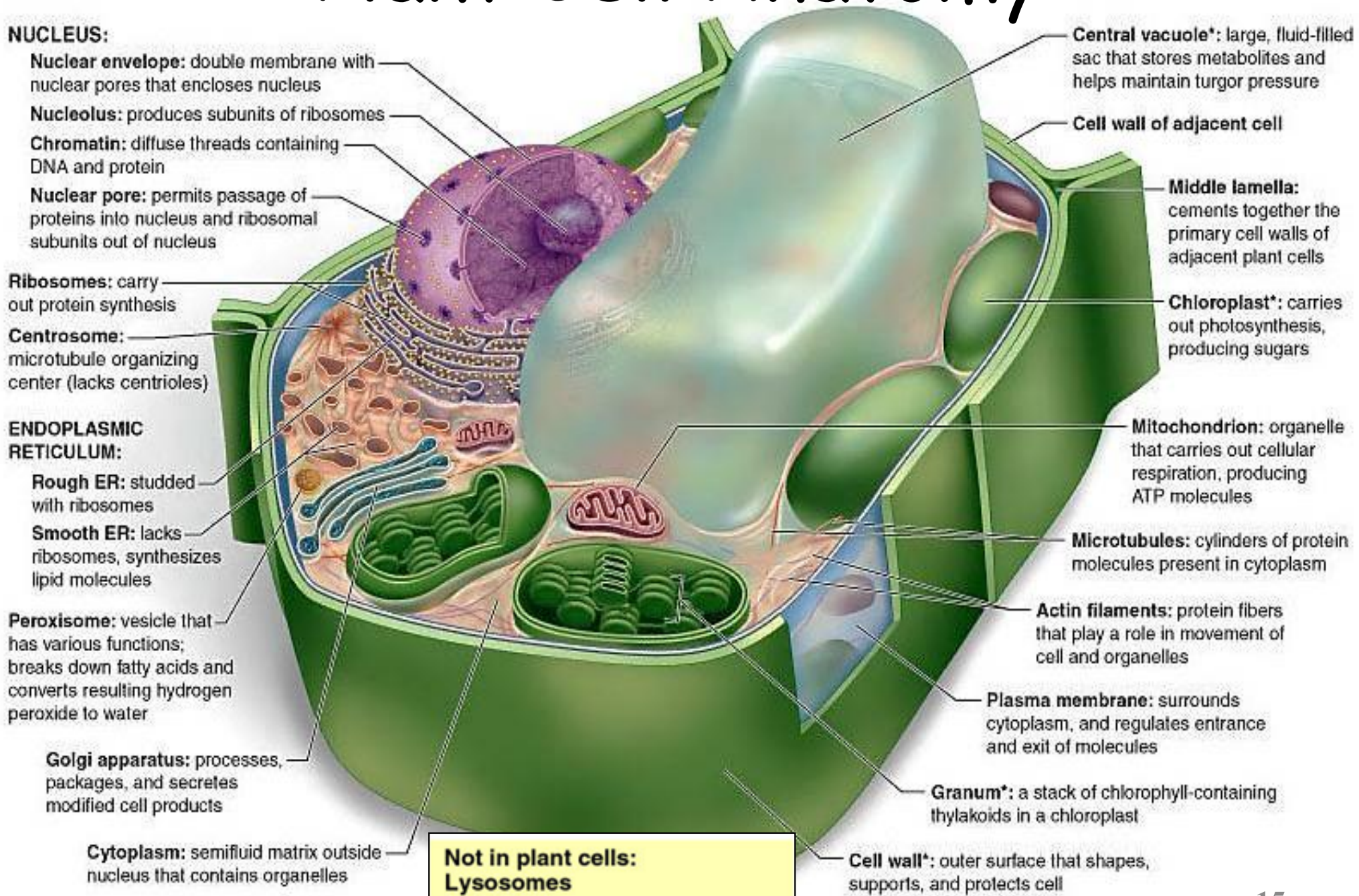
- Cell coat: Cell wall, Cell membrane
- Protoplasm
  - Nucleus : nuclear membrane, nucleoplasm (chromatin fiber, nucleolus)
  - Cytoplasm
    - cytosol
    - organelle
      - no membrane bounded: ribosome, centriole, cytoskeleton
      - single membrane bounded: ER, Golgi complex, lysosome, peroxisome, vacuole
      - double membrane bounded: mitochondria, chloroplast

Animal Cell Anatomy



http://traddude.blogspot.com/2008/06/cells-compendium-1.html

Plant Cell Anatomy

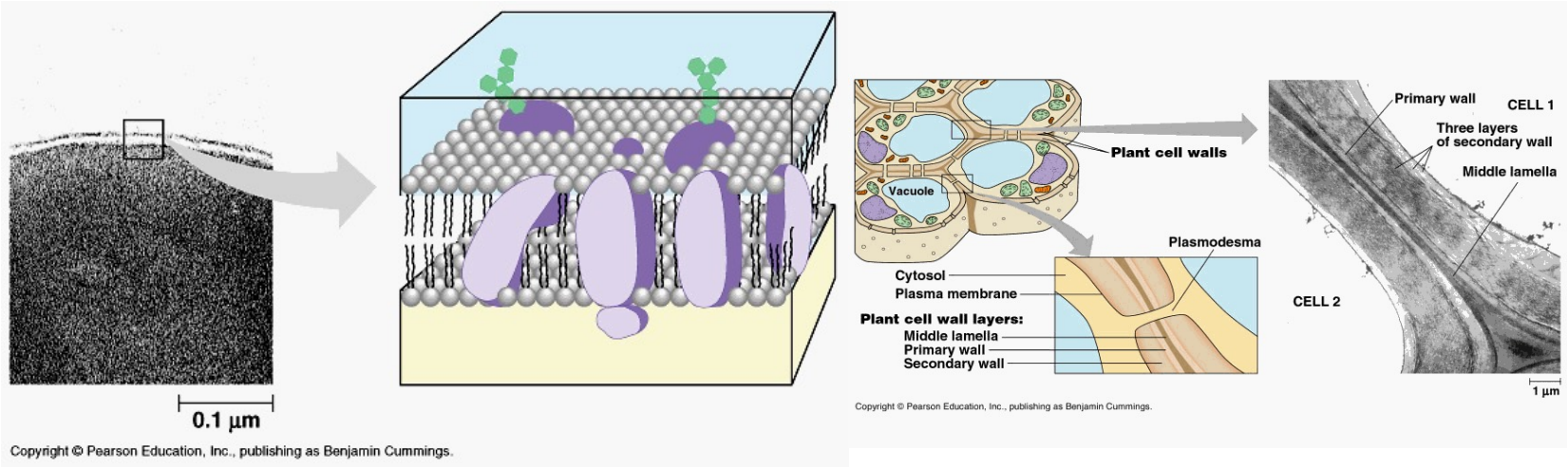


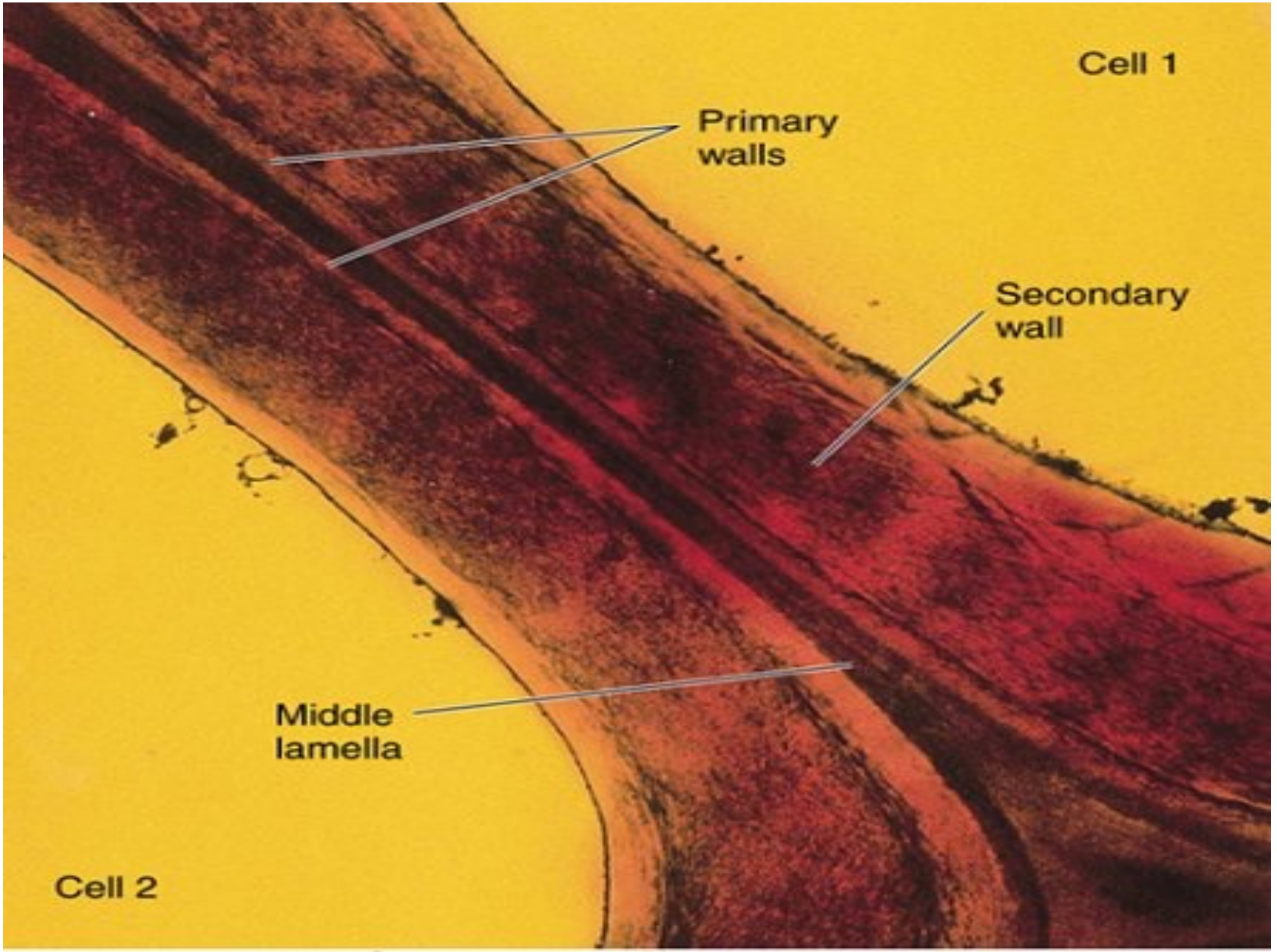
http://minhalogia.blogspot.com/2013_03_01_archive.html

Parts of CELL

Cell Boundaries

- **Cell walls** – rigid layer around the membrane found only in bacteria, fungi and plants.
- **Cell membrane** – thin, flexible membrane that surrounds the cell.




Cell 1
Primary walls
Secondary wall
Middle lamella
Cell 2

Cell walls

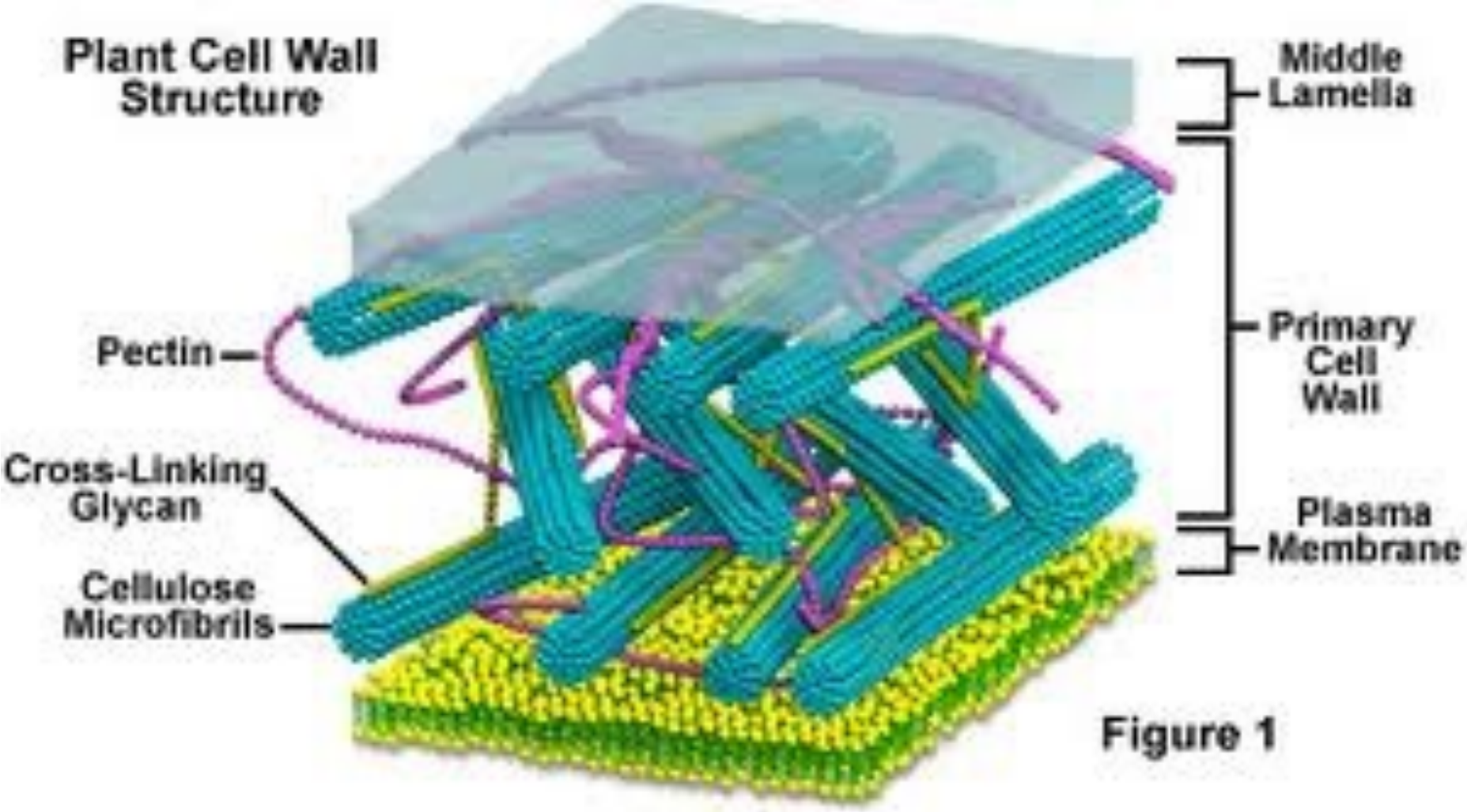


Figure 1

Cellulose

- Cell walls are made of specialized sugars called cellulose.
- Cellulose is called a structural carbohydrate (complex sugar) because it is used in protection and support.

Cross Linking Glycans

- Diverse group of carbohydrates that used to be called hemicellulose.
- Play a major role in maintaining the structural integrity of the wall by their tight association with cellulose microfibrils.

Peptic Polysaccharides

- determining wall porosity
- providing a charged wall surface for cell-cell adhesion
- cell-cell recognition
- pathogen recognition and others.

Proteins

- The proteins may serve as the scaffolding used to construct the other wall components.

Lignin

- Lignin is primarily a strengthening agent in the wall. It also resists fungal/pathogen attack.

Suberin, wax, cutin

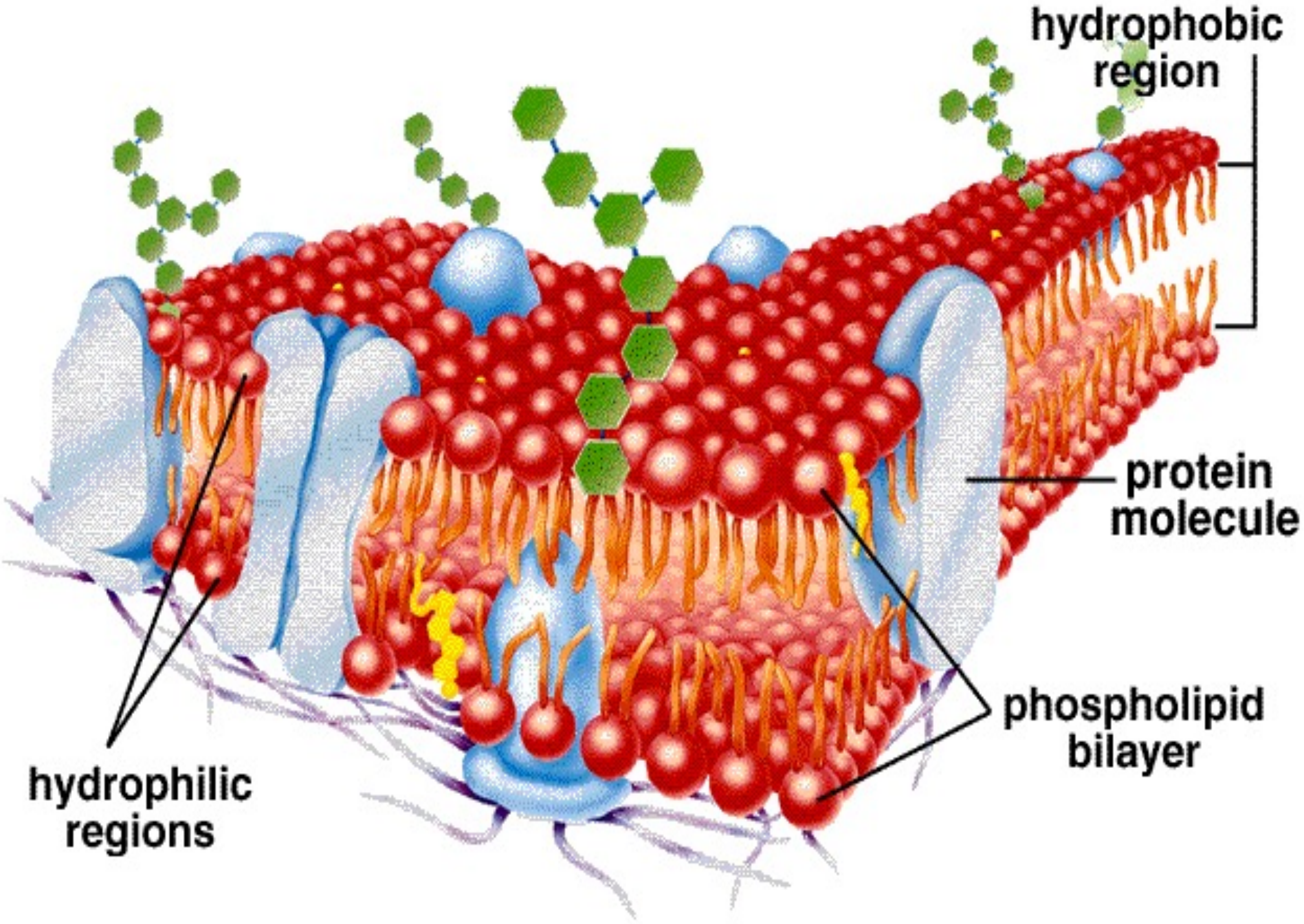
A variety of lipids are associated with the wall for strength and waterproofing.

Water

- Comprise 75-80% of the cell wall.
- Determines the flexibility and extensibility of the wall.

The Cell Membrane

- Also known as the plasma membrane is a biological membrane that separates the interior of all cells from the outside environment.
- The cell membrane is selectively permeable to ions and organic molecules and controls the movement of substances in and out of cells.


hydrophobic region
protein molecule
phospholipid bilayer
hydrophilic regions

Components of the Cell Membrane

Lipids

- Insoluble, fatty materials the cell can use to construct membranes
- Help to give membranes their flexibility.
- Used as energy source in the form of fats.

Proteins

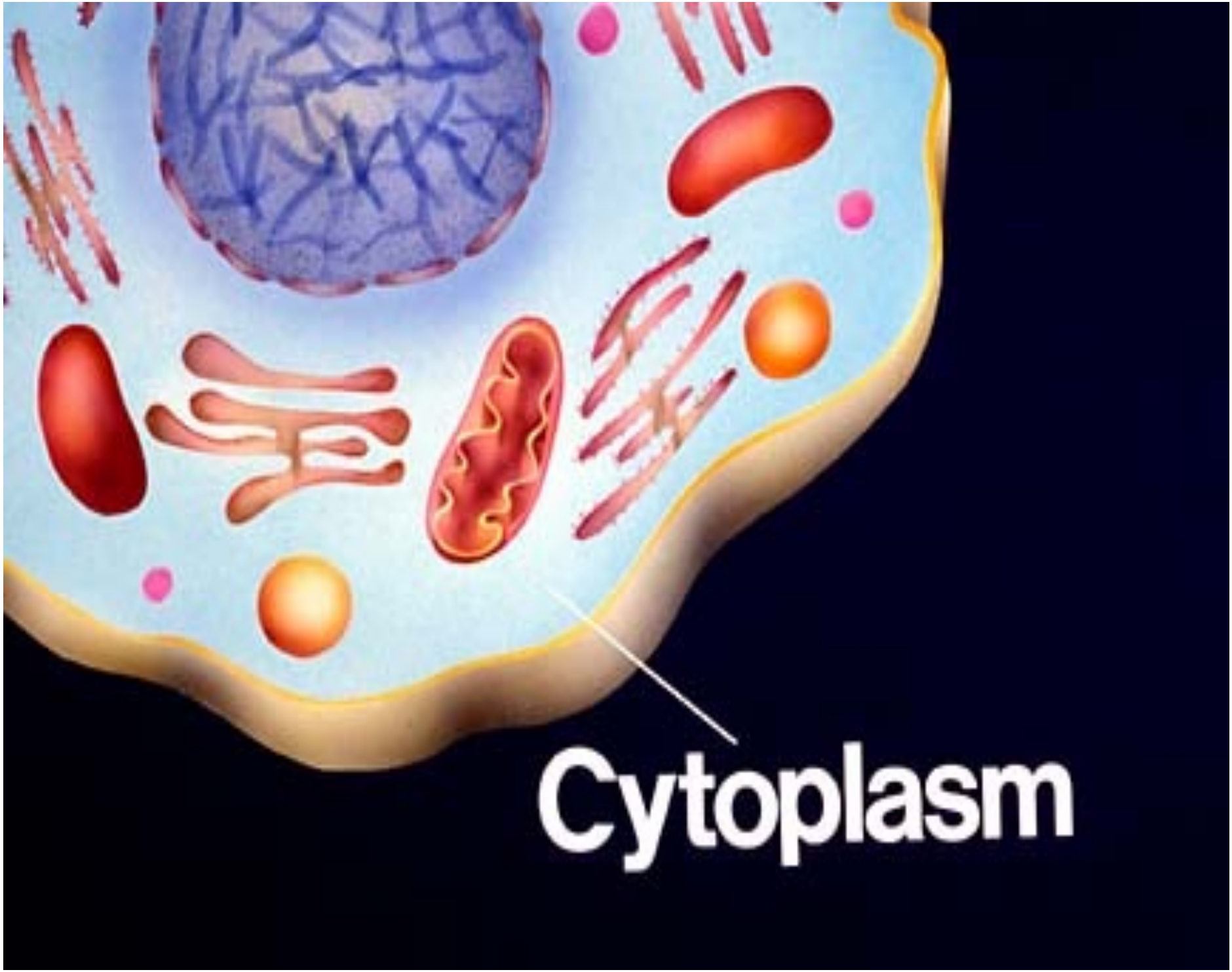
- Proteins maintain and monitor the cell's chemical climate and assist in the transfer of molecules across the membrane.
- Cell adhesion molecules allow cells to identify each other and interact.

Functions

- surrounds the cytoplasm of a cell.
- protect the integrity of the interior of the cell
- serves as a base of attachment for the cytoskeleton
- serves to help support the cell and help maintain its shape.

Cytoplasm

- The **cytoplasm** is a the gel-like substance enclosed within the cell membrane.
- The cytoplasm is about 70% to 90% water and usually colorless.


Cytoplasm

Organelles

- Organelles (literally "little organs"), are usually membrane-bound, and are structures inside the cell that have specific functions. Some major organelles are the **mitochondria, ribosomes, golgi bodies etc.**

Mitochondria

- They are **organelles** that act like a digestive system that takes in nutrients, breaks them down, and creates energy for the cell. The process of creating cell energy is known as **cellular respiration.**

- Most of the chemical reactions involved in cellular respiration happen in the mitochondria. A mitochondrion is shaped perfectly to maximize its efforts.

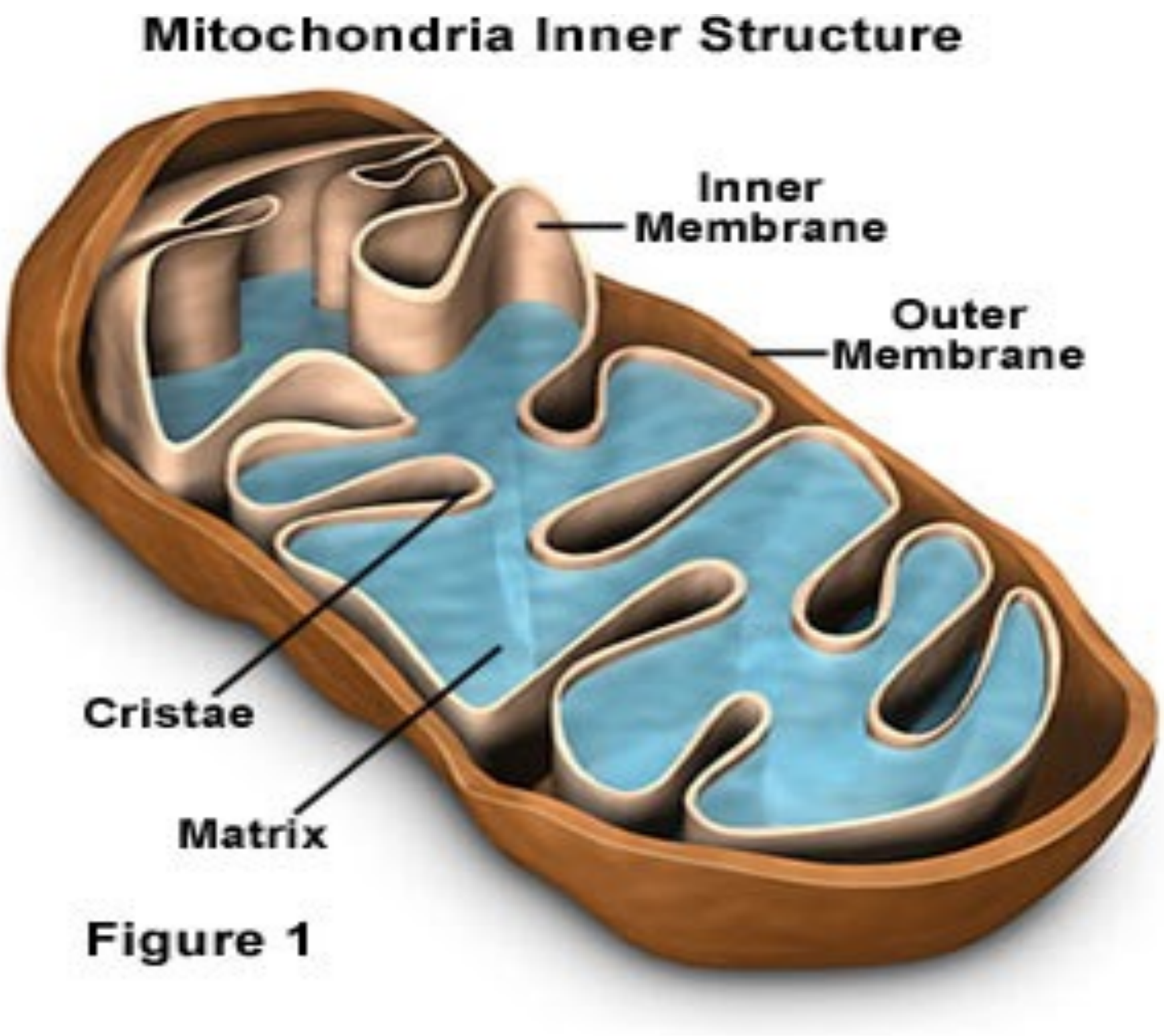
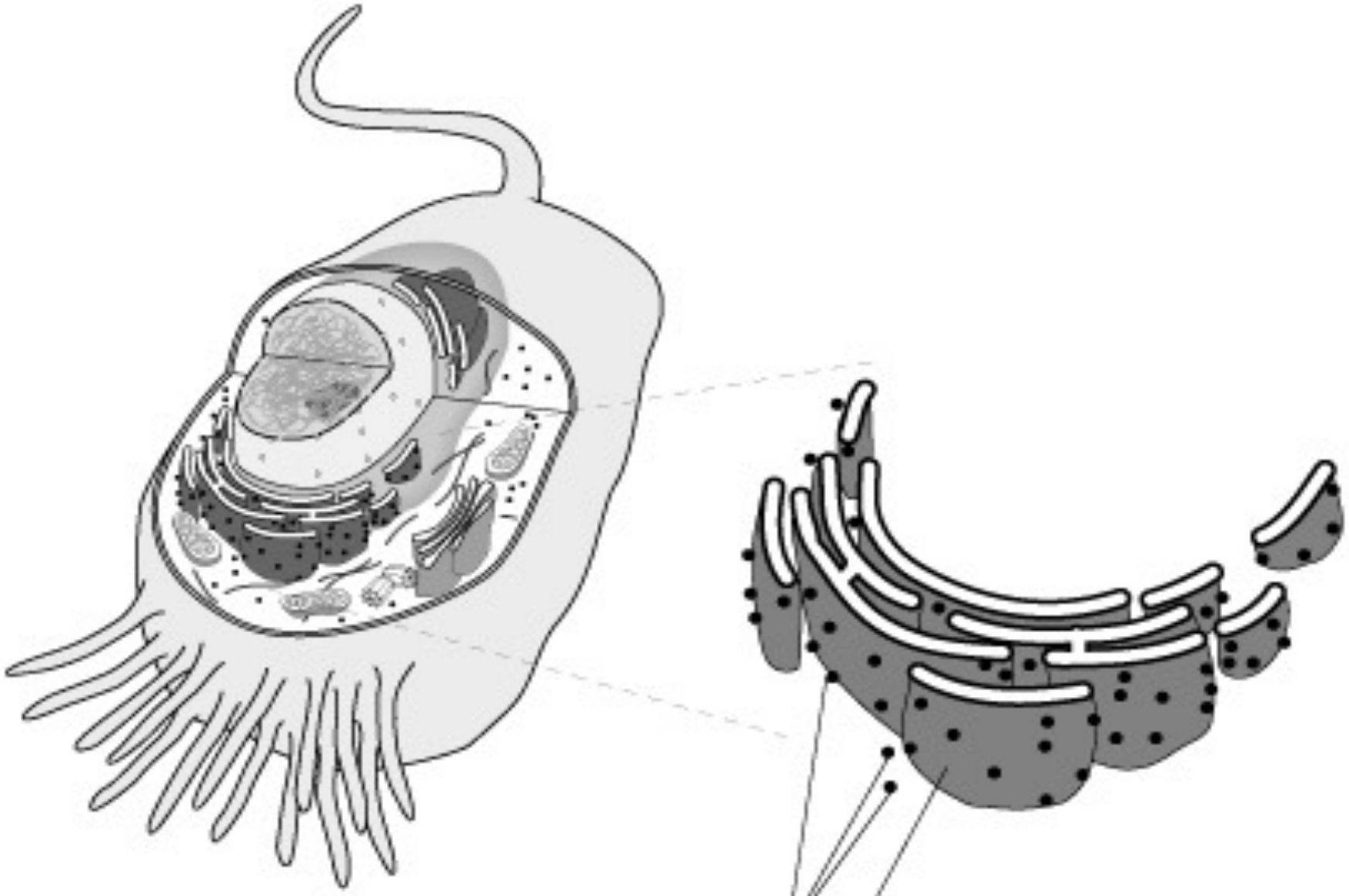

Mitochondria Inner Structure
Inner Membrane
Outer Membrane
Cristae
Matrix

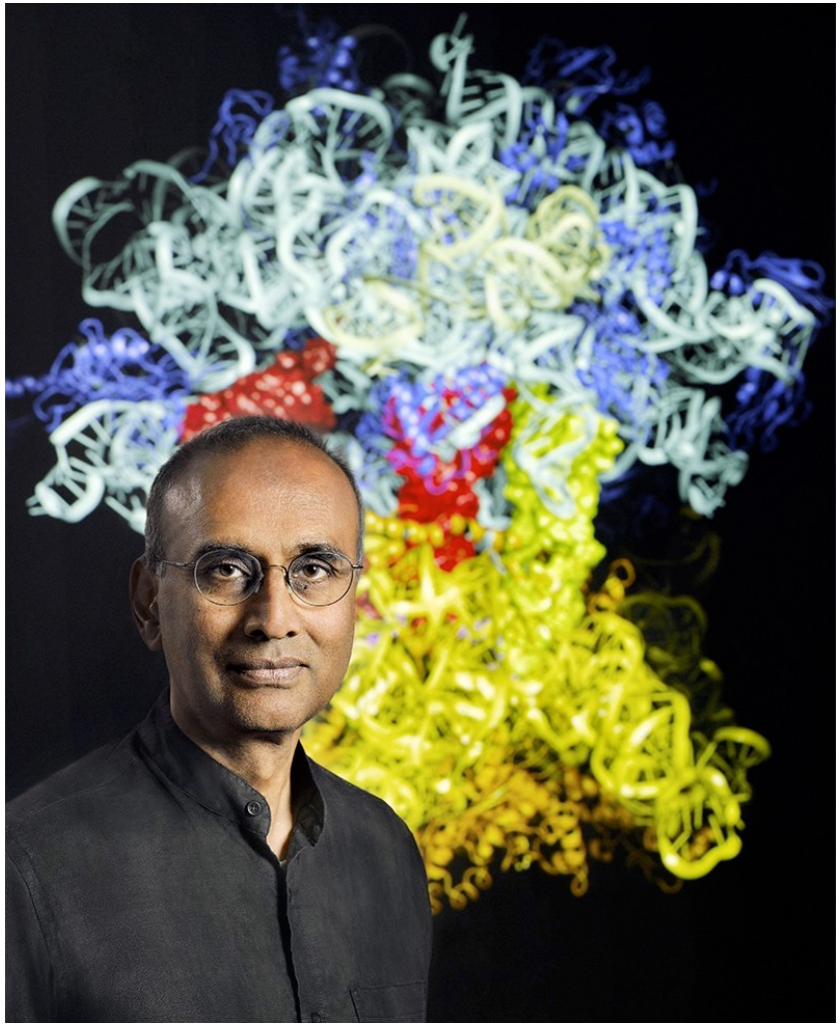
Figure 1

Ribosomes

- Cells need to make **proteins.** Those proteins might be used as enzymes or as support for other cell functions.
- **Ribosomes** are the protein builders or the protein **synthesizers** of the cell.

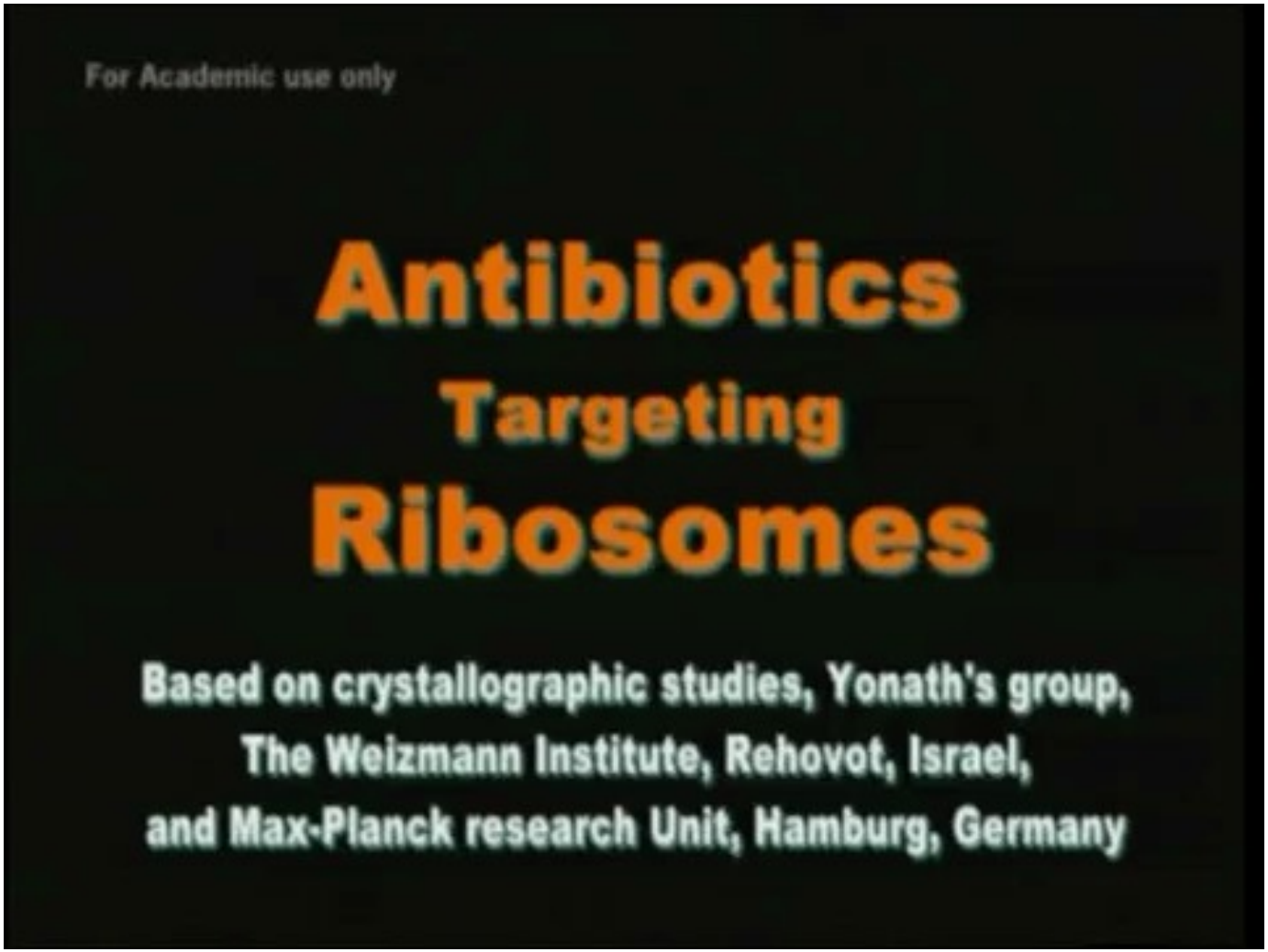

[ribosomal proteins,
ribosomal RNA(rRNA)]
Ribosomes
Rough endoplasmic reticulum

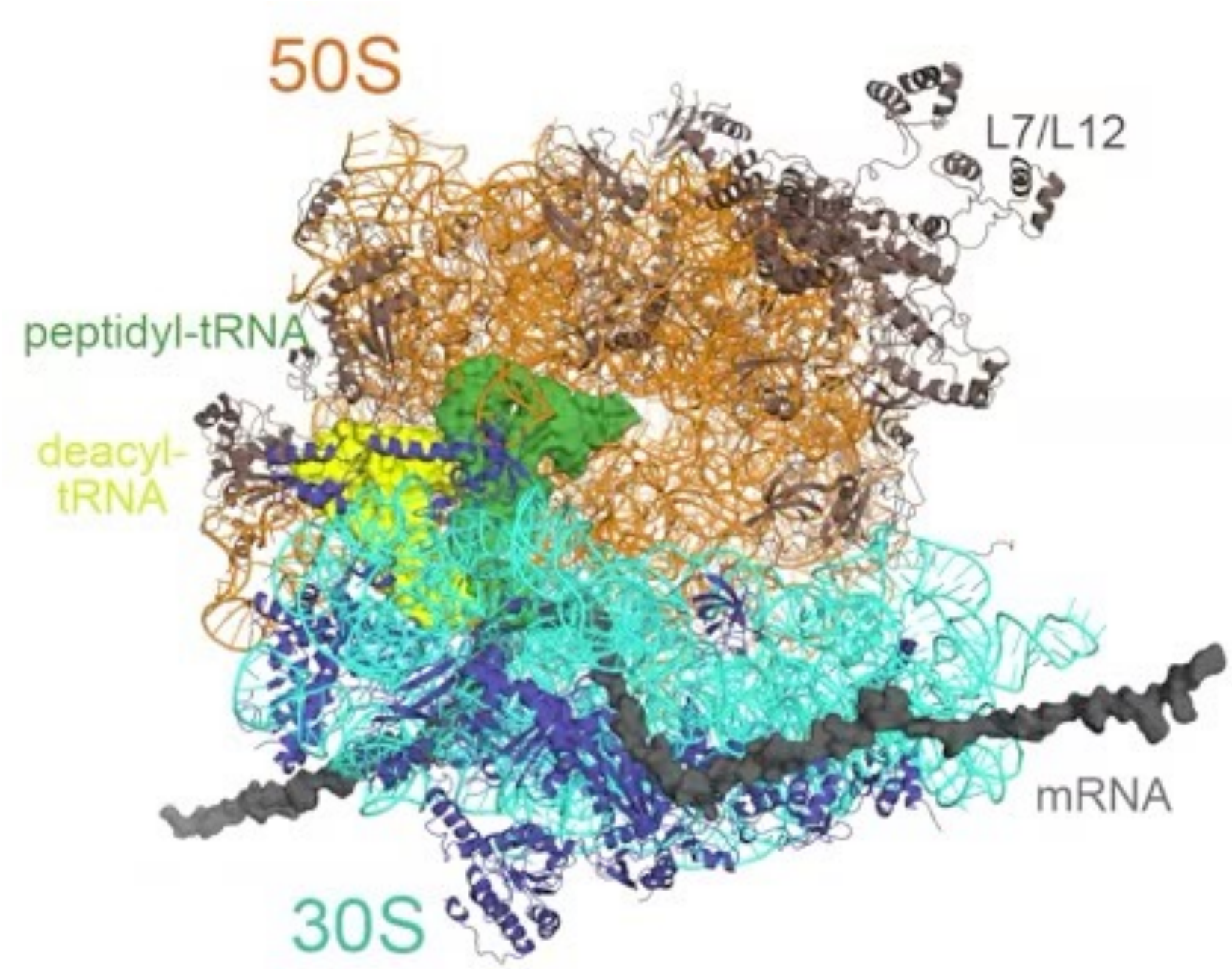
Venki Ramakrishnan received the Nobel Prize in Chemistry in 2009 for **his work on "studies of the structure and function of the ribosome**." In 2000, Ramakrishnan reported the structure of the 30S subunit of the ribosome.



Books

•Why We Die: The New Science of Ageing and Longevity. ...
•Gene Machine: The Race to Decipher the Secrets of the Ribosome.


For Academic use only
Antibiotics
Targeting
Ribosomes
Based on crystallographic studies, Yonath's group,
The Weizmann Institute, Rehovot, Israel,
and Max-Planck research Unit, Hamburg, Germany


50S
L7/L12
peptidyl-tRNA
deacyl-
tRNA
mRNA
30S

Endoplasmatic Reticulum

- The endoplasmic reticulum (ER) is an organelle found in the cells of eukaryotic organisms. It is an interconnected network of flattened sacs or tubes encased in membranes. These membranes are continuous, joining with the outer membrane of the nuclear membrane. ER occurs in almost every type of eukaryotic cell except red blood cells and sperm cells.

  Endoplasmic reticulum has two types, rough endoplasmic reticulum (RER) and smooth endoplasmic reticulum (SER). Rough ER is studded with ribosomes, the site of protein synthesis. This type of ER is especially prominent in certain kinds of cells like hepatocytes where active protein synthesis occurs. Smooth ER doesn't have ribosomes and is very important to the process of metabolism.

Endoplasmatic Reticulum

- Endoplasmic reticulum has a number of jobs within the cell. This includes the folding and transport of various proteins, specifically carrying them to the Golgi apparatus. Some other proteins, mostly the glycoproteins, move across the ER's membrane.

  The ER is also responsible for marking these proteins that it transports with a signal sequence. Other proteins are headed outside the ER, so they are packed into transport vesicles and moved out of the cell via the cytoskeleton.

  Basically, the ER is the transportation system of the eukaryotic cell, and its proteins are contained

Golgi Bodies

- **Golgi Bodies** is an organelle found in most eukaryotic cells. It was identified in 1897 by the Italian physician Camillo Golgi and named after him in 1898.
- It is important in the processing of proteins for secretion.

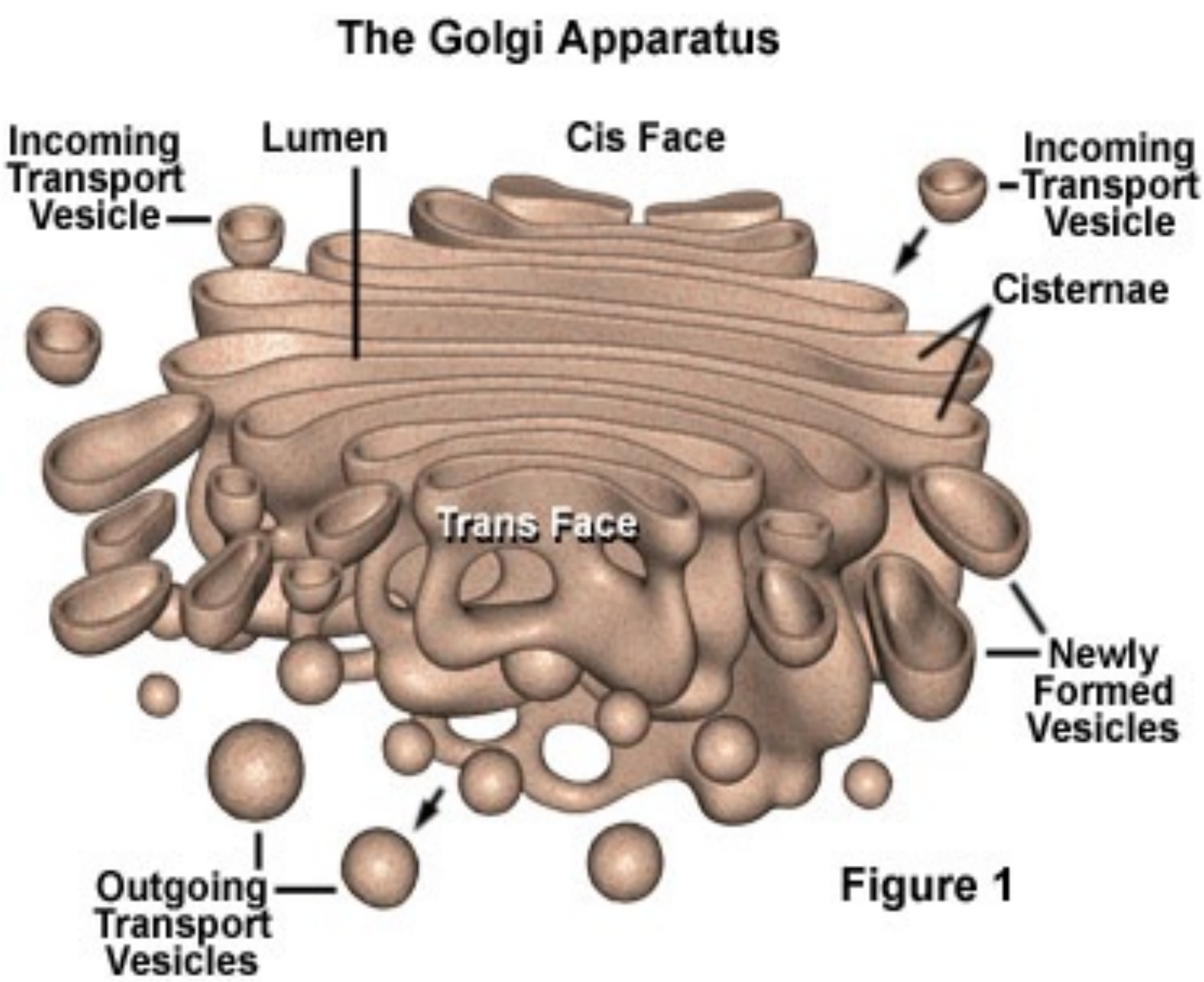

The Golgi Apparatus
Incoming Transport Vesicle
Lumen
Cis Face
Incoming Transport Vesicle
Cisternae
Trans Face
Newly Formed Vesicles
Outgoing Transport Vesicles

Figure 1

Nucleus

- The cell nucleus acts like the brain of the cell. It helps control eating, movement, and reproduction. The nucleus is not always in the center of the cell. It will be a big dark spot somewhere in the middle of all of the **cytoplasm .**

Nucleoid

- If there is no defined nucleus, then the DNA is probably floating around the cell in a region called the **nucleoid**. A defined nucleus that holds the genetic code is an advanced feature in a cell.

- Nucleus is separated from the cytoplasm by a membrane called the **nuclear membrane.**
- The smaller spherical body in the nucleus is known as the **nucleolus**.
- Nucleus contains thread like structures known as the **chromosomes.** These carry the **genes.**

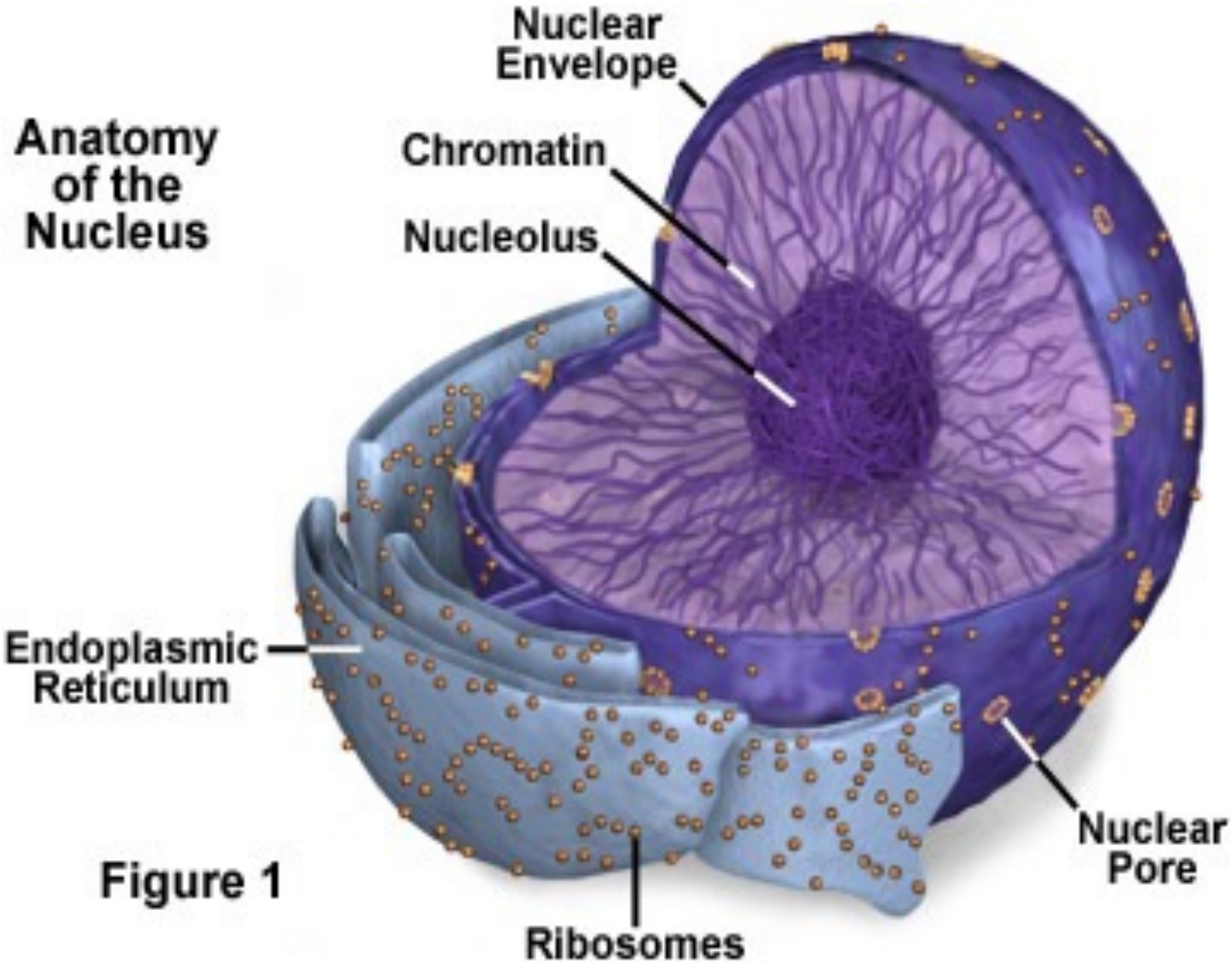
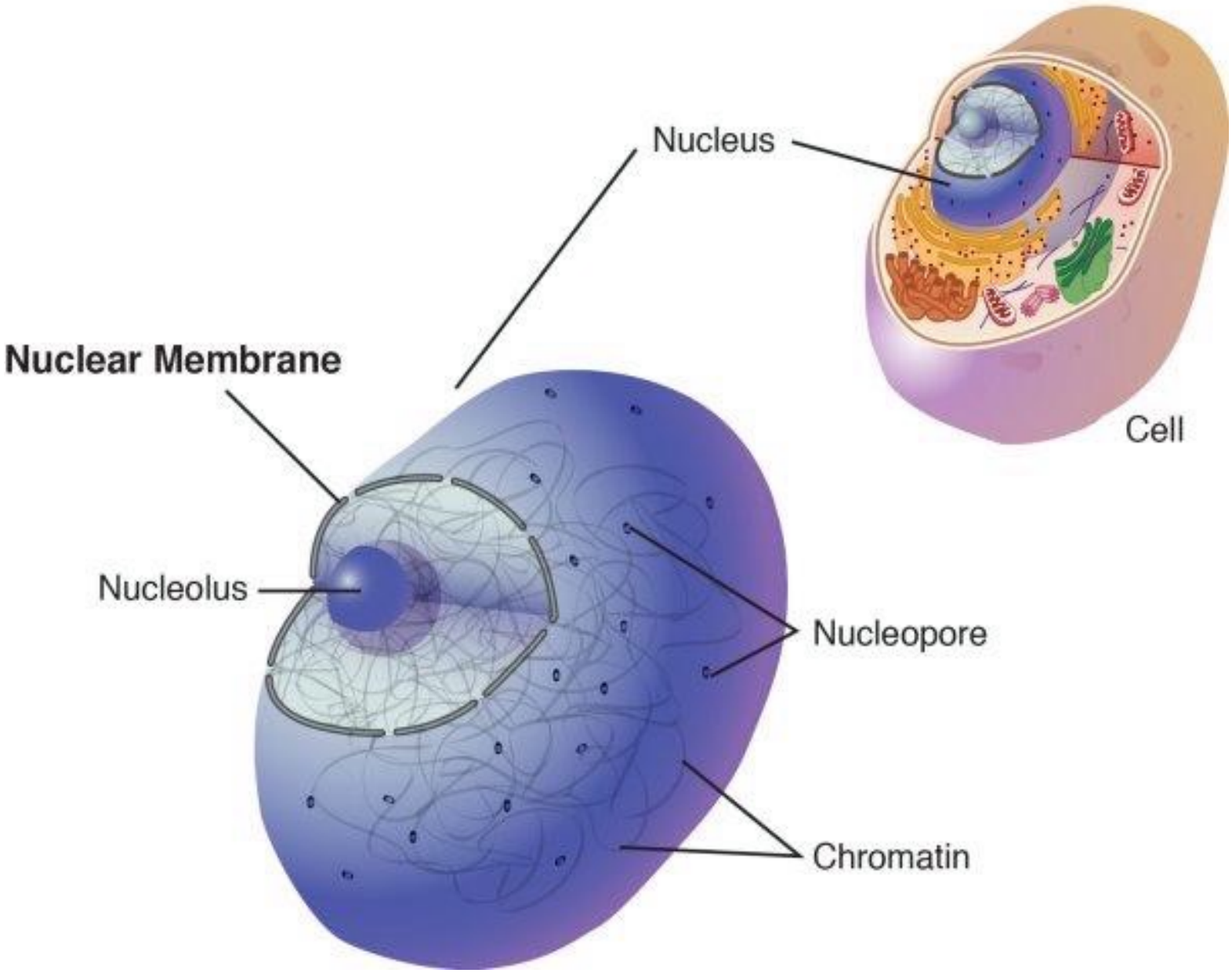

Anatomy of the Nucleus
Nuclear Envelope
Chromatin
Nucleolus
Endoplasmic Reticulum
Nuclear Pore
Ribosomes

Figure 1

Nuclear Membrane

- The **nuclear membrane** encloses the nucleus in eukaryotes. The membrane is penetrated by nuclear pore complexes.


Nucleus
Nuclear Membrane
Cell
Nucleolus
Nucleopore
Chromatin

Chromosomes

- Chromosomes are made up of **DNA**. Segments of DNA in specific patterns are called **genes**.
- The chromosomes and genetic material can be found in the nucleus of a cell.

Vacuole

- The blank looking structures in the cytoplasm is known as the **vacuole.**
- Animal Cells have smaller vacuole.
- Plant Cells have larger vacuole.

Plant Cell Central Vacuole

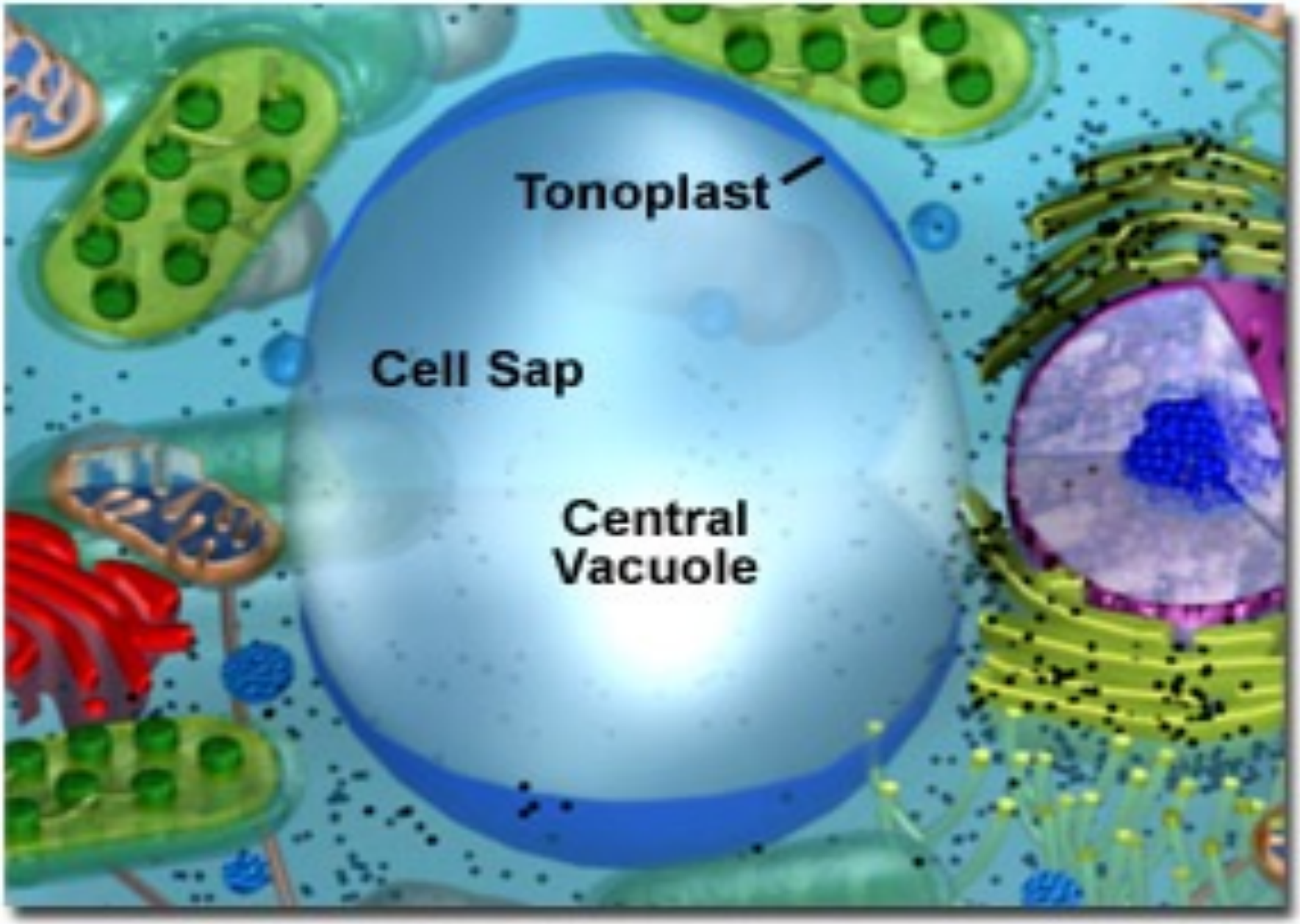


Figure 1

Chloroplasts

- **Chloroplasts** are the food producers of the cell. They are only found in plant cells. Animal cells do not have chloroplasts.
- The purpose of the chloroplast is to make sugars and starches. They use a process called **photosynthesis** to get the job done.

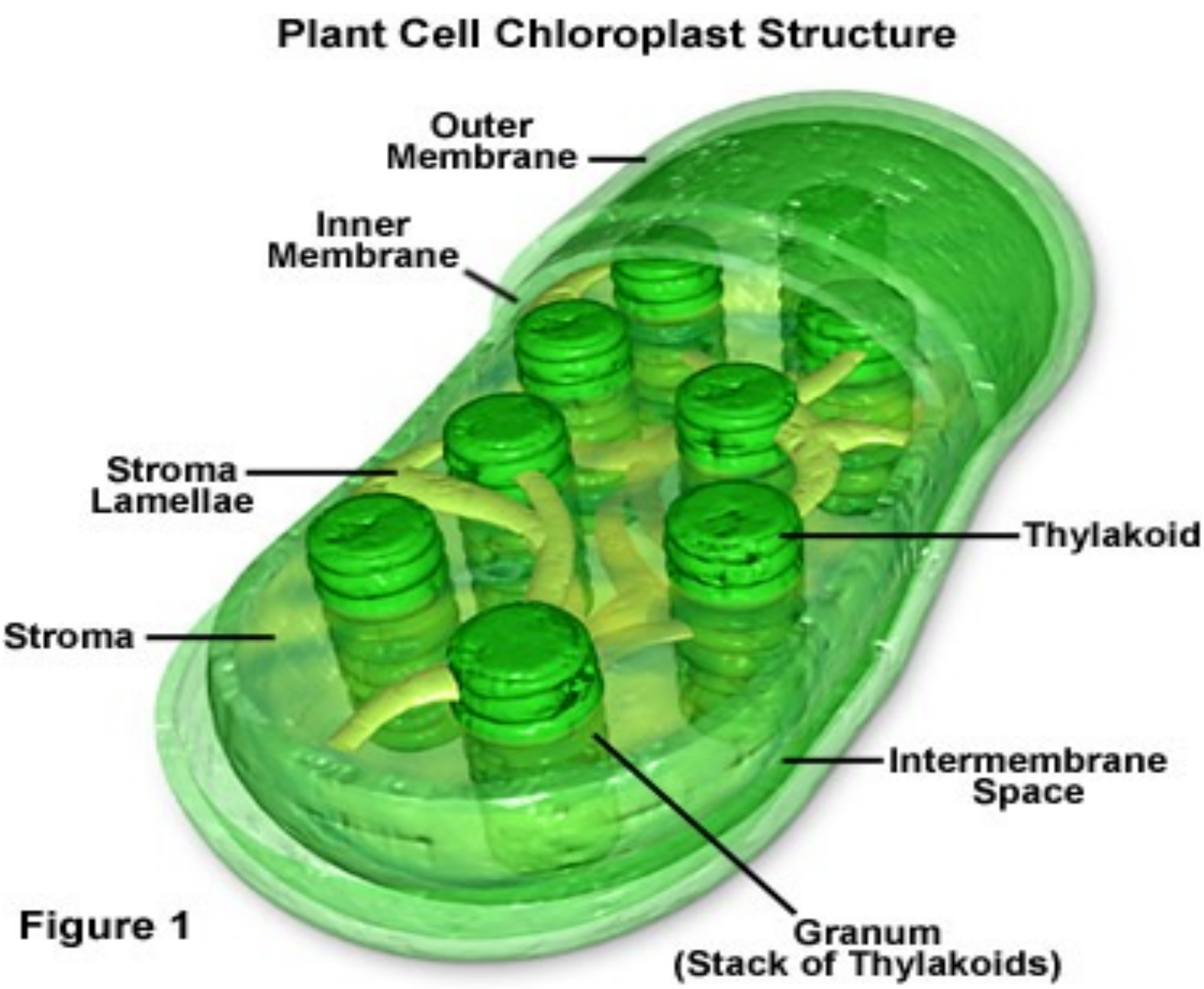

Plant Cell Chloroplast Structure
Outer Membrane
Inner Membrane
Stroma Lamellae
Stroma
Thylakoid
Intermembrane Space
Granum (Stack of Thylakoids)

Figure 1

Plastids

- **Plastids** are major organelles found in the cells of plants and algae.
- Plastids often contain pigments used in photosynthesis and the types of pigments present can change or determine the cell's color.