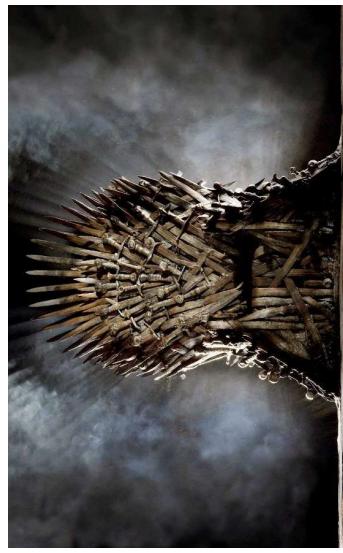


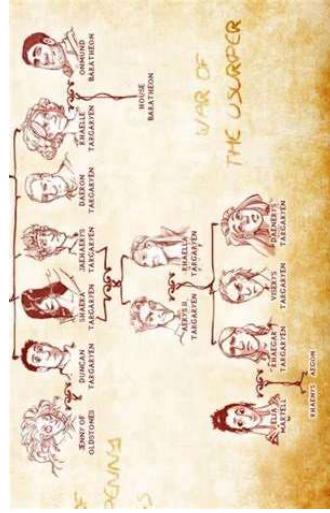
Lecture – 2

Prof. Sanjeeva Srivastava
BSBE, IIT Bombay

Domains, kingdoms and cells



Game of Thrones: Targaryen family tree



Outline

Exploring the Essence of Life: A Journey into Cell Biology

- Definition of life: what is it and why should we bother?
- Domains of life
- Cells as the smallest units of life
- Cell compartments: functionalization
- How do we study cells?
- What are the applications of understanding cell structure?

Are we alone in the universe? Can we recognize 'life' if we see it?

The screenshot shows a web browser window with the following details:

- Address Bar:** https://astrobiology.nasa.gov/about-astrobiology/ — NASA Astrobiology: Life in the Universe
- Toolbar:** Includes icons for back, forward, search, and other standard browser functions.
- Header:** NASA Astrobiology: Life in the Universe
- Sub-Header:** LIFE IN THE UNIVERSE
- Navigation:** NAI | ASTEP | ASTID | EXOBIOLOGY
- Content Area:**
 - About Astrobiology:** This section contains a sub-navigation menu:
 - About Astrobiology
 - Roadmap
 - Funding Opportunities
 - Focus Groups
 - Education and Outreach
 - Collaboration
 - Careers and Employment
 - Seminars and Workshops
 - Events
 - Directory
 - Articles
 - A timestamp: August 15, 2012
 - A detailed paragraph about Astrobiology's scope and focus on habitable environments in the Solar System and beyond.
 - A sidebar with links: About this Site, Astrobiology in Missions, Ask an Astrobiologist.
- Right Sidebar:** A large blue box with the text "Why should we define 'life' at all?"
- Bottom Footer:** A small note: "MacBook Air - Print Screen - Mac - Forums Discussions for Apple Products" and a "Logout" link.

Biology is the study of life

The phenomenon we call **life**: defies a simple, one-sentence definition

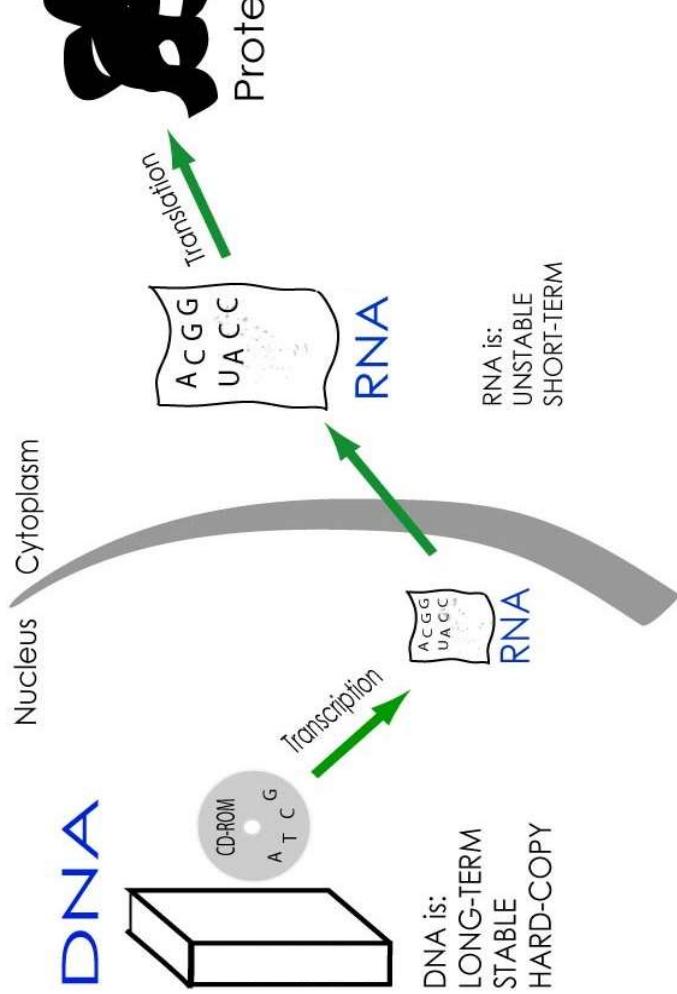
The condition that distinguishes organisms from inorganic objects and dead organisms, being manifested by growth through metabolism, reproduction, and the power of adaptation to environment through changes originating internally.

-From Dictionary.com

Perhaps, the key words in the definition are "originating internally".

If DNA is the hard drive, then what is the computer?

Today we will talk about cells as the smallest unit of life



Schematic of a cell

The Central Dogma

Some basic characteristics of life

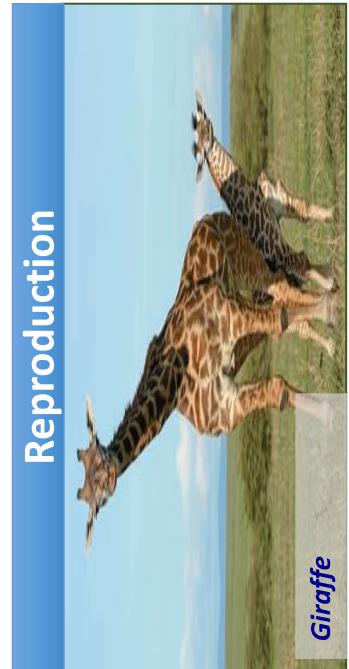
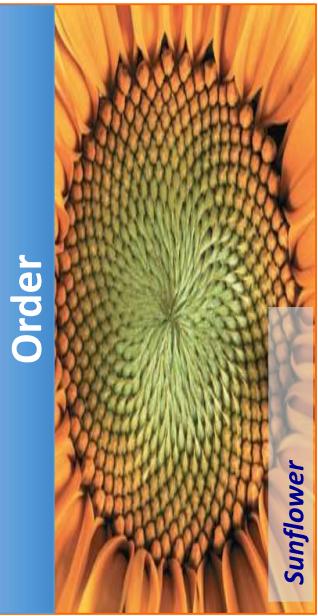


Figure 1.2

Due to common principles of life, biologists study model systems

Some model systems that represent different kingdoms, also *Mus musculus* (mouse; for mammals)



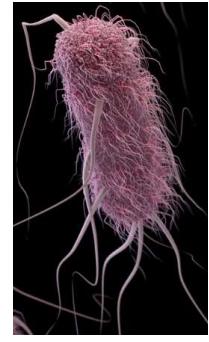
Arabidopsis thaliana
A weed (www.esa.int)



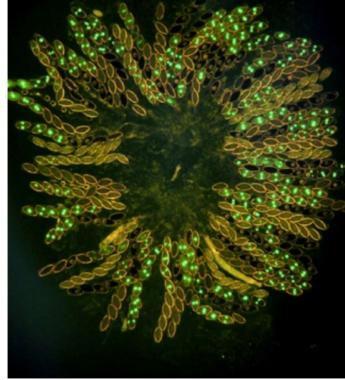
Caenorhabditis elegans
A free living round worm
[wikipedia](https://en.wikipedia.org)



Zebra fish (*Danio rerio*)
[wikipedia](https://en.wikipedia.org)
Tropical fresh water fish



Escherichia coli
www.cdc.gov
Some strains inhabit our gut
Some strains are pathogenic



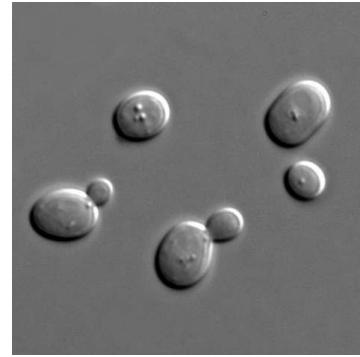
Neurospora crassa
Bread mold (fungus)



Xenopus laevis
African clawed frog, [wikipedia](https://en.wikipedia.org)



Drosophila melanogaster
Fruit fly, [wikipedia](https://en.wikipedia.org)



Saccharomyces cerevisiae
Baker's yeast, [wikipedia](https://en.wikipedia.org)

Study of life reveals common themes

- **Organization** - New properties emerge at successive levels of biological organization
- **Information** - Life's processes involve expression and transmission of genetic information
- **Energy and matter** - Life requires transfer and transformation of energy and matter
- **Interactions** - From ecosystems to molecules, interactions are important in biological systems
- **Evolution** - the core theme of biology

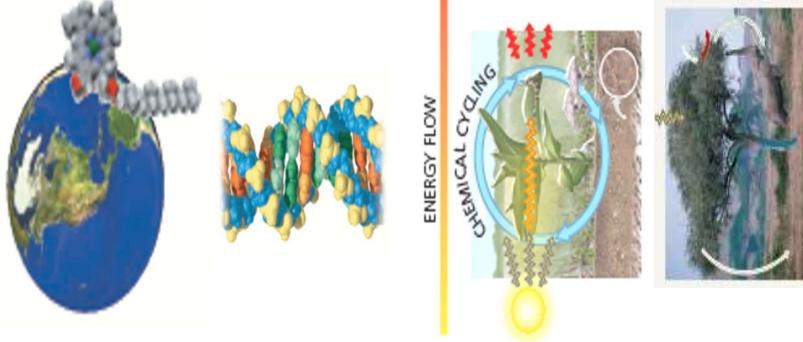


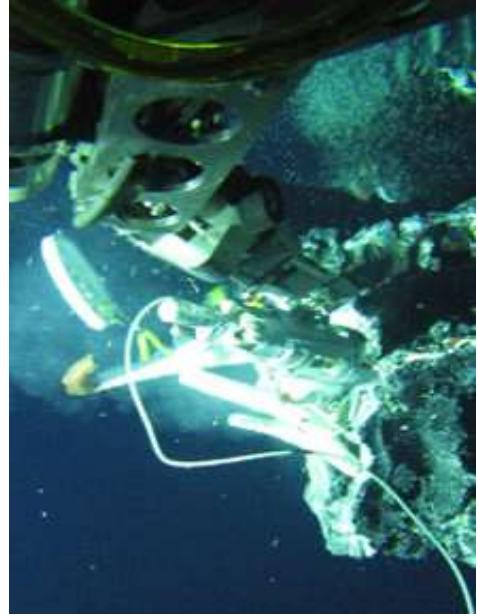
Figure 1.9



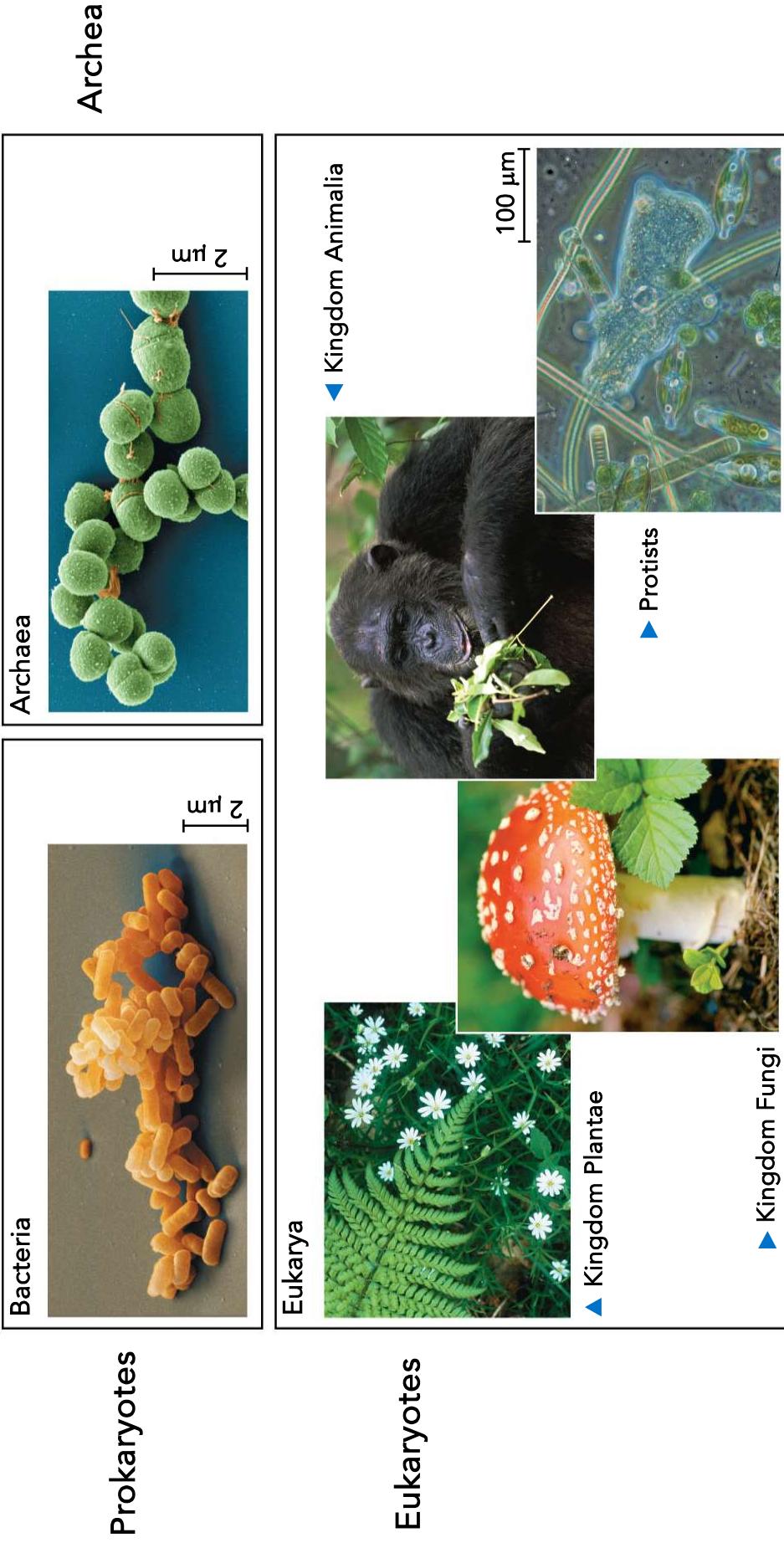
Domains of life

- Definition of life ✓
- **Domains of life**
- Cell-unit of life
- Cell-compartment
- How do we study cells?
- Understanding cell structure

A hallmark of life: diversity

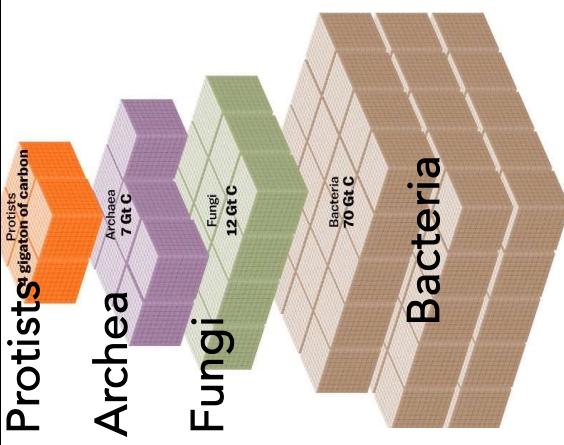


In order to make sense of the diversity of life: classification into three domains



© 2011 Pearson Education, Inc.

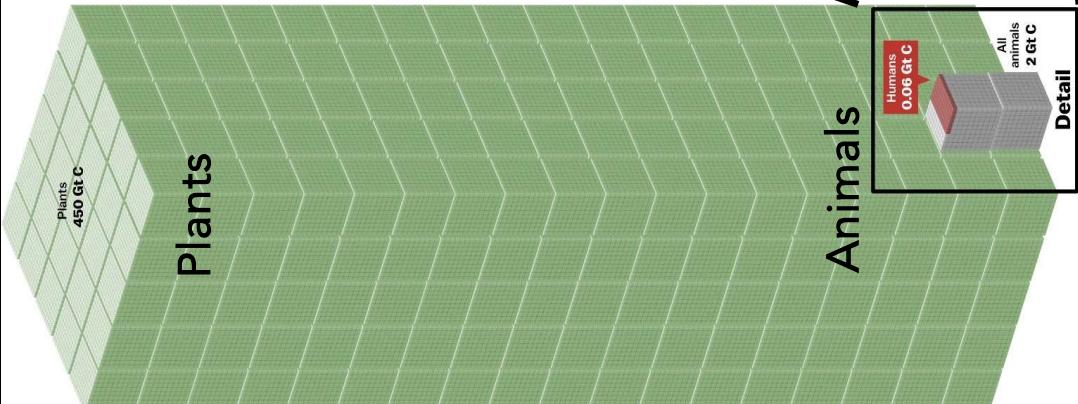
Diversity and biomass



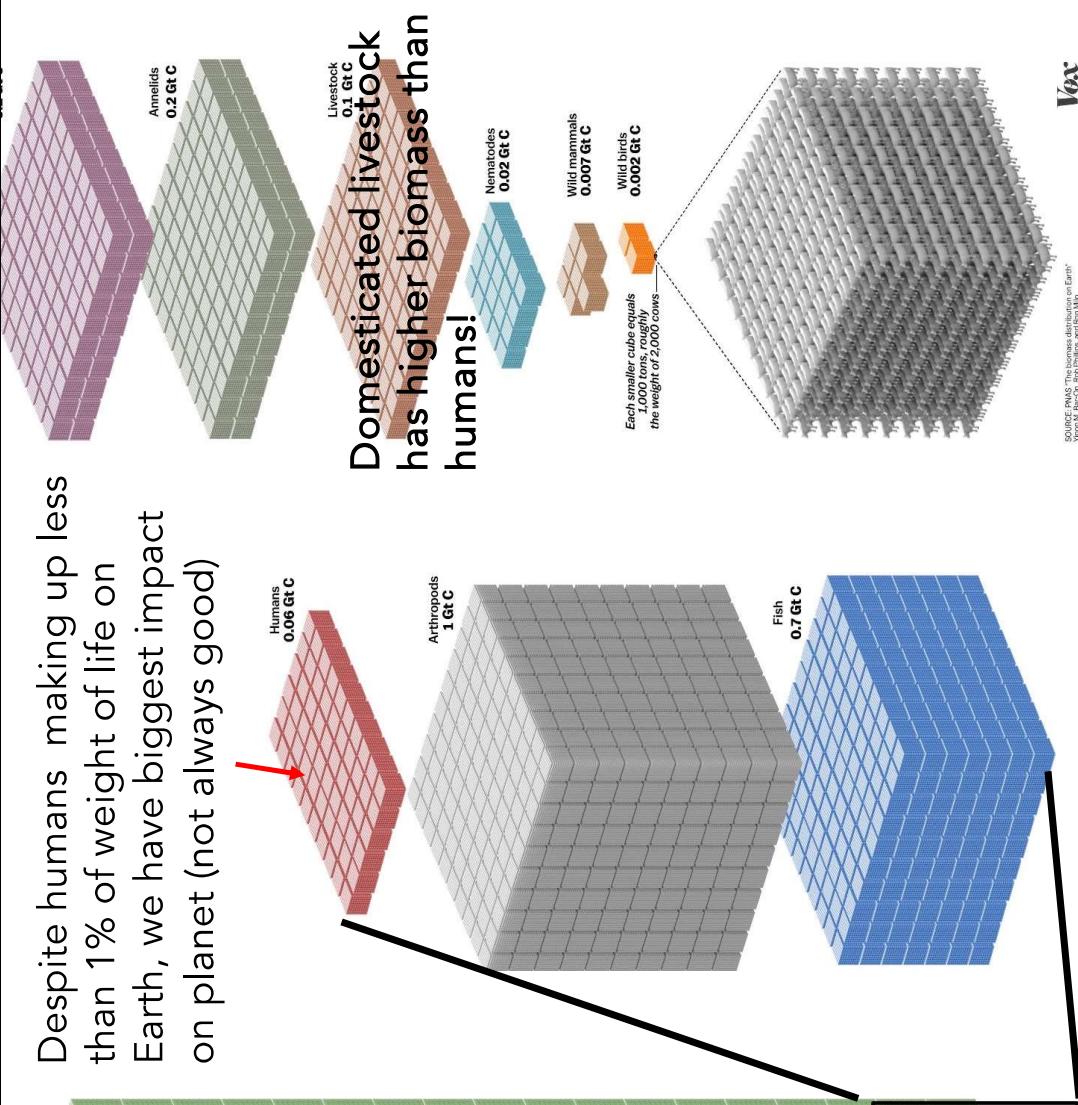
A brief digression

Scientists estimate the giga-tonnes of carbon from different kingdoms

From: Vox Science, based on a paper in PNAS



Despite humans making up less than 1% of weight of life on Earth, we have biggest impact on planet (not always good)



A tangled web of life

- Diverse organisms divided into three fundamental groups
 - **Bacteria** (Eubacteria), **Archaea** (Archaeabacteria) & **Eukarya** (Eukaryotes)
 - on the basis of biochemical characteristics
 - fundamental groups known as "domains"
- Carl Woese suggested to group organisms into 3 domains
 - on the basis of 16S ribosomal RNA

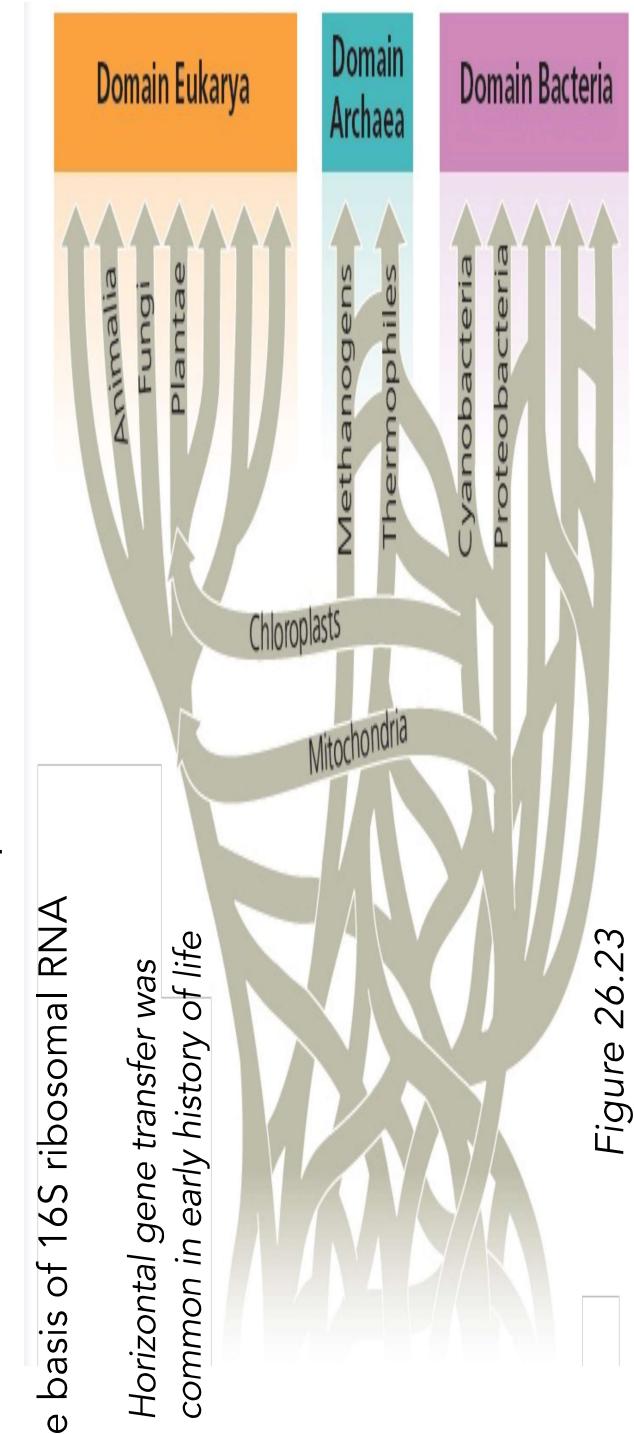


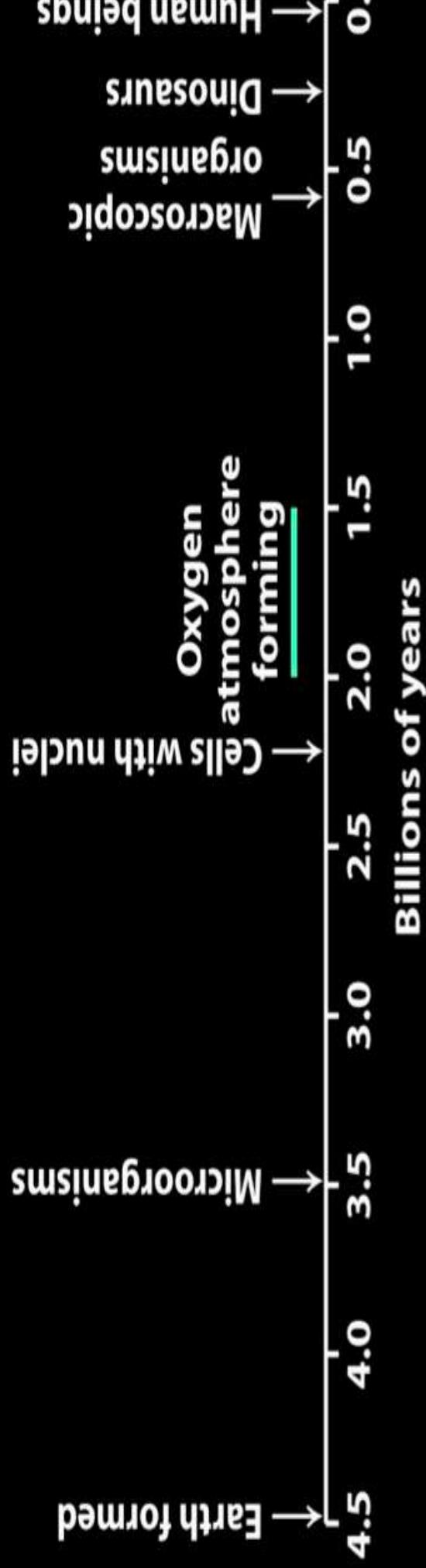
Figure 26.23

- Definition of life ✓
- Domains of life ✓
- **Cell-unit of life**
- Cell-compartment
- How do we study cells?
- Understanding cell structure

Cells as the smallest units of life

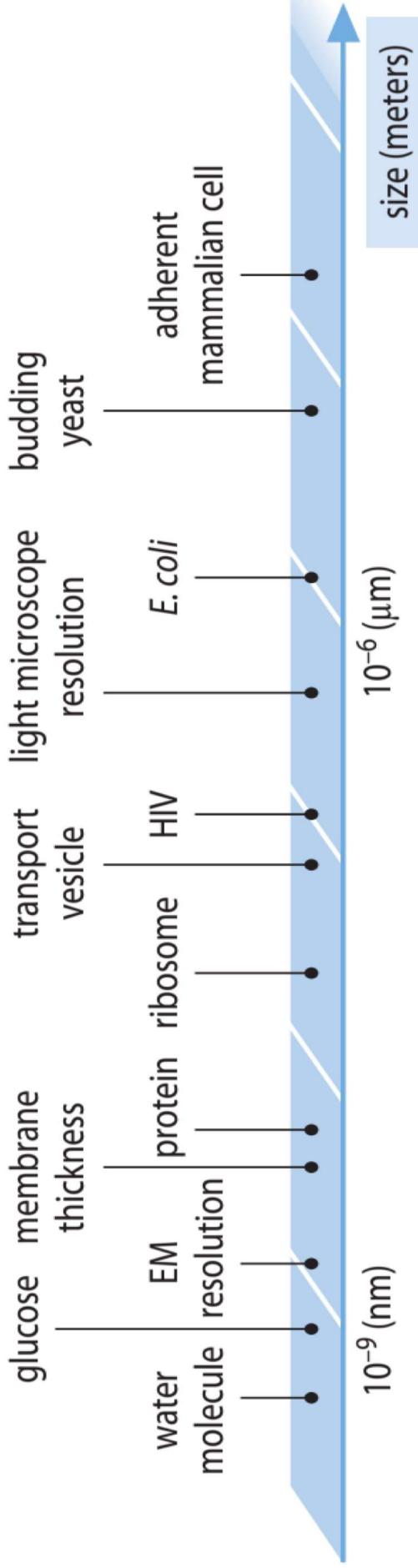
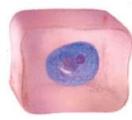
Cell and its Properties

An organism's basic unit of structure and function



The basic unit underlying the diversity of life: a cell

Cells are not visible to the naked eye and were first discovered when microscopes were made



What is the size range of cells?

The diameter of a cell from:

Prokaryotes: 0.1 to 5 mm

Archea: 0.1 to 0.2 mm

Eukaryotes: 10 to 100 mm

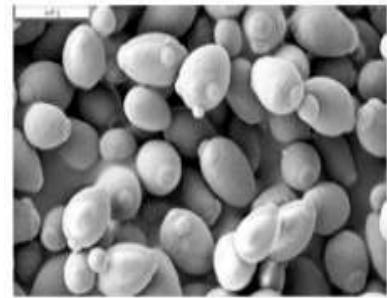
The basic unit underlying the diversity of life: a cell

Organisms can be unicellular or multi-cellular (images below not drawn to scale)



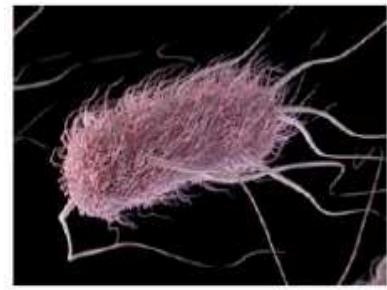
Elephant

(multi-cellular)



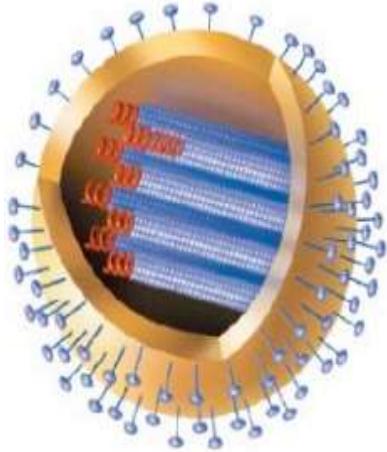
Yeast

(uni-cellular)



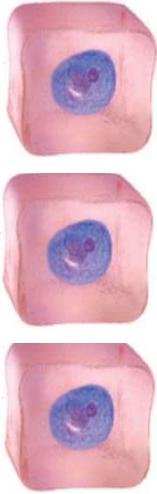
E. coli

(uni-cellular)

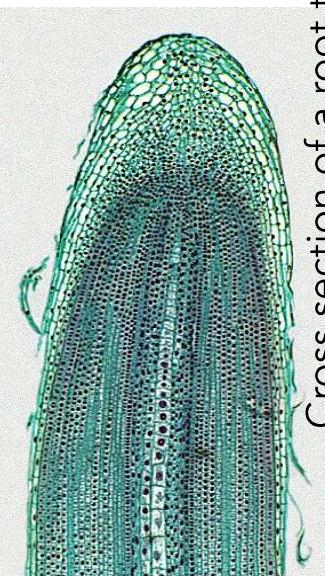


Influenza virus

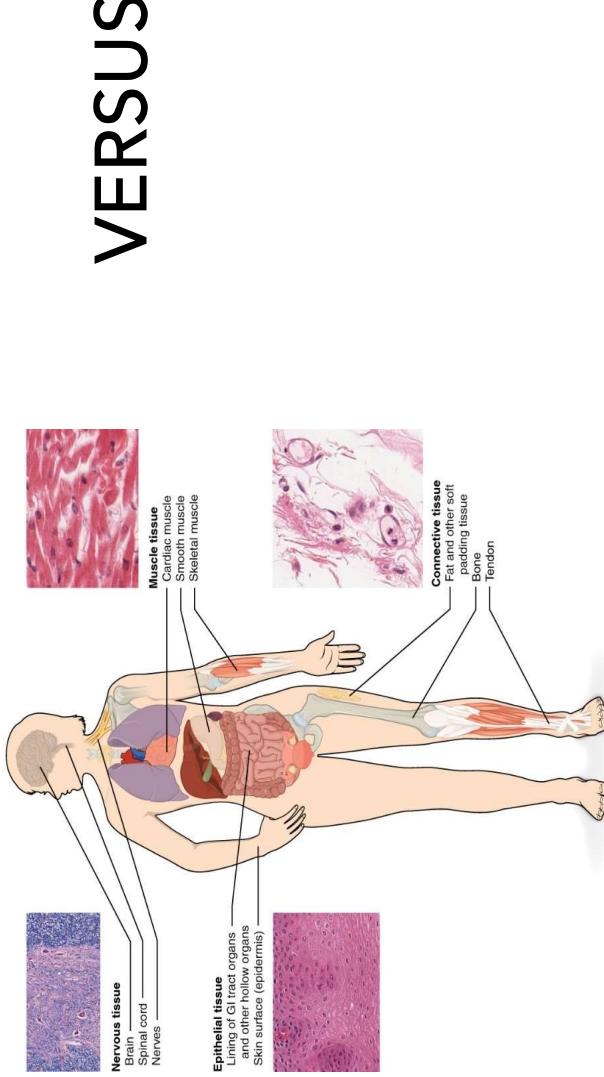
(alive?)



Why bother with multi-cellularity? Why not one large cell?



Cross section of a root tip

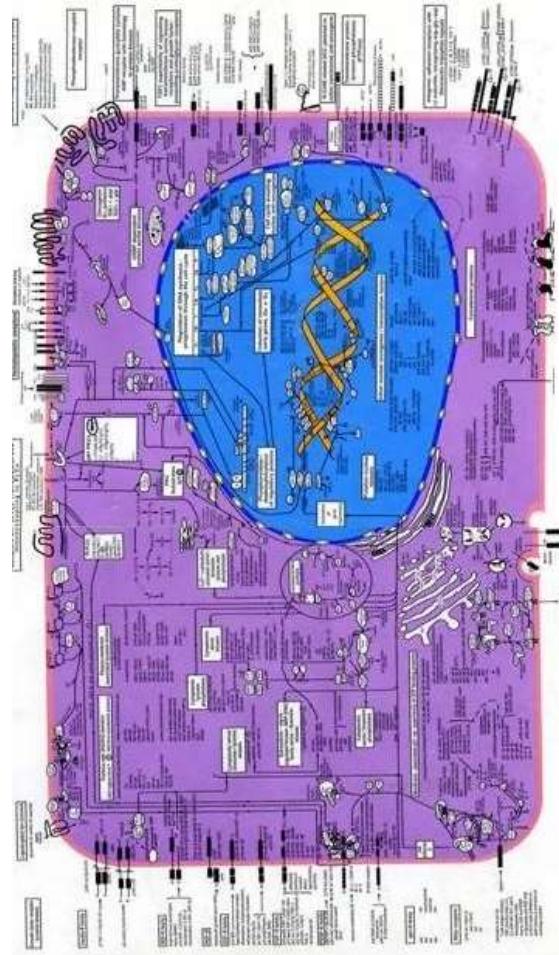
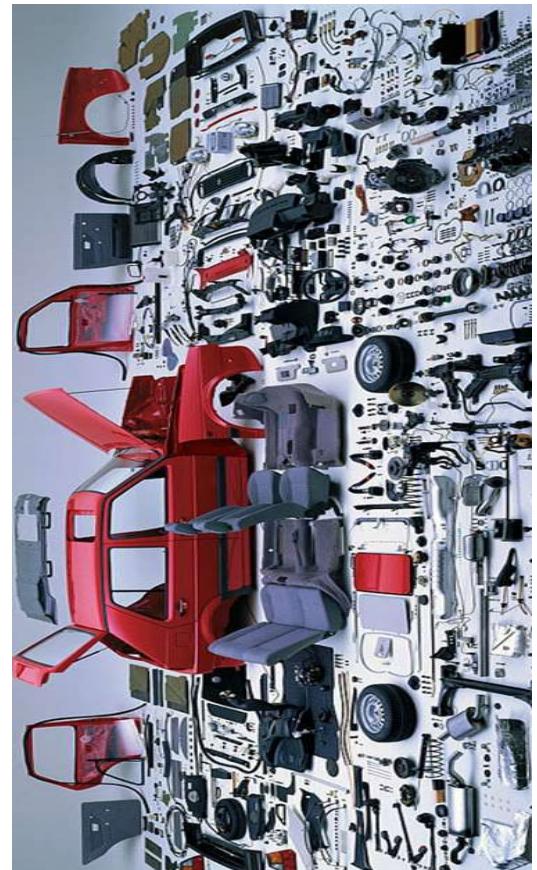
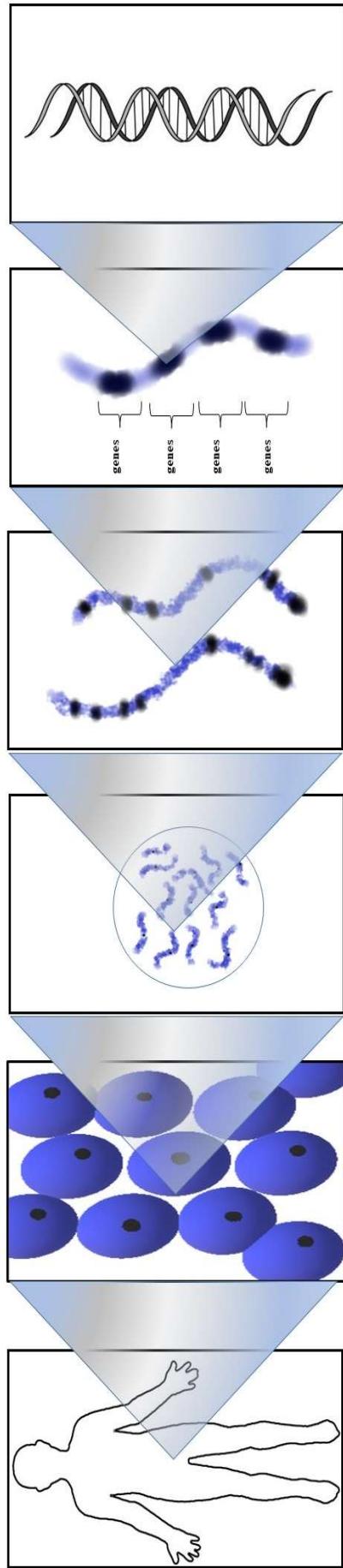


Human body consisting of organs, tissues and cells



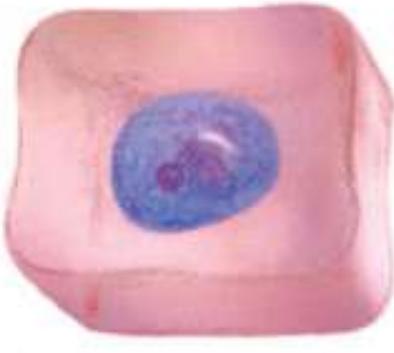
STEVEN MCQUEEN ANITA CORSEAU · EARL ROWE
PRODUCED BY IRWIN S. YEAMAN, JR. · THEODORE SIMONSON AND KATE PHILLIPS
DIRECTED BY EARL ROWE
SCREENPLAY BY IRWIN S. YEAMAN, JR.
A RKO PRODUCTION · 1958 · RATED PG

Basics: An Overview of Cell



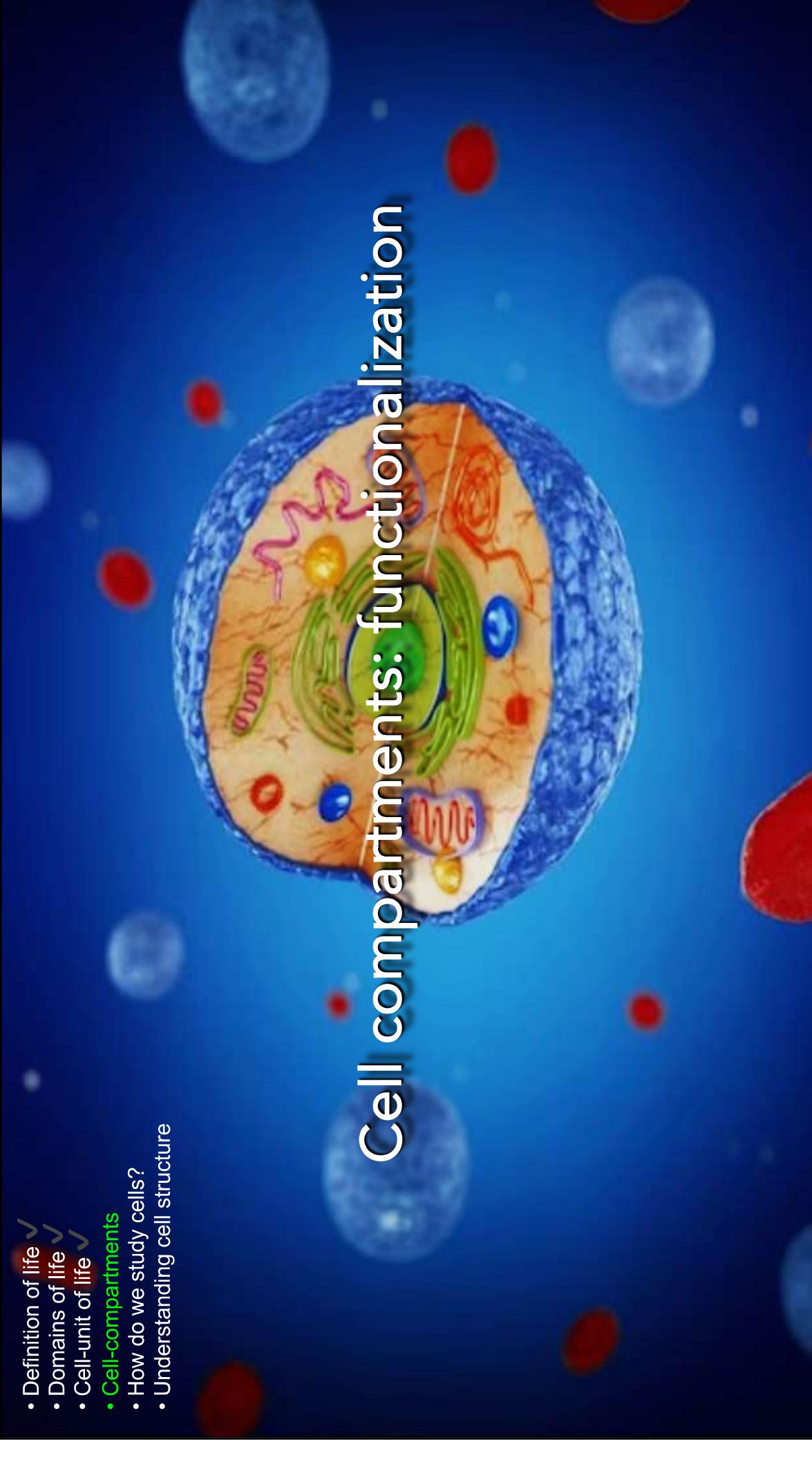
Natural laws limit cell size

- At a minimum, a cell must contain enough volume to house the parts it needs to survive and reproduce
- The maximum size of a cell is limited by the amount of surface area needed to obtain nutrients from the environment and dispose of wastes
- Surface area relative to the volume decreases as the size of a cell increases.
 - limits the size of cells



- Definition of life ✓
- Domains of life ✓
- Cell-unit of life
- **Cell-compartment**
- How do we study cells?
- Understanding cell structure

Cell compartments: functionalization



Compartmentalization: cells can be compartmentalized or not

Floor plan of an affluent home



http://zenlibs.com/a_floorplan-of-a-house/

Specific compartment for each function
Privacy and independence of activity

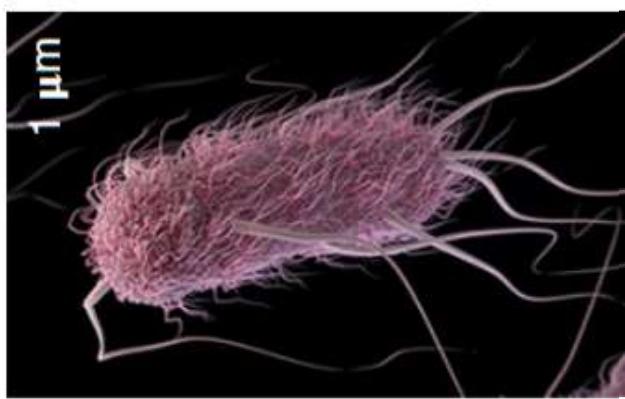
A 1-room tenement
Tenement: a room that by itself is a residence



www.studenthandouts.com/01-Web-Pages/01-Picture-Pages/10.07-Industrial-Revolution/1-Riis-Family-Living-in-One-Room-New-York-City-Slum-1890.htm

Easy and cheap to maintain (small)
Easy to adapt; Easy to pack and move

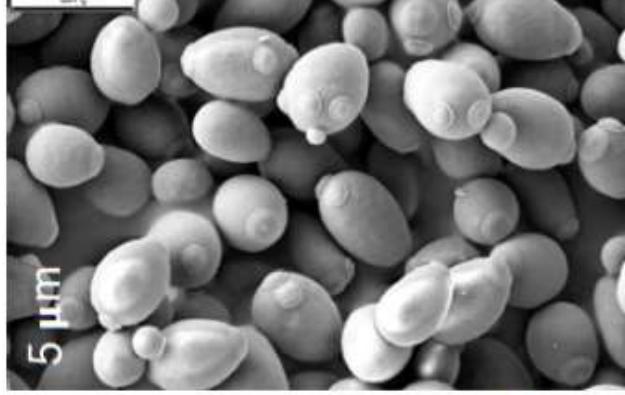
Classification of organisms: prokaryotes & eukaryotes (before nucleus & good nucleus)



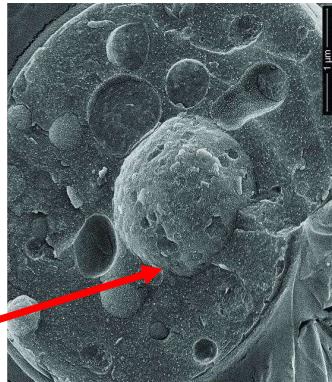
Escherichia coli (*E. coli*)
A unicellular bacterium
A prokaryote
Lacks internal compartments

Nucleus

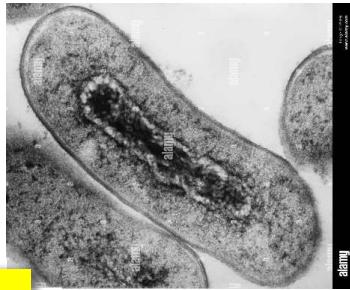
Saccharomyces cerevisiae
Baker's yeast
A single-celled microorganism
A eukaryote
Has internal compartments



Electron micrograph
of a section through
a yeast cell



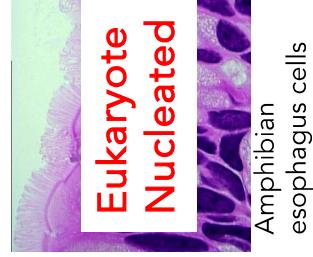
No nucleus, DNA is a nucleoid



Electron micrograph
of a section through
an *E. coli* cell

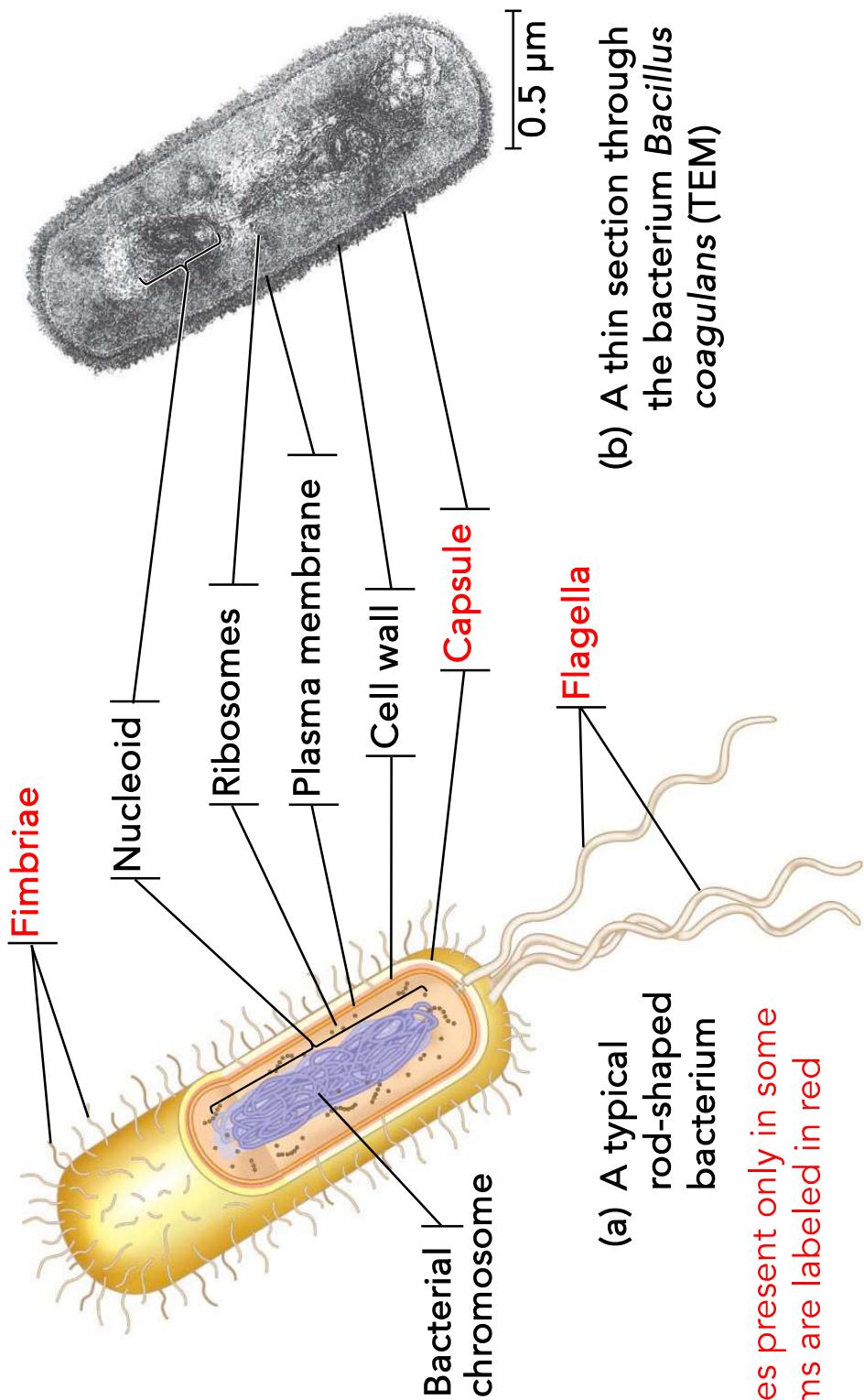
There are two successful cellular plans of organization

- Eukaryotes
(true nucleus, that contains DNA)
 - cell plan of multi-cellular organisms
- Prokaryotes and Archaea
(before nucleus, DNA in the form of a nucleoid)
 - primitive, simple, versatile, ubiquitous, unicellular life form
 - a most successful life form
 - 2,500 different species known



See 4 types of cells
↑
Prokaryote or eukaryote?
Nucleated or not?

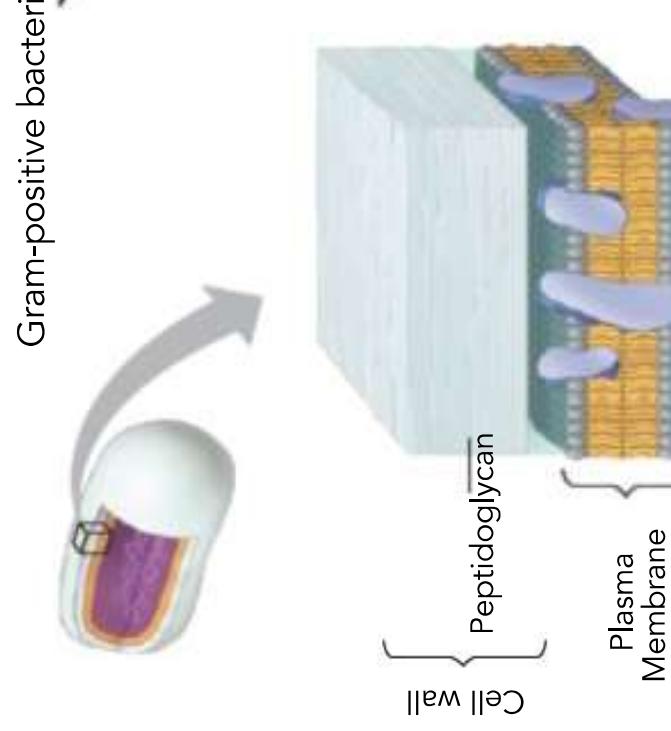
A typical bacterial cell: carries out all its functions without any compartmentalization



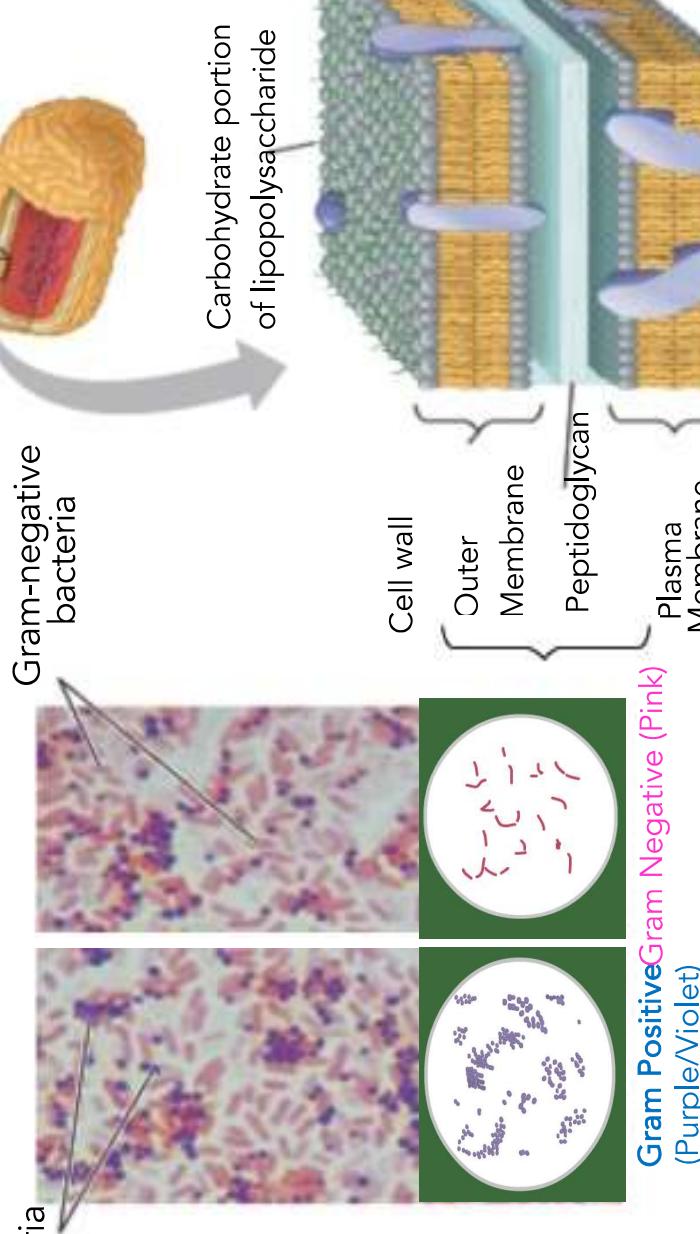
Structures present only in some organisms are labeled in red

Structure of Bacterium: Cell Wall & Staining

Gram-positive bacteria



Gram-negative bacteria



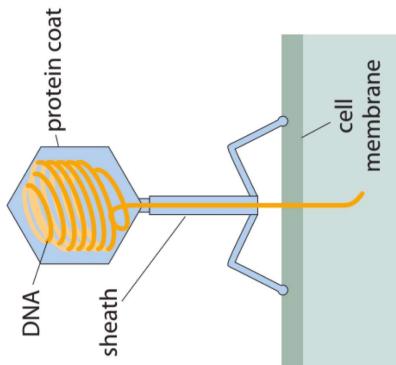
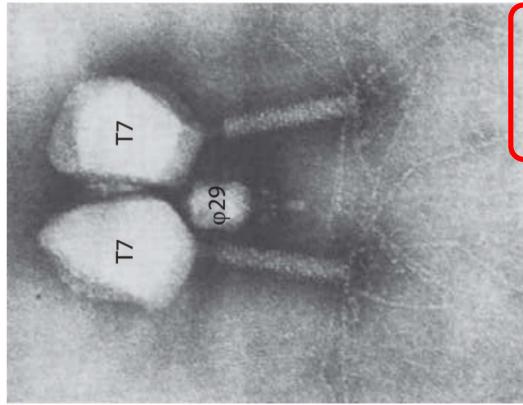
Thick cell wall made of peptidoglycan;
it traps **crystal violet**; alcohol rinse does not
remove the crystal violet

Thin layer of peptidoglycan;
Crystal violet easily rinsed from cytoplasm, **Safranin**
stains gram-ve & cell appears pink

Figure 27.3

Classification of organisms: viruses (completely different)

Small viruses



This is one of the smaller viruses

Sizes of viruses vary greatly

Some viruses are larger than bacteria

100 nm

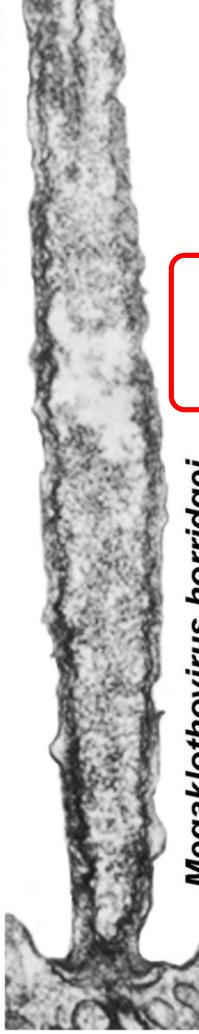
Giant viruses



HIV

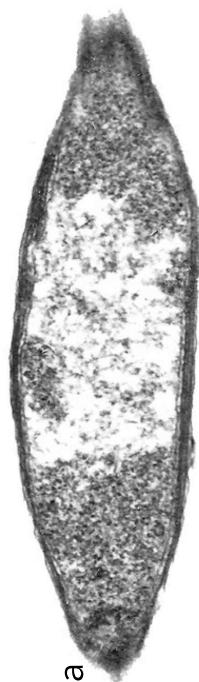
Escherichia coli

Pithovirus sibericum

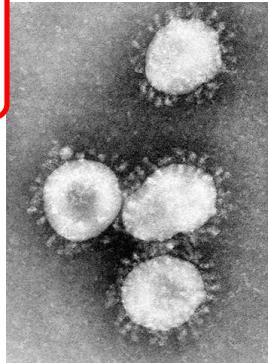


Megaklothovirus horridgei

500 nm



Klothovirus casanovai



Mimivirus

https://en.wikipedia.org/wiki/Giant_virus

SARS-CoV2

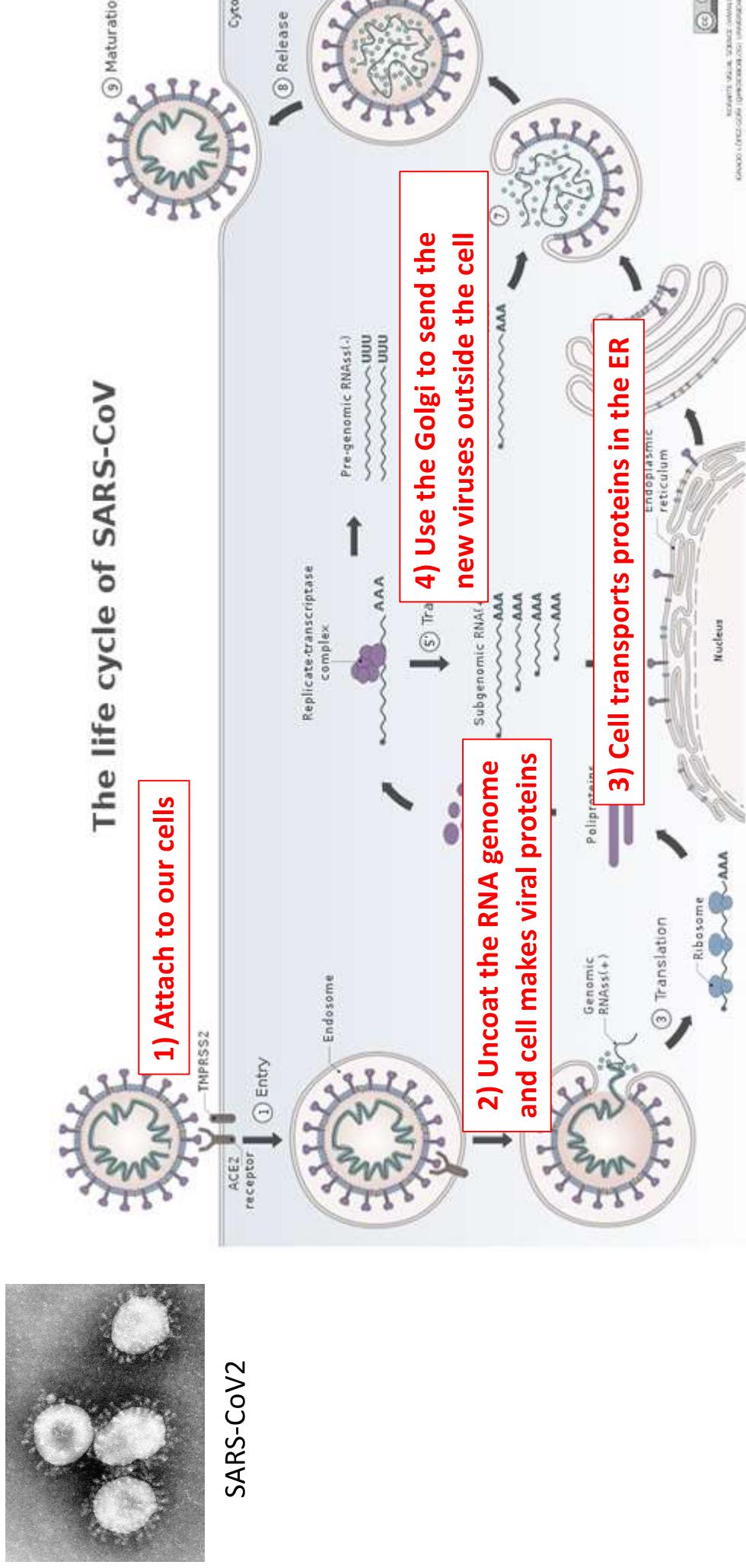
Viruses cannot survive without a host cell to infect: are they even alive?

BB101

Lecture 2

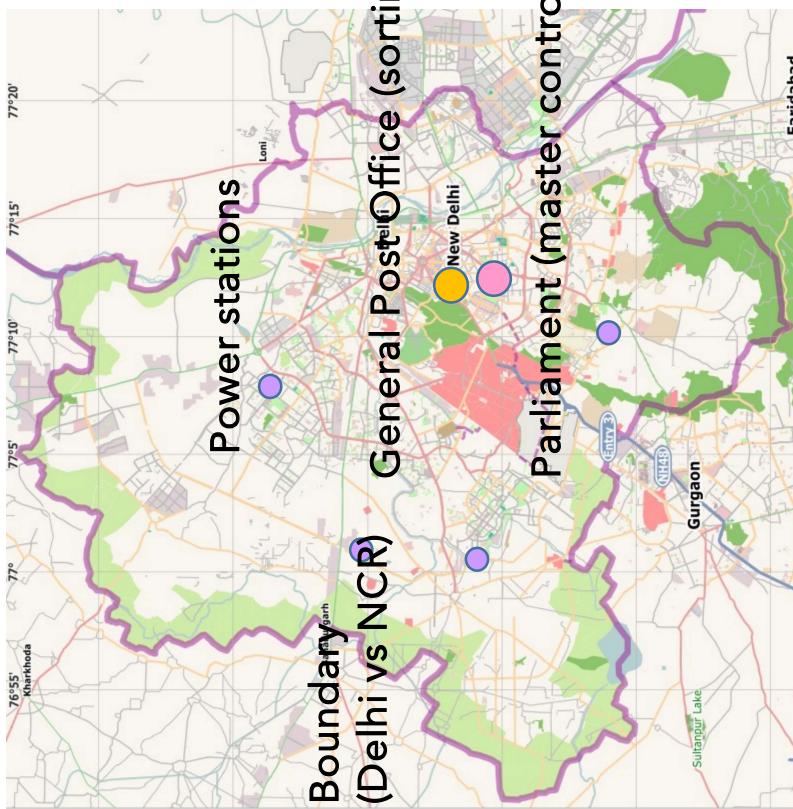
IIT Bom

Viruses cannot survive without host cells: all machinery to make new viruses is in host cell



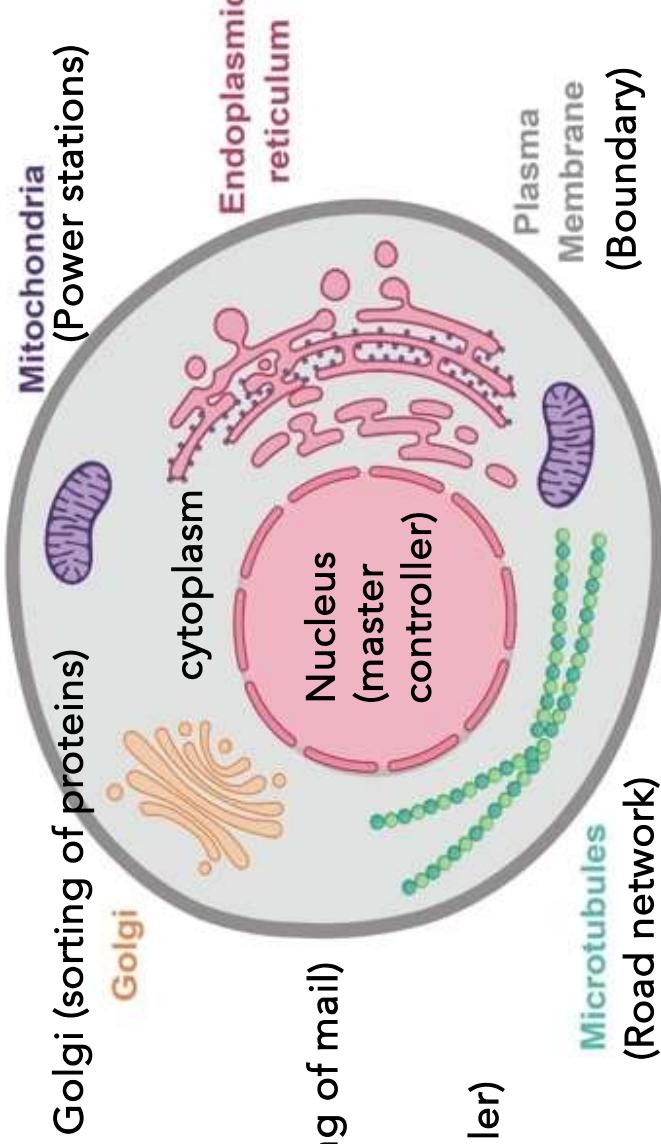
What are the compartments in eukaryotic cells? Analogy between a city and a cell

Compartments in eukaryotic cells carry out specialized functions & are called "organelles".

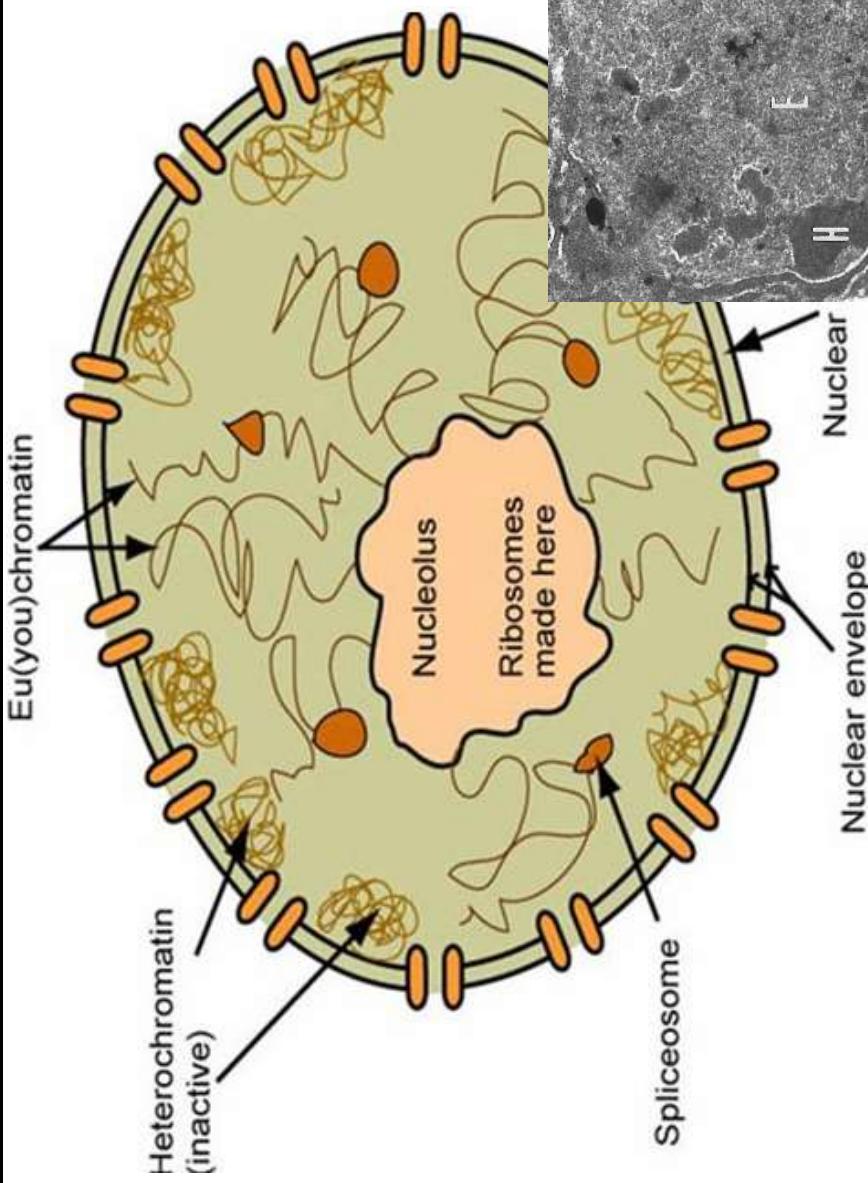


Map of New Delhi

Schematic of a cell

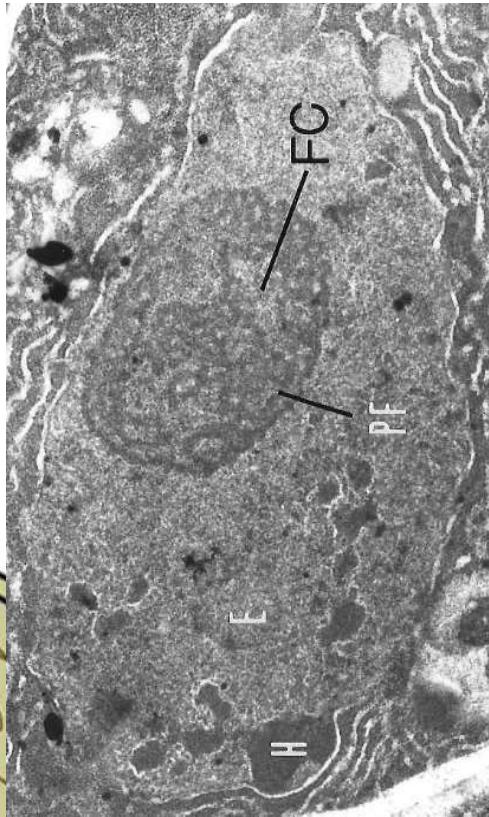


Compartmentalization and function: The nucleus contains DNA

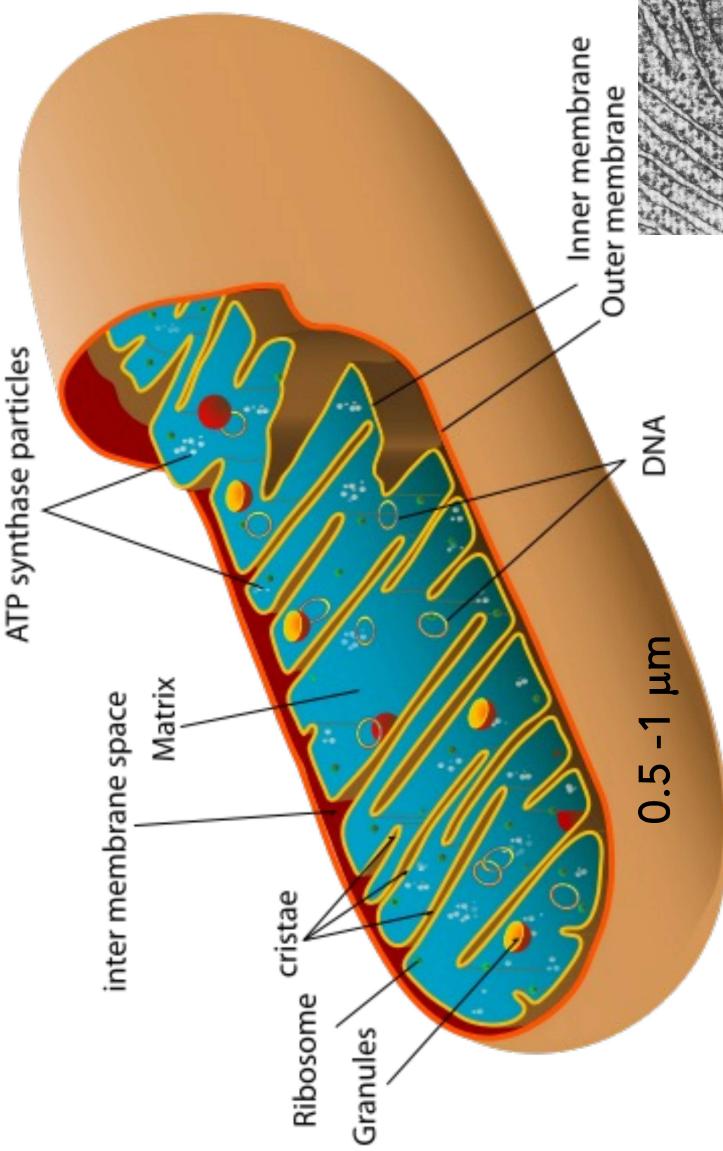


DNA is the genetic material that gives instructions for cellular function.

In the city analogy, the nucleus is the government



Compartmentalization and function: Mitochondria generate energy

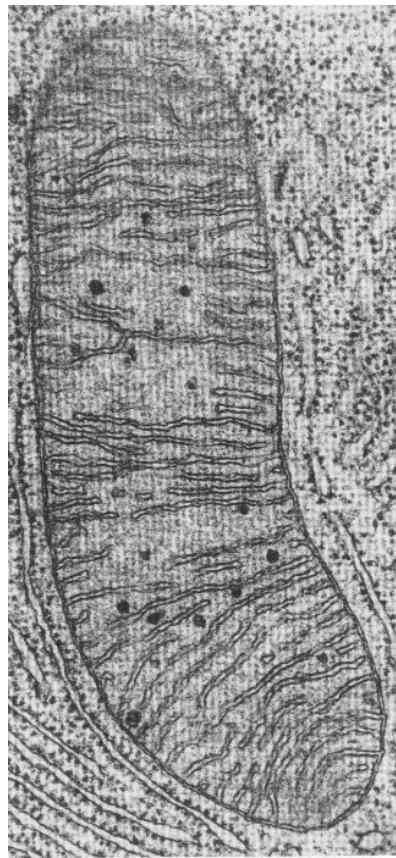


**"Mitochondria are the powerhouse
the cell."**

Based on our city analogy, have you
power outage in your city?

What would happen if mitochondria
not function?

Mitochondrial diseases: Leigh
syndrome, MELAS



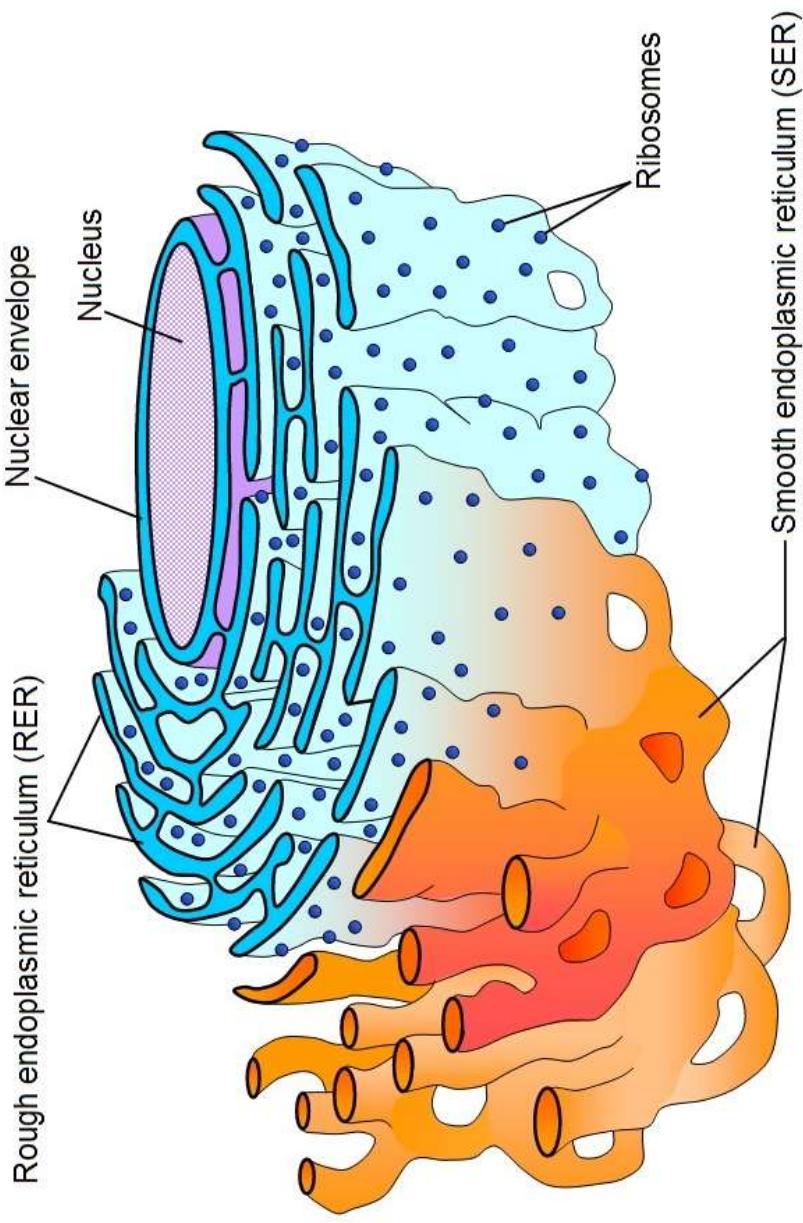
When any organism 'eats food',
mitochondria in the cells convert
the food to energy

How do proteins get to the right location in a cell?

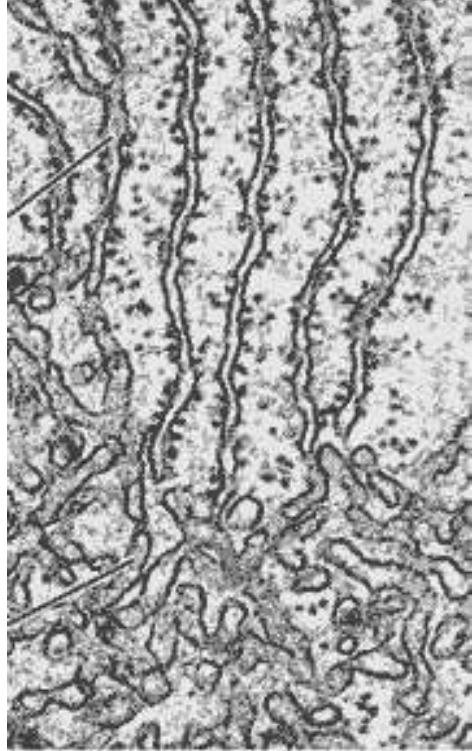
The cell has its own Molecular FedEx system:
Endoplasmic Reticulum and Golgi Apparatus



Endoplasmic Reticulum transports proteins that are synthesized in the cytosol



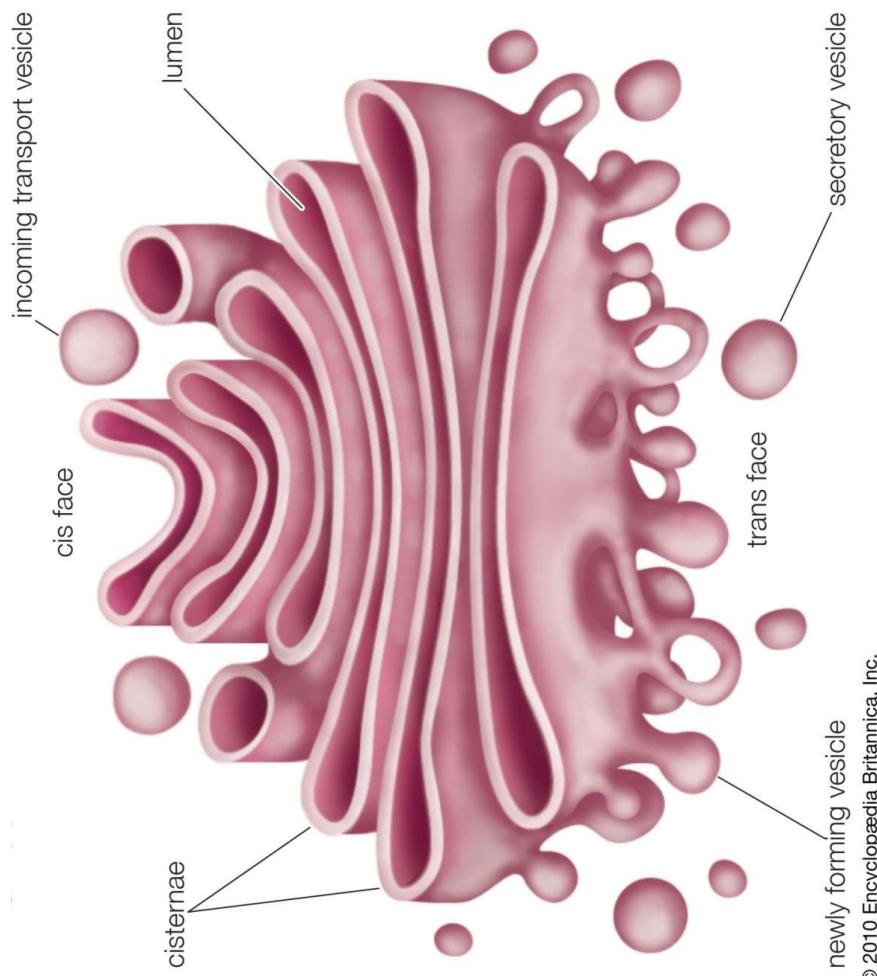
Proteins are synthesized in the cytoplasm and many proteins carry out their functions in different organelles.



Golgi Apparatus sorts the proteins for their destinations

Golgi is like a Post Office

Sends proteins: outside the cell, to different organelles, to the plasma membrane, etc



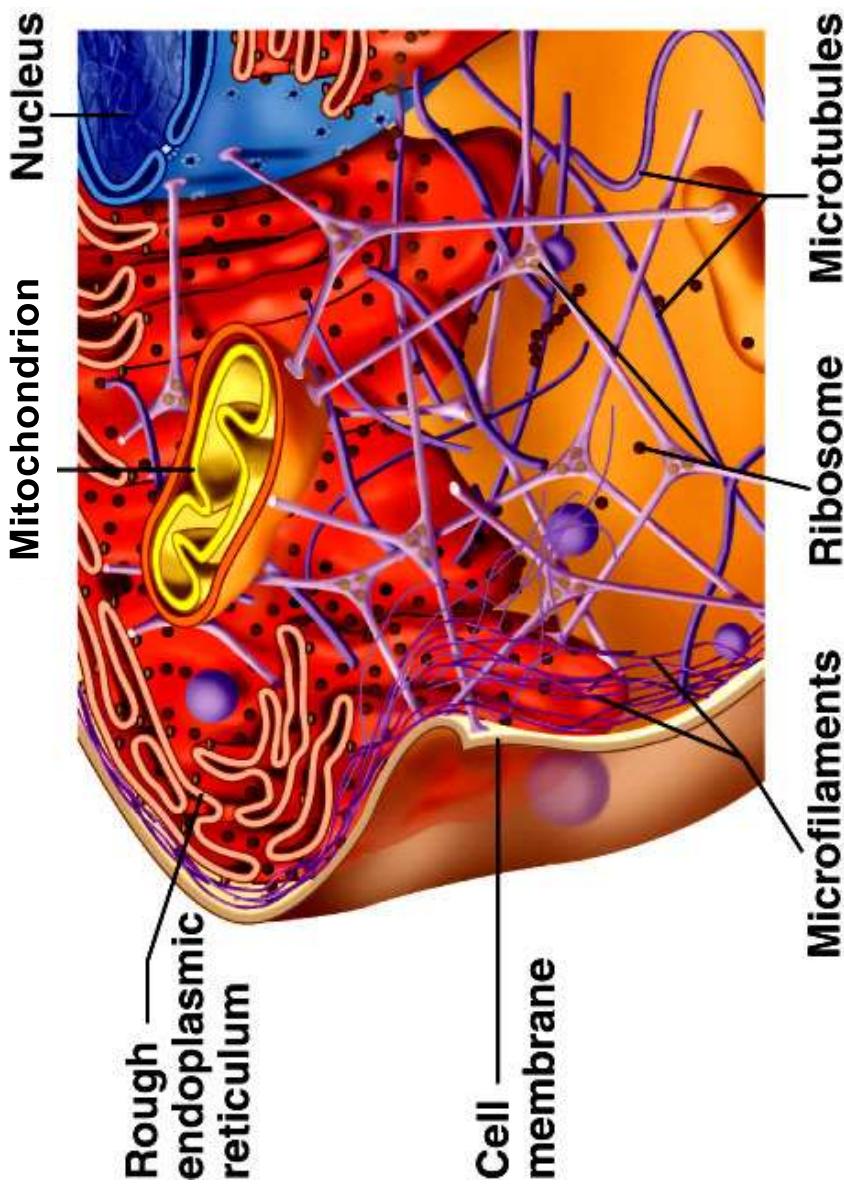
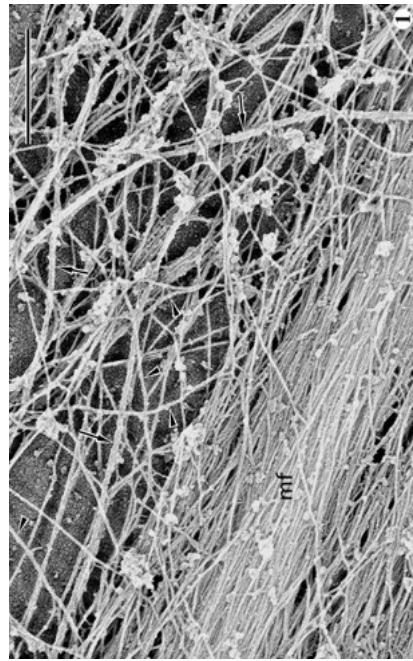
© 2010 Encyclopædia Britannica, Inc.

Cytoskeleton is structural support for cell & provides tracks for movement

Cytoskeleton:

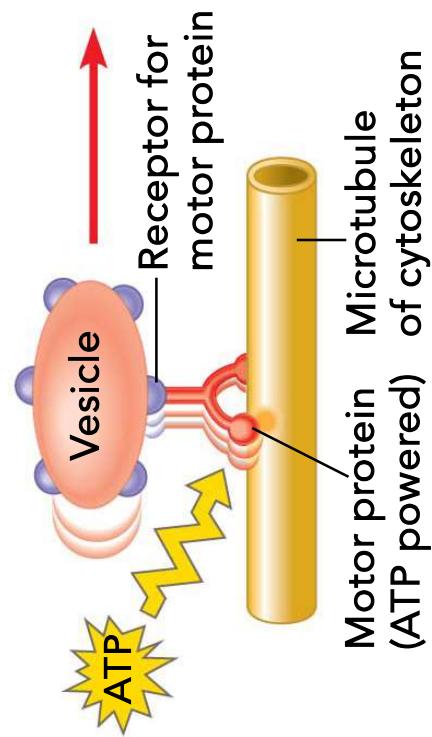
- Actin
- Microtubules
- Intermediate filaments

BUT ... as cells can move, the cytoskeleton is rigid, but can also be flexible



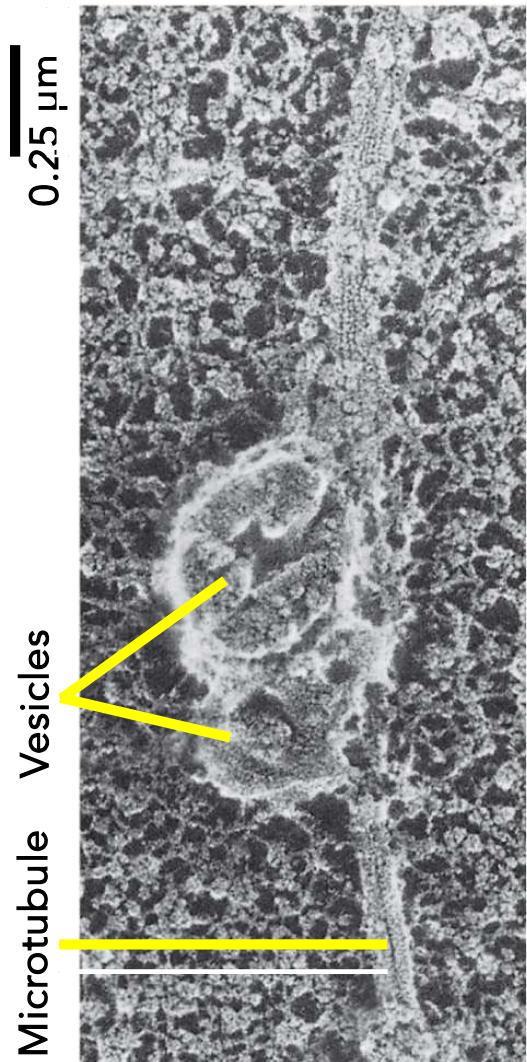
Molecular motors carry cargo on the microtubule tracks

Motor proteins bind to microtubules and move in a specific direction.



One end of the protein can bind to cellular components and carry them to their destinations.

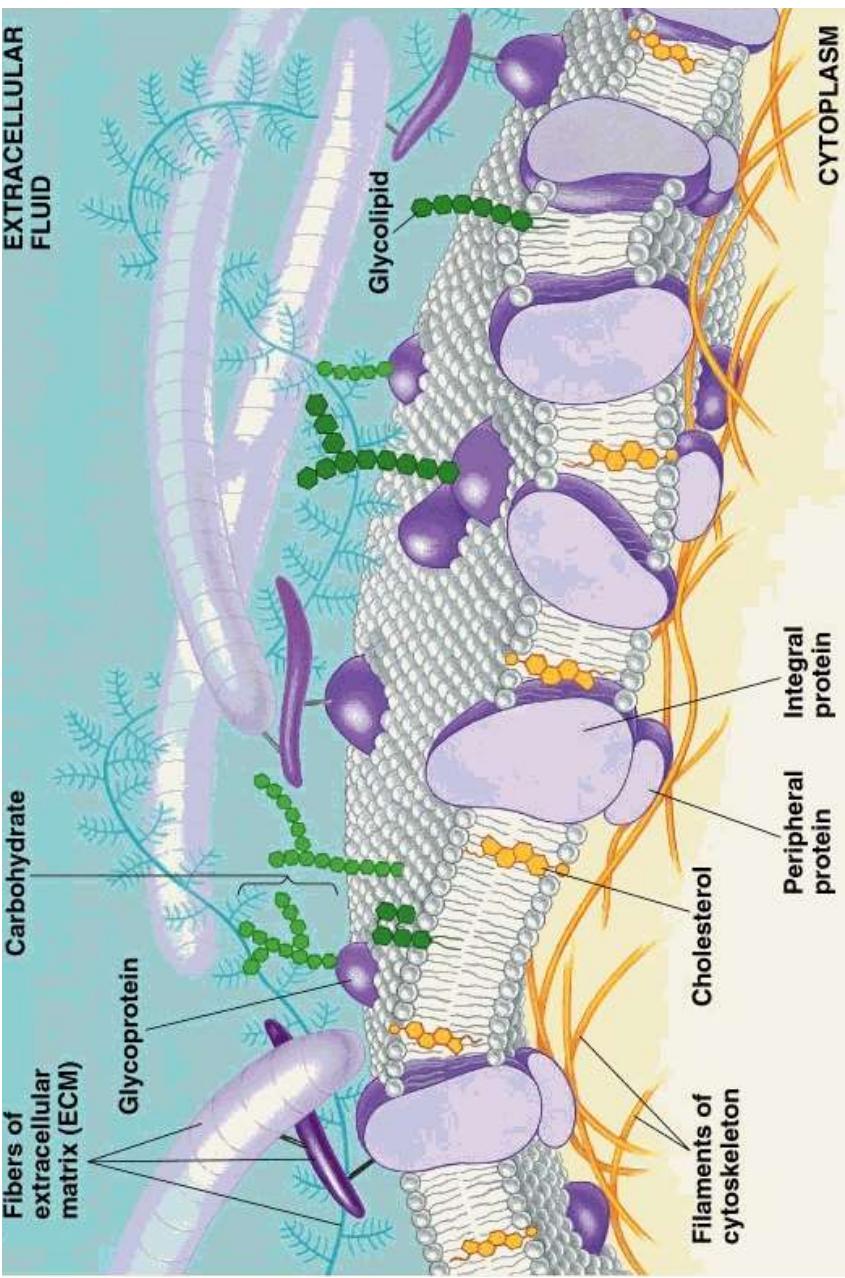
These are like
postmen of the
General Post
Office in a city



Scanning electron micrograph
of a squid giant axon

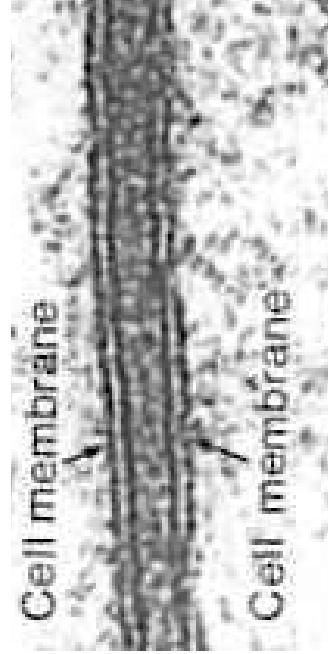
Axon: is the extension of a nerve cell (or neuron)
Shown are two neurotransmitter-containing vesicles moving towards the tip of the axon

Plasma membrane is the barrier between the cell and the world



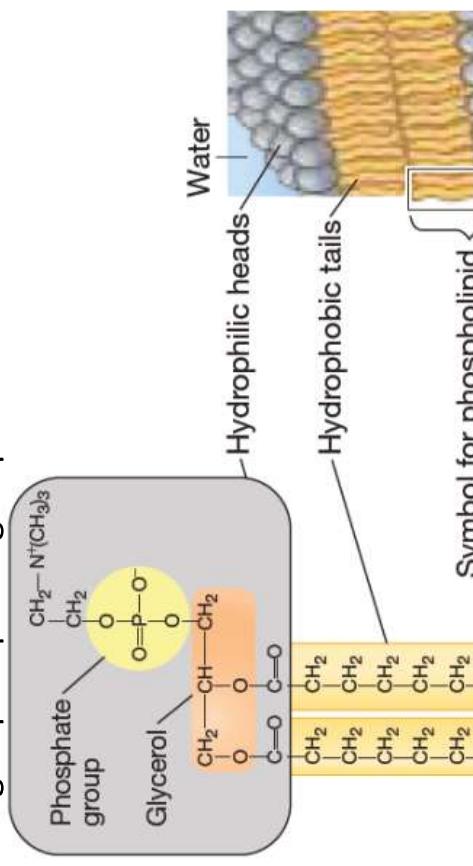
Plasma membrane is made of lipids, proteins & carbohydrates

- Functional separation between cell & external environment
- Molecular transport, receipt of cell signals



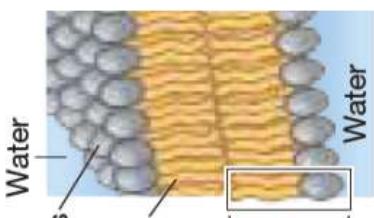
The properties of lipids drive compartmentalization and membrane formation

Charged phosphate groups



Phospholipids have **hydrophilic heads** (water loving) due to the negatively charged phosphate groups. They have **hydrophobic tails** (water hating) that have no charged groups.

Because of this structure phospholipids **spontaneously assemble** into structures that form membranes.



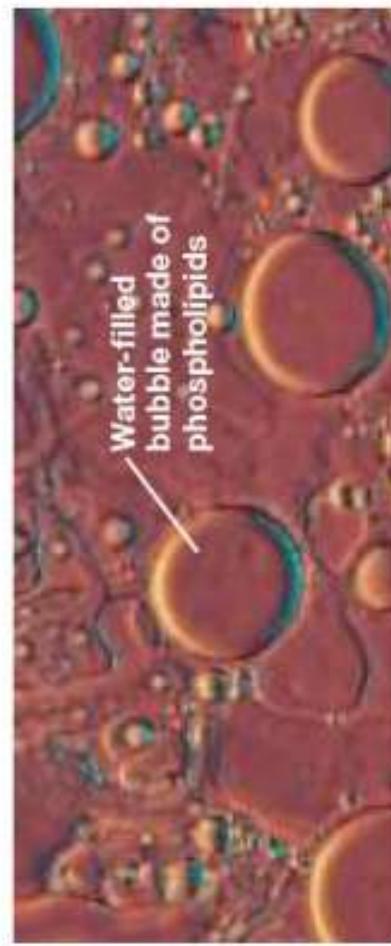
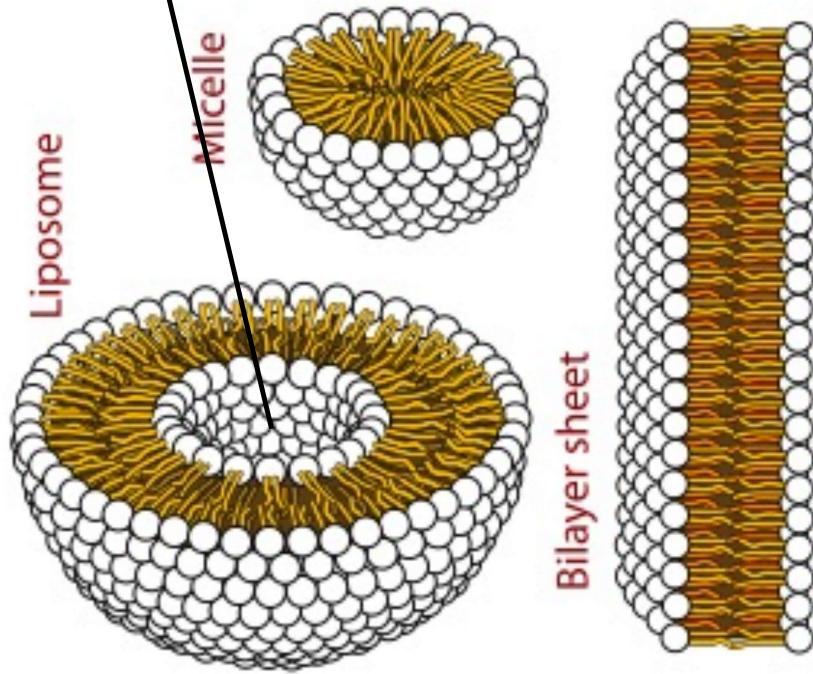
▲ **Figure 3.10B** Section of a phospholipid membrane. Each gray-headed, yellow-tailed structure is a phospholipid molecule; this visual representation is used throughout this book.

Hydrophobic tails

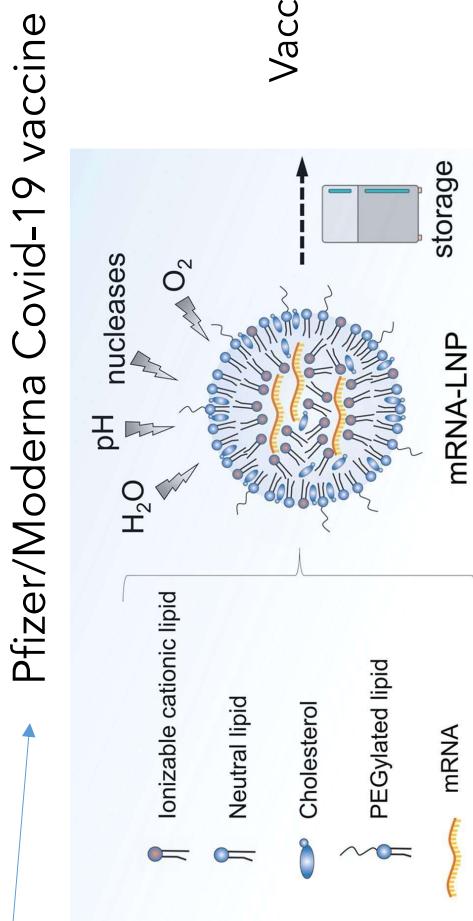
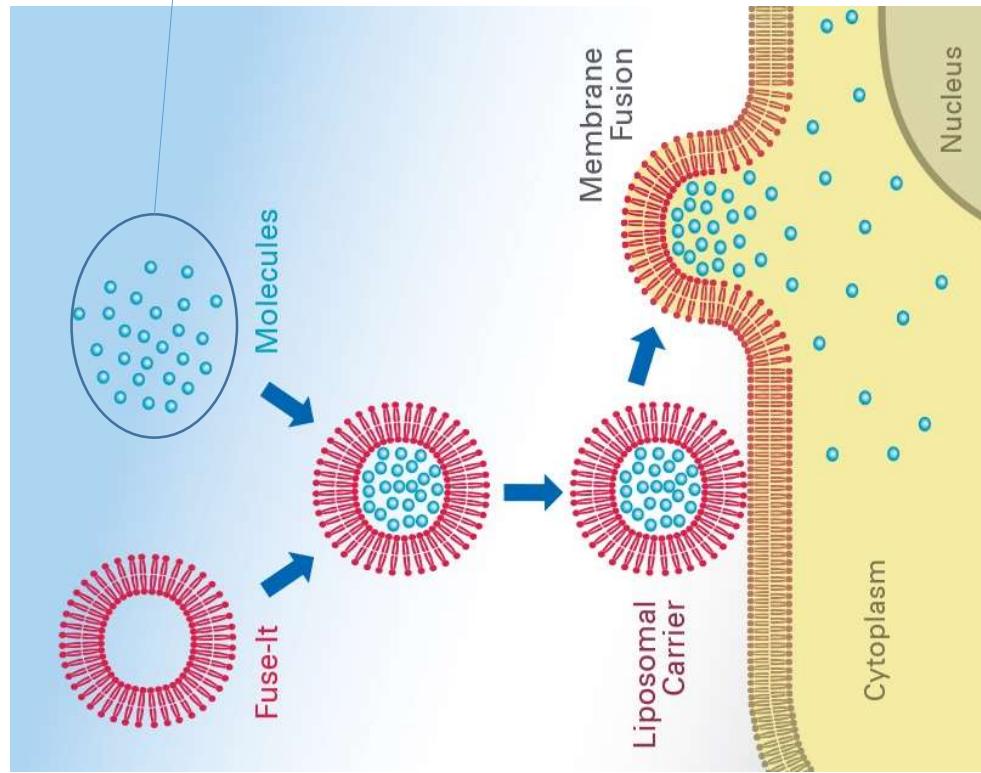
▲ **Figure 3.10A** Chemical structure of a phospholipid molecule

The properties of lipids allow spontaneous formation of ordered structures

- Can put drugs and other useful molecules into this aqueous compartment for delivery
- Can fuse membranes together



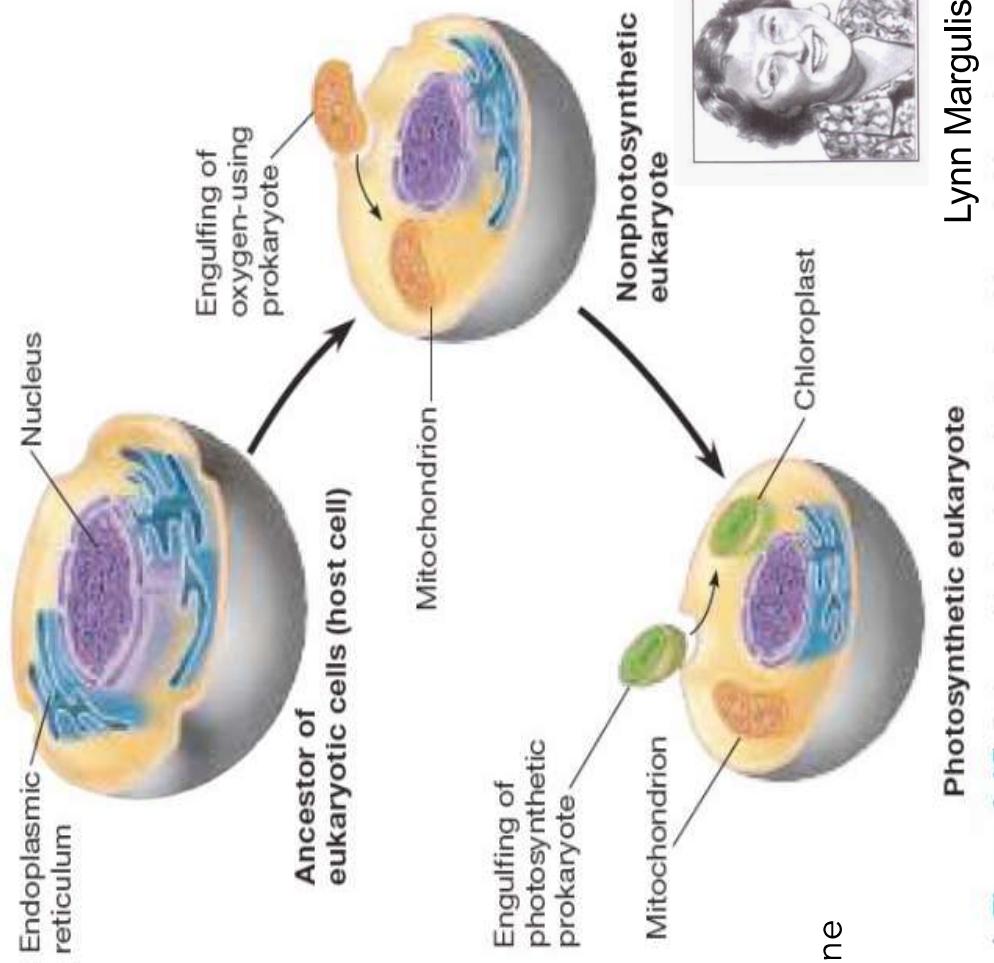
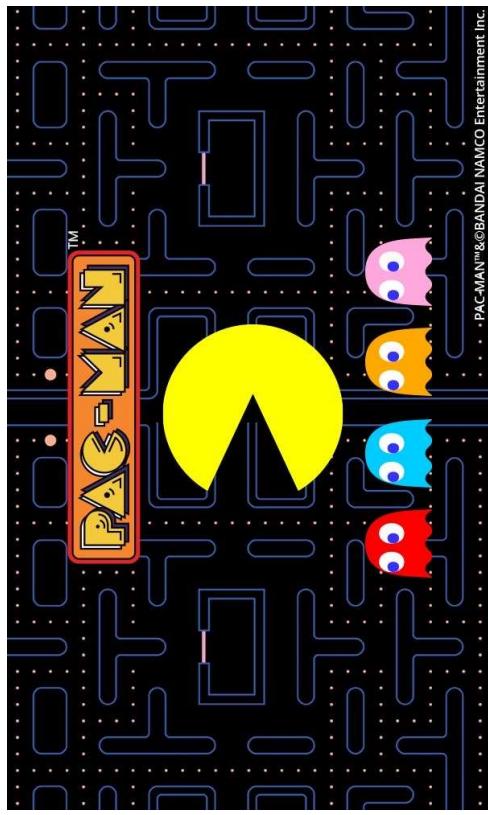
The properties of lipids lead to membrane fusion



Membranes do not easily fuse with each other:

Liposomes and Lipid Nanoparticles (LNPs) have certain lipids that promote fusion

Where did organelles come from: Model for Endosymbiotic Origin



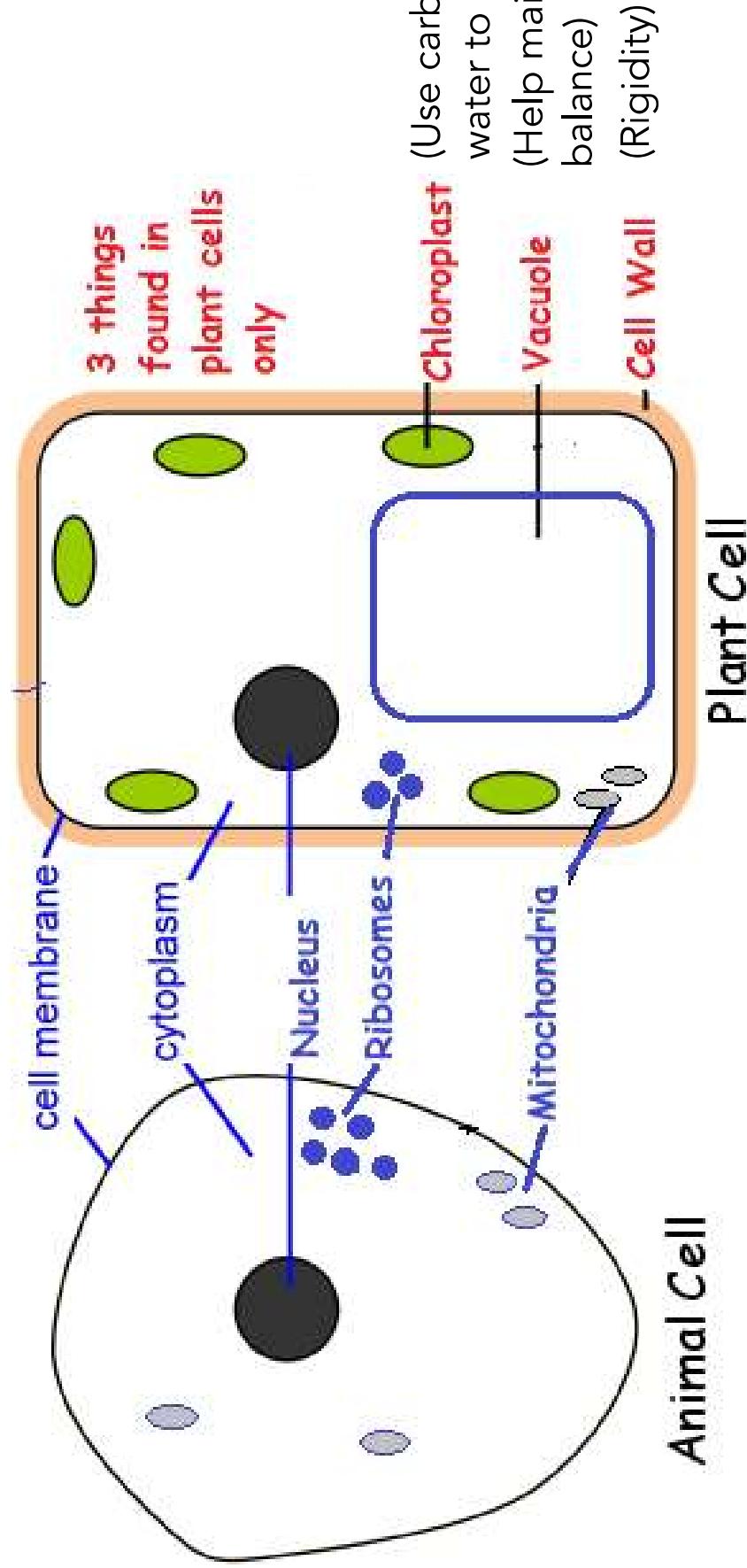
Prokaryotes were engulfed by eukaryotes to create endosymbiotic organelles

- Generation of double membrane organelle
 - Outer membrane from eukaryotic plasma membrane
 - Inner membrane from bacterial plasma membrane

▲ Figure 4.15 Endosymbiotic origin of mitochondria and chloroplasts

Lynn Margulis (19)

Animal vs plant cells: structure is essential for function



Animal vs plant cell(s): structure is essential for function

	Plant cell	Animal cell
Cell wall	Present	Absent
Vacuole	Large	Small
Plastid	Present	Absent
Glyoxysome	Present	Absent
Lysosome	Absent	Present
Centrosome	Absent	Present

Cells: Two Major Classification (1)

- Cell: morphological and functional unit of all living organisms

	Prokaryotes	Eukaryotes
Examples	<ul style="list-style-type: none">• Various types of bacteria<ul style="list-style-type: none">• Almost all unicellular Cyanobacteria	<ul style="list-style-type: none">• All members of plant and animal kingdoms• Fungi (unicellular e.g. yeast, multicellular e.g. molds)• Protozoan (unicellular)
Cell diameter	1-10 μm	10 – 100 μm
Nucleus	Lacks nucleus	Defined membrane bound nucleus

Cells: Two Major Classification (2)

	Prokaryotes	Eukaryotes
Internal organization	Lacks membrane-bound compartments but many proteins are localized in cytosol	Extensive internal membranes enclose other compartments known as organelles
Cytoskeleton	Absent	Present
Cytoplasmic organelles	Absent	Extensive internal membranes enclose other compartments known as organelles
Internal organization	Lacks membrane-bound compartments but many proteins localized in cytosol	

Cells: Two Major Classification (3)

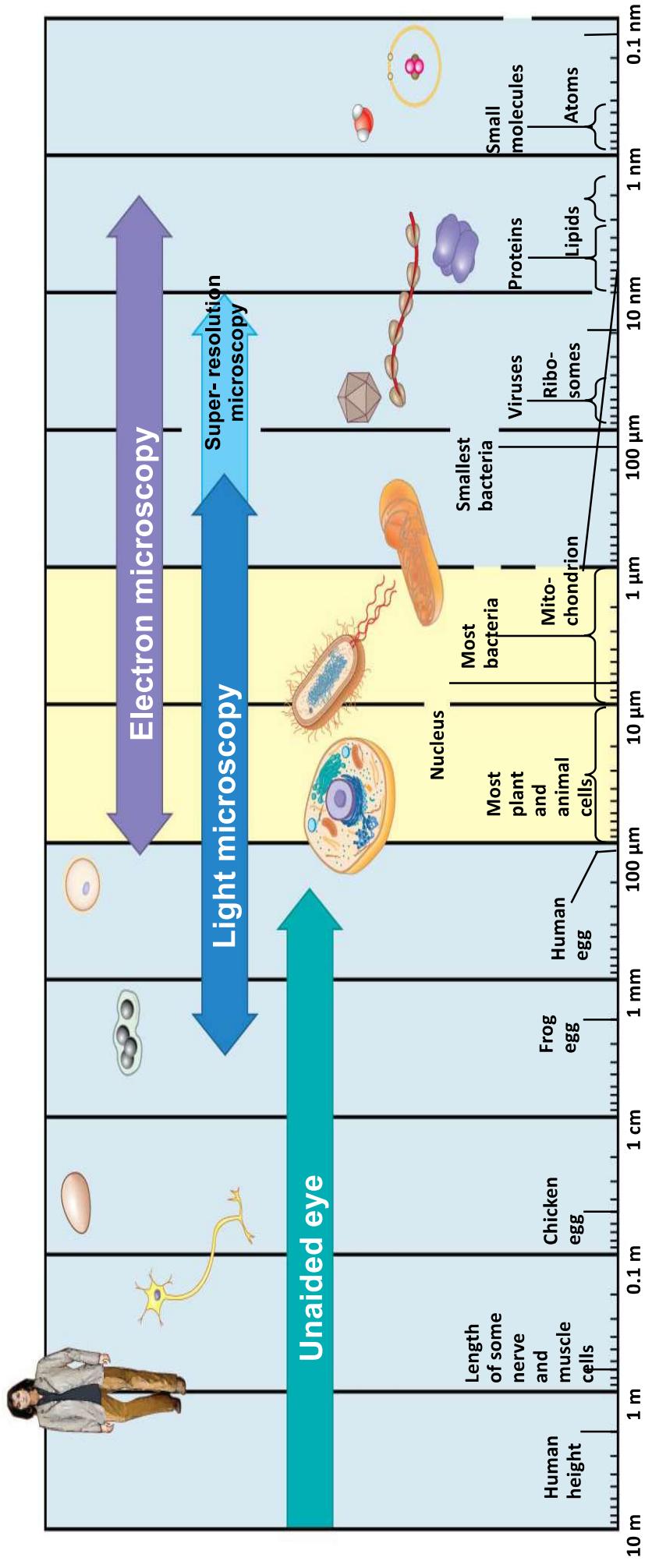
Prokaryotes	Eukaryotes
Chromosome	Single circular DNA molecule Multiple linear DNA molecules
DNA content	1×10^6 to 5×10^6 base pairs 1.5×10^7 to 5×10^9
mRNA	<ul style="list-style-type: none">mRNA transcript is mature, directly used for translationTranscription & translation are coupledmRNA transcript is processed (not mature)Transcription & translation are separate

- Definition of life ✓
- Domains of life ✓
- Cell-unit of life ✓
- Cell-compartment ✓
- How do we study cells? ✓
- Understanding cell structure



How do we study cells?

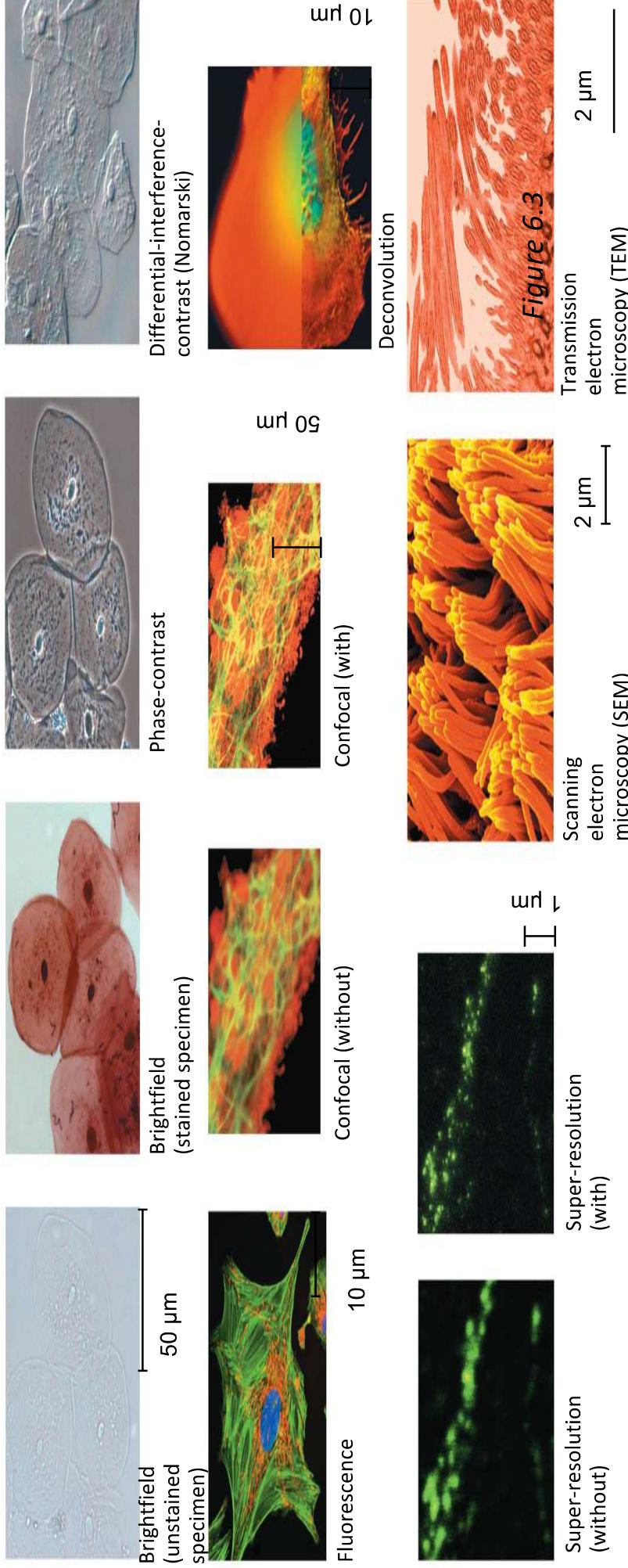
How to study cell?



- Most cells are between 1 - 100 μm in diameter

Figure 6.2

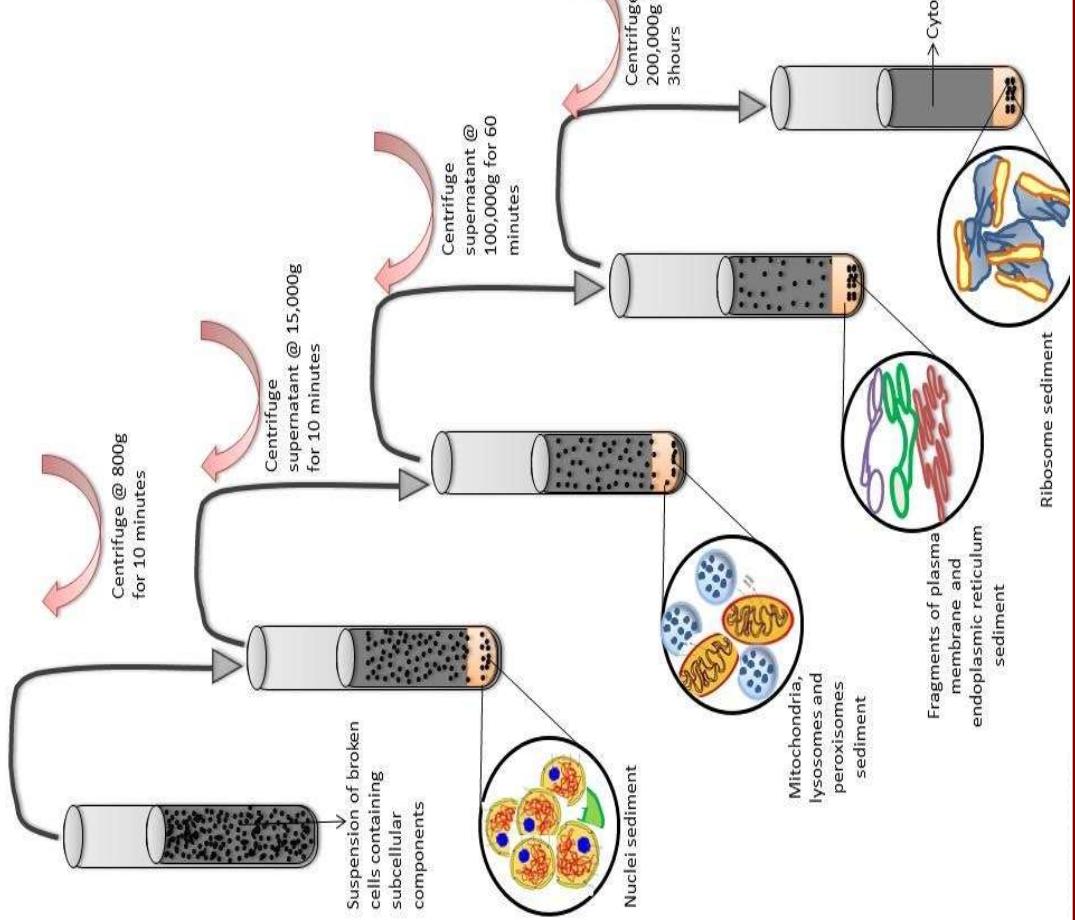
Studying Cells Using Microscopy



- All are variants of light microscopy except SEM & TEM
- Light microscopy allows imaging of a live cells; SEM/TEM: dead cells

How to break up cells into component parts?

- Take your favorite cells
- Break cells by physical shearing, chemical lysis
- Centrifugation: subject cell lysate to centrifugal forces that separate components based on density/size.
- Biochemical methods: determine the functions of each component
- Microscopy: visualize the components in each fraction

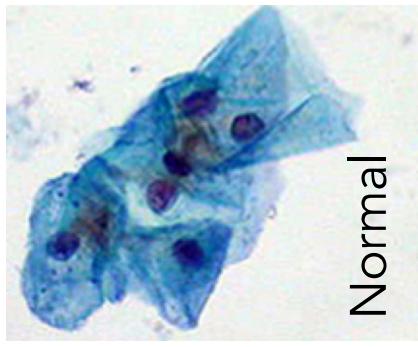


- Definition of life ✓
- Domains of life ✓
- Cell-unit of life ✓
- Cell-compartment ✓
- How do we study cells? ✓
- **Understanding cell structure**

Applications of understanding cell structure

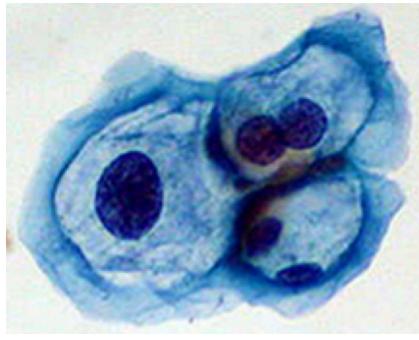
Knowledge of cells is useful in medicine

Uterine cervix cells



Normal

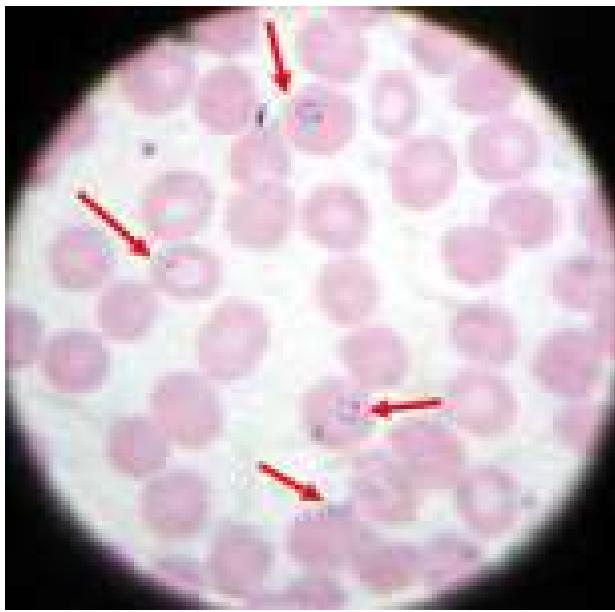
- Pap smear test is a non-invasive procedure used for early detection of cancer and viral infections
- Routine test... followed up by other sensitive tests, if warranted
- Cells from an affected individual are larger in size and may be multi-nucleated
- Image analysis is being tested to make this more accurate and efficient (Tata Centre for Technology Development)
 - Happiness & well-being (individual)
 - Lower healthcare burden (economy)



Infected with papilloma virus

Knowledge of cells is useful in medicine

- Diagnosis of malaria is by visualizing blood cells stained with a dye that turns DNA purple
- Microscopy is done in the hospital to detect malaria parasites in red blood cells so that treatment with anti-malarial drugs can start
- Image analysis is being tested to make the process more efficient and reliable (many labs @IITB)
- Happiness & well-being (individual)
- Lower healthcare burden (economy)



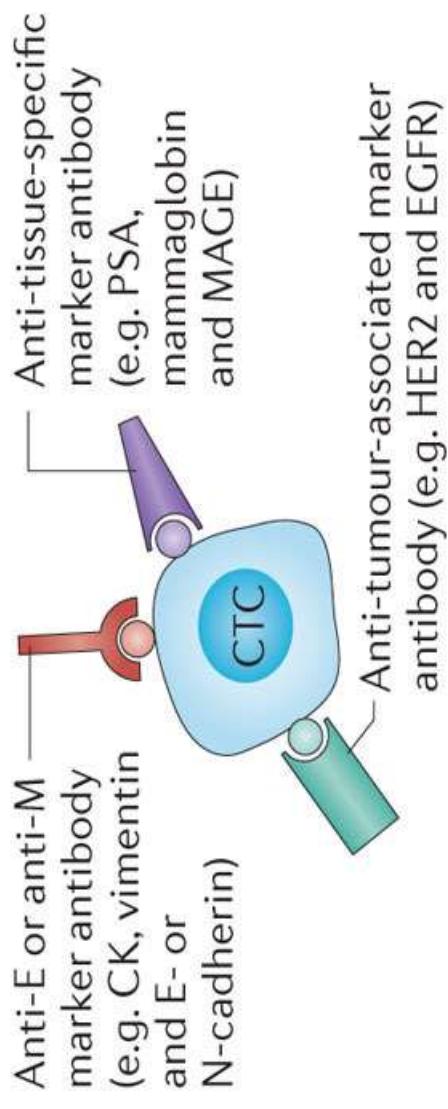
https://www.cdc.gov/malaria/diagnosis_treatment/diagnostic_tools.html

Food for thought:

Circulating Tumour Cell (CTC) Detection Technologies

US Food and Drug Administration (FDA)-cleared technology that allows a sensitive positive capture of CTCs by antibodies against epithelial cell adhesion molecule (EPCAM) coated with ferrofluid

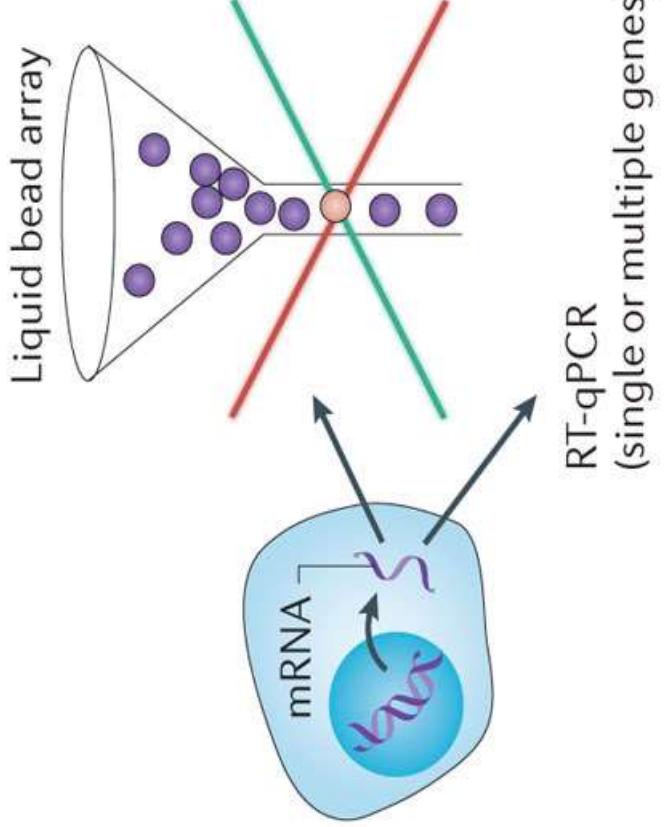
a Immunocytological technologies



Technologies

- Immunocytometry
- CellSearch® system
- Flow cytometry
- DEPArray®

b Molecular (RNA-based) technologies



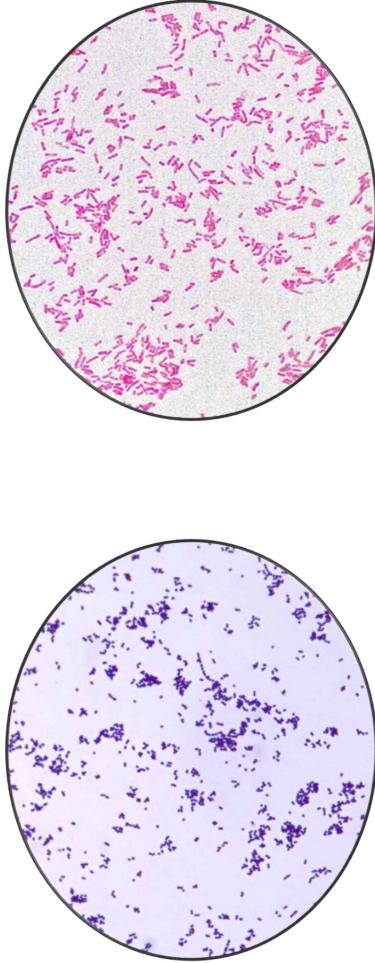
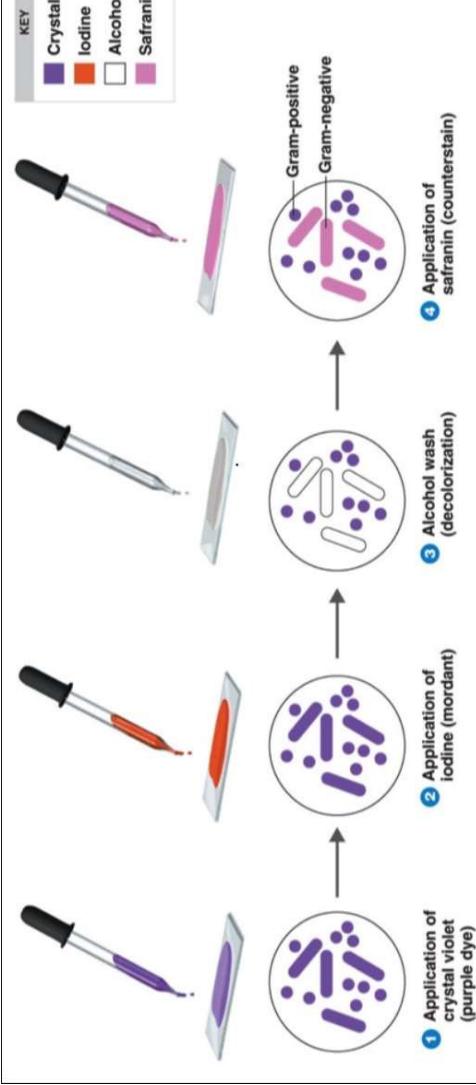
Summary

- Defined life as a complex and dynamic phenomenon.
- Discussed the major domains of life: Archaea, Bacteria, and Eukarya.
- Emphasized that living cell is more than the sum of its individual components.
- Explored the concept of a cell as the fundamental unit of life.
- Introduced various techniques used in cell biology and molecular biology.
- Highlighted how knowledge of cell structure contributes to advances in medicine, biotechnology, and other fields.
- *Food for Thought:* to stimulate critical thinking about the implications of cell biology in our daily lives.

Demonstration



Gram Staining of Bacteria



Step-1: Put the bacterial smear on the slide and heat fix it

Step-2: Add two drops of Gram's **crystal violet**, remove the excess stain with water

Step-3: Add few drops of Gram's **iodine** followed by washing

Step-4: Add few drops of decolorizer followed by washing

Step-5: Now, add drops of **Safranin** followed by washing

Step-6: Put the slide for air drying

Gram Negative (pink)
Escherichia coli

Gram Positive (Purple/ Violet)
Streptococcus Sp.

References

- Campbell Biology - Reece, Urry, Cain, Wasserman, Minorsky, Jackson 10th Edition, Pearson

- A New Biology for the 21st Century

http://www.nap.edu/catalog.php?record_id=12764

The cover features a large orange micrograph of a cell with internal structures like the nucleus and organelles. The number '6' is prominently displayed in the center. The title 'A Tour of the Cell' is at the top, and 'The Fundamental Units of Life' is below it. A small inset image shows a person in a lab coat looking at a microscope.

KEY CONCEPTS

- 6.1 Biogels use microscopes and the tools of biochemistry to study cells
- 6.2 Embryonic cells have different properties than adult cells because they have different functions
- 6.3 The embryonic cells' genetic instructions are housed in the nucleus and carried out by the ribosomes
- 6.4 The endomembrane system regulates protein traffic and controls cell-cell interactions in a cell
- 6.5 Mitochondria and chloroplasts change energy from one form to another
- 6.6 The cytoskeleton is a network of fibers that organize structures and move materials in the cell
- 6.7 Extracellular components and connections between cells help coordinate activities of the cell

Inquiring About Life

The dandelion shown in Figure 6.1 uses their seeds held for dispersal. A seed is an embryo surrounded by a layer of food and protective coat. The dandelion seeds, shown at the lower left, are brown, as we buy purchased-like structure made from middle flower parts. The structure turns to wind, which carries seeds to new locations where conditions may prove spreading conditions. Seeds travel in the wind, and are transported by animals worldwide.

An organism's adaptation to its environment, such as the dandelion seeds' parachute, are the result of evolution. Evolution is a process of change that has transformed life on Earth from its earliest beginning to the diversity of organisms living today. Because evolution is the fundamental organizing principle of biology, it is the core concept of this book. Although biology is a general field of life, many particular research questions lead to the origin of living among plants such as the ones pictured above. Posing questions to the central activities of biology, the scientific study of life, is a logical question on its own. In addition, there may be a single tiny cell somewhere in a tree or a dog; how the human mind works, or how the different plant and animal cells in our body work together to keep us healthy.

A Figure 6.1 How is the dandelion adapted to its environment?

The cover features a large orange micrograph of a cell with internal structures like the nucleus and organelles. The number '6' is prominently displayed in the center. The title 'A Tour of the Cell' is at the top, and 'The Fundamental Units of Life' is below it. A small inset image shows a person in a lab coat looking at a microscope.

Figure 6.1 How do your cells help you learn about biology?

Cells are fundamental to the living systems of biology as the atoms in them are worked for you right now. The contrast of many different types of cells are shown in this sentence. Figure 6.1 shows extensions from a nerve cell (orange) making contact with muscle cells (red). The words on the page are translated into signals that nerve cells carry to your brain, where they are passed on to other nerve cells. As you study, you are reading all concepts like this one, and your brain is translating the paper signals into action. All of the simple collection of matter that can also be called living forms of life, eat at single-celled organisms. Larger more complex organisms, including plants and animals, that bodies are cooperative as family units of specialized cells that could not survive for long on their own. Even when cells are arranged into higher level organizations such as tissues and organs, the cell remains the basic unit of life. During the long evolution of an organism, an entire cell can be replaced by another from another source. Cells are used in many different ways. In that chapter, I'll first examine the tools and techniques that allow us to understand cells, then how the cell and become acquainted with its components.