Lecture – 2

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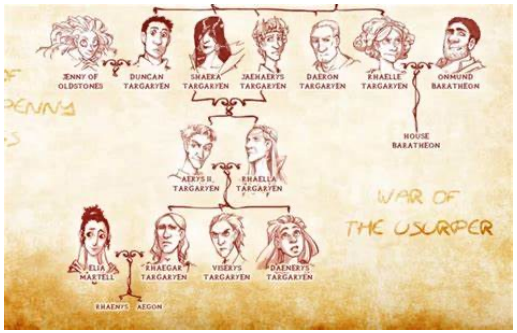
Domains, kingdoms and cells



Game of Thrones: Targaryen family tree

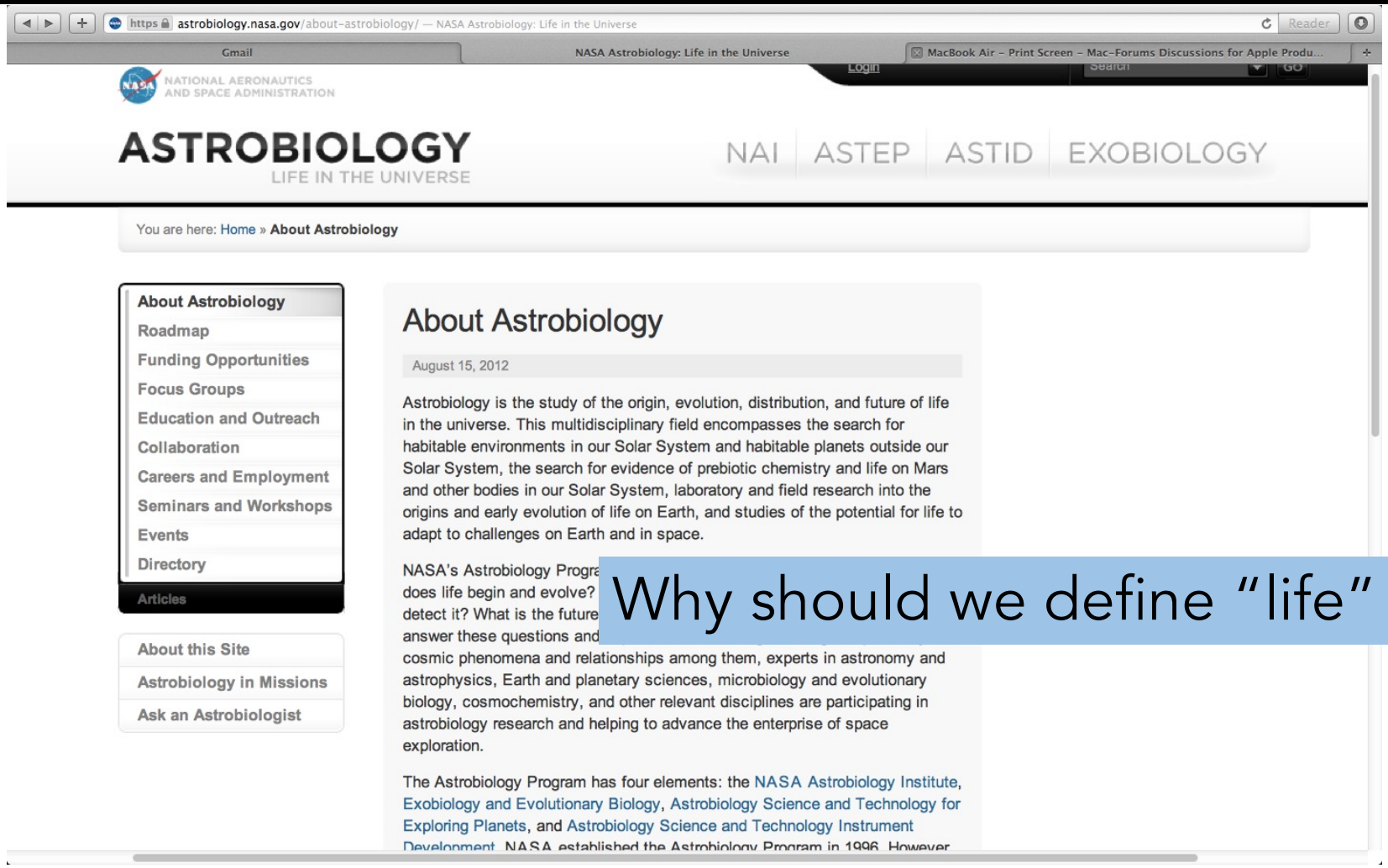
Game of Thrones: The Iron Throne

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?



Why should we define "life" at all?

Biology is the study of life

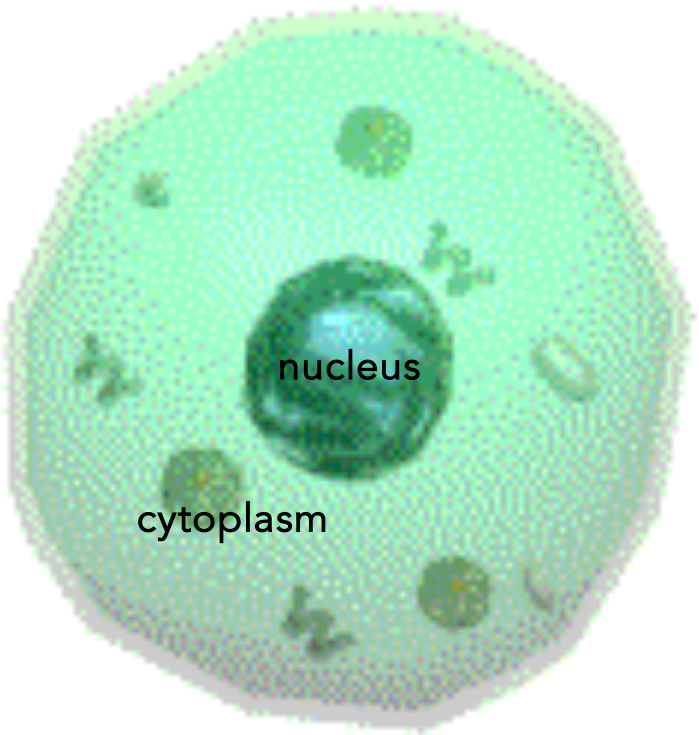
The phenomenon we call life: defies a simple, one-sentence definition

> 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*

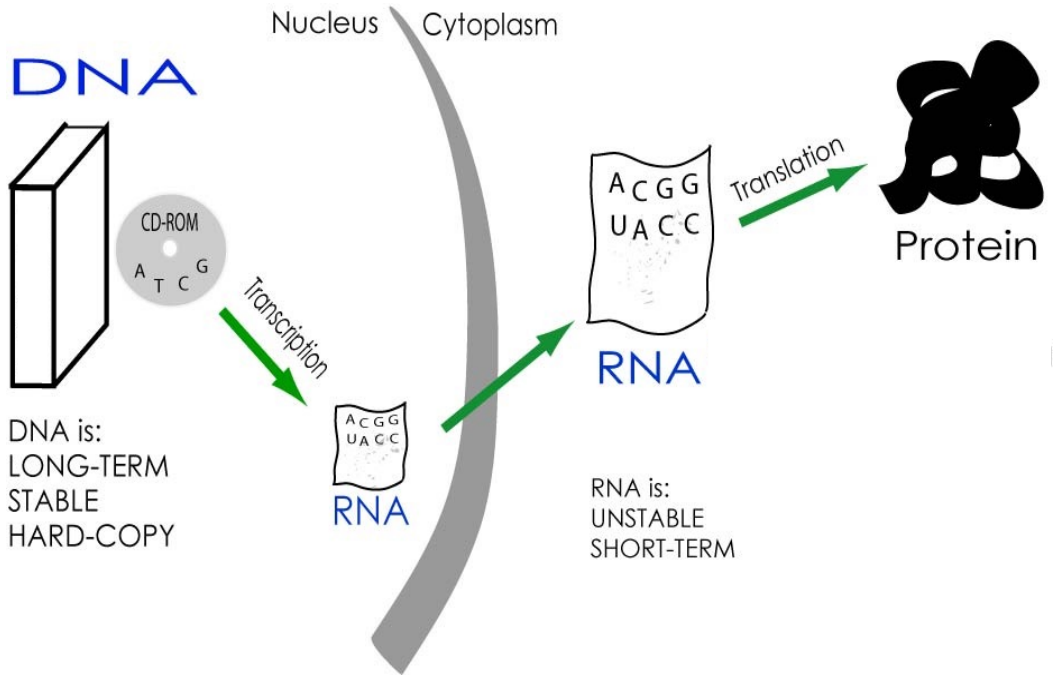
Perhaps, the key words in the definition are "originating internally".

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

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



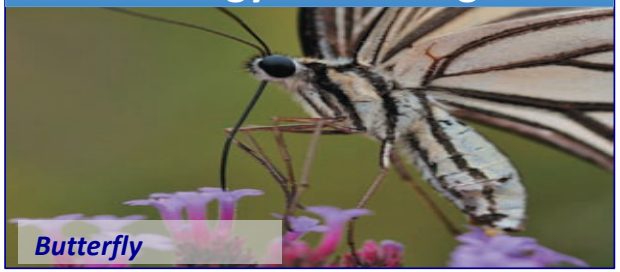
Schematic of a cell



The Central Dogma

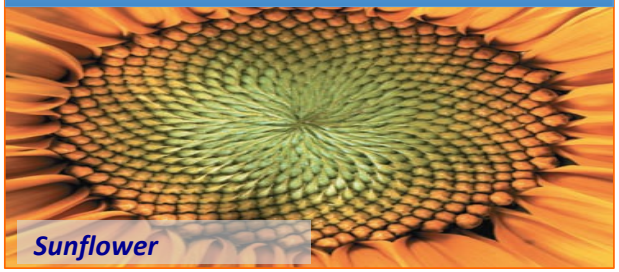
Some basic characteristics of life

Energy Processing



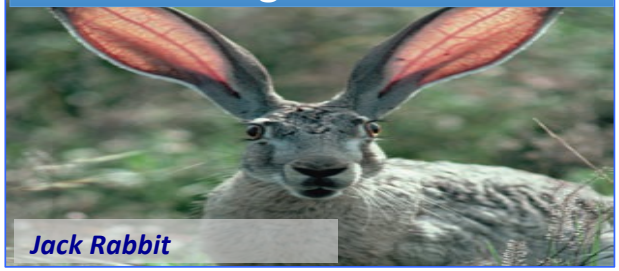
Butterfly

Order



Sunflower

Regulation

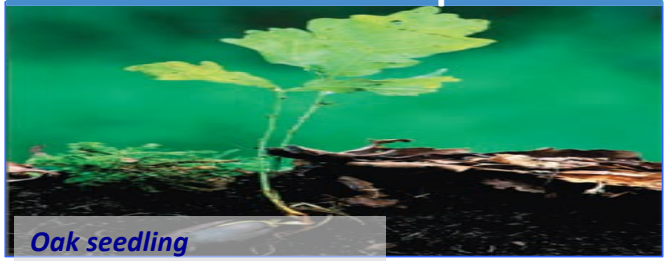


Jack Rabbit

Evolutionary adaption

Pygmy Sea Horse

Growth & Development

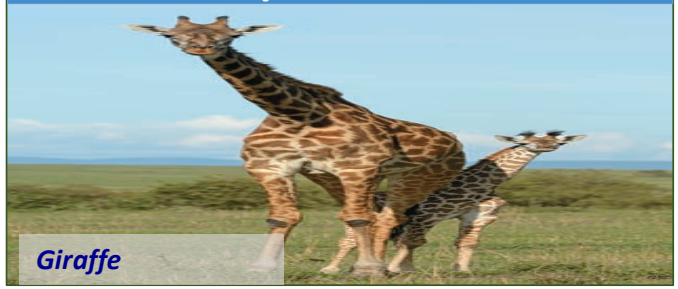


Oak seedling

Response to Environment

Venus flytrap

Reproduction

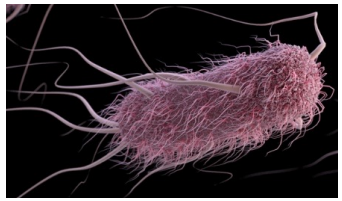


Giraffe

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)

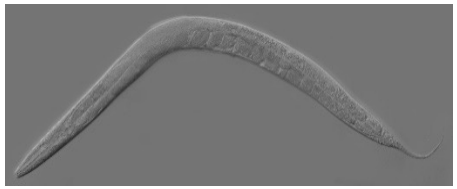


Escherichia coli
www.cdc.gov

Some strains inhabit our gut
Some strains are pathogenic

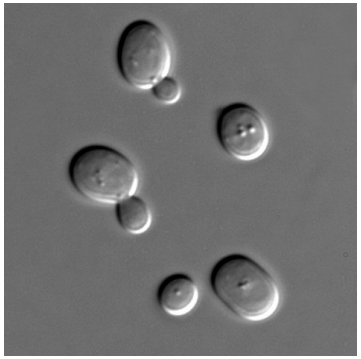
Zebra fish (*Danio rerio*)
wikipedia

Tropical fresh water fish



Caenorhabditis elegans
A free living round worm
wikipedia

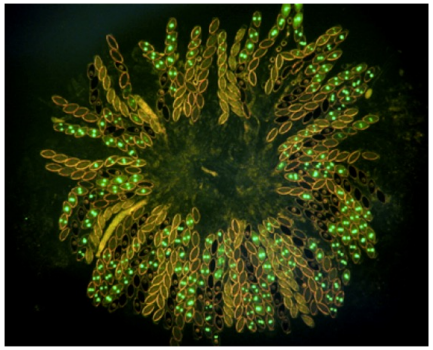
Arabidopsis thaliana
A weed (www.esa.int)



Saccharomyces cerevisiae
Baker's yeast, wikipedia

Drosophila melanogaster
Fruit fly, wikipedia

Xenopus laevis
African clawed frog, wikipedia



Neurospora crassa
Bread mold (fungus)

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

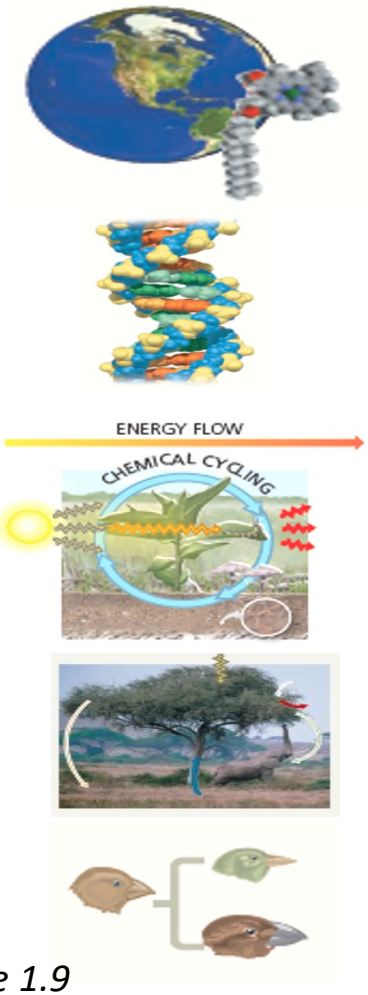
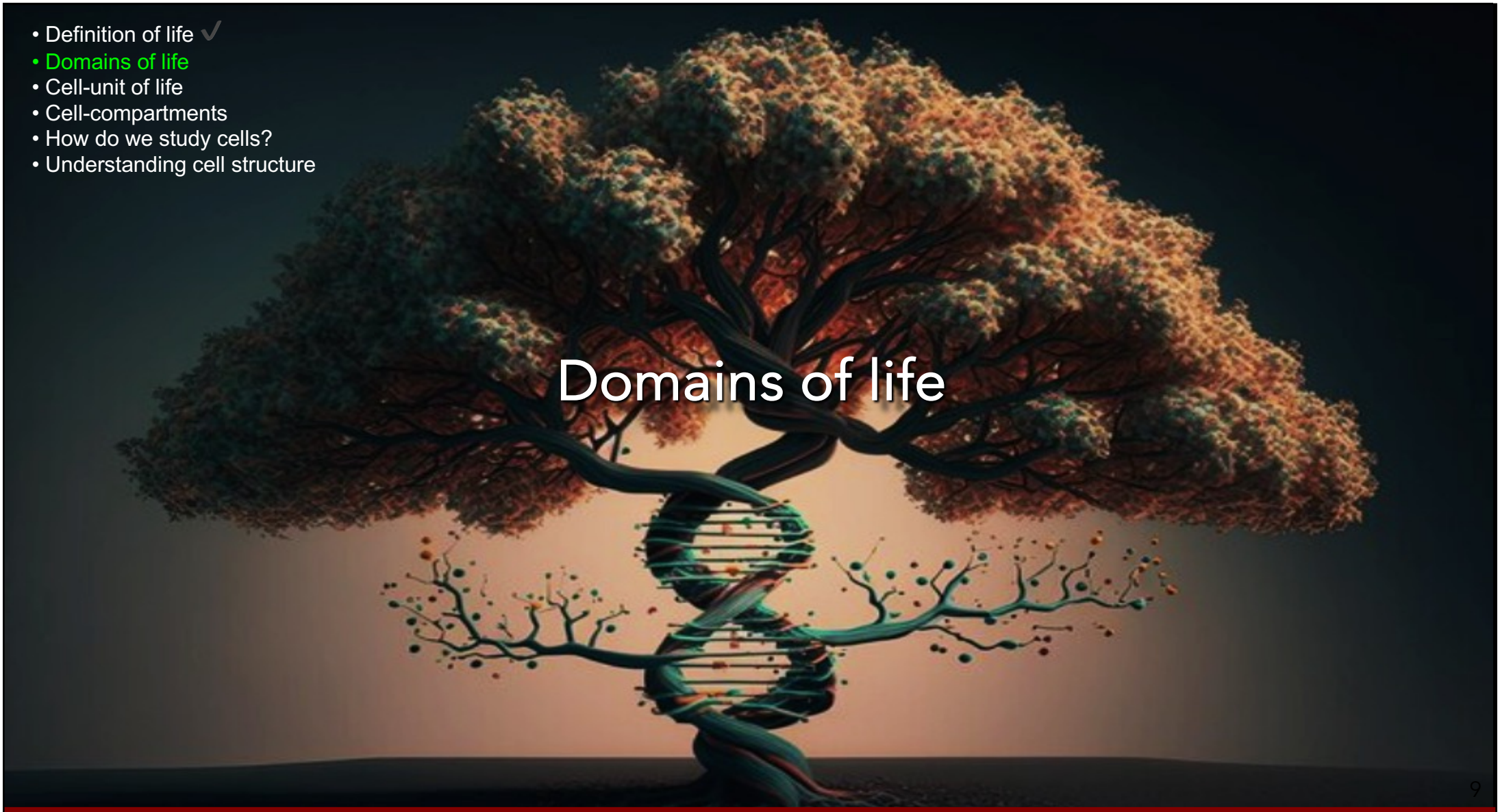


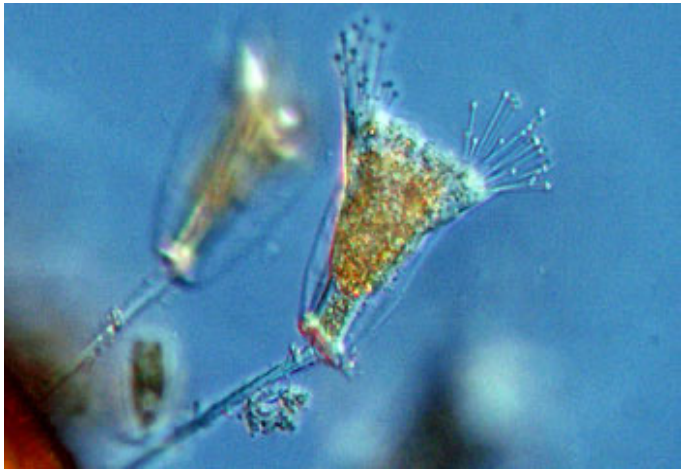
Figure 1.9

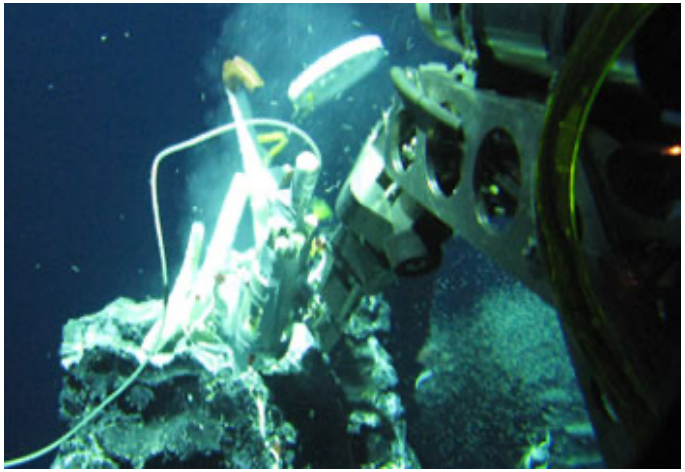
- Definition of life ✓
- Domains of life
- Cell-unit of life
- Cell-compartments
- How do we study cells?
- Understanding cell structure



Domains of life

A hallmark of life: diversity

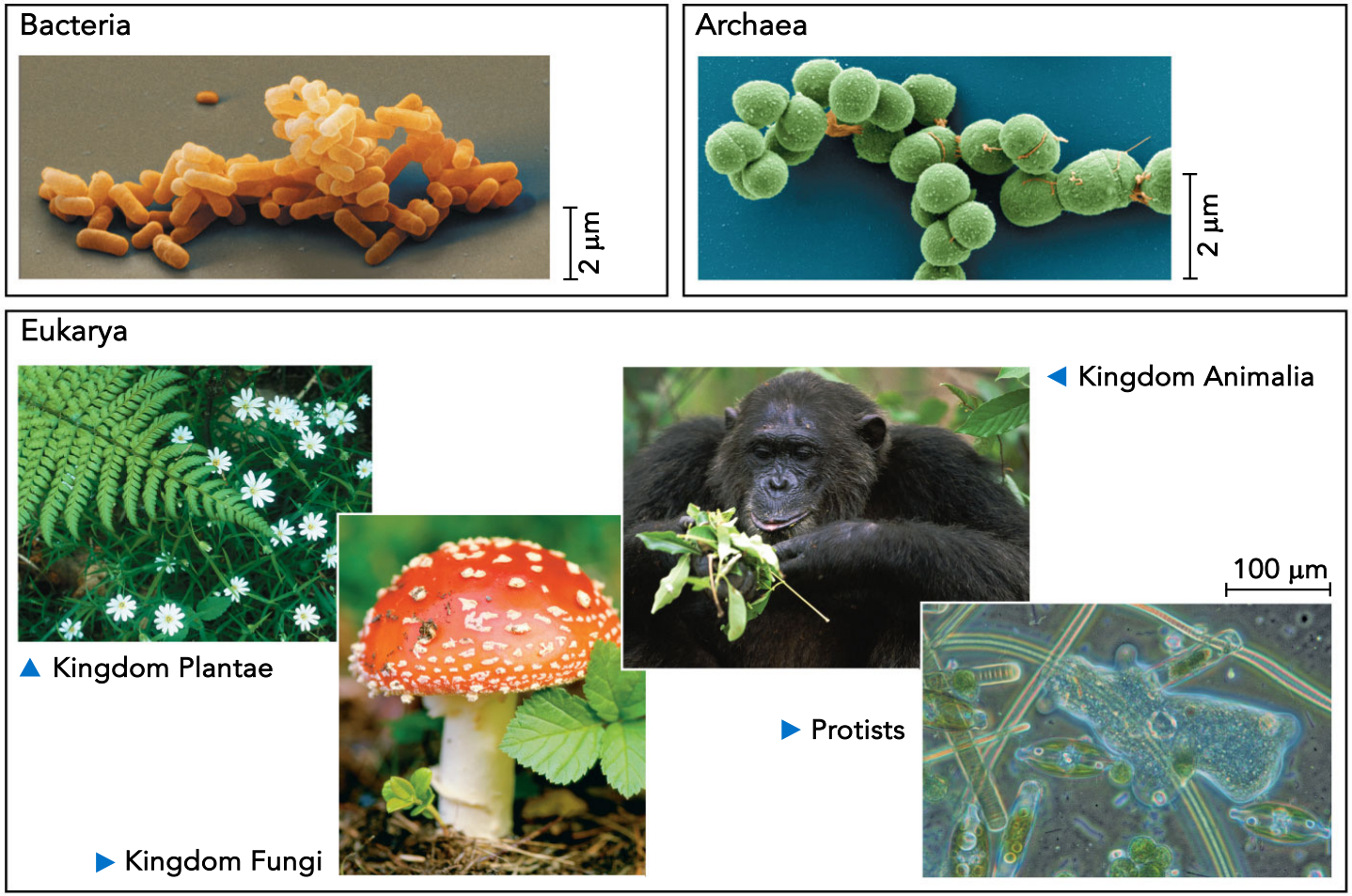




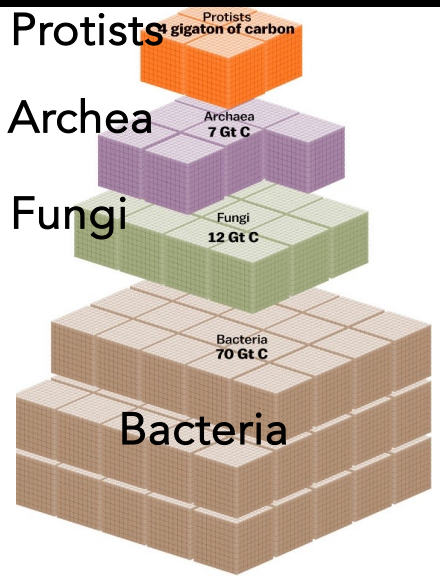
In order to make sense of the diversity of life: classification into three domains

Prokaryotes

Eukaryotes



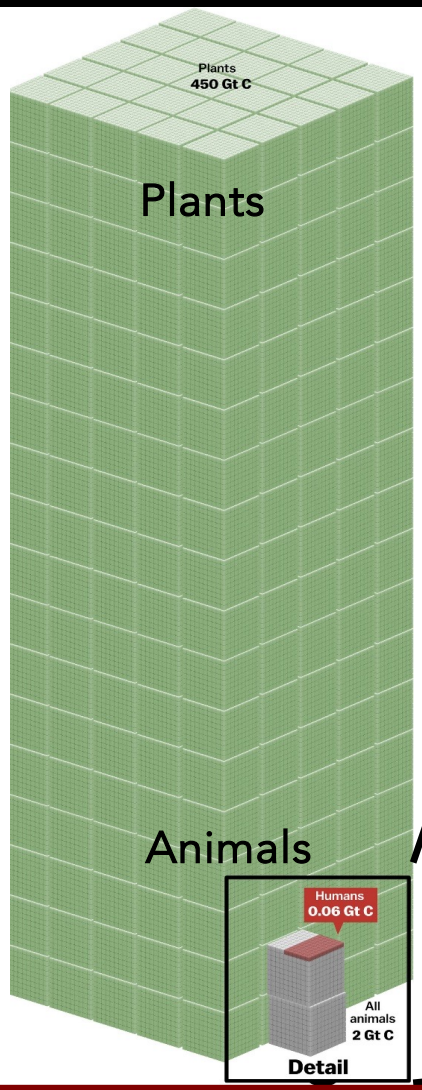
Diversity and biomass



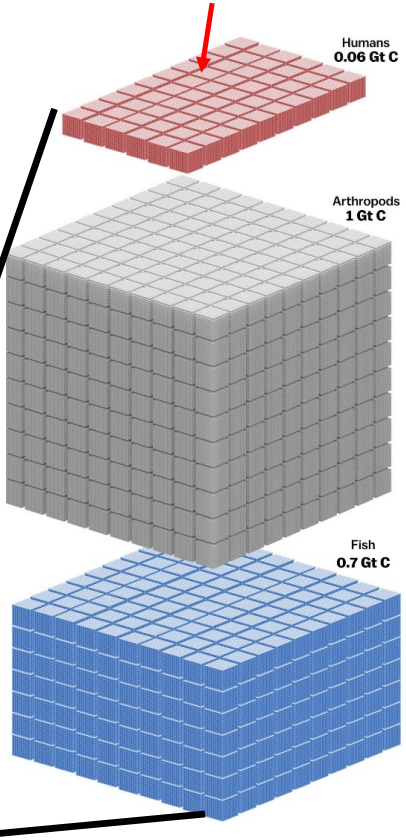
A brief digression

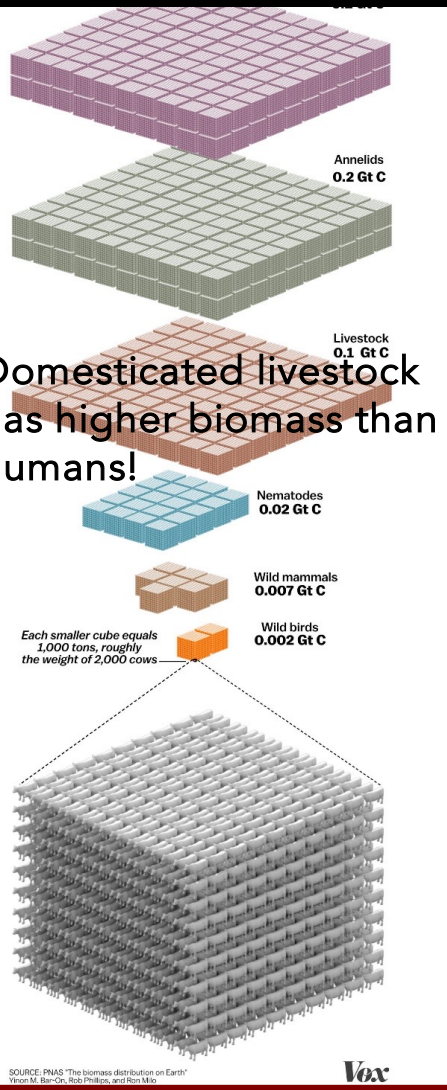
Scientists estimate the giga-tons of carbon from different kingdoms

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)





Domesticated livestock has higher biomass than humans!

A tangled web of life

- Diverse organisms divided into three fundamental groups
  - Bacteria (Eubacteria), Archaea (Archaebacteria) & 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

Horizontal gene transfer was common in early history of life

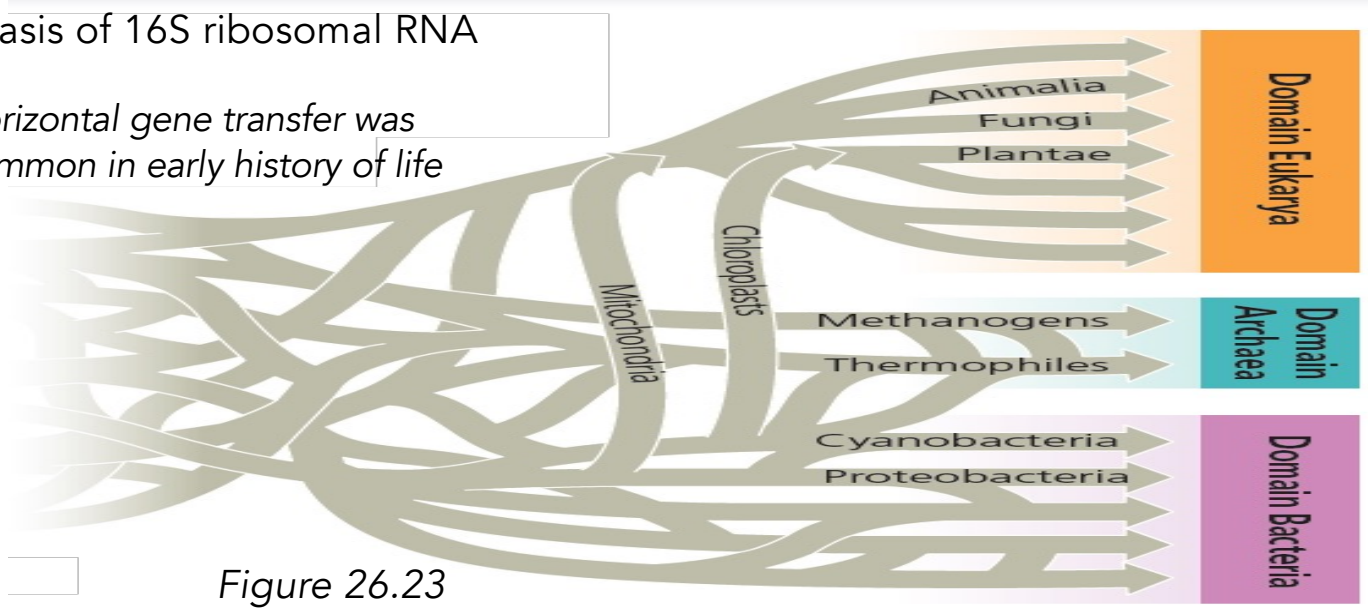


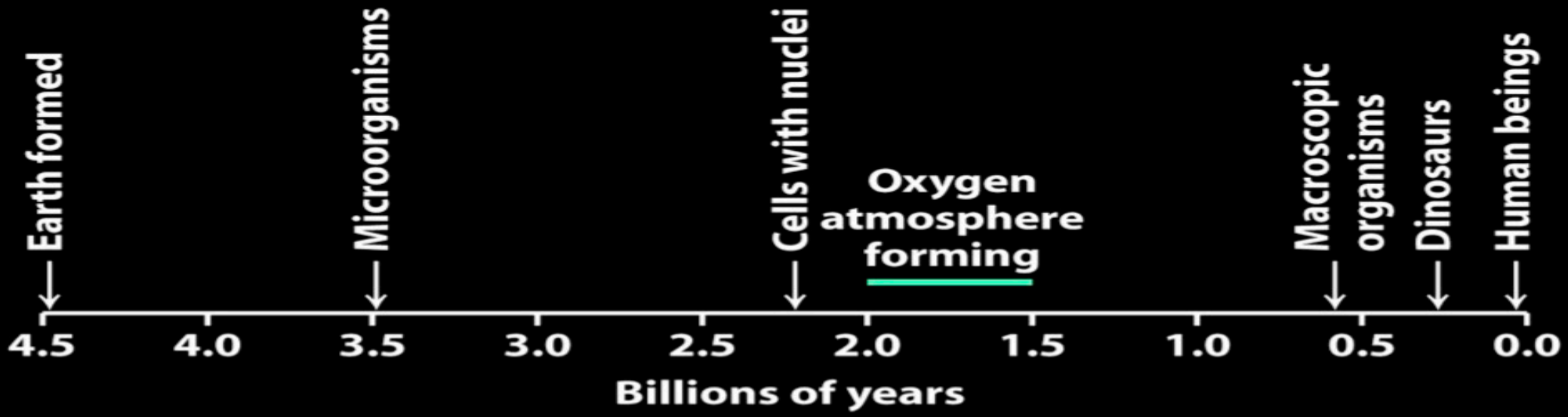
Figure 26.23

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

Cells as the smallest units of life

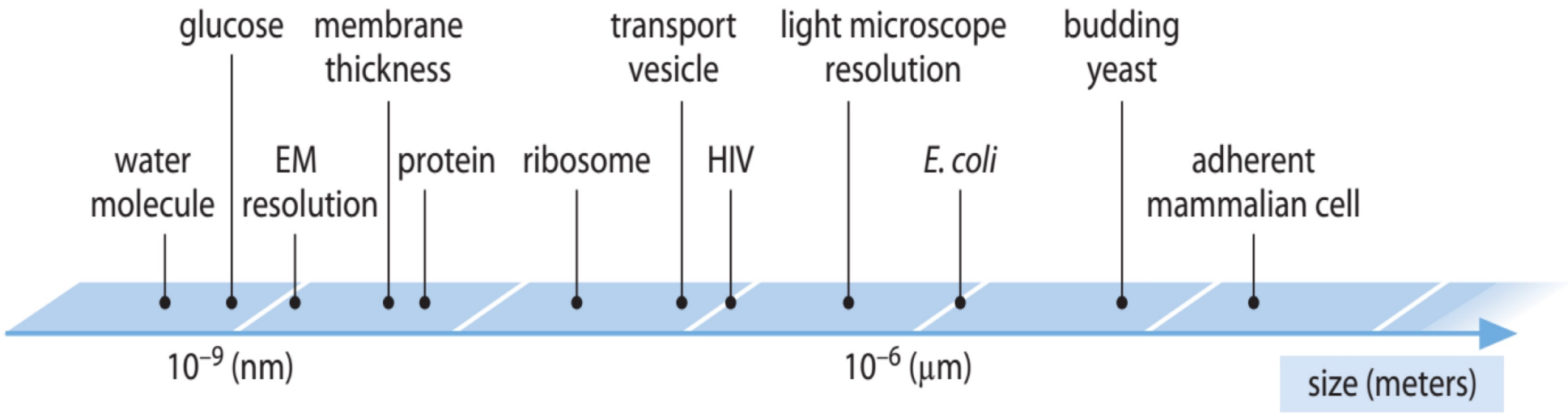
Cell and its Properties

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?

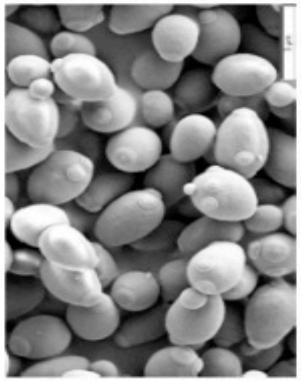
The diameter of a cell from:
Prokaryotes: 0.1 to 5 mm
Archea: 0.1 to 0.2 mm
Eukaryotes: 10 to 100 mm

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)

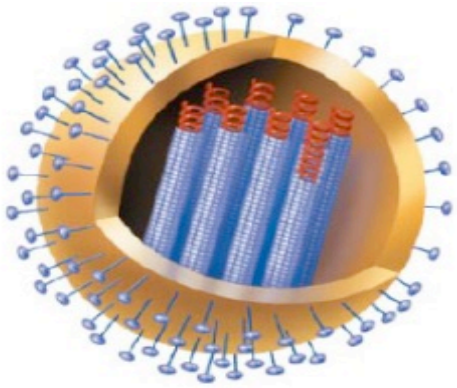


Yeast

(uni-cellular)

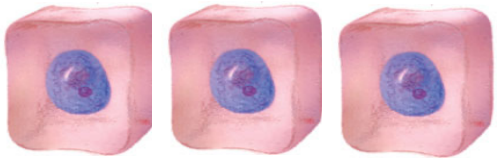
E. coli

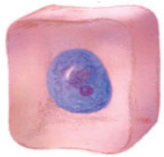
(uni-cellular)



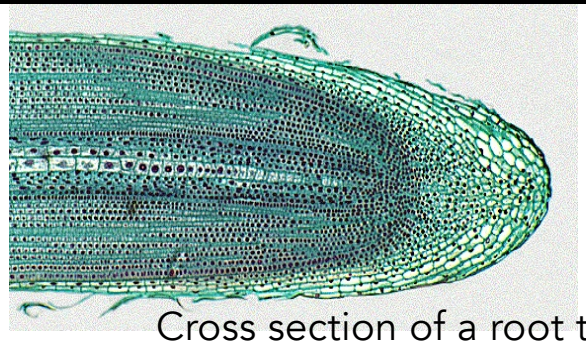
Influenza virus

(alive?)

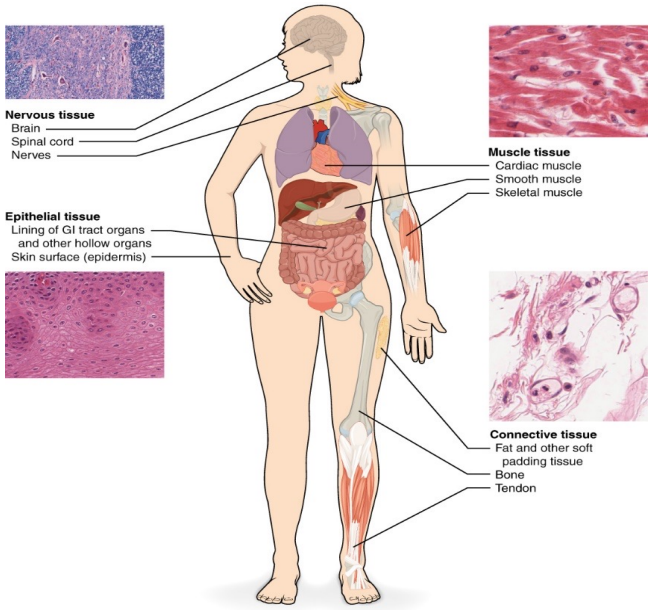




Why bother with multi-cellularity? Why not one large cell?

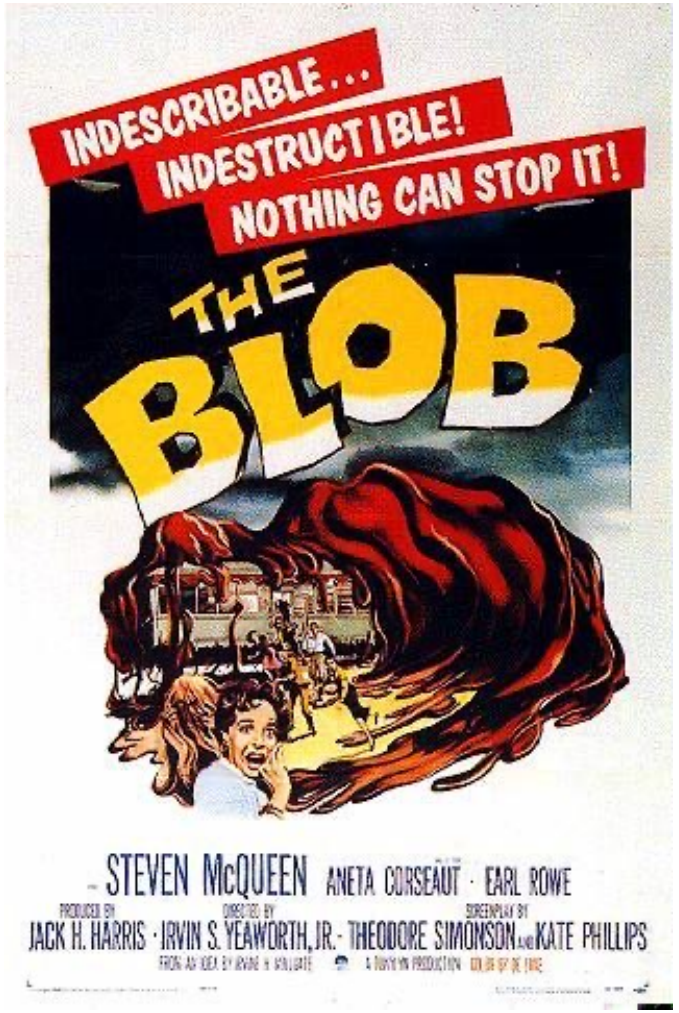


Cross section of a root tip

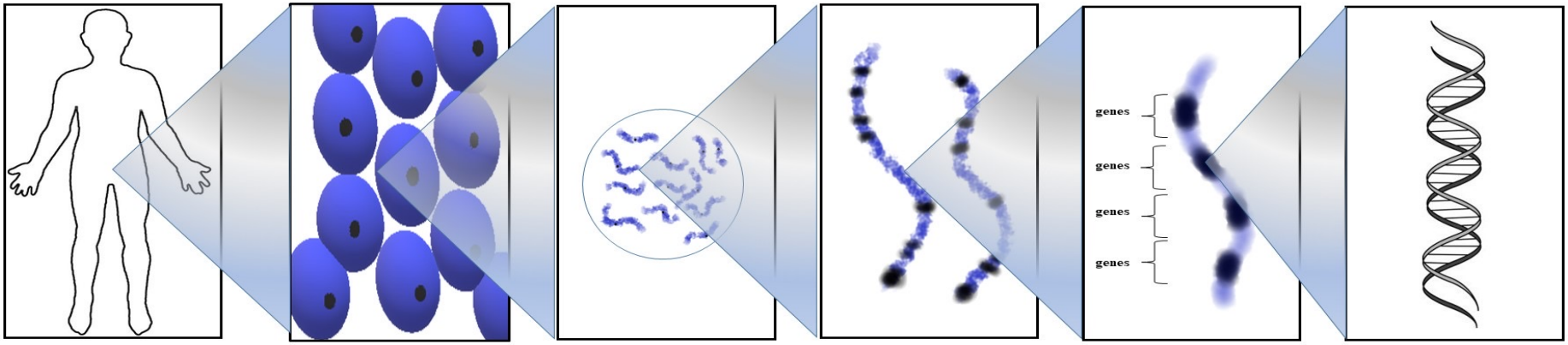


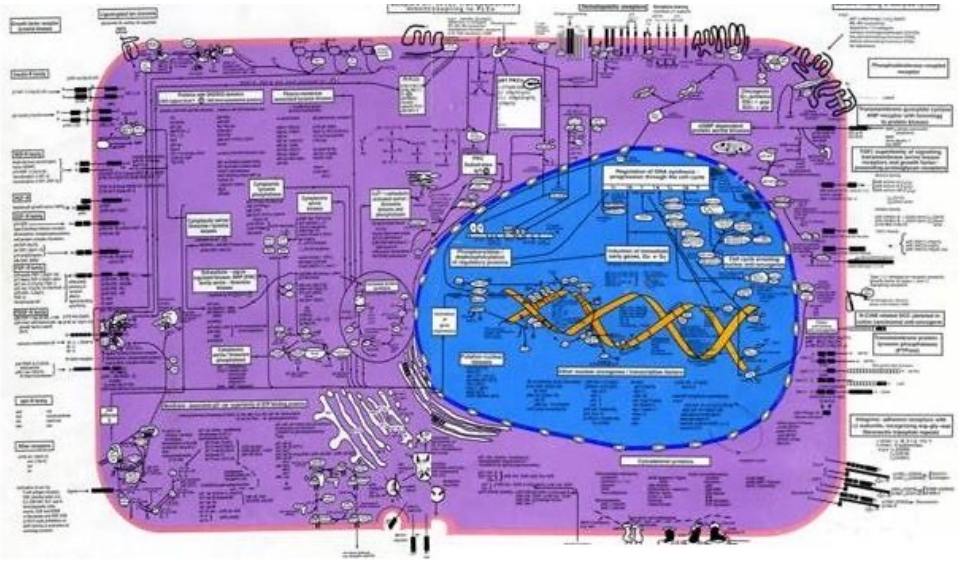
Human body consisting of organs, tissues and cells

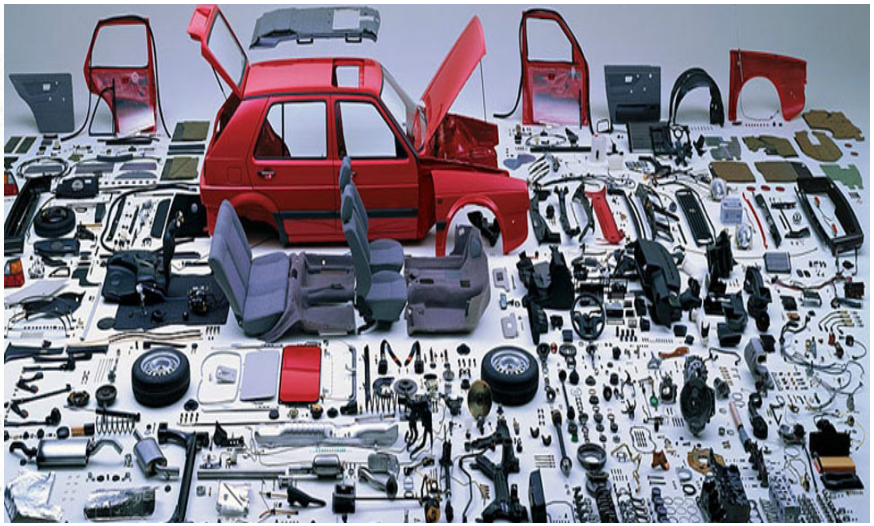
VERSUS



Basics: An Overview of Cell

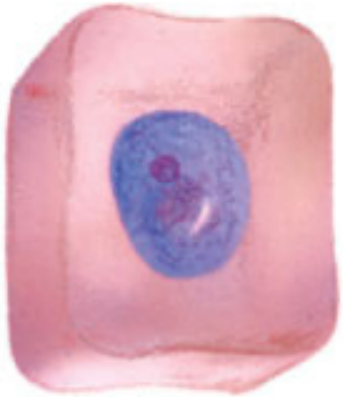






Natural laws limit cell size

- 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



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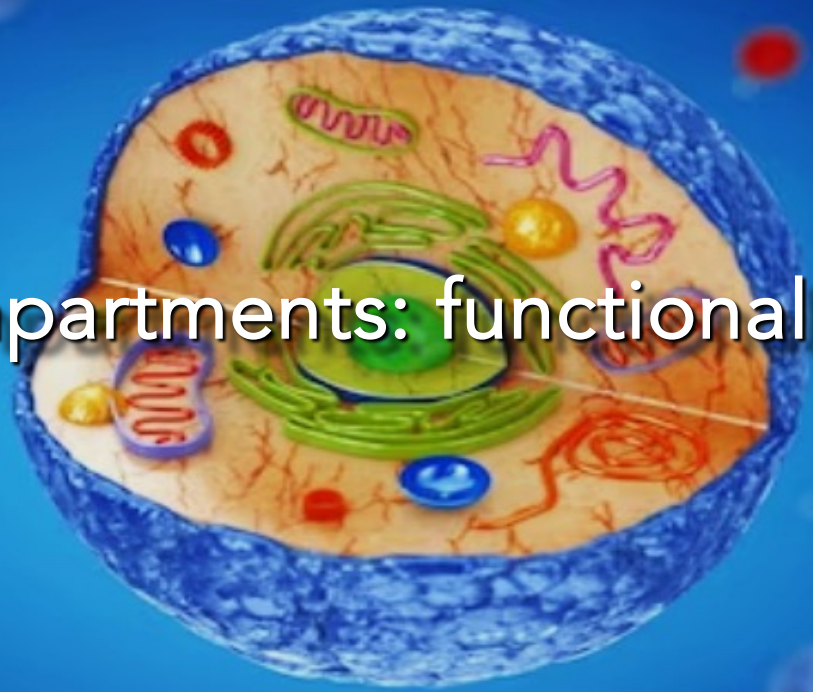
Cell compartments: functionalization



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

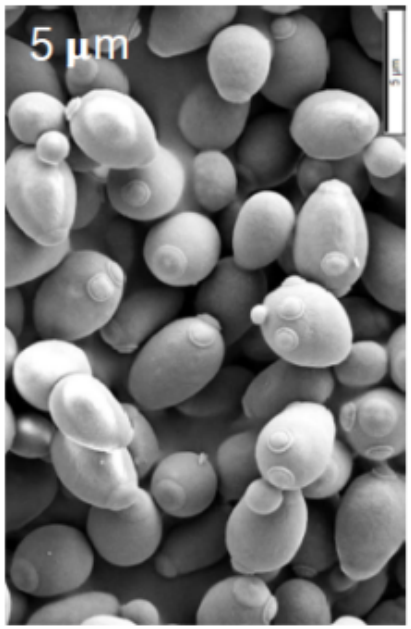
Classification of organisms: prokaryotes & eukaryotes (before nucleus & good nucleus)

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

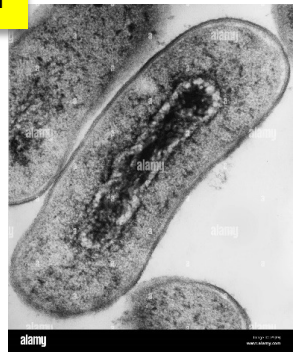
No nucleus, DNA is a nucleoid

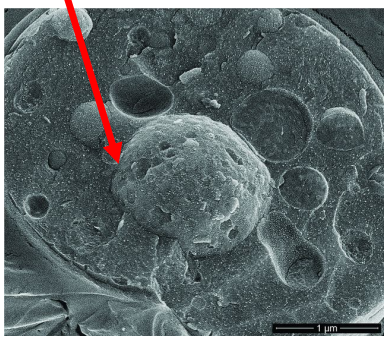
Nucleus

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



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





Electron micrograph of a section through a yeast cell

There are two successful cellular plans of organization

- Eukaryotes

(true nucleus, that contains DNA)

- cell plan of multi-cellular organisms

- Prokaryotes and Archea

(before nucleus, DNA in the form of a nucleoid)

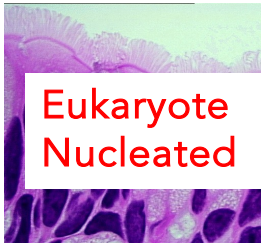
- primitive, simple, versatile, ubiquitous, unicellular life form
- a most successful life form
- 2,500 different species known

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

Common soil bacteria
Pseudomonas aeruginosa

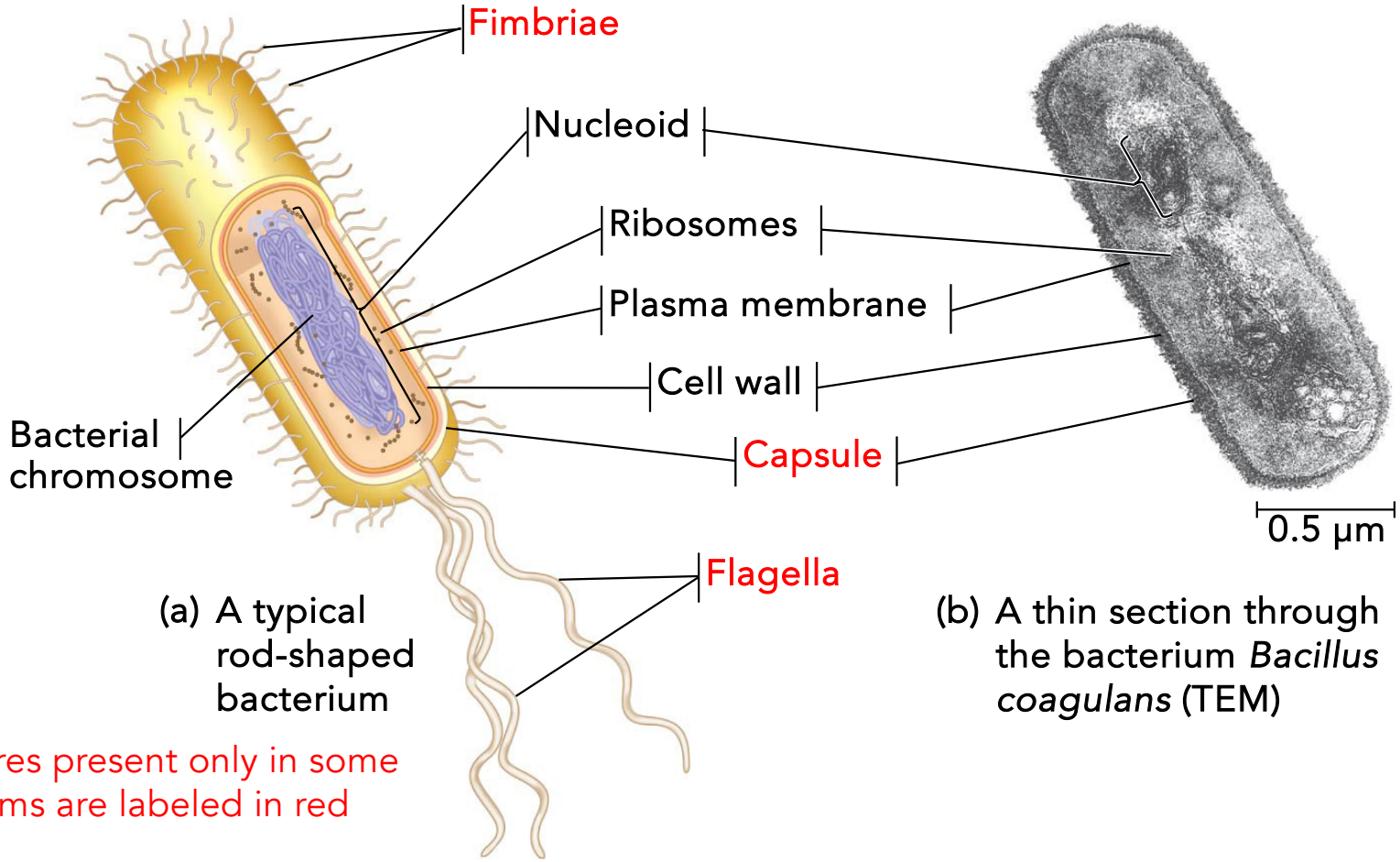
Human red blood cells

Monkey heart muscle



Amphibian
esophagus cells

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



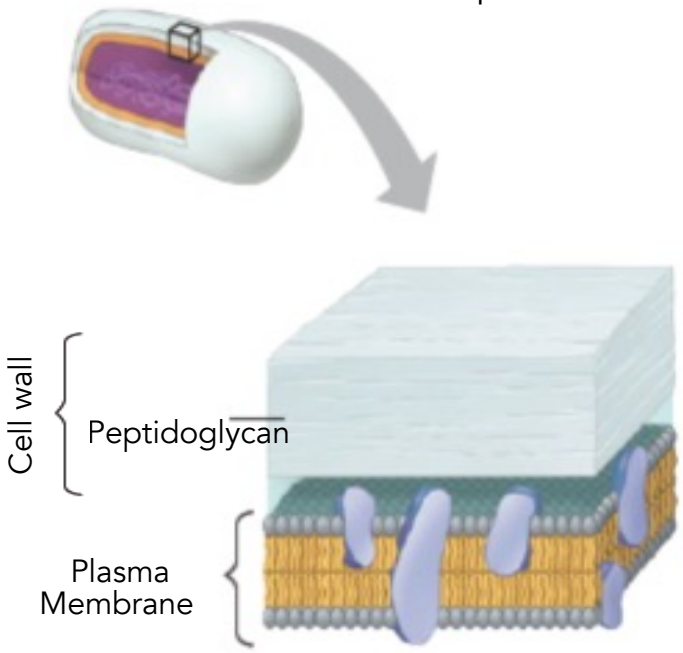
(a) A typical rod-shaped bacterium

(b) A thin section through the bacterium *Bacillus coagulans* (TEM)

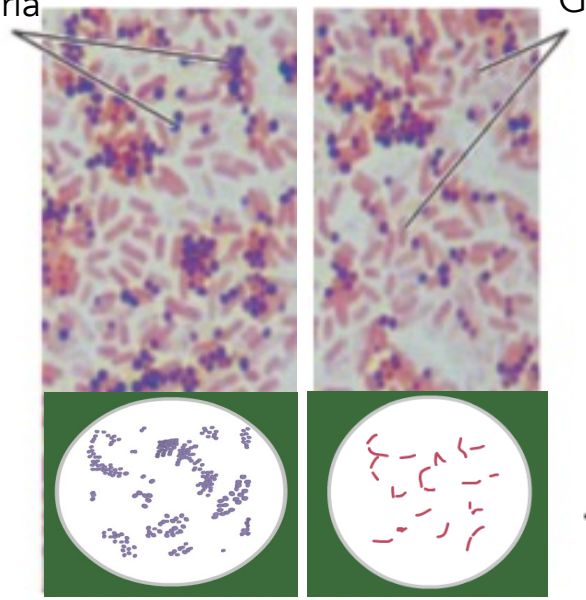
Structures present only in some organisms are labeled in red

Structure of Bacterium: Cell Wall & Staining

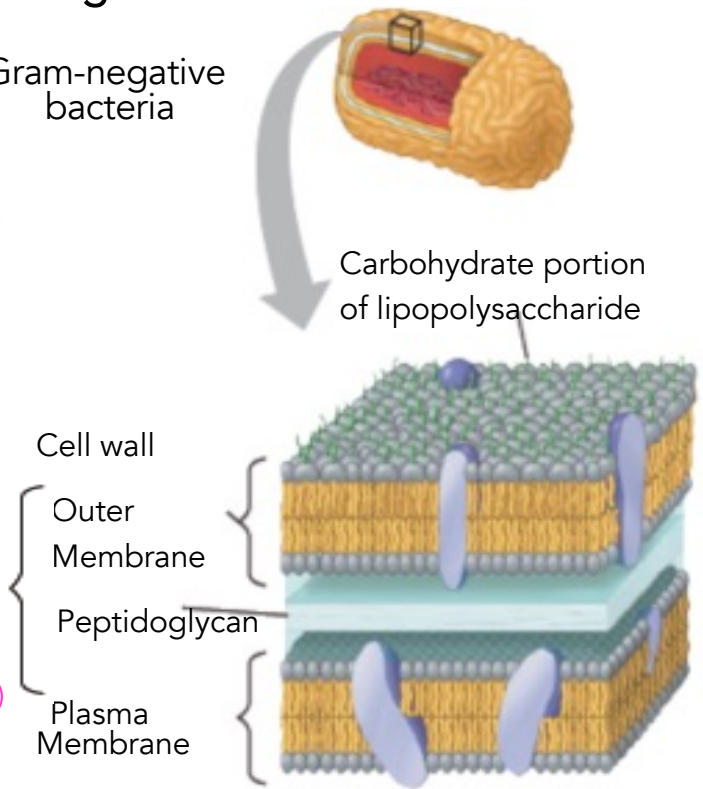
Gram-positive bacteria



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



Gram-negative bacteria

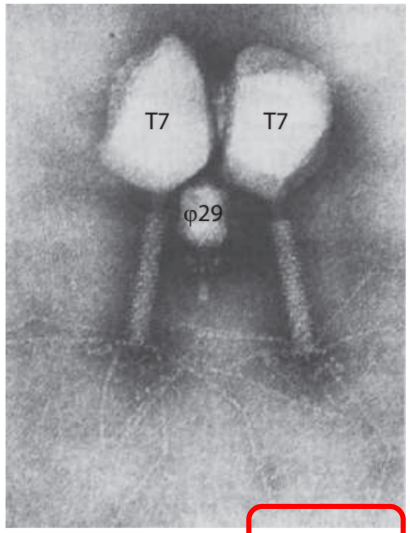


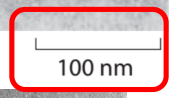
Thin layer of peptidoglycan; Crystal violet easily rinsed from cytoplasm, **Safranin** stains gram-ve & cell appears pink

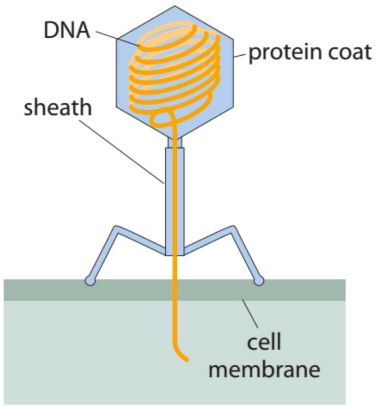
Figure 27.3

Classification of organisms: viruses (completely different)

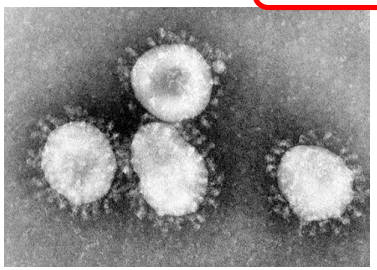
Small viruses





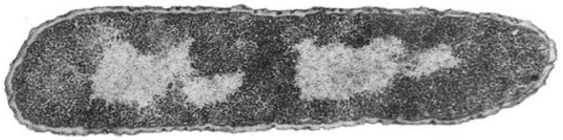


This is one of the smaller viruses
Sizes of viruses vary greatly
Some viruses are larger than bacteria



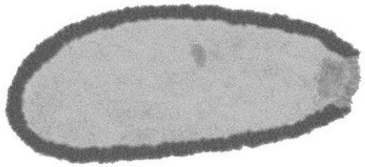
SARS-CoV2

Giant viruses



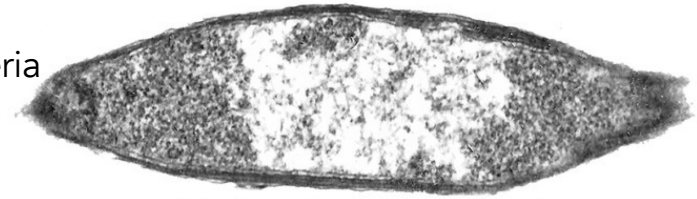
Escherichia coli

HIV

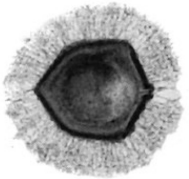


Pithovirus sibericum

Megaklothovirus horridgei



Klothovirus casanovai

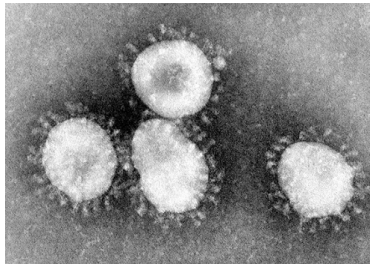


Mimivirus

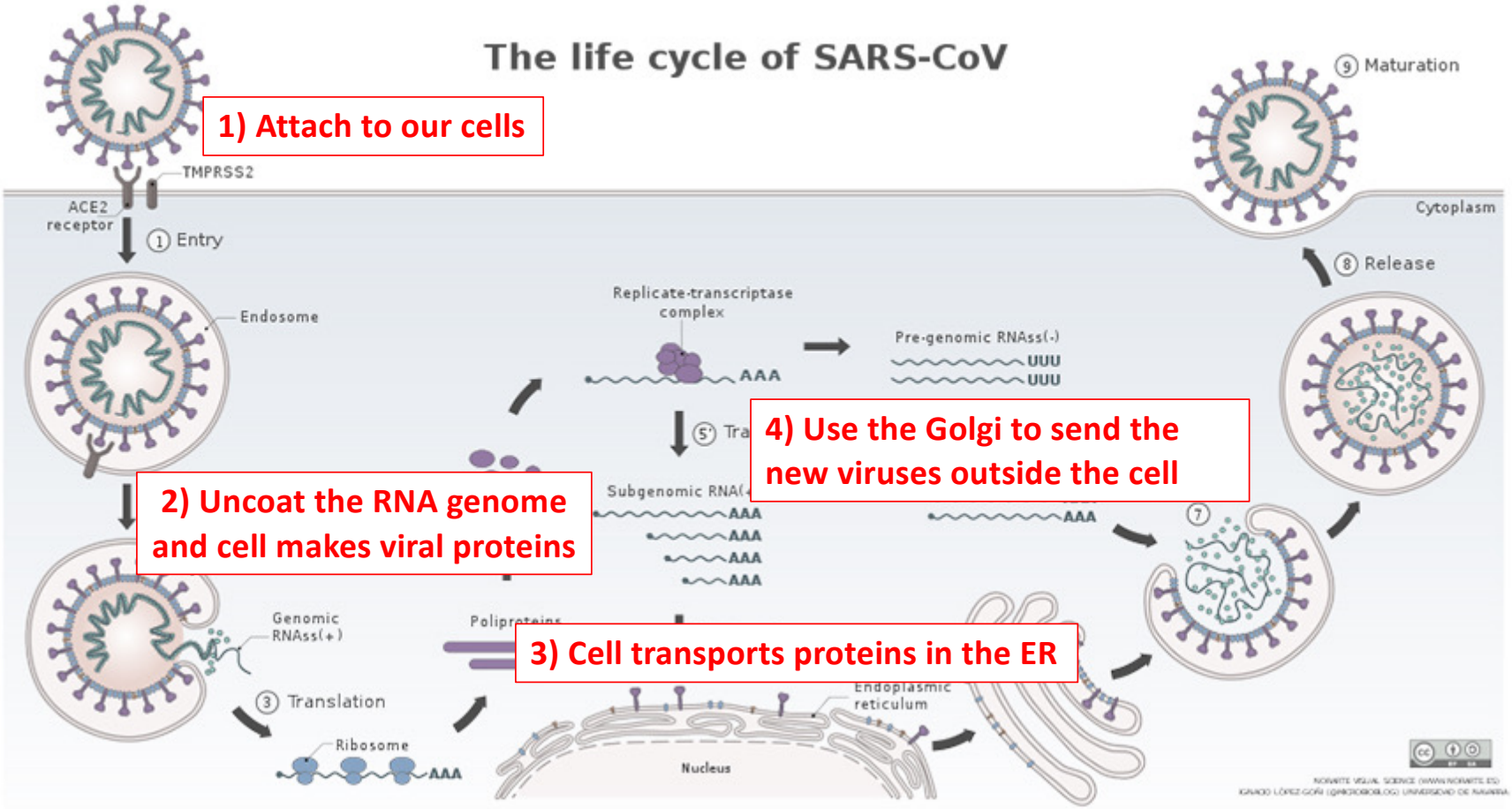
https://en.wikipedia.org/wiki/Giant_virus

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

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

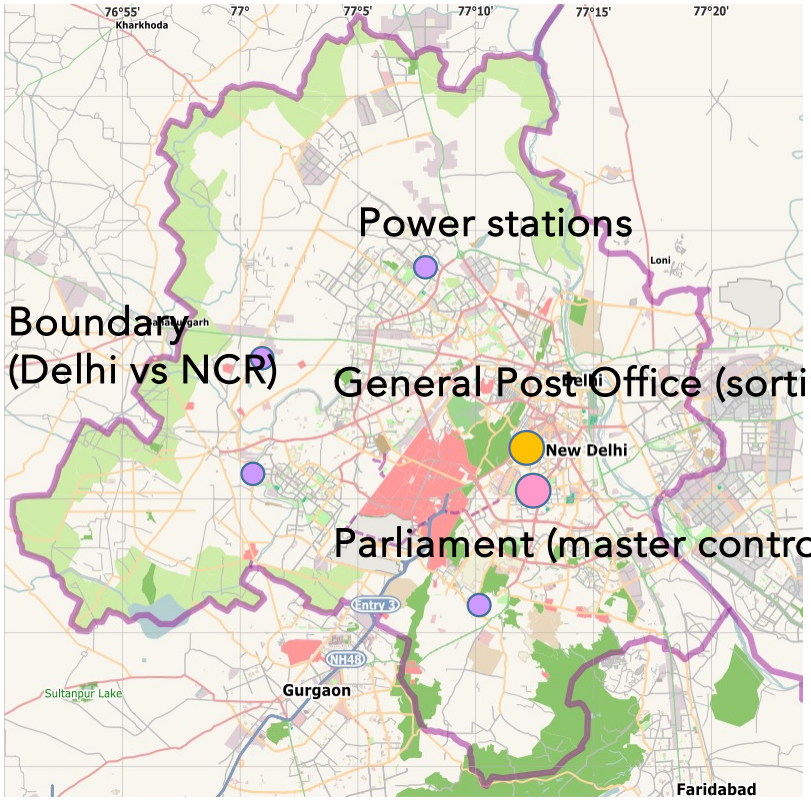


SARS-CoV2

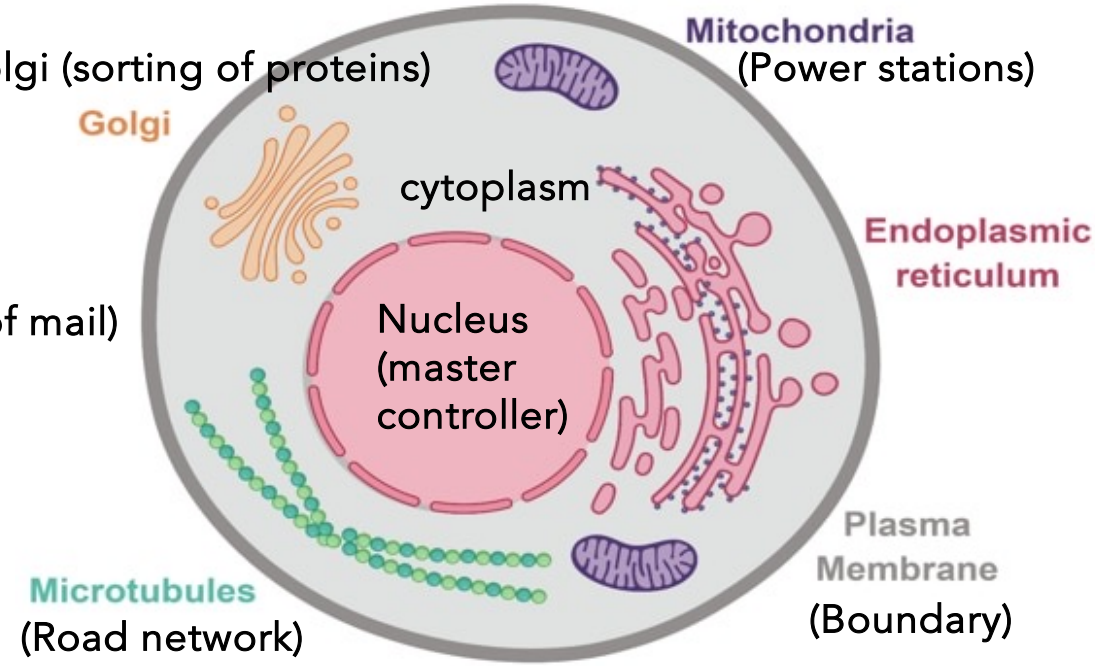


What are the compartments in eukaryotic cells? Analogy between a city and a cell

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

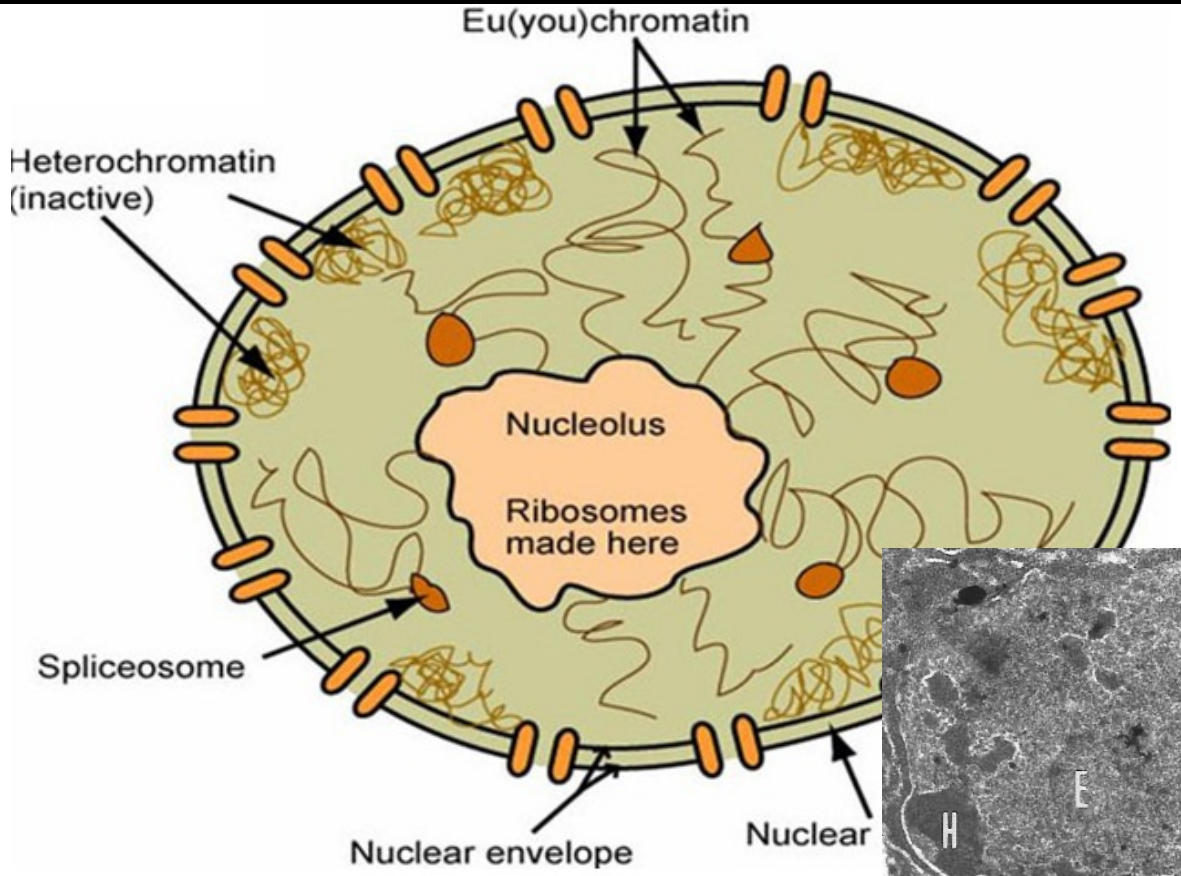


Map of New Delhi



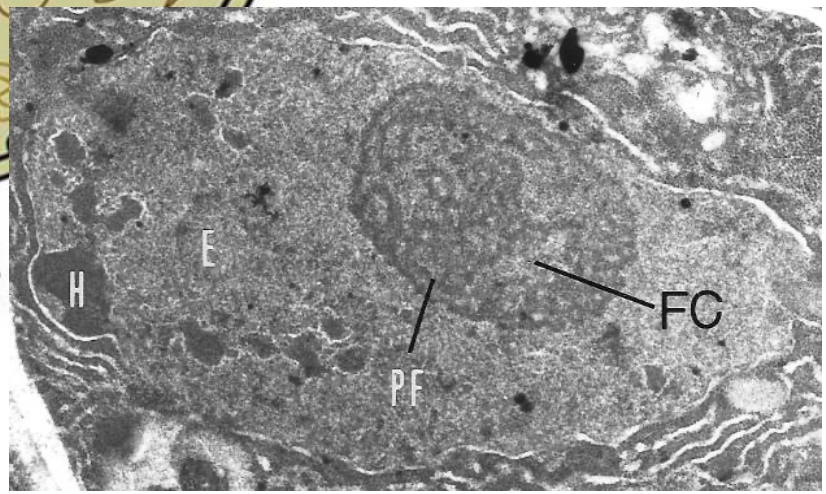
Schematic of a cell

Compartmentalization and function: The nucleus contains DNA

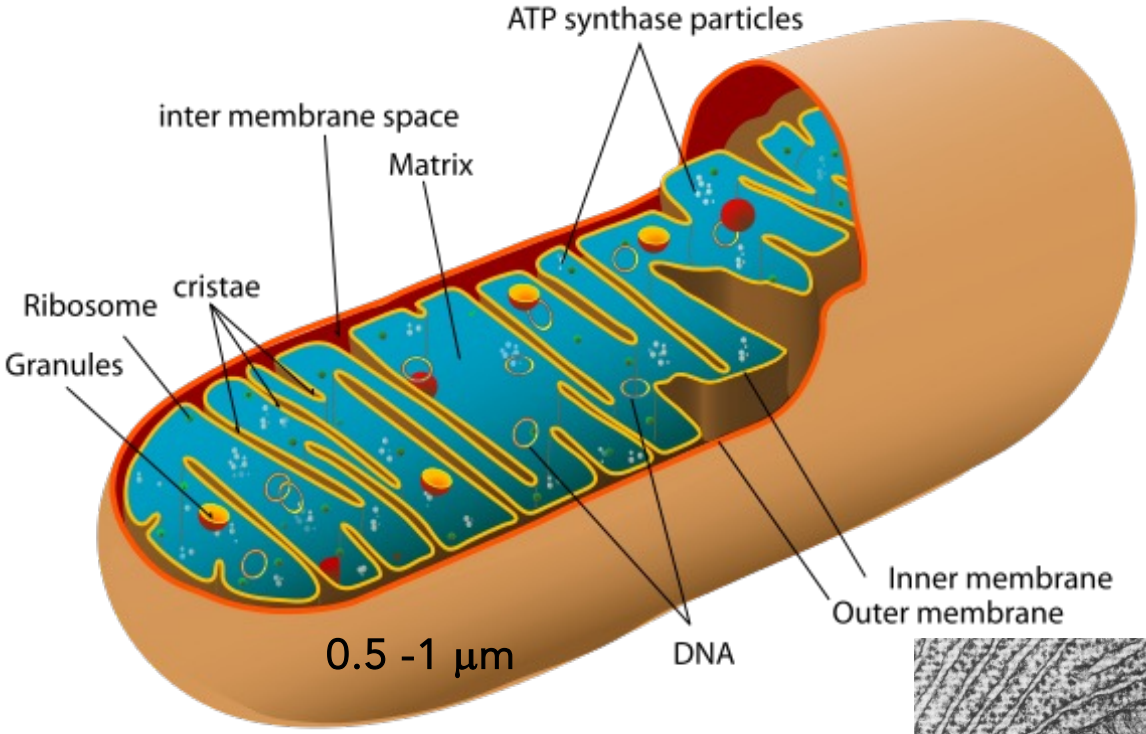


DNA is the genetic material that gives instructions for cellular function.

In the city analogy, the nucleus is the government



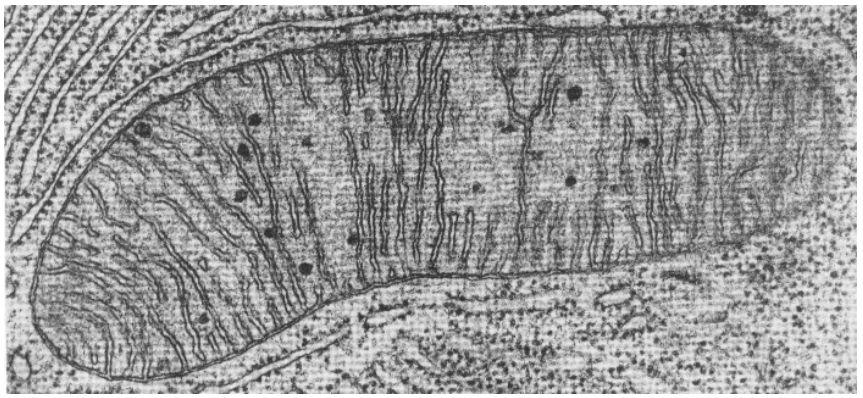
Compartmentalization and function: Mitochondria generate energy



"Mitochondria are the powerhouse of the cell."
Based on our city analogy, have you had power outage in your city?

What would happen if mitochondria do not function?
Mitochondrial diseases: Leigh syndrome, MELAS

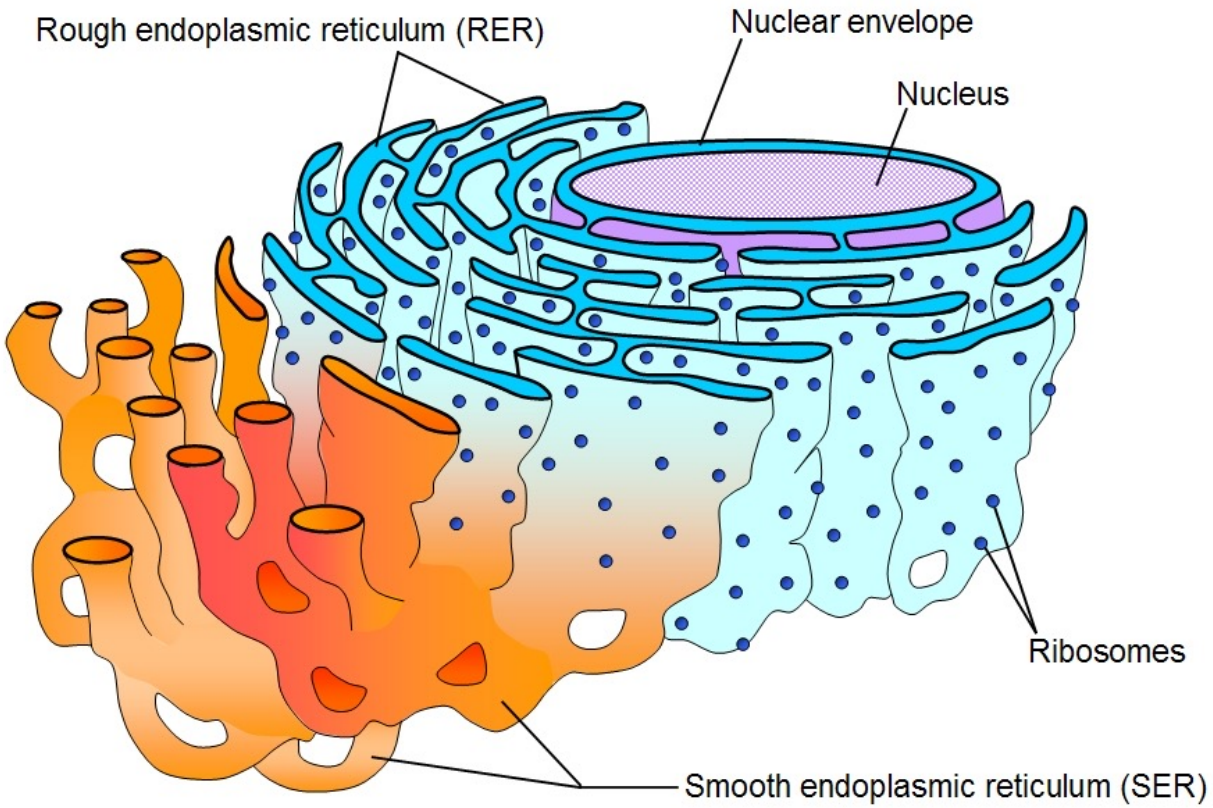
When any organism 'eats food', mitochondria in the cells convert the food to energy



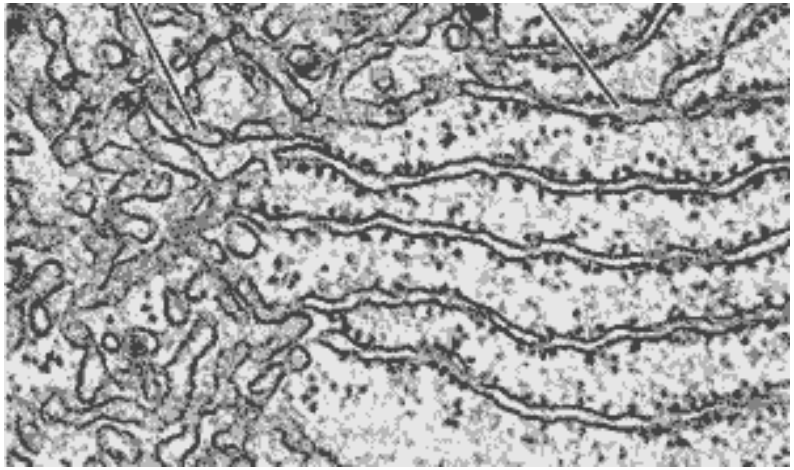
How do proteins get to the right location in a cell?

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

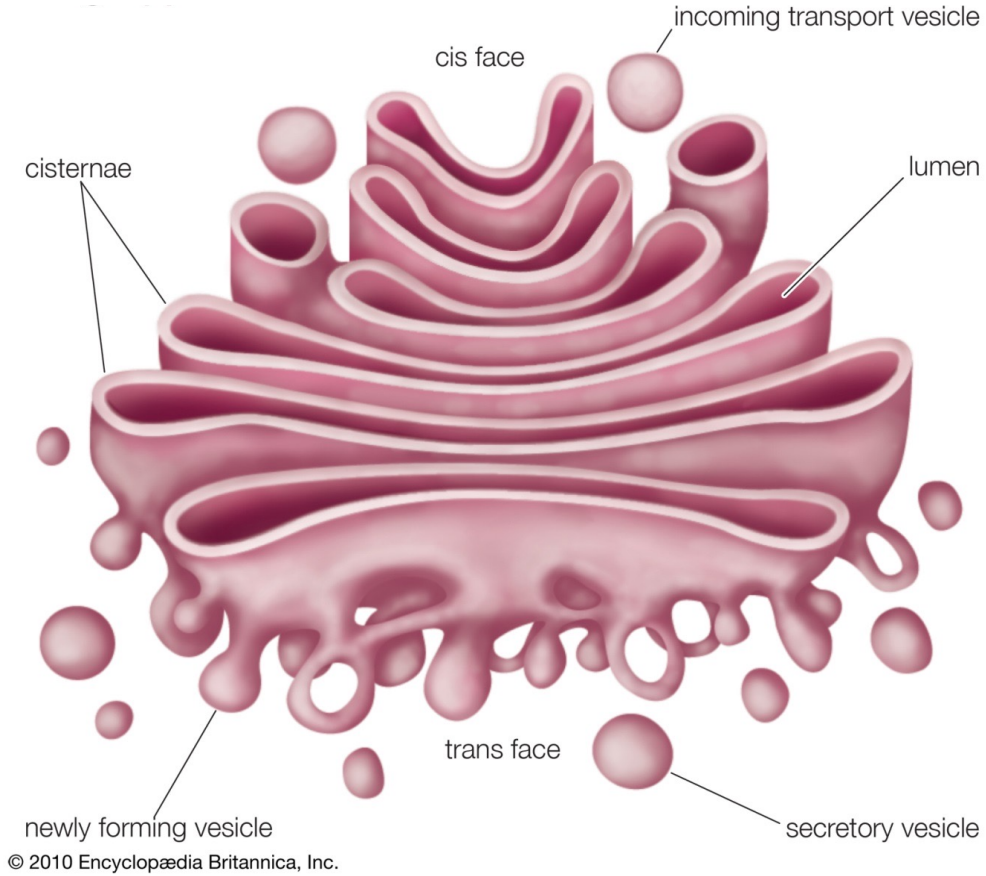
Endoplasmic Reticulum transports proteins that are synthesized in the cytosol



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

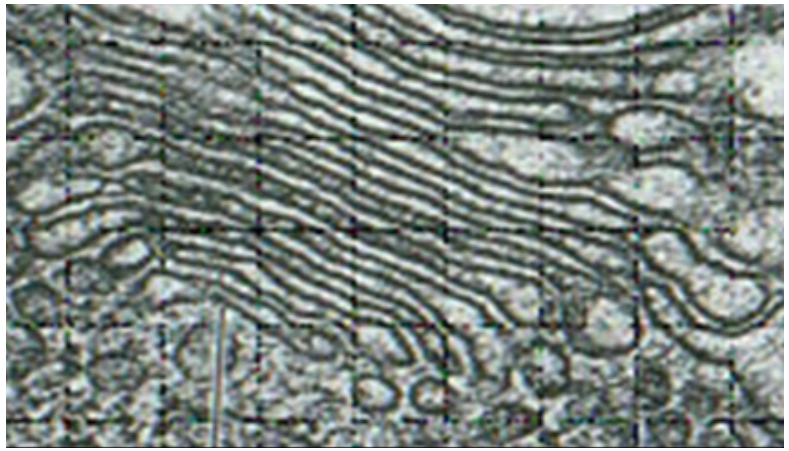


Golgi Apparatus sorts the proteins for their destinations

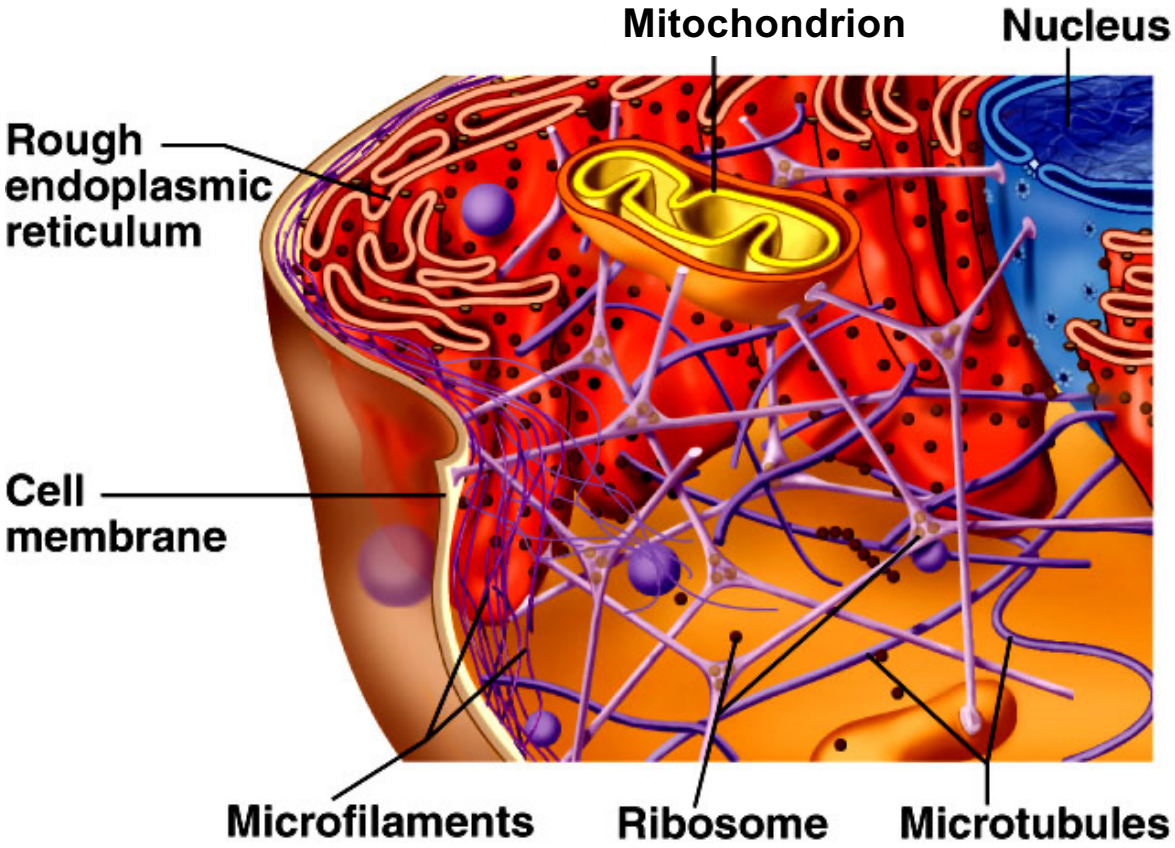


Golgi is like a Post Office

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



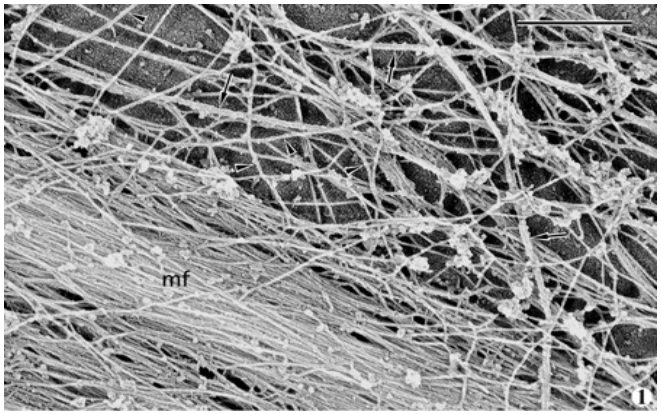
Cytoskeleton is structural support for cell & provides tracks for movement



Cytoskeleton:

- Actin
- Microtubules
- Intermediate filaments

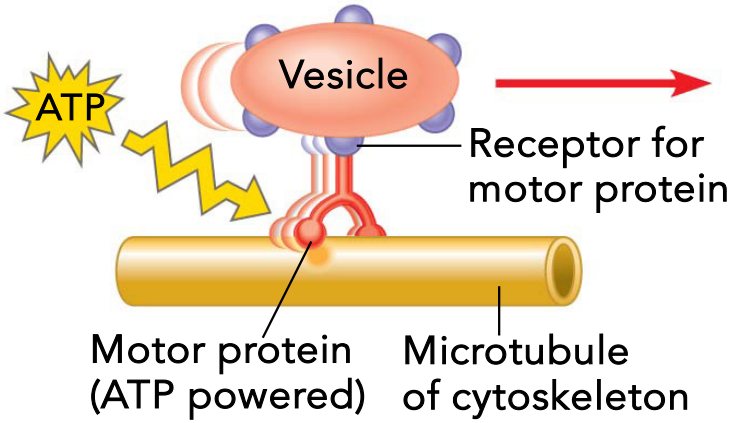
BUT … as cells can move, the cytoskeleton is rigid, but can also be flexible



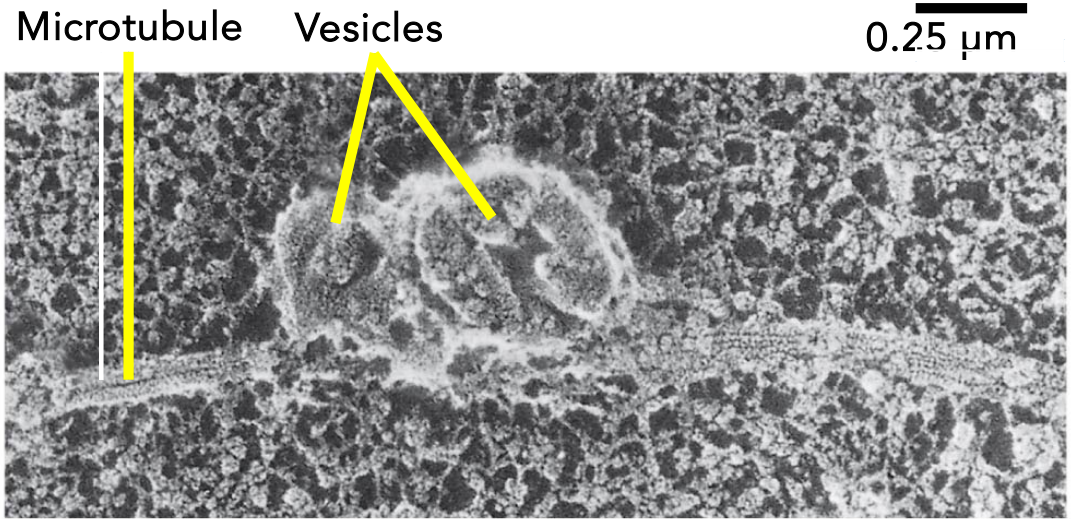
Molecular motors carry cargo on the microtubule tracks

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

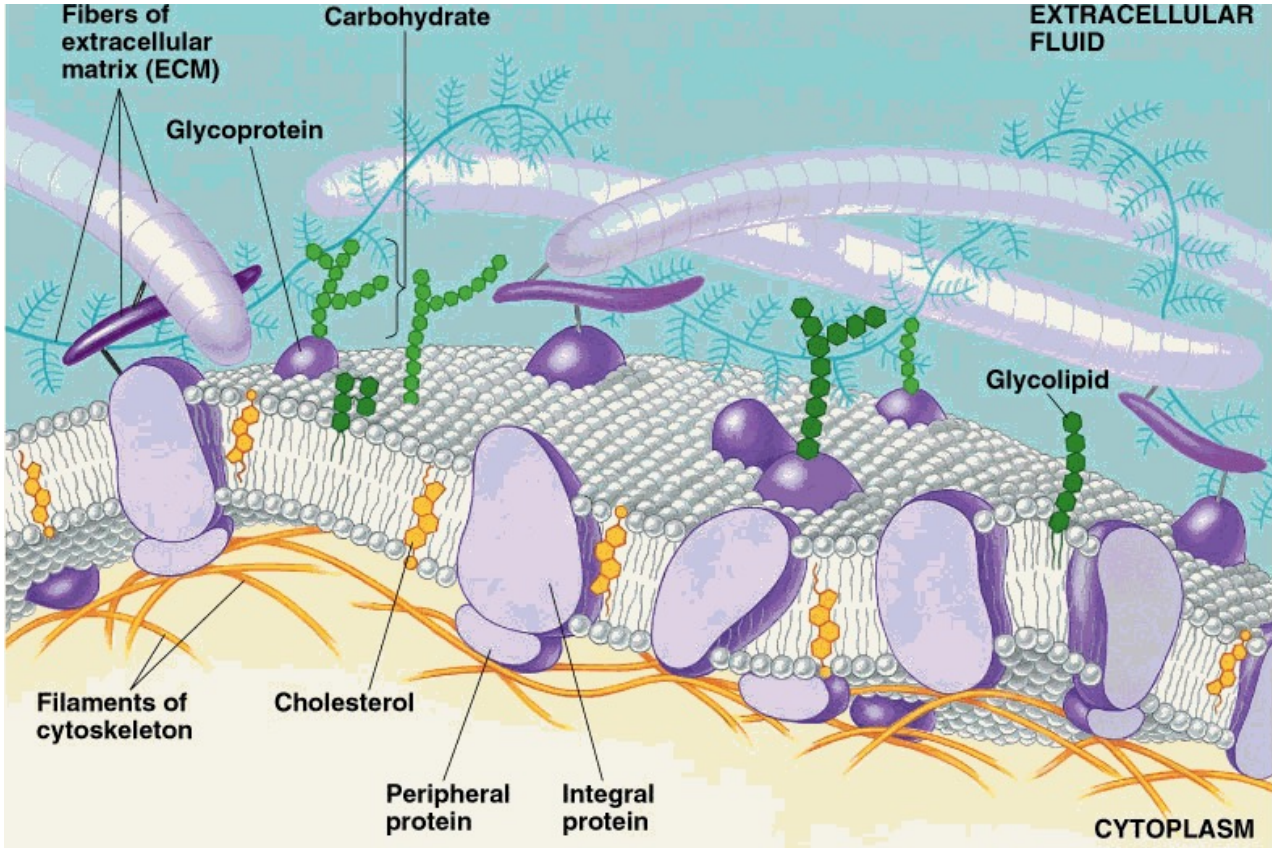


Scanning electron micrograph of a squid giant axon

Axon: is the extension of a nerve cell (or neuron)

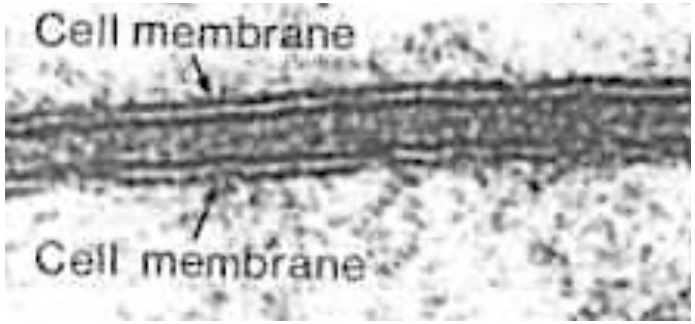
Shown are two neurotransmitter-containing vesicles moving towards the tip of the axon

Plasma membrane is the barrier between the cell and the world



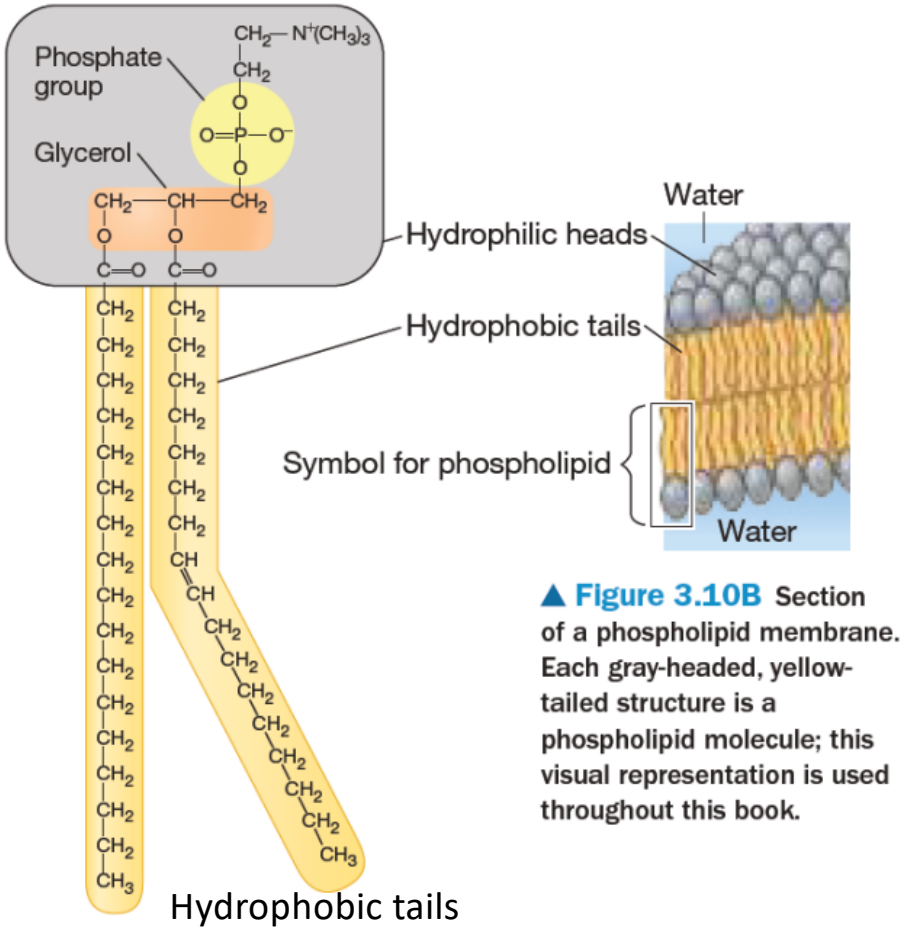
Plasma membrane is made of lipids, proteins & carbohydrates

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



The properties of lipids drive compartmentalization and membrane formation

Charged phosphate groups



▲ **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.

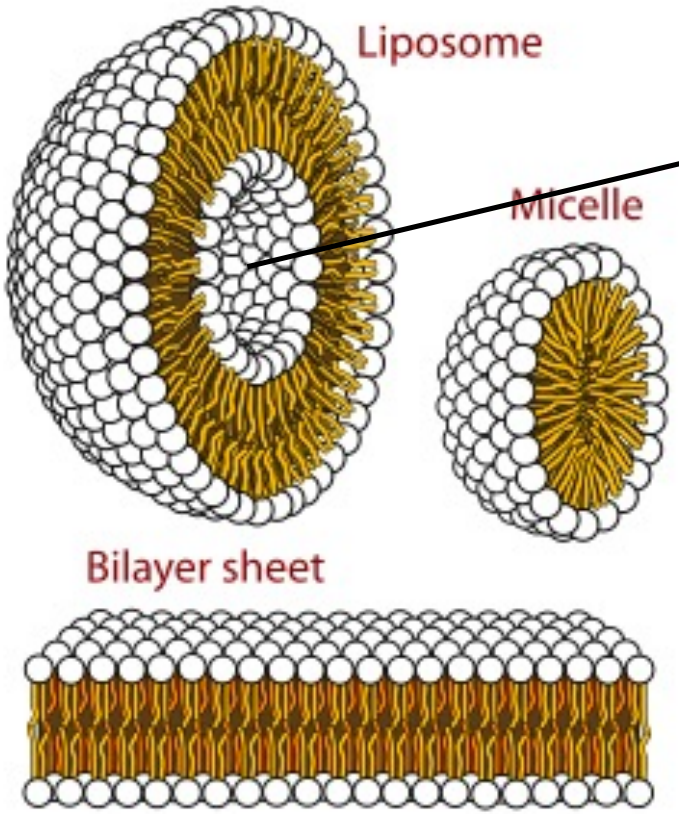
▲ **Figure 3.10A** Chemical structure of a phospholipid molecule

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 <u>spontaneously assemble</u> into structures that form membranes.

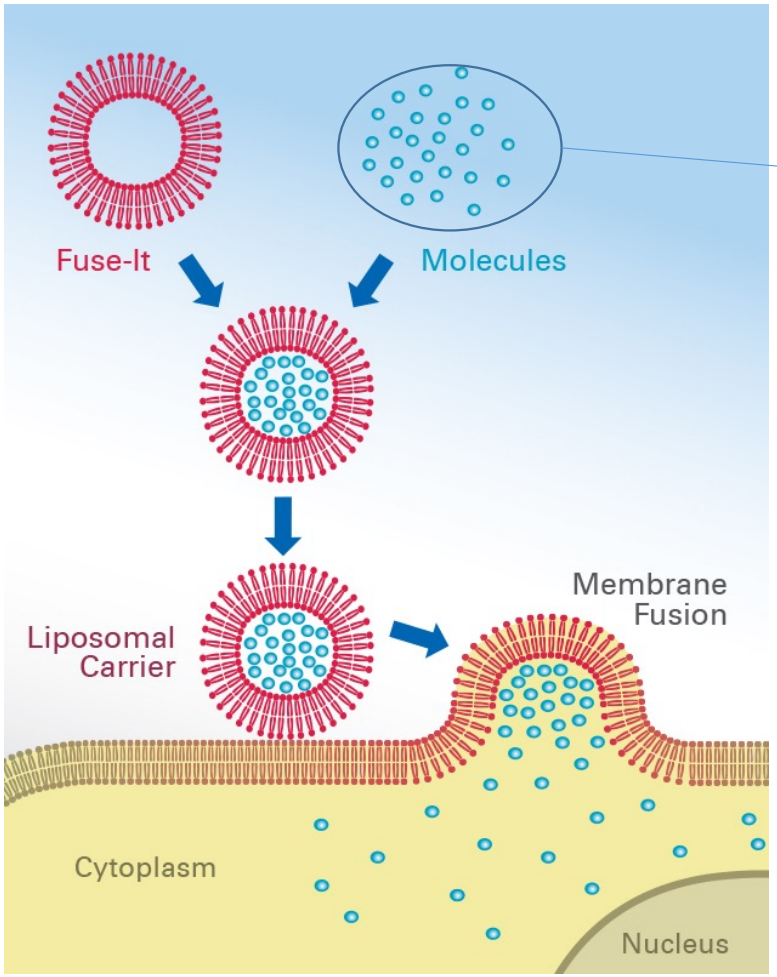
Cholesterol and proteins embed in the lipid membranes: fluid mosaic model

The properties of lipids allow spontaneous formation of ordered structures

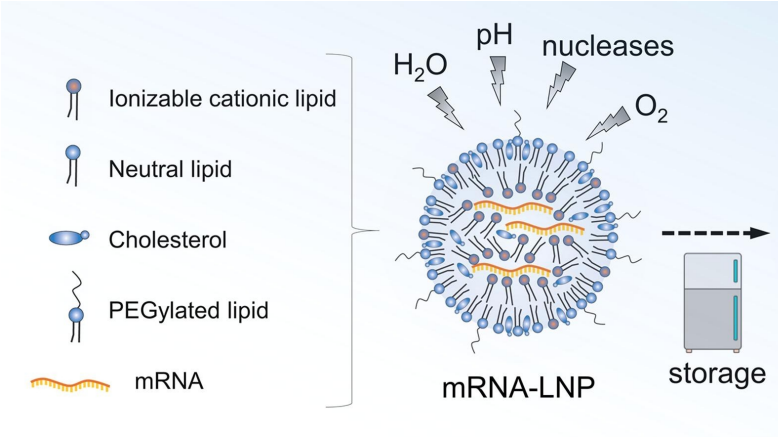


- Can put drugs and other useful molecules into this aqueous compartment for delivery
- Can fuse membranes together

The properties of lipids lead to membrane fusion



Pfizer/Moderna Covid-19 vaccine

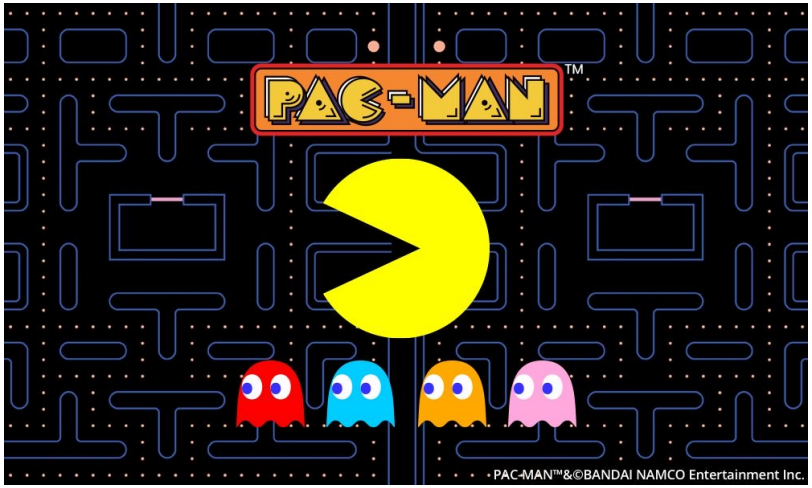


Vaccinate

Membranes do not easily fuse with each other:

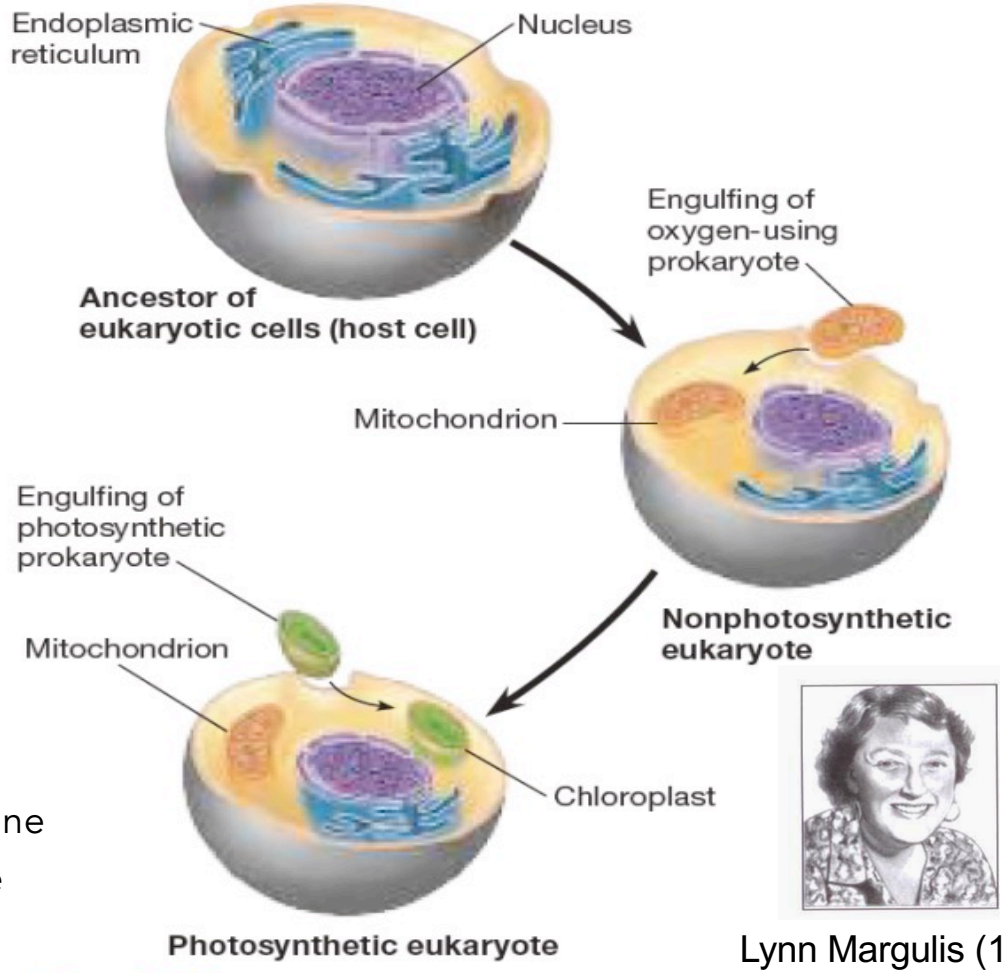
Liposomes and Lipid Nanoparticles (LNPs) have certain lipids that promote fusion

Where did organelles come from: Model for Endosymbiotic Origin



Prokaryotes were engulfed by eukaryotes to create endosymbiotic organelles

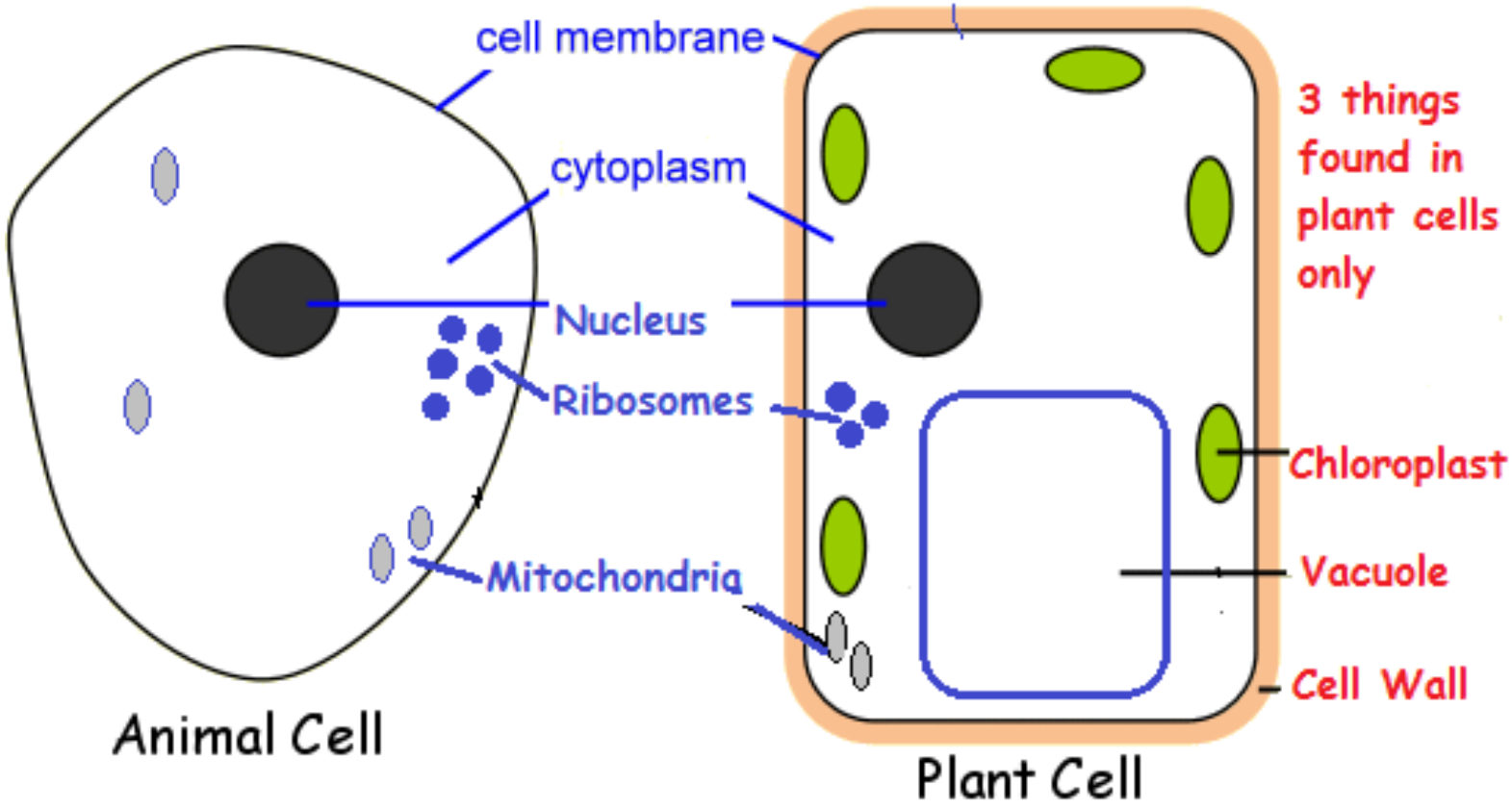
- Generation of double membrane organelle
  - Outer membrane from eukaryotic plasma membrane
  - Inner membrane from bacterial plasma membrane



Lynn Margulis (1981)

▲ Figure 4.15 Endosymbiotic origin of mitochondria and chloroplasts

Animal vs plant cells: structure is essential for function



(Use carbon dioxide and water to make "food")

(Help maintain water balance)

(Rigidity)

Animal vs plant cells: 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	• Various types of bacteria • Almost all unicellular Cyanobacteria	• 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	Present
Internal organization	Lacks membrane-bound compartments but many proteins localized in cytosol	Extensive internal membranes enclose other compartments known as organelles

Cells: Two Major Classification (3)

	Prokaryotes	**Eukaryotes**
Chromosome	Single circular DNA molecule	Multiple linear DNA molecules
DNA content	1 X 10^6 to 5 X 10^6 base pairs	1.5 X 10^7 to 5 X 10^9
mRNA	• mRNA transcript is mature, directly used for translation • Transcription & translation are coupled	• mRNA transcript is processed (not mature) • Transcription & translation are separate

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

How do we study cells?

How to study cell?

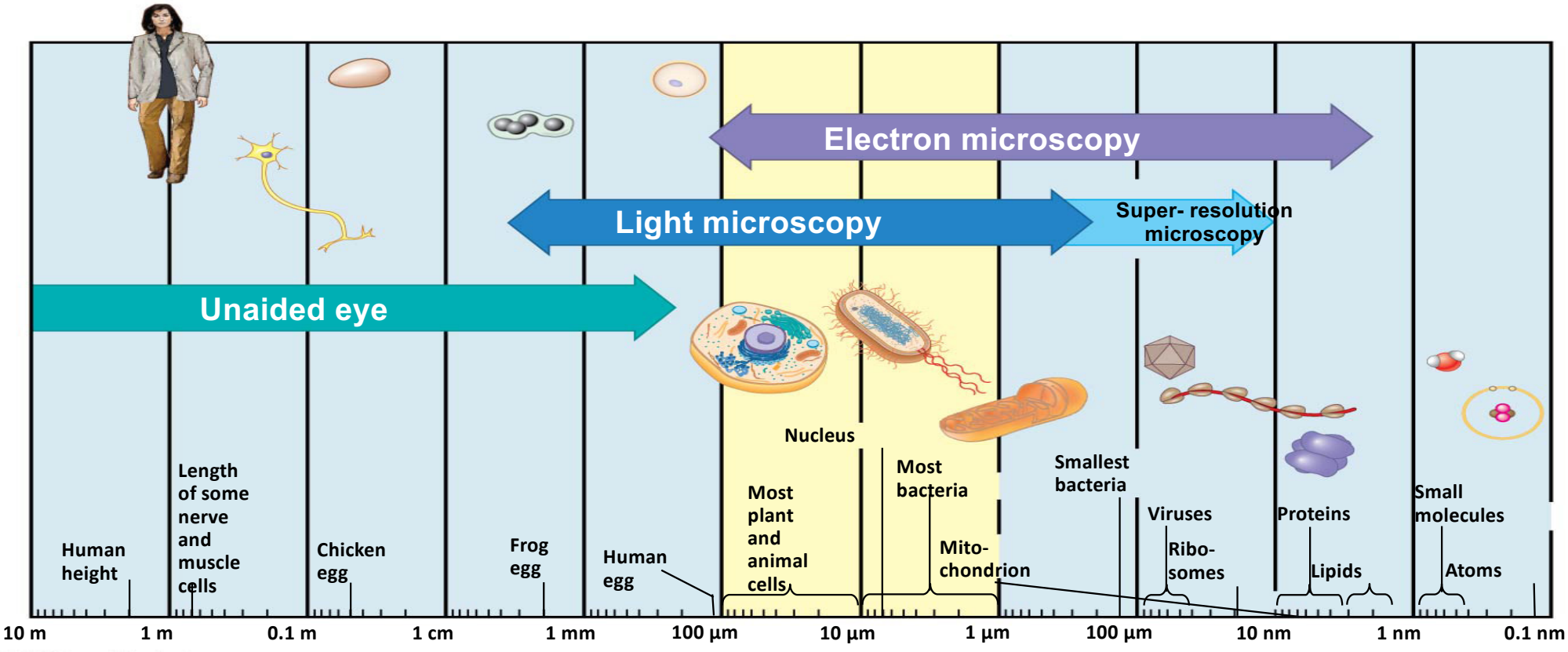
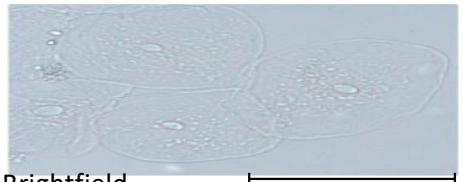


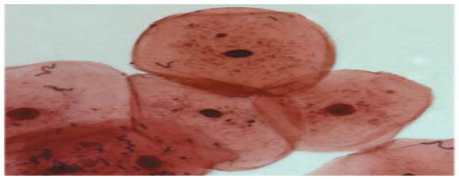
Figure 6.2

- Most cells are between 1 - 100 µm in diameter

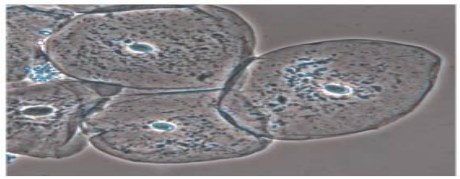
Studying Cells Using Microscopy



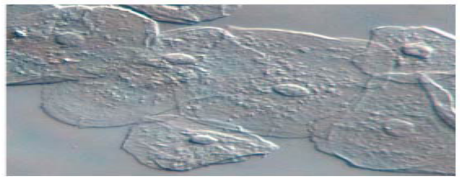
Brightfield (unstained specimen)



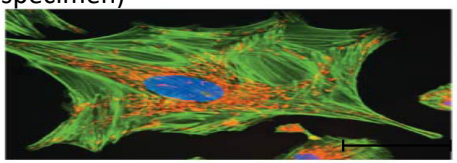
Brightfield (stained specimen)



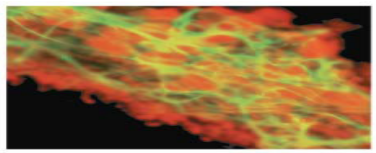
Phase-contrast



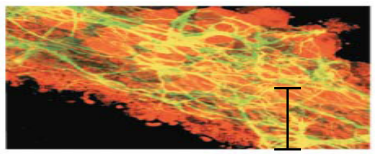
Differential-interference-contrast (Nomarski)



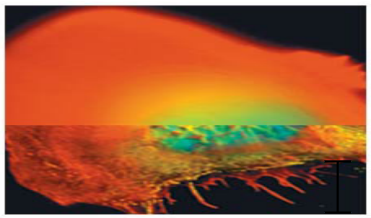
Fluorescence



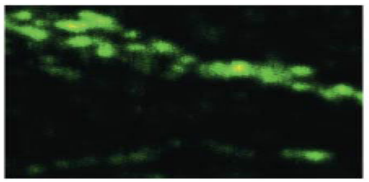
Confocal (without)



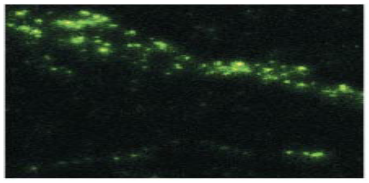
Confocal (with)



Deconvolution

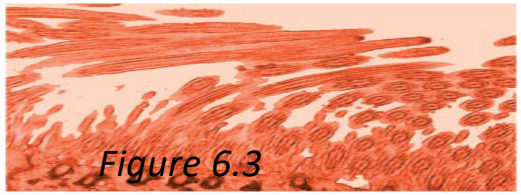


Super-resolution (without)



Super-resolution (with)

Scanning electron microscopy (SEM)

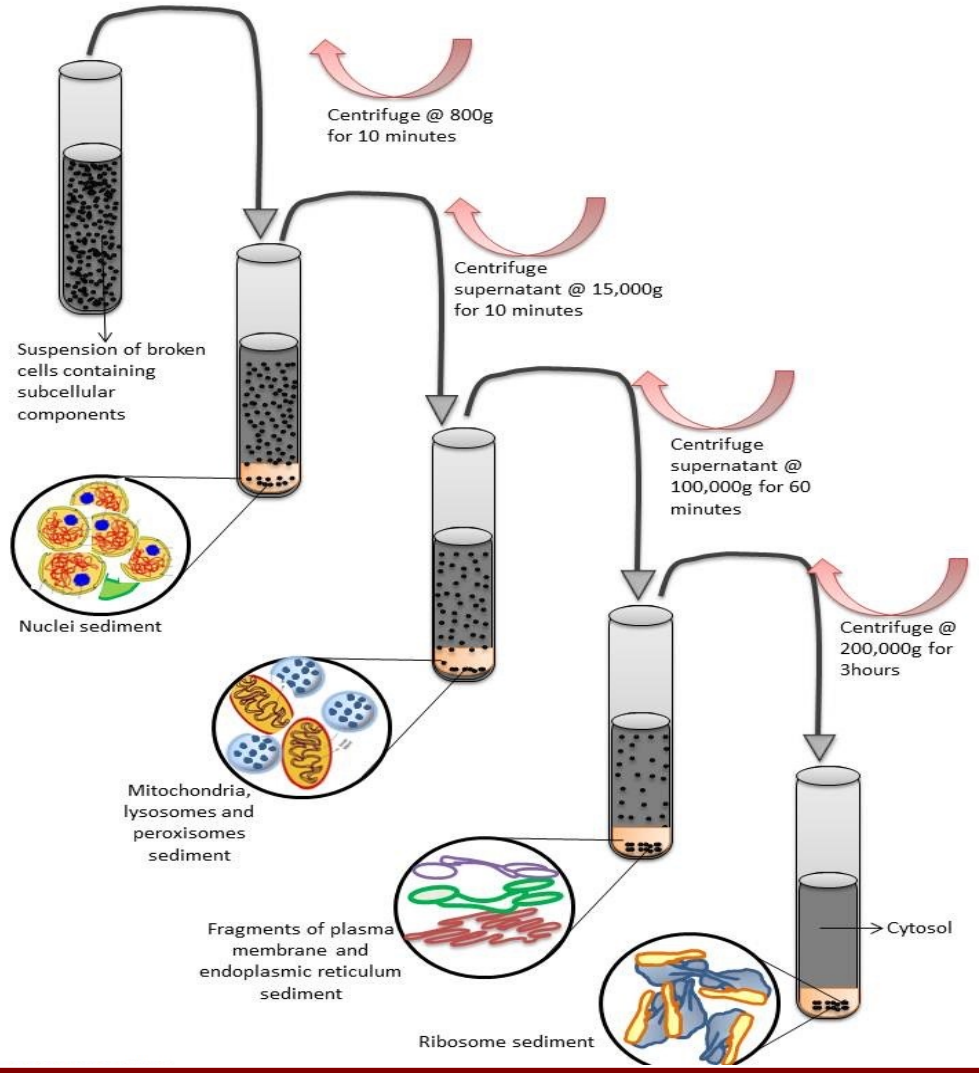


Transmission electron microscopy (TEM)

- 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 ✓
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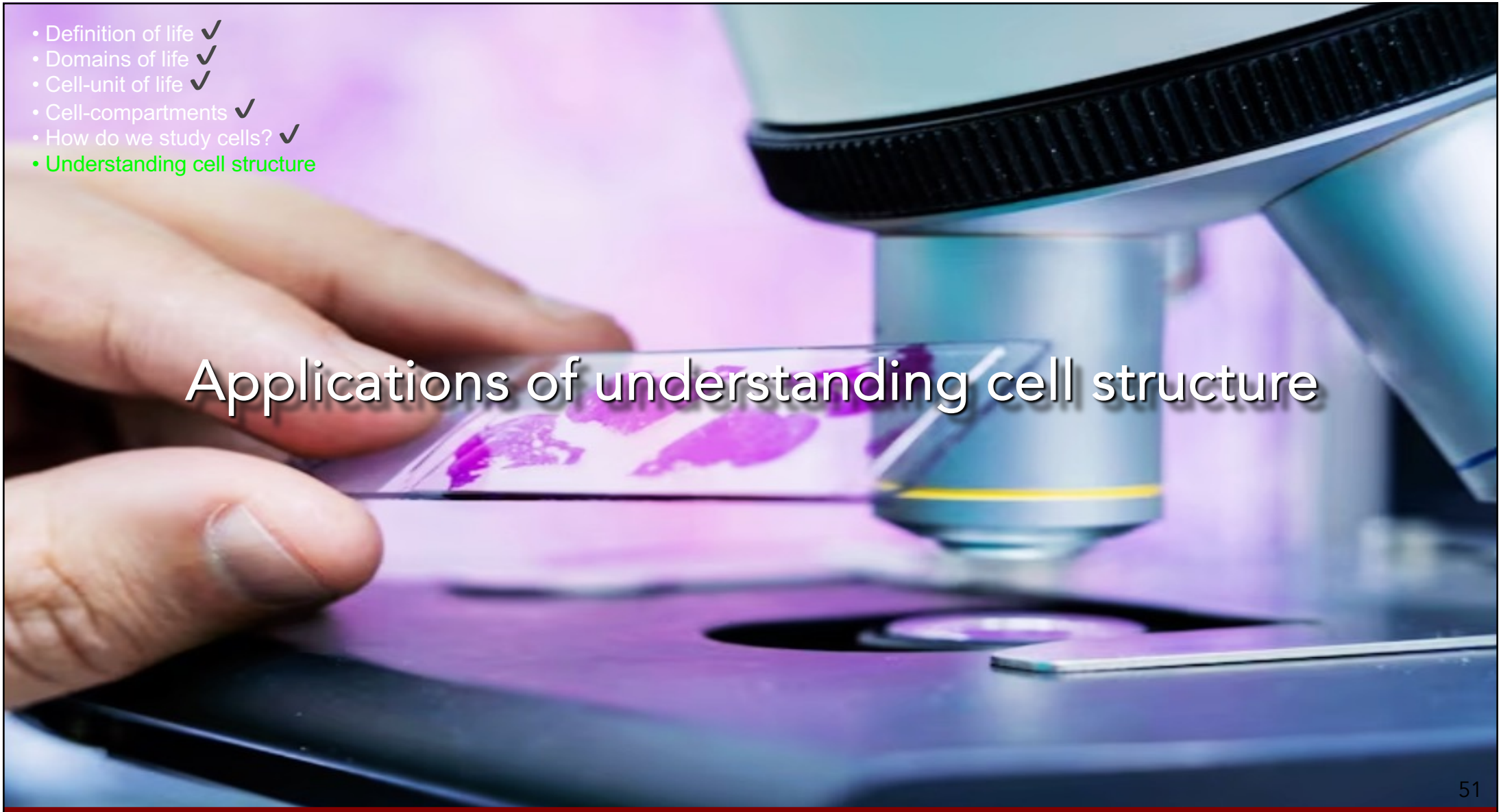
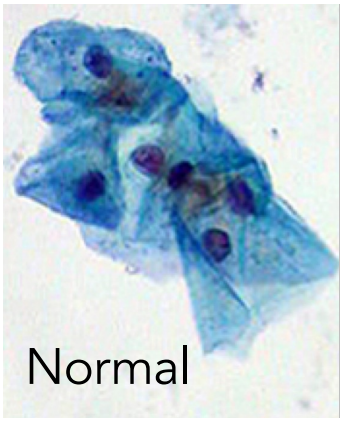


Applications of understanding cell structure

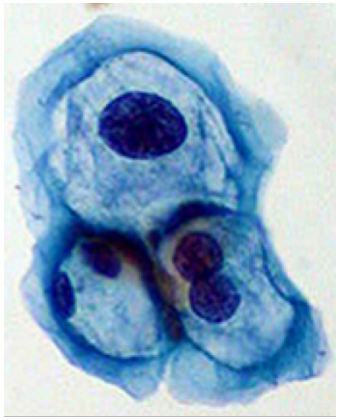
Knowledge of cells is useful in medicine

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)

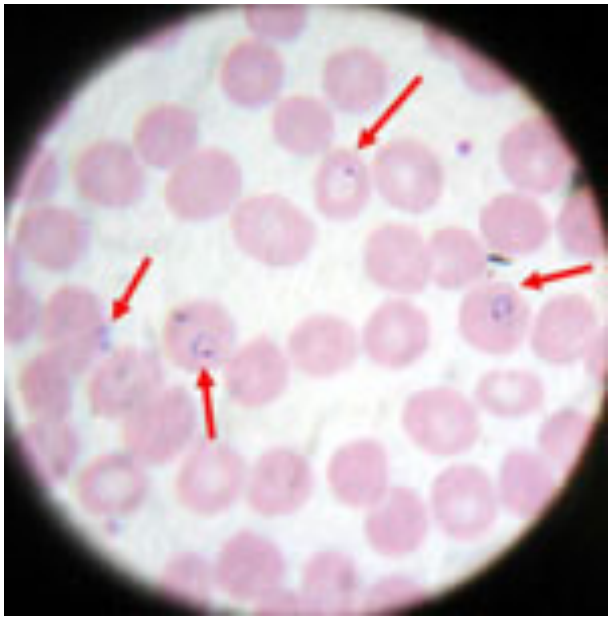


Infected with papilloma virus

- Happiness & well-being (individual)
- Lower healthcare burden (economy)

https://cnx.org/contents/GFy_h8cu@11.2:ADrtuvNU@8/Studying-Cells

Knowledge of cells is useful in medicine



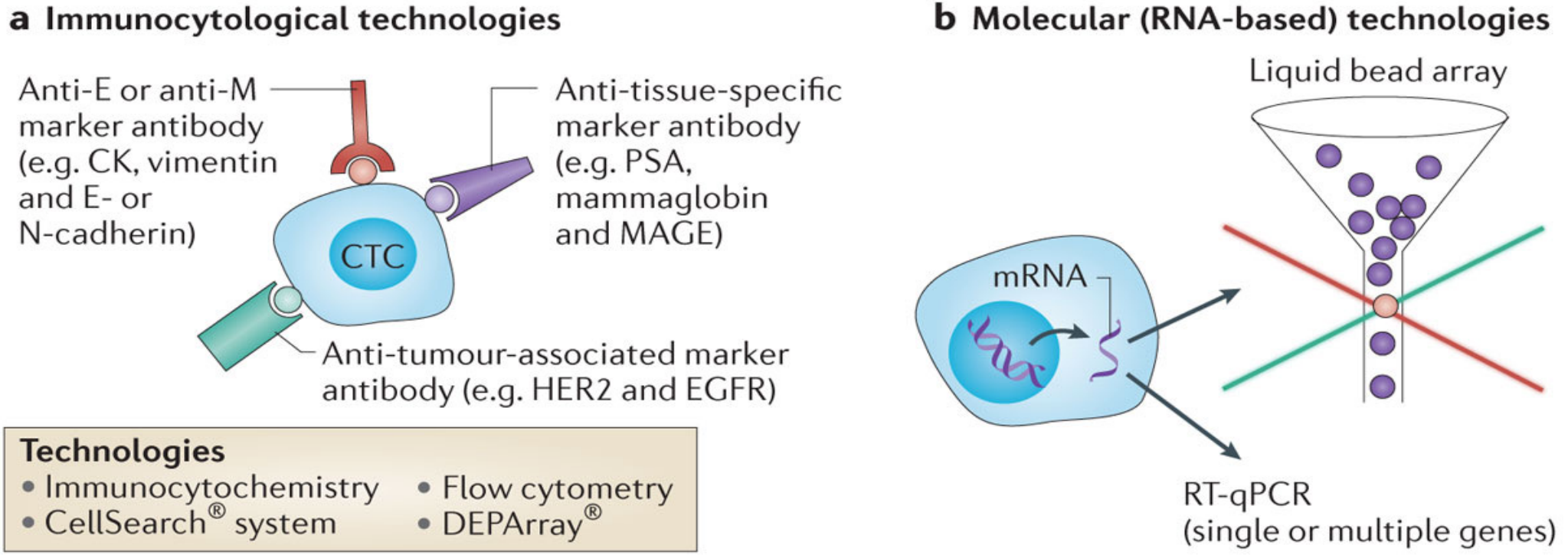
- Diagnosis of malaria is by visualizing blood cells stained with a dye that turns DNA purple
- Microscopy is done in the hospital to detect malaria parasites in red blood cells so that treatment with anti-malarial drugs can start
- Image analysis is being tested to make the process more efficient and 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

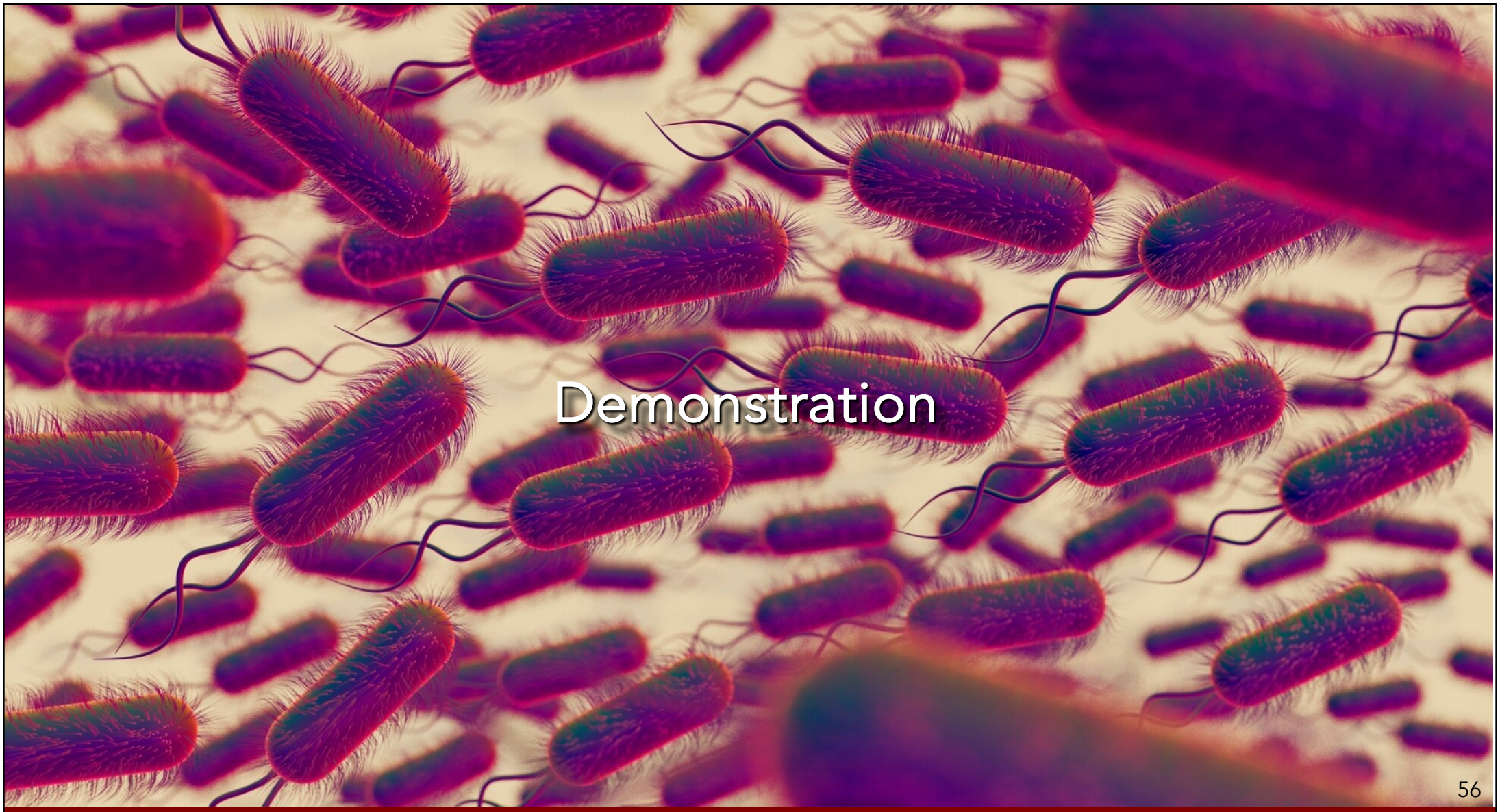
US Food and Drug Administration (FDA)-cleared technology that allows a sensitive positive capture of CTCs by antibodies against epithelial cell adhesion molecule (EPCAM) coated with ferrofluids



NATURE REVIEWS | CANCER VOL 14 | SEP 2014

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

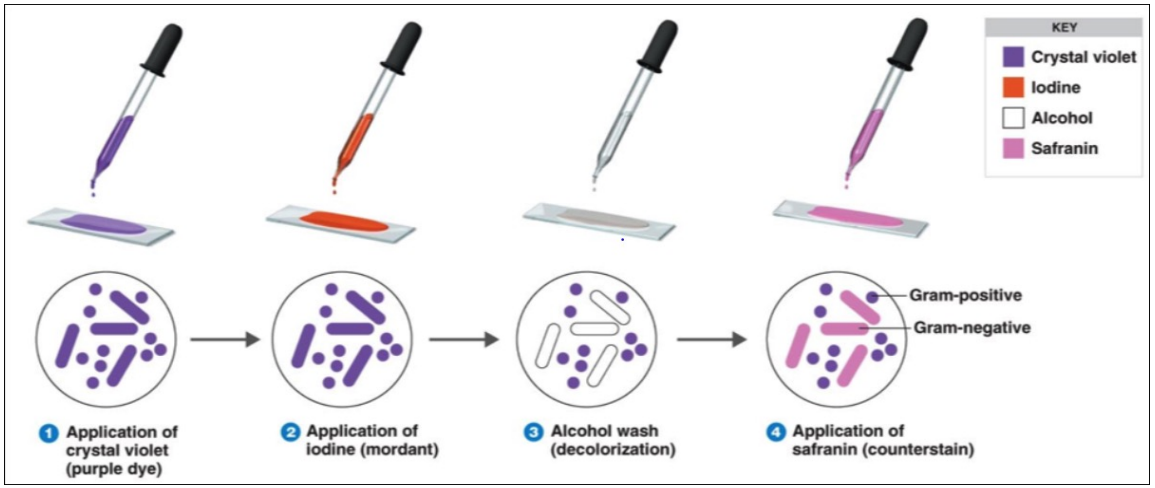
Step-2: Add two drops of Gram's **crystal violet**, remove the excess stain with water

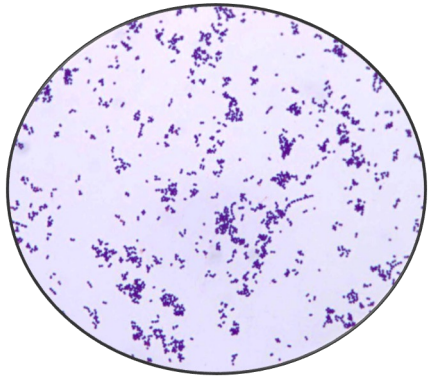
Step-3: Add few drops of Gram's **Iodine** followed by washing

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

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

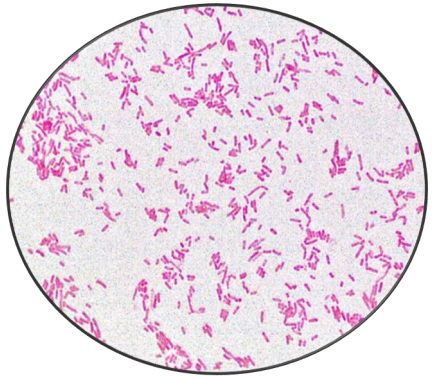
Step-6: Put the slide for air drying





Gram Positive (Purple/ Violet)

Streptococcus Sp.



Gram Negative (pink)

Escherichia coli

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


1

Evolution, the Themes of Biology, and Scientific Inquiry

KEY CONCEPTS

1.1 The study of life reveals common themes

1.2 The Core Theme: Evolution accounts for the unity and diversity of life

1.3 In studying nature, scientists make observations and form and test hypotheses

1.4 Science benefits from a cooperative approach and diverse viewpoints

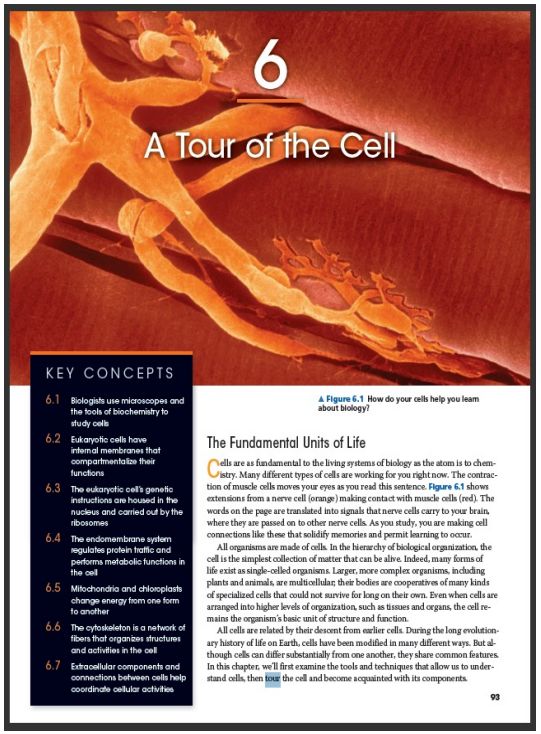
▲ Figure 1.1 How is the dandelion adapted to its environment?

Inquiring About Life

The dandelions shown in Figure 1.1 send their seeds aloft for dispersal. A seed is an embryo surrounded by a store of food and a protective coat. The dandelion's seeds, shown at the lower left, are borne on the wind by parachute-like structures made from modified flower parts. The parachutes harness the wind, which carries such seeds to new locations where conditions may favor sprouting and growth. Dandelions are very successful plants, found in temperate regions worldwide.

An organism's adaptations to its environment, such as the dandelion seed's parachute, are the result of evolution. Evolution is the process of change that has transformed life on Earth from its earliest beginnings to the diversity of organisms living today. Because evolution is the fundamental organizing principle of biology, it is the core theme of this book.

Although biologists know a great deal about life on Earth, many mysteries remain. For instance, what processes led to the origin of flowering among plants such as the ones pictured above? Posing questions about the living world and seeking answers through scientific inquiry are the central activities of **biology**, the scientific study of life. Biologists' questions can be ambitious. They may ask how a single tiny cell becomes a tree or a dog, how the human mind works, or how the different


6

A Tour of the Cell

KEY CONCEPTS

6.1 Biologists use microscopes and the tools of biochemistry to study cells

6.2 Eukaryotic cells have internal membranes that compartmentalize their functions

6.3 The eukaryotic cell's genetic instructions are housed in the nucleus and carried out by the ribosomes

6.4 The endomembrane system regulates protein traffic and performs metabolic functions in the cell

6.5 Mitochondria and chloroplasts change energy from one form to another

6.6 The cytoskeleton is a network of fibers that organizes structures and activities in the cell

6.7 Extracellular components and connections between cells help coordinate cellular activities

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

The Fundamental Units of Life

Cells are as fundamental to the living systems of biology as the atom is to chemistry. Many different types of cells are working for you right now. The contraction of muscle cells moves your eyes as you read 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 making cell connections like these that solidify memories and permit learning to occur.

All organisms are made of cells. In the hierarchy of biological organization, the cell is the simplest collection of matter that can be alive. Indeed, many forms of life exist as single-celled organisms. Larger, more complex organisms, including plants and animals, are multicellular; their bodies are cooperatives of many kinds of specialized cells that could not survive for long on their own. Even when cells are arranged into higher levels of organization, such as tissues and organs, the cell remains the organism's basic unit of structure and function.

All cells are related by their descent from earlier cells. During the long evolutionary history of life on Earth, cells have been modified in many different ways. But although cells can differ substantially from one another, they share common features. In this chapter, we'll first examine the tools and techniques that allow us to understand cells, then tour the cell and become acquainted with its components.

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