About the course

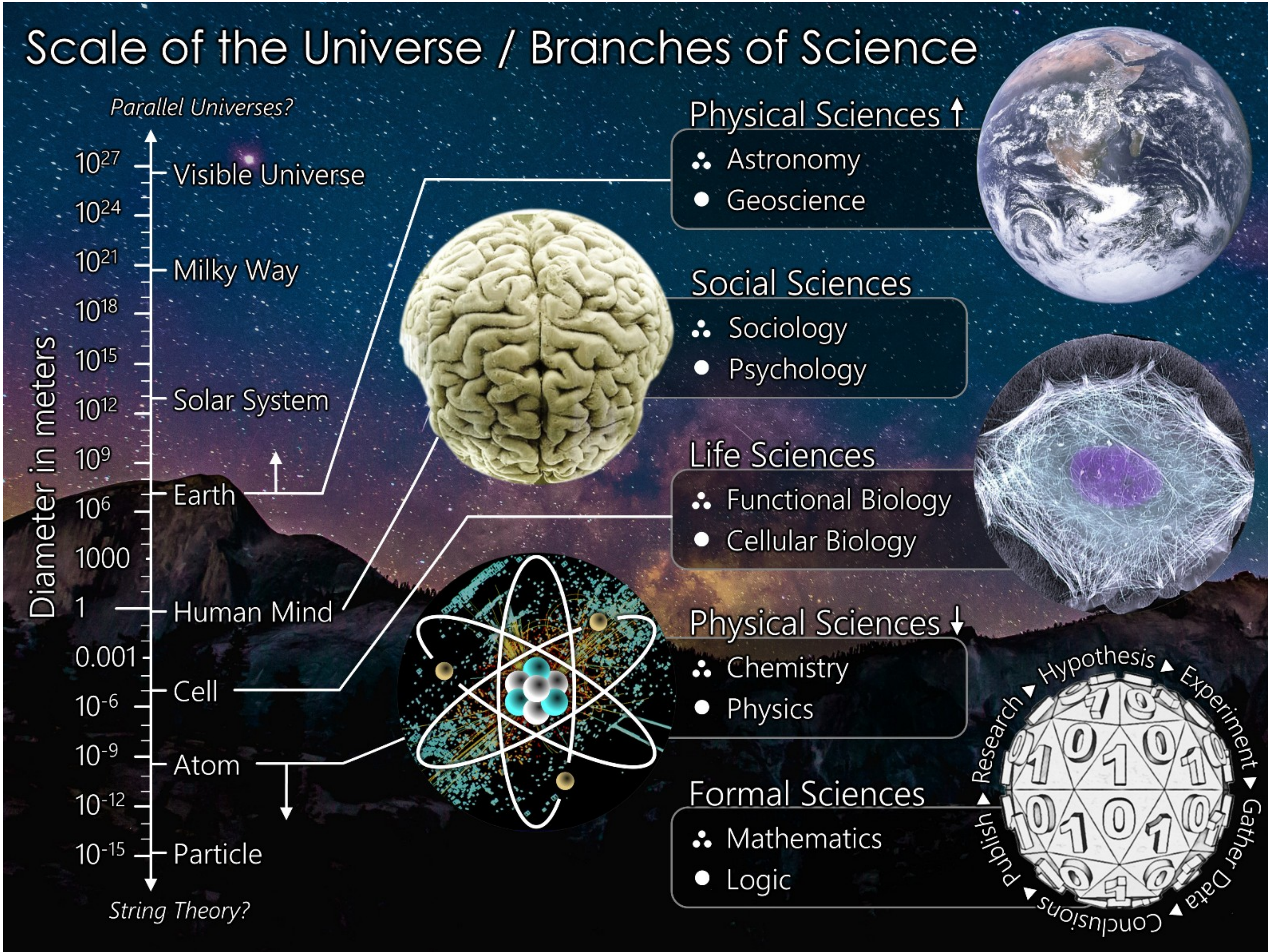
Topics to be covered:

- Introduction to biology
- Cell theory: cell structure, Cell cycle Culture growth; cell nutrients
- Cell construction: biomolecules (Protein, carbohydrates and lipids)
- Genetic material: nucleic acids, Chromatin, DNA structure, replication, transcription & translation ,
- Enzymes and metabolism basics
- Biotechnology

Introduction to biology

Science

"What Defines living object"?



Scale of the Universe / Branches of Science
Parallel Universes?
Diameter in meters
10^{27}
10^{24}
10^{21}
10^{18}
10^{15}
10^{12}
10^{9}
10^{6}
1000
1
0.001
10^{-6}
10^{-9}
10^{-12}
10^{-15}
Visible Universe
Milky Way
Solar System
Earth
Human Mind
Cell
Atom
Particle
String Theory?
Physical Sciences ↑
Astronomy
Geoscience
Social Sciences
Sociology
Psychology
Life Sciences
Functional Biology
Cellular Biology
Physical Sciences ↓
Chemistry
Physics
Formal Sciences
Mathematics
Logic
Hypothesis
Experiment
Gather Data
Conclusions
Publish
Research

Ref.:

“What Defines living object”?

Ref: NPTEL Lecture on Basic Biology

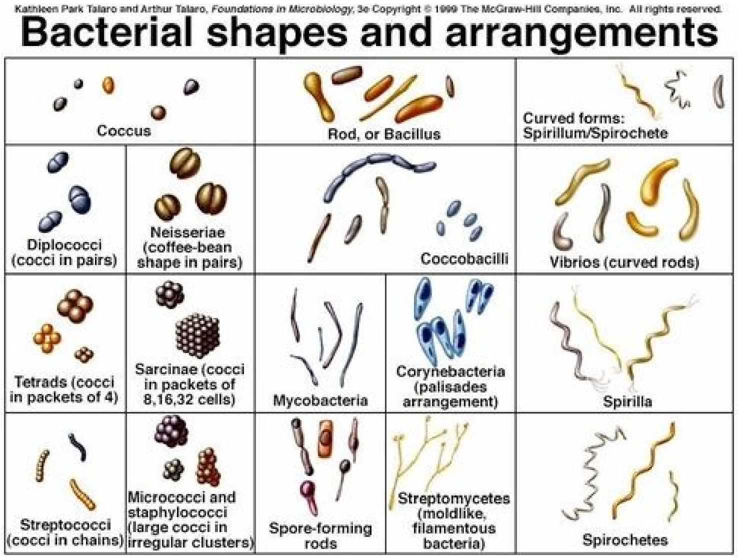
As per the rough estimate, a total of 8.7 million species are present on planet earth, widely distributed on terrestrial earth and inside the ocean.

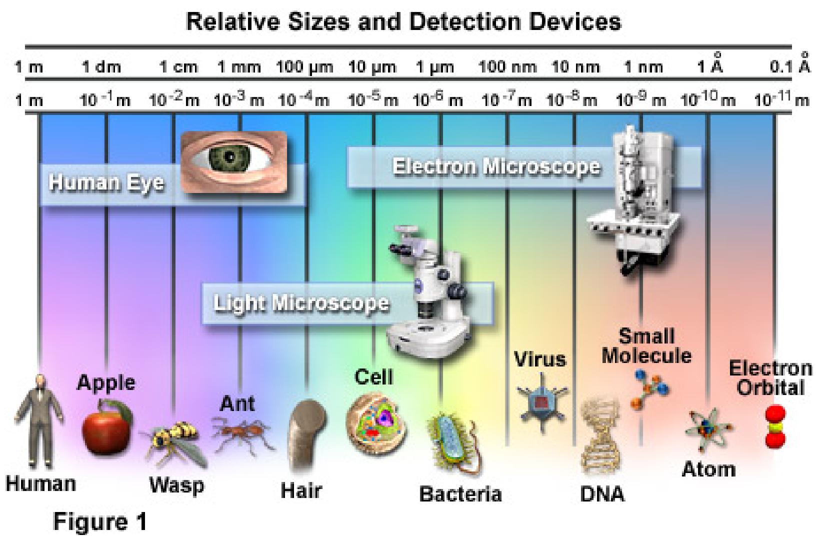
Species	**Earth**			**Ocean**		
	Catalogued	**Predicted**	**±SE**	**Catalogued**	**Predicted**	**±SE**
Eukaryotes						
Animalla	953,434	7,770,000	958,000	171,082	2,150,000	145,0000
Chromista	13,033	27,500	30,500	4,859	7,400	9,640
Fungi	43,271	611,000	297,000	1,097	5,320	11,100
Plantae	215,644	298,000	8,200	8,600	16,600	9,130
Total	1,233,500	8,740,000	1,300,000	193,756	2,210,000	182,000
Prokaryotes						
Archaea	502	455	160	1	1	0
Bacteria	10,358	9,680	3,470	652	1,320	436
Total	10,860	10,100	3,630	653	1,320	436
Grand Total	1,244,360	8,750,000	1,300,000	194,409	2,210,000	182,000

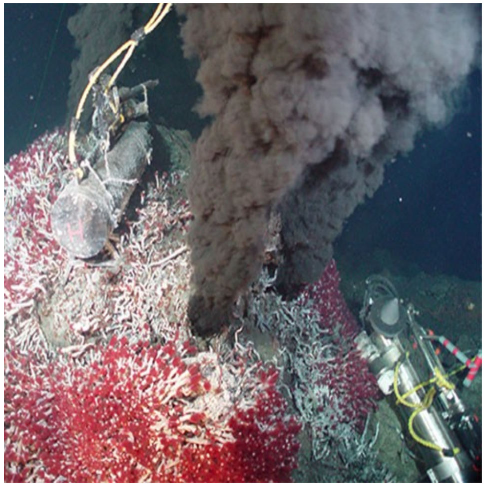
Ref: NPTEL Lecture on Basic Biology

Some salient feature of living organisms

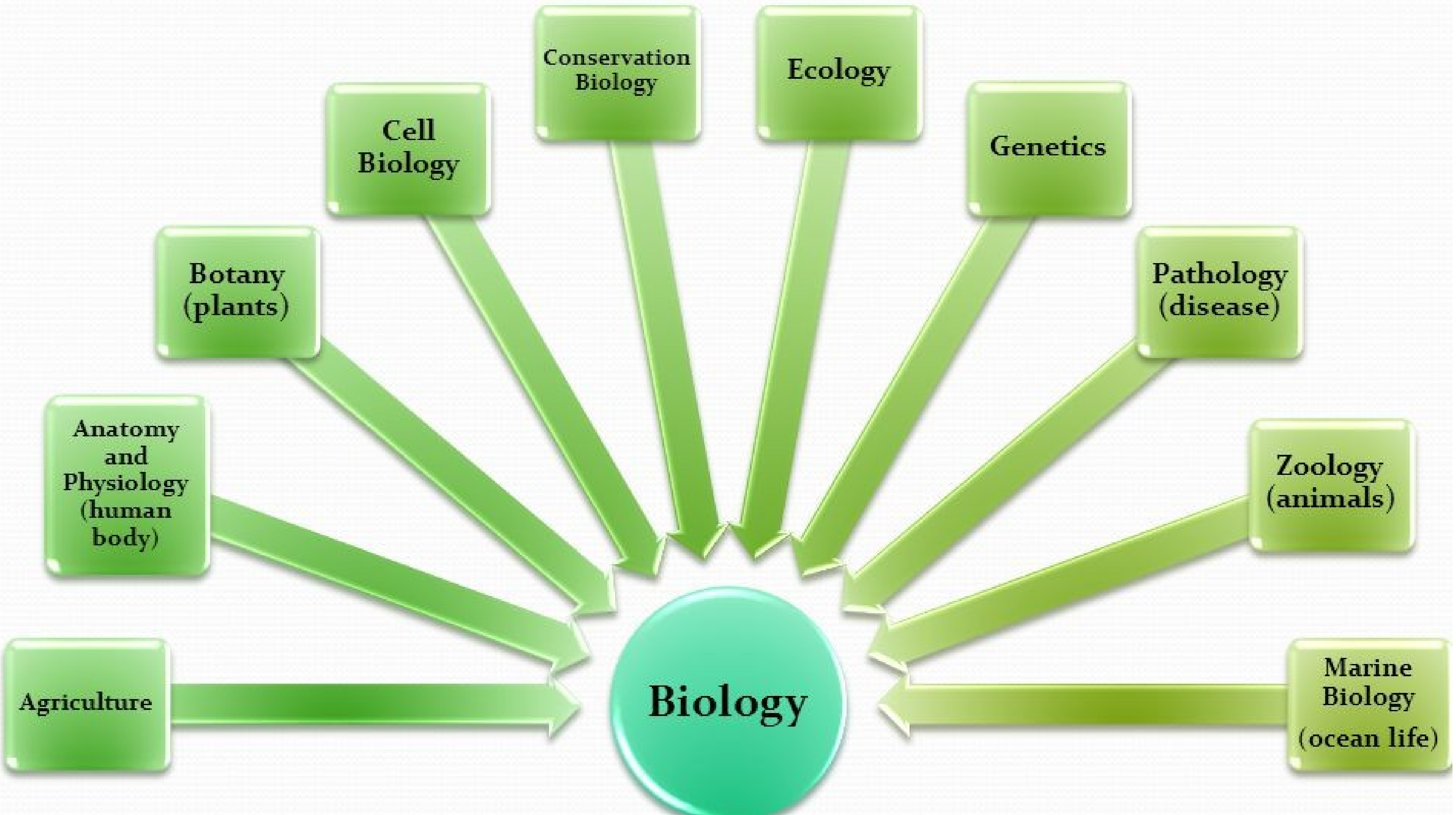
- Shape
- Size
- Spatial distribution: extremophile
- Biological activity



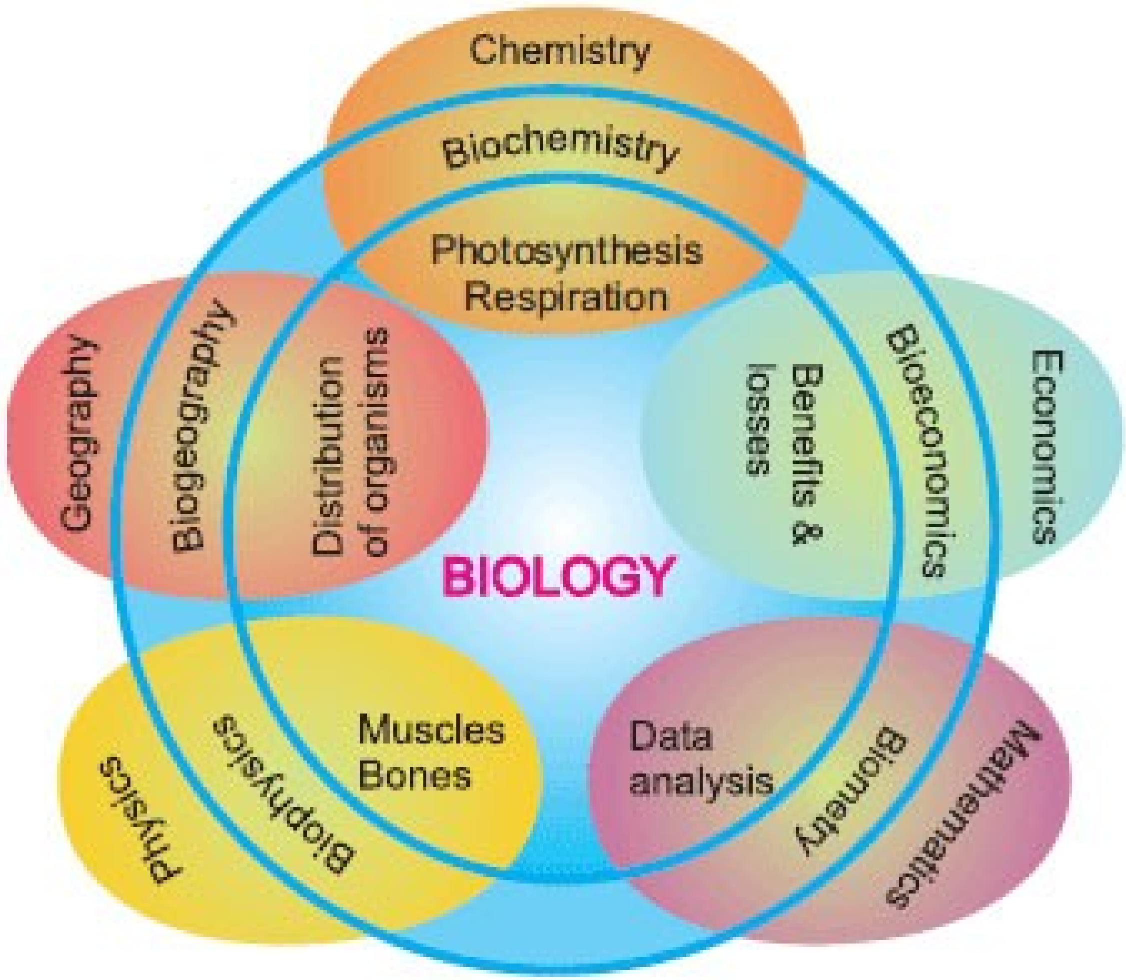




Various Branches of Biology

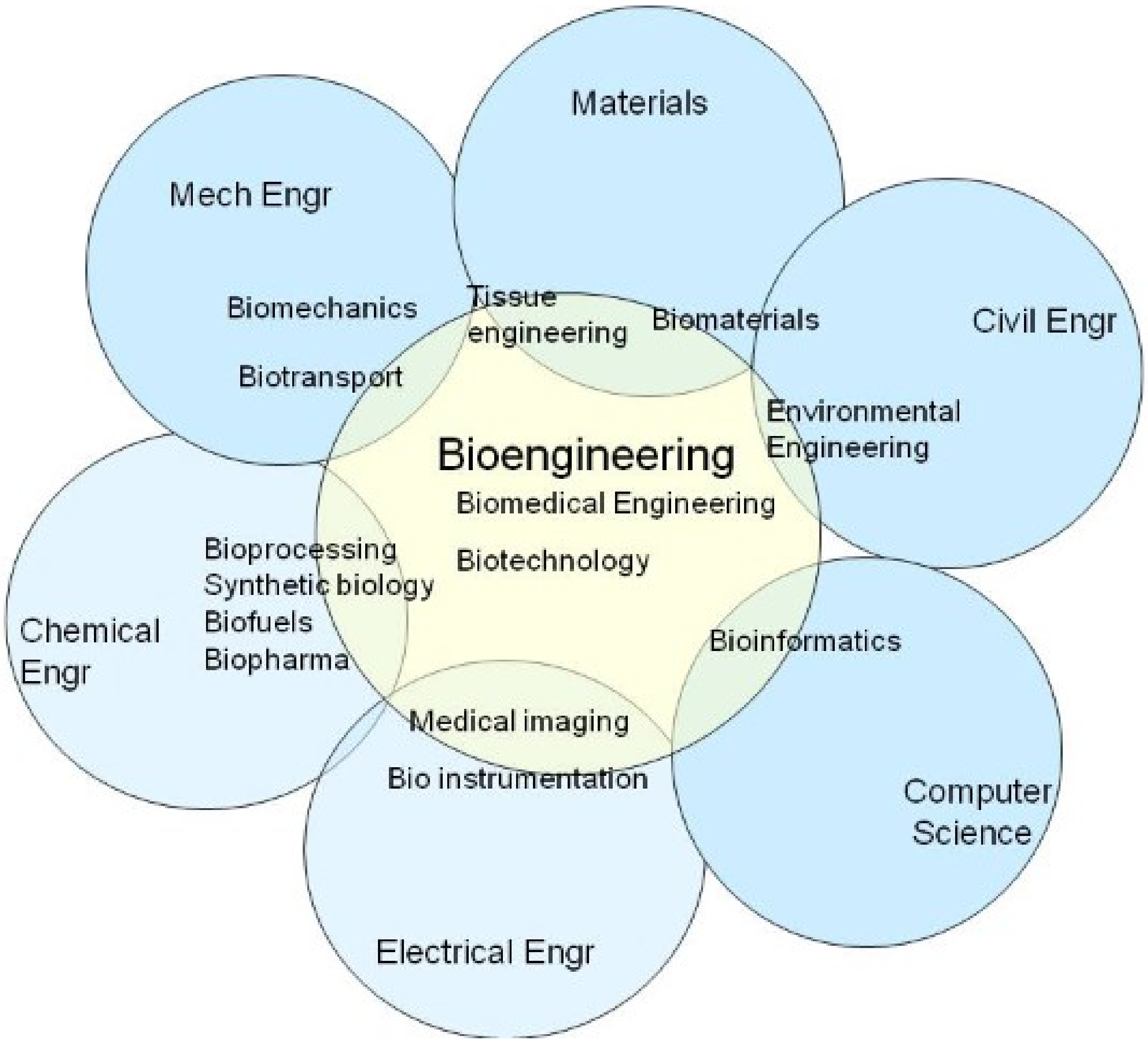


Biology & other sciences



Further reading: https://www.kullabs.com/classes/subjects/units/lessons/notes/note-detail/1765

Biology & Engineering



Ref: http://www.umassd.edu/engineering/bng/about/bioengineeringinrelationtootherdisciplines/

Classification of Living Organisms

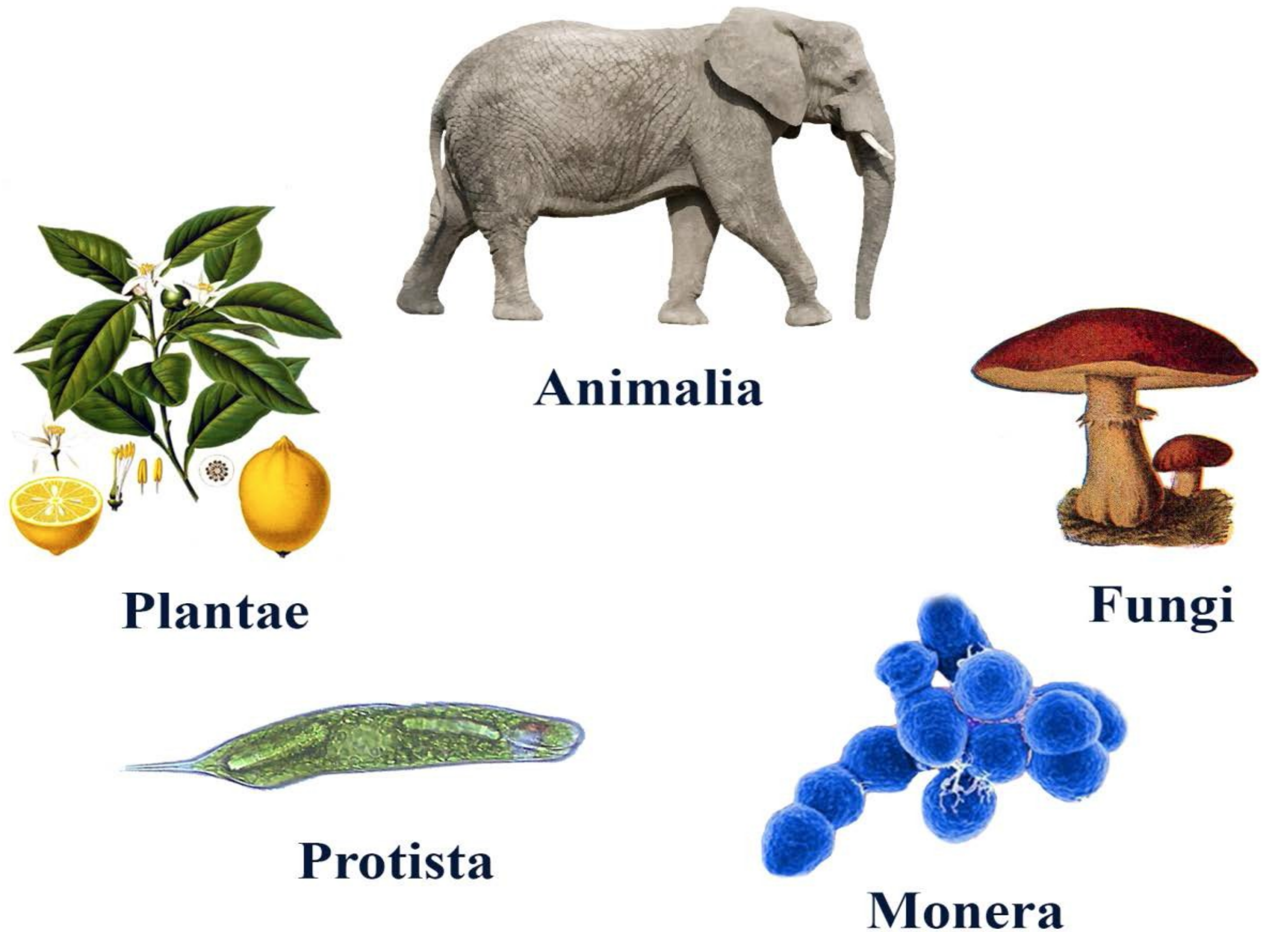
- In earlier day when number of species were limited, **Aristotle** **(born 384 bce, Stagira, Chalcidice, Greece—died 322, Chalcis, Euboea)** has used morphological differences as a criteria classified in two groups: **plant and animals**

- But as number goes up this kind of classification didn't hold and the organism were classified into two kingdom: **plantae and animalia.**

- This type of classification was easy to do but several organism were difficult to classify of either of these kingdoms.

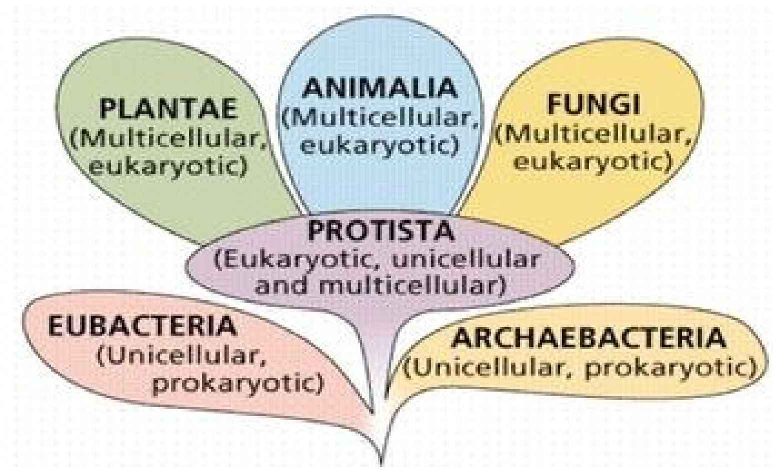
- Later, R.H. Whittaker have grouped the organisms using five kingdom classification

Five Kingdom for classification of living organism



Properties of The Five Kingdoms

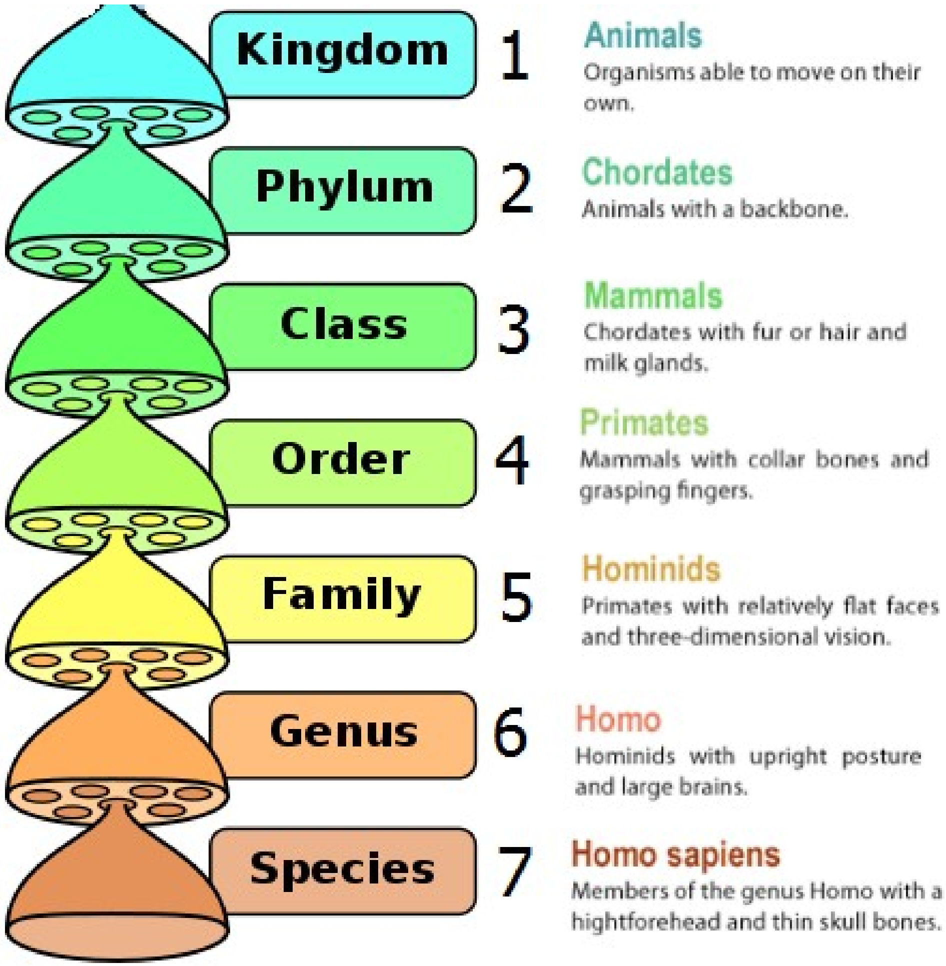
	FIVE KINGDOMS				
Property	**Monera**	**Protista**	**Fungi**	**Plantae**	**Animalia**
Cell Type	Prokaryotic	Eukaryotic	Eukaryotic	Eukaryotic	Eukaryotic
Cell Wall	Non-Cellulosic	Present	Present	Non-Cellulosic	Absent
Nuclear Membrane	Absent	Present	Present	Present	Present
Organization	Unicellular	Unicellular	Multicellular	Tissue/Organ	Tissue/Organ/ Organ System
Mode of Nutrition	Autotrophic and	Autotrophic	Heterotrophic	Autotrophic	Heterotrophic



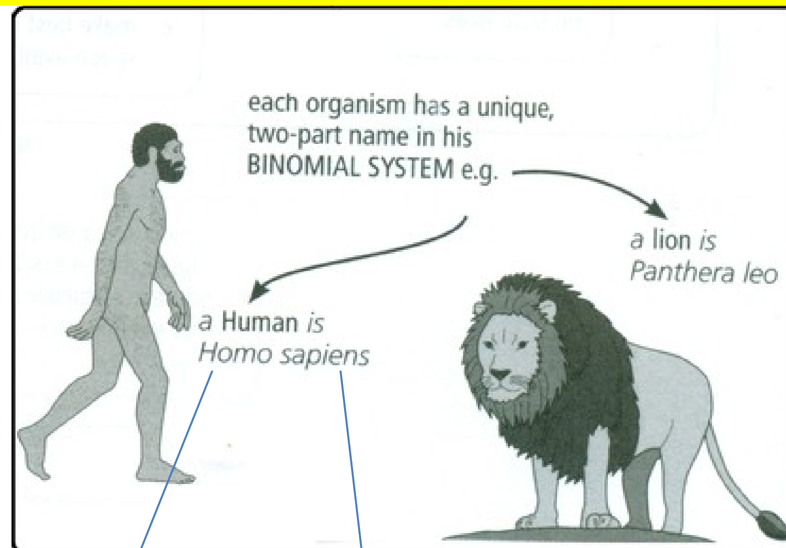
Other species:

- **Virus**: non-nucleated & acellular; DNA/ RNA with protein coat.
- **Viroids**: organisms which contains only free RNA
- **Lichens**: symbiont of algae and fungi

Classification tools and criteria: Human as an Example



The most popular method of naming organism is **binomial system** which involves the information of genus and species to name each organism (Proposed by Carl Linnaeus: Born: 1707, Died: 1778)



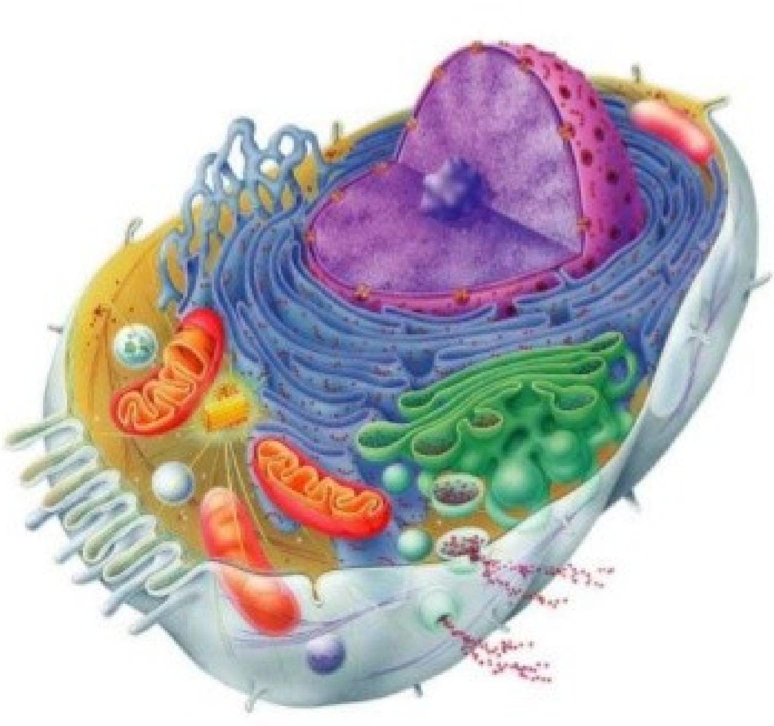
genus

species

Similarly, Scientific name of mango is *Mangifera indica*

Further readings: http://biology-igcse.weebly.com/classification-of-living-organisms.html

Cell



Cell: A basic unit of life

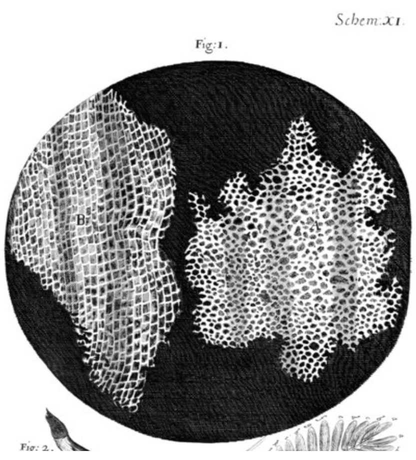
Schleiden

Schwann

- The cell is the structural and functional unit of life.
- Also regarded as the basic unit of biological activity.
- The cell was discovered by Robert Hooke in 1665.
- Cell concept: finally originated in 1838 -1839 from the contributions of Schleiden and Schwann .
- However, it was only after 1940, the complexities of cell structure were exposed.

Robert Hooke examined (under a coarse, compound microscope) very thin slices of cork and saw a multitude of tiny pores that he remarked looked like the walled compartments of a honeycomb. Because of this association, Hooke called them cells, the name they still bear.

The first man to witness a live cell under a microscope was Antony van Leeuwenhoek, who in 1674 described the algae *Spirogyra* and named the moving organisms animalcules, meaning "little animals”



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. The cell theory states:

- All living things or organisms are made of cells.
- New cells are created by old cells dividing into two.
- Cells are the basic building units of life.

Cell Theory

Classical interpretation

1. All living organisms are made up of one or more cells.
2. Cells are the basic unit of life.
3. All cells arise from pre-existing cells.(***omni cellulae e cellula***)
4. The cell is the unit of structure, physiology, and organization in living things.
5. The cell retains a dual existence as a distinct entity and a building block in the construction of organisms.

Modern interpretation

The generally accepted parts of modern cell theory include:

1.
2.
3.
4.
5.
6.

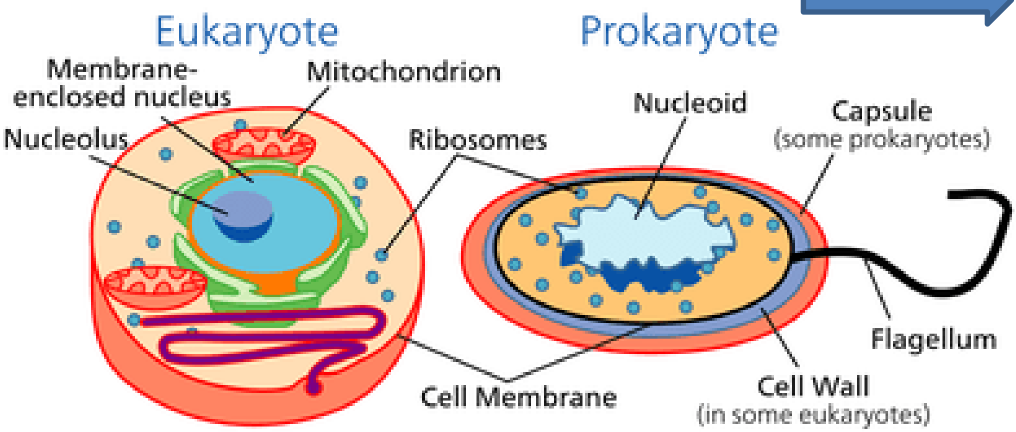
Exceptions

1. Viruses are considered alive by some, yet they are not made up of cells. Viruses have many features of life, but by definition of the cell theory, they are not alive.
2. The first cell did not originate from a pre-existing cell. There was no exact first cell since the definition of cell is imprecise.
3. Mitochondria and chloroplasts have their own genetic material, and reproduce independently from the rest of the cell.

7. Some organisms are made up of only one cell and are known as unicellular organisms.
8. Others are multicellular, composed of a number of cells.
9. The activity of an organism depends on the total activity of independent cells.

Ref: https://www.saylor.org/site/wp-content/uploads/2010/11/Wiki-Cell-Theory.pdf

Cell Type or classification



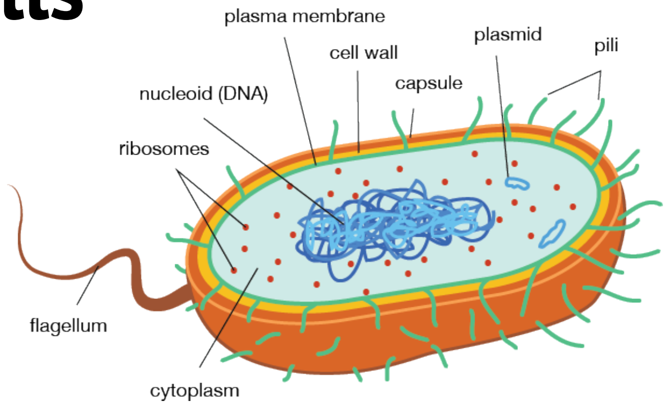
(Greek: pro-before; karyon – nucleus)
Lack a well-defined nucleus and possess relatively simple structure. e.g., all bacteria.

(Greek: eu-true; karyon-nucleus) possess a well-defined nucleus and are more complex in their structure and function.
e.g., animals and plants cells

Table 62.1 Comparison between prokaryotic and eukaryotic cells

Character	*Prokaryotic cell*	*Eukaryotic cell*
Size	Small (generally 1-10 µm)	Large (generally 10-100 µm)
Cell membrane	Cell is enveloped by a rigid cell wall	Cell is enveloped by a flexible plasma membrane
Sub-cellular organelles	Absent	Distinct organelles are found (e.g. mitochondria, nucleus, lysosomes)
Nucleus	Not well defined; DNA is found as nucleoid, histones are absent	Nucleus is well defined, surrounded by a membrane; DNA is associated with histones
Energy metabolism	Mitochondria absent, enzymes of energy metabolism bound to membrane	Enzymes of energy metabolism are located in mitochondria
Cell division	Usually fission and no mitosis	Mitosis
Cytoplasm	Organelles and cytoskeleton absent	Contains organelles and cytoskeleton (a network of tubules and filaments)

Prokaryotic Cells



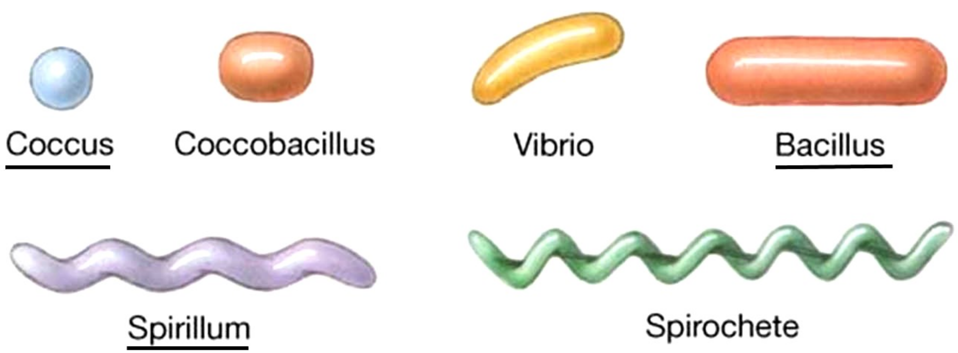
- Mainly bacteria and cynobacteria
- Grow rapidly; typical doubling time 0.5 to 3-4 hrs
- utilize a variety of nutrients as carbon source such as carbohydrates, proteins , hydrocarbons and CO_2

Size:

- typically range in size from 0.2 µm to 2.0 µm in diameter
- and from 1 to over 6 µm in length (some time upto 10 µm)
- Several exceptions:
  - Some may be as large as 600 x 80 µm
  - Ultramicrob acteria (or nannobacteria) : 0.05 µm in diameter

Shape:

- Different shapes for bacteria

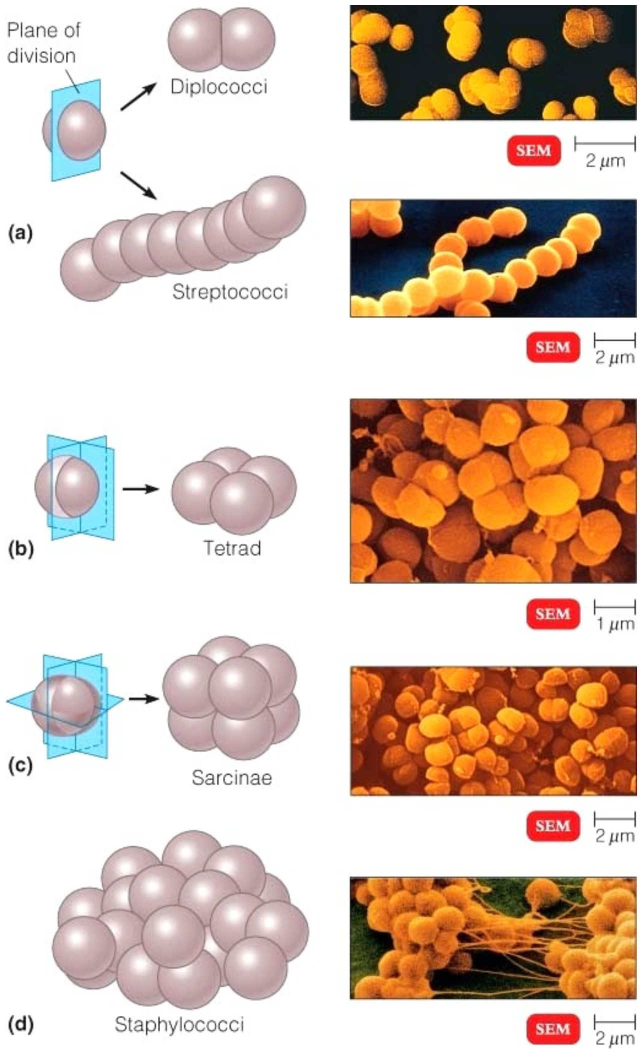


Further readings: http://biologicalexceptions.blogspot.in/2013/08/how-prokaryotes-shape-up.html

Prokaryotes cell division

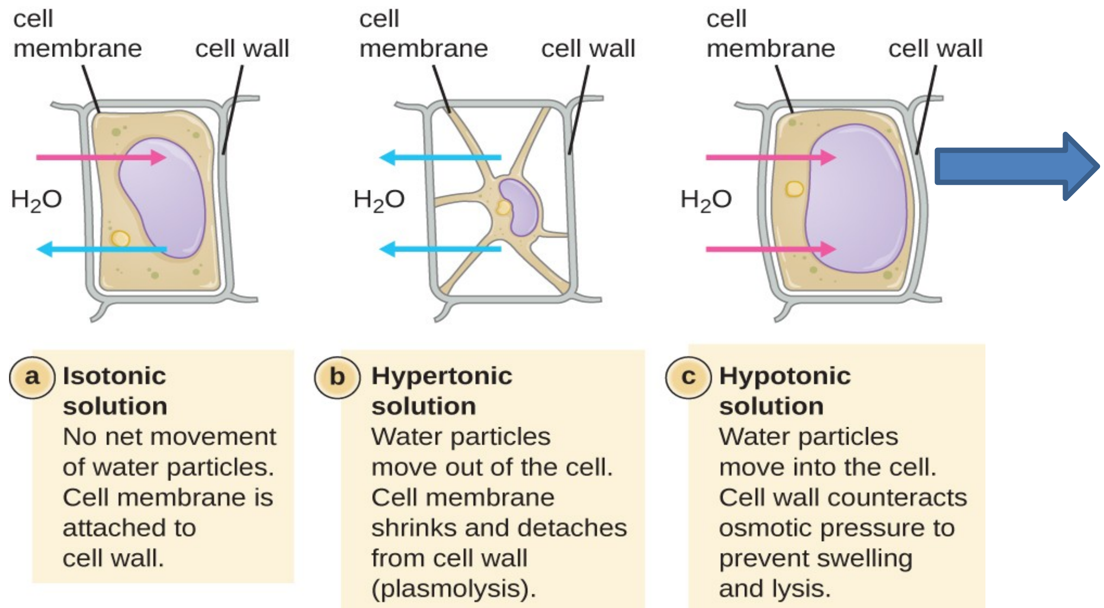
When certain prokaryotes divide, they cling to each other in a distinct arrangement.

- A **diplococcus**, for example, consists of a pair of cocci,
- while a **streptococcus** consists of a chain of cocci, and
- a **tetracoccus** consists of four cocci arranged in a cube.
- Cocci that divide in three planes and remain in groups cube like groups of eight.: **Sarcinae**
- A grapelike cluster of cocci is called a **staphylococcus.**



The cell wall and cell membrane

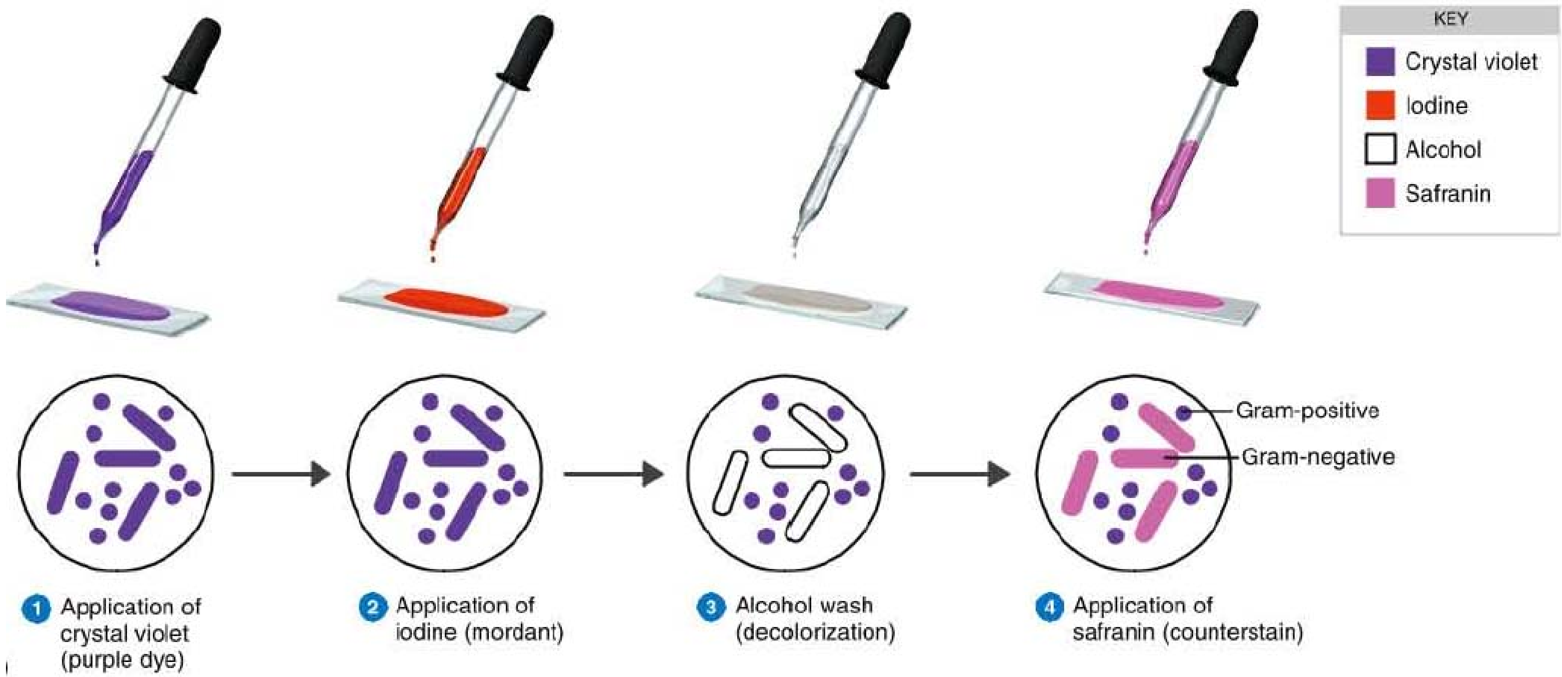
- All bacteria have a semi-rigid cell wall (**with the exception of mycoplasmas**)
- The cell wall gives shape to the organisms and prevents them from bursting, especially since materials in the cytoplasm exert osmotic pressures

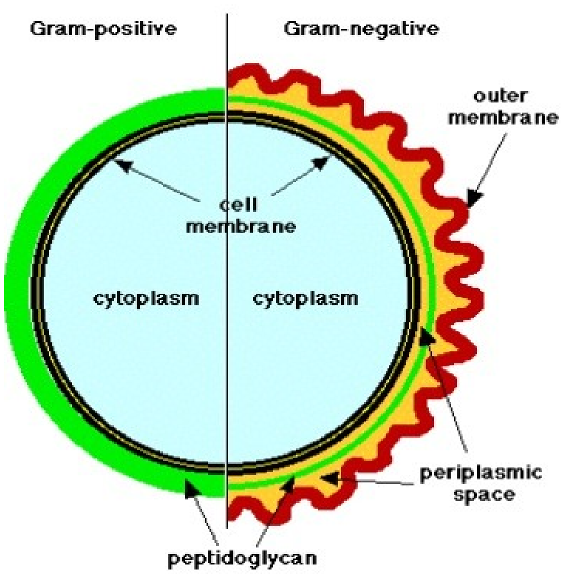


If no cell wall; cell shall burst

- Chief component of cell wall is **peptidoglycan** (also called murein), a large polymer composed of N-acetylglucosamine and N-acetylmuramic acid
- Since **peptidoglycan** is unique to bacteria, many antibiotic drugs are designed to interfere with peptidoglycan synthesis, weakening the cell wall and making bacterial cells more susceptible to the effects of osmotic pressur

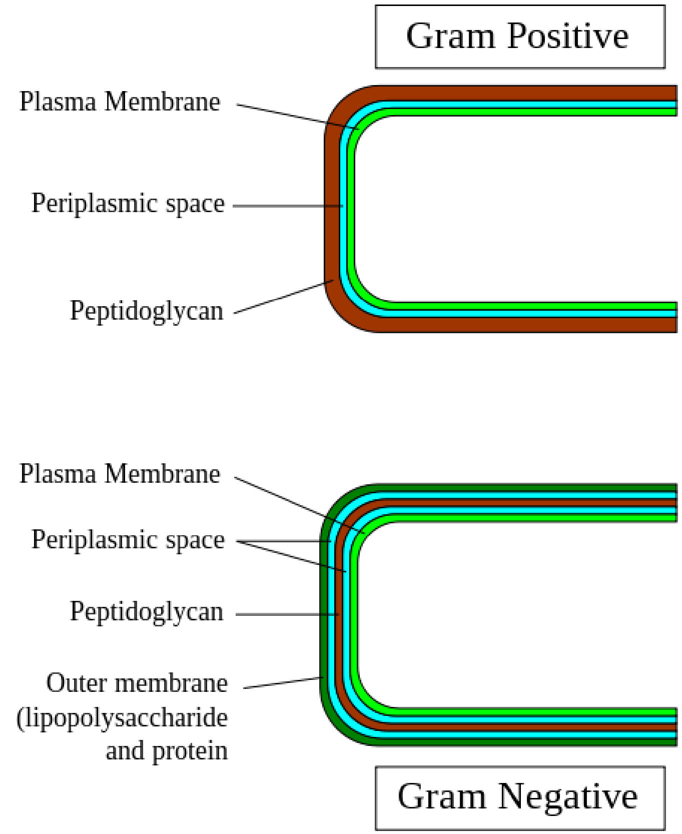
Gram positive and negative cell wall: Gram Staining





Gram-positive bacteria do not have an outer cell membrane found in Gram-negative bacteria. The cell wall of Gram-positive bacteria is high in peptidoglycan which is responsible for retaining the crystal violet dye.

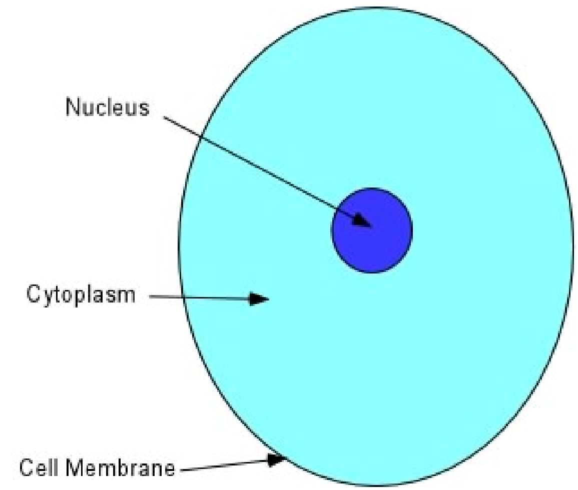
Gram-negative Bacteria versus Gram-positive Bacteria comparison chart		
	Gram-negative Bacteria	**Gram-positive Bacteria**
Gram reaction	Can be decolourized to accept counter stain (Safranin or Fuchsine); stain red or pink, they don't retain the Gram stain when washed with absolute alcohol and acetone.	Retain crystal violet dye and stain dark violet or purple, they remain coloured blue or purple with gram stain when washed with absolute alcohol and water.
Peptidoglycan layer	Thin (single-layered)	Thick (multilayered)
Teichoic acids	Absent	Present in many
Periplasmic space	present	Present
Outer membrane	Present	Absent
Lipopolysaccharide (LPS) content	High	Virtually none
Lipid and lipoprotein content	High (due to presence of outer membrane)	Low (acid-fast bacteria have lipids linked to peptidoglycan)

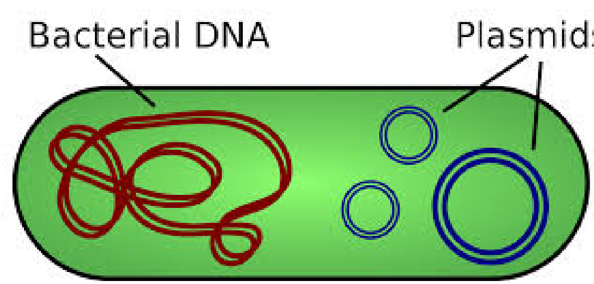


https://www.diffen.com/difference/Gram-negative_Bacteria_vs_Gram-positive_Bacteria

The cytoplasm and other internal components

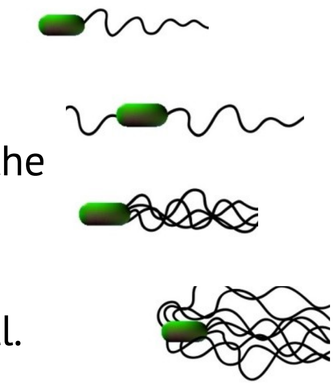
- All prokaryotes have cytoplasm surrounded by a **cell membrane**, also known as the **plasma membrane**
- The **cytoplasm** of prokaryotic cells contains ribosomes and various other granules used by the organism.
- The DNA is contained in the nuclear region (the **nucleoid**) and has **no histone** protein to support it.
- Prokaryotic cells have in their cytoplasm a single, looped **chromosome**, as well as numerous small loops of DNA called **plasmids.**
- Genetic information in the plasmids is apparently not essential for the continued survival of the organism.
- Prokaryotic **ribosomes** contain protein and ribonucleic acid (RNA) and are the locations where protein is synthesized.
- Prokaryotic ribosomes have a sedimentation rate of 70S, and are therefore known as 70S ribosomes. (Eukaryotic cells have **80S ribosomes**.)
- Certain antibiotics bind to these ribosomes and inhibit protein synthesis.



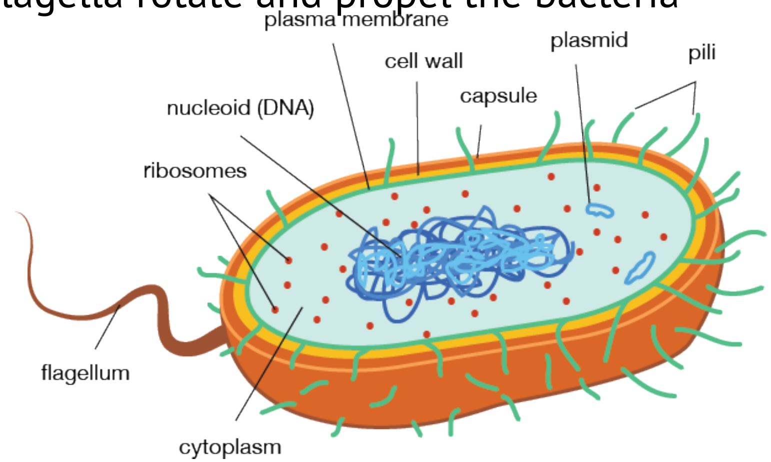


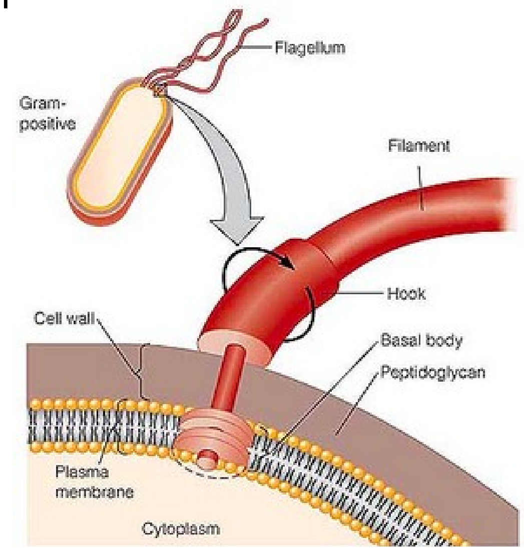
External cellular structures

- **Flagella:** Flagella are found primarily in bacterial rods and are used for motility.
  - **A monotrichous bacterium** : a bacterium with a single flagellum
  - **An amphitrichous bacterium**: flagella at both ends of the cell
  - **A lophotrichous bacterium**: two or more flagella at one end of the cell
  - **A peritrichous bacterium**: it may be surrounded by flagella.

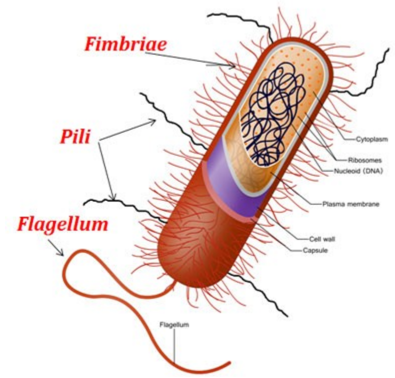


- Flagella are long, ultrathin structures, many times the length of the cell.
- They are composed of the protein **flagellin** arranged in long fibers.
- A hook like structure and basal body connect the flagellum to the cell membrane.
- Flagella rotate and propel the bacteria





External cellular structures

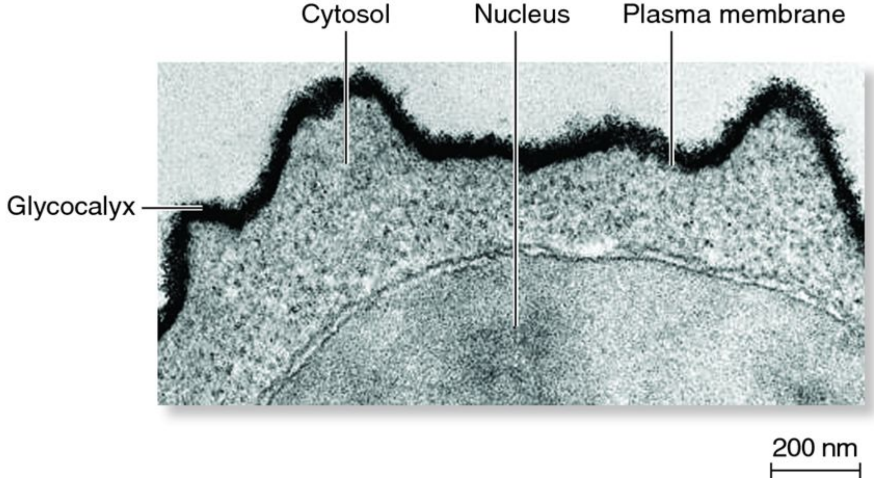


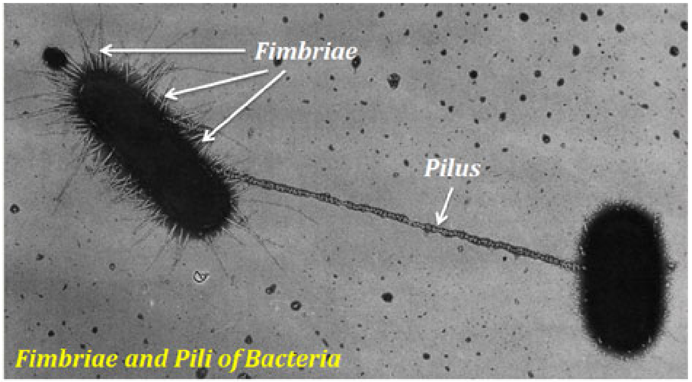
Pili (singular**, pilus):**

- Pili are used for attachments to surfaces such as tissues.
- Many pathogens possess pili, which are composed of the protein **pilin.**
- Certain pili, known as **conjugation pili**, unite prokaryotic cells to one another and permit the passage of DNA between the cells.

Glycocalyx

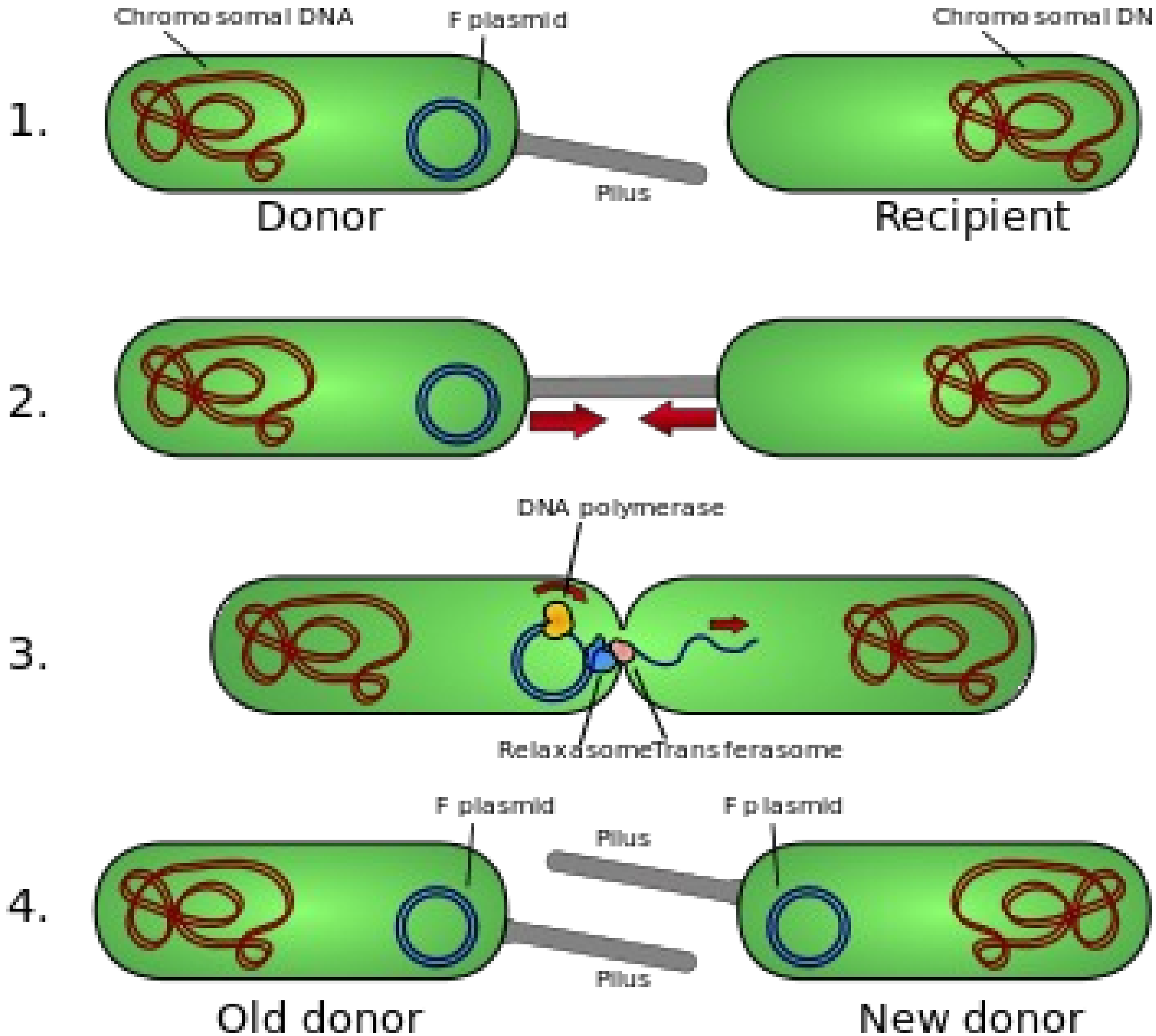
- Many bacteria, especially pathogens, are enclosed at their surface by a layer of polysaccharides and proteins called **Glycocalyx :**
  - tightly bound Glycocalyx : **capsule**
  - poorly bound Glycocalyx: **slime layer**





References:
http://nadiamicrobejournal.blogspot.in/2016/03/
http://www.easybiologyclass.com/bacterial-cell-surface-structures-and-appendages-flagella-fimbriae-and-pili/
https://www.cliffsnotes.com/study-guides/biology/microbiology/prokaryotes-and-eukaryotes/prokaryotic-cells

Bacterial Conjugation Process



Endospores

- Bacteria of the genera *Bacillus* and *Clostridium* are able to form highly resistant internal structures called **endospores**, or simply **spores**
- One vegetative (multiplying) cell produces one spore.
- Spores are able to withstand extremely high temperatures, long periods of drying, and other harsh environments.
- When conditions are favorable, the spore germinates and releases a new vegetative cell, which multiplies and reforms the colony

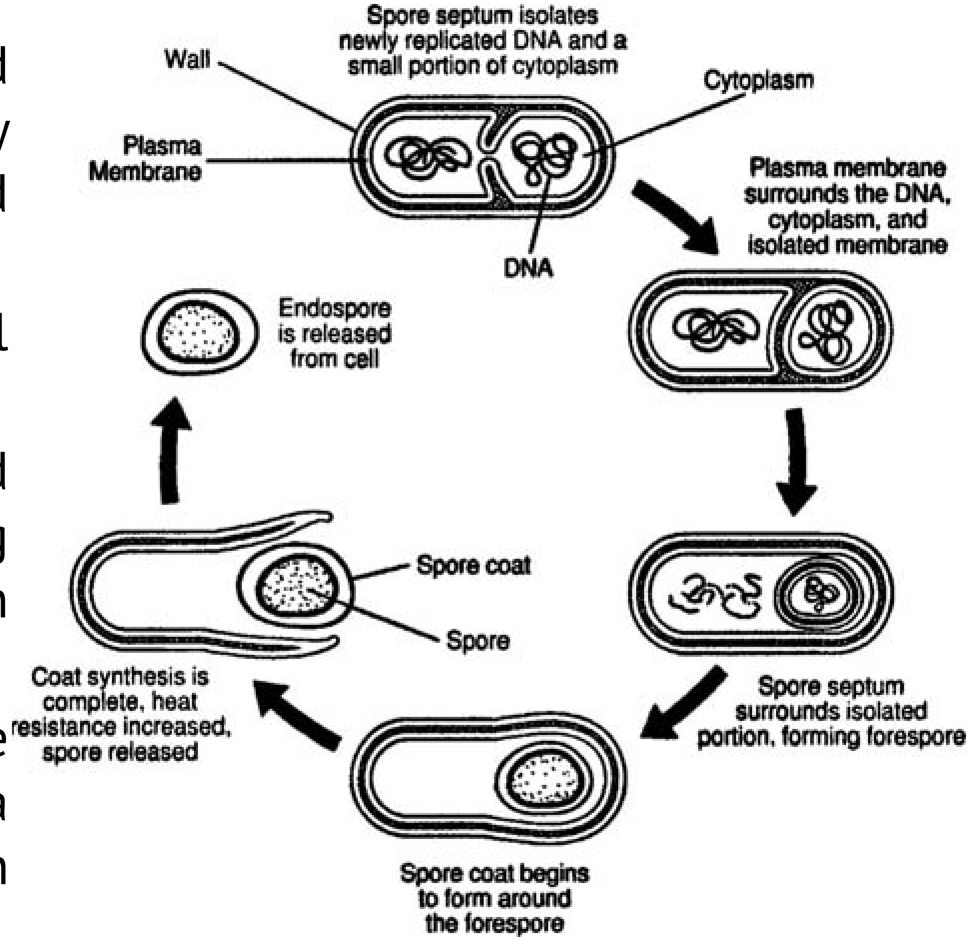


TABLE 2.3 Characteristics of Various Components of Bacteria

Part	Size	Composition and comments
Slime layer		
Microcapsule	5–10 nm	Protein–polysaccharide–lipid complex responsible for the specific antigens of enteric bacteria and other species.
Capsule	0.5–2.0 μm	Mainly polysaccharides (e.g., *Streptococcus*); sometimes polypeptides (e.g., *Bacillus antracis*).
Slime	Indefinite	Mainly polysaccharides (e.g., *Leuconostoc*); sometimes polypeptides (e.g., *Bacillus subtilis*).
Cell wall		
Gram-positive species	10–20 nm	Confers shape and rigidity upon the cell. 20% dry weight of the cell. Consists mainly of macromolecules of a mixed polymer of *N*-acetyl muramic-peptide, teichoic acids, and polysaccharides.
Gram-negative species	10–20 nm	Consists mostly of a protein–polysaccharide–lipid complex with a small amount of the muramic polymer.
Cell membrane	5–10 nm	Semipermeable barrier to nutrients. 5% to 10% dry weight of the cell, consisting of 50% protein, 28% lipid, and 15% to 20% carbohydrate in a double-layered membrane.
Flagellum	10–20 nm by 4–12 μm	Protein of the myosin–keratin–fibrinogen class, MW of 40,000. Arises from the cell membrane and is responsible for motility.
Pilus (fimbria)	5–10 nm by 0.5–2.0 μm	Rigid protein projections from the cell. Especially long ones are formed by *Escherichia coli.*
Inclusions		
Spore	1.0–1.5 μm by 1.6–2.0 μm	One spore is formed per cell intracellularly. Spores show great resistance to heat, dryness, and antibacterial agents.
Storage granule	0.5–2.0 μm	Glycogenlike, sulfur, or lipid granules may be found in some species.
Chromatophore	50–100 nm	Organelles in photosynthetic species. *Rhodospirillum rubrum* contains about 6000 per cell.
Ribosome	10–30 nm	Organelles for synthesis of protein. About 10,000 ribosomes per cell. They contain 63% RNA and 37% protein.
Volutin	0.5–1.0 μm	Inorganic polymetaphosphates that stain metachromatically.
Nuclear material		Composed of DNA that functions genetically as if the genes were arranged linearly on a single endless chromosome, but that appears by light microscopy as irregular patches with no nuclear membrane or distinguishable chromosomes. Autoradiography confirms the linear arrangement of DNA and suggests a MW of at least 1000×10^6.

With permission, from S. Aiba, A. E. Humphrey, and N. F. Millis, *Biochemical Engineering*, 2d ed., University of Tokyo Press, Tokyo, 1973.

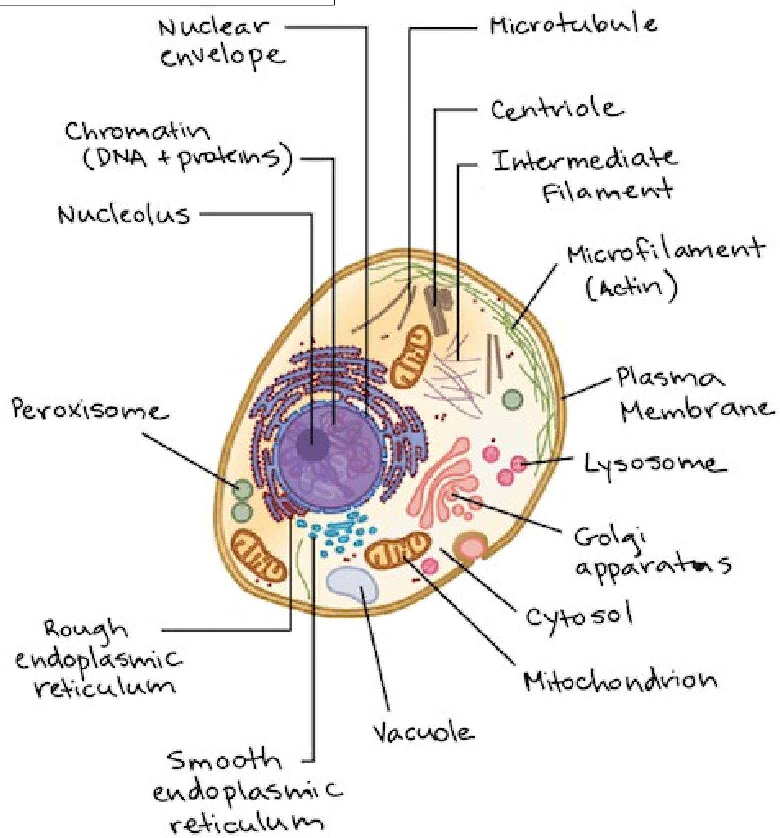
Eukaryotic cells

Eukaryotic cells have:

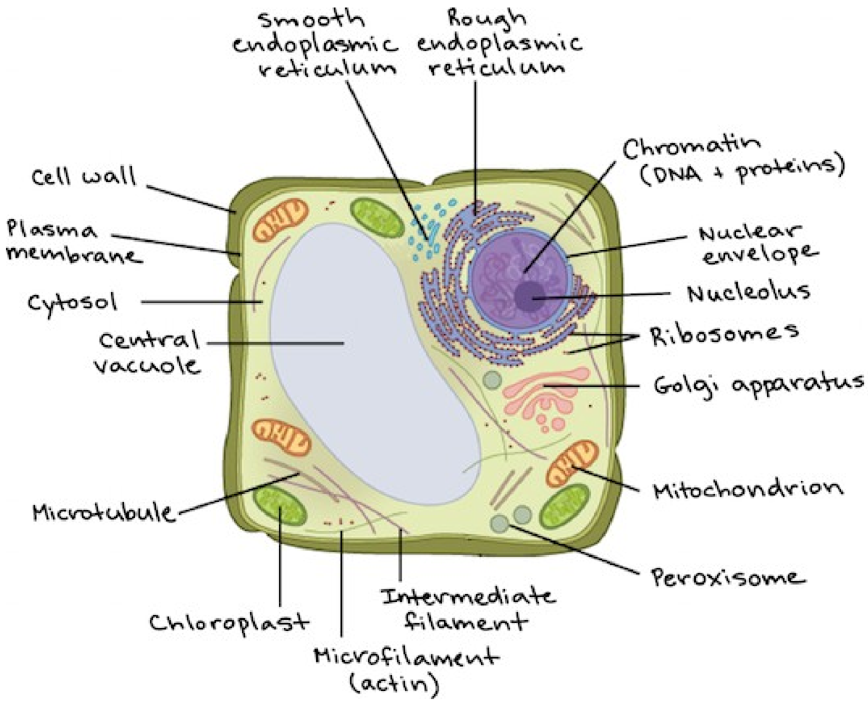
- A membrane-bound nucleus
- A number of membrane-bound organelles in cytosol
- Multiple linear chromosomes

Eukaryotes are much more complicated as compared to prokaryotic cells
Fungi, algae, protozoa, animal and plant cells constitute the eukaryotes.

A typical Animal cell



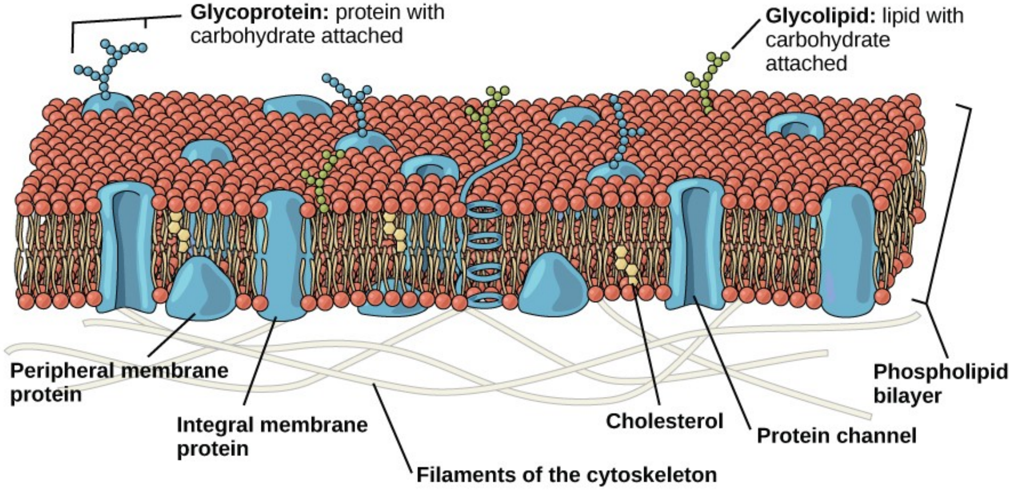
A typical Plant cell



https://www.khanacademy.org/science/biology/structure-of-a-cell/prokaryotic-and-eukaryotic-cells/a/intro-to-eukaryotic-cells

Cell wall & Membrane

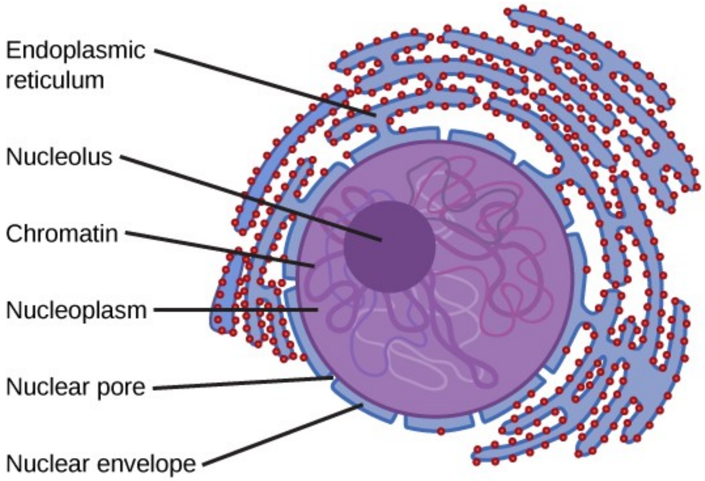
- Cell wall/membrane are similar in both Eu and Pro
- Plasma membrane: made of protein (majorly hydorphobic) and phospholipids forming a bilayer structure
- Sterols are present in cytoplasmic membrane of eukaryotes: sterols strengthen the structure and make the membrane less flexible.
- Some eukaryotes have peptidoglycan layer in their cell wall; some have polysaccharides and cellulose
- Plant cell wall is composed of cellulose fiber embedded in pectin aggregates – **gives strength to plant cells**
- Animal cells do not have cell wall but only cytoplasmic membrae- **shear sensitive and fragile**



The eukaryotic plasma membrane

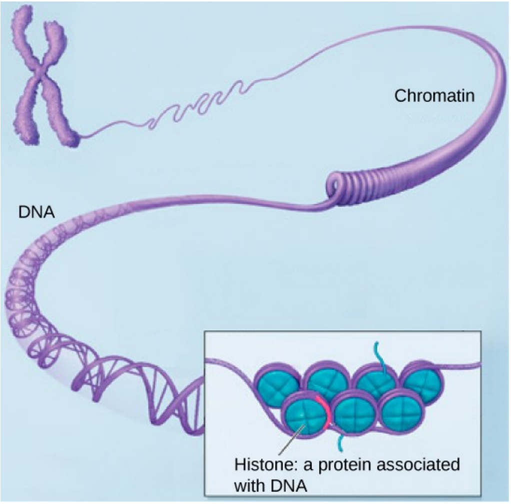
The nucleus

- Chromosomes as nuclear material surrounded by membrane: **The Nucleus**
- The nucleus in eukaryotes is the site for ribosome synthesis
- Chromosome: DNA molecule with some closely associated small proteins (histones)
- Each chrmosome contains a single linear DNA moleule on which the histone are attached
- Nuclear pore is 100nm is diameter and consists of several proteins. It is a gateway for transfer of material between nucleus and cytosol.



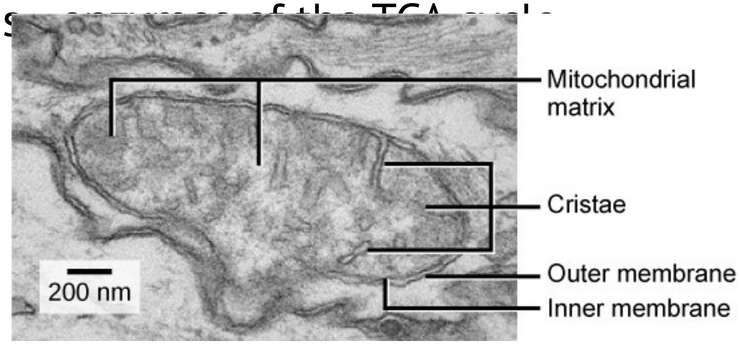
The nucleolus

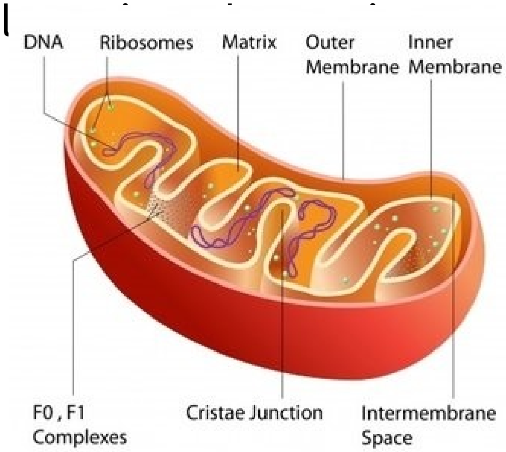
- Some chromosomes have sections of DNA that encode ribosomal RNA.
- A darkly staining area within the nucleus called the nucleolus (plural = nucleoli)
- The nucleolus aggregates the ribosomal RNA with associated proteins to assemble the ribosomal subunits that are then transported out to the nucleoplasm through the pores in the nuclear envelope



Mitochondria

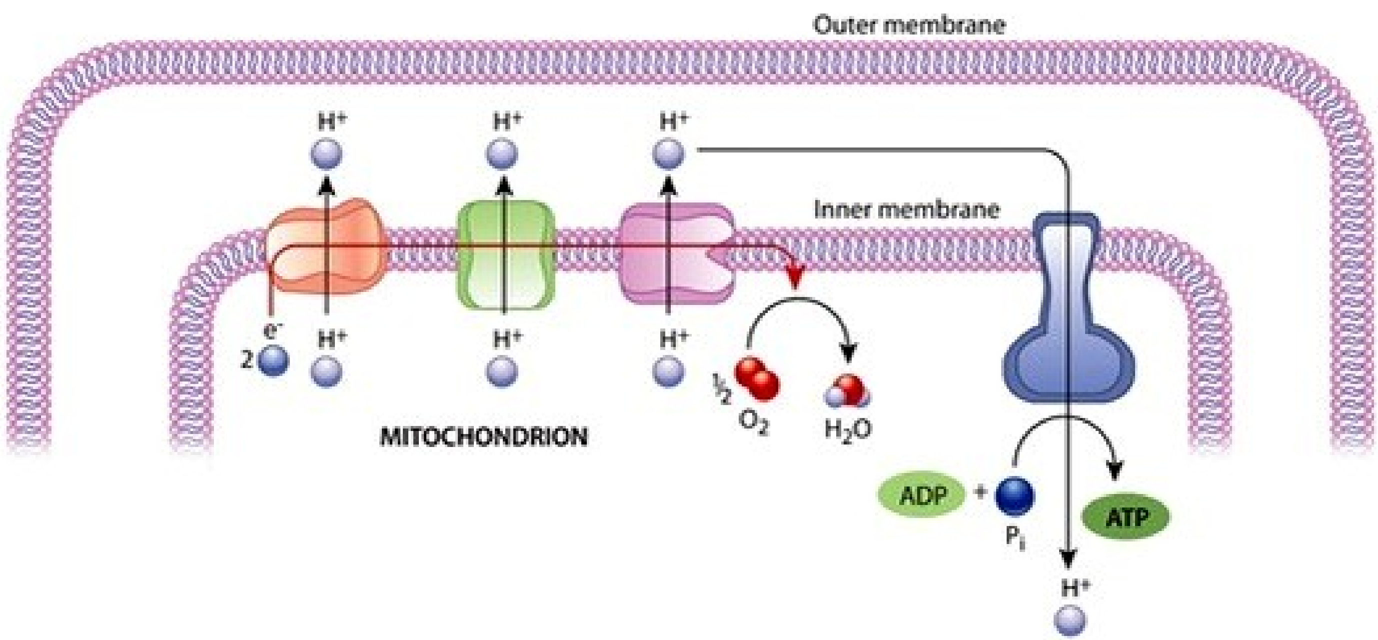
- Often called the “powerhouses” or “energy factories” of a cell
- Primary site of metabolic respiration in eukaryotes: actively involved in the generation of ATP (oxidative phosphorylation) to run the cellular activities
- Depending upon the species, the respiratory pathways may be anaerobic or aerobic but the final result is production of ATP
- Have their own genetic (DNA) material which independent of the cells DNA
- For some specific cases, the number of mitochondria per cell is tunable, depending, typically, on energy demand
- Both the inner and outer membranes are phospholipid bilayers embedded with proteins (called **porins**) that mediate transport across them and catalyze various other biochemical reactions.
- The inner membrane layer has folds called ***cristae*** that increase the surface area into which respiratory chain proteins can be embedded.
- The region within the cristae is called the mitochondrial ong other things





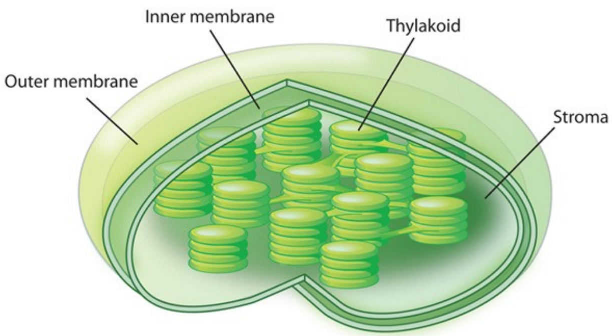
- During respiration, protons are pumped by respiratory chain complexes from the matrix into a region known as the *intermembrane space* (between the inner and outer membranes).

- This creates a concentration gradient of protons that another protein complex, called **ATP synthase**, uses to power synthesis of the energy carrier molecule ATP

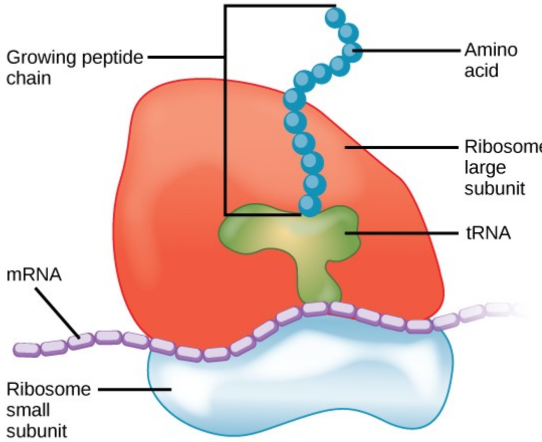


https://www.nature.com/scitable/topicpage/mitochondria-14053590

Chloroplasts



- found in plant, algae and other lower invertebrates such as euglena
- allow plants (and other organism having it) to capture the energy of the Sun in energy-rich molecules
- chloroplasts retain small, circular genomes that resemble those of cyanobacteria, although they are much smaller. (Mitochondrial genomes are even smaller than the genomes of chloroplasts)
- Like mitochondria, chloroplasts are surrounded by two membranes:
  - The outer membrane permeable to small organic molecules and
  - the inner membrane less permeable and studded with transport proteins.
- The innermost matrix of chloroplasts, called the **stroma**, contains metabolic enzymes and multiple copies of the chloroplast genome.
- Chloroplasts also have a third internal membrane called the **thylakoid** membrane
- The thylakoids contain the **light-harvesting complex**, including pigments such as chlorophyll, as well as the electron transport chains used in photosynthesis



Ribosomes

- cellular structures responsible for protein synthesis
- are large complexes of protein and RNA
- consist of two subunits, called large and small
- Ribosomes receive their "instructions" for protein synthesis from the nucleus, where the DNA is transcribed into messenger RNA (mRNA)

Peroxisomes

- *Peroxisomes* are small, round organelles enclosed by single membranes.
- These organelles carry out redox reactions that oxidize and break down fatty acids and amino acids

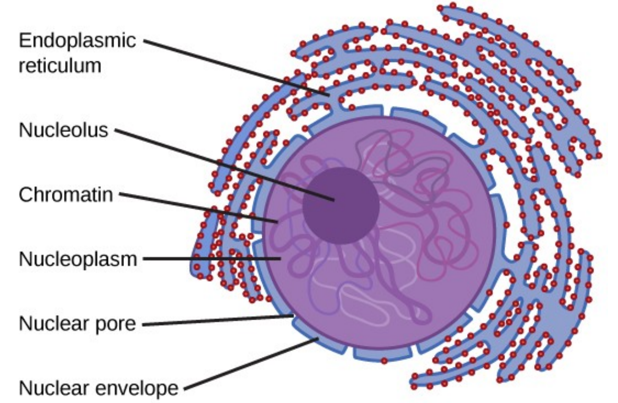
Vesicles and vacuoles

- are membrane-bound sacs that function in storage and transport

Lysosomes

- Animal cells have another set of organelles not found in plant cells: lysosomes.
- the *lysosomes* are sometimes called the cell's "garbage disposal".

Endoplasmic Reticulum



- The vesicular network starts from nuclear membrane and spread throughout the cytosol constitutes endoplasmic reticulum
- Two type:
  - RER: has ribosome attached to it to give a rough appearance
  - SER: don not have ribosome and are smooth
- **Functions of endoplasmic reticulum:**
  - Synthesis of steroid hormone in gonad cells.
  - Detoxification
  - Ca2+ sequestration
  - Synthesis of protein, phospholipid and carbohydrate.
  - Protein sorting to different organelles.
  - Protein modifications such as glycosylation etc.

Golgi Bodies- take part in Protein sorting ,Protein modifications (Glycosylation) and Proteolysis

Bacterial Growth in Batch

Cell growth and binary fission

- increase in cellular constituents that may result in:
  - increase in cell number
    - e.g., when microorganisms reproduce by budding or binary fission
  - increase in cell size
    - e.g., coenocytic microorganisms have nuclear divisions that are not accompanied by cell divisions
- microbiologists usually study population growth rather than growth of individual cells

Binary fission

- A process in which a cell grows to twice its normal size and divides in half to produce two daughter cells of equal size.

- Binary fission generally involves four steps as illustrated in next Figure for a prokaryotic cell.

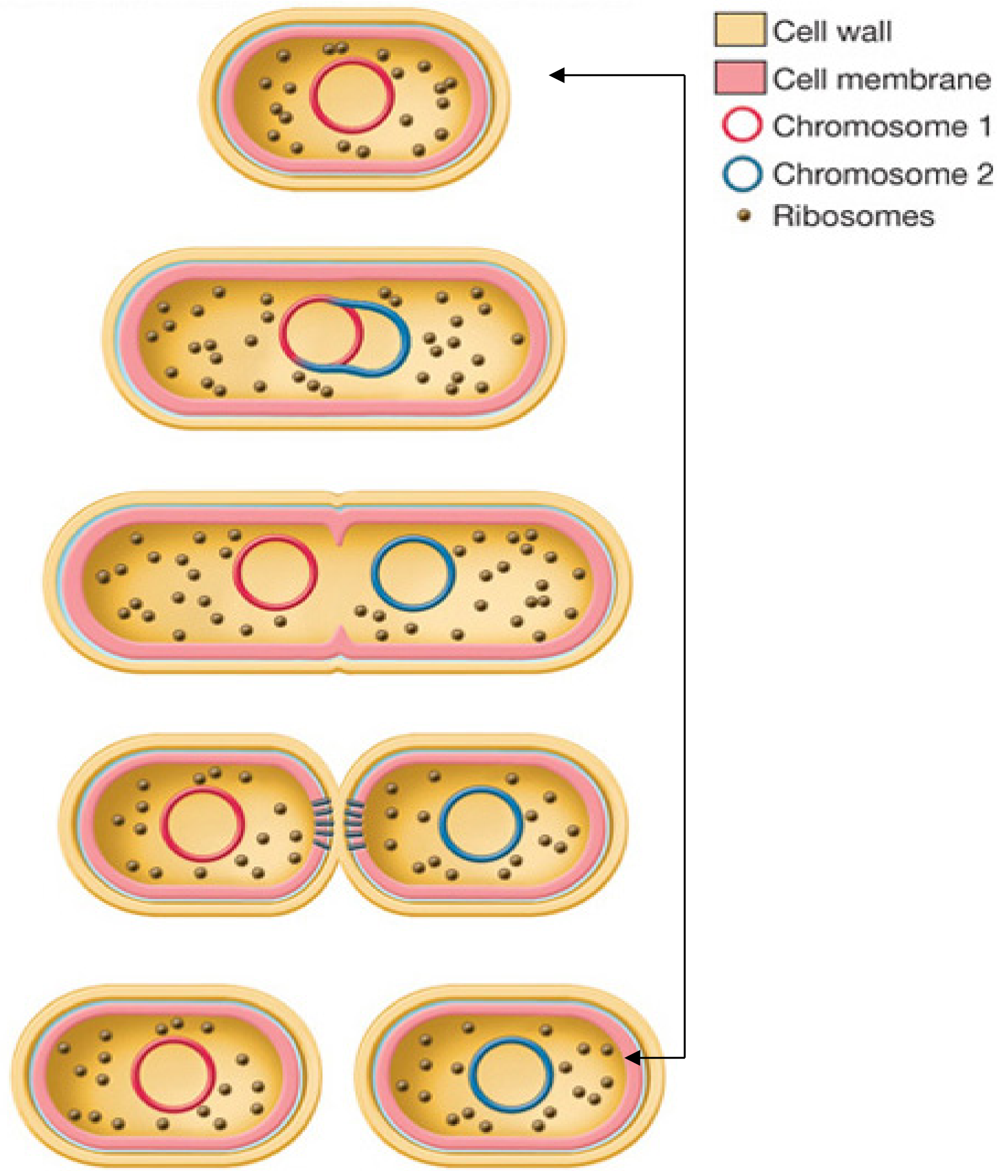
(a) A young cell at early phase of cycle

(b) A parent cell prepares for division by enlarging its cell wall, cell membrane, and overall volume.

(c) The septum begins to grow inward as the chromosomes move toward opposite ends of the cell. Other cytoplasmic components are distributed to the two developing cells.

(d) The septum is synthesized completely through the cell center, and the cell membrane patches itself so that there are two separate cell chambers.

(e) At this point, the daughter cells are divided. Some species separate completely as shown here, while others remain attached, forming chains, doublets, or other cellular arrangements.



1. The cell replicates its chromosome (DNA molecule). The duplicated chromosomes are attached to the cytoplasmic membrane. (In eukaryotic cells chromosomes are attached to microtubules).

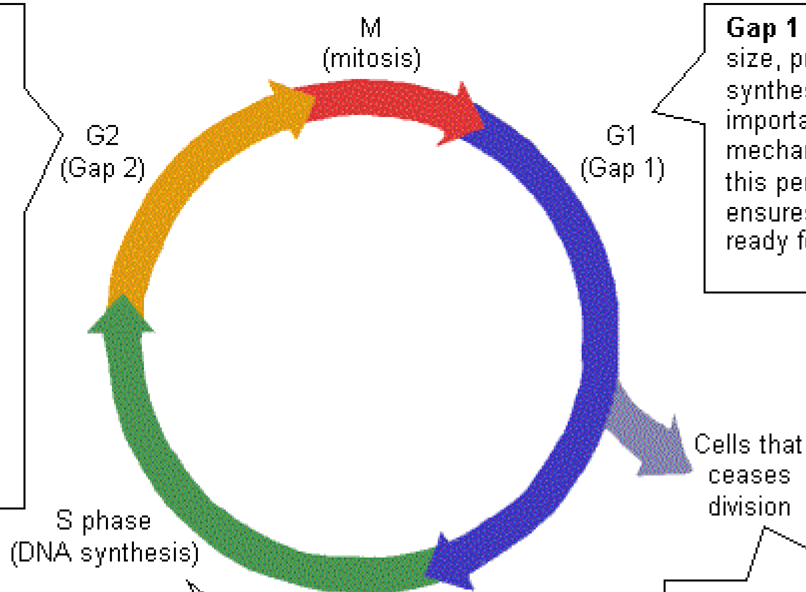
2. The cell elongates and growth between attachment sites pushes the chromosomes apart. (Eukaryotic cells segregate their chromosomes by *mitosis*).

3. The cell forms a new cytoplasmic membrane and wall (septum) across the midline.

- 4. When the septum is completed, the daughter cells may remain attached, or they may separate completely. When the cells remain attached, further binary fission in parallel planes produces a chain. When further divisions are in different planes, the cells become a cluster.

- 5. The process repeats

Gap 2 - the cell will continue to grow and produce new proteins required for cell division. At the end of this gap is another control checkpoint (G2 Checkpoint) to determine if the cell can now proceed to enter M (mitosis) and divide



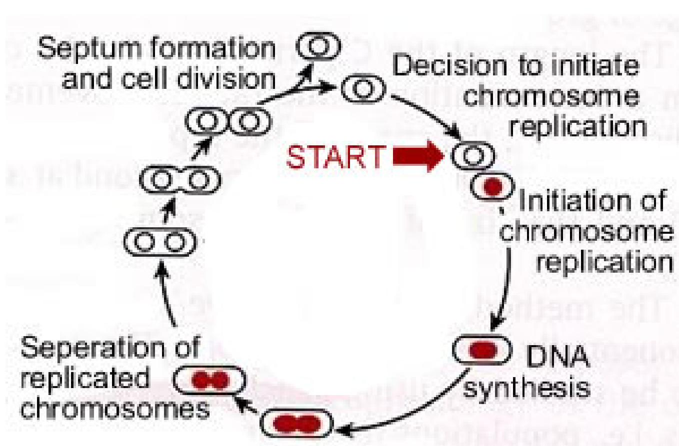
Gap 1 - Cells increase in size, produce RNA and synthesize proteins. An important cell cycle control mechanism activated during this period (G1 Checkpoint) ensures that everything is ready for DNA synthesis.

Eukaryotes

Interphase = G1 + S + G2

Synthesis phase – DNA replication takes place

Gap 0 -There are times when a cell will leave the cycle and quit dividing. This may be a temporary resting period i.e. liver cell, or more permanent, i.e. a cell that has reached an end stage of development and will no longer divide (e.g. nerve cells in the brain).



Prokaryotes

Growth Terminology and the concept of exponential growth

- The interval for the formation of two cells from one is called a **generation**

- The *time required* for this to occur is called the **generation time**.

- Generation time is the time required for the cell population to double (the cell *mass* doubles during this period as well).

- Because of this, the generation time is also called the *doubling time*.

- In nature, microbial doubling times may be much longer than those obtained in laboratory culture.
- This is because in nature, ideal growth conditions for a given organism may exist only intermittently.
- Depending on resource availability, physiochemical conditions (temperature, pH, and the like), moisture availability, and seasonal changes, bacterial populations in nature double only once every few weeks, or even longer.

A mathematical relationship exists between the number of cells present in a culture *initially* and the number present *after a period of exponential growth:*

$$N = N_0 2^n$$

where

N is the final cell number,

N_o is the initial cell number,

n is the number of generations that have occurred during the period of exponential growth.

The Mathematics of Exponential Growth

- As one cell divides to become two cells,

  2° --'> 2^{1}.

- As two cells become four,

  2^{1} --'> 2^{2}, and so on

The <u>generation time</u> (g) of the exponentially growing population is (t / n),

where

t is the duration of exponential growth expressed in days, hours, or minutes, depending on the organism and the growth conditions.

From a knowledge of the initial and final cell numbers in an exponentially growing cell population, it is possible to calculate n, and from n and knowledge of t, the generation time g.

Relation equation of N and N_o to n

The equation $N = N_o 2^n$ can be expressed in terms of n as follows:

$$N = N_o 2^n$$

$$\log N = \log N_o + n \log 2$$

$$\log N - \log N_o = n \log 2$$

$$n = \frac{\log N - \log N_o}{\log 2} = \frac{\log N - \log N_o}{0.301}$$

$$\boxed{n = 3.3\,(\log N - \log N_o)}$$

example

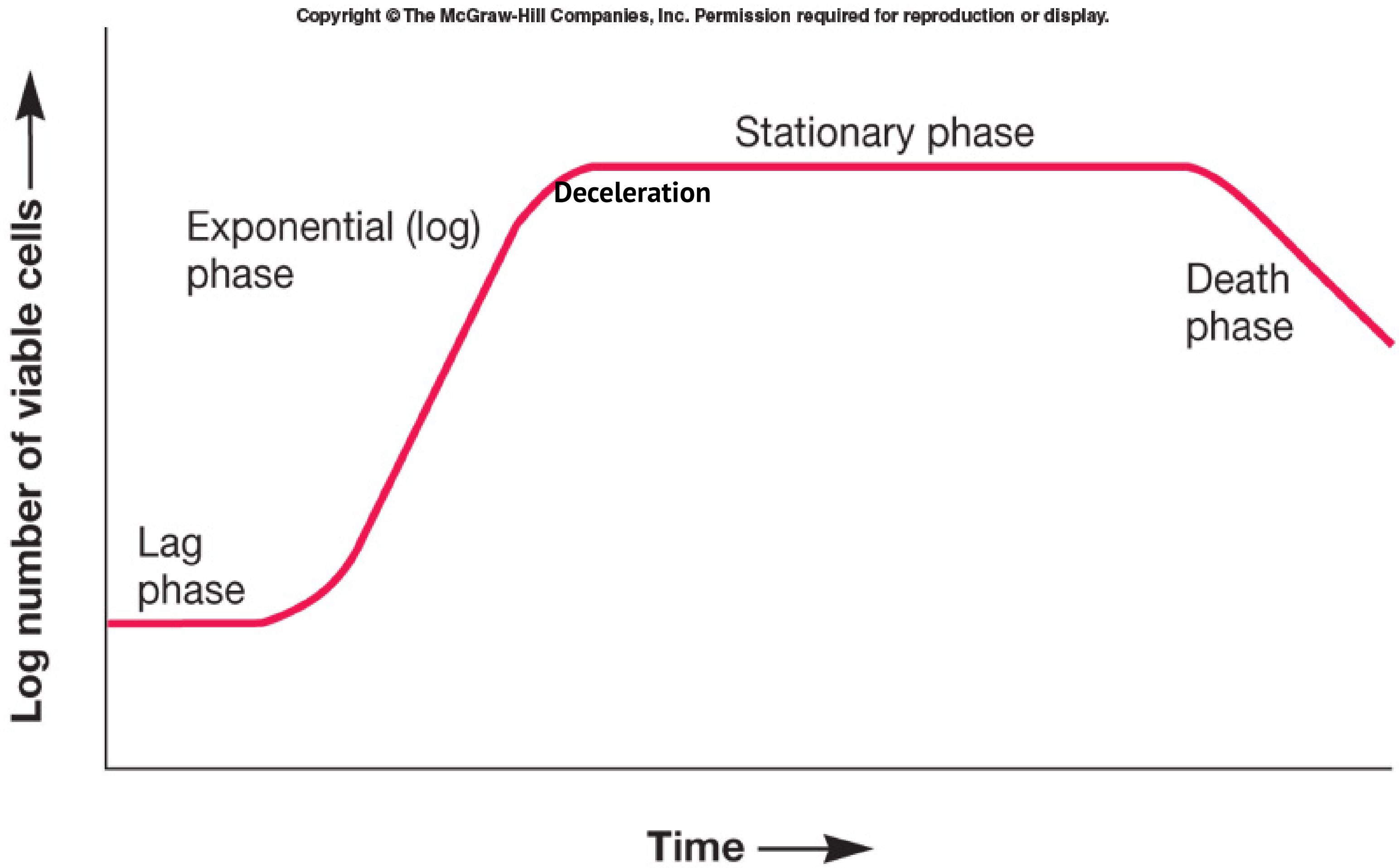
$N = 10^8$, $N_o = 5 \times 10^7$, and $t = 2$

$$n = 3.3\ (\log N - \log N_o)$$

$$\begin{aligned} n &= 3.3\ [\log(10^8) - \log(5 \times 10^7)] \\ &= 3.3(8 - 7.69) \\ &= 3.3(0.301) \\ &= 1 \end{aligned}$$

generation time, $g = t/n = 2 / 1 = 2$ h

The Growth cycle or phases of microbial growth



The information in the all below slides was taken from Prof. Elteen's lecture ppt on "Microbial Nutrition and Growth" for discussion and better understanding of the topic.

Classification of Microorganisms by Temperature Requirements

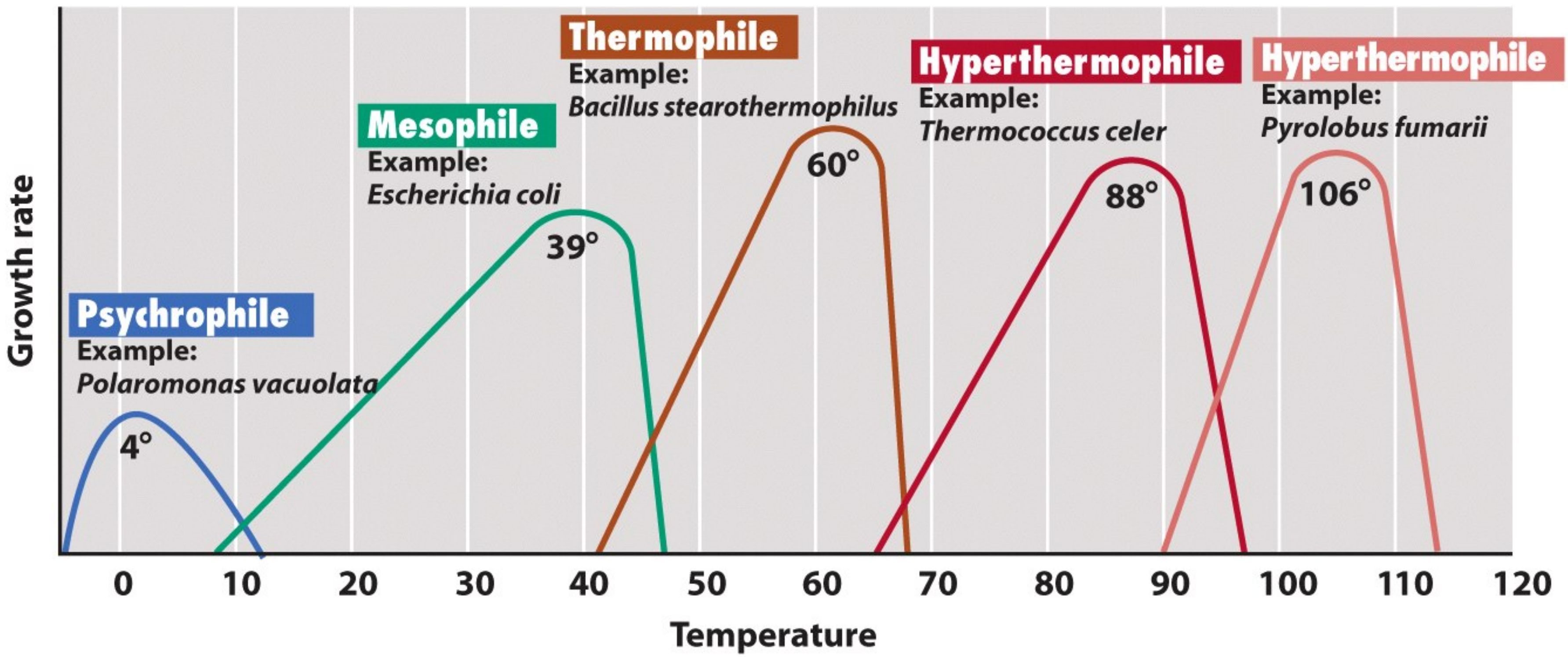


Figure 6-17 Brock Biology of Microorganisms 11/e

Temperature Classes of Organisms

- **Mesophiles (20 – 45C)**
  - **Midrange temperature optima**
  - **Found in warm-blooded animals and in terrestrial and aquatic environments in temperate and tropical latitudes**
- **Psychrophiles (0-20C)**
  - **Cold temperature optima**
  - **Most extreme representatives inhabit permanently cold environments**
- **Thermophiles (50- 80C)**
  - **Growth temperature optima between 45ºC and 80ºC**
- **Hyperthermophiles**
  - **Optima greater than 80°C**
  - **These organisms inhabit hot environments including boiling hot springs, as well as undersea hydrothermal vents that can have temperatures in excess of 100ºC**

pH and Microbial Growth

pH – measure of $[H^+]$

each organism has a pH range and a pH optimum

acidophiles – optimum in pH range 1-4
alkalophiles – optimum in pH range 8.5-11

lactic acid bacteria – 4-7
***Thiobacillus thiooxidans* – 2.2-2.8**
fungi – 4-6

internal pH regulated by BUFFERS and near neutral adjusted with ion pumps

Human blood and tissues has pH 7.2 ± 0.2

Environmental factors and growth

1. Osmotic Effect and water activity

organisms which thrive in high solute – osmophiles
organisms which tolerate high solute – osmotolerant

organisms which thrive in high salt – halophiles
organisms which tolerate high salt – halotolerant

organisms which thrive in high pressure – barophiles
organisms which tolerate high pressure – barotolerant

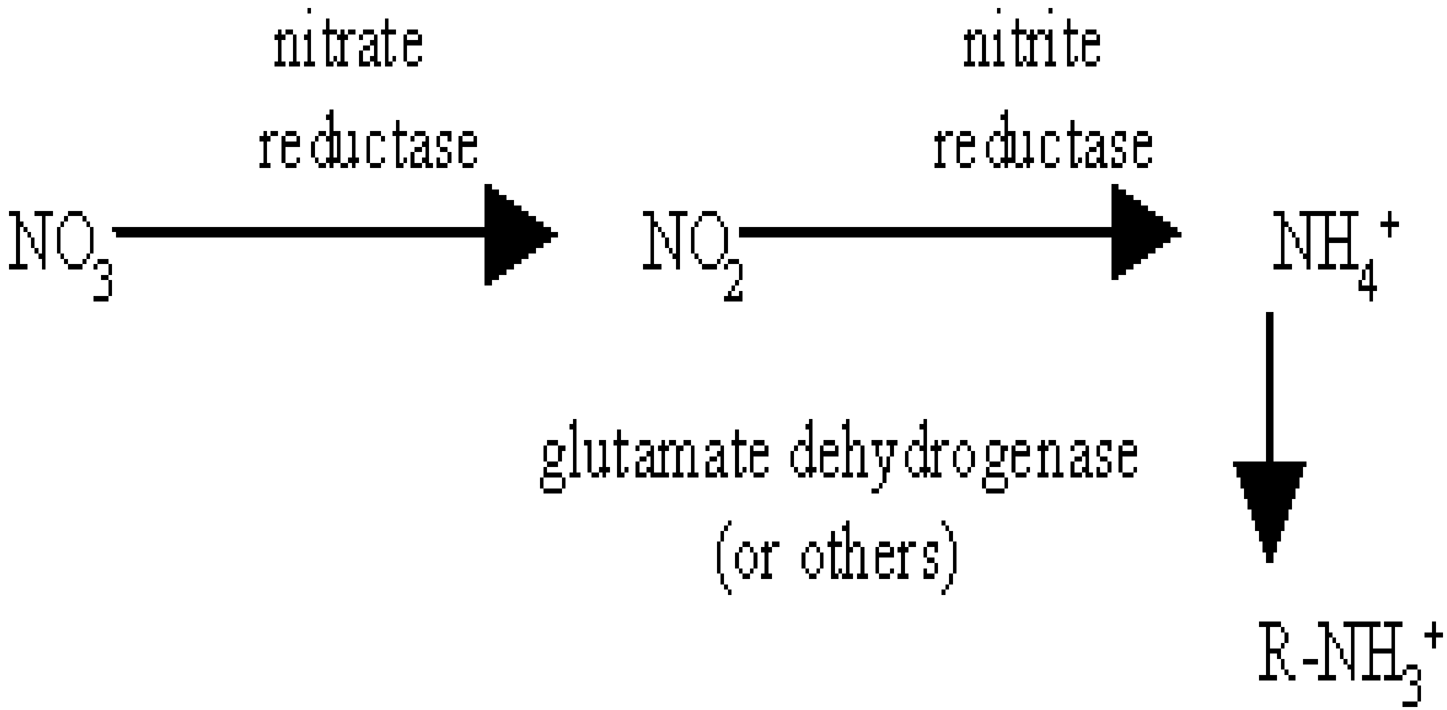
Microbial Nutrition

- Why is nutrition important?
  - The hundreds of chemical compounds present inside a living cell are formed from nutrients.

- **Macronutrients** : elements required in fairly large amounts
- **Micronutrients** : metals and organic compounds needed in very small amounts

Main Macronutrients

- Carbon (C, 50% of dry weight) and nitrogen (N, 12% of dry weight)
- **Autotrophs** are able to build all of their cellular organic molecules from carbon dioxide
- Nitrogen mainly incorporated in proteins, nucleic acids
- Most Bacteria can use Ammonia -NH_3 and many can also use NO_3^-
- Nitrogen fixers can utilize atmospheric nitrogen (N_2)


nitrate
reductase
NO_3
NO_2
nitrite
reductase
NH_4^+
glutamate dehydrogenase
(or others)
$R\text{-}NH_3^+$

Microbial growth requirements

- Source of carbon for basic structures
- Source of cellular energy (ATP or related compounds) to drive metabolic reactions
- Source of high energy electrons/H, reducing power, typically in form of NADH/NADPH

Classification of organisms based on sources of C and energy used

		Energy Source	
		Light *(photo-)*	Chemical compounds *(chemo-)*
Carbon Source	Carbon dioxide *(auto-)*	***Photoautotrophs*** • Plants, algae, and cyanobacteria use H_2O to reduce CO_2, producing O_2 as a byproduct • Photosynthetic green sulfur and purple sulfur bacteria do not use H_2O nor produce O_2	***Chemoautotrophs*** • Hydrogen, sulfur, and nitrifying bacteria
	Organic compounds *(hetero-)*	***Photoheterotrophs*** • Green nonsulfur and purple nonsulfur bacteria	***Chemoheterotrophs*** • Aerobic respiration: most animals, fungi, and protozoa, and many bacteria • Anaerobic respiration: some animals, protozoa, and bacteria • Fermentation: some bacteria and yeasts

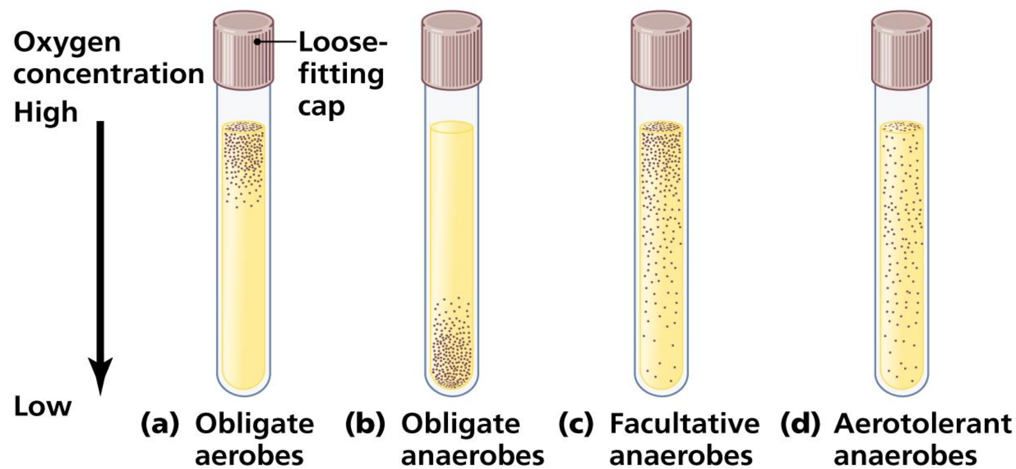
Nitrogen requirements

- Although many biological components within living organisms contain N, and N_2 is the most abundant component of air, very few organisms can “fix” or utilize N_2 by converting it to NH_3
- N is often growth limiting as organisms must find source as NH_4^+ for biosynthesis
- Photosynthetic organisms and many microbes can reduce NO_3^- to NH_4^+

Classification of organisms based on O_2 utilization

- Utilization of O_2 during metabolism yields toxic by-products including O_2^-, singlet oxygen ($^1O_2$) and/or H_2O_2.
- Toxic O_2 products can be converted to harmless substances if the organism has catalase (or peroxidase) and superoxide dismutase (SOD)
- SOD converts O_2^- into H_2O_2 and O_2
- Catalase breaks down H_2O_2 into H_2O and O_2
- Any organism that can live in or requires O_2 has SOD and catalase (peroxidase)

Classification of organisms based on O_2 utilization



- Obligate (strict) aerobes require O_2 in order to grow
- Obligate (strict) anaerobes cannot survive in O_2
- Facultative anaerobes grow better in O_2
- Aerotolerant organisms don’t care about O_2

Table 6.4	Oxygen relationships of microorganisms			
Group	**Relationship to O_2**	**Type of metabolism**	**Example**[a]	**Habitat**[b]
Aerobes				
Obligate	Required	Aerobic respiration	*Micrococcus luteus* (B)	Skin, dust
Facultative	Not required, but growth better with O_2	Aerobic respiration, anaerobic respiration, fermentation	*Escherichia coli* (B)	Mammalian large intestine
Microaerophilic	Required but at levels lower than atmospheric	Aerobic respiration	*Spirillum volutans* (B)	Lake water
Anaerobes				
Aerotolerant	Not required, and growth no better when O_2 present	Fermentation	*Streptococcus pyogenes* (B)	Upper respiratory tract
Obligate	Harmful or lethal	Fermentation or anaerobic respiration	*Methanobacterium formicicum* (A)	Sewage sludge digestors, anoxic lake sediments

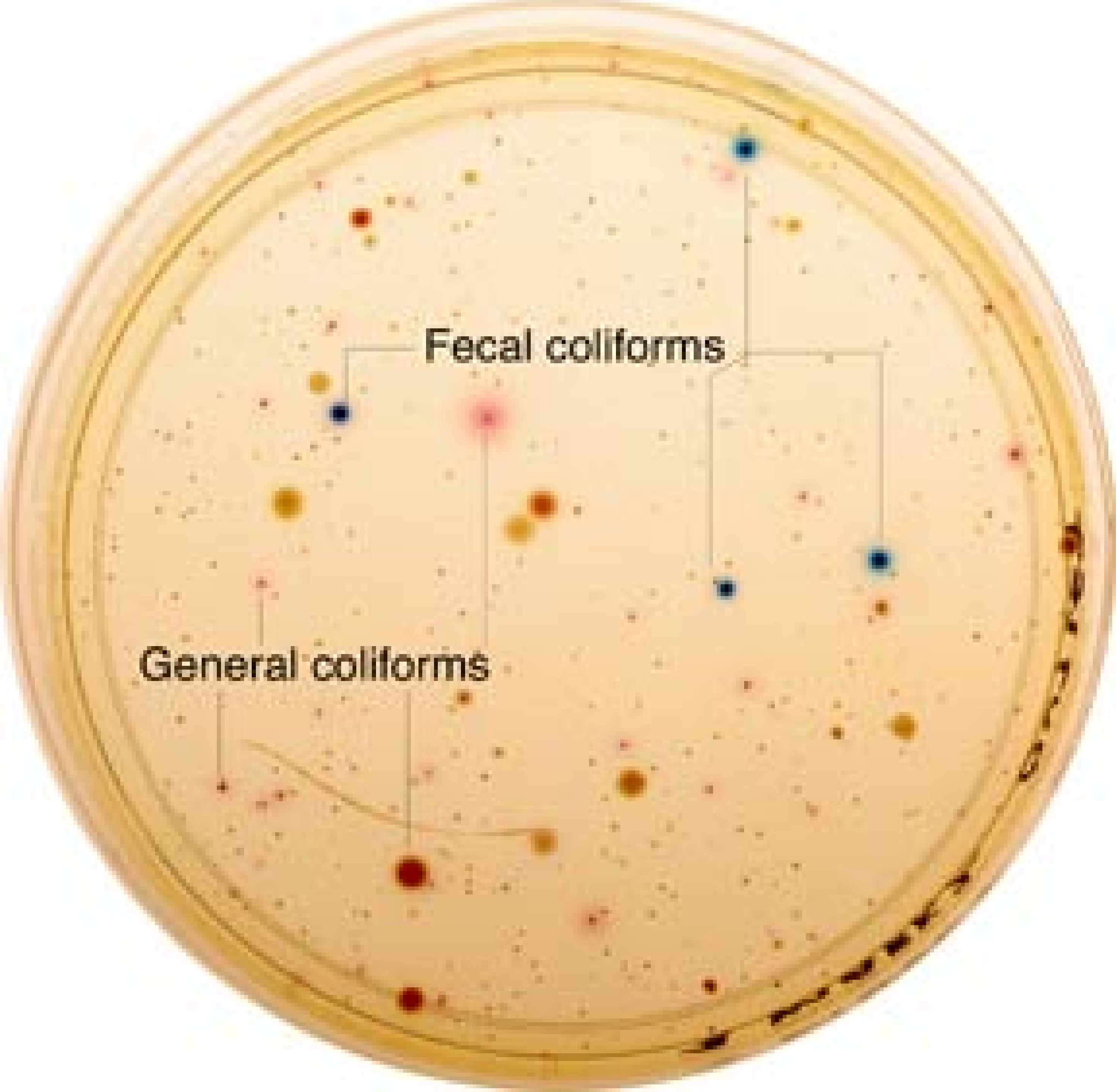
[a] Letters in parentheses indicate phylogenetic status (B, *Bacteria*; A, *Archaea*). Representatives of either domain of prokaryotes are known in each category. Most eukaryotes are obligate aerobes, but facultative aerobes (for example, yeast) and obligate anaerobes (for example, certain protozoa and fungi) are known.

[b] Listed are typical habitats of the example organism.

Table 6-4 Brock Biology of Microorganisms 11/e

Culture Media: Composition

- **Culture media** supply the nutritional needs of microorganisms (C ,N, Phosphorus, trace elements, etc)
  - **defined medium** : precise amounts of highly purified chemicals
  - **complex medium** (or undefined) : highly nutritious substances.
- **In clinical microbiology,**
  - **Selective :** contains compounds that selectively inhibit
  - **Differential:** contains indicator
  - terms that describe media used for the isolation of particular species or for comparative studies of microorganisms


Fecal coliforms
General coliforms

Bacterial Colonies on Solid Media

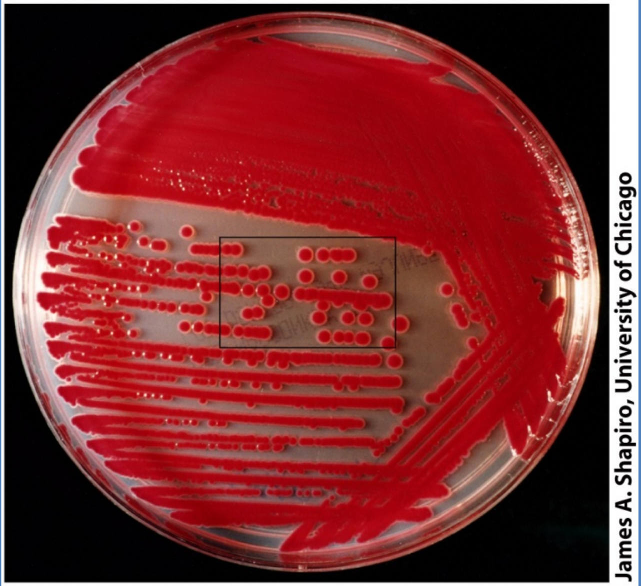


Figure 5-2a Brock Biology of Microorganisms 11/e
© 2006 Pearson Prentice Hall, Inc.

Figure 5-2c Brock Biology of Microorganisms 11/e
© 2006 Pearson Prentice Hall, Inc.

P. aeruginosa (TSA)

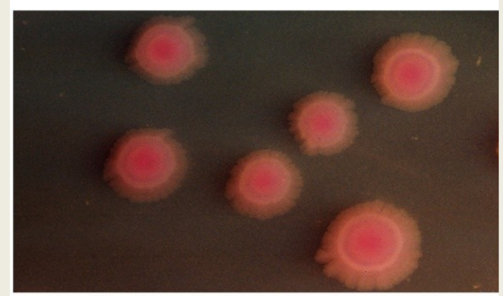


Figure 5-2d Brock Biology of Microorganisms 11/e
© 2006 Pearson Prentice Hall, Inc.

Shigella Flexneri or
S. Flexneri (Mac)

Serratia Marcescens (Mac)

Figure 5-2b Brock Biology of Microorganisms 11/e
© 2006 Pearson Prentice Hall, Inc.

Growth of *Staphylococcus aureus* on Manitol Salt Agar results in a color change in the media from pink to yellow.