Microbial Physiology
BIO 336

With Joud Rasheed

Lecture 1: Cell Structure and Function

Objectives

By the end of lesson, you should be able to:

1. Evaluate the macronutrients and micronutrients that are required for structural aspects of cellular composition and metabolic activities.
2. Classify Prokaryotes based on the carbon and energy sources they use.
3. Sort microorganisms into groups based on how they react to O_2.
4. Describe the differences between prokaryotic and eukaryotic structures.

The chemical composition of the cell

- Microorganisms grow and metabolize, utilizing environmental materials to grow and replicate.

- Chemical elements required for cellular composition structure and metabolic activities such as enzyme regulation and redox process.

- To understand bacterial metabolism, it is necessary to study and understand the chemical composition of cell component structure.

- In general, microbial cells contain only 12 significant amounts of nutrients.

Table 2.1. *Major elements found in microbial cells with their functions and predominant chemical forms used by microorganisms*

Element	Atomic number	Chemical forms used by microbes	Function
C	6	organic compounds, CO, CO_2	major constituents of cell material in proteins, nucleic acids, lipids, carbohydrates and others
O	8	organic compounds, CO_2, H_2O, O_2	
H	1	organic compounds, H_2O, H_2	
N	6	organic compounds, NH_4^+, NO_3^-, N_2	
S	16	organic sulfur compounds, SO_4^{2-}, HS^-, S^0, $S_2O_3^{2-}$	proteins, coenzymes
P	15	HPO_4^{2-}	nucleic acids, phospholipids, teichoic acid, coenzymes
K	19	K^+	major inorganic cation, compatible solute, enzyme cofactor
Mg	12	Mg^{2+}	enzyme cofactor, bound to cell wall, membrane and phosphate esters including nucleic acids and ATP
Ca	20	Ca^{2+}	enzyme cofactor, bound to cell wall
Fe	26	Fe^{2+}, Fe^{3+}	cytochromes, ferredoxin, Fe-S proteins, enzyme cofactor
Na	11	Na^+	involved in transport and energy transduction
Cl	17	Cl^-	major inorganic anion

Table 1: Major components of microbial cells

The chemical composition of the cell

- Minor nutrients can also be found in microbial cells.
- A rare element with a higher atomic number is required for microbial cells.
- Microorganisms are required in minor quantities and are essential for cell function, just as macronutrients are.
- Micronutrients are metals, many of which play structural roles in various enzymes catalyzed by the cell.

Table 2.2. *Minor elements found in microbial cells with their functions and predominant chemical form used by microorganisms*

Element	Atomic number	Chemical form used by microbes	Function
Mn	23	Mn^{2+}	superoxide dismutase, photosystem II
Co	27	Co^{2+}	coenzyme B_{12}
Ni	28	Ni^{+}	hydrogenase, urease
Cu	29	Cu^{2+}	cytochrome oxidase, oxygenase
Zn	30	Zn^{2+}	alcohol dehydrogenase, aldolase, alkaline phosphatase, RNA and DNA polymerase, arsenate reductase
Se	34	SeO_3^{2-}	formate dehydrogenase, glycine reductase
Mo	42	MoO_4^{2-}	nitrogenase, nitrate reductase, formate dehydrogenase, arsenate reductase
W	74	WO_4^{2-}	formate dehydrogenase, aldehyde oxidoreductase

Table 2: Minor elements of microbial cells

1. Carbon

- It is the element found in the greatest abundance in all living organisms.
- It can be classified according to its carbon and energy sources.
- It accounts for 50% of the dry weight of cells.
- All organic compounds have a structural backbone.
- Carbon source is divided into two categories:

1. Litho/Auto → uses inorganic compounds
2. Hetero/Organo → uses organic compounds

- There are two types of energy sources:

1. Chemo → uses a chemical reaction derived from a redox reaction
2. Photo → uses sunlight to generate ATP

- Capnophilic → are microorganisms that grow in the presence of high concentrations of CO_2

❖ Chemo + auto/lithotrophs =

❖ Chemo + hetero/organotrophs =

❖ Photo + auto/lithotrophs =

❖ Photo + hetero/organotrophs =

1. Carbon

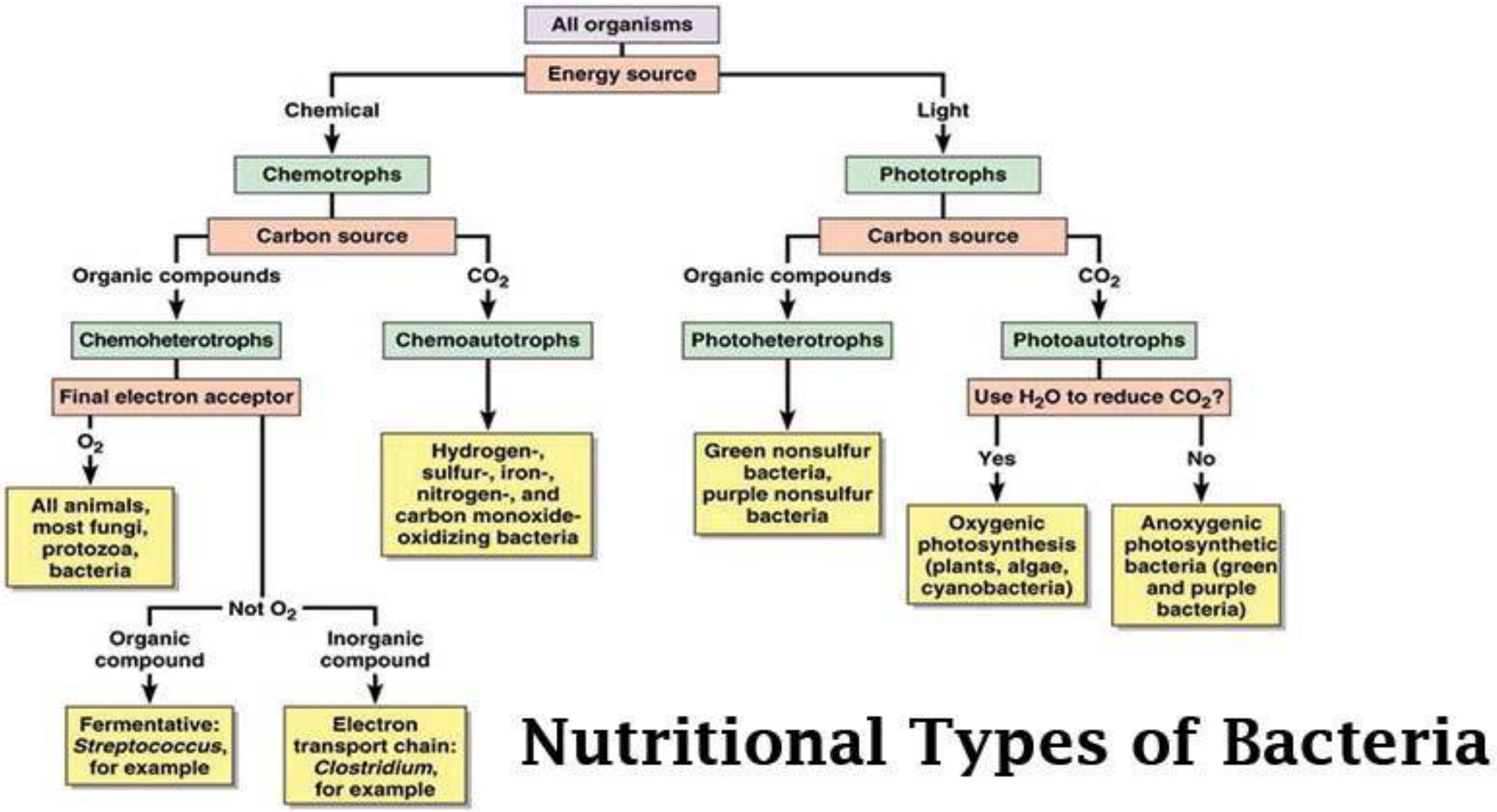


Figure 1: Bacterial nutrition types based on carbon and energy sources

2. Nitrogen

- Nitrogen is the second element that microbes frequently use.

- Nitrogen is an essential element that can be found in both organic (amino acid) and inorganic nitrogenous compounds such as ammonium (NH_3), nitrate (NO_3^-), and nitrogen gas (N_2).

- Most bacteria can use ammonia as their only nitrogen source, and many can also use nitrate.

- Nitrogen-fixing prokaryotes can obtain nitrogen from gaseous N_2.

- Denitrifying chemolithotrophs use ammonium as an energy source and nitrate as an electron acceptor.

3. Sulfur

- The third element required for microbial growth is sulfur.
- Sulfur is necessary for the structural roles of the amino acids cysteine and methionine.
- It is found in a variety of vitamins, including thiamine, biotin, and lipoic acid, as well as coenzyme A.
- It goes through a number of chemical transformations in nature, many of which are carried out solely by microorganisms, and it is available to organisms in a variety of forms.
- The majority of cell sulfur comes from inorganic sources, either sulfate (SO_4^{2-}) or sulfide (HS^-)

4. Oxygen

- Organic compounds, water, and CO_2 are the sources of oxygen.

- Based on microbial requirements, oxygen is classified into several categories:

1. Obligate aerobes → required oxygen to be present.
2. Facultative anaerobes → When O_2 is available, it is used, but it can grow without it.
3. Obligate anaerobes → grow in the absence of oxygen.
4. Aerotolerant anaerobes → tolerates oxygen presence but does not use O_2.

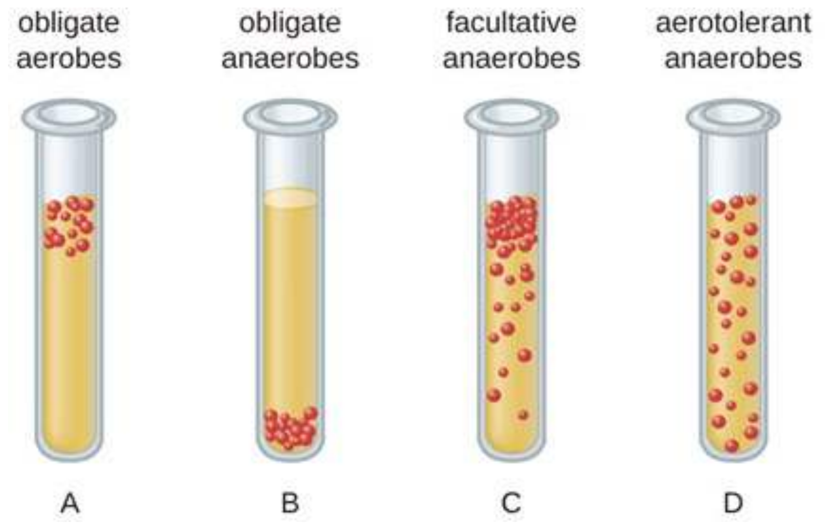


Figure 2: Microbial distribution determined by oxygen demand

4. Oxygen

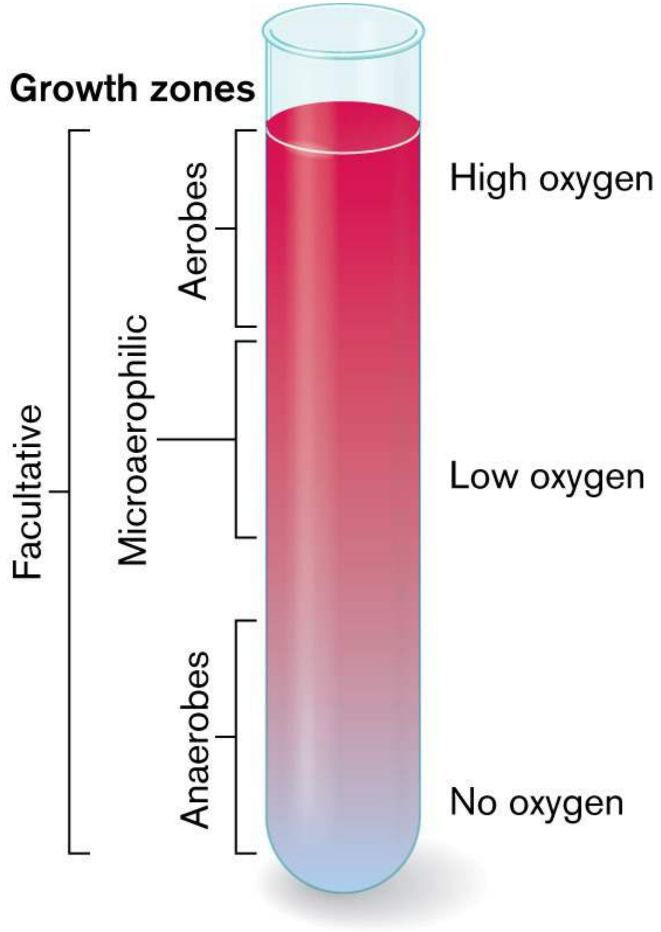


Figure 3: The oxygen demand determines microbial distribution.

Other chemical factors

Chemical factors	Functions
5. Potassium	• It is necessary in all organisms. • Potassium is essential in a variety of enzymes, including those involved in protein synthesis.
6. Magnesium	• It aids in maintaining ribosomes, cell membranes, and nucleic acids stable. • It is necessary for many enzyme activities.
7. Calcium	• Many microorganisms do not require this nutrient to grow. • It aids in the stabilization of the bacterial cell wall. • Plays an important role in endospore heat stability.
8. Sodium	• It is required by some organisms and must frequently reflect the organisms' habitat.
9. Iron	• Plays an important role in cellular respiration. • As a constituent of the cytochromes and iron sulfur proteins involved in electron transport • Iron is generally in +2 oxidation state and soluble in anoxic conditions.

Growth factors

- *E.coli* and some organotrophs can grow in simple media.

- Lactic acid bacteria required complex media containing a variety of vitamins, amino acids, and nucleic acid bases.

- **Growth factors** → are required chemical compounds that influence microbial growth on media.

- Vitamins are one example of growth factors.

Table 2.3. *Common growth factors required by prokaryotes and their major function*

Growth factor	Function
p-aminobenzoate	part of tetrahydrofolate, a one-carbon unit carrier
Biotin	prosthetic group of carboxylase and mutase
Coenzyme M	methyl carrier in methanogenic archaea
Folate	part of tetrahydrofolate
Hemin	precursor of cytochromes and hemoproteins
Lipoate	prosthetic group of 2-keto acid decarboxylase
Nicotinate	precursor of pyridine nucleotides (NAD^+, $NADP^+$)
Pantothenate	precursor of coenzyme A and acyl carrier protein
Pyridoxine	precursor of pyridoxal phosphate
Riboflavin	precursor of flavins (FAD, FMN)
Thiamine	precursor of thiamine pyrophosphate
Vitamin B_{12}	precursor of coenzyme B_{12}
Vitamin K	precursor of menaquinone

Table 3: a variety of vitamins required for prokaryotic cell growth

Cell Structure and Function

Higher Eukaryotes	Lower Eukaryotes			Prokaryotes
Metazoan	Protozoan	Algae	Fungi	Eukaryotes and Archaebacteria[a]
Nucleus	Macronucleus	Nucleus	Nucleus	Nucleoid
Nuclear membrane	Nuclear membrane	Nuclear membrane	Nuclear membrane	No nuclear membrane[b]
Nucleolus	Nuclear elements			
Ribosomes	Ribosomes	Ribosomes	Ribosomes	Ribosomes
40S, 60S/80S	40S, 60S/80S	40S, 60S/80S	40S, 60S/80S	30S, 50S/70S
Cell respiration in mitochondria 70S ribosomes	Cell respiration in mitochondria 70S ribosomes	Cell respiration in mitochondria 70S ribosome	Cell respiration in mitochondria 70S ribosomes	Cell respiration in cytoplasmic membrane
Endoplasmic reticulum	Endoplasmic reticulum	Endoplasmic reticulum	Cytoplasm	Cytoplasm
Golgi apparatus	Dictyosomes	Dictyosomes		
Inclusions	Specialized organelles	Chloroplasts	Inclusions	Inclusions
Lysosomes				
Peroxisomes				
Phycobilisomes				
Plasma membrane	Plasma membrane	Plasma membrane	Cytoplasmic membrane	Cytoplasmic membrane
No cell wall	No cell wall	Cell wall chitin, glycans	Cell wall chitin, glycans	Cell wall peptidoglycan[a]
Undulating flagella or cilia	Undulating flagella or cilia	Undulating flagella or cilia	Undulating flagella or cilia	Rotating flagella

[a] Although comparable to eubacteria in many respects, the archaebacteria (*Archaea*) do not produce a cell wall peptidoglycan comparable to that produced by eubacteria. They also differ from eubacteria in a number of other characteristics not included in this table.
[b] Some species of eubacteria and archaebacteria have now been shown to have a nuclear membrane.

Table 4: major cell component in various classes of organisms

The eukaryotic nucleus

- Nucleus → All of the cell's biochemical and hereditary processes are organized and regulated by the central organelle.

- Normally, animal cells have two layers of nuclear membrane that are separated.

- The pores in the outer membrane are connected by small tubes that extend between the layers.

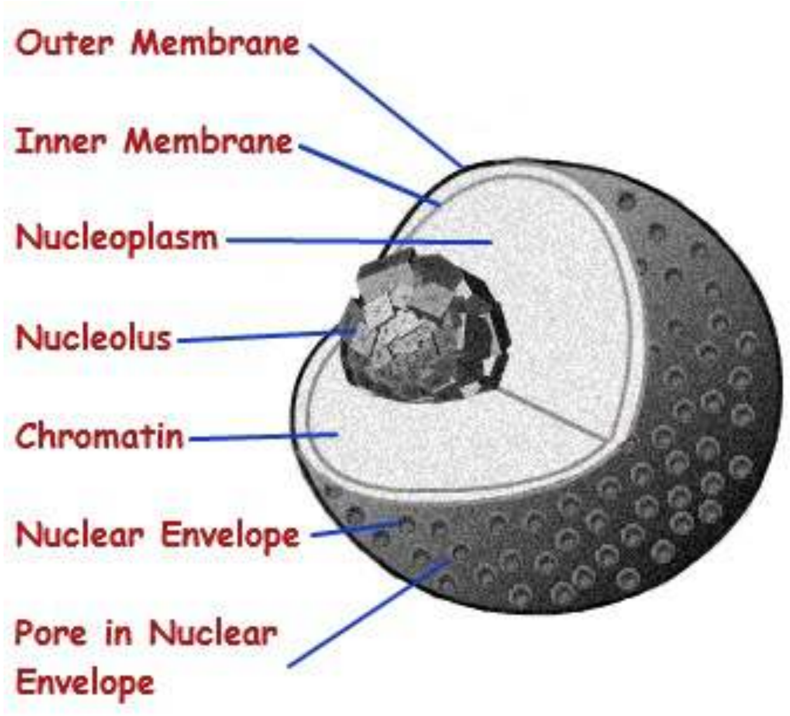


Figure 4: Structure of the nucleus

Bacterial nucleoids

- Nucleoid → A cytologically distinct region of bacterial cells that contains DNA as a chromosome.
- It is not associated with the nuclear membrane.
- Histone-like proteins → Proteins that bind to DNA and cause chromosome compacting.
- While the histone-like protein binds to the DNA, it compacts it further until it separates the nucleoid from the cytoplasm.
- The shape of the nucleoid is similar to the coralline-like shape found in the center of the cell.

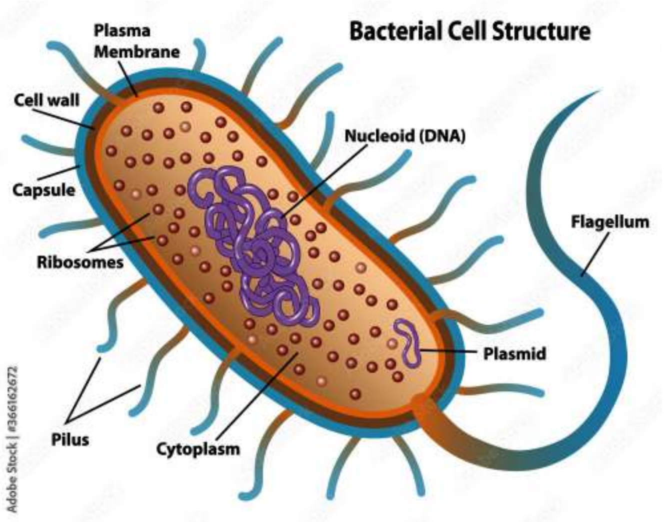


Figure 5: Nucleoid from bacteria

Bacterial nucleoids

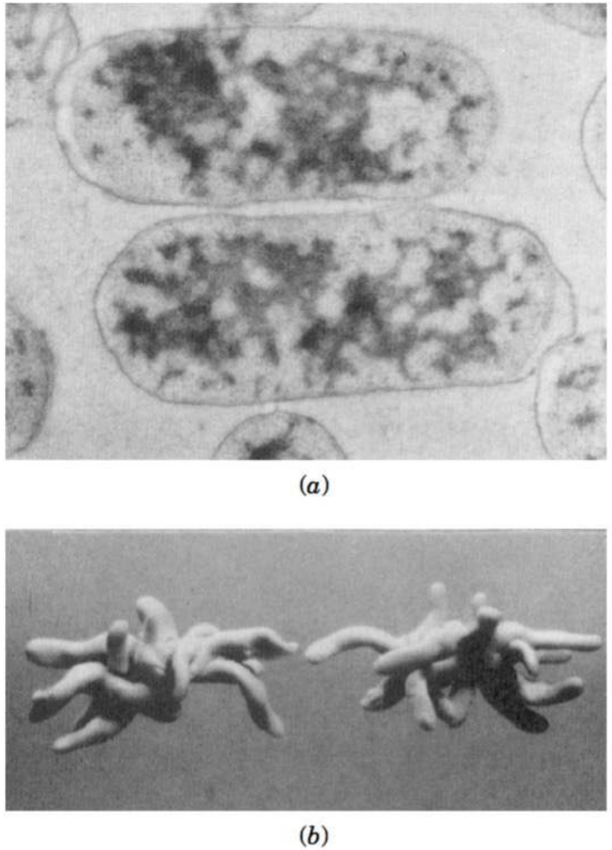
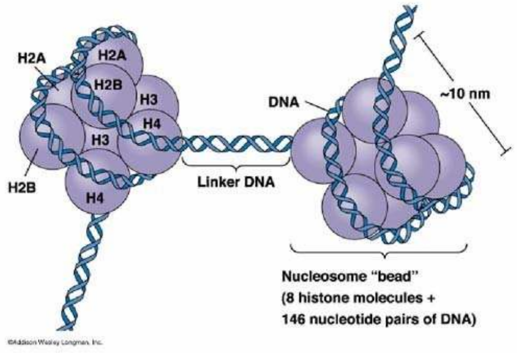


Fig. 7-6. Coralline shape of the bacterial nucleoid. (*a*) Immunostaining of

Figure 6: Bacterial nucleoid has a coralline appearance.

Nucleosomes

- Nucleosomes → DNA protein complex found within eukaryotic chromosomes.
- Histones → plays a critical role in chromosomes by determining chromatin conformation.
- The DNA and protein complex repeating units will produce beads on a string configuration.
- Each histone protein binds to another complex in 146bp of DNA, and the proteins are made up of two of the four major histone proteins.
- For example: H2A, H2B, H3 and H4



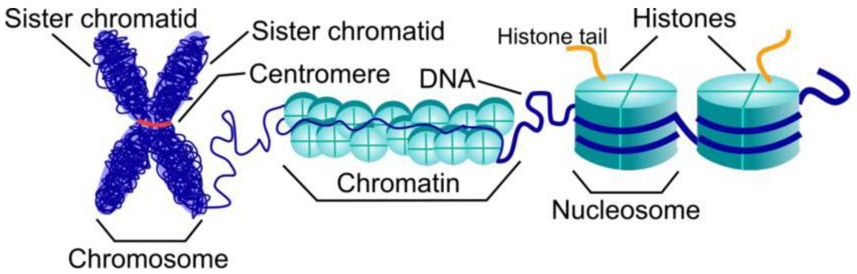


Figure 7: Nucleosomes combine to form chromatin.

Nucleosomes-like in prokaryotic cell

- By binding DNA with histone-like proteins, *E.coli's* genomic is compacted into a nucleosome-like structure.

- HU is the histone found in prokaryotic cells (heat unstable nucleoid protein)

- The HU is made up of two closely related subunits, HU-α and HU-β from *hupA* and *hupB.*

- The primary function of HU protein is to stabilize the higher order nucleoprotein structure.

- Gene mutants → lack of HU protein → defects cell division, DNA folding and separation of DNA

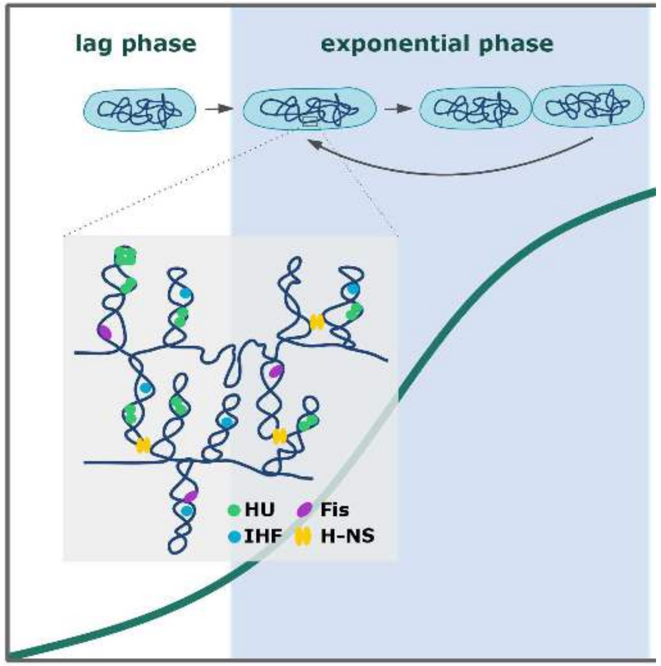


Figure 8: nucleosome like in bacterial cell

Nucleosomes-like in prokaryotic cell

Protein	Identified Function
CbpA	Curved DNA-binding protein A
CbpB	Curved DNA-binding protein B [also known as Rob (right origin-binding protein)]
DnaA	DNA-binding protein A
Dps	DNA-binding protein from starved cells
Fis	Factor for inversion stimulation
Hfq	Host factor for phage Q_β
H-NS	Histone-like nucleoid structuring protein
HU	Heat-unstable nucleoid protein
IciA	Inhibitor of chromosome initiation A
IHF	Integration host factor
Lrp	Leucine-responsive regulatory protein
StpA	Suppressor of *td* mutant phenotype A
H1	?

Tabel 5: Histones like proteins in bacterial nucleoid

Nucleosomes-like in prokaryotic cell

- FIS stood for Factor Inversion Stimulation.

- FIS → is a small, basic DNA-binding protein that regulates gene expression by binding to the *E.coli* replication site.

- This protein was discovered in E.coli due to its ability to influence flagella phase variation by stimulating DNA inversion.

- FIS binds to the OriC of the bacterial chromosome's origin of initiation replication.

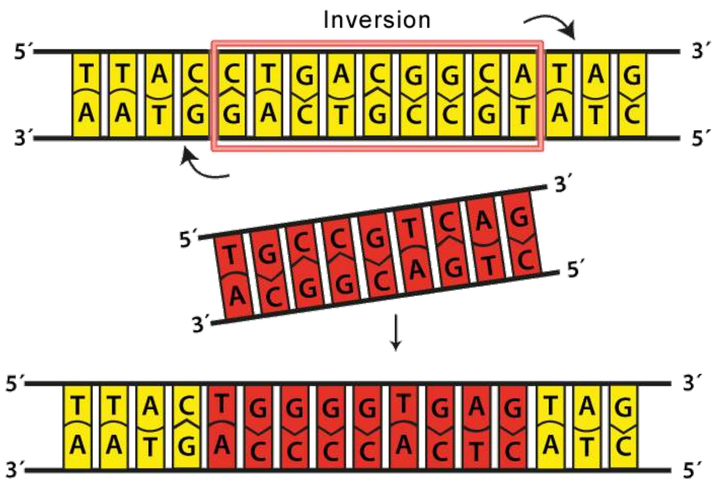


Figure 9: The process of DNA inversion

Mitochondria

- Mitochondria → are sub-cellular organelles that play an important role in eukaryotic cell oxidative respiratory metabolism.

- Inside the cell's complex membranous interior are cytochrome systems and oxidative phosphorylation processes, which essentially produce ATP energy.

- Lower eukaryotes have mitochondria, and each cell has a different number and arrangement of mitochondria based on cultural conditions and growth phase.

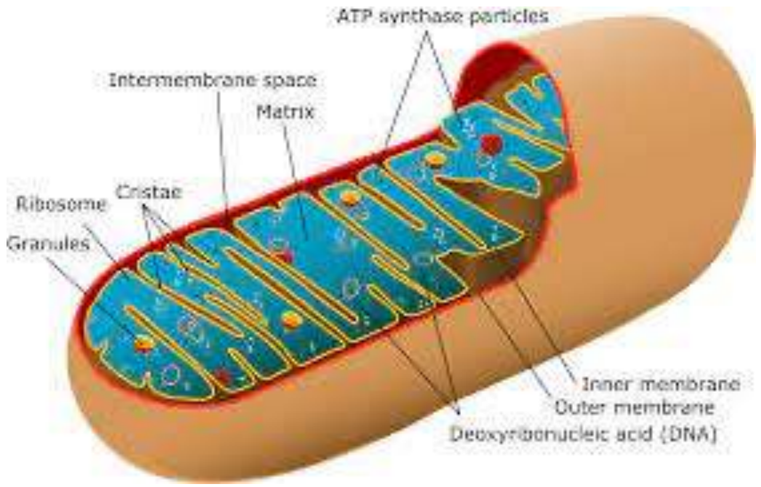


Figure 10: Structure of Mitochondria

Mitochondria

- The mitochondria have two distinct membranes: the outer membrane and the inner membrane.

- Cristea → has an inner membrane that is highly invaginated and forms pleats.

- Under aerobic conditions, yeast mitochondria are active.

- The mitochondria are not visible under anaerobic conditions, but they appear quickly when the aerobic conditions return.

- Promitochondria → are mitochondria-like particles that grow in yeast cells under strict anaerobic conditions.

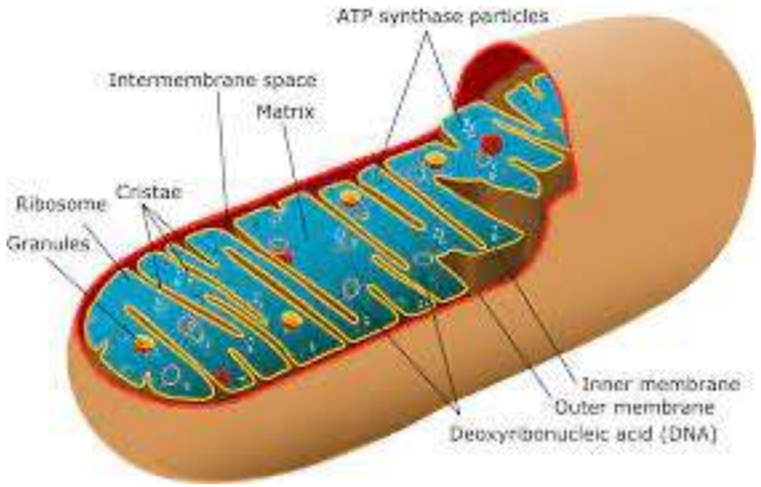


Figure 10: Structure of Mitochondria.

Mitochondria

- Promitochondria lacks the majority of the respiratory chain components found in real mitochondria but still contains ATPase, mitochondrial DNA (mtDNA), and various structural proteins.

- Mitochondrial DNA (mtDNA) → mapped as a closed circular molecule, but linear forms may also exist.

- Because mitochondria are genetically independent, but not genetically sufficient.

- Proteins are complex components that carry out mitochondrial respiratory functions as well as RNA components of their protein synthetic apparatus such as rRNA and tRNAs.

Mitochondria

- Varl gene encodes the ribosome-binding protein complex Varl, which is found on mtDNA and may be found in yeast and other lower eukaryotes.

- According to genetic studies, mtDNA transferred from mitochondria to the nuclear genome.

- The mitochondria are involved in the process of programmed cell death in eukaryotic cells.

- Stress factors (nutrient deprivation, or exposure to irradiation) → mitochondria rupture or leak → release factors triggers caspases → disruption proteins in the cell membrane and nucleus → rapid cell death

Mitochondria

- BAK and BAX are two important proteins that act as gatekeepers for apoptotic signals in mitochondria.
- Activation of BAK and BAX results in mitochondrial cytochrome C release and, eventually, cell death.
- Mutation on genes → Lack BAK and BAX proteins → fail undergo apoptosis process

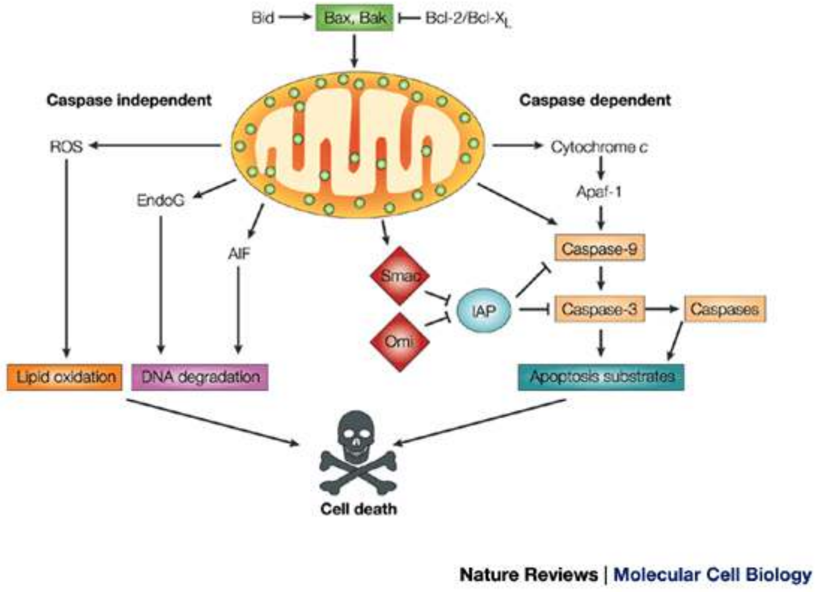


Figure 11: Mitochondria are important in the cell apoptosis pathway.

Thank you! See you next time!

References

- Moat, A. G., Foster, J. W., & Spector, M. P. (Eds.). (2002). *Microbial physiology*. John Wiley & Sons.
- Brock Madigan, M. T., Martinko, J. M., Stahl, D. A., & Clark, D. P. (2009). Brock Biology of microorganisms.