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MICROBIOLOGY

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Bacterial metabolism and physiology

Topics covered in this lecture

1- the General introduction to bacterial metabolism and physiology
2- Metabolism components and the role of ATP
3- metabolic pathways of energy generation
4- the requirements for bacterial growth

1- the General introduction to bacterial metabolism and physiology

- What is the benefit of studying the metabolism of bacteria?

Understanding physiology & metabolism is necessary for bacterial identification & to design antibacterial agents.

- Metabolism in bacteria is essential for their existence, for environment, and products are commercially and medically important for human beings.

General information	Explain
Metabolism in bacteria leads to faster growth than our bodies metabolism.	because it uses so many compounds as an energy source
Bacterial nutritional requirements much more diverse than our cells requirement.	To construct carbohydrate, proteins, and lipids
Some biosynthetic processes, such as those producing peptidoglycan, lipopolysaccharide (LPS), and teichoic acid, are unique to bacteria.	helps for bacterial viability to keep alive

- Metabolism: sum of the chemical reactions occurring in the cell (i.e., biosynthetic, and degradative)
- Energy Production = Energy Consumption. Because when we want to consume energy, we must had produced energy for this consumption. And if we want to produce energy, then this energy must be consumed, so:

Anabolism = synthesis.
Catabolism = degradation.

Metabolism= Anabolism + Catabolism

-catabolic reactions: reactions that cause breakdown of complex molecules into simpler form with release of energy

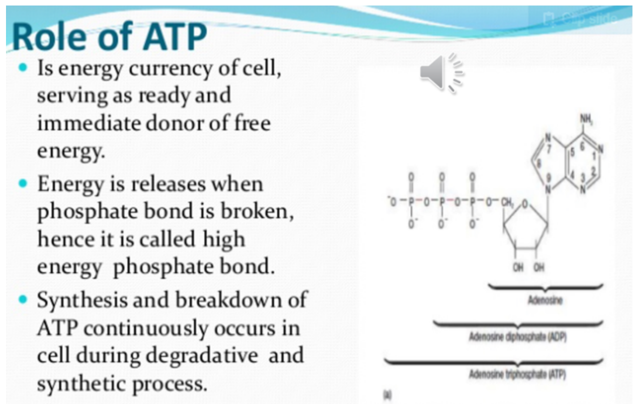
-anabolic reactions: energy requiring reactions that build complex organic molecules from simpler ones

A comparison of two key aspects of cellular metabolism	
anabolism	catabolism
Build-up of small molecules	Breakdown of large molecules
Products are large molecules	Products are small molecules
photosynthesis	Glycolysis, citric acid cycle
Mediated by enzymes	Mediated by enzymes
Energy generally is required (endergonic)	Energy generally is released (exergonic)

2- Metabolism components and the role of ATP

components	functions
Enzymes	Biological catalyst, facilitates each step of metabolic reaction by lowering the activation energy of reaction
Adenosine triphosphate (ATP)	Serves as energy currency of cell
Energy source	Compound that is oxidised to release energy, also called an electron donor
Electron carriers	Carry the electrons that are removed during the oxidation of energy source (NAD^+, $NADP^+$, and FAD (their reduced form NADH, NADPH, and $FADH_2$).
Precursor metabolites	Intermediate metabolite that links anabolic and catabolic pathways, like pyruvate, acetyl-CoA, glucose-6-p, etc.

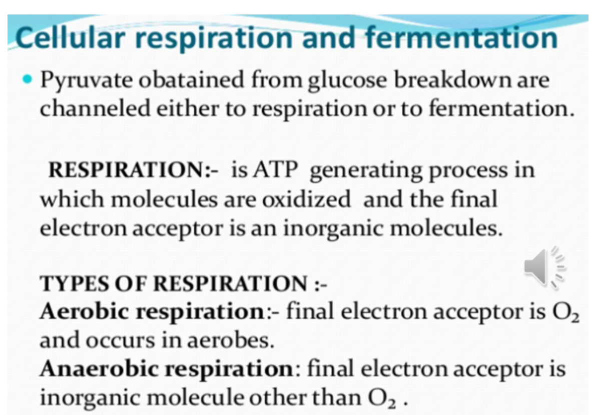
- Role of ATP:
  - Is energy currency of cell, serving as ready and immediate doner of free energy.
  - energy is released when phosphate bond is broken, hence it is called high energy phosphate bond.
  - synthesis and breakdown of ATP continuously occurs is cell during degradative and synthesis process.
- generation of ATP:
  - Bacteria uses three mechanisms of phosphorylation to generate ATP from ADP.
  1-Substrate level phosphorylation.
  2-Oxidative phosphorylation.
  3-Photophosphorylation.



3- metabolic pathways of energy generation

- Some bacteria can metabolize sugars or complex carbohydrates to produce energy
-There are several central pathways for carbohydrate utilization, including the Embden-Meyerhof pathway of glycolysis and the pentose phosphate pathway, both of which are also present in eukaryotic cells. Some bacteria possess the Entner-Doudoroff pathway, which converts glucose primarily to pyruvate

- Sugar metabolism produces energy for the cell via two different processes, fermentation, and respiration.
1-Fermentation: is a metabolic process that produces chemical changes in organic compounds through the action of enzymes, that takes place in the absence of oxygen. The change usually results in the production of organic acids and energy.
2- Respiration: The biochemical process in which the cells of an organism obtain energy, typically with the intake of oxygen and the release of CO2 from the oxidation of the complex organic substances.



** Krebs cycle: is a second phase of aerobic respiration.

-Cellular respiration formula:

glucose+ oxygen → carbon dioxide+ water+ energy (ATP)

-Types of respiration:

1-Aerobic respiration

2-Anaerobic respiration

- Generation of ATP (energy) is mediated by electrons and/or protons transfer to a final acceptor.

Summary of carbohydrate consumption (glucose break down) in the bacteria

1- glycolysis: We have three pathways

A- Embden-Meyerhof pathway

B- pentose phosphate pathway

c- Entner-Doudoroff pathway

After one of these pathways is used, will go either fermentation or cellular respiration (Aerobic or Anaerobic), if go aerobic respiration will continue to:

2-kreb’s cycle

3-Electron transport chain

comparison of metabolism:

1- Aerobic respiration (oxidation): Total ATP Prokaryotes=38, Eukaryotes=34

- Final electron receptor is usually oxygen.

2-Fermentation: Yield = 2 ATP (less efficient).

-Final electron receptor is organic molecule.

-End products: acids/Alcohol.

CO_2 is produced in both.

4- the requirements for bacterial growth

-What are the requirements for bacterial growth?

A-Nutrient’s source: water, carbon source, nitrogen source, inorganic salts, growth factor, sulfur source, phosphorus source

B-Energy source.

C-Environmental factors: temperature, gas(oxygen), pH, osmatic pressure

A-Nutrient's source

-Nutritional requirements differ among bacteria and can be used for differentiation

1-includes many elements like:
a-carbon, hydrogen, O2, nitrogen, phosphorus & sulphur: needed for the synthesis of structural components.
b-potassium, calcium magnesium and iron: needed for cellular functions.
2-Can be obtained from simple elements or by breaking down large molecules such as protein breakdown into amino acids using bacterial enzymes.

3-many bacteria have to synthesize some nutrients such as folic acid which makes these bacteria susceptible to agents that interfere with the biosynthesis of folic acid, e.g., by trimethoprim & sulfonamides antibiotics.
The effectiveness of these combinations (trimethoprim & sulfonamides) is attributed to their synergistic effect in inhibiting folic acid metabolism in bacteria. Sulfonamides are competitive inhibitors by preventing addition of para aminobenzoic acid (PABA) into the folic acid molecule. Trimethoprim inhibits the enzyme dihydrofolate reductase, the enzyme that catalyzes the last step of bacterial folic acid synthesis.

- Nutrients can be obtained from different sources

1-Elements such as:
a-hydrogen & oxygen: are obtained from water
b-Carbon: usually obtained from degradation of carbohydrates by oxidation or fermentation. Carbon is necessary to provide energy in the form of ATP (adenosine triphosphate).
c-Nitrogen: from ammonia in the environment or proteins 'deamination' using bacterial enzymes.

2-Organic factors (from exogenous source/can't be synthesized by bacteria) such as:
a-Amino acids: e.g., from proteins breakdown, an important precursor for Purines and pyrimidines synthesis.

b-Nucleic acids are polymers of nucleotides. Nucleotide synthesis is an anabolic mechanism generally involving the chemical reaction of phosphate, pentose sugar, and a nitrogenous base, and must be converted into nucleotides & nucleosides before being incorporated into the DNA or RNA.

3-Vitamins: most are needed for the formation of coenzymes in some bacteria.

Element	% Of dry weight	source	Function
Carbon	50	Organic compounds or CO_2	Main constituent of cellular material
Oxygen	20	H_2O, organic compounds, CO_2 and O_2	Constituent of cell material and cell water: O_2 is electron acceptor in aerobic respiration
nitrogen	14	NH_3, NO_3, organic compounds, N_2	Constituent of amino acids, nucleic acids nucleotides, and coenzymes
Hydrogen	8	H_2O, organic compounds, H_2	Main constituent of organic compounds and cell water
Phosphorus	3	Inorganic phosphates (PO_4)	Constituent of nucleic acids, nucleotides, phospholipids, LPS, teichoic acid
Sulfur	1	SO_4, H_2S, So, organic sulfur compounds	Constituent of cysteine, methionine, glutathione, several coenzymes
Potassium	1	Potassium salts	Main cellular inorganic cation and cofactor for certain enzymes
Magnesium	0.5	Magnesium salts	Inorganic cellular cation, cofactor for certain enzymatic reaction
Calcium	0.5	Calcium salts	Inorganic cellular cation, cofactor for certain enzymes and a component of endospores
iron	0.2	Iron salts	Component of cytochromes and certain nonheme iron-proteins and a cofactor for some enzymatic reactions

-Source and functions of elements are required.

B-Energy source

-According to how bacteria take energy or hydrogen or carbon, we put them in categories

1- **Energy source**

- Phototrophs — They use the light as their energy (photosynthesis)
- Chemotrophs — They obtain their energy from oxidation-reduction of chemical compounds (either organic or inorganic)

2- **Hydrogen source**

- Organotrophs — They extract electron or hydrogen from organic compounds
- lithotrophs — They can use inorganic sources (ex: ammonia or hydrogen sulfide) use reduced inorganic substances

- Energy and Hydrogen donor designations are referred to routinely by combining the two terms:

a- Chemo-organotrophs: (chemo) that's mean it obtained energy from oxidation-reduction external chemical
compounds, and (organo) means it extract hydrogen from organic compounds.
(The vast majority of currently recognized medically important organisms).

b- Chemo-lithotrophs: It obtained energy from oxidation-reduction external chemical compounds and use
inorganic sources. Example: Some Pseudomonas species

3- **Carbon source**

- Autotrophs — can draw carbon from carbon dioxide
- Heterotrophs — carbon from organic compounds
- Mixotrophic — carbon is obtained from both organic compounds and by fixing carbon dioxide

- These requirements can be combined (Energy + Carbon) sometimes:

a- Chemoheterotrophs energy from chemical compounds, carbon from organic compounds, this group includes most of the bacteria as well as all protozoa, fungi, and animals.

C-Environmental factors

Environmental factors that contribute to the growth of bacteria:

1-Temperature

2-gas replacements (oxygen)

3-PH

1-Temperature

-different microbial species are vary widely in their optimal temperature ranges for growth:

a-mesophilic form: 30-37 C all human microbial pathogens belong to these forms

b-psychrophilic form: 15-20 C

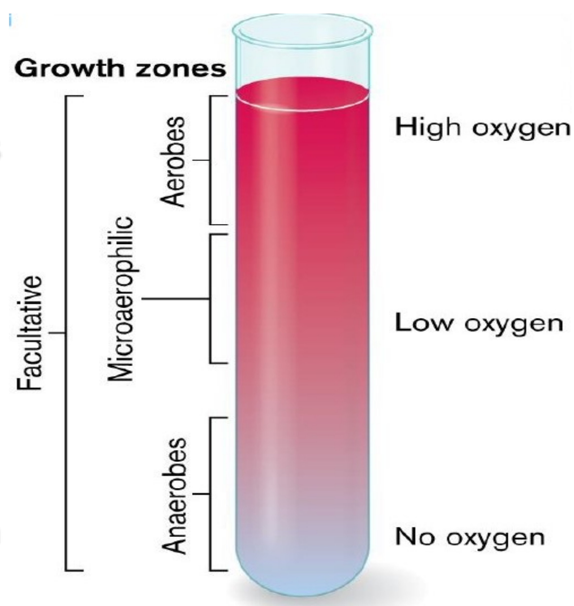
c-thermophilic form: 50-60 C

2-gas requirements (oxygen)

-according to the requirement of O_2 during bacteria growth, bacteria can be divided into four group:

	Aerobic	**Anaerobic**	
Obligate aerobe	growth	No growth	cannot grow without oxygen
Microaerophile	Growth at low O2	No growth	Oxygen-loving, but in small quantities
Obligate anaerobe	No growth	Growth	Cannot live with oxygen (anaerobic)
Facultative aerobe	growth	Growth	(Optional) Can you live with or without oxygen?

Oxygen related growth zones in a standing test tube



This image helps us identify the areas of bacterial growth associated with oxygen, for example:

a-The upper part of the test tube: We note that it contains a high percentage of oxygen, and therefore there are bacteria that need high amounts of oxygen (Obligate aerobe)

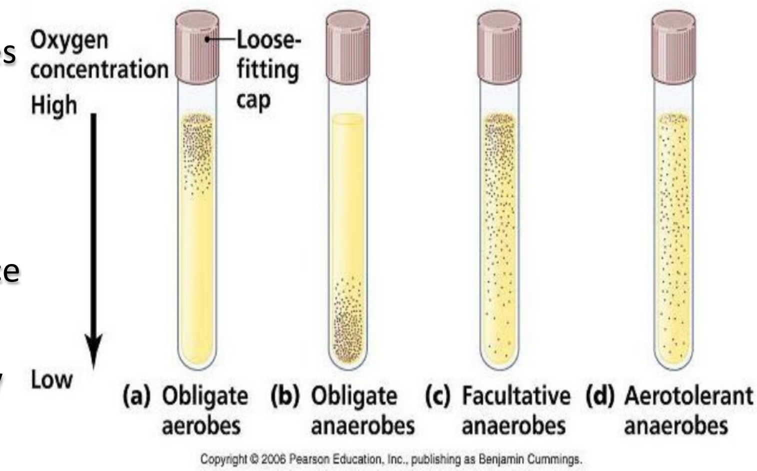
b-In the middle of the test tube: We note that there was low oxygen, which contain bacteria live in low oxygen (Microaerophile)

c-Bottom of the test tube: We note that there is no oxygen , which contain bacteria anaerobes' (Obligate anaerobe)

d- There are bacteria that can live with or without oxygen (Facultative aerobe)

- There is a fifth type of bacteria classified according to their need for oxygen, which is: Aerotolerance: E.g., Enterococcus faecalis ignore O2 and grow equally well whether if it present or not.

- This is another picture that contains the types of bacteria according to their need for oxygen and contains the type of Aerotolerance



-What is the difference between Aerotolerance and Facultative?
facultative anaerobes grow best in aerobically environment (but also grow anaerobically)

- There is a problem with bacteria that use oxygen in their metabolism, may give rise to some toxic substances, hydrogen peroxide (H_2O_2) and the superoxide radical (O2-), Therefore Obligate aerobes and facultative anaerobes usually contain the enzymes superoxide dismutase and catalase, which catalyse the destruction of superoxide radical (O2-) and hydrogen peroxide (H_2O_2), respectively.

2(O2-) + 2H +→O2+H2O2. (superoxide dismutase)

2H2O2→2 H2O+O2. (Catalase)

- for this reason, Bacteria that possess these protective enzymes can grow in the presence of oxygen.

3-PH

Distribution of bacteria according to the pH that live in:

1-neutrophiles: Majority of bacteria grow BEST at neutral or slightly alkaline pH (It is around 7 – 7.4)

2- Acidophiles: grow BEST at low pH (it is around 0 – 1).
Example: Thiobacillus (pH = 6.5 – 6.8).
Helicobacter pylori

3-Alkalophiles: grow BEST at high pH (it is around 10).
Example: Vibrio Cholerae (pH = 8.4 – 9.2).

descriptive terms used to categorize bacteria according to their growth requirement

Summary of what was mentioned of (Growth atmosphere & Growth temperature)

Growth atmosphere	Property	Example
Strict (obligate) aerobe	Requires atmospheric oxygen for growth	Pseudomonas aeruginosa
Strict (obligate) anaerobe	Will not tolerate oxygen	Bacteroides fragilis
Facultative anaerobe	Grows best aerobically, but can grow anaerobically	Staphylococcus spp, E. coli
Aerotolerant anaerobe	Anaerobic, but tolerates exposure to oxygen	Clostridium perfringens
Micro-aerophilic organism	Requires or prefers reduced oxygen levels	Campylobacter spp, helicobacter spp
Capnophilic organism	Requires or prefers increased carbon dioxide levels	Neisseria spp

Growth temperature	Property	Example
psychrophile	Grow's best at low temperature (e.g., <10 C^0)	Flavobacterium spp
thermophile	Grow's best at high temperature (e.g., >60 C^0)	Bacillus stearothermophilus
mesophile	Grow's best between 20-40 C	Most bacterial pathogens

Note: this table is for memorizing, the doctor said you can memorize it now or later when we take each type of bacteria in details.

Good luck