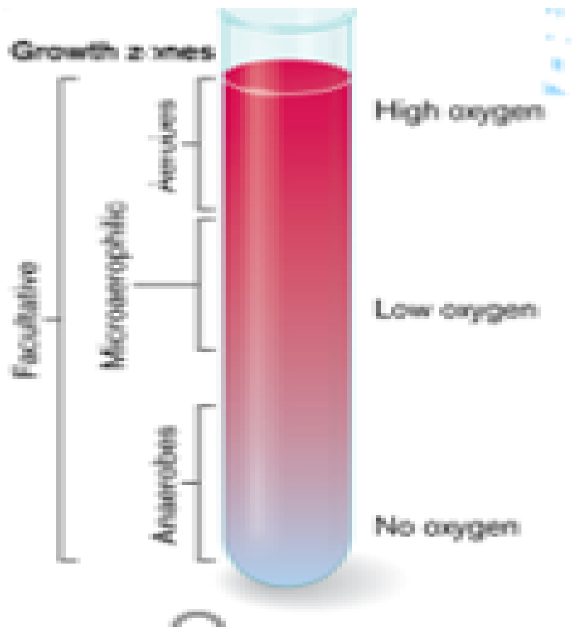
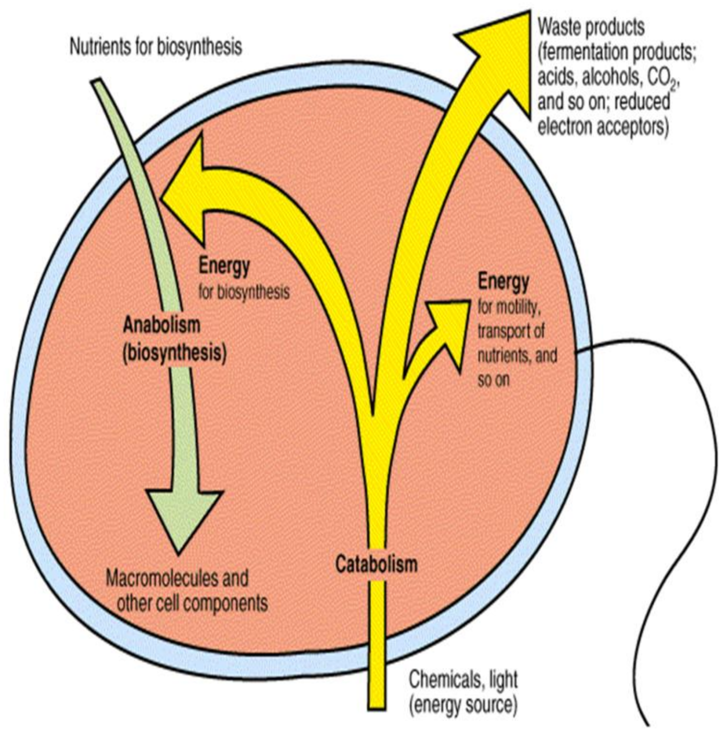
Bacterial metabolism and physiology





Bacterial metabolism and physiology

- Metabolism in bacteria leads to faster growth than our bodies metabolism.
- Bacteria use many compounds as energy sources.
- Bacterial nutritional requirements much more diverse than our cells requirement.
- Some biosynthetic processes, such as those

  producing peptidoglycan, lipopolysaccharide (LPS), and teichoic acid, are unique to bacteria.

Bacterial metabolism and physiology

*Metabolism: sum total of the chemical reactions occurring in the cell (i.e. biosynthetic and degradative)
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* Energy Production = Energy Consumption.
* Metabolism = Anabolism + Catabolism.

Anabolism = synthesis.

Catabolism = degradation.

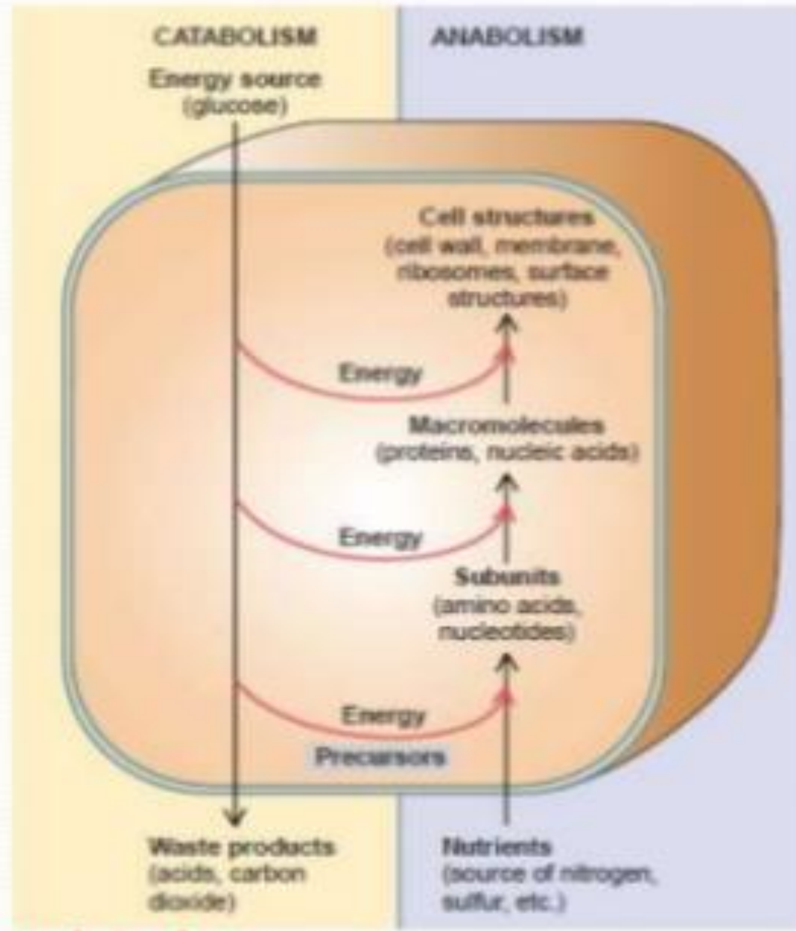
* Metabolism in bacteria is essential for their existence, for environment, and products are commercially and medically important for human beings.

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

CATABOLIC AND ANABOLIC REACTIONS

- Reactions that cause breakdown of complex molecules into simpler form with relase of energy is **catabolic reactions.**

- Energy requiring reactions that build up complex organic molecules from simpler ones is **anabolic reactions.**



TABLE

6.1 A Comparison of Two Key Aspects of Cellular Metabolism

Anabolism	Catabolism
Buildup 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)

Components of metabolism

COMPONENTS	FUNCTIONS
Enzymes	Biological catalyst, fascilitates each step of metabolic reaction by lowering the activation energy of reaction.
Adenosine triphosphate (ATP)	serves as energy currency of cell ,
Energy source	Compund 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 link anabolic and catabolic pathways, like pyruvate, acetyl-coA, glucose -6-p, etc.

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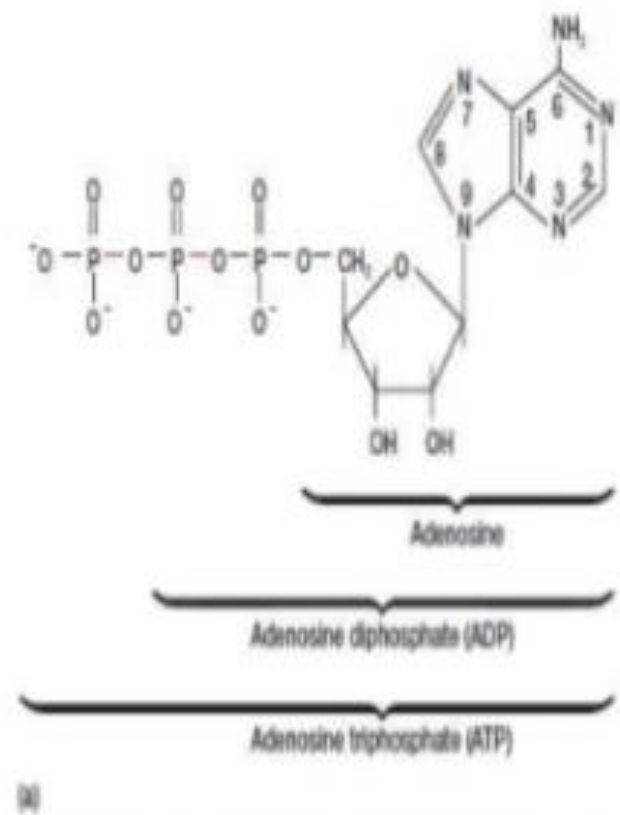
Role of ATP

- Is energy currency of cell, serving as ready and immediate donor of free energy.
- Energy is releases when phosphate bond is broken, hence it is called high energy phosphate bond.
- Synthesis and breakdown of ATP continuously occurs in cell during degradative and synthetic process.



Generation of ATP

- * Bacteria uses three mechanisms of phosphorylation to generate ATP from ADP.

1- Substrate level phosphorylation.

2- Oxidative phosphorylation .

3- Photophosphorylation.

Metabolic pathways of Energy Generation

* Glycolysis
  - the Embden–Meyerhof glycolytic pathway

** Pathways alternative to glycolysis : many bacteria have another pathway in addition to glycolysis for degradation of glucose.

1 - Pentose phosphate pathway; and

2- Entner Doudoroff pathway.

* Bacteria generate energy by two ways fermentation and / or oxidation.

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

Source of metabolic energy

*__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.

*__Respiration__: The biochemical process in which the cells of an organism obtain energy, typically with the intake of oxygen and the release of carbon dioxide from the oxidation of complex organic substances.

-Cellular respiration formula:

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

*Types of respiration:

1- Aerobic respiration

2- Anaerobic respiration

Cellular respiration and fermentation

- Pyruvate obatained from glucose breakdown are channeled either to respiration or to fermentation.

RESPIRATION:- is ATP generating process in which molecules are oxidized and the final electron acceptor is an inorganic molecules.

TYPES OF RESPIRATION :-
Aerobic respiration:- final electron acceptor is O_2 and occurs in aerobes.
Anaerobic respiration: final electron acceptor is inorganic molecule other than O_2 .

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

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.

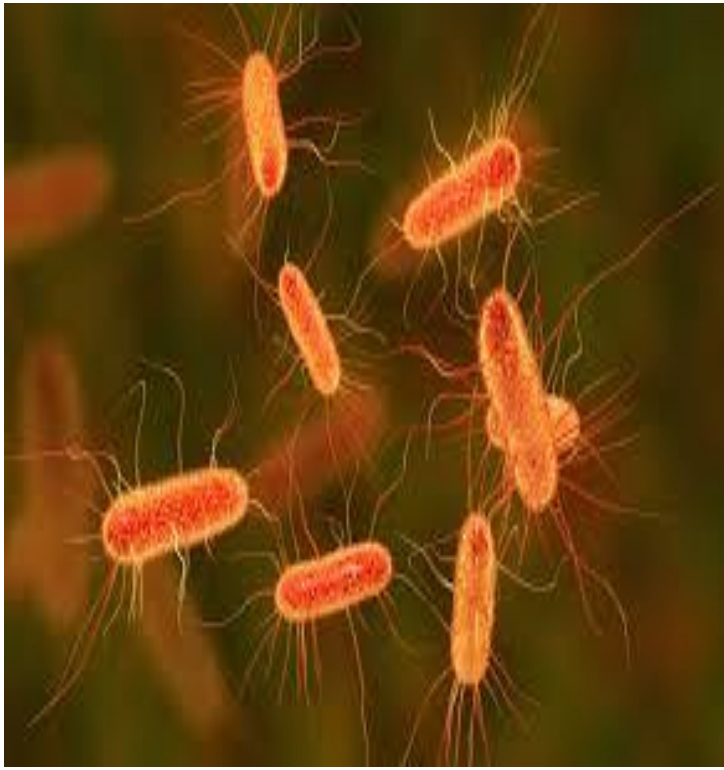
CO_2 is produced in both.

What are the requirements for bacterial growth

A- Nutrients source.

B- Energy source.

C- Environmental factors



Bacterial Nutrition and Growth

- **Nutrient Requirements:**
  - Water
  - Carbon source (C)
  - Nitrogen source (N)
  - Inorganic salts
  - Growth factors
  - Sulfur source (S)
  - Phosphorus source (P)

- **Environmental factors for bacteria growth:**
  - Temperature
  - Gas (oxygen)
  - pH
  - Osmotic pressure

Bacterial physiology and metabolism

Nutritional requirements:

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.

Bacterial physiology and metabolism

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 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.

Bacterial physiology and metabolism

* Nutritional requirements differ among bacteria and can be used for identification.

*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.

Bacterial physiology and metabolism

2. Organic factors (from exogenous source/can’t be synthesized by bacteria) such as:

**Amino acids: e.g. from proteins breakdown, an important precursor for Purines and pyrimidines synthesis.

**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.

Major elements, their sources and functions in bacterial cells.

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 acids
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 reactions
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

* ENERGY SOURCE

a. Phototrophs —can use light energy

b. Chemotrophs —must obtain energy from oxidation-reduction of external chemical compounds

HYDROGRN DONOR:

- organotroph if bacteria requires organic sources of hydrogen

- lithotroph if it can use inorganic sources (e.g. ammonia or hydrogen sulphide

Energy and Hydrogrn

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

- Chemo-organotrophs
- (the vast majority of currently recognized medically important organisms)

- chemolithotrophs e.g. some Pseudomonas spp.

*CARBON SOURCE

a. Autotrophs —can draw carbon from carbon dioxide

b. Heterotrophs —carbon from organic compounds

c. Mixotrophic – carbon is obtained from both organic compounds and by fixing carbon dioxide

Energy and Carbon

- Energy and carbon sometimes:

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

Environmental conditions governing growth:

Environmental factors for bacteria growth

Temperature

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

Mesophilic forms 30-37 °C

All human microbial pathogens belong to this forms

Psychrophilic forms 15-20 °C

Thermophilic forms 50-60 °C

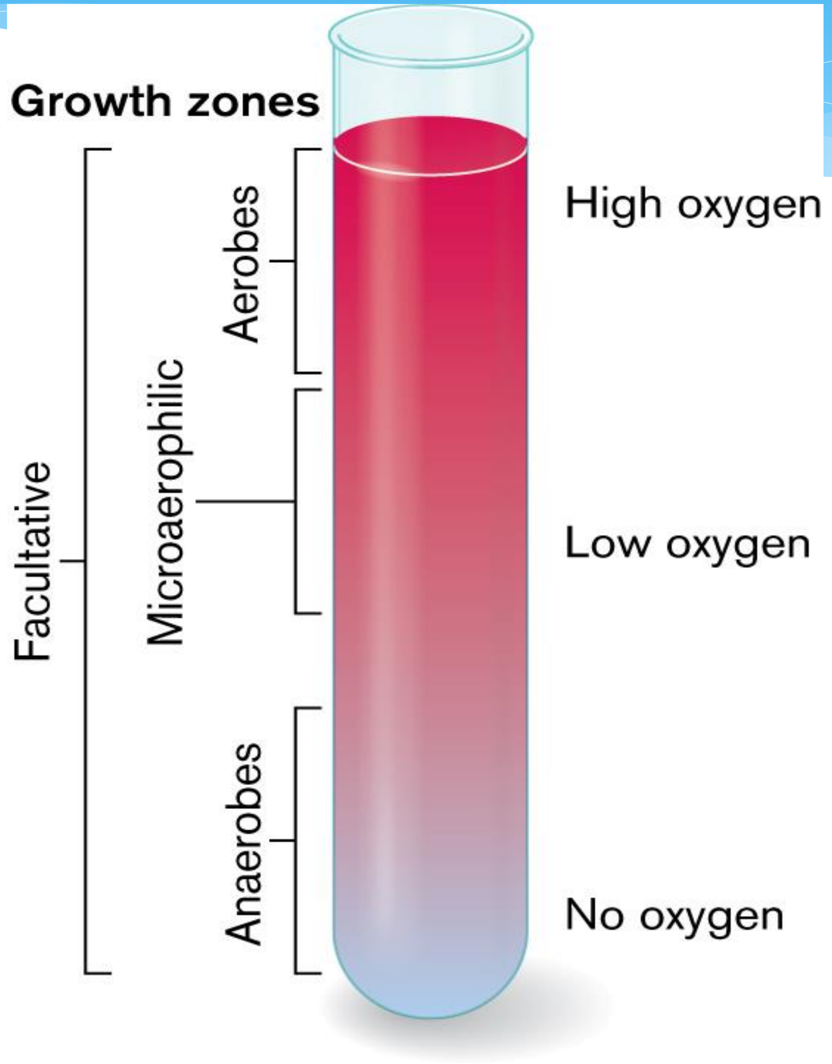
Environmental factors for bacteria growth

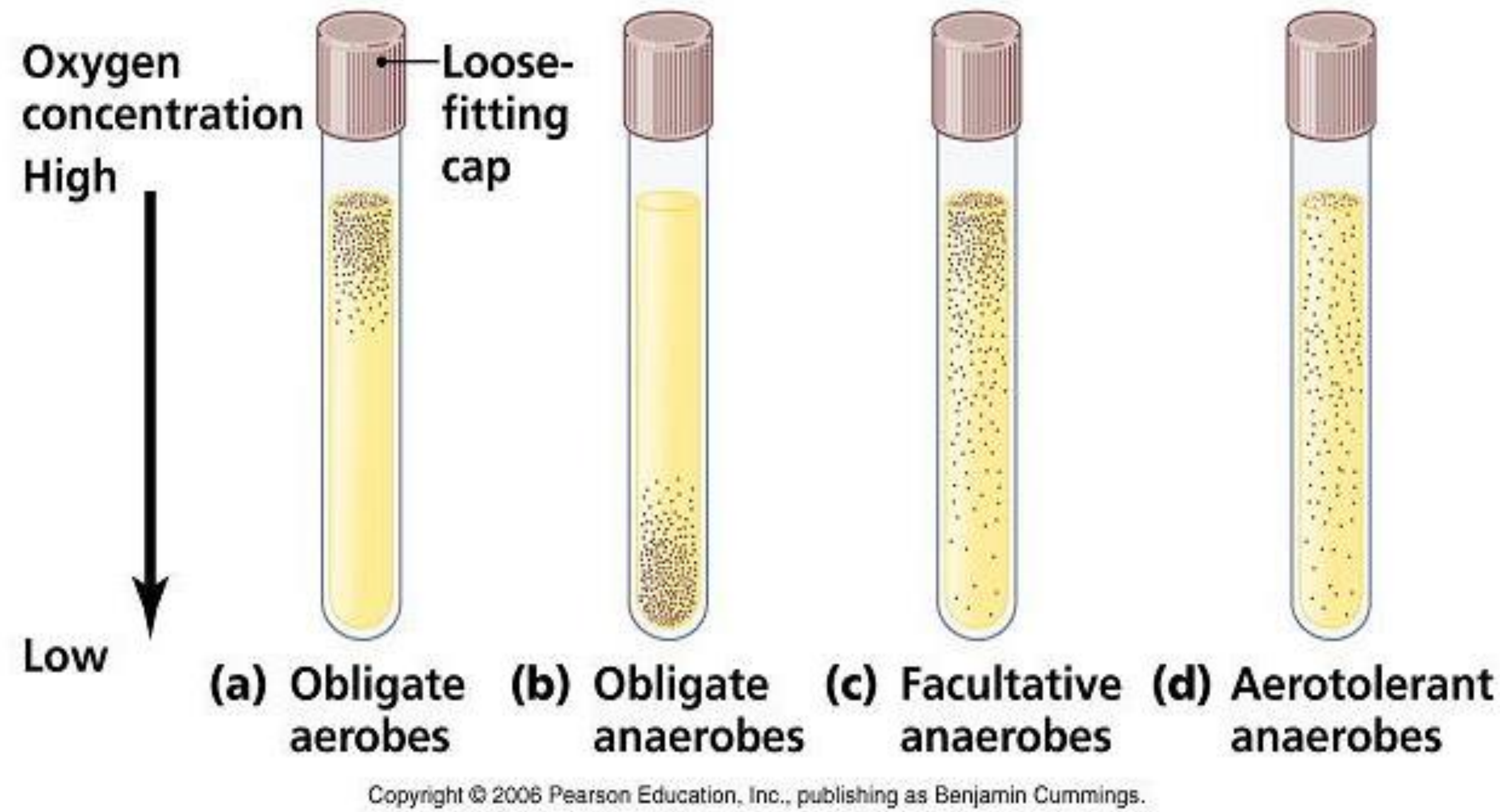
Gas Requirements

According to the requirement of O_2 during bacteria growth, bacteria can be divided into four groups:

	Aerobic	Anaerobic
1. Obligate aerobe:	Growth	No growth
2. Microaerophile:	Growth at low O_2	No growth
3. Obligate Anaerobe:	No growth	Growth
4. Facultative aerobe:	Growth	Growth

Oxygen-related growth zones in a standing test tube





5- Aerotolerance.

E.g. Enterococcus faecalis ignore O2 and grow equally well whether if it present or not.

* Metabolism in the presence of oxygen may give rise to some toxic substances, hydrogen peroxide **(H_2O_2)** and the superoxide radical **(O^{2-})**

* Obligate aerobes and facultative anaerobes usually contain the enzymes **superoxide dismutase** and **catalase** ,which catalyse the destruction of superoxide radicle and hydrogen peroxide, respectively.

- Bacteria that possess these protective enzymes can grow in the presence of oxygen.

$2(O^{2-}) + 2H^{+} \rightarrow O_2 + H_2O_2$ (superoxide dismutase)

$2\ H_2O_2 \rightarrow 2\ H_2O + O_2$ (Catalase)

pH

- Most organisms grow BEST at neutral or slightly alkaline pH 6 and 8, **neutrophiles**
- **Acidophiles**: grow BEST at low pH (acid: pH 0 – 1.0)
  - (Helicobacter pylori)
- **Alkalophiles:** grow BEST at high pH (alkaline: pH 10.0)
  - V. cholera - pH 8.4-9.2

descriptive terms used to categorize bacteria according to their growth requirement

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, etc.
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	
Psychrophilic	Grows best at low temperature (e.g. <10°C)	Flavobacterium spp.
Thermophilic	Grows best at high temperature (e.g> 60°C)	Bacillus stearothermophilus
Mesophilic	Grows best between 20-40°C	Most bacterial pathogens