

21,22 . Conditions for growth - temperature requirements - aerobes and anaerobes – factors influencing growth and methods of assessment of growth

Nutritional types of Bacteria

Lecture 21; Nutritional types of Bacteria

All the bacteria essentially need energy, electron and carbon for their normal cellular activity, growth and reproduction.

Energy : Based on the source of energy, bacteria can be divided into two groups namely, chemotrophs and phototrophs.

- a. Chemotrophs – utilize chemicals for their energy
- b. Phototrophs – utilize sun light for their energy

Electron : based on the source of electron, bacteria can be divided into two groups namely lithotrophs and organotrophs

- a. Lithotrophs – utilize inorganic substances as electron source
- b. Organotrophs – utilize organic substances as electron source

Carbon : based on the sole source of carbon for their utilization, the bacteria can be divided into two groups namely autotrophs and heterotrophs

- i. Autotrophs – uses CO₂ as sole carbon source
- ii. Heterotrophs – uses organic carbon as sole source

The combinations are as follows :

1. Photolithotrophs
2. Chemolithotrophs
3. Photoorganotrophs
4. Chemoorganotrophs
5. Photoautotrophs
6. Photoheterotrophs
7. Chemoautotrophs
8. Chemoheterotrophs

Examples:

Organism	Energy		Electron		Carbon	
	Photo	Chemo	Litho	Organo	Auto	hetero
<i>E. coli</i>		X Glucose		X Glucose		X Glucose
<i>Chromatium</i> (Purple sulphur bacteria)	X		X		X	

			H ₂ S		CO ₂	
Cyanobacteria	X		X H ₂ O		X	
<i>Rhodospirillum</i> (Purple Non sulphur bacteria)	X			X fatty acid		X fatty acid, alcohol
<i>Nitrosomonas</i>		X	X NH ₃		X	
<i>Nitrobacter</i>		X	X NO ₂		X	
<i>Thiobacillus</i> (Sulphur oxidizing bacteria)		X Sulfide, sulphur, thiosulfide	X		X	

X – refers the appropriate source Some organisms exhibit different nutritional types like **Chemo lithotrophic heterotrophs**.

(Chemo – chemical for energy; litho – inorganic for electron donor and hetero – organic carbon)

Some organisms utilize inorganic compounds as energy and electron donors are inorganic compounds but utilize organic compounds for carbon source, referred as **mixotrophs**. Ex. *Desulfovibrio desulfuricans*.

Physical condition for growth :

The prokaryotes exist in nature under enormous range of physical condition such as O₂ concentration, hydrogen ion concentration (pH), temperature, salt concentration and water activity. The exclusive limit of life on the planet is set by the prokaryotes especially the archaea.

a. Temperature : Microorganisms have been found growing in virtually all environments where there is liquid water, regardless of its temperature. In 1966, Professor Thomas D. Brock at Indiana University made the amazing discovery in **boiling hot springs of Yellowstone National Park** that bacteria were not just surviving there, they were growing and flourishing. Boiling temperature could not inactivate any essential enzyme. Subsequently, prokaryotes have been detected growing around black smokers and hydrothermal vents in the deep sea at temperatures at least as high as 115°C. Microorganisms have been found growing at very low temperatures as well. In super cooled solutions of H₂O as low as -20°C, certain organisms can extract water for growth, and many forms of life flourish in the icy waters of the Antarctic, as well as household refrigerators, near 0°C.

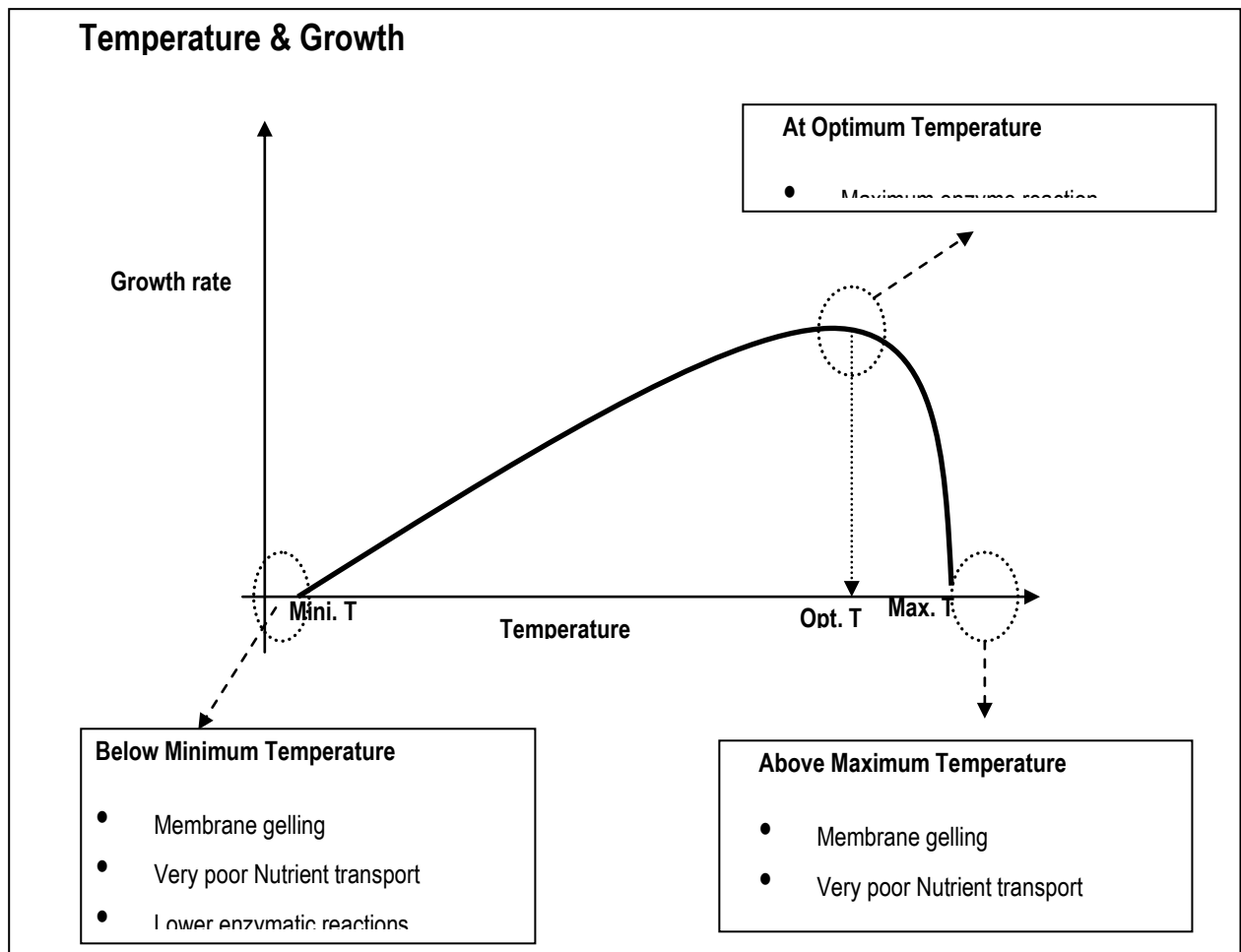
Based on the growth of bacteria at different temperatures, there are three different temperatures are available.

1. Minimum temperature – The temperature below which the organism will not grow at all.
2. maximum temperature – above which there won't be any growth of organism
3. Optimum temperature – The temperature in which maximum growth occurs.

The following table shows some of the organisms and their min, max and opt. temperature requirements.

Bacterium	Minimum	Optimum	Maximum
<i>Listeria monocytogenes</i>	1	30-37	45
<i>Vibrio marinus</i>	4	15	30
<i>Pseudomonas maltophilia</i>	4	35	41
<i>Thiobacillus novellus</i>	5	25-30	42
<i>Staphylococcus aureus</i>	10	30-37	45
<i>Escherichia coli</i>	10	37	45
<i>Clostridium kluyveri</i>	19	35	37
<i>Streptococcus pyogenes</i>	20	37	40
<i>Streptococcus pneumoniae</i>	25	37	42
<i>Bacillus flavothermus</i>	30	60	72
<i>Thermus aquaticus</i>	40	70-72	79
<i>Methanococcus jannaschii</i>	60	85	90
<i>Sulfolobus acidocaldarius</i>	70	75-85	90
<i>Pyrobacterium Brockii</i>	80	102-105	115

The effect of these temperatures on the growth rate of bacteria is represented as the following graph:



Based on the optimum temperature requirement, the organisms can be classified as :

1. **Psychrophiles** : The organisms which prefer low temperature (15°C) as optimum temperature are referred as psychrophiles. They have about 0°C and 20°C as their minimum and maximum temperature respectively. Ex. *Poloromonas vaculata*
2. **Psychrotolerant** : They are the psychrophiles but can grow even at higher temperature of 20-40°C (as the maximum temperature not optimum)
3. **Mesophiles** : The organisms which prefer 35°C (room temperature) as optimum temperature are referred as mesophiles. They have about 10°C and 48°C as their minimum and maximum temperature respectively. Ex. *bacillus, Pseudomonas, E. coli*
4. **Thermotolerants** - They are the mesophiles but can grow even at higher temperatures (Ex. 45° to 55°C)
5. **Thermophiles** – The organisms which prefers high temperature (55-65°C) as optimum temperature are referred as thermophiles. They have 40°C and 70°C as their minimum and maximum temperatures respectively. Ex. *Bacillus stearothermophilus*
6. **Hyper thermophiles** – The organisms which prefer very high temperatures (80 – 100°C) as their optimum temperature are referred as hyper thermophiles. They have 60°C and 110°C as their minimum and maximum temperature respectively. (Ex. *Thermococcus*)

Optimum growth temperature of some prokaryotes

Genus and species	Optimal growth temp (°C)
<i>Vibrio cholerae</i>	18-37

<i>Photobacterium phosphoreum</i>	20
<i>Rhizobium leguminosarum</i>	20
<i>Streptomyces griseus</i>	25
<i>Rhodobacter sphaeroides</i>	25-30
<i>Pseudomonas fluorescens</i>	25-30
<i>Erwinia amylovora</i>	27-30
<i>Staphylococcus aureus</i>	30-37
<i>Escherichia coli</i>	37
<i>Mycobacterium tuberculosis</i>	37
<i>Pseudomonas aeruginosa</i>	37
<i>Streptococcus pyogenes</i>	37
<i>Treponema pallidum</i>	37
<i>Thermoplasma acidophilum</i>	59
<i>Thermus aquaticus</i>	70
<i>Bacillus caldolyticus</i>	72
<i>Pyrococcus furiosus</i>	100

Hyperthermophilic Archaea

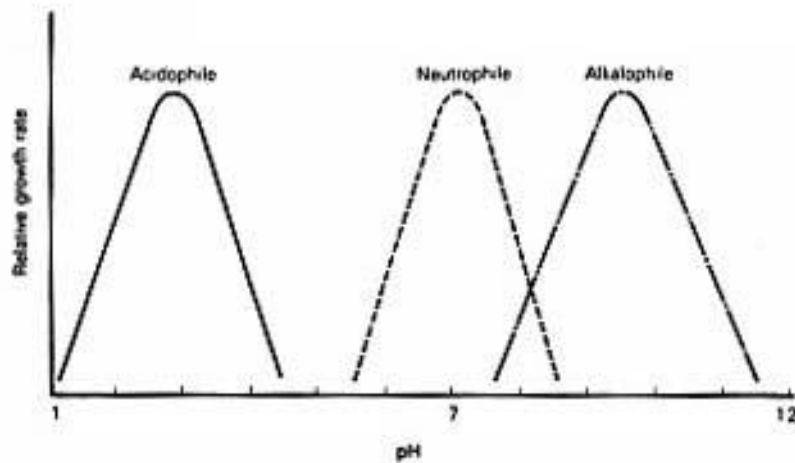
Genus	Min. T (°C)	Opt. T (°C)	Maxi. T (°C)	Optimum pH
<i>Sulfolobus</i>	55	75-85	87	2-3
<i>Desulfurococcus</i>	60	85	93	6
<i>Methanothermus</i>	60	83	88	6-7
<i>Pyrodictium</i>	82	105	113	6
<i>Methanopyrus</i>	85	100	110	7

b. pH

The pH, or hydrogen ion concentration, $[H^+]$, of natural environments varies from about 0.5 in the most acidic soils to about 10.5 in the most alkaline lakes. Most free-living prokaryotes can grow over a range of 3 pH units, about a thousand fold change in $[H^+]$. The range of pH over which an organism grows is defined by **three cardinal points**: the **minimum pH**, below which the organism cannot grow, the **maximum pH**, above which the organism cannot grow, and the **optimum pH**, at which the organism grows best. For most bacteria there is an orderly increase in growth rate between the minimum and the optimum and a corresponding orderly decrease in

growth rate between the optimum and the maximum pH, reflecting the general effect of changing $[H^+]$ on the rates of enzymatic reaction.

Microorganisms which grow at an optimum pH well below neutrality (7.0) are called **acidophiles**. Those which grow best at neutral pH are called **neutrophiles** and those that grow best under alkaline conditions are called **alkaliphiles**. Obligate acidophiles, such as some *Thiobacillus* species, actually require a low pH for growth since their membranes dissolve and the cells lyse at neutrality. Several genera of Archaea, including *Sulfolobus* and *Thermoplasma*, are obligate acidophiles. Among eukaryotes, many fungi are acidophiles, and the champion of growth at low pH is the eukaryotic alga *Cyanidium* which can grow at a pH of 0.



Relation between growth rate and pH

The following table shows the mini. pH, opt. pH, and maxi. pH requirement of few bacteria

Organism	Minimum pH	Optimum pH	Maximum pH
<i>Thiobacillus thiooxidans</i>	0.5	2.0-2.8	4.0-6.0
<i>Sulfolobus acidocaldarius</i>	1.0	2.0-3.0	5.0
<i>Bacillus acidocaldarius</i>	2.0	4.0	6.0
<i>Zymomonas lindneri</i>	3.5	5.5-6.0	7.5
<i>Lactobacillus acidophilus</i>	4.0-4.6	5.8-6.6	6.8
<i>Staphylococcus aureus</i>	4.2	7.0-7.5	9.3
<i>Escherichia coli</i>	4.4	6.0-7.0	9.0
<i>Clostridium sporogenes</i>	5.0-5.8	6.0-7.6	8.5-9.0
<i>Erwinia caratovora</i>	5.6	7.1	9.3
<i>Pseudomonas aeruginosa</i>	5.6	6.6-7.0	8.0
<i>Thiobacillus novellus</i>	5.7	7.0	9.0
<i>Streptococcus pneumoniae</i>	6.5	7.8	8.3

<i>Nitrobacter</i> sp	6.6	7.6-8.6	10.0
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c. Oxygen

Oxygen is a universal component of cells and is always provided in large amounts by H₂O. However, prokaryotes display a wide range of responses to molecular oxygen O₂.

Molecular oxygen is both beneficial and harmful for biologicals.

Beneficial :The act as terminal electron acceptor in the respiratory chain – Electron transport chain reaction enable to form ATP.

Harmful : The oxygen derivatives such as hydrogen **peroxide**, **singlet oxygen** and **super oxide** are highly toxic and oxidizing agents.

The organisms can be divided into 4 or 5 different groups based on their oxygen requirement.

Obligate aerobes require O₂ for growth; they use O₂ as a final electron acceptor in aerobic respiration.

Ex. *Micrococcus*

Obligate anaerobes - do not need or use O₂ as a nutrient. In fact, O₂ is a toxic substance, which either kills or inhibits their growth. Obligate anaerobic prokaryotes may live by fermentation, anaerobic respiration, bacterial photosynthesis, or the novel process of methanogenesis. Ex. *Clostridium*, *Methanobacterium*

Facultative anaerobes (or **facultative aerobes**) are organisms that can switch between aerobic and anaerobic types of metabolism. Under anaerobic conditions (no O₂) they grow by fermentation or anaerobic respiration, but in the presence of O₂ they switch to aerobic respiration. Ex. *E. coli*

Aerotolerant anaerobes are bacteria with an exclusively anaerobic (fermentative) type of metabolism but they are insensitive to the presence of O₂. They live by fermentation alone whether or not O₂ is present in their environment. Ex. *Streptococcus*

Microaerophiles – They need very low level of oxygen for their growth, but cannot tolerate the level of atmospheric O₂ level. Ex. *Spirillum volutans*

Table 6. Terms used to describe O₂ Relations of Microorganisms

Environment			
Group	Aerobic	Anaerobic	O ₂ Effect
Obligate Aerobe	Growth	No growth	Required (utilized for aerobic respiration)
Microaerophile	Growth if level not too high	No growth	Required but at levels below 0.2 atm
Obligate Anaerobe	No growth	Growth	Toxic
Facultative Anaerobe	Growth	Growth	Not required for growth but utilized when

(Facultative Aerobe)			available
Aerotolerant Anaerobe	Growth	Growth	Not required and not utilized

Oxygen detoxification : Most of the aerobes (and aerotolerant organisms too) have three major enzymes either all or two to detoxify the oxygen derivatives. They are **catalase, peroxidase and super oxide dismutase**. Obligate anaerobes lack these enzymes, and therefore undergo lethal oxidations by various oxygen radicals when they are exposed to O₂.

d. Water activity

Water is the solvent in which the molecules of life are dissolved, and the availability of water is therefore a critical factor that affects the growth of all cells. The availability of water for a cell depends upon its presence in the atmosphere (relative humidity) or its presence in solution or a substance (**water activity**). The water activity (Aw) of pure H₂O is 1.0 (100% water). Water activity is affected by the presence of solutes such as salts or sugars, that are dissolved in the water. The higher the solute concentration of a substance, the lower is the water activity and vice-versa. Microorganisms live over a range of Aw from 1.0 to 0.7. The Aw of human blood is 0.99; seawater = 0.98; maple syrup = 0.90; Great Salt Lake = 0.75. Water activities in agricultural soils range between 0.9 and 1.0. The water requirement (Aw) of few bacteria are as follows:

Caulobacter - 1.00; *Pseudomonas*, *Salmonella*, *E. coli* - 0.91; *Lactobacillus* - 0.90; *Bacillus* - 0.90; *Staphylococcus* - 0.85; *Halococcus* - 0.75

(Note: The concept of lowering water activity in order to prevent bacterial growth is the basis for preservation of foods by drying (in sunlight or by evaporation) or by addition of high concentrations of salt or sugar.)

e. salt concentrations

The only common solute in nature that occurs over a wide concentration range is salt [NaCl], and microorganisms are named based on their growth response to salt. Microorganisms that require some NaCl for growth are **halophiles**.

Mild halophiles require 1-6% salt, (Ex: *Staphylococcus aureus*)

moderate halophiles require 6-15% salt; (Ex. *Vibrio fischeri*)

extreme halophiles require 15-30% NaCl for growth. (Ex. *Halobacterium salinarum*)

Bacteria that are able to grow at moderate salt concentrations, even though they grow best in the absence of NaCl, are called **halotolerant**. Although halophiles are "osmophiles" (and halotolerant organisms are "osmotolerant") the term **osmophiles** is usually reserved for organisms that are able to live in environments high in sugar.

Organisms which live in dry environments (made dry by lack of water) are called **xerophiles**.