Bacterial Growth, Metabolism and Genetic
It is an increase in all the cell components, which ends in multiplication of cell leading to an increase in population.

It involves - an increase in the size of the cell & an increase in the number of individual cells.

Bacteria divide by binary fission.
Binary Fission

1. Cell elongates and DNA is replicated
   Cell wall       Plasma membrane
   DNA (nuclear area)

2. Cell wall and plasma membrane begin to divide
   DNA (nuclear area)    Partially formed cross-wall
   Cell wall

3. Cross-wall forms completely around divided DNA

4. Cells separate

(a) A diagram of the sequence of cell division.
(b) A thin section of a cell of *Bacillus licheniformis* starting to divide.
Generation time

- Interval of time between two cell divisions
  OR
- The time required for a bacterium to give rise to 2 daughter cells under optimum conditions

Also called population doubling time.

- *Escherichia coli* 20 minutes
- *Mycobacterium tuberculosis* 18 hours
- *Mycobacterium leprae* 14 days
The population of bacterial cells divide at a constant rate so that the total number of cells doubles with each division.
The graph illustrates the bacterial growth curve over time.

- **Log, or exponential growth, phase**: The bacterial population grows rapidly, doubling at regular intervals.
- **Stationary phase**: The bacterial population reaches a plateau as growth slows due to limited resources.
- **Death, or logarithmic decline, phase**: The bacterial population begins to decrease as conditions become unfavorable.

The x-axis represents time (in hours), ranging from 0 to 10, and the y-axis represents the log of the number of bacteria.

Key points:
- **Lag phase**: Initial period where bacteria acclimate to the new environment.
- **Early-log phase**: Rapid exponential growth.
- **Mid-log phase**: Continued logarithmic growth.
- **Late-log phase**: Slower exponential growth.
- **Stationary phase**: Population reaches a plateau.
- **Death phase**: Population begins to decline.

Understanding these phases is crucial in microbiology for predicting and controlling bacterial growth.
<table>
<thead>
<tr>
<th>Phase</th>
<th>Growth Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lag</td>
<td>Zero</td>
</tr>
<tr>
<td>Exponential</td>
<td>Constant</td>
</tr>
<tr>
<td>Maximum stationary</td>
<td>Zero</td>
</tr>
<tr>
<td>Decline</td>
<td>Negative (death)</td>
</tr>
</tbody>
</table>
Factors affecting Bacterial Growth

- Amount of nutrients
- Temperature
- pH
- Other Environmental factors
Classification based upon Nutrient requirements

**Prototrophs**
- Can live on simple compounds
- Make all Amino Acids, Vitamins, etc.

**Auxotrophs**
- Require complex compounds
  - Vitamins, Amino Acids
  - Fastidious
  - Most Pathogens
Classification based upon temperature requirements

- **Mesophiles**
  - Organisms which are able to grow at \(20-40^\circ C\)
  - Most of the human pathogens

- **Psychrophiles**
  - Organisms which grow best at \(<10^\circ C\)
  - Capable of growth in pharmaceuticals and foods stored in refrigerator

- **Thermophiles**
  - Organisms which grow best at \(>60^\circ C\)
Effect of Temp on Growth
- **Acidophiles** (pH < 5.0)
  - Organisms that grow at a low pH e.g. *Lactobacillus* spp.,
- **Neutrophiles** (pH 6.0-8.0)
  - Organisms that grow at a neutral pH
  - Most of human pathogens
- **Alkaliphiles** (pH 8.5-10.5)
  - Organisms that grow at a high salt conc. or at high pH e.g. *Vibrio* spp., *Bacillus alcalophilus*
• **Strict Aerobes**
  - Grow only in the presence of ambient oxygen (21%)
  - e.g. *Mycobacterium tuberculosis*, *Pseudomonas aeruginosa*

• **Strict Anaerobes**
  - Grow only in the absence of oxygen
  - *Bacteroides fragilis*
• **Facultative Anaerobes**
  
  • Can grow in anaerobic environment but grow best in aerobic environment
  
  • e.g. *Staphylococcus aureus, Escherichia coli*

• **Aerotolerant anaerobes**
  
  • Are anaerobes but can tolerate exposure to oxygen
  
  • Aerotolerant organisms do not require oxygen as they metabolise energy anaerobically. Unlike obligate anaerobes however, they are not poisoned by oxygen.
  
  • e.g. *Clostridium perfringens*, lactic acid bacteria
• Microaerophilic
  o Require or prefer decreased oxygen environment (5%)  
  o Small amounts of catalase and superoxide dismutase  
  o grow best under increased CO2 tension  
  o e.g. Campylobacter jejuni, Helicobacter pylori

• Capnophilic
  • Require or prefer increased CO2 environment  
  • e.g. Neisseria meningitidis
All organisms produce superoxide (O$_2^{-}$)
Superoxide is toxic to cells
Superoxide must be neutralized

**Oxygen is lethal to some organisms**
Superoxide dismutase

\[ \text{O}_2^- + \text{O}_2^- + 2 \text{H}^+ \rightarrow \text{H}_2\text{O}_2 + \text{O}_2 \]

Hydrogen peroxide is also toxic to cells and it must be neutralized
Catalase

\[ 2 \text{H}_2\text{O}_2 \rightarrow 2 \text{H}_2\text{O} + \text{O}_2 \]

Obligate Anaerobes lack:

- Superoxide dismutase (SOD)
- Catalase

Catalase
All organisms

Energy source

Chemical

Chemotrophs

Carbon source

Organic compounds

Chemoheterotrophs

CO₂

Chemoautotrophs

Light

Phototrophs

Carbon source

Organic compounds

Photoheterotrophs

CO₂

Photoautotrophs
Bacterial cell

Synthesis of Cell Structures

Sources of energy
- Carbohydrates
- Lipids
- Proteins

Catabolism
- Releases energy

End products with reduced energy
- CO₂, H₂O

ATP
NADH

Macromolecules
- Carbohydrates
- Proteins
- Lipids

Anabolism
- Requires energy

Simple building blocks
- Sugars
- Amino acids

Increasing complexity
Catabolism

Polysaccharides
Lipids
Proteins
Nucleic acids

Monosaccharides
Fatty acids, glycerol
Amino acids
Nucleotides

CO₂
H₂O, O₂
NH₄⁺, NO₃⁻
PO₄⁻, SO₄²⁻

Polymers
Monomers
Molecules

Anabolism
Energy Generating Patterns

– After Sugars are made or obtained, they are the energy source of life.
– Breakdown of sugar (catabolism) in different ways:

  • Aerobic respiration
  • Anaerobic respiration
  • Fermentation
Aerobic Cellular Respiration

- 4 subpathways
  - 1. Glycolysis
  - 2. Transition Reaction
  - 3. Kreb’s Cycle
  - 4. Electron Transport System
1. Glycolysis (splitting of sugar)

- Oxidation of Glucose into 2 molecules of Pyruvic acid
- Embden-Meyerhof Pathway
End Products of Glycolysis:

2 Pyruvic acid
2 NADH
2 ATP
2. Transition Reaction

- Connects Glycolysis to Krebs Cycle

- End Products:
  - 2 Acetyl CoEnzyme A
  - 2 CO$_2$
  - 2 NADH$_2$
3. Krebs Cycle (Citric Acid Cycle)

- Series of chemical reactions that begin and end with citric acid

- Products:
  - 2 ATP
  - 6 NADH₂
  - 2 FADH₂
  - 4 CO₂
4. Electron Transport System

- Occurs within the cell membrane of Bacteria
- Function: Extract energy from NADH and FADH$_2$ in order to add a phosphate group to ADP to make ATP.

**Requires**

NADH or FADH$_2$

ADP and P

O$_2$
<table>
<thead>
<tr>
<th><strong>Source</strong></th>
<th><strong>ATP Yield (Method)</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Glycolysis</strong></td>
<td>2 ATP (substrate-level phosphorylation)</td>
</tr>
<tr>
<td>1. Oxidation of glucose to pyruvic acid</td>
<td>6 ATP (oxidative phosphorylation in electron transport chain)</td>
</tr>
<tr>
<td>2. Production of 2 NADH</td>
<td></td>
</tr>
<tr>
<td><strong>Preparatory Step</strong></td>
<td></td>
</tr>
<tr>
<td>1. Formation of acetyl CoA produces 2 NADH</td>
<td>6 ATP (oxidative phosphorylation in electron transport chain)</td>
</tr>
<tr>
<td><strong>Krebs Cycle</strong></td>
<td></td>
</tr>
<tr>
<td>1. Oxidation of succinyl CoA to succinic acid</td>
<td>2 GTP (equivalent of ATP; substrate-level phosphorylation)</td>
</tr>
<tr>
<td>2. Production of 6 NADH</td>
<td>18 ATP (oxidative phosphorylation in electron transport chain)</td>
</tr>
<tr>
<td>3. Production of 2 FADH</td>
<td>4 ATP (oxidative phosphorylation in electron transport chain)</td>
</tr>
<tr>
<td><strong>Total:</strong></td>
<td>38 ATP</td>
</tr>
</tbody>
</table>
1 Glycolysis

2 Pyruvic acid

2 Acetyl Coenzyme A

3 Krebs Cycle

4 Electron Transport Chain

1. Glucose
   - 2 ATP
   - 2 NADH + 2 H⁺

2. Formation of Acetyl Coenzyme A
   - 2 CO₂
   - 2 NADH + 2 H⁺

3. Krebs Cycle
   - 4 CO₂
   - 2 FADH₂

4. Electron Transport Chain
   - 32 or 34 ATP

O₂ -> H₂O
Glycolytic Pathways

- 4 major glycolytic pathways found in different bacteria:
  - **Embden-Meyerhoff-Parnas pathway**
    - “Classic” glycolysis
    - Found in almost all organisms
  - **Hexose monophosphate pathway**
    - Also found in most organisms
    - Responsible for synthesis of pentose sugars used in nucleotide synthesis
  - **Entner-Doudoroff pathway**
    - Found in *Pseudomonas* and related genera
  - **Phosphoketolase pathway**
    - Found in *Bifidobacterium* and *Leuconostoc*
• Electrons released by oxidation are passed down an E.T.S., but oxygen is not the final electron acceptor

• Nitrate (NO$_3^-$) ----> Nitrite (NO$_2^-$)
• Sulfate (SO$_4^{2-}$) ----> Hydrogen Sulfide (H$_2$S)
• Carbonate (CO$_2^{4-}$) ----> Methane (CH$_4$)

Anaerobic Respiration
Fermentation Summary

- Anaerobic
- Cytoplasm
- Partial Oxidation
- Small amounts of ATP generated via substrate level phosphorylation
- Organic intermediaries as final electron acceptors
- End products
  - Acid: Lactic Acid, Acetic Acid, Butyric Acid, Acetone
  - Alcohol: Ethanol, Isopropyl
  - Gas: CO2, H2
- Contaminants
Glucose (or other sugar) → Glycolysis → Pyruvic Acid

Pyruvic Acid:
- Homolactic acid fermentation: Lactic acid
- Butyric-butylic fermentation: Butyric acid, butanol, isopropyl alcohol, acetone, and CO₂
- Alcoholic fermentation: Ethyl alcohol and CO₂
- Mixed-acid fermentation
- Propionic fermentation: Propionic acid, acetic acid, and CO₂
- Butanediol fermentation: Butanediol and CO₂
# Metabolic strategies

<table>
<thead>
<tr>
<th>Pathways involved</th>
<th>Final e-acceptor</th>
<th>ATP yield</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Aerobic respiration</strong></td>
<td>Glycolysis, TCA, ET</td>
<td>$O_2$</td>
</tr>
<tr>
<td><strong>Anaerobic respiration</strong></td>
<td>Glycolysis, TCA, ET</td>
<td>$NO_3^-, SO_4^{2-}, CO_3^{3-}$</td>
</tr>
<tr>
<td><strong>Fermentation</strong></td>
<td>Glycolysis</td>
<td>Organic molecules</td>
</tr>
</tbody>
</table>
Molecular energy source

Aerobic
- Hydrogen e⁻ acceptor: O₂
  - ATP + CO₂ + H₂O

Anaerobic
- Hydrogen e⁻ acceptor: Inorganic (e.g., NO₃⁻)
  - ATP + H₂O + reduced acceptor (e.g., NO₂⁻)
- Hydrogen e⁻ acceptor: Organic (e.g., pyruvate)
  - ATP + CO₂ + reduced organic (i.e., alcohol)

Fermentation
Bacterial Genetics
The figure illustrates the structure of nucleotides. The nucleotide consists of a phosphate group, a sugar, and one of the four nitrogenous bases: adenine (A), guanine (G), cytosine (C), or thymine (T). Purines are adenine and guanine, while pyrimidines are cytosine and thymine.

(a) Ribonucleotides: The sugar is ribose, and the nucleotide contains the sugar and a phosphate group attached to the 5' position.

(b) Deoxyribonucleotides: The sugar is deoxyribose, and the nucleotide contains the sugar and a phosphate group attached to the 5' position.

The structures show the typical connectivity of the sugar and the base, with the 5' phosphate and other functional groups.
Structure of DNA:
How RNA differs from DNA

• RNA contains - Sugar Ribose instead of Deoxyribose

• Uracil is present instead of Thymine

• Types of RNA
  - Messenger RNA  \(\text{mRNA}\)
  - Ribosomal RNA  \(\text{rRNA}\)
  - Transfer RNA  \(\text{tRNA}\)
Cytosine (C)

Guanine (G)

Adenine (A)

Uracil (U)

Nucleobases of RNA

Nucleobases of DNA

Nucleobases

RNA: Ribonucleic acid

DNA: Deoxyribonucleic acid

Base pair

helix of sugar-phosphates
TRANSCRIPTION

DNA

RNA polymerase

mRNA
The Central Dogma

The process of gene expression/protein synthesis follows a specific order:
1. DNA is transcribed into mRNA.
2. mRNA is then translated into protein.
The Genetic Code

ATG CTAGGCC

three bases code for one amino acid
Bacterial Chromosome

- Contains a Double stranded molecules of DNA arranged in circular form.
- Length 1,000 microns.
- Bacterial DNA contains about 4,000 kilobases
- **1 kb = 1000 base pairs (A-T) (G-C)**
- Genome contains one chromosomal DNA and many plasmids
Asexual Bacterial Reproduction

- Binary fission
- Asexual form of reproduction
- rapid
- Bacterial colony = identical clone
- Replication complex binds to origin of replication
  - helicases & topoisomerases unwind and separate the 2 DNA strands
  - DNA polymerase – high proof-reading capability
- Bi-directional → 2 replication forks in opposite directions
- One parental DNA gives rise to two identical copies of daughter DNAs
- Semi-conservative – one new stand & one parental strand
Transcription
Translation

Growing peptide chain

Ribosome

MessengerRNA

Peptide Synthesis

Outgoing empty tRNA

TRNA

 ACC

Trp

Lys

Asp

TRNA

TRNA

U U U

C U A

Phe

TRNA

A A G

Incoming tRNA bound to Amino Acid
Extra chromosomal Genetic Elements

- Bacteria posses Extra chromosomal genetic elements
- Not Essential for survival of Bacteria
- But makes the Bacteria Resistant to antibiotics, and makes them survive
- Able to produce toxins
Bacterial Extrachromosomal Elements

1- Plasmids
2- Insertion Sequences (IS)
3- Transposons
4- Integron

In most cases can be transmitted from one cell to another
Plasmids

- Plasmids are circular DNA molecules present in the cytoplasm of the Bacteria
- Capable of Autonomous replication
- Can transfer genes from one cell to other
Types of Bacterial Plasmids

Based on their function, there are five main classes:

**Fertility-(F) plasmids:** they are capable of conjugation or mating.

**Resistance-(R) plasmids:** containing antibiotic or drug resistant gene(s). Also known as R-factors, before the nature of plasmids was understood.

**Col-plasmids:** contain genes that code for colicines, proteins that can kill other bacteria.

**Degrative plasmids:** enable digestion of unusual substances, e.g., toluene or salicylic acid.

**Virulence plasmids:** turn the bacterium into a pathogen.

Plasmids can belong to more than one of these functional groups.
Mutation

A change in a gene or chromosome
Mutations

- Changes in base sequence of DNA/lethal and inheritable
- Can be:
  - Harmful
  - Lethal
  - Helpful
  - Silent
Transitions:  

pyrimidine to pyrimidine  

T ←→ C  
C ←→ A  
A ←→ G

Transversions:  

pyrimidine to purine  

T → A  
C → G  
G → A

purine to pyrimidine  

T → C  
A → T  
G → T
## Effects of point mutations

<table>
<thead>
<tr>
<th>No mutation</th>
<th>Silent</th>
<th>Nonsense</th>
<th>Missense</th>
</tr>
</thead>
<tbody>
<tr>
<td>DNA level</td>
<td>TTC</td>
<td>TTT</td>
<td>ATC</td>
</tr>
<tr>
<td>mRNA level</td>
<td>AAG</td>
<td>AAA</td>
<td>UAG</td>
</tr>
<tr>
<td>protein level</td>
<td>Lys</td>
<td>Lys</td>
<td>STOP</td>
</tr>
</tbody>
</table>

- **Silent**: No change in amino acid.
- **Nonsense**: Changes to a stop codon.
- **Missense**: Changes to a different amino acid.

**Conservative vs. Non-conservative**

- **Conservative**: Changes to a similar amino acid.
- **Non-conservative**: Changes to a different amino acid.
Frameshift Mutations

Wild-type gene

Gene with insertion

Gene with deletion
Gene exchange

**Transformation**
Transformation involves uptake of short fragments of naked DNA by naturally transformable bacteria.

**Transduction**
Transduction involves transfer of DNA from one bacterium into another via bacteriophages.

**Conjugation**
Conjugation involves transfer of DNA material via sexual pilus and requires cell-to-cell contact.
Transduction by a Bacteriophage

1. A phage infects the donor bacterial cell.
2. Phage DNA and proteins are made, and the bacterial chromosome is broken down into pieces.
3. Occasionally during phage assembly, pieces of bacterial DNA are packaged in a phage capsid. Then the donor cell lyse and releases phage particles containing bacterial DNA.
4. A phage carrying bacterial DNA infects a new host cell, the recipient cell.
5. Recombination can occur, producing a recombinant cell with a genotype different from both the donor and recipient cells.

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Transformation

1. Recipient cell takes up donor DNA

2. Recombination occurs between donor DNA and recipient DNA

Genetically transformed cell
Conjugation

(a) When an F factor (a plasmid) is transferred from a donor $\left(F^+\right)$ to a recipient $\left(F^-\right)$, the $F^-$ cell is converted into an $F^+$ cell.
## Types of cells involved in conjugation

<table>
<thead>
<tr>
<th></th>
<th>F plasmid</th>
<th>Bacterial chromosome</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>F&lt;sup&gt;+&lt;/sup&gt; cell</strong> – with F plasmid</td>
<td><img src="image" alt="F&lt;sup&gt;+&lt;/sup&gt; cell" /></td>
<td><img src="image" alt="Bacterial chromosome" /></td>
</tr>
<tr>
<td><strong>F&lt;sup&gt;-&lt;/sup&gt; cell</strong> – without F plasmid</td>
<td><img src="image" alt="F&lt;sup&gt;-&lt;/sup&gt; cell" /></td>
<td><img src="image" alt="Bacterial chromosome" /></td>
</tr>
<tr>
<td><strong>F&lt;sup&gt;′&lt;/sup&gt; cell</strong> – with F plasmid containing few chromosomal genes</td>
<td><img src="image" alt="F&lt;sup&gt;′&lt;/sup&gt; cell" /></td>
<td><img src="image" alt="Bacterial chromosome" /></td>
</tr>
<tr>
<td><strong>Hfr cell</strong> – F plasmid integrated in the bacterial chromosome</td>
<td><img src="image" alt="Hfr cell" /></td>
<td><img src="image" alt="Bacterial chromosome" /></td>
</tr>
</tbody>
</table>
Thank You!