Binary fission

- In prokaryotes, growth = increase in number of cells
- Generation time is the time required for 1 bacterium to become 2 bacteria
- *E. coli* generation time is ~ 20 min

Diagram showing the process of binary fission removed due to copyright restrictions. See Figure 6-1 in Madigan, Michael, and John Martinko. *Brock Biology of Microorganisms*. 11th ed. Upper Saddle River, NJ: Pearson Prentice Hall, 2006. ISBN: 0131443291
Fts proteins and the “divisome”

Image removed due to copyright restrictions.
Peptidoglycan synthesis

- New cell wall is synthesized from the FtsZ ring
- Need to extend existing chains without compromising integrity
- Autolysins without autolysis

Images removed due to copyright restriction
Exponential growth

- From semi-log plot of cell density as a function of time can determine generation time \( g \) from time \( t \) and number of generations \( n \)
- \( g = \frac{t}{n} \)

Growth parameters

- Number of cells (N) after n generations beginning with $N_0$ cells
  
  \[ N = 2^n N_0 \]

\[ \log N = n \log 2 + \log N_0 \]

\[ n = \frac{\log N - \log N_0}{\log 2 - 0.301} \]

Graph of cell growth over time removed due to copyright restrictions.
Related growth parameters

- Slope = 0.301 n/t
  = the specific growth rate (k)

- Division rate (v) = 1/g
- Slope = v/3.3

- If you know n and t, you can calculate g, k, and v for organisms growing under different conditions
The growth cycle

- Lag phase
- Exponential phase
- Stationary phase

Total cell count

1. Does not distinguish live from dead
2. Can be hard to see small/moving cells
3. Not very precise
4. Need phase contrast microscope to count unstained cells
5. Need to concentrate dilute samples

Diagram showing the process of a cell count removed due to copyright restrictions.
Viable count

• Prepare 10-fold serial dilutions
• Plate sample of each dilution
• Yields colony-forming units (CFU)
• Can be discrepancy between viability and ability to form colonies

Plating methods

Diagram showing plating methods removed due to copyright restrictions.
Turbidity as an indirect measure

- Light scattering is proportional to the density of cells
- Can create a standard curve from optical density
OD measurement of growth

Bacterial Growth, Semi-Log

Absorbancy 660 nm vs. Minutes Incubation, 37 C

- CSHA Minimal media
- Tryptone Soy Broth

Figure by MIT OCW.

Photograph of a test tube of cells undergoing an OD measurement of growth removed due to copyright restrictions.
Chemostat culture

- **Continuous culture device**
- **Open system**
- **At steady state, volume, cell number, and rate of growth are constant**

- **Dilution rate**
  - Growth rate

- **Limiting nutrient**
  - Yield or density

Batch culture

Nutrient Concentration (mg/ml)

Growth Rate (---)

Growth Yield (---)

Rate & Yield Affected

Only Yield Affected

0 0.1 0.2 0.3 0.4 0.5

Nutrient Concentration (mg/ml)

Figure by MIT OCW.
A = Bacterial concentration
B = Doubling time
Cardinal temperatures

• For any given organism there is a:
  • Minimum temp.
  • Optimum temp.
  • Maximum temp.

• Microbes can grow wherever there is liquid water

Classes of organisms

Graph showing the optimal growth temperatures for a variety of organisms removed due to copyright restrictions. See Figure 6-17 in Madigan, Michael, and John Martinko. *Brock Biology of Microorganisms*. 11th ed. Upper Saddle River, NJ: Pearson Prentice Hall, 2006. ISBN: 0131443291.
Psychrophiles

- Optimal ≤ 15°C, maximal ≤ 20°C, minimal ≤ 0°C

- Psychrotolerant organisms grow at 0°C but have optima between 20 and 40°C

Images of Psychrophiles removed due to copyright restrictions
Hyperthermophiles

• Optimum $\geq 80^\circ$C
• Hot springs, deep sea vents
• Most are archaea
• Protein changes
• DNA stability
• Membrane stability
Thermophiles

• Optimum $\geq 45^\circ C$

• Both archea and bacteria

• Important source of enzymes for biotechnology
pH and osmolarity

- **Acidophiles**
- **Alkaliphiles**
- **Halophiles**
  - Mild 1-6%
  - Moderate 7-15%
  - Extreme 15-30%

- Accumulate inorganic ions or make organic solutes

http://en.wikipedia.org/wiki/Salt_evaporation_pond
## Compatible Solutes of Microorganisms

<table>
<thead>
<tr>
<th>Organism</th>
<th>Major Solute(s) Accumulated</th>
<th>Minimum $a_w$ for Growth</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Bacteria</em>, nonphototrophic</td>
<td>Glycine betaine, proline (mainly gram-positive), glutamate (mainly gram-negative)</td>
<td>0.97-0.90</td>
</tr>
<tr>
<td>Freshwater cyanobacteria</td>
<td>Sucrose, trehalose</td>
<td>0.98</td>
</tr>
<tr>
<td>Marine cyanobacteria</td>
<td>$\alpha$-Glucosylglycerol</td>
<td>0.92</td>
</tr>
<tr>
<td>Marine algae</td>
<td>Mannitol, various glycosides, proline, dimethylsulfoniopropionate</td>
<td>0.92</td>
</tr>
<tr>
<td>Salt lake cyanobacteria</td>
<td>Glycine betaine</td>
<td>0.90-0.75</td>
</tr>
<tr>
<td>Halophilic anoxygenic phototrophic <em>Bacteria</em> (<em>Ectothiorhodospira/Halorhodospira</em> and <em>Rhodovibrio</em> species)</td>
<td>Glycine betaine, ectoine, trehalose</td>
<td>0.90-0.75</td>
</tr>
<tr>
<td>Extremely halophilic <em>Archaea</em> (for example, <em>Halobacterium</em>) and some <em>Bacteria</em> (for example, <em>Haloanaerobium</em>)</td>
<td>KCl</td>
<td>0.75</td>
</tr>
<tr>
<td><em>Dunaliella</em> (halophilic green alga)</td>
<td>Glycerol</td>
<td>0.75</td>
</tr>
<tr>
<td>Xerophilic yeasts</td>
<td>Glycerol</td>
<td>0.83-0.62</td>
</tr>
<tr>
<td>Xerophilic filamentous fungi</td>
<td>Glycerol</td>
<td>0.72-0.61</td>
</tr>
</tbody>
</table>

Figure by MIT OCW.
### Oxygen Relationships of Microorganisms

<table>
<thead>
<tr>
<th>Group</th>
<th>Relationship to O₂</th>
<th>Type of Metabolism</th>
<th>Example*</th>
<th>Habitat**</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Aerobes</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Obligate</td>
<td>Required</td>
<td>Aerobic respiration</td>
<td><em>Micrococcus luteus</em> (B)</td>
<td>Skin, dust</td>
</tr>
<tr>
<td>Facultative</td>
<td>Not required, but growth better with O₂</td>
<td>Aerobic respiration, anaerobic respiration, fermentation</td>
<td><em>Escherichia coli</em> (B)</td>
<td>Mammalian large intestine</td>
</tr>
<tr>
<td>Microaerophilic</td>
<td>Required but at levels lower than atmospheric</td>
<td>Aerobic respiration</td>
<td><em>Spirillum volutans</em> (B)</td>
<td>Lake water</td>
</tr>
<tr>
<td><strong>Anaerobes</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aerotolerant</td>
<td>Not required, and growth no better when O₂ present</td>
<td>Fermentation</td>
<td><em>Streptococcus pyogenes</em> (B)</td>
<td>Upper respiratory tract</td>
</tr>
<tr>
<td>Obligate</td>
<td>Harmful or lethal</td>
<td>Fermentation or anaerobic respiration</td>
<td><em>Methanobacterium (A)</em> formicicum</td>
<td>Sewage sludge digestors, anoxic lake sediments</td>
</tr>
</tbody>
</table>

*Letters in parentheses indicate phylogenetic status (B, *Bacteria*; A, *Archaea*). Representatives of either domain of prokaryotes are known in each category. Most eukaryotes are obligate aerobes, but facultative aerobes (for example, yeast) and obligate anaerobes (for example, certain protozoa and fungi) are known.

**Listed are typical habitats of the example organism.
Toxic forms of oxygen

\[ \text{O}_2 + e^- \rightarrow \text{O}_2^- \text{ Superoxide} \]

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

\[ \text{H}_2\text{O}_2 + e^- + H^+ \rightarrow \text{H}_2\text{O} + \text{OH}^- \text{ Hydroxyl radical} \]

\[ \text{OH}^- + e^- + H^+ \rightarrow \text{H}_2\text{O} \text{ Water} \]

Overall: \( \text{O}_2 + 4e^- + 4H^+ \rightarrow 2\text{H}_2\text{O} \)
1) Catalase:

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

2) Peroxidase:

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

3) Superoxide dismutase:

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

4) Superoxide dismutase / catalase in combination:

\[ 4\text{O}_2^- + 4\text{H}^+ \rightarrow 2\text{H}_2\text{O} + 3\text{O}_2 \]

5) Superoxide reductase:

\[ \text{O}_2^- + 2\text{H}^+ + \text{cyt} \text{c}_{\text{reduced}} \rightarrow \text{H}_2\text{O}_2 + \text{cyt} \text{c}_{\text{oxidized}} \]