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.

See Figure 6-2b in Madigan, Michael, and John Martinko. *Brock Biology of Microorganisms*. 11th ed. Upper Saddle River, NJ: Pearson Prentice Hall, 2006. ISBN: 0131443291.

Peptidoglycan synthesis

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

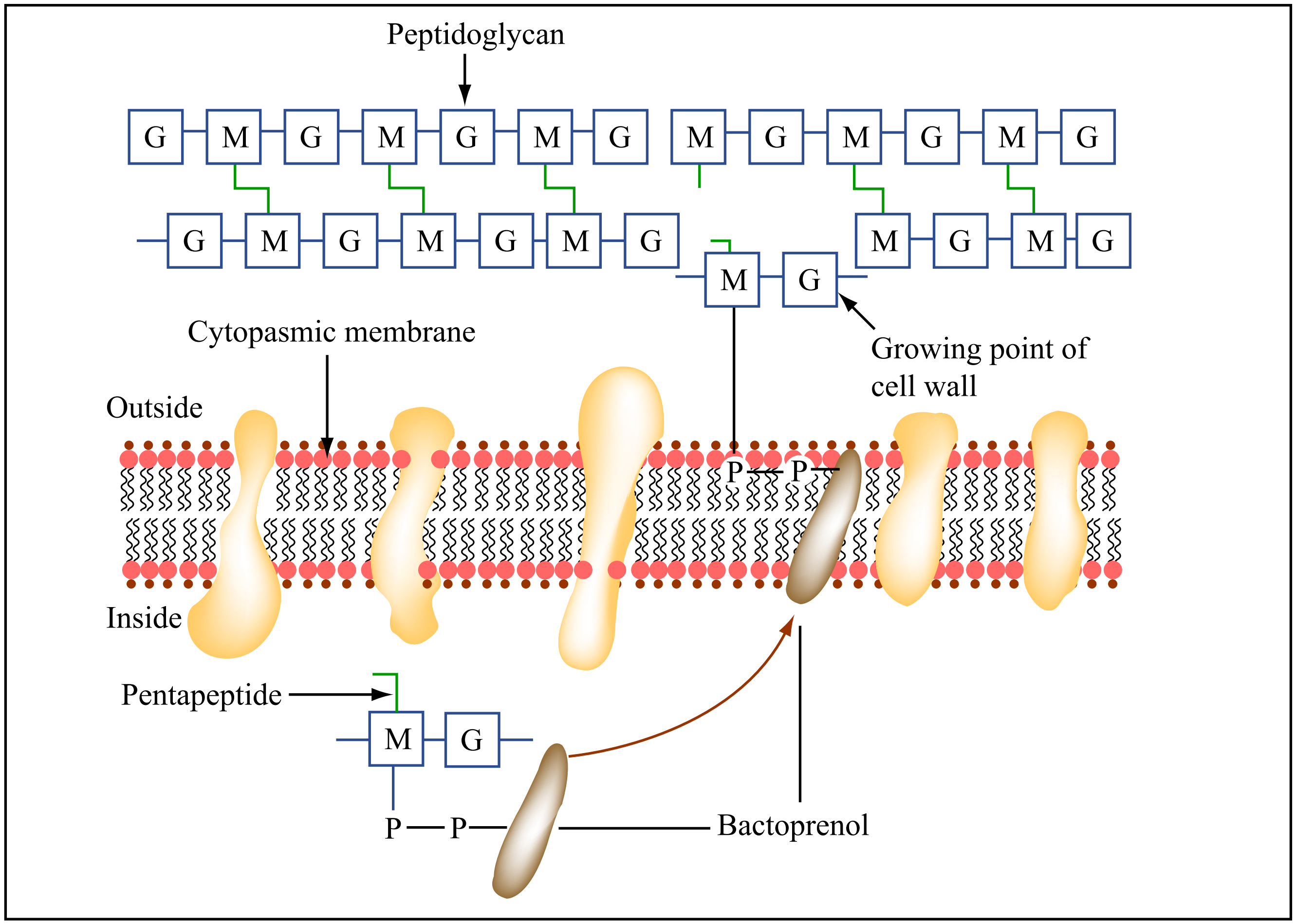


Figure by MIT OCW.

Exponential growth

- From semi-log plot of cell density s a function of time can determine generation time (g) from time (t) and number of generations (n)
- $g = t/n$

Growth parameters

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

$$\log N = n \log 2 + \log N_0$$

$$n = \frac{\log N - \log N_0}{0.301}$$

Graph of cell growth over time removed due to copyright restrictions. See Figure 6-7b in Madigan, Michael, and John Martinko. Brock Biology of Microorganisms.11th ed. Upper Saddle River, NJ: Pearson Prentice Hall, 2006. ISBN: 0131443291.

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

Graph showing the lag, exponential, stationary, and death phases of cell growth removed due to copyright restrictions. See Figure 6-8 in Madigan, Michael, and John Martinko. *Brock Biology of Microorganisms.* 11th ed. Upper Saddle River, NJ: Pearson Prentice Hall, 2006. ISBN: 0131443291.

Total cell count

Diagram showing the process of a cell count removed due to copyright restrictions.
See Figure 6-9 part 1 in Madigan, Michael, and John Martinko. *Brock Biology ofMicroorganisms*. 11th ed. Upper Saddle River, NJ: Pearson Prentice Hall, 2006. ISBN: 0131443291.

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

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

Diagram showing the process of a viable count removed due to copyright restrictions. See Figure 6-11 in Madigan, Michael, and John Martinko. *Brock Biology of Microorganisms*. 11th ed. Upper Saddle River, NJ: Pearson Prentice Hall, 2006. ISBN: 0131443291.

Plating methods

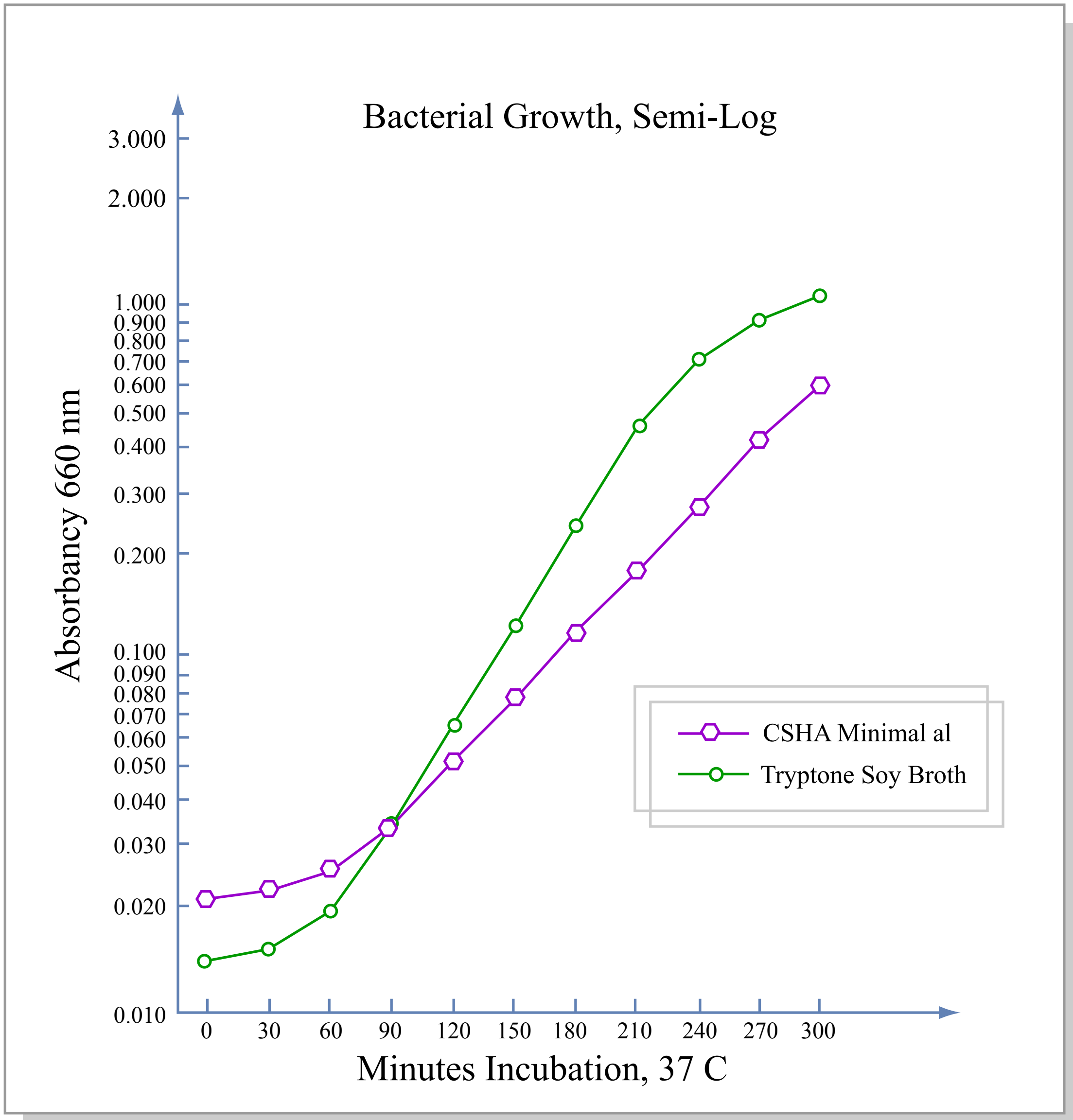
Diagram showing plating methods removed due to copyright restrictions.
See Figure 6-10 in Madigan, Michael, and John Martinko. *Brock Biology of Microorganisms*.
11th ed. Upper Saddle River, NJ: Pearson Prentice Hall, 2006. ISBN: 0131443291.

Turbidity as an indirect measure

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

Diagram showing the process of measuring turbidity removed due to copyright restrictions
See Figure 6-12a in Madigan, Michael, and John Martinko. Brock Biology of Microorganisms. 11th ed. Upper Saddle River, NJ: Pearson Prentice Hall, 2006. ISBN: 0131443291.

OD measurement of growth



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

Figure by MIT OCW.

biology.clc.uc.edu/fankhauser/Labs/Microbiology

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

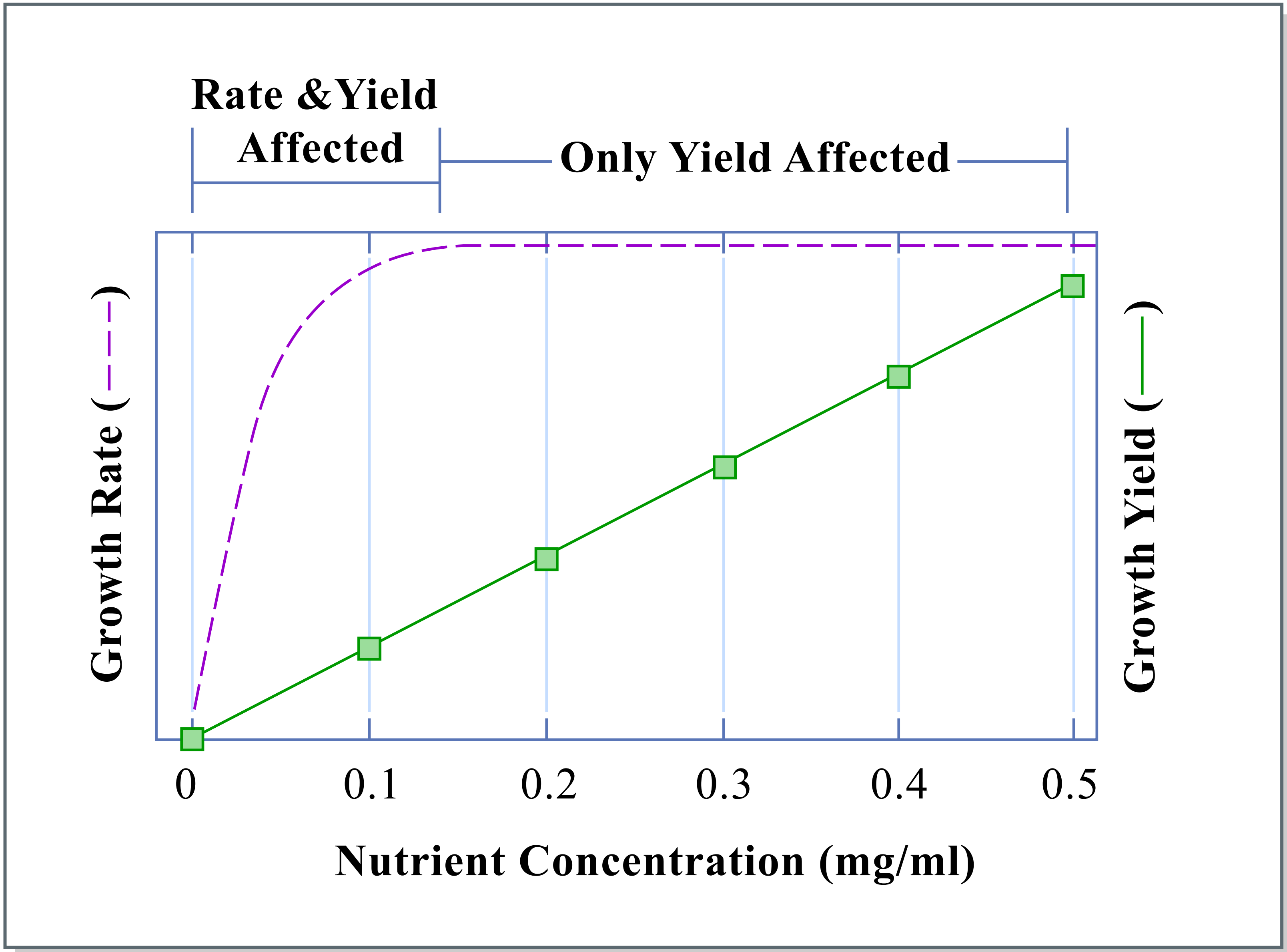


Figure by MIT OCW.

Chemostat

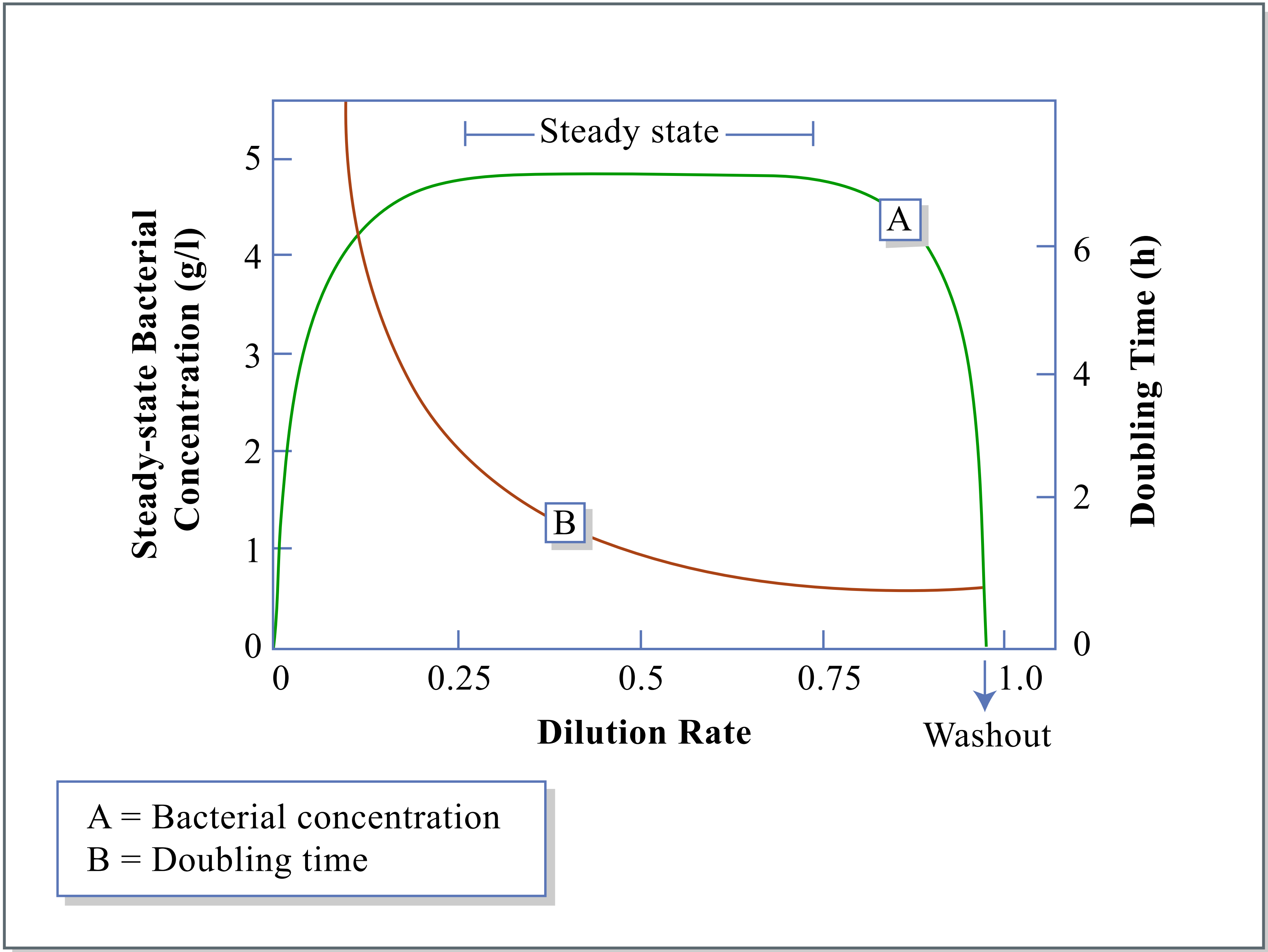


Figure by MIT OCW.

Cardinal temperatures

- For any given organism there is a:

- Minimum temp.
- Optimum temp.
- Maximum temp.

- Microbes can grow wherever there is liquid water

Graph showing cell growth vs. temperature removeddue to copyright restrictions. See Figure 6-16 inMadigan, Michael, and John Martinko. *Brock Biology of Microorganisms*. 11th ed. Upper SaddleRiver, NJ: Pearson Prentice Hall, 2006. ISBN: 0131443291.

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 Saddl River, NJ: Pearson Prentice Hall, 2006. ISBN: 0131443291.

Psychrophiles

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

Images of Psychrophiles removed due to copyright restrictions
See Figure 6-19 in Madigan, Michael, and John Martinko. Brock Biology of Microorganisms. 11th ed. Upper Saddle River, NJ: Pearson Prentice Hall, 2006. ISBN: 0131443291.

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

Hyperthermophiles

- Optimum ≥ 80°C
- Hot springs, deep sea vents

- Most are archea

- Protein changes
- DNA stability
- Membrane stability

Thermophiles

- Optimum ≥ 45°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

Compatible Solutes of Microorganisms

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

Figure by MIT OCW.

Oxygen and microbial growth

Oxygen Relationships of Microorganisms

Group	Relationship to O_2	Type of Metabolism	Example*	Habitat**
Aerobes				
Obligate	Required	Aerobic respiration	*Micrococcus luteus* (B)	Skin, dust
Facultative	Not required, but growth better with O_2	Aerobic respiration, anaerobic respiration, fermentation	*Escherichia coli* (B)	Mammalian large intestine
Microaerophilic	Required but at levels lower than atmospheric	Aerobic respiration	*Spirillum volutans* (B)	Lake water
Anaerobes				
Aerotolerant	Not required, and growth no better when O_2 present	Fermentation	*Streptococcus pyogenes* (B)	Upper respiratory tract
Obligate	Harmful or lethal	Fermentation or anaerobic respiration	*Methanobacterium formicicum* (A)	Sewage sludge digestors, anoxic lake sediments

*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.

Figure by MIT OCW.

Toxic forms of oxygen

$O_2 + e^- \rightarrow O_2^-$ **Superoxide**

$O_2^- + e^- + 2H^+ \rightarrow H_2O_2$ **Hydrogen peroxide**

$H_2O_2 + e^- + H^+ \rightarrow H_2O + OH\cdot$ **Hydroxyl radical**

$OH\cdot + e^- + H^+ \rightarrow H_2O$ **Water**

Overall: $O_2 + 4e^- + 4H^+ \rightarrow 2H_2O$

Figure by MIT OCW.

1) Catalase:

$$H_2O_2 + H_2O_2 \rightarrow 2H_2O + O_2$$

2) Peroxidase:

$$H_2O_2 + NADH + H^+ \rightarrow 2H_2O + NAD^+$$

3) Superoxide dismutase:

$$O_2^- + O_2^- + 2H^+ \rightarrow H_2O_2 + O_2$$

4) Superoxide dismutase / catalase in combination:

$$4\,O_2^- + 4H^+ \rightarrow 2H_2O + 3O_2$$

5) Superoxide reductase:

$$O_2^- + 2H^+ + \text{cyt } c_{\text{reduced}} \rightarrow H_2O_2 + \text{cyt } c_{\text{oxidized}}$$

Figure by MIT OCW.