ENVE 424
Anaerobic Treatment

Review Lecture

2012-2013 Fall

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Basics of Microbiology

Principles of microbiology is applied to the solution of environmental problems

- Treatment of municipal and industrial ww
- Enhancement of the quality of drinking water
- Restoration of sites contaminated with hazardous materials
- Protection or restoration of rivers, lakes etc.
- Prevention of spread of pathogens
- Production of environmentally benign chemicals

The Cell

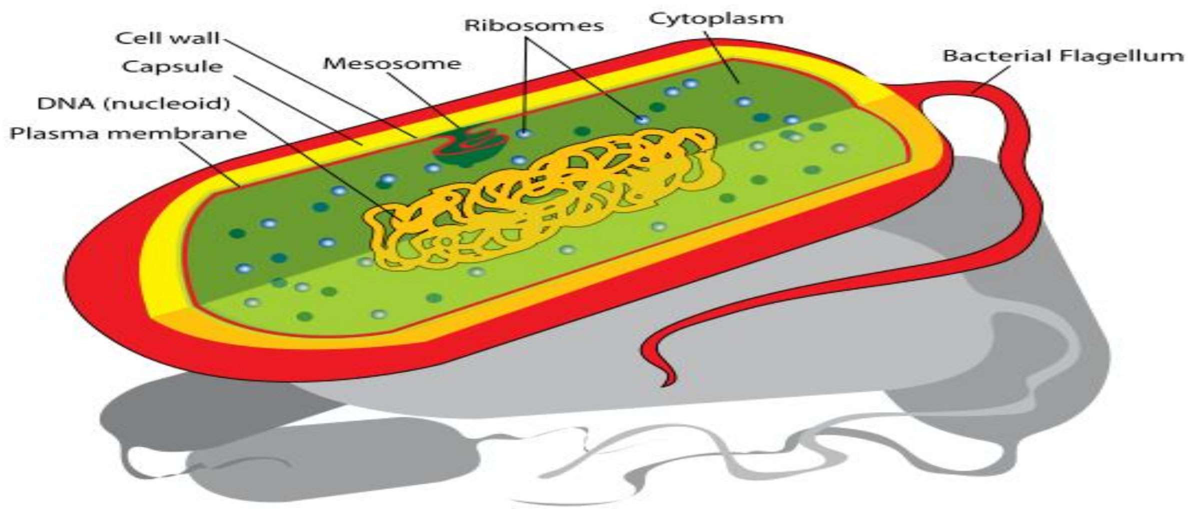
- The cell is the fundamental building block of life
- Cells are capable of growth and reproduction
- Cells are highly organized and selectively restrict what crosses their boundaries
- Cells are composed of C, N, O, S in particular and are chemically reduced
- Cells are self feeding

The Cell

- *Cell Membrane:* a barrier between the cell and its environment. It restricts what crosses its boundaries.
- *Cell Wall*: gives rigidity to the cell and protects the membrane
- *Cytoplasm*: Comprises most of the inside of the cell. It contains water and the macromolecules
- *Chromosome*: Store's the genetic code
- *Ribosomes*: Convert the genetic code into working catalysyst
- *Enzymes*: catalysts that carry out the desired biochemical reaction

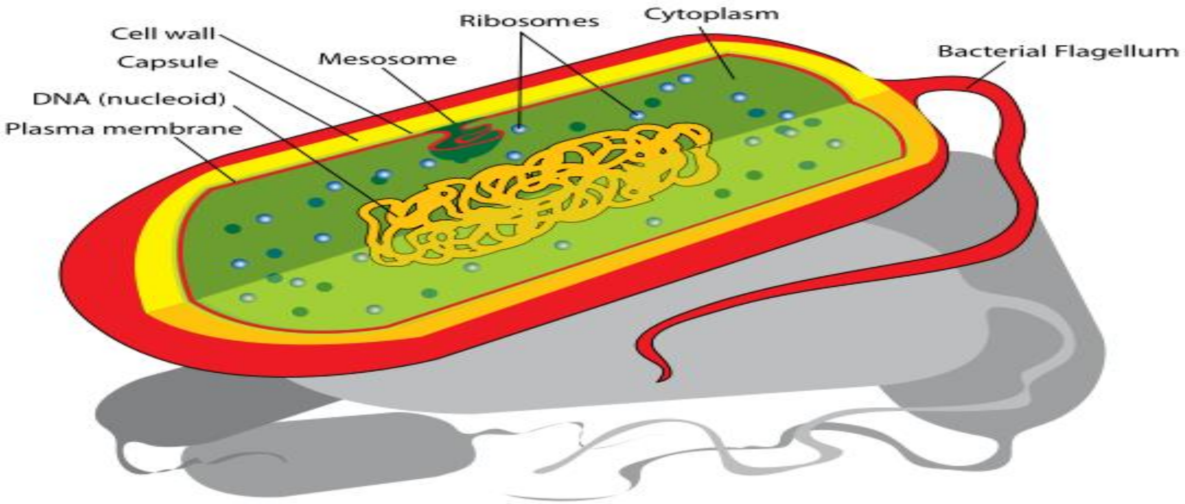
Cell Membrane

- Cell membrane is simple in most bacteris
- more complex in *autotrophic bacteria*, which synthesize essentially all cellular components from inorganic materials
- even more complex in the *phototrophic bacteria*, which obtain energy from sunlight



FLAGELLA

- Protein hairlike structures that extend from the cytoplasm
- Provide mobility by rotating at high speeds



FIMBRIAE and PILI

- Short protein hairlike structures
- Enable bacteria to stick to surfaces
- Pili enable bacteria to attach to each other

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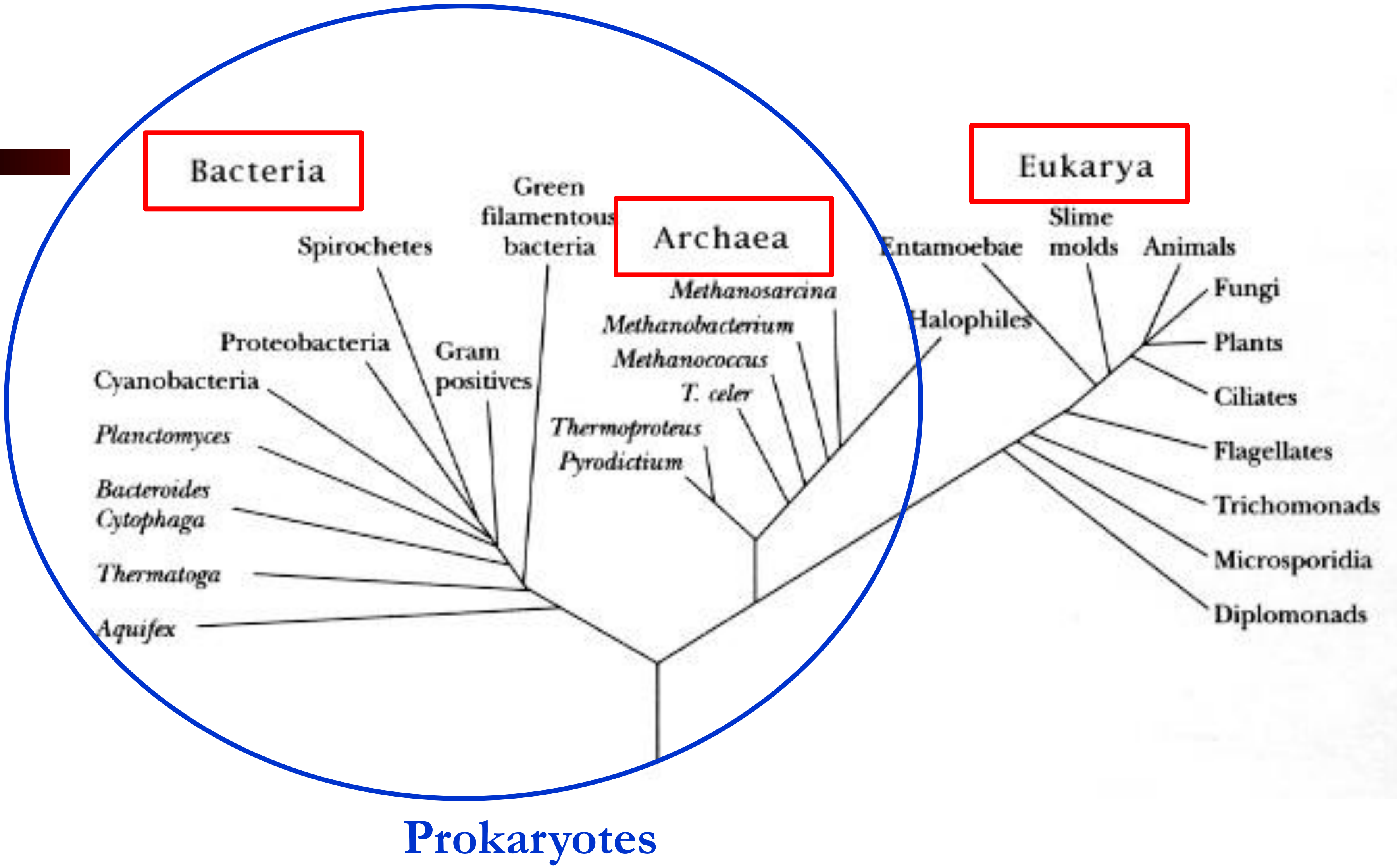

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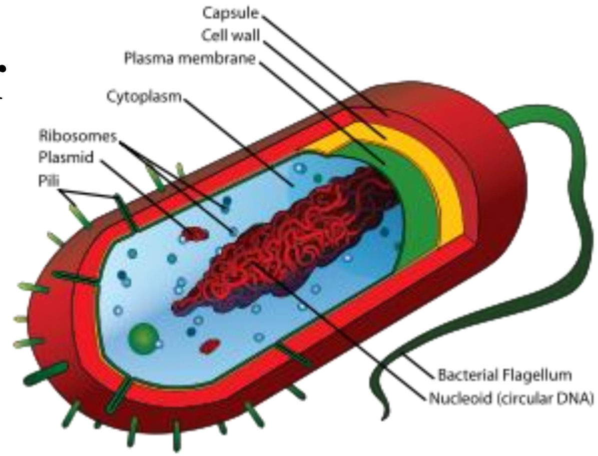
Ref: http://textbookofbacteriology.net/procaryotes.html

Basic Microbiology

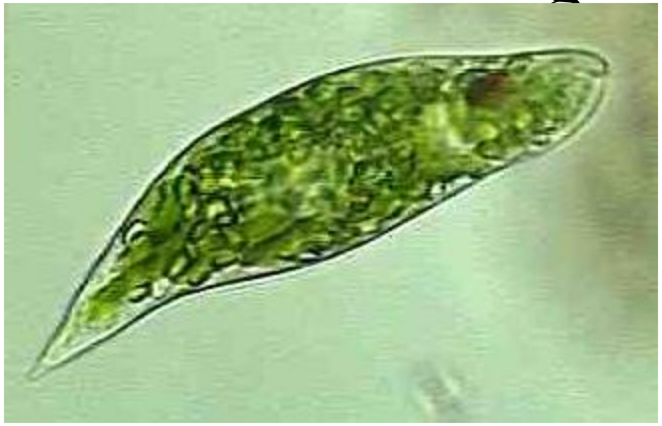
- *Prokaryotes* are single cellular



Ref: http://en.wikipedia.org/wiki/Prokaryote

- *Eukarya* is the other major domain, can be either single (algae, protozoa) or multicellular → higher plants and animals

Ref: http://blogs.scientificamerican.com/a-blog-around-the-clock/2012/03/13/biological-clocks-in-protista/



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Bacteria

- Principal microorganism used in biological wastewater treatment
- single cell, prokaryotic organism
- their usual mode of reproduction binary fission
- are composed of

  80 % water

  20 % dry material (90% organic, 10 % inorganic)
- approximated emprical formula for the organic fraction (may vary with time and species)

$C_5H_7O_2N$ $\qquad$ $C_{60}H_{87}O_{23}N_{12}P$

Typical Composition of Bacteria

Emprical formula for bacteria

$C_5H_7O_2N$

Emprical molecular weight is

113 g

12.4 % N (w)

53% C (w)

$$C_{60}H_{87}O_{23}N_{12}P$$

Constituent	Percentage
Water	75
Dry Matter	25
Organics	90
C	45 – 55
O	22 – 28
H	5 – 7
N	8 – 13
Inorganic	10
P_2O_5	50
K_2O	6.5
Na_2O	10
MgO	8.5
CaO	10
SO_3	15

To continue to reproduce and function properly bacteria must have sources of :

- Carbon
- Energy
- Inorganic elements (nutrients)

Classification of Bacteria Based on Nutrition

Group	Energy Source	Carbon Source
Autotrophic		
- chemolithotrophic	inorganic redox	CO_2
- photolithotrophic	radiant energy	CO_2
Heterotrophic		
- chemoorganotrophic	organic redox	organics
- photoorganotrophic	radiant energy	organics
Mixotrophic	Inorganic redox	organics

- Heterotrophs derive cell carbon from organic carbon sources
- Autotrophs derive cell carbon from CO_2
- Autotrophs spend more energy for synthesis compared to that of heterotrophs

The energy producing reactions by chemotrophs;
oxidation-reduction reactions

electron transfer from electron donor to electron acceptor

electron donor → is oxidized electron acceptor → is reduced

- in respiratory metabolism → external electron acceptor is used
- in fermantative metabolism → internal electron acceptor is used
  - less sufficient energy yielding process than respiration

Growth rate and cell yield of strictly fermentative heterotrophic organisms $<$ Growth rate and cell yield of respiratory heterotrophs

Classification of Bacteria Based on Oxygen

Group	O_2 Effect
Aerobes	
- Obligate	Required
- Facultative	Not required but grow better with O_2
- Microaerophilic	Required, but at levels lower than atmospheric
Anaerobes	
- Aerotolerant	Not required; grow no better when O_2 present
- Obligate (strict)	Harmful or lethal

Energy- Producing Chemical Reactions

- Aerobic:
  - Electron acceptor → O_2
- Anoxic
  - Possible electron acceptors; NO_3-, NO_2^- etc.
- Anaerobic
  - Electron acceptors → Organics, Fe(III)

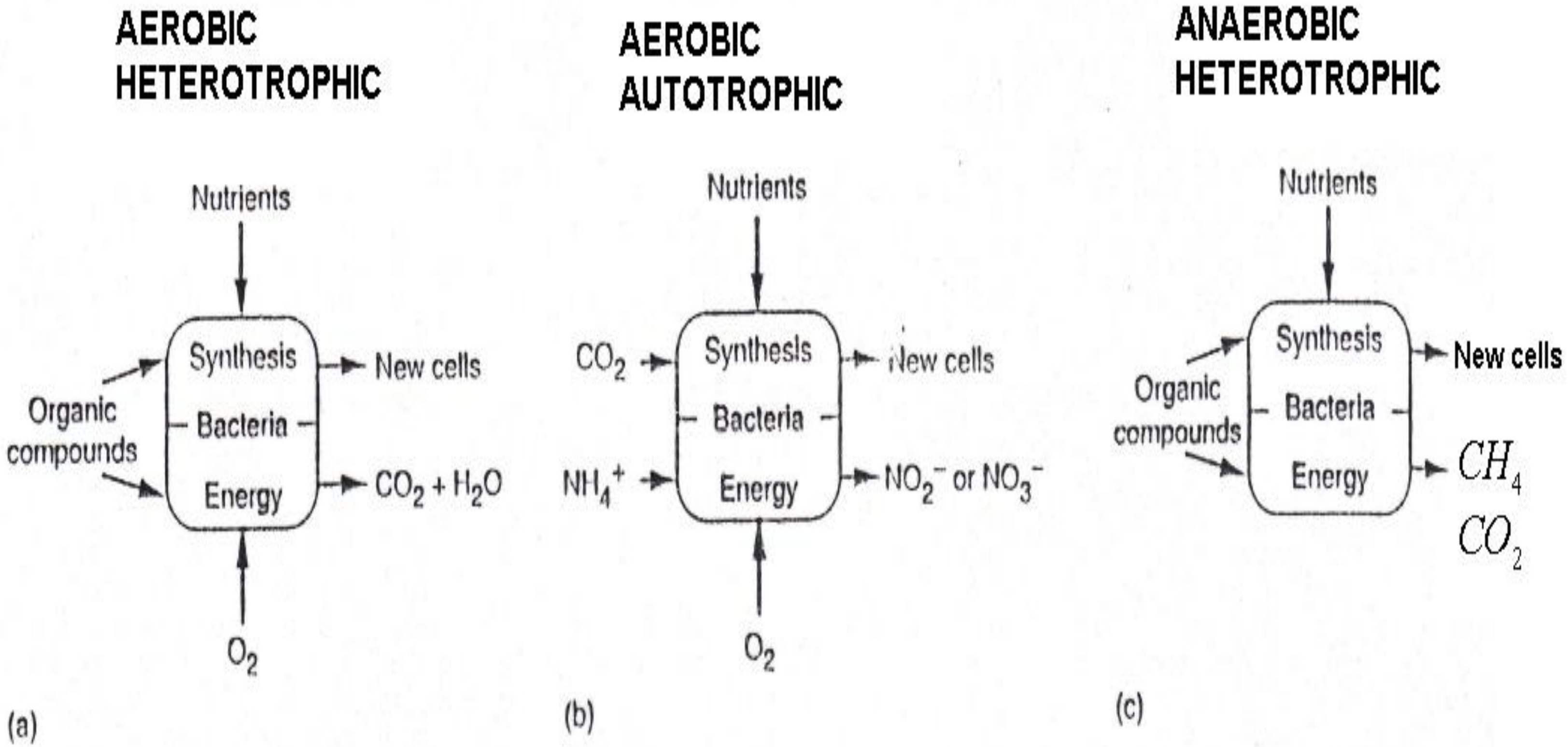

Figure 7–9

Examples of bacteria metabolism: (a) aerobic, heterotrophic, (b) aerobic, autotrophic, (c) anaerobic, heterorophic

Ref: Metcalf & Eddy, Inc. (2003). *Wastewater Engineering-Treatment and Reuse*, 4th ed., McGraw-Hill, New York, NY.

Classification of microorganisms by electron, electron acceptor, sources of cell carbon and end products

	Common reaction name	Carbon Source	Electron Donor	Electron acceptor	End Products
Aerobic Heterotrophic	Aerobic oxidation	Organic compounds	Organic compounds	O_2	CO_2, H_2O
Aerobic Autotrophic	Nitrification	CO_2	NH_3^- NO_2^-	O_2	NO_2^- NO_3^-
	Iron oxidation	CO_2	Fe(II)	O_2	Ferric Iron, Fe(III)
	Sulfur oxidation	CO_2	H_2S, S, $S_2O_3^{2-}$	O_2	SO_4^{2-}
Facultative Heterotrophic	Denitrification anıxic reaction	Organic compounds	Organic compounds	NO_2^- NO_3^-	N2, CO_2, H_2O
Anaerobic Heterotrophic	Acid fermentation	Organic compounds	Organic compounds	Organic compounds	Volatile fatty acids (VFAs) (acetate,propionate)
	Iron reduction	Organic compounds	Organic compounds	Fe(III)	Fe(II), CO_2, H_2O
	Sulfate reduction	Organic compounds	Organic compounds	SO_4	H_2S, CO_2, H_2O
	Methanogenesis	Organic compounds	Volatile fatty acids (VFAs)	CO_2	Methane

•Metcalf & Eddy, Inc. (2003). *Wastewater Engineering- Treatment and Reuse*, 4th ed., McGraw-Hill, New York, NY.

Classification of Bacteria Based on Temperature

Temperature Class	Normal Temperature Range for Growth (°C)
Psycrophile	-5 – 20
Mesophile	8 – 45
Thermophile	40 – 70
Hyperthermophile	65 - 110

Growth rate double with approximately every 10°C increase in temperature until the optimum temperature is reached

Most bacteria can not tolerate pH levels above 9.5 or below 4.

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BACTERIAL GROWTH

•Reproduction of bacteria → by BINARY FISSION

⇕

•Original cell become two new organisms

Time required for each division → GENERATION TIME

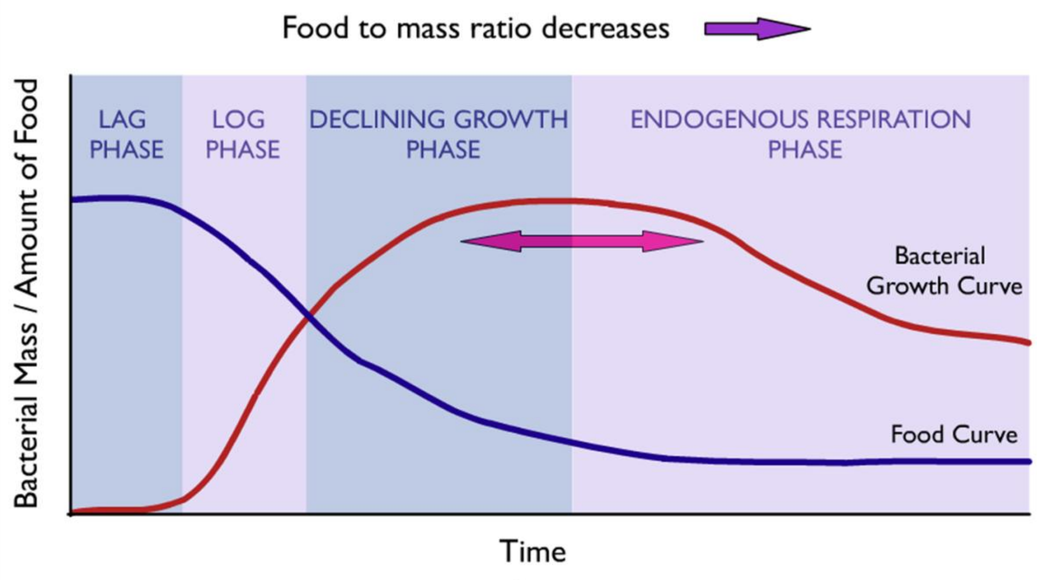
⇕

•can vary from days to less than 20 min
•depending on species and environmental condition

BACTERIAL GROWTH

•**BACTERIAL GROWTH PATTERNS IN A BATCH REACTOR**

•Consider the case of a single species of bacteria inoculated in (that is, added to) a medium containig substrate and all nutrients required for growth.



http://www.ebsbiowizard.com/2010/11/24/biological-growth-curve-in-aerated-stabilization-basins/

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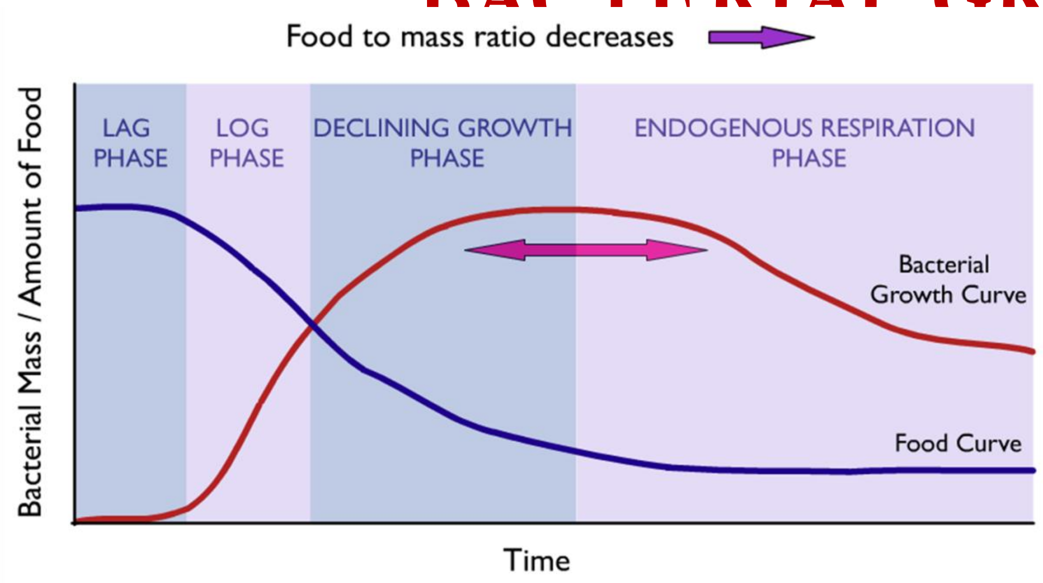
BACTERIAL GROWTH



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LAG PHASE

- Time required for microorganisms to acclimate to their environment before significant cell division and biomass production occur
- No increase in the number of cells
- Duration of lag phase is greatly dependent upon the age of inoculum culture an the amount of inoculum

If the parent culture is young and biologically active } the lag phase will be extremely short

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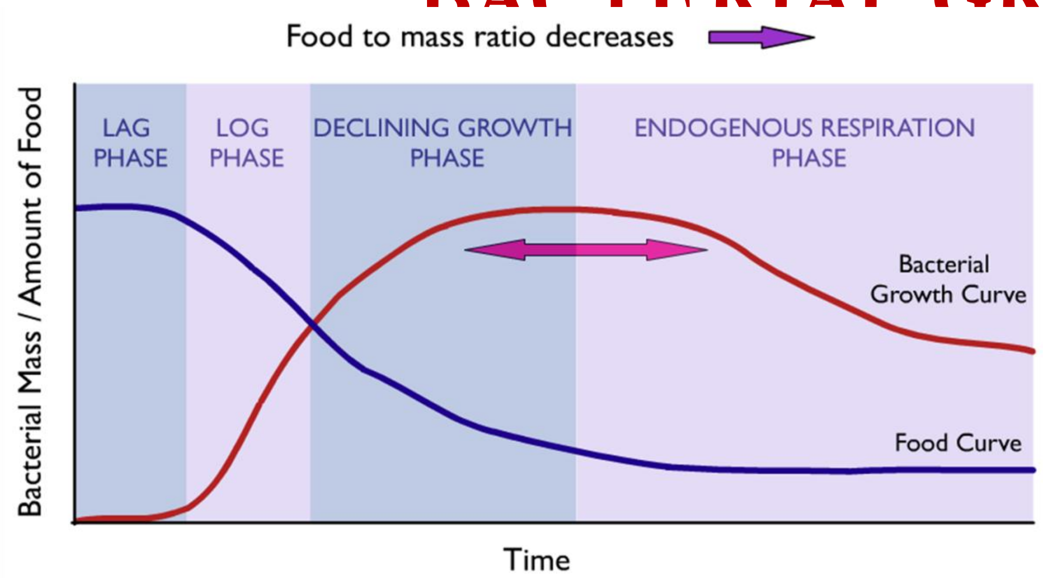
BACTERIAL GROWTH



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- **EXPONENTIAL GROWTH PHASE (log-growth phase)**
- The rate of fission is the maximum possible as there is no limitation due to substrate or nutrients

- Towards to the end of this phase

  depletion of the substrate or an essential nutrient

  accumulation of toxic end products

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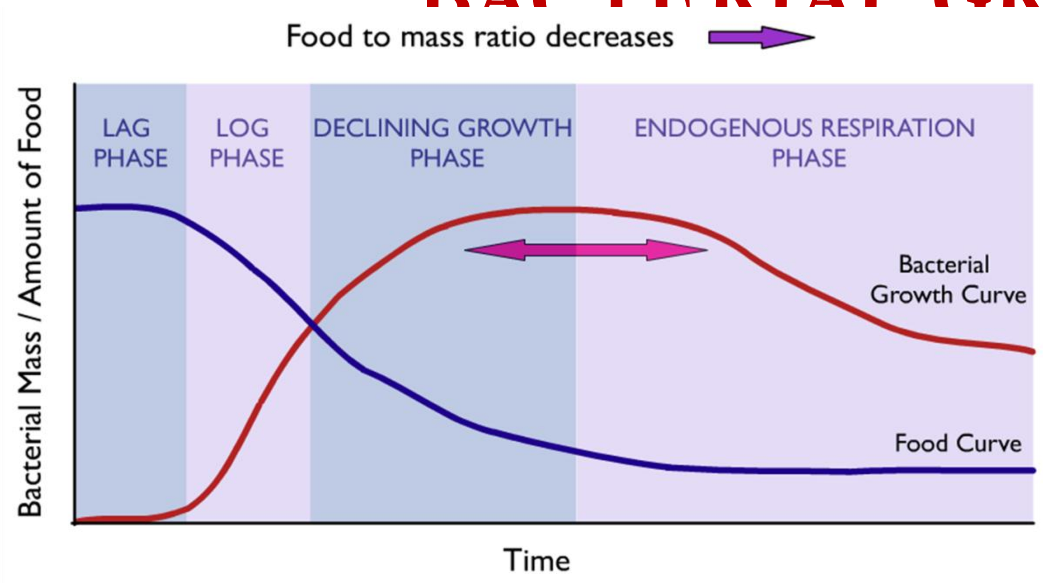
BACTERIAL GROWTH



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STATIONARY PHASE

- number of cells dying = number of cells being produced
- bacterial population remains relatively constant with respect to time

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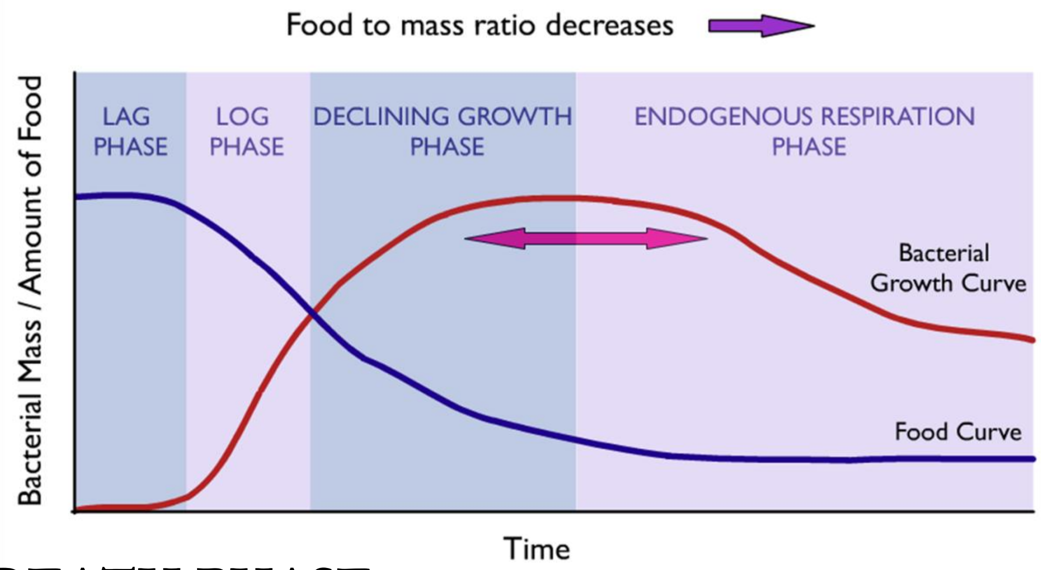
BACTERIAL GROWTH



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DEATH PHASE

As the environment becomes more and more adverse to microbial growth (e.g depletion of substrate)

Cells reproduce more slowly

Cell die rate exceeds cell growth rate

- Microorganisms start to utilize their own stored food materials and protoplasm in addition to a part of dead cells in the environment as food
- An exponential decline in the biomass concentration

$$\text{BIOMASS YIELD}, Y = \frac{\text{g biomass produced}}{\text{g substrate utilized (i.e consumed)}}$$

for aerobic heterotrohic rxns w/ organic substrates $\longrightarrow$ $Y = \frac{\text{g biomass}}{\text{g organic substrate}}$

for nitrification $\longrightarrow$ $Y = \frac{\text{g biomass}}{\text{g } NH_4\text{-N oxidized}}$

for anaerobic rxns $\longrightarrow$ $Y = \frac{\text{g biomass}}{\text{g VFAs used}}$

Growth Condition	Electron Donor	Electron Acceptor	Synthesis Yield
Aerobic	Organic Compound	Oxygen	0.40 g VSS/g COD
Aerobic	Ammonia	Oxygen	0.12 g VSS/g NH_4-N
Anoxic	Organic Compound	Nitrate	0.3 g VSS/g COD
Anaerobic	Organic Compound	Organic Compound	0.06 g VSS/g COD
Anaerobic	Acetate	CO_2	0.05 g VSS/g COD

Cell yield of anaerobic bacteria degrading organics < Cell yield of nitrifiers < Cell yield of aerobic heterotrophs degrading organic substrate

Anaerobic bacteria degrading organics use internal electron acceptor (fermantative metabolism)

Nitrifiers & aerobic heterotrophs use external electron acceptor (respiratory metabolism)