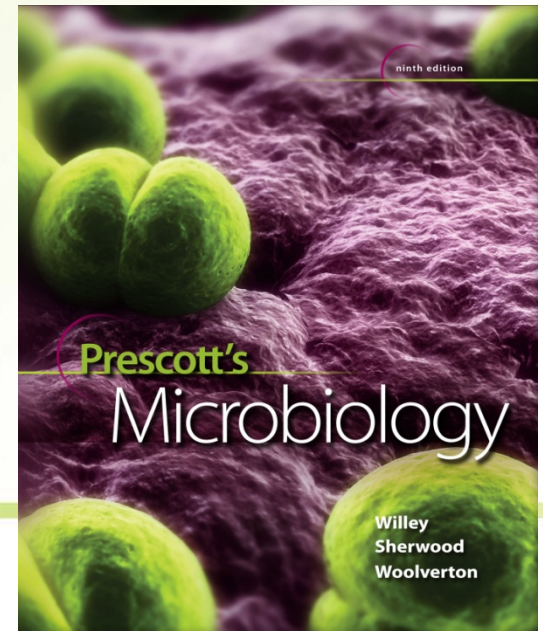


# 19



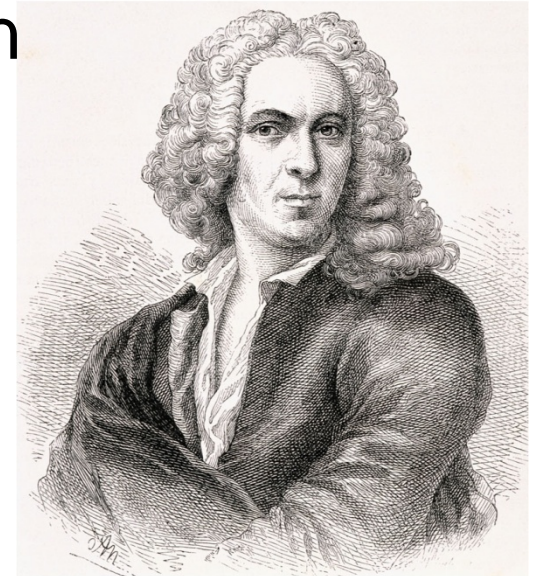
## Microbial Taxonomy and the Evolution of Diversity

# Introduction to Microbial Taxonomy

- Taxonomy
  - science of biological classification
  - consists of three separate but interrelated parts
    - classification – arrangement of organisms into groups (taxa; s., taxon)
    - nomenclature – assignment of names to taxa
    - identification – determination of taxon to which an isolate belongs

# Natural Classification

- Arranges organisms into groups whose members share many characteristics
  - first such classification in 18<sup>th</sup> century developed by Linnaeus
    - based on anatomical characteristics
- This approach to classification does not necessarily provide information on evolutionary relatedness



# Polyphasic Taxonomy

- Used to determine the genus and species of a newly discovered prokaryote
- Incorporates information from genetic, phenotypic, and phylogenetic analysis

# Phenetic Classification

- Groups organisms together based on mutual similarity of phenotypes
- Can reveal evolutionary relationships, but not dependent on phylogenetic analysis
  - i.e., doesn't weigh characters
- Best systems compare as many attributes as possible

# Phylogenetic Classification

- Also called phyletic classification systems
- Phylogeny
  - evolutionary development of a species
- Usually based on direct comparison of genetic material and gene products
  - Woese and Fox proposed using small subunit (SSU) rRNA nucleotide sequences to assess evolutionary relatedness of organisms

# Genotypic Classification

- Comparison of genetic similarity between organisms
  - individual genes or whole genomes can be compared
  - 70% homologous belong to the same species

# Taxonomic Ranks - 1

- Microbes are placed in hierarchical taxonomic levels with each level or rank sharing a common set of specific features
- Highest rank is domain
  - *Bacteria* and *Archaea* – microbes only
  - *Eukarya* – microbes and macroorganisms
- Within domain
  - phylum, class, order, family, genus, species epithet, some microbes have subspecies



# Species

- Definition
  - collection of strains that share many stable properties and differ significantly from other groups of strains
- Also suggested as a definition of species
  - collection of organisms that share the same sequences in their core housekeeping genes

# Strains

- Descended from a single, pure microbial culture
- Vary from each other in many ways
  - biovars – differ biochemically and physiologically
  - morphovars – differ morphologically
  - serovars – differ in antigenic properties

# Type Strain

- Usually one of first strains of a species studied
- Often most fully characterized
- Not necessarily most representative member of species
- Cataloged by the ATCC American Type Culture Collection

# Genus

- Well-defined group of one or more strains
- Clearly separate from other genera
- Often disagreement among taxonomists about the assignment of a specific species to a genus

# Binomial System of Nomenclature

- Devised by Carl von Linné (Carolus Linnaeus)
- Each organism has two names
  - genus name – italicized and capitalized (e.g., *Escherichia*) or underlined
  - species epithet – italicized but not capitalized (e.g., *coli*) or underlined
- Can be abbreviated after first use (e.g., *E. coli*)
- A new species cannot be recognized until it has been published in the *International Journal of Systematic and Evolutionary Microbiology*

# Techniques for Determining Microbial Taxonomy and Phylogeny

- Classical characteristics
  - morphological
  - physiological
  - biochemical
  - ecological
  - genetic

**Table 19.1** Some Morphological Features Used in Classification and Identification

<b>Feature</b>	<b>Microbial Groups</b>
Cell shape	All major groups <sup>1</sup>
Cell size	All major groups
Colonial morphology	All major groups
Ultrastructural characteristics	All major groups
Staining behavior	Bacteria, some fungi
Cilia and flagella	All major groups
Mechanism of motility	Gliding bacteria, spirochetes, protists
Endospore shape and location	Some Gram-positive bacteria
Spore morphology and location	Bacteria, protists, fungi
Cellular inclusions	All major groups
Colony color	All major groups

<sup>1</sup> Used in classifying and identifying at least some bacteria, archaea, fungi, and protists.

**Table 19.2** Some Physiological and Metabolic Characteristics Used in Classification and Identification

Carbon and nitrogen sources

Cell wall constituents

Energy sources

Fermentation products

General nutritional type

Growth temperature optimum and range

Luminescence

Mechanisms of energy conversion

Motility

Osmotic tolerance

Oxygen relationships

pH optimum and growth range

Photosynthetic pigments

Salt requirements and tolerance

Secondary metabolites formed

Sensitivity to metabolic inhibitors and antibiotics

Storage inclusions



# Ecological Characteristics

- Life-cycle patterns
- Symbiotic relationships
- Ability to cause disease
- Habitat preferences
- Growth requirements

# Molecular Approaches

- Extremely important because almost no fossil record was left by microbes
- Allows for the collection of a large and accurate data set from many organisms
- Phylogenetic inferences based on these provide the best analysis of microbial evolution currently available

# Molecular Characteristics

- Nucleic acid base composition
  - G + C content - Mol% G + C =  $(G + C / G + C + A + T)100$ 
    - variation within a genus usually <10%
- Nucleic acid hybridization
- Nucleic acid sequencing
  - Small subunit rRNAs (SSU rRNAs)
    - sequences of 16S and 18S rRNA most powerful and direct method for inferring microbial phylogenies and making taxonomic assignments at genus level
  - When comparing rRNA sequences between 2 organisms, their relatedness is represented by percent sequence homology
    - 70% is cutoff value for species definition
- Genomic fingerprinting
- Amino acid sequencing

# Evolution of the Three Domains of Life

- Hypothesized that when RNA became enclosed in a lipid sphere, the first primitive life forms were generated
- Last universal common ancestor (LUCA)
  - the root of the tree of life, based on SSU rRNA, shows the earliest region is on the bacterial branch
  - thought that *Archaea* and *Eukarya* evolved independently of *Bacteria*

**Table 19.4** Comparison of *Bacteria*, *Archaea*, and *Eukarya*

Property	<i>Bacteria</i>	<i>Archaea</i>	<i>Eukarya</i>
<i>Membrane-Enclosed Nucleus with Nucleolus</i>	Absent	Absent	Present
<i>Complex Internal Membranous Organelles</i>	Absent	Absent	Present
<i>Cell Wall</i>	Almost always have peptidoglycan containing muramic acid	Variety of types, no muramic acid; some have pseudomurein	No muramic acid
<i>Membrane Lipid</i>	Have ester-linked, straight-chained fatty acids	Have ether-linked, branched isoprene-derived chains	Have ester-linked, straight-chained fatty acids
<i>Gas Vesicles</i>	Present	Present	Absent
<i>Transfer RNA</i>	Thymine present in most tRNAs  <i>N</i> -formylmethionine carried by initiator tRNA	No thymine in T or TΨC arm of tRNA  Methionine carried by initiator tRNA	Thymine present  Methionine carried by initiator tRNA
<i>Polycistronic mRNA</i>	Present	Present	Present in some protists
<i>mRNA Introns</i>	Rare	Rare	Present
<i>mRNA Splicing, Capping, and Poly-A Tailing</i>	Absent	Absent	Present
<i>Ribosomes</i>			
Size	70S	70S	80S (cytoplasmic ribosomes)
Elongation factor 2 reaction with diphtheria toxin	Does not react	Reacts	Reacts
Sensitivity to chloramphenicol and kanamycin	Sensitive	Insensitive	Insensitive
Sensitivity to anisomycin	Insensitive	Sensitive	Sensitive
<i>DNA-Dependent RNA Polymerase</i>			
Number of enzymes	One	One	Three
Structure	Simple subunit pattern (6 subunits)	Complex subunit pattern similar to eukaryotic enzymes (8–12 subunits)	Complex subunit pattern (12–14 subunits)
Rifampicin sensitivity	Sensitive	Insensitive	Insensitive
<i>RNA Polymerase II Type Promoters</i>	Absent	Present	Present
<i>Metabolism</i>			
Similar ATP synthase	No	Yes	Yes
Methanogenesis	Absent	Present	Absent
Nitrogen fixation	Present	Present	Absent
Chlorophyll-based photosynthesis	Present	Absent	Present <sup>1</sup>
Chemolithotrophy	Present	Present	Absent

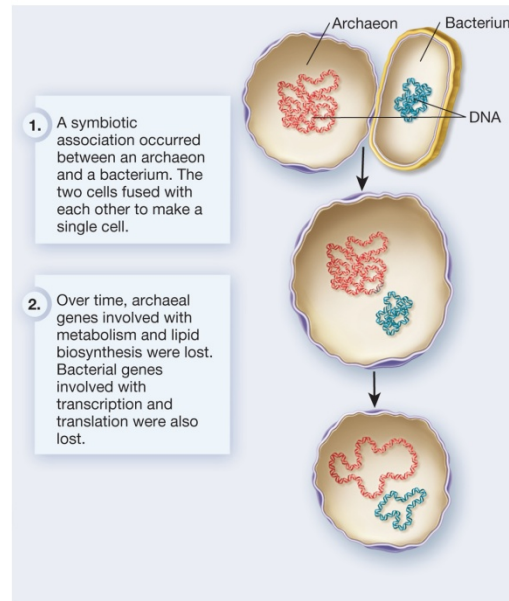
<sup>1</sup> Present in chloroplasts (of bacterial origin).

# Steps in Endosymbiotic Hypothesis

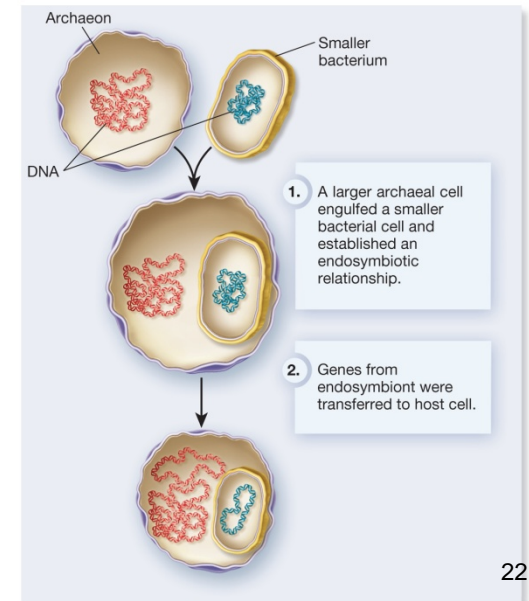
- Ancestral eukaryotic cell had lost cell wall
- Engulfment of an endosymbiote occurred
  - produced needed product such as ATP
- Genome reduction occurred
- Evolution of organelles

- mitochondria
- hydrogenosome
- chloroplasts

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(a) Origin from cellular fusion

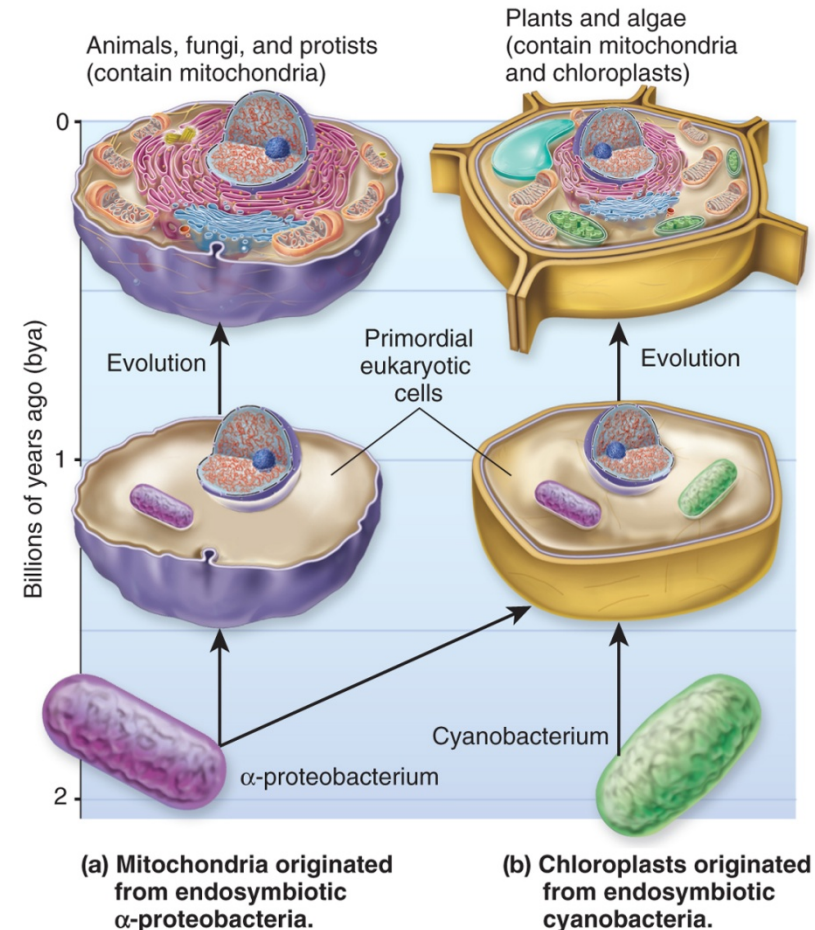


(b) Origin from endosymbiotic relationship

# Mitochondria and Chloroplasts

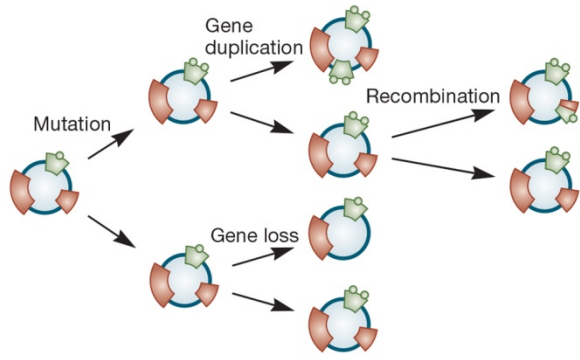
- Believed to be descended from *Rickettsiae* and *Prochlorococcus*, engulfed in a precursor cell
  - provided essential function for host
    - engulfed organism thought to be aerobic, thereby eliminating oxygen toxicity to the host cell
  - host provided nutrients/safety for engulfed organism

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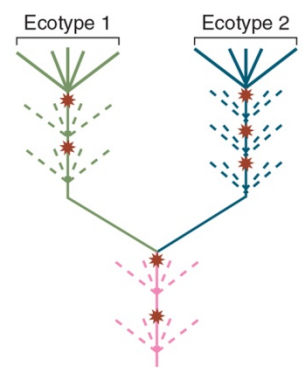


# Microbial Evolutionary Processes

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(a) Mechanisms of genetic variation within a homogeneous population



(b) Stable ecotype model

- *Bacteria* and *Archaea* are asexual
- Heritable changes occur
  - mutation and natural selection
  - gene loss or gain
  - intragenomic recombination
  - horizontal gene transfer (HGT)



# Anagenesis Model of Microbial Diversity

- Microevolution
  - also known as genetic drift
- Small, random genetic changes over generations which slowly drive either speciation or extinction, both of which are forms of macroevolution
  - only adaptive mutants are selected

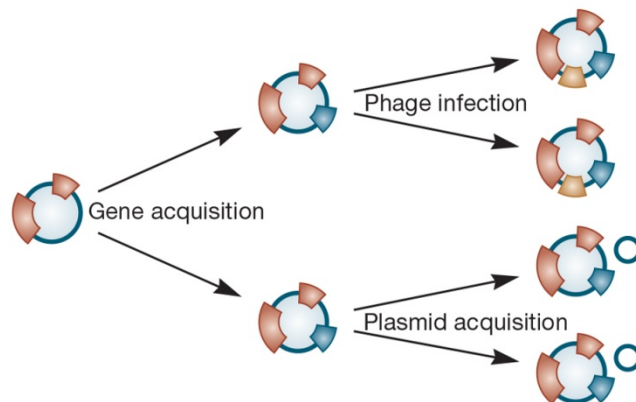
# Ecotype Model for Microbial Diversity

- Genetically similar population of microbes is ecologically distinct
- Members of specific ecosystem diversify and gain adaptive mutation to compete for resources
- Extinction occurs in other ecosystems and reduced genetic variation
- Punctuated equilibria

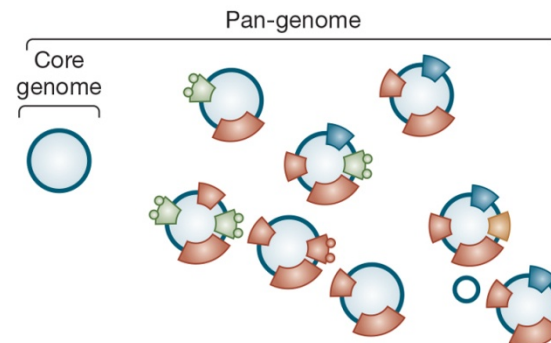
# Horizontal Gene Transfer (HGT) Model for Microbial Diversity

- Pan-genome is complete gene repertoire of a taxon
  - includes the core genome plus “housekeeping” and dispensable genes
  - pan-genome genes acquired through HGT
  - requires genetically heterogeneous group of microbes

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(a) Mechanisms of HGT



(b) Core and pan-genome

# ***Bergey's Manual of Systematic Bacteriology***

- Accepted system of bacterial taxonomy
- Detailed work containing descriptions of all bacterial species currently identified
- First edition published in 1984, with significantly updated editions since