The Evolution of Microorganisms and Microbiology
The Importance of Microorganisms

- Most populous and diverse group of organisms
- Found everywhere on the planet
- Play a major role in recycling essential elements
- Source of nutrients and some carry out photosynthesis
- Benefit society by their production of food, beverages, antibiotics, and vitamins
- Some cause disease in plants and animals
Members of the Microbial World

• Organisms and acellular entities too small to be clearly seen by the unaided eye
  – some < 1 mm, some macroscopic

• These organisms are relatively simple in their construction and lack highly differentiated cells and distinct tissues
Organisms and biological entities studied by microbiologists can be

- **Cellular**
  - **Fungi**
    - e.g. Yeasts, Molds
  - **Protists**
    - e.g. Algae, Protozoa, Slime molds
  - **Bacteria**
    - e.g. *Escherichia coli*
  - **Archaea**
    - e.g. Methanogens

- **Acellular**
  - **Viruses**
    - composed of Protein and nucleic acid
  - **Viroids**
    - composed of RNA
  - **Satellites**
    - composed of Nucleic acid, often RNA
  - **Prions**
    - composed of Protein
Type of Microbial Cells

• Prokaryotic cells lack a true membrane-delimited nucleus
  – this is not absolute, there are prokaryotes with membrane bound structures and other eukaryotic characteristics

• Eukaryotic cells have a membrane-enclosed nucleus, are more complex morphologically, and are usually larger than prokaryotic cells
Classification Schemes

- Three domain system, based on a comparison of ribosomal RNA genes, divides microorganisms into
  - *Bacteria* (true bacteria),
  - *Archaea*,
  - *Eukarya* (eukaryotes)
Domain *Bacteria*

- Prokaryotic
- Usually single-celled
- Majority have cell wall with peptidoglycan
- Most lack a membrane-bound nucleus
- Ubiquitous and some live in extreme environments
- Cyanobacteria produce significant amounts of oxygen
Domain *Archaea*

- Prokaryotic
- Distinguished from *Bacteria* by unique rRNA gene sequences
- Lack peptidoglycan in cell walls
- Have unique membrane lipids
- Some have unusual metabolic characteristics
- Many live in extreme environments
Domain *Eukarya* - *Eukaryotic*

- Protists – generally larger than *Bacteria* and *Archaea*
  - algae – photosynthetic (photolithoautotrophs)
  - protozoa – chemoorganoheterotrophs
  - slime molds – two life cycle stages (protist-like and fungus-like)
  - water molds – devastating disease in plants
- Fungi
  - yeast - unicellular
  - mold - multicellular
Acellular Infectious Agents

• Viruses
  – smallest of all microbes
  – requires host cell to replicate
  – cause range of diseases, some cancers

• Viroids and Satellites (previously called virusoids)
  – infectious agents composed of RNA

• Prions – infectious proteins
Origins of Life

- Microbial fossils
  - Swartkoppie chert – granular silica
  - 3.5 billion years old
- Fossil record sparse
- Indirect evidence and scientific method are used to study origins of life
- 533–525 mya—Cambrian explosion creates diverse animal life.
- 520 mya—First vertebrates; first land plants.
- 450 mya—Large terrestrial colonization by plants and animals.
- 300 mya—Reptiles first appear.
- 225 mya—Dinosaurs and mammals first appear.
- 7 mya—Hominids first appear.

- 1.5 bya—Multicellular eukaryotic organisms first appear.
- 2.5–2.0 bya—Eukaryotic cells first appear.
- 3.5 bya—Fossils of primitive filamentous microbes.
- 3.8–3.5 bya—First cells appear.
Earliest Molecules - RNA

- Original molecule must have fulfilled protein and hereditary function
- Ribozymes
  - RNA molecules that form peptide bonds
  - perform cellular work and replication
- Earliest cells may have been RNA surrounded by liposomes
Earliest Molecules – RNA - 2

• Cellular pool of RNA in modern day cells exists in and is associated with the ribosome (rRNA, tRNA, mRNA)
  – RNA catalytic in protein synthesis
  – RNA may be precursor to double stranded DNA

• Adenosine 5’ triphosphate (ATP) is the energy currency and is a ribonucleotide

• RNA can regulate gene expression
Earliest Metabolism

• Early energy sources under harsh conditions
  – inorganics, e.g., FeS

• Photosynthesis
  – cyanobacteria evolved 2.5 billion years ago
  – stromatolites – mineralized layers of microorganisms

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Evolution of 3 Domains of Life

- Universal phylogenetic tree
  - based on comparisons of small subunit rRNA (SSU rRNA)
  - aligned rRNA sequences from diverse organisms are compared and differences counted to derive a value of evolutionary distance
  - relatedness, but not time of divergence, is determined this way

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Last Universal Common Ancestor (LUCA)

- The root or origin of modern life is on bacterial branch but nature still controversial
- *Archaea* and *Eukarya* evolved independently of *Bacteria*
- *Archaea* and *Eukarya* diverged from common ancestry
Endosymbiotic Hypothesis

- Origin of mitochondria, chloroplasts, and hydrogenosomes from endosymbiont
- Mitochondria and chloroplasts
  - SSU rRNA genes show bacterial lineage
  - Genome sequences closely related to *Rickettsia* and *Prochloron*, respectively
- Hydrogenosomes
  - Anaerobic endosymbiont
Evolution of Cellular Microbes

- Mutation of genetic material led to selected traits
- New genes and genotypes evolved
- *Bacteria* and *Archaea* increase genetic pool by horizontal gene transfer within the same generation (HGT – gene transfer from one mature microbe to another)
Microbial Species

- Eukaryotic microbes fit definition of reproducing isolated populations
- *Bacteria* and *Archaea* do not reproduce sexually and are referred to as strains
  - a strain consists of descendents of a single, pure microbial culture
  - may be biovars, serovars, morphovars, pathovars (variants with respect to morphology, physiology, antibody production, etc.)
- binomial nomenclature - genus and species epithet: ex. *Escherichia coli* or *Escherichia coli*
  - genus is capitalized and italicized (or underlined)
  - species is in lowercase and italicized (or underlined)
  - After first use, can be abbreviated *E. coli* or *E. coli*
Microbiology - Origins

• Study of microorganisms
• Tools used for the study
  – microscopes
  – culture techniques
  – molecular genetics
  – genomics
Discovery of Microorganisms

- Antony van Leeuwenhoek (1632-1723)
  - first person to observe and describe microorganisms accurately
The Conflict over Spontaneous Generation

• Spontaneous generation
  – Idea that living organisms can develop from nonliving or decomposing matter

• Francesco Redi (1626-1697)
  – discredited spontaneous generation
  – showed that maggots on decaying meat came from fly eggs
But Could Spontaneous Generation Be True for Microorganisms?

• John Needham (1713-1781)
  – his experiment:
    mutton broth in flasks $\rightarrow$ boiled $\rightarrow$ sealed
  – results: broth became cloudy and contained microorganisms

• Lazzaro Spallanzani (1729-1799)
  – his experiment:
    broth in flasks $\rightarrow$ sealed $\rightarrow$ boiled
  – results: no growth of microorganisms
Louis Pasteur (1822-1895)

• ‘Swan-neck flask’ experiments
  – placed nutrient solution in flasks
  – created flasks with long, curved necks
  – boiled the solutions
  – left flasks exposed to air

• results: no growth of microorganisms
Microbes being destroyed

Vigorous heat is applied.

Broth free of live cells (sterile)

Neck on second sterile flask is broken; growth occurs.

Neck intact; airborne microbes are trapped at base, and broth is sterile.
Final Blow to Theory of Spontaneous Generation

• John Tyndall (1820-1893)
  – demonstrated that dust carries microorganisms
  – showed that if dust was absent, nutrient broths remained sterile, even if directly exposed to air
  – also provided evidence for the existence of exceptionally heat-resistant forms of bacteria

• Ferdinand Cohn (1828-1898)
  – heat-resistant bacteria could produce endospores
The Role of Microorganisms in Disease

• Was *not* immediately obvious

• Infectious disease believed to be due to supernatural forces or imbalances of 4 bodily-fluid ‘humors’

• Establishing connection depended on development of techniques for studying microbes
Evidence for the Relationship between Microorganisms and Disease

• Agostini Bassi (1773-1856)
  – showed that a disease of silkworms was caused by a fungus

• M. J. Berkeley (ca. 1845)
  – demonstrated that the great Potato Blight of Ireland was caused by a water mold

• Heinrich de Bary (1853)
  – showed that smut and rust fungi caused cereal crop diseases
More Evidence...

• Louis Pasteur
  – demonstrated microorganisms carried out fermentations, helping French wine industry
  – developed pasteurization to avoid wine spoilage by microbes
  – showed that the pébrine disease of silkworms was caused by a protozoan
Other Evidence…

• Joseph Lister
  – provided indirect evidence that microorganisms were the causal agents of disease
  – developed a system of surgery designed to prevent microorganisms from entering wounds as well as methods for treating instruments and surgical dressings
  – utilized phenol as an antimicrobial and sterilized instruments with heat
  – his patients had fewer postoperative infections
Final Proof…

• Robert Koch (1843-1910)
  – established the relationship between *Bacillus anthracis* and anthrax
  – used criteria developed by his teacher Jacob Henle (1809-1895)
  – these criteria now known as Koch’s postulates

  • still used today to establish the link between a particular microorganism and a particular disease
**Postulate**

1. The microorganism must be present in every case of the disease but absent from healthy organisms.

2. The suspected microorganisms must be isolated and grown in a pure culture.

3. The same disease must result when the isolated microorganism is inoculated into a healthy host.

4. The same microorganisms must be isolated again from the diseased host.

**Experimentation**

Koch developed a staining technique to examine human tissue. *Mycobacterium tuberculosis* could be identified in diseased tissue.

Koch grew *M. tuberculosis* in pure culture on coagulated blood serum.

Koch injected cells from the pure culture of *M. tuberculosis* into guinea pigs. The guinea pigs subsequently died of tuberculosis.

Koch isolated *M. tuberculosis* in pure culture on coagulated blood serum from the dead guinea pigs.
Limitations of Koch’s Postulates

• Some organisms cannot be grown in pure culture
• Using humans in completing the postulates is unethical
• Molecular and genetic evidence may replace and overcome these limits
The Development of Techniques for Studying Microbial Pathogens

• Koch’s work led to discovery or development of:
  – agar
  – Petri dishes
  – nutrient broth and nutrient agar
  – methods for isolating microorganisms
Other Developments...

- Charles Chamberland (1851-1908)
  - developed porcelain bacterial filters used by Ivanoski and Beijerinck to study tobacco mosaic disease
  - determined that extracts from diseased plants had infectious agents present which were smaller than bacteria and passed through the filters
  - infectious agents were eventually shown to be viruses
Other Developments...

• Pasteur and Roux
  – discovered that incubation of cultures for long intervals between transfers caused pathogens to lose their ability to cause disease (termed ‘attenuation’)

• Pasteur and his coworkers
  – developed vaccines for chicken cholera, anthrax, and rabies
Immunological Studies

• once established, led to study of host defenses - immunology

• Edward Jenner (ca. 1798)
  – used a vaccination procedure to protect individuals from smallpox

  NOTE: this preceded the work establishing the role of microorganisms in disease!
More Developments…

• Emil von Behring (1854-1917) and Shibasaburo Kitasato (1852-1931)
  – developed antitoxins for diphtheria and tetanus
  – evidence for humoral (antibody-based) immunity

• Elie Metchnikoff (1845-1916)
  – discovered bacteria-engulfing, phagocytic cells in the blood
  – evidence for cellular immunity
The Development of Industrial Microbiology and Microbial Ecology

• Louis Pasteur
  – demonstrated that alcohol fermentations and other fermentations were the result of microbial activity
  – developed the process of pasteurization to preserve wine during storage
Developments in Microbial Ecology

• Sergei Winogradsky (1856-1953) and Martinus Beijerinck (1851-1931)
  – studied soil microorganisms and discovered numerous interesting metabolic processes (e.g., nitrogen fixation)
  – pioneered the use of enrichment cultures and selective media
Microbiology Has Basic and Applied Aspects

• Basic aspects are concerned with individual groups of microbes, microbial physiology, genetics, molecular biology and taxonomy

• Applied aspects are concerned with practical problems – disease, water, food and industrial microbiology
Molecular and Genomic Methods

- Led to a second golden age of microbiology (rapid expansion of knowledge)
- Discoveries
  - restriction endonucleases (Arber and Smith)
  - first novel recombinant molecule (Jackson, Symons, Berg)
  - DNA sequencing methods (Woese, Sanger)
  - bioinformatics and genomic sequencing and analysis
Major Fields in Microbiology

- Medical microbiology – diseases of humans and animals
- Public health microbiology – control and spread of communicable diseases
- Immunology – how the immune system protects a host from pathogens
More Fields…

• Microbial ecology is concerned with the relationship of organisms with their environment
  – less than 1% of earth’s microbial population has been cultured

• Agricultural microbiology is concerned with the impact of microorganisms on agriculture
  – food safety microbiology
  – animal and plant pathogens
More Fields…. 

• Industrial microbiology began in the 1800s
  – fermentation
  – antibiotic production
  – production of cheese, bread, etc.

• Microbial physiology studies metabolic pathways of microorganisms
More Fields....

• Molecular biology, microbial genetics, and bioinformatics study the nature of genetic information and how it regulates the development and function of cells and organisms

• Microbes are a model system of genomics