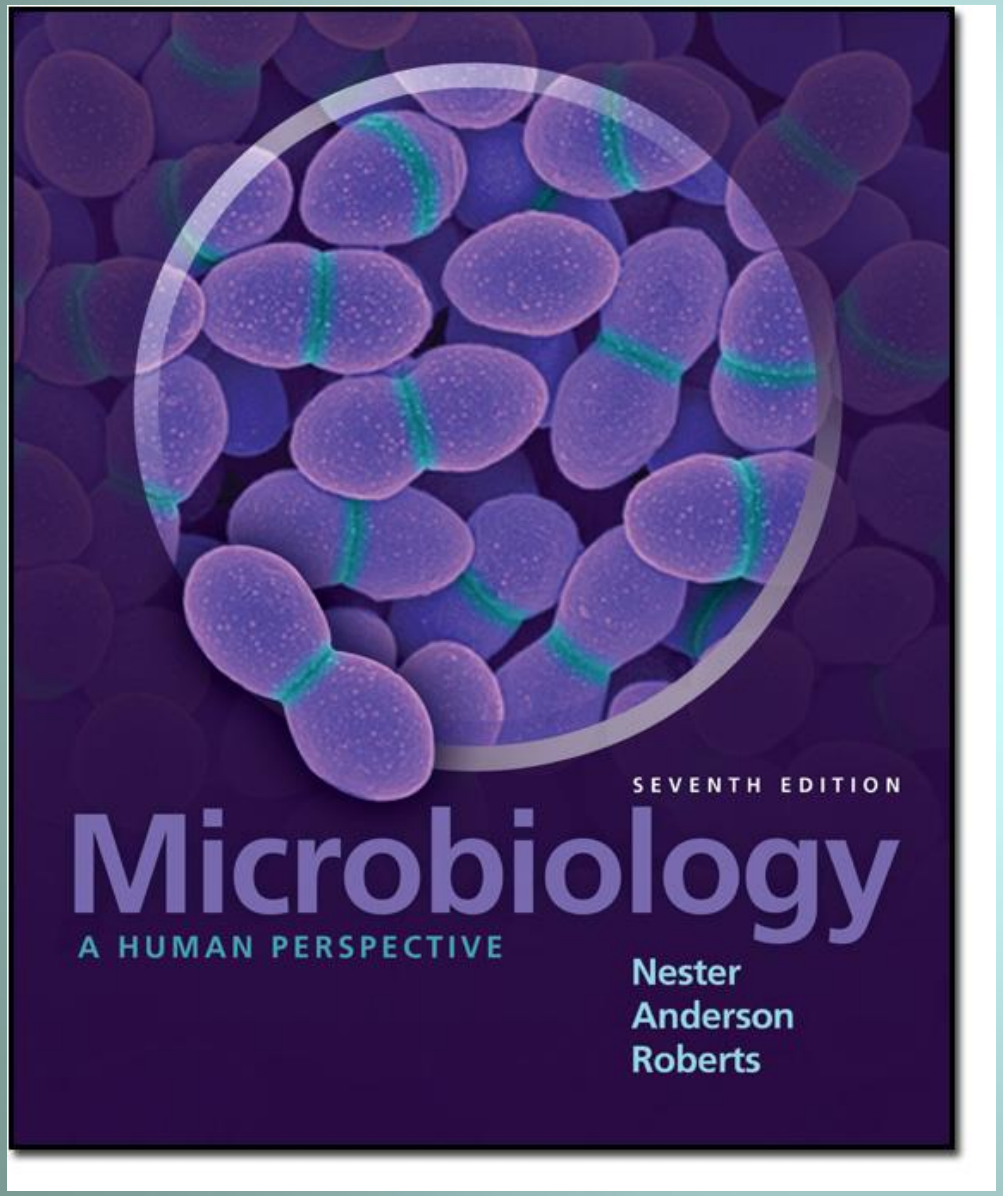
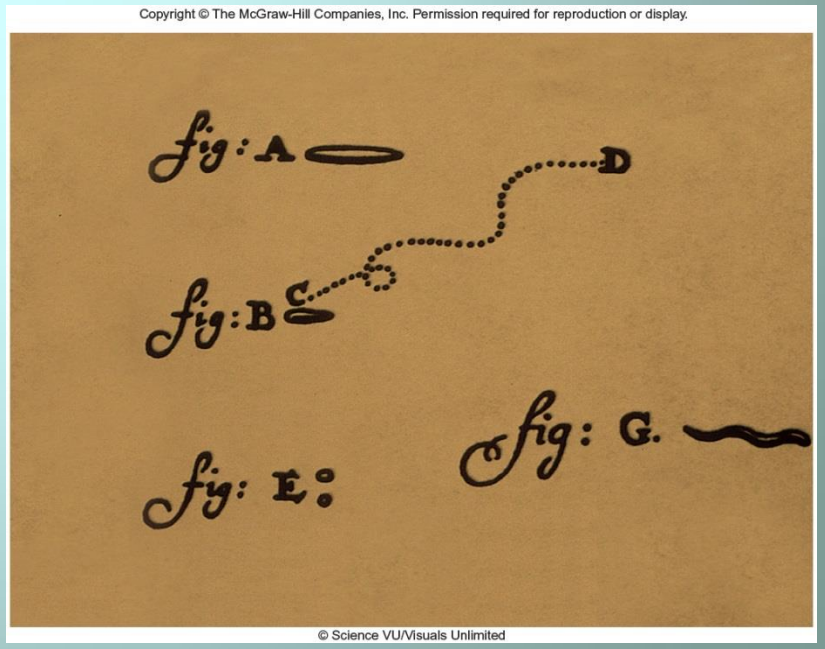


Chapter 01

Lecture

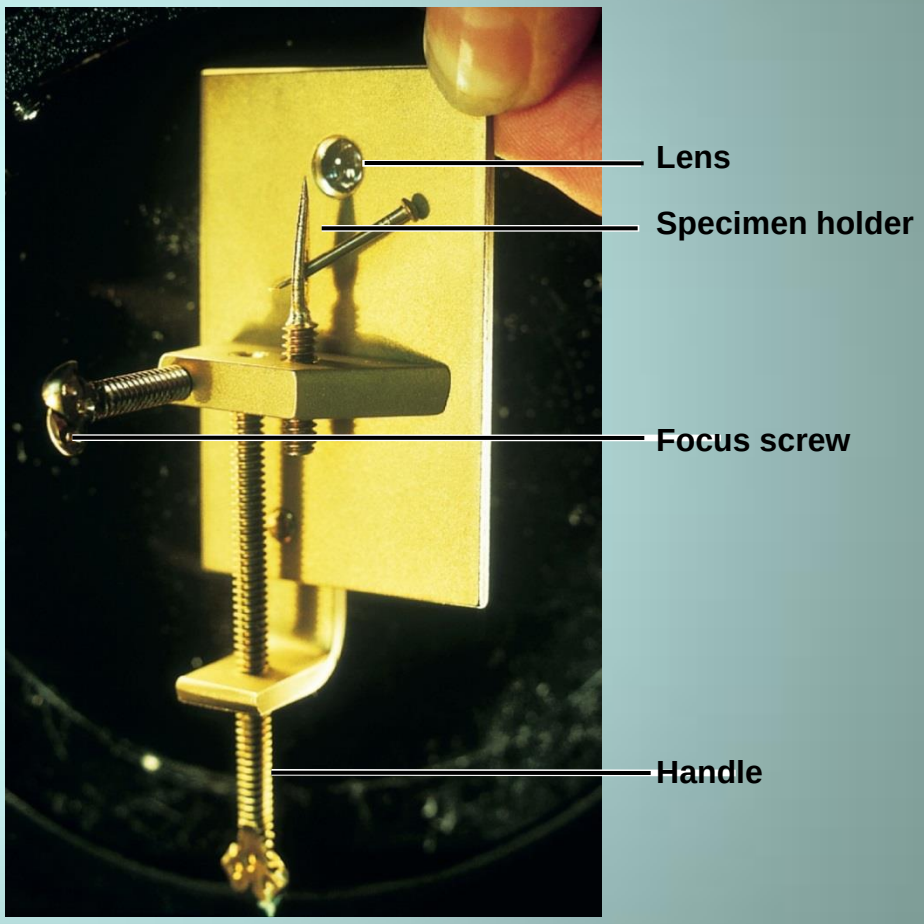
A Glimpse of History

- Science of microbiology born in 1674
- Antony van Leeuwenhoek (1632–1723)
  - Drapery merchant
  - Made simple magnifying glass
  - Studied lake water
  - Observed ‘animalcules’!
- Robert Hooke
  - Also credited with discovery
  - Described ‘microscopical mushroom’ (common bread mold) in 1665



Importance of Microorganisms

- Microorganisms are foundation for all life on earth
- Have existed for ~3.5 billion years
- Plants, animals, modern microorganisms all evolved from ancestral bacteria
- Our life depends on their activities



1.1. The Dispute Over Spontaneous Generation

- Theory of Spontaneous Generation
  - "Life arises spontaneously from non-living material"
  - Theory had supporters and detractors
    - Detractors included
      - Francesco Redi
      - Louis Pasteur
      - John Tyndall
    - Each contributed to disproving the theory

1.1. The Dispute Over Spontaneous Generation

- Italian biologist and physician Francesco Redi
- Demonstrated worms on rotting meat came from eggs of flies landing on meat (1668)
  - Placed meat in two jars
  - Covered one jar with gauze
  - Gauze prevented flies from depositing eggs
  - No eggs → no worms
- Took another 200 years to convincingly disprove spontaneous generation of microorganisms
  - One reason: conflicting results between laboratories

1.1. The Dispute Over Spontaneous Generation

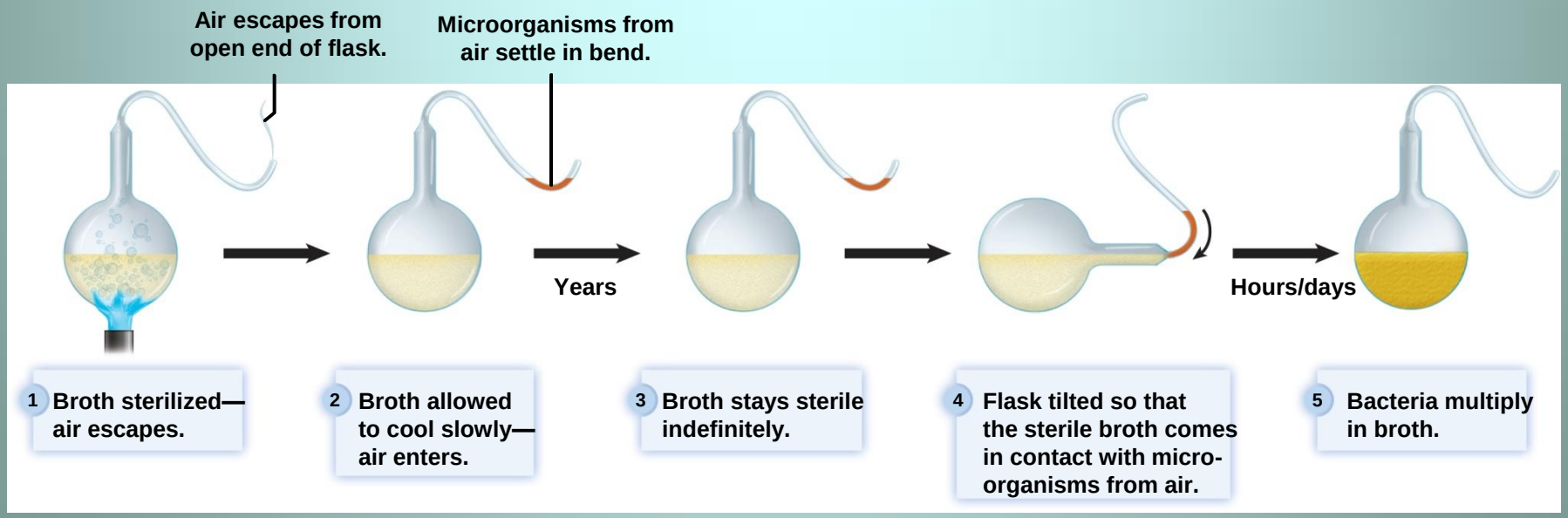
- Multiple contributions helped define
- In 1749, John Needham demonstrated boiled broths still produced microorganisms
- In 1776, Father Spallanzani contradicted Needham's results
  - Boiled broths longer; sealed flasks by melting necks
  - Broths remained sterile unless neck cracked
- Controversy still unsolved
  - Some argued heating destroyed "vital force" necessary for spontaneous generation

1.1. The Dispute Over Spontaneous Generation

- French chemist Louis Pasteur
- Considered “father of modern microbiology”
- Demonstrated air is filled with microorganisms
- Filtered air through cotton plug
  - Observed trapped microorganisms
  - Many looked identical to those found in broths

1.1. The Dispute Over Spontaneous Generation

- Developed swan-necked flask
  - Boiled infusions remained sterile despite opening to air
  - Ended arguments that unheated air or broths contained “vital force” necessary for spontaneous generation



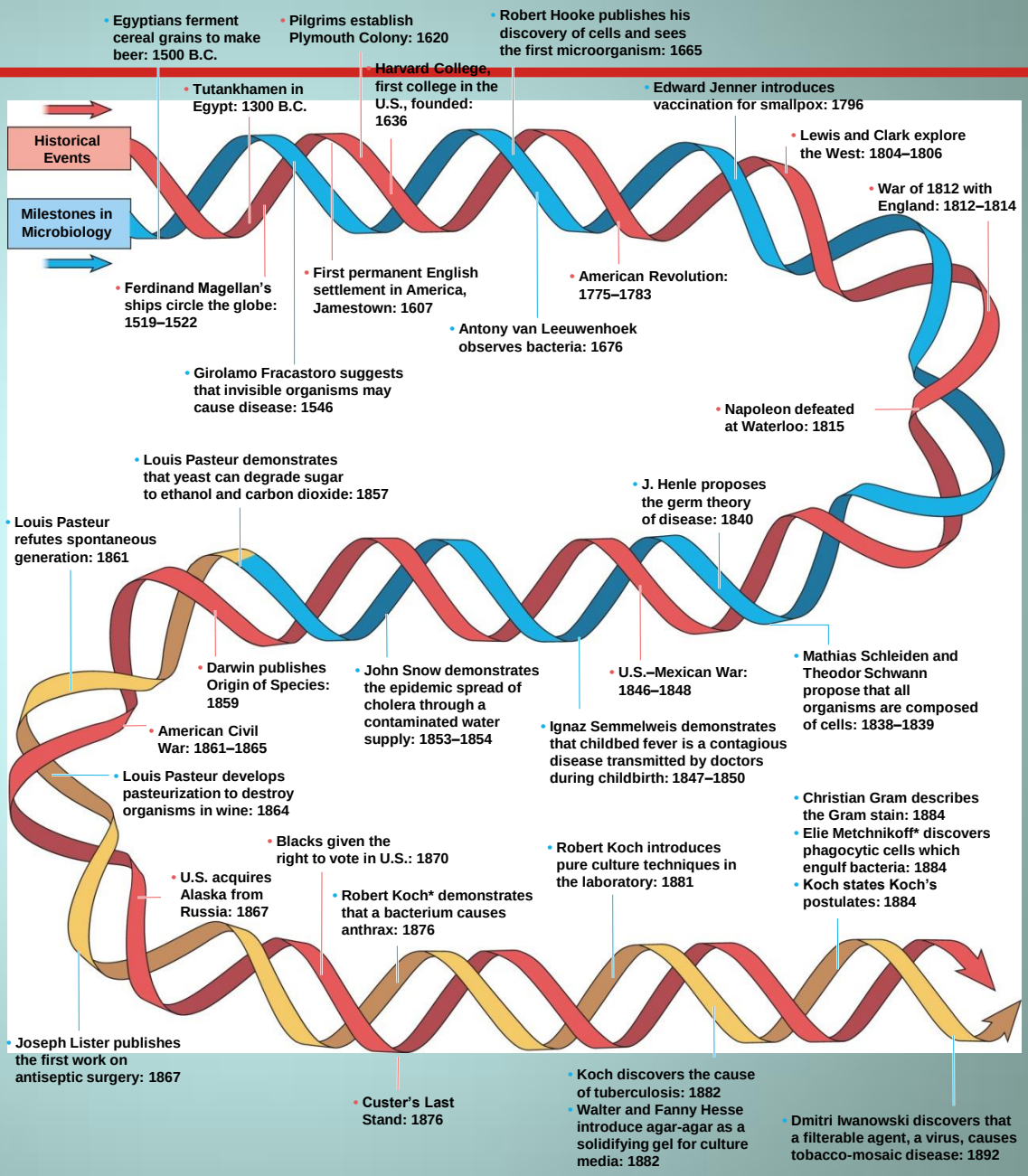
1.1. The Dispute Over Spontaneous Generation

- Some scientists remained skeptical
- Pasteur's results not fully reproducible
- English physicist John Tyndall finally explained conflicting data
  - Proved Pasteur correct
  - Sterilizing broths required different times
    - Some sterilized in 5 minutes
    - Others not despite 5 hours!
  - Realized hay infusions contained heat-resistant microbes
    - Contaminated labs using hay

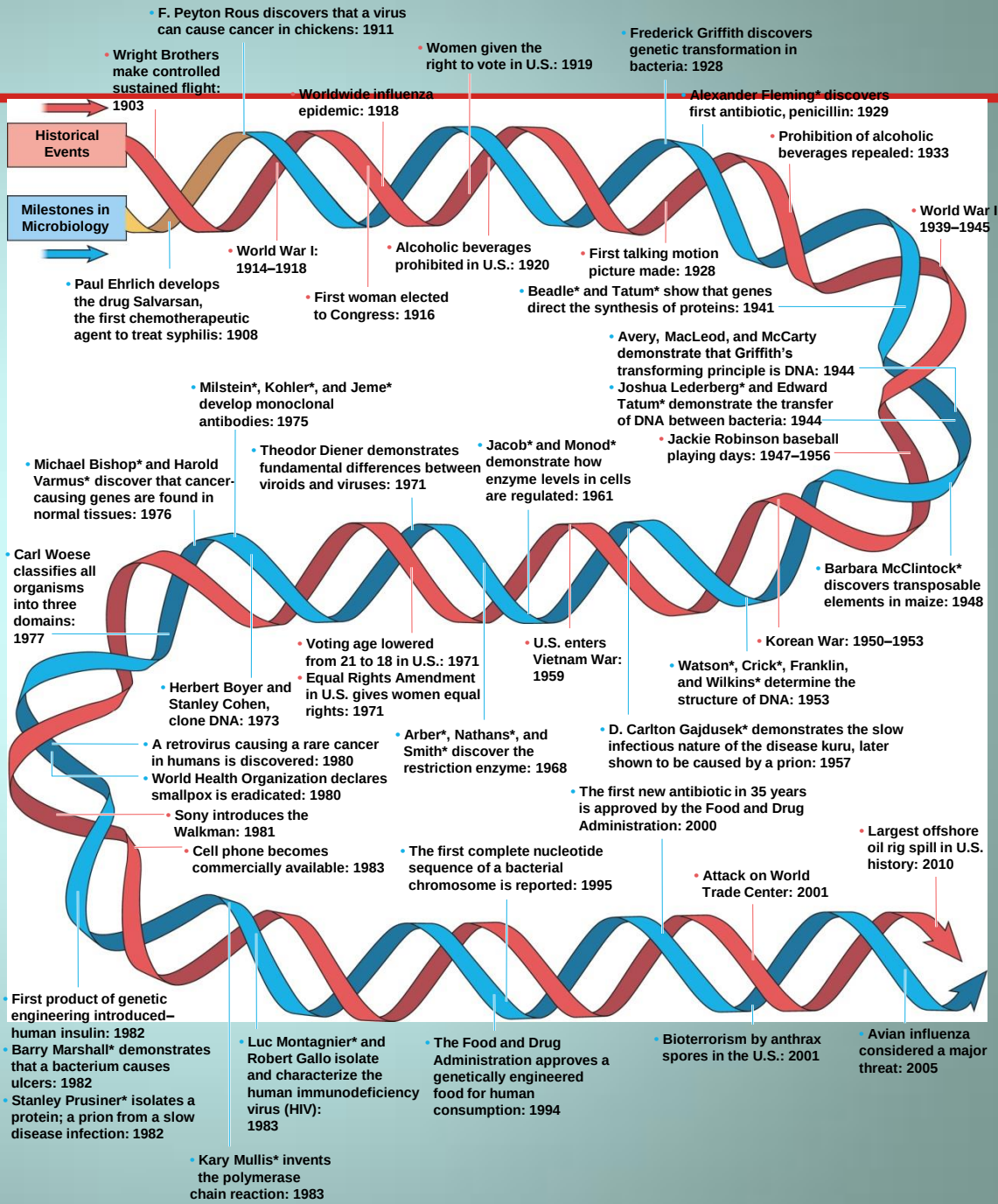
1.1. The Dispute Over Spontaneous Generation

- In same year (1876), German botanist Ferdinand Cohn discovered endospores
  - Heat-resistant form of bacteria
- Following year, Robert Koch demonstrated anthrax caused by a spore-forming bacterium
- Extreme heat resistance of endospores explains differences between Pasteur's results and those of other investigators
  - Pasteur used broths made with sugar or yeast extract
  - Highlights importance of reproducing all conditions as closely as possible when conducting research

- Some major milestones in microbiology in relation to other historical events



- Some major milestones in microbiology in relation to other historical events (continued…)



1.2. Microbiology: A Human Perspective

- We could not survive without microorganisms
- Numerous benefits
  - Examples include nitrogen fixation, oxygen production, degradation of materials (e.g., cellulose, also sewage and wastewater)
- But microorganisms have also killed more people than have ever been killed in war
  - Have even been used as weapons, and recently, in bioterrorism attacks

Applications of Microbiology

- Food production
  - Baking bread using yeast
    - Egyptian bakers as early as 2100 B.C.
  - Fermentation of grains to produce beer
    - Egyptian tombs revealed as early as 1500 B.C.
  - Fermentation of milk → yogurt, cheeses, buttermilk
- Biodegradation
  - Degrade PCBs, DDT, trichloroethylene and others
  - Help clean up oil spills
  - Bioremediation: using microorganisms to hasten decay of pollutants

Applications of Microbiology

- Bacteria synthesize commercially valuable products
- Examples include:
  - Cellulose (stereo headsets)
  - Hydroxybutyric acid (manufacture of disposable diapers and plastics)
  - Ethanol (biofuel)
  - Hydrogen gas (possible biofuel)
  - Oil (possible biofuel)
  - Insect toxins (insecticides)
  - Antibiotics (treatment of disease)
  - Amino acids (dietary supplements)

Applications of Microbiology

- Biotechnology
  - Use of microbiological and biochemical techniques to solve practical problems
- Genetic engineering
  - Introduction of genes into another organism
  - Disease-resistant plants
  - Production of medications (e.g., insulin for diabetes)

Medical Microbiology

- Most microorganisms are not harmful
- Some are pathogens
  - Cause disease
  - Influenza in 1918–1919 killed more Americans than died in WWI, WWII, Korean, Vietnam, and Iraq wars combined
  - Modern sanitation, vaccination, and effective antimicrobial treatments have reduced incidences of the worst diseases

Golden Age of Microbiology

- As theory of spontaneous generation was disproved, Golden Age of Microbiology was born
  - Most pathogenic bacteria identified (1875–1918)
  - Work on viruses began
  - Understanding that microscopic agents could cause disease led to control efforts
  - Huge improvements in past century in human health
    - Antibiotics to treat infectious diseases
    - Vaccines to prevent diseases

Past Triumphs

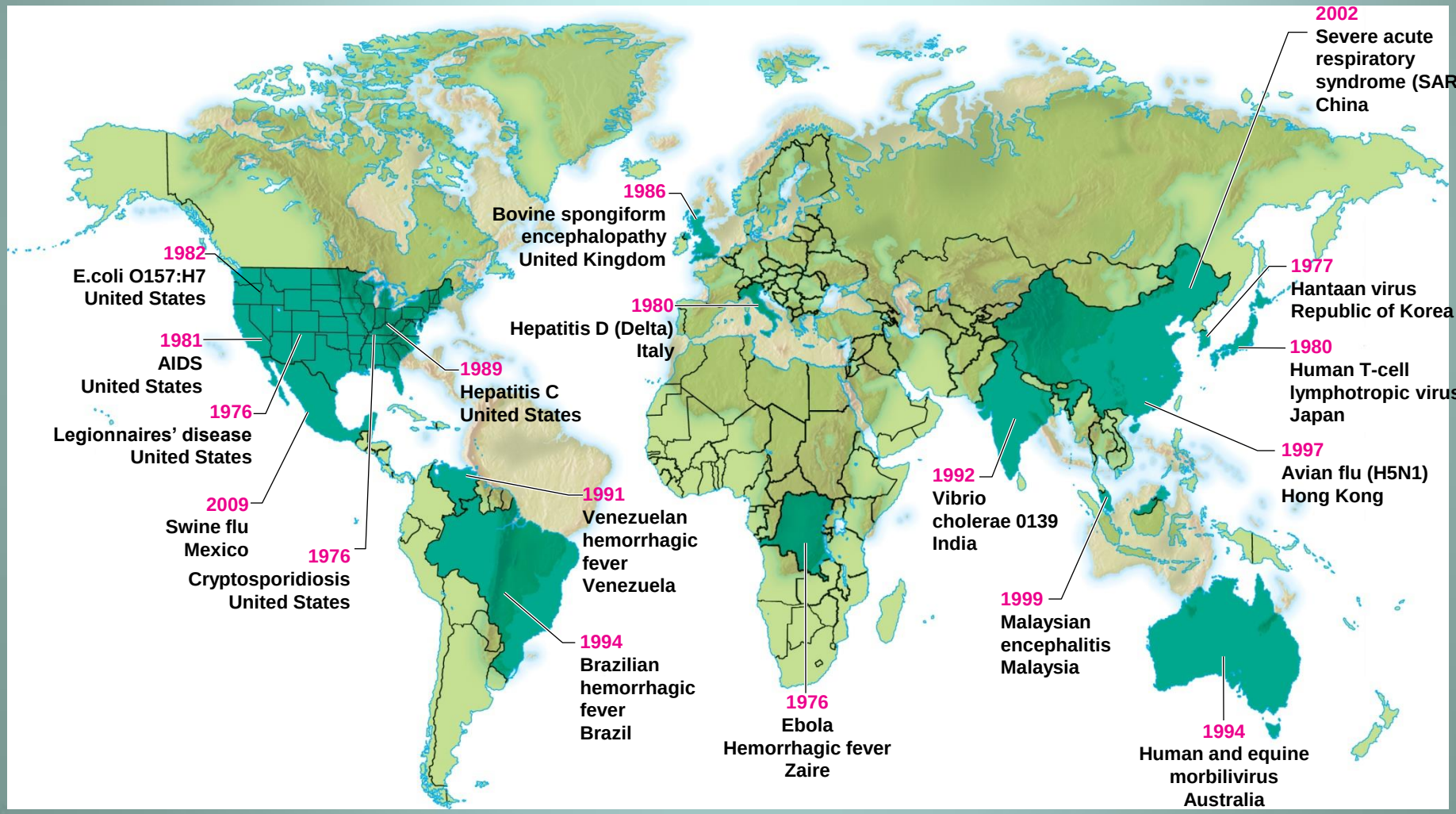
- Viral disease smallpox once a leading killer
  - ~10 million deaths over 4,000 years
  - Devastating on unexposed populations (e.g., Aztecs in New World)
  - Worldwide eradication attempts eliminated disease
    - No reported cases since 1977
- Plague another major killer in history
  - ~1/3 of population of Europe (or ~25 million individuals) died between 1346–1350
  - Today, fewer than 100 die worldwide
  - Control of rodent population harboring bacterium
  - Antibiotics available

Present and Future Challenges

- Despite impressive progress, much work remains
  - Especially true for viral diseases and diseases associated with poverty
  - Respiratory infections, diarrheal diseases cause most illness and deaths in world today
- In United States, ~750 million infections
  - ~200,000 deaths
  - Cost in tens of billions of dollars

Present and Future Challenges

- Emerging diseases continue to arise



Present and Future Challenges

- Emerging diseases
  - Most newly recognized
  - Multiple examples
    - Swine flu
    - Severe acute respiratory syndrome (SARS)
    - Multidrug-resistant tuberculosis
    - Lyme disease
    - Hepatitis C
    - Acquired immunodeficiency syndrome
    - Hemolytic uremic syndrome
    - Hantavirus pulmonary syndrome
    - Mad cow disease
    - West Nile encephalitis

Present and Future Challenges

- Emerging diseases
  - Changing lifestyles increase opportunities to spread
    - Closer contact with animals (e.g., hantavirus)
  - Evolution of infectious agents previously unable to infect humans (e.g., HIV/AIDS, SARS)
- Re-emerging diseases
  - Vaccination can become victim of own success
  - Lack of firsthand knowledge of dangers of diseases can lead people to fear vaccines more than the diseases
    - Diseases such as measles, mumps, whooping cough nearly eradicated from U.S. but could re-emerge with declining vaccination rates

Present and Future Challenges

- Emerging diseases
  - Pathogens can become resistant to antimicrobial medications (e.g., tuberculosis, malaria)
  - Increased travel and immigration
    - Many diseases eliminated from developed countries still exist in many parts of world (e.g., malaria, cholera, plague, yellow fever)
  - Changes in population
    - Weakened immune systems (e.g., elderly, HIV/AIDS)
  - Chronic diseases may be caused by bacteria
    - E.g., peptic ulcers caused by *Helicobacter pylori*
    - Possibly indigestion, Crohn's disease, others

Host-Microbe Interactions

- All surfaces of human body populated by microorganisms
- Beneficial microbes
  - Termed normal microbiota or normal flora
  - Prevent diseases by competing with pathogens
  - Development of immune system response
  - Aid in digestion
- Pathogens
  - Damage body tissues → disease symptoms

Microorganisms as Model Organisms

- Wonderful model organisms
  - Metabolism, genetics same as higher life-forms
    - All cells composed of same elements
    - Synthesize structures in similar ways
    - Replicate DNA
    - Degrade foods via metabolic pathways
    - “What is true of elephants is also true of bacteria, and bacteria are much easier to study” (Nobel Prize–winning microbiologist Dr. Jacques Monod)

1.3. The Living World of Microbes

- Enormous numbers
  - Bacterial species outnumber mammalian species by factor of 10,000!
  - Considerations of biodiversity typically overlook enormous contribution of microbes
  - Less than 1% of all microbial species can be grown and studied in laboratory

The Microbial World

- All living things can be classified into one of three groups, or domains
  - *Bacteria*
  - *Archaea*
  - *Eucarya*
- Organisms in each domain share certain important properties

Domain *Bacteria*

- *Bacteria*
  - Single-celled prokaryotes
  - Prokaryote = “prenucleus”
  - No membrane-bound nucleus
  - No other membrane-bound organelles
  - DNA in nucleoid
  - Most have specific shapes (rod, spherical, spiral)
  - Rigid cell wall contains peptidoglycan (unique to bacteria)
  - Multiply via binary fission
  - Many move using flagella

Domain *Archaea*

- *Archaea*
  - Like *Bacteria*, *Archaea* are prokaryotic
  - Similar shapes, sizes, and appearances to *Bacteria*
  - Multiply via binary fission
  - May move via flagella
  - Rigid cell walls
- However, major differences in chemical composition
  - Cell walls lack peptidoglycan
  - Ribosomal RNA sequences different
- Many are extremophiles
  - High salt concentration, temperature

Domain *Eucarya*

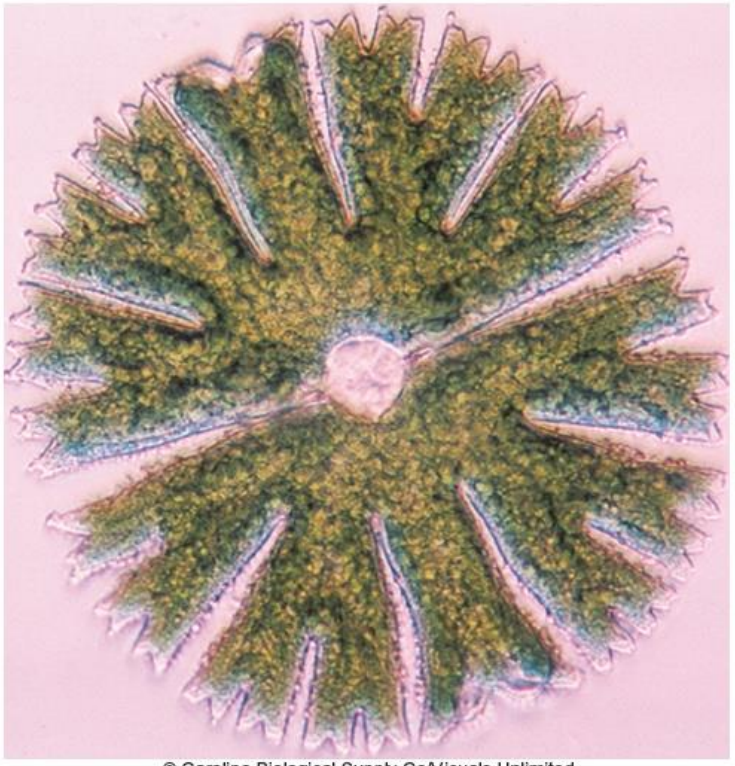
- *Eucarya*
  - Eukaryotes = “true nucleus”
  - Membrane-bound nucleus and other organelles
  - More complex than prokaryotes
  - Microbial members include fungi, algae, protozoa
    - Algae and protozoa also termed protists
    - Some multicellular parasites including helminths (roundworms, tapeworms) considered as well

TABLE 1.2 Comparison of Eukaryotic Members of the Microbial World

	Algae	Fungi	Protozoa
Cell organization	Single- or multicellular	Single- or multicellular	Single-celled
Source of energy	Sunlight	Organic compounds	Organic compounds
Size	Microscopic or macroscopic	Microscopic or macroscopic	Microscopic

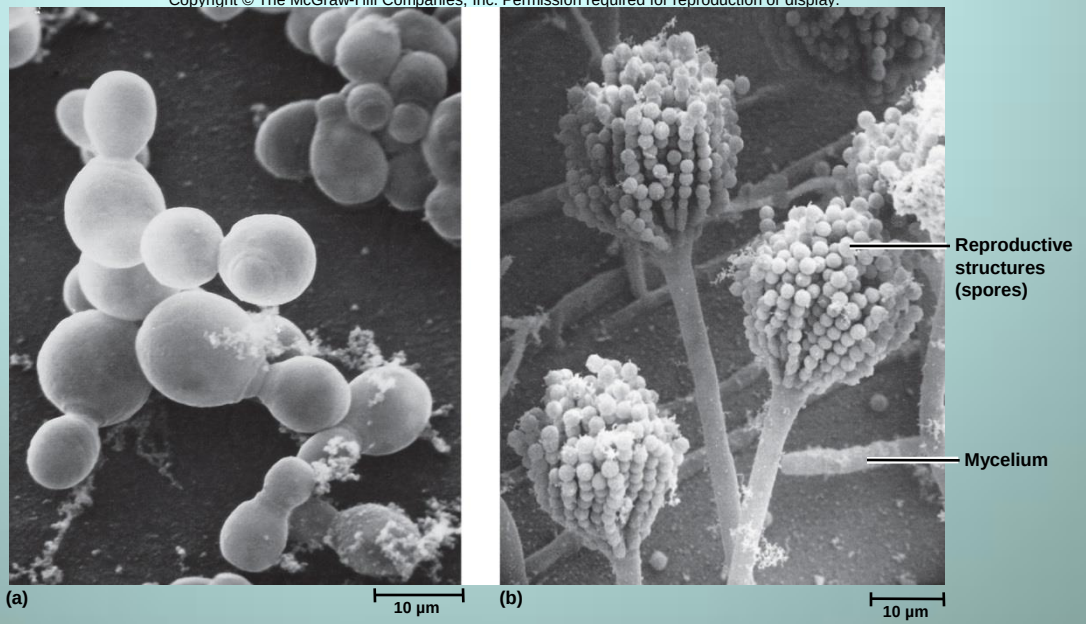
Domain *Eucarya*

- Algae
  - Diverse group
  - Single-celled or multicellular
  - Photosynthetic
    - Contain chloroplasts with chlorophyll or other pigments
  - Primarily live in water
  - Rigid cell walls
  - Many have flagella
    - Cell walls, flagella distinct from those of prokaryotes



Domain *Eucarya*

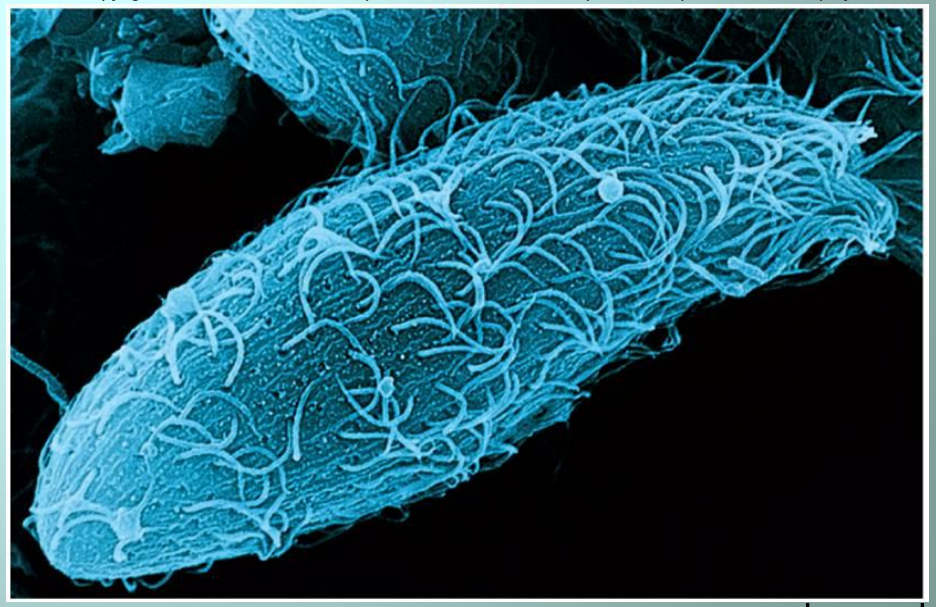
- Fungi
  - Diverse group
  - Single-celled (e.g., yeasts) or multicellular (e.g., molds, mushrooms)
  - Energy from degradation of organic materials
  - Primarily live on land



a: © CDC/Janice Haney Carr; b: © Dr. Richard Kessel & Dr. Gene Shih/Visuals Unlimited

Domain *Eucarya*

- Protozoa
  - Diverse group
  - Single-celled
  - Complex, larger than prokaryotes
  - Most ingest organic compounds
  - No rigid cell wall
  - Most motile



Nomenclature

- Binomial System of Nomenclature: two words
  - Genus (capitalized)
  - Specific epithet, or species name (not capitalized)
  - Genus and species always italicized or underlined
  - E.g., *Escherichia coli*
  - May be abbreviated (e.g., *E. coli*)

1.4. Non-Living Members of the Microbial World

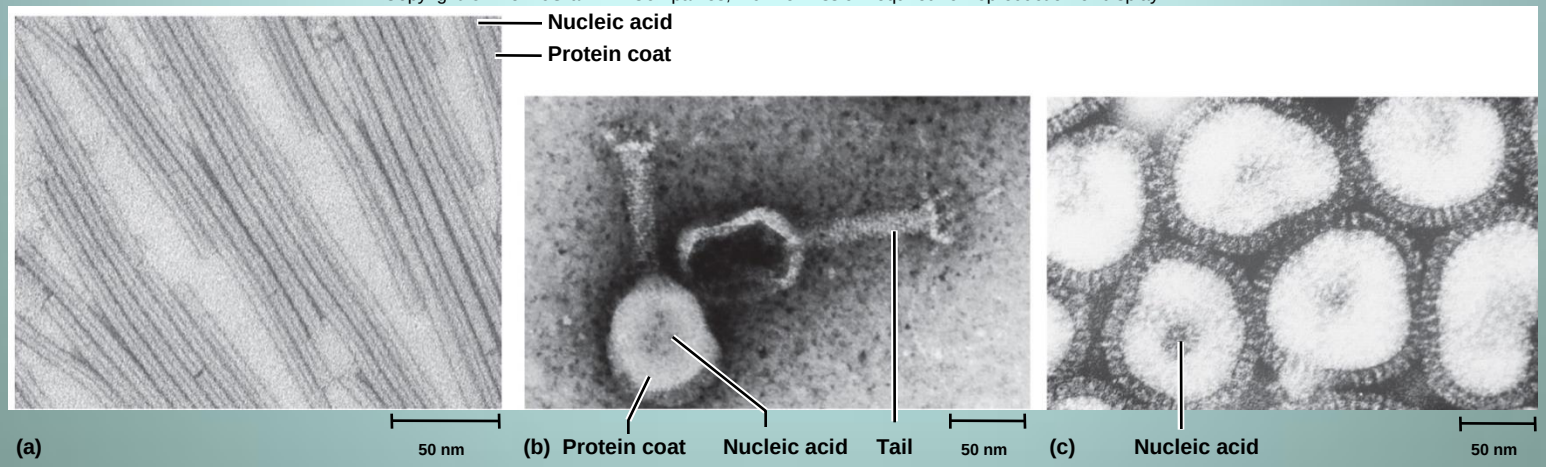
- Viruses, viroids, prions
- Acellular infectious agents
- Not alive
- Not microorganisms, so general term microbe often used to include

TABLE 1.3 Distinguishing Characteristics of Viruses, Viroids, and Prions

Viruses	Viroids	Prions
Obligate intracellular agents	Obligate intracellular agents	Abnormal form of a cellular protein
Consist of either DNA or RNA, surrounded by a protein coat	Consist only of RNA; no protein coat	Consist only of protein; no DNA or RNA

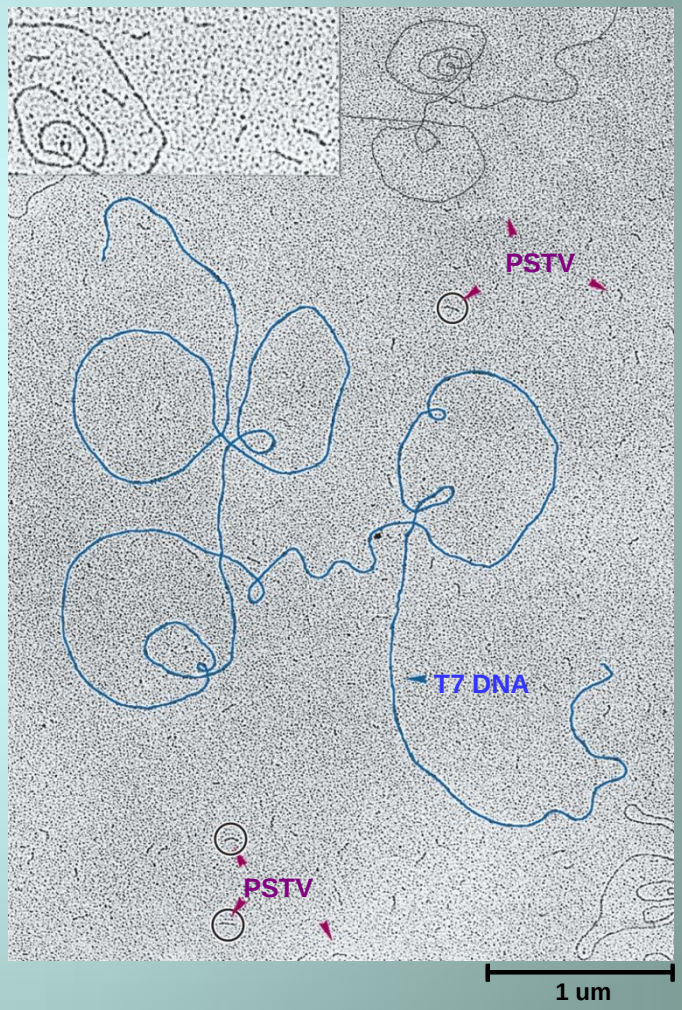
1.4. Non-Living Members of the Microbial World

- Viruses
  - Nucleic acid packaged in protein coat
  - Variety of shapes
  - Infect living cells, termed hosts
  - Multiply using host machinery, nutrients
  - Inactive outside of hosts: obligate intracellular parasites
  - All forms of life can be infected by different types



1.4. Non-Living Members of the Microbial World

- Viroids
  - Simpler than viruses
  - Require host cell for replication
  - Consist of single short piece of RNA
  - No protective protein coat
  - Cause plant diseases
  - Some scientists speculate they may cause diseases in humans
    - No evidence yet

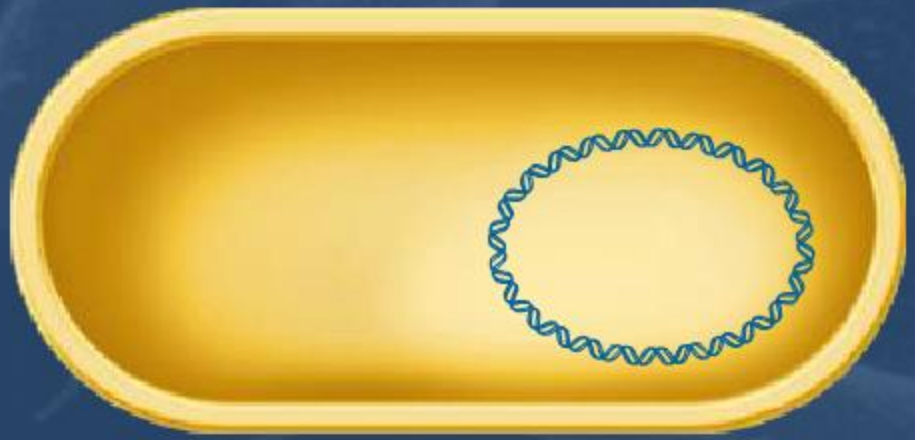


U.S. Department of Agriculture/Dr. Diemer

1.4. Non-Living Members of the Microbial World

- Prions
  - Infectious proteins: misfolded versions of normal cellular proteins found in brain
  - Misfolded version forces normal version to misfold
    - Abnormal proteins bind to form fibrils
    - Cells unable to function
  - Cause several neurodegenerative diseases in humans, animals
  - Resistant to standard sterilization procedures

Life Cycle of T2 Phage



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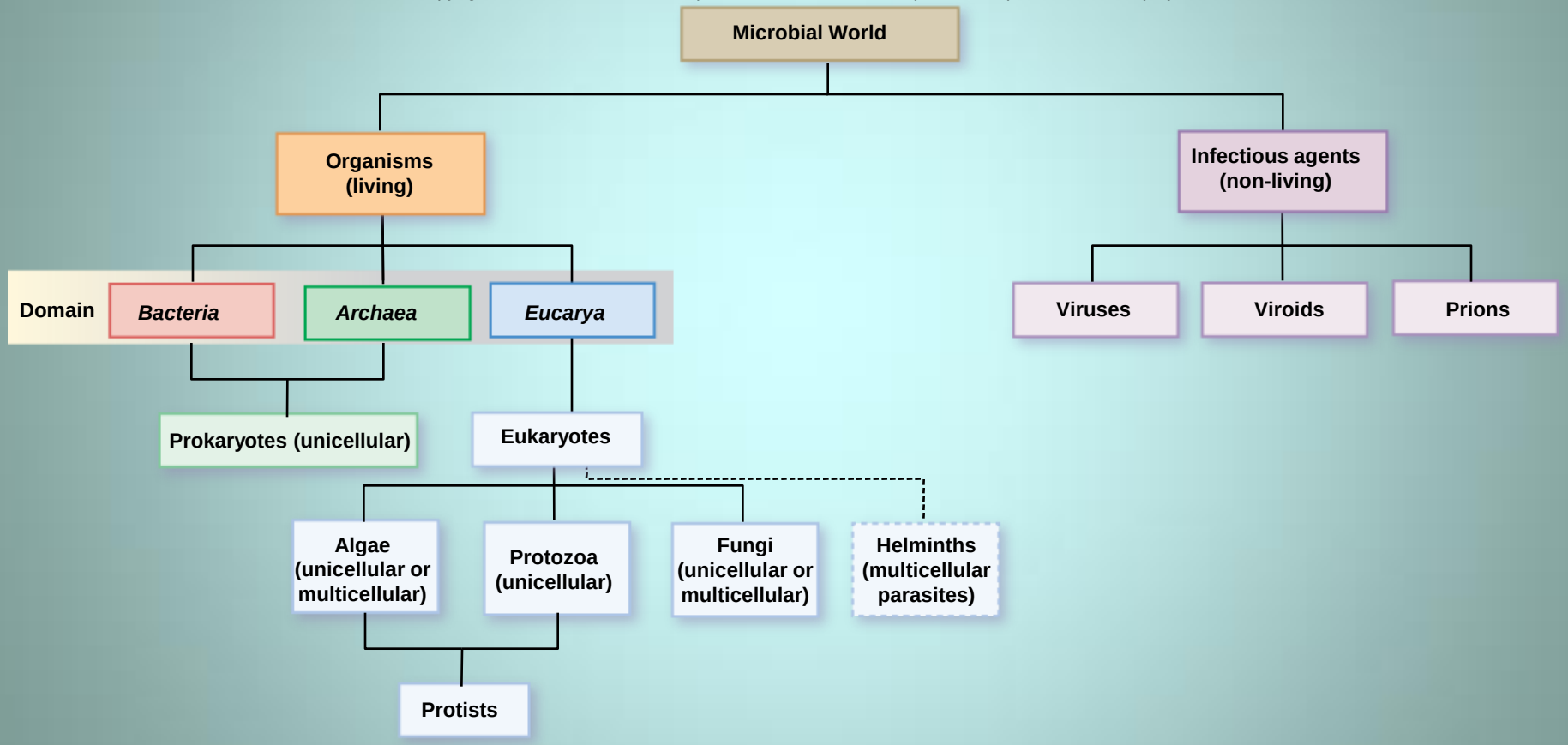
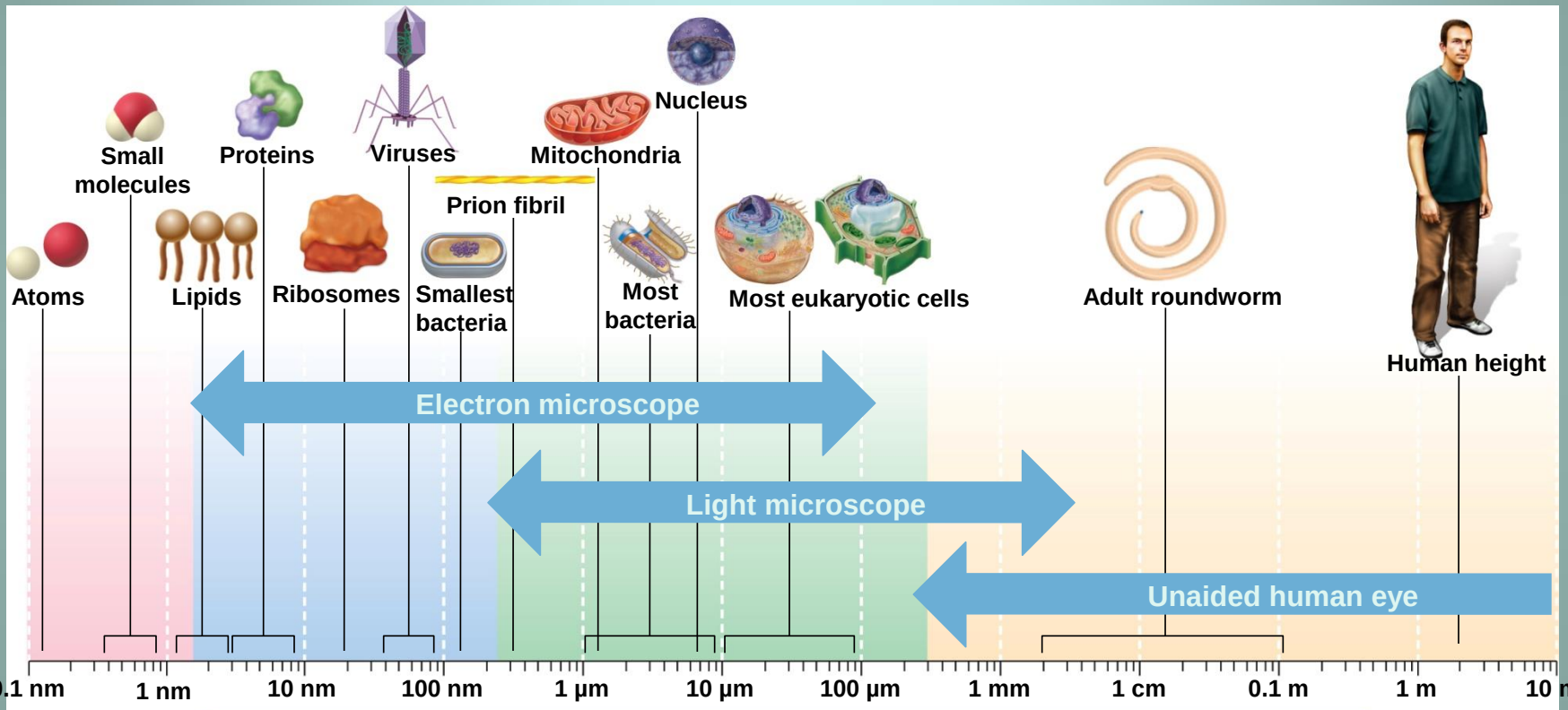
The life cycle of bacteriophage T2 begins with a bacteriophage particle binding to the surface of the bacterial cell.

Major Groups of Microbial World



1.5. Size in the Microbial World



The basic unit of length is the meter (m), and all other units are fractions of a meter.

nanometer (nm) = 10^{-9} meter = .000000001 meter
micrometer (µm) = 10^{-6} meter = .000001 meter
millimeter (mm) = 10^{-3} meter = .001 meter
1 meter = 39.4 inches

These units of measurement correspond to units in an older but still widely used convention.

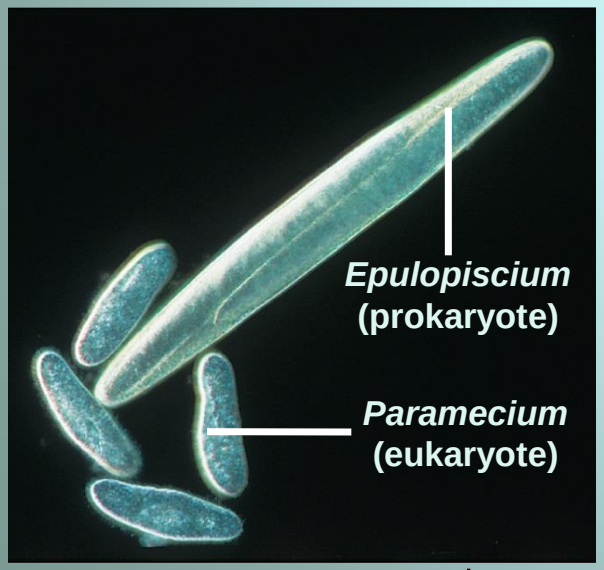
1 angstrom (Å) = 10^{-10} meter
1 micron (µ) = 10^{-6} meter

1.5. Size in the Microbial World

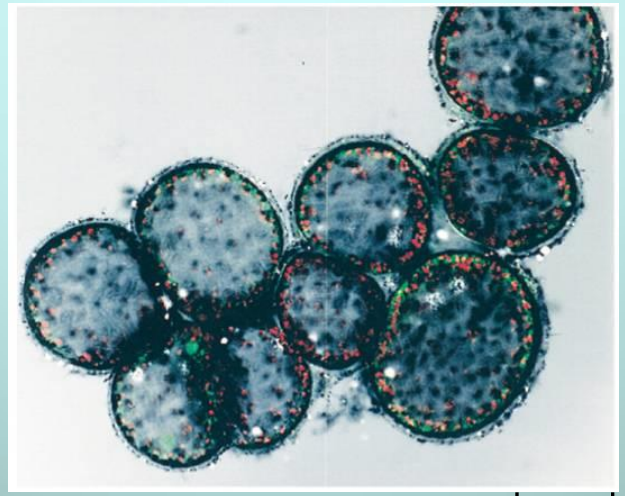
- Enormous range
  - Largest eukaryotic cells ~a million times larger than smallest viruses
- Wide variations even within a group
  - Bacterium ~600 µm x 80 µm discovered in mid 1990s
    - Visible to naked eye
  - Bacterium 70 times larger in volume discovered in 1999
  - Eukaryotic cell ~1 µm found
    - Similar in size to typical bacteria

Every Rule Has an Exception

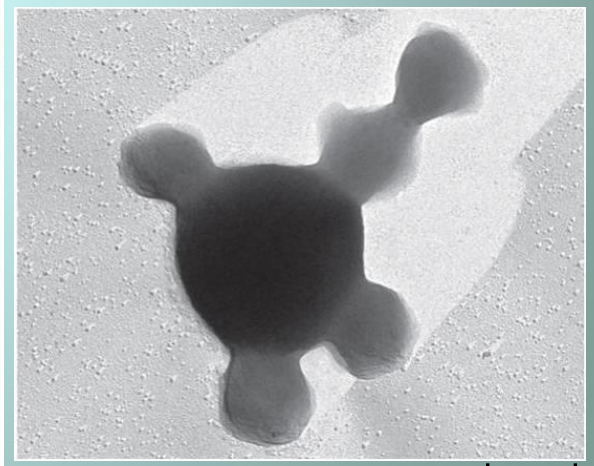
- Extremes of size
  - Enormous prokaryote; tiny eukaryote
  - Smallest prokaryote ~400 nm, contains ~1/10th as much DNA as *E. coli*
- Internal structures
  - Prokaryotic *Planctomyces* have membrane surrounding nucleoid; carry out endocytosis



Courtesy of Esther R. Angert



Courtesy of Dr. Heide N. Schulz/Max Planck Institute for Marine Microbiology



Courtesy of Reinhard Rachel and Harald Huber, University of Regensburg, Germany

Second Golden Age of Microbiology

- Less than 1% of prokaryotes ever studied
- Most do not grow in lab
- New sequencing approaches revealing enormous biodiversity of microbial world
  - E.g., 1,800 new bacterial species found in Sargasso Sea
- Major challenges remain
- Exploring microbial world should answer many fundamental biological questions