

Chapter 1: An Invisible World



Introduction to Microbiology



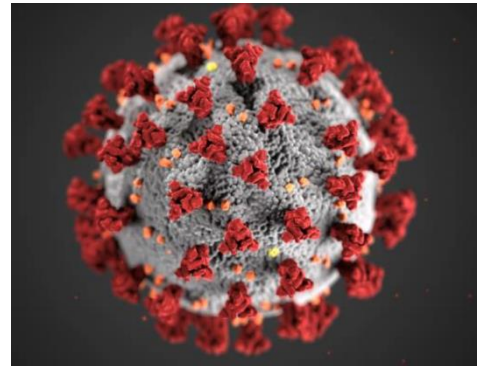
What our Ancestors Knew



A Systematic Approach



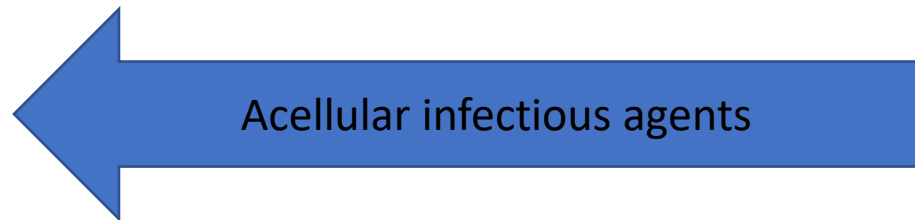
Types of Microorganisms



Microbiology: The Study of Microorganisms

Commonly cannot be seen by the naked eye:

- Prokaryotes: Bacteria and Archaea
- Fungi: Yeasts, Molds, Mushrooms
- Protists: Algae, Protozoa
- Helminths: Flatworms and Roundworms
- Viruses
- Viroids
- Virusoids
- Prions

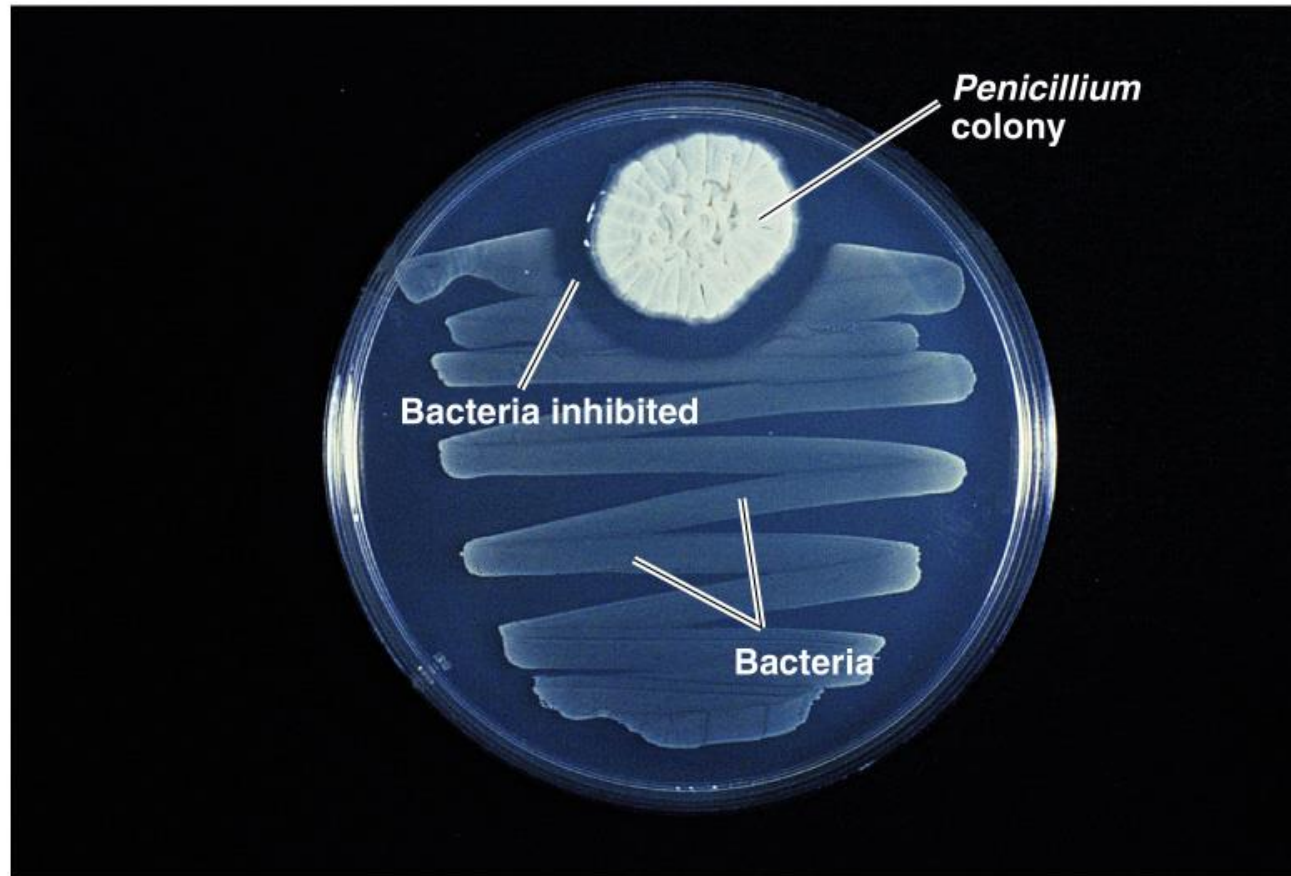


Microbes are Essential for Life on Earth

Microbes Have Many Beneficial Roles

1. **Photosynthesis:** Algae and some bacteria use sunlight and CO₂ to form basis of food chain
2. **Decomposers:** Break down dead and decaying matter and recycle nutrients (saprobes)
3. **Nitrogen Fixation:** Some bacteria incorporate atmospheric nitrogen into soil
4. **Digestion:** Microbes are essential for digestion, vitamin synthesis, and overall health
 - Cellulose digestion (cows, termites, rabbits)
 - Synthesis of vitamins K and B in humans
 - Normal Microflora: Prevent the growth of harmful bacteria, yeast, and other pathogens
 - Dysbiosis: Condition caused by abnormal microbial flora. Treated with probiotics, antifungals.
5. **Medicine:** Microbes naturally make many antibiotics and other drugs

Penicillin is Naturally Produced by a Mold



Beneficial Roles of Microbes Continued

- 6. Food and Beverage Production:** Bread, yogurt, chocolate, vinegar, soy sauce, coffee, pickles, alcoholic beverages, cheese, hams, sour cream, olives, sauerkraut, kimchi, etc.
- 7. Genetically Engineered Microbes:** Can be genetically modified to produce pharmaceutical products such as vaccines, human growth hormone, insulin, human clotting factors, antibodies, etc.
- 8. Medical Research:** Microbes are small, simple, easy to study, grow quickly, low cost, short generation times, and scientists can easily manipulate their genetic material.

Pharmaceutical Products Made Using Microbes



Microbial Pathogens

- **Less than 1% of microbes cause human disease**
- Today approximately 20% of all deaths worldwide are due to infectious diseases
- In 1962, after antibiotics and several vaccines had become widely available, the US Surgeon General declared: “The war against infectious diseases has been won.”
- **Emerging Diseases:** New diseases have appeared including COVID-19, Ebola, Zika, AIDS, Hantavirus, West Nile Virus, MERS, SARS, etc.
- **Development of Antibiotic and Drug Resistance:** Many “old” diseases are becoming resistant to treatment (Malaria, tuberculosis, gonorrhea, Staphylococcus aureus, etc.)

The Top Ten Leading Causes of Death

Rank	Worldwide	Low Income Countries	High Income Countries
1	Heart disease	Lower respiratory infections	Heart disease
2	Stroke	Diarrheal diseases	Stroke
3	COPD*	Heart disease	Alzheimer's disease
4	Lower respiratory Infections	HIV/AIDS	Lung cancers
5	Alzheimer's disease	Stroke	COPD
6	Lung cancers	Malaria	Lower respiratory infections
7	Diabetes	Tuberculosis	Colon cancers
8	Road injury	Preterm birth complications	Diabetes
9	Diarrheal diseases	Birth asphyxia and trauma	Kidney diseases
10	Tuberculosis	Road injury	Breast cancer

Source:

World Health Organization (2018)

*COPD, Chronic obstructive pulmonary disease

Top Ten Causes of Worldwide Mortality in 2018: Comparison of Low Income Versus High Income Countries

Top Fatal Infectious Diseases in 2017*:

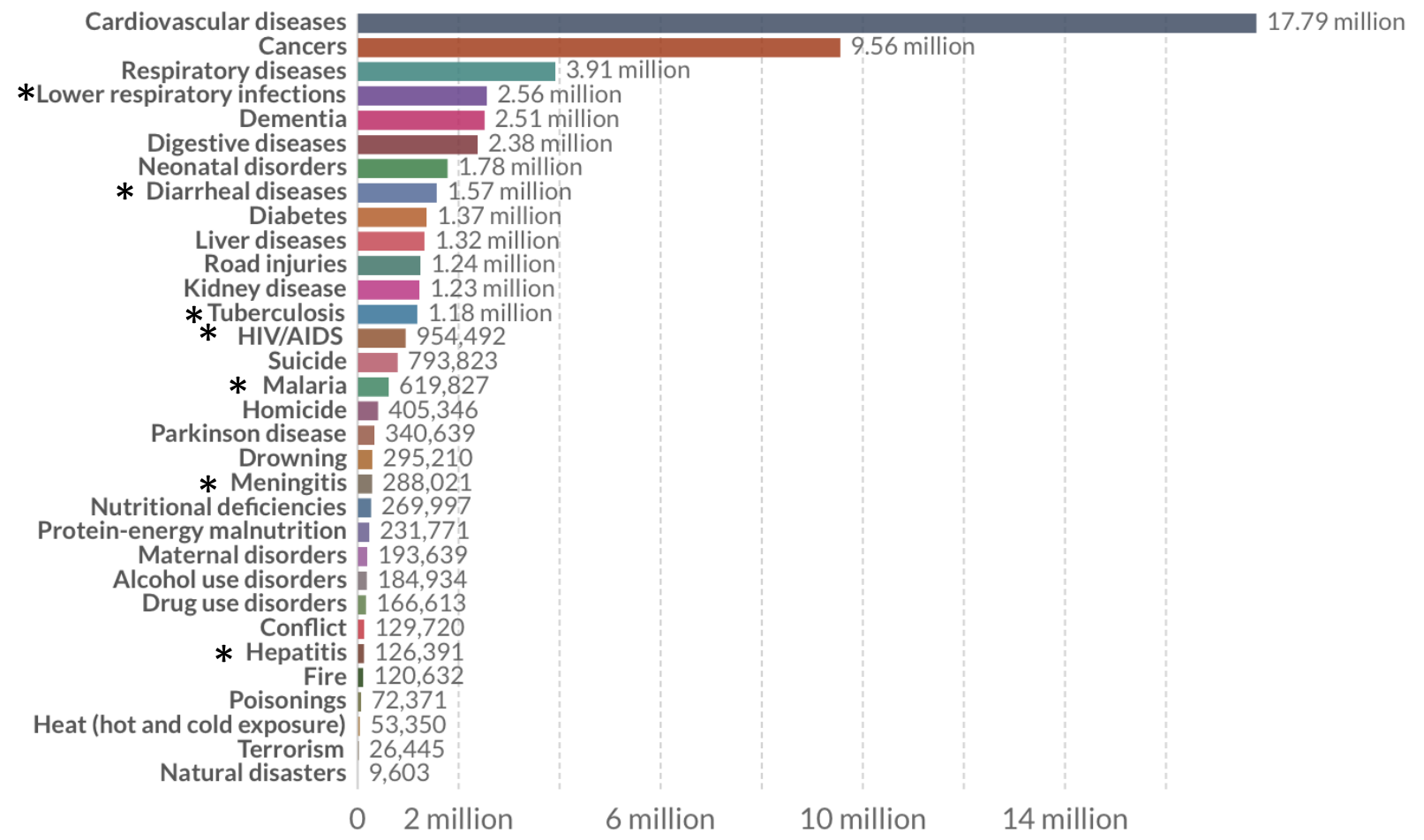
- Lower respiratory infections
- Diarrheal diseases
- Tuberculosis
- HIV/AIDS
- Malaria
- Meningitis
- Hepatitis

* Before COVID-19 pandemic

As of 2/9/2021 2.3 million deaths reported worldwide from COVID-19

Hannah Ritchie (2018) - "Causes of Death". Published online at [OurWorldInData.org](https://ourworldindata.org). Retrieved from: 'https://ourworldindata.org/causes-of-death' [Online Resource]

Number of deaths by cause, World, 2017



Source: IHME, Global Burden of Disease

CC BY

1990
▶
○
 2017

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CHART
TABLE
SOURCES
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Deadliest Animal Disease Vectors and Pathogens:

Mosquito (Malaria, Zika, Dengue)

Sandfly (Leishmaniasis)

Freshwater snail (Schistosomiasis)

Kissing bug (Chagas Disease)

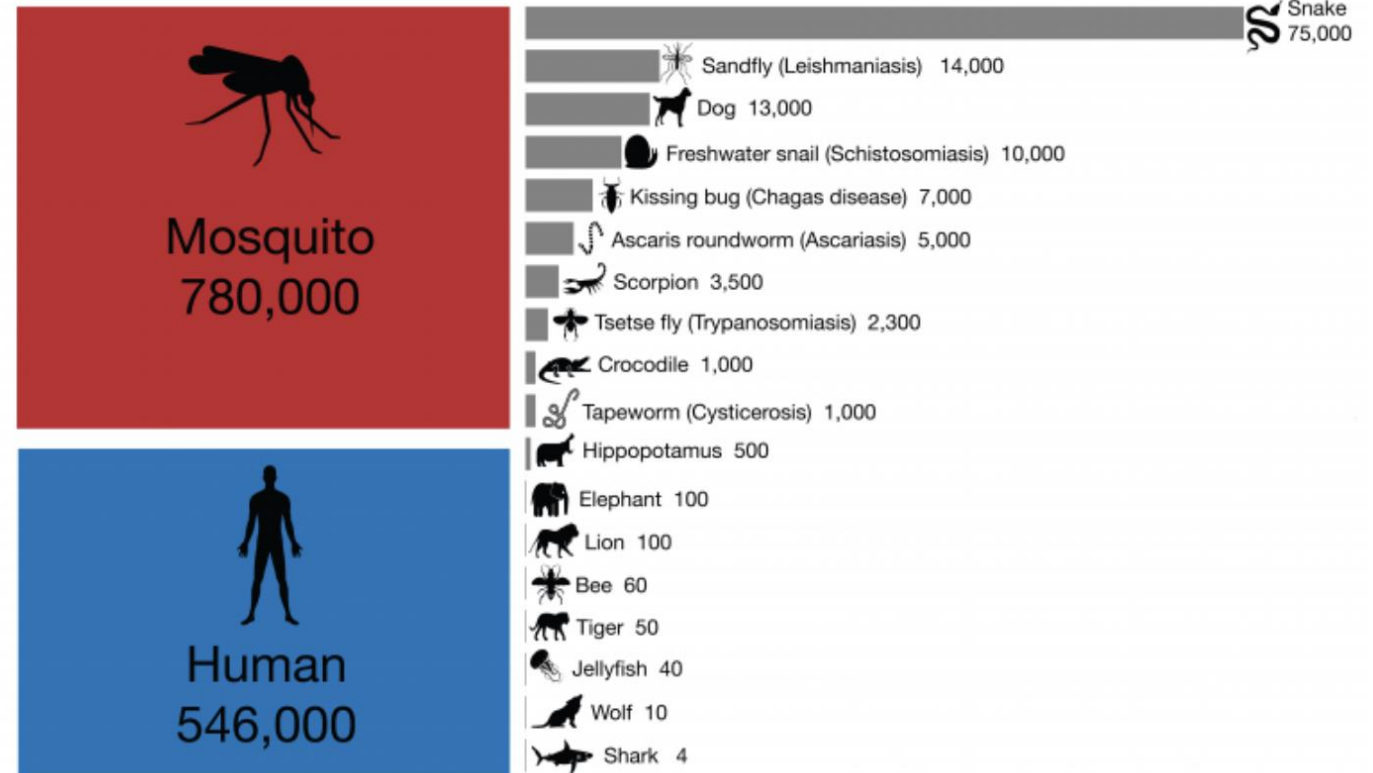
Ascaris roundworm

Tsetse fly (Trypanosomiasis)

Tapeworm (Cysticercosis)

Deadliest animals: global deaths by animal, 2016

Our World
in Data



Based on data by IHME, WHO, Shark Attack File, CrocBITE, GatesNotes, National Geographic, UN FAO, WWF. Logo source: Noun Project.

Global estimates for some animals have a significant error margin, but expected to be representative of relative magnitude.

The data visualization is available at [OurWorldinData.org](https://ourworldindata.org). There you find research and more visualizations on this topic.

Licensed under CC-BY-SA by the authors Hannah Ritchie and Max Roser.

<https://ourworldindata.org/causes-of-death>

Estimated number of global human deaths by animal, either from direct contact/attack or transmission of disease.

Major Pandemics Throughout History: Bubonic Plague

- High mortality: Up to 80% of those infected died
 - In 1347-1351: Over 75 million died worldwide
 - 25% of population of Europe died
- Unknown cause for centuries led to superstition, hysteria and persecution
- Swollen lymph nodes (buboes), blackened skin, high fever, lung infections, pain
- Bacterial disease transmitted by rat flea bite
- Rare today but still occurs

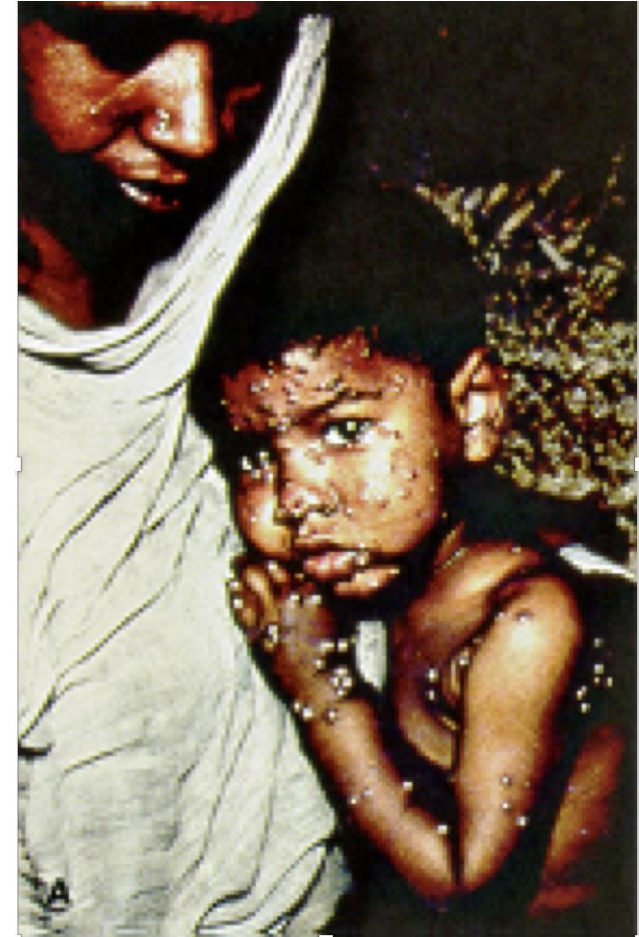


Plague patient with swollen lymph nodes and blackened skin
Source: Center for Disease Control and Prevention/W. Archibald

Major Pandemics Throughout History:

Smallpox

- Highly contagious viral infection
- One of deadliest infectious diseases in history
 - First known death Pharaoh Ramses V in 1175 B.C.
 - Killed several hundred million people over centuries
 - ~30% mortality rate & 75% survivors severely scarred and/or blind
 - Used as biological weapon against Native Americans
 - Population of America was decimated by novel diseases (smallpox, measles, syphilis, tuberculosis, plague) dropping from 130 to 2 million
- Vaccine developed in 1870s by Edward Jenner (cowpox)
- First human disease to be completely eradicated in 1977
 - Smallpox only infects humans
 - Vaccine no longer routinely administered since late 1970s

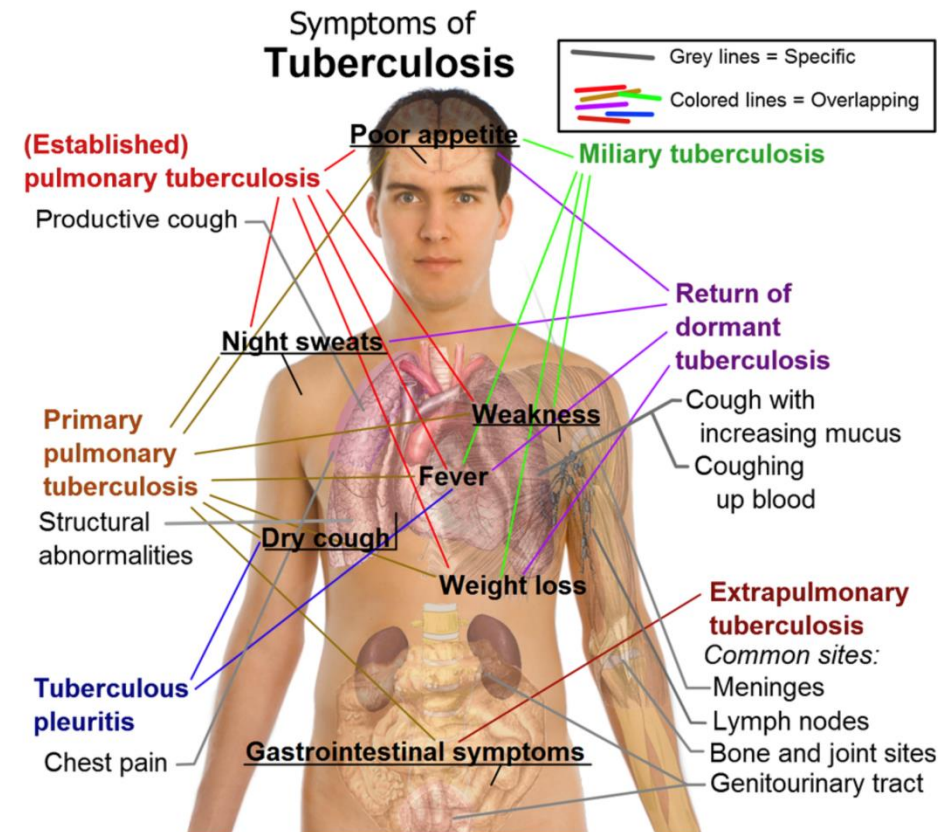


Child with smallpox infection

Source: Microbiology Perspectives, 1999

Major Pandemics Throughout History: Tuberculosis

- Bacterial infection of the lungs that can spread to other organs
- Leading killer of infectious diseases today
 - One in three people infected worldwide
 - Caused ~1.2 million deaths worldwide in 2017
 - Most healthy individuals do not develop active TB
 - In U.S. ~10 million infected, but only 5% develop active disease
 - AIDS and immunocompromised patients at higher risk
- Prevention & Treatment: Skin test, if positive X-ray, lengthy course of antibiotics (12 months+)
 - Low patient compliance has led to problems with antibiotic resistance
 - TB vaccine used in some countries may cause false positive skin test



Source: <http://www.cchd.net/tuberculosis.html>

Major Pandemics Throughout History: Childbirth Fever (Puerperal Sepsis)

- Primarily nosocomial (hospital acquired) bacterial infection after childbirth, miscarriage, or abortion.
- Can cause fever, peritonitis, sepsis, and death of mother and/or infant.
- Linked to hospital physicians who delivered babies after performing autopsies on cadavers
 - By 1800s many women died after childbirth, especially at large hospitals
 - Austrian doctor Ignaz Semmelweis hypothesized that “cadaver particles” were transferred by physicians
 - He showed that washing hands and disinfecting instruments reduced infections drastically (18.3% to 1.3%)
 - Semmelweis was fired and later died in a mental hospital
- Today mostly linked to illegal abortions, especially in third world countries



Maternity ward of a hospital in 1800s

Major Pandemics Throughout History: Influenza 1918 (Spanish Flu)

- Near the end of World War I in the Spring of 1918, a new deadly H1N1 influenza virus strain emerged and spread rapidly causing a devastating worldwide pandemic
 - Infected about one-third of human population
 - Caused 40-50 million deaths worldwide
 - In the U.S. over 650,000 deaths (5X more than in WWI)
- Crowding, poor hygiene, and movement of large number of troops helped fuel the spread
- Several waves ended by 1919-1920
- Influenza virus was not identified at the time because virology was not a well-established science



To Prevent Influenza, *Illustrated Current News*, October 18, 1918

1918 Advice on How to Prevent Influenza

Major Pandemics Throughout History: Acquired Immune Deficiency Syndrome (AIDS)

- First cases were reported in 1981 at UCLA
 - Five previously healthy young men came down with rare infection, *Pneumocystis carinii* pneumonia (PCP)
- Caused by Human Immunodeficiency Virus (HIV)
- Spread by sexual contact, blood transfusions, contaminated needles, and from mother to infant.
- HIV destroys key immune system cells, making individuals susceptible to infections and cancers.
- In 2020 AIDS is a treatable chronic disease
 - Up to ~40 million people have died worldwide from AIDS
 - Close to 1 million people died from AIDS in 2018
 - Up to ~45 million people are living with AIDS



AIDS patients with wasting and Kaposi's Sarcoma

Source: Tropical Medicine and Parasitology, 1997 and AIDS, 1999

Major Pandemics Throughout History: COVID-19

Severe Acute Respiratory Syndrome Coronavirus 2

- First cases reported in December of 2019 in Wuhan, China. Moved rapidly to Europe, U.S. and the rest of the world.
- Virus spreads through droplets, air, and fomites.
- Symptoms: Fever, sore throat, cough, pneumonia, shortness of breath (SOB), hypoxia (low blood oxygen), fatigue, headache, inflammation, blood clots, heart attacks, pulmonary embolism, strokes, loss of smell/taste, nausea, diarrhea, pediatric multisystem inflammatory syndrome (PMIS), COVID-19 toes, multiple organ failure, respiratory failure, and circulatory failure.
- Risk factors: Advanced age, diabetes, obesity, kidney, spleen, or liver disease, COPD, AIDS, and immune disorders.
- By February 9, 2021 ([For updated COVID-19 figures](#))
 - World: Over 107 million cases and 2.3 million deaths
 - US: Over 27 million cases and 466,000 deaths
 - Los Angeles County: 1.15 million cases and 18,146 deaths



Young COVID-19 patient with PMIS



COVID-19 Patient in a Prone Position to Help Lung Function

Source: Reuters. <https://images.app.goo.gl/Zzj9cy7ATc48hAoL7>

Causes of death ^b											
Age, y	COVID-19	Heart disease	Malignant neoplasms	Chronic lower respiratory disease	Unintentional injuries		Intentional injuries		Leading causes of infant deaths		
					Transport accidents	Accidental drug overdoses	Suicide	Homicide	Birth defects	Short gestation	SUID
<1	7.4	51.6	8.6	2.9	15.5	1.6	0.0	46.7	773.7	682.2	603.4
1-4	1.0	4.8	13.1	2.0	17.5	0.3	0.0	15.6	15.9		
5-14	1.0	2.7	13.5	2.0	14.6	0.4	9.4	4.7	6.4		
15-24	9.9	13.8	20.9	2.8	108.3	66.1	97.0	72.1	5.5		
25-34	38.6	52.1	53.7	4.2	113.2	220.7	120.9	78.8	6.4		
35-44	109.9	169.1	172.0	10.1	93.8	234.0	128.1	54.7	7.2		
45-54	294.8	509.7	597.5	56.1	100.7	208.2	140.3	33.9	11.2		
55-64	683.3	1239.8	1802.4	285.8	105.0	161.2	139.8	23.7	17.8		
65-74	1574.6	2516.9	3702.0	809.9	99.2	50.8	114.1	15.7	13.4		
75-84	3832.4	6478.5	6845.7	2117.3	129.9	16.0	129.6	13.2	14.9		
≥85	10 699.7	24 530.2	10 442.4	4278.4	139.1	14.7	133.4	13.3	31.2		
Total	698.8	1287.7	1219.8	307.5	89.2	122.3	102.3	39.0	19.4		

US COVID-19 & Other Mortality Rates* by Age

JAMA. 2021;325(2):123-124. doi:10.1001/jama.2020.24865

* Deaths per million

Abbreviations: COVID-19, coronavirus disease 2019; SUID, sudden unexpected infant death (including sudden infant death syndrome).

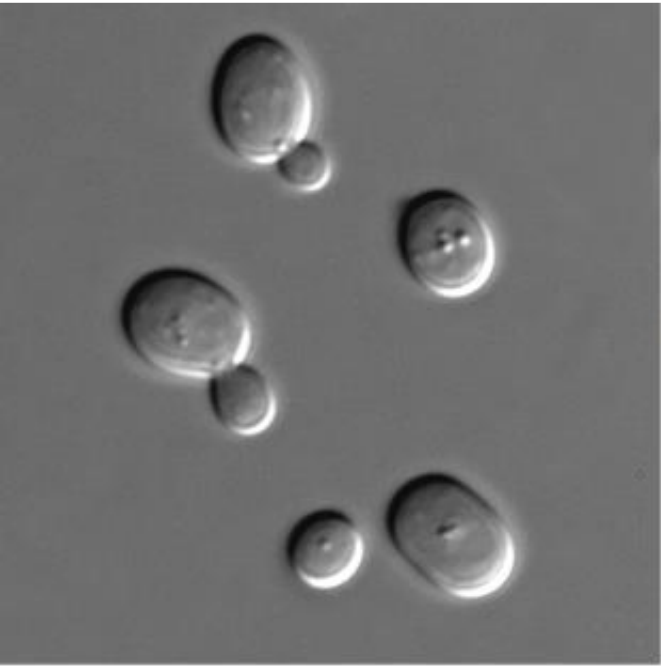
^a Table presents 8-month aggregate COVID-19 mortality rates during the period of March through October 2020⁵ and mortality rates for other causes during the period of March through October 2018,⁴ the most recent year for which detailed

^b Causes of death are defined by *International Statistical Classification of Diseases and Related Health Problems* codes for heart disease (I00-I09, I11, I13, I20-I51), malignant neoplasms (C00-C9), chronic lower respiratory disease (J40-J47), transport accidents (injuries) (V01-V99, Y85), accidental drug overdoses (X40-X44), suicide (*U03, X60-X84, Y87.0), homicide (*U01-*U02, X85-Y09, Y87.1), birth defects (Q00-Q99), short gestation (P05-P08) and sudden

1.1. What Our Ancestors Knew



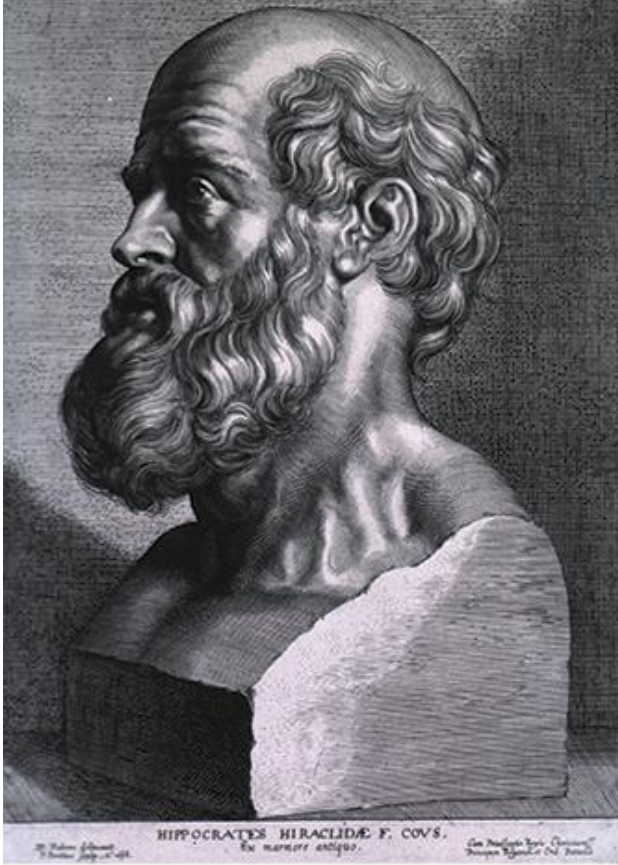
Fermented Foods & Beverages



Evidence for fermented foods (e.g., yogurt, beer, wine, etc) dates back as far as 7000 BC!

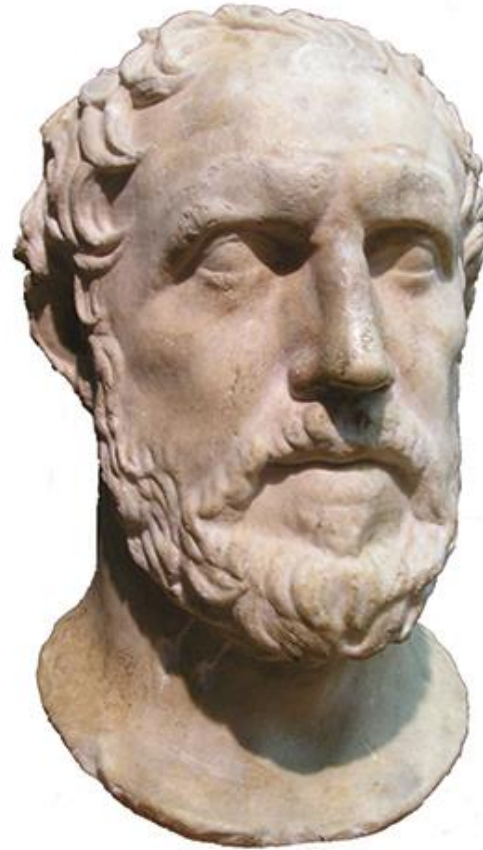
- the microbial basis (i.e., yeast and bacteria) was, of course, not known

Ancient Scholars of Health and Disease



Hippocrates (400 BC)

- Diseases have natural causes
- First cause no harm



Thucydides (400 BC)

- Evidence-based
- plague survivors immune

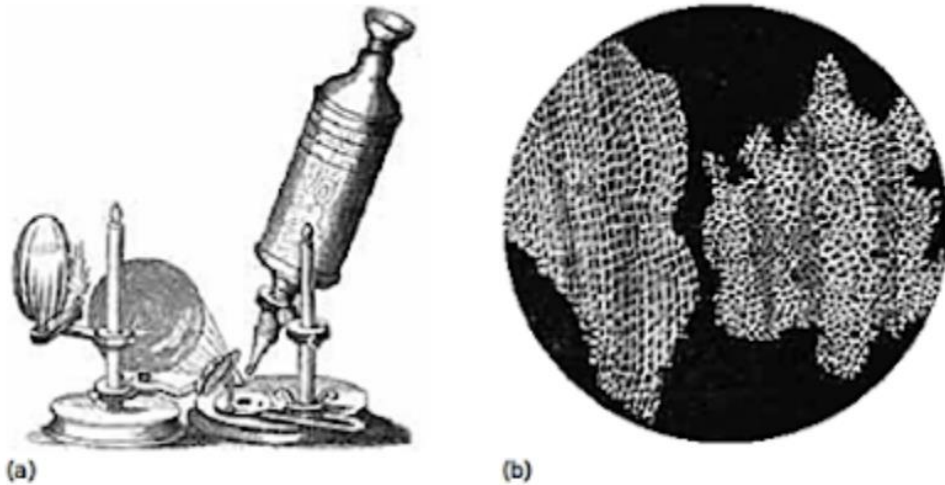


Varro (36 BC)

- Proposed unseen “minute creatures” cause disease

Early Microscopy

Robert Hooke & Anton Leeuwenhoek



Robert Hooke used an early microscope (a) to see cells in thin slices of cork. His drawings of what he saw (b) indicate that he had clearly observed the remains of cork cells (300x)

Robert Hooke developed an early compound light microscope and coined the word cell (1665)



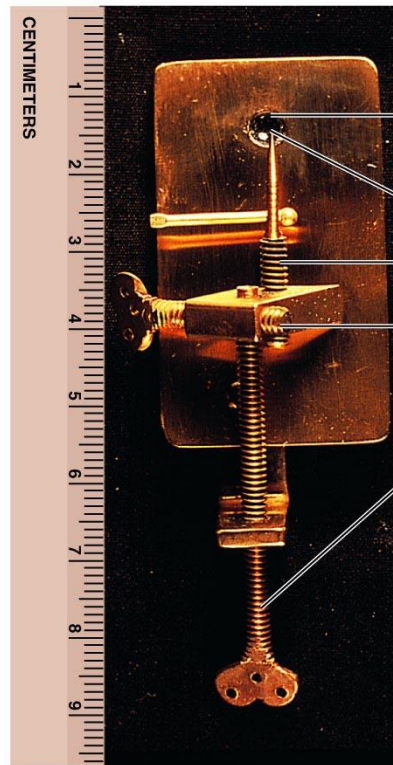
Leeuwenhoek was the first to see microbes using a single-lens microscope (1673)

The Discovery of Microorganisms

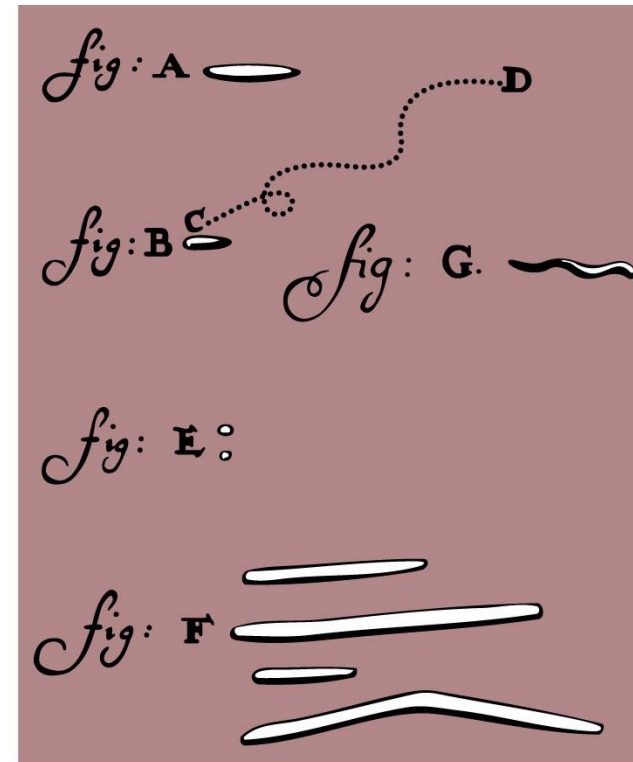
Anton van Leeuwenhoek (1673)

The first to observe microorganisms using his “magnifying lenses”.

- essentially began the field of microbiology
- the importance of microorganisms for human welfare was not appreciated until almost 200 years later!



(b) Microscope replica

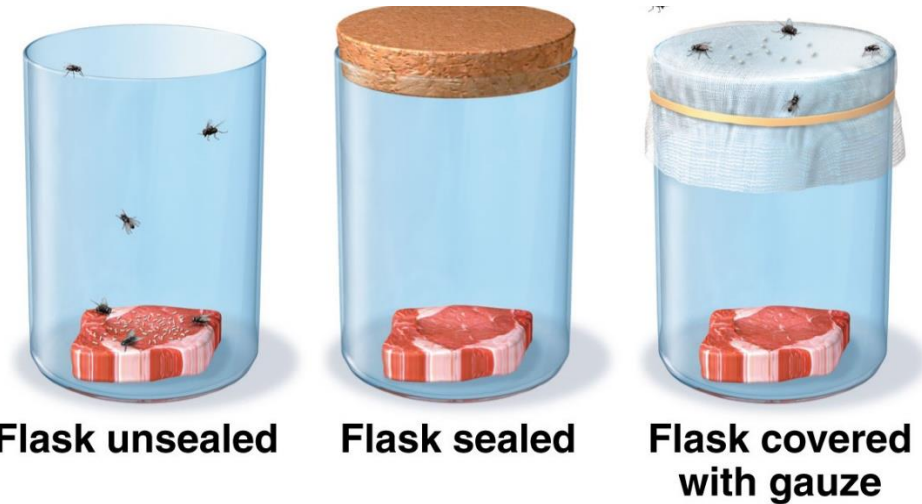


(c) Drawings of bacteria

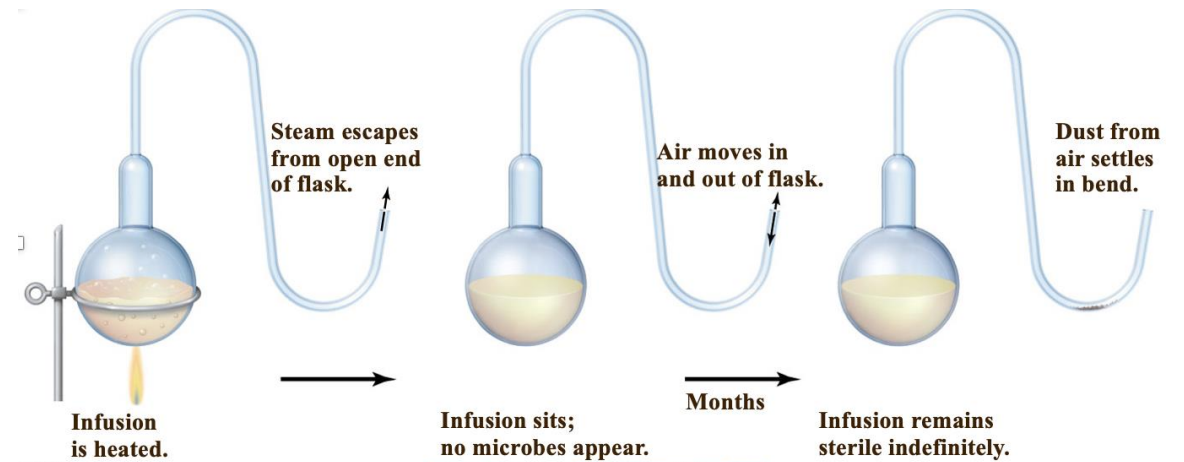
Biogenesis Versus Spontaneous Generation Debate

- **Spontaneous Generation:** Belief that living matter could arise from nonliving matter.
 - Example: Ants from honey, maggots from dead meat, mice from rags, and bacteria from spoiled broth.
- **Biogenesis:** Theory that living organisms can only originate from other cells or living organisms.
- Intense debate raged for over 200 years
 - Francesco Redi's experiments with maggots in 1668
 - Louis Pasteur's experiments with bacteria growth in broth finally settled the debate in 1861

Francesco Redi's Experiment with Maggots (1668)

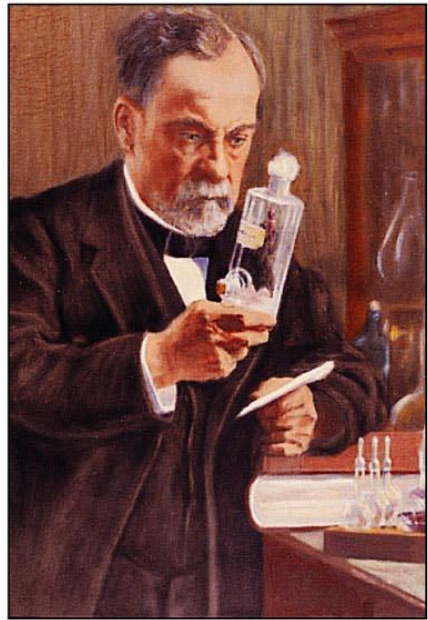


Louis Pasteur's Experiments with Broth (1861)

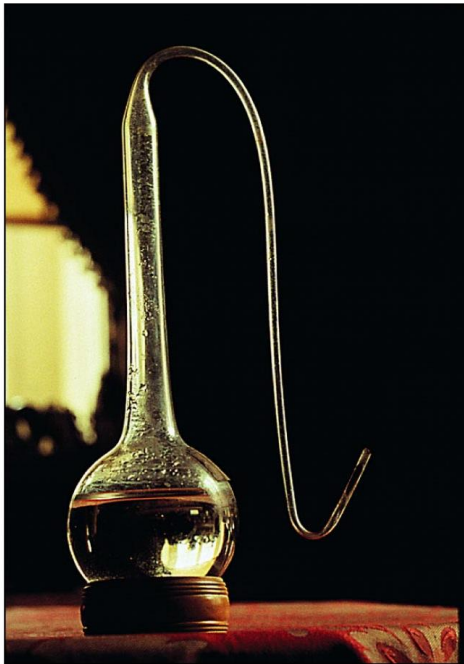


Golden Age of Microbiology (1857-1914)

Contributions of Louis Pasteur



Louis Pasteur (1822–1895)



1. Proposed Germ Theory of disease (1857)
2. Used swan-neck flasks to disprove spontaneous generation (1861)
3. Studied fermentation and found out it was carried out by yeasts cells. Bacterial contamination caused souring and spoilage of wine (1861).
4. Developed process of pasteurization by heating liquids (at 65°C) to prevent the spoilage of beverages.
5. Developed vaccines for anthrax and for rabies from spinal cords of infected rabbits.
6. Identified the pathogens that cause three different silkworm diseases.
7. Directed Pasteur Institute until his death in 1895.

Golden Age of Microbiology (1857-1914)

Germ Theory of Disease: Microbes cause specific diseases.

□ **Joseph Lister (1860):** Used disinfectant to treat surgical wounds, greatly reducing infection rates. Considered the **founder of antiseptic surgery**.

□ **Florence Nightingale (1820-1910):** English nurse who introduced cleanliness and other aseptic techniques into nursing practice.

Founded the first nursing school.



Golden Age of Microbiology (1857-1914)

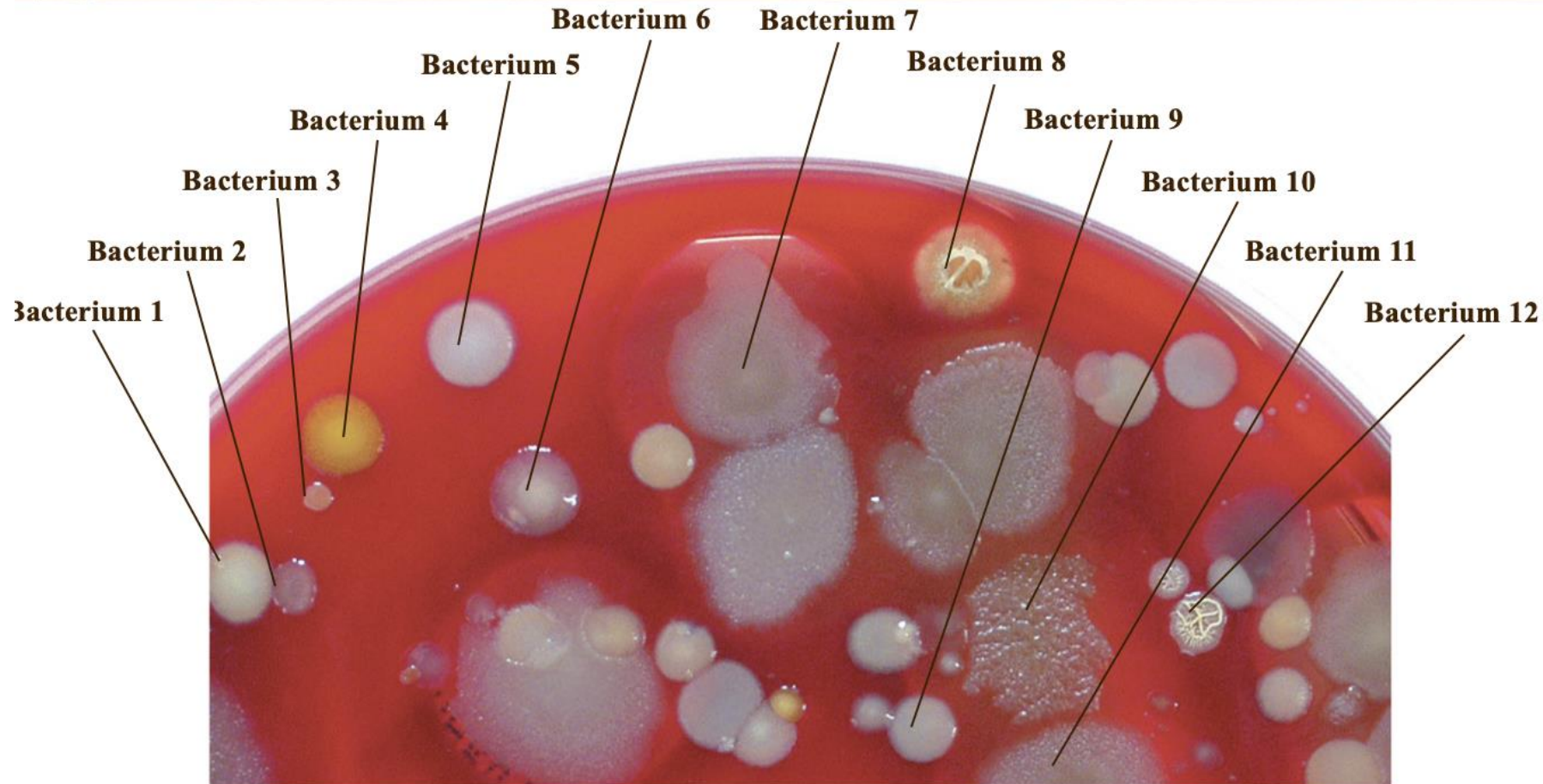
Robert Koch

- Advanced Germ Theory of Disease
- First person to conclusively prove that a specific bacterium caused disease
 - *Bacillus anthracis* (anthrax) in 1876
 - *Mycobacterium tuberculosis* (TB) in 1882
- Developed Koch's postulates: Series of steps used to identify bacteria
- Simple staining techniques and fixation of bacteria to slides
- First photomicrograph of bacteria
- Techniques for estimating bacterial counts
- Use of steam to sterilize growth media
- Use of Petri dishes to grow bacteria
- Aseptic (pure culture) techniques to transfer bacteria
- Identified bacteria as distinct species



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Koch Isolated and Identified Bacterial Pathogens



1.2

TABLE

Other Notable Scientists of the “Golden Age of Microbiology” and the Agents of Disease They Discovered

Scientist	Year	Disease	Agent
Albert Neisser	1879	Gonorrhea	<i>Neisseria gonorrhoeae</i> (bacterium)
Charles Laveran	1880	Malaria	<i>Plasmodium</i> species (protozoa)
Carl Eberth	1880	Typhoid fever	<i>Salmonella enterica</i> serotype Typhi (bacterium)
Edwin Klebs	1883	Diphtheria	<i>Corynebacterium diphtheriae</i> (bacterium)
Theodore Escherich	1884	Traveler’s diarrhea Bladder infection	<i>Escherichia coli</i> (bacterium)
Albert Fraenkel	1884	Pneumonia	<i>Streptococcus pneumoniae</i> (bacterium)
David Bruce	1887	Undulant fever (brucellosis)	<i>Brucella melitensis</i> (bacterium)
Anton Weichselbaum	1887	Meningococcal meningitis	<i>Neisseria meningitidis</i> (bacterium)
A. A. Gartner	1888	Salmonellosis (form of food poisoning)	<i>Salmonella</i> species (bacterium)
Shibasaburo Kitasato	1889	Tetanus	<i>Clostridium tetani</i> (bacterium)
Dmitri Ivanowski and Martinus Beijerinck	1892 1898	Tobacco mosaic disease	<i>Tobamovirus tobacco mosaic virus</i>
William Welch and George Nuttall	1892	Gas gangrene	<i>Clostridium perfringens</i> (bacterium)
Alexandre Yersin and Shibasaburo Kitasato	1894	Bubonic plague	<i>Yersinia pestis</i> (bacterium)
Kiyoshi Shiga	1898	Shigellosis (a type of severe diarrhea)	<i>Shigella dysenteriae</i> (bacterium)
Walter Reed	1900	Yellow fever	<i>Flavivirus yellow fever virus</i>
Robert Forde and Joseph Dutton	1902	African sleeping sickness	<i>Trypanosoma brucei gambiense</i> (protozoan)

Modern Microbiology: 20th Century and Beyond

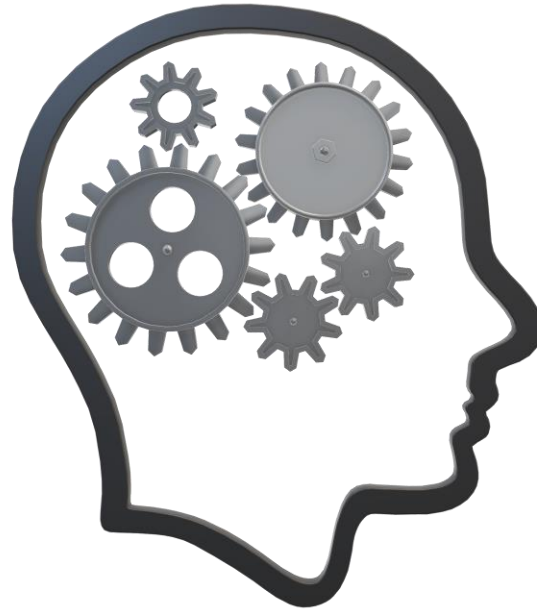
The Development of Antimicrobial Agents

- **Alexander Fleming (1928):** Discovered that penicillin produced by the mold *Penicillium notatum* was able to prevent microbial growth. Penicillin was not mass produced until the 1940s.
- **Rene Dubos (1939):** Discovered two antibiotics (gramidin and tyrocidine) produced by bacterium (*Bacillus brevis*).

Problems with Antimicrobial Chemotherapy:

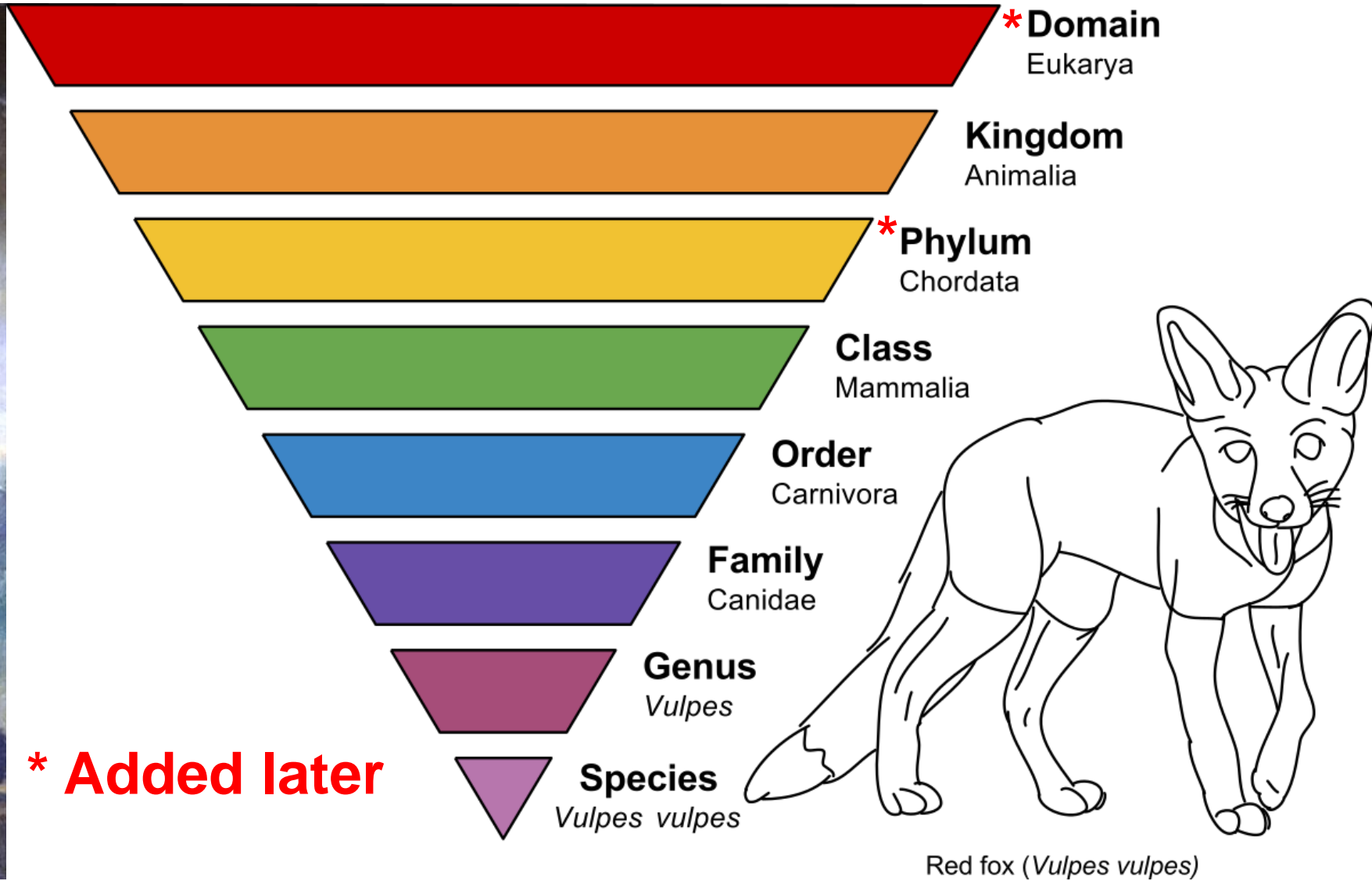
- **Side Effects**
 - **Toxicity:** Damage to liver, kidney, bone marrow, teeth, fetus, etc.
 - **Dysbiosis:** Destruction of beneficial microbes can cause diarrhea, nausea, cramps, yeast infections, etc.
 - **Allergic reactions:** Anaphylactic reactions to penicillin, rashes, etc.
- **Drug resistant microbes:** Multi-Drug Resistant Strains: *Staphylococcus aureus* (MRSA), Tuberculosis (XDR TB), and Malaria

1.2 A Systematic Approach



The Taxonomic Hierarchy

First proposed by Carolus Linnaeus in 1735.



Binomial Nomenclature

To avoid confusion, Linnaeus also proposed a way of naming organisms that is still used today:

- every type of organism is referred by its genus name followed by its specific epithet (i.e., species name)
- name should be in *italics* and only the genus is capitalized which can also be abbreviated

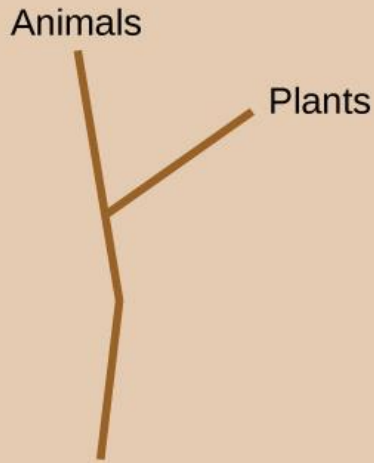
Tyrannosaurus rex (T. rex)

Escherichia coli (E. coli)

- names are Latin (or “Latinized” Greek) with the genus being a noun and the specific epithet an adjective

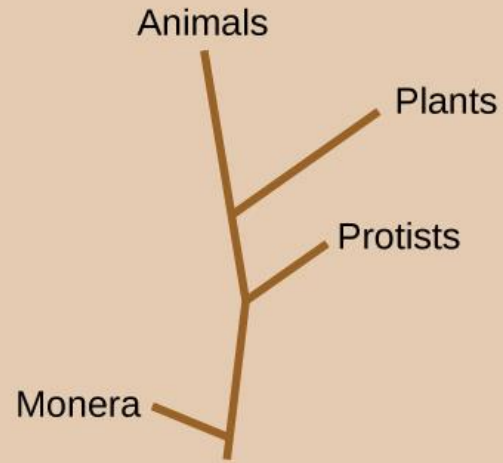
****strain info can be listed after the specific epithet (e.g., *E. coli* O157:H7)****

“Evolution” of the Tree of Life



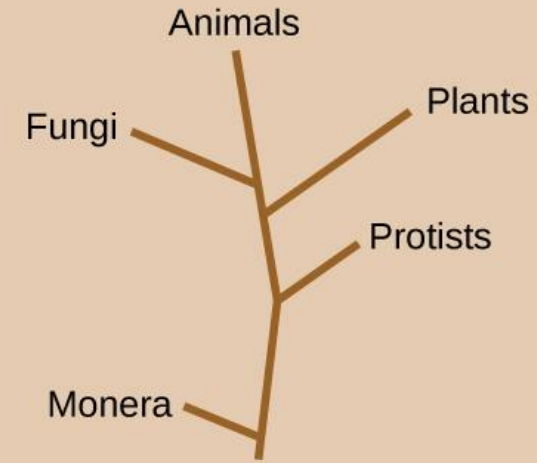
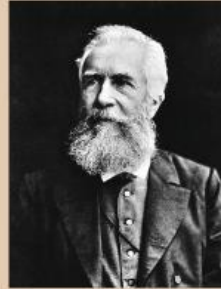
1758

Carolus Linnaeus developed a new way to categorize plants and animals



1866

Ernst Haeckel wrote *General Morphology of Organisms*, proposing four kingdoms



1969

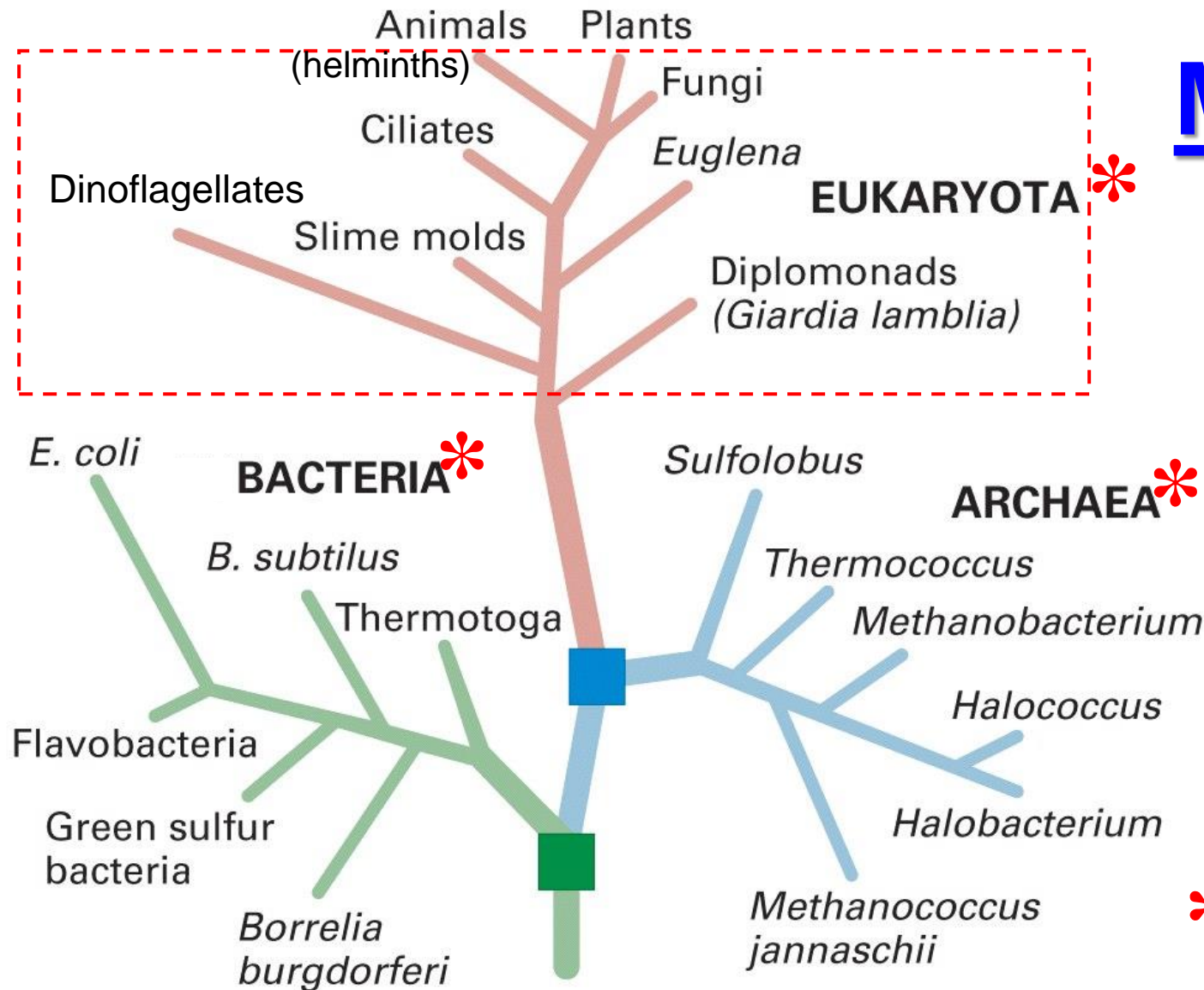
Robert Whittaker proposed adding a fifth kingdom—fungi—to the tree of life



Modern Tree of Life

Carl Woese & George Fox (1970s):

- discovered the Archaea
- created the taxon “Domain”
- based on rRNA analysis

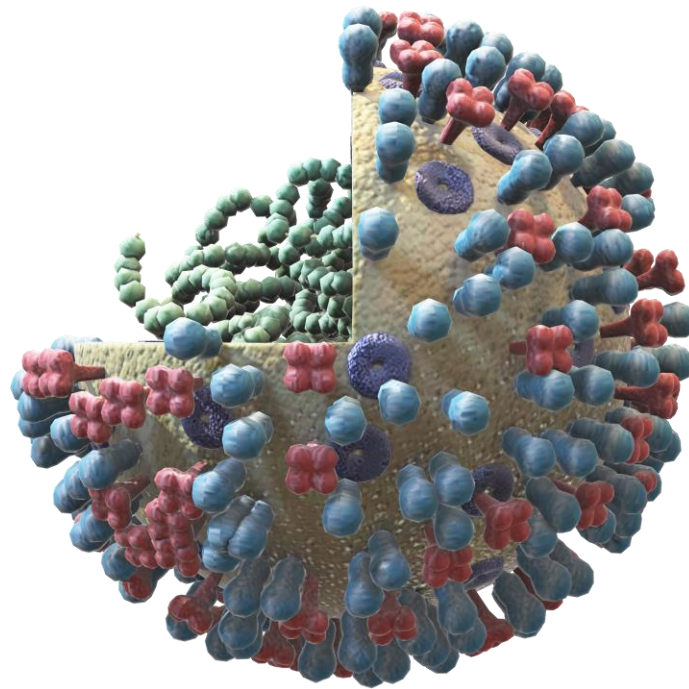


* organisms covered in this course

■ Presumed common progenitor of all extant organisms

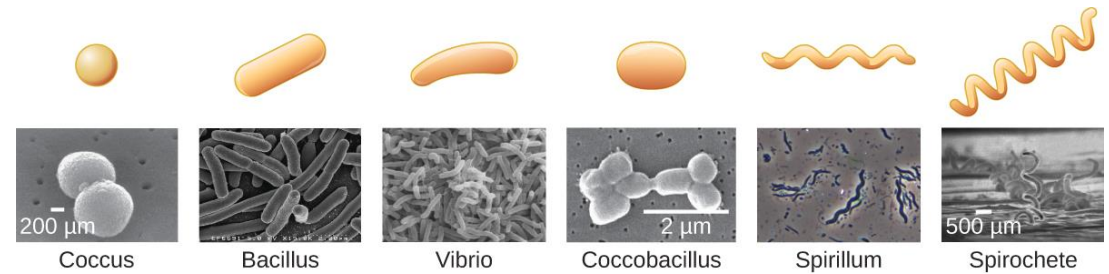
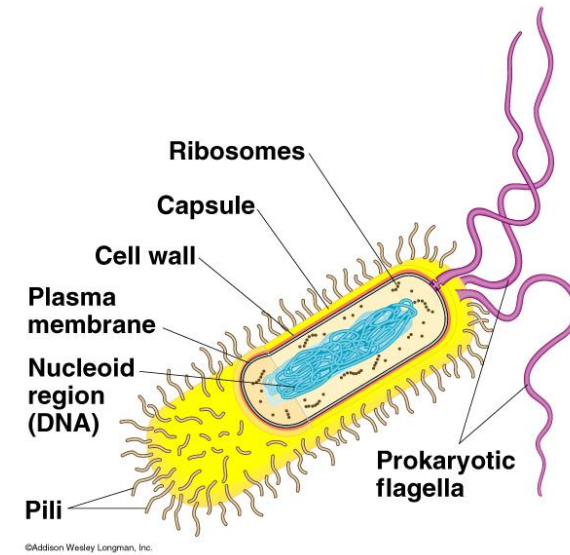
■ Presumed common progenitor of archaeobacteria and eukaryotes

1.3 Different Types of Microorganisms



Prokaryotes-Bacteria

- Small, single-celled organisms
- Lack a nucleus and membrane bound organelles
- Have a single circular chromosome
- Divide by binary fission
- Most have peptidoglycan cell walls
- Susceptible to antibiotics
- Common morphologies and arrangements include:
 - Coccus, bacillus, vibrio, spirillum, and spirochete
 - Pairs, chains, clusters, tetrads
- Wide range of metabolic strategies:
 - Photosynthetic versus non-photosynthetic
 - Aerobes versus anaerobes
- Sometimes called “eubacteria” or true bacteria
- Metabolically and chemically different from Archaea
- Include most human prokaryotic pathogens
- Classified in **Bergey’s Manuals of Bacteriology**



Prokaryotes-Archaea



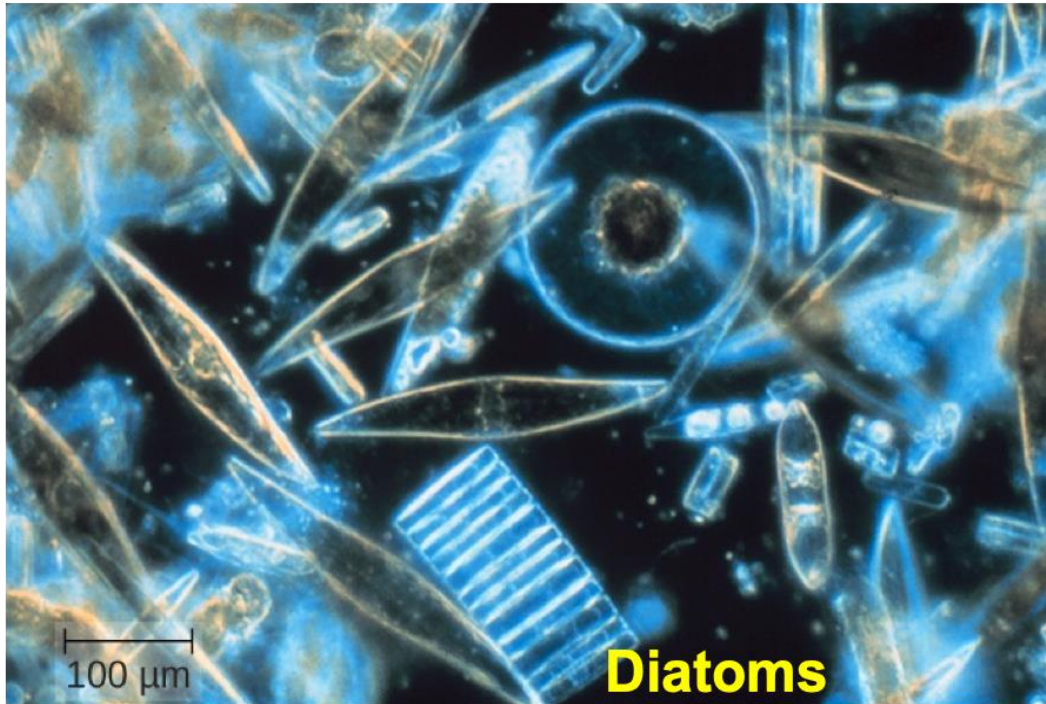
- Direct ancestors of and more closely related to Eukaryotes
- Not very well studied or understood
- Many colonize very harsh or extreme environments
 - High temperature
 - Acidic
 - High salt (hypertonic)

Eukaryotes - Protists

Protists are mostly single-celled eukaryotes:

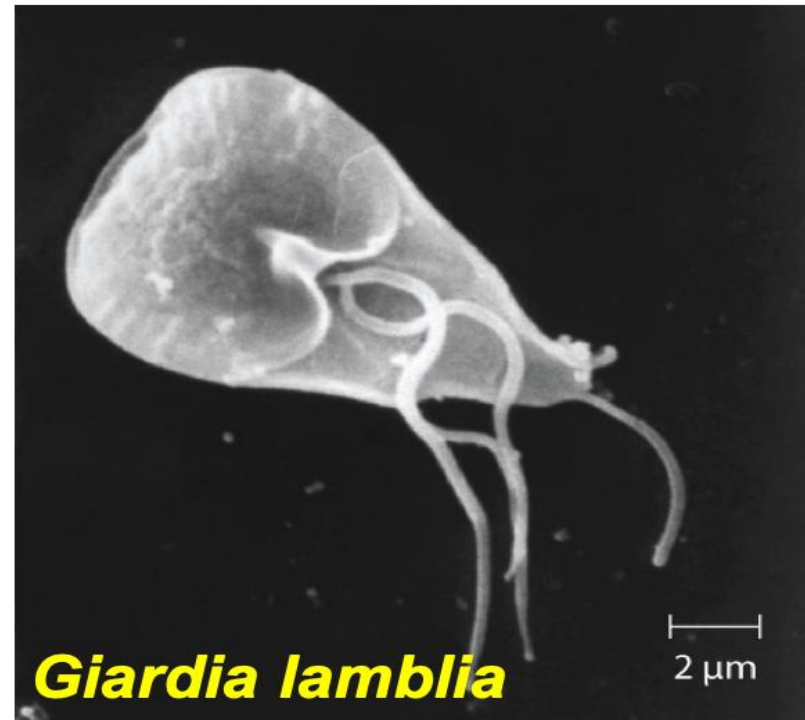
Algae

photosynthetic protists (“plant-like”)

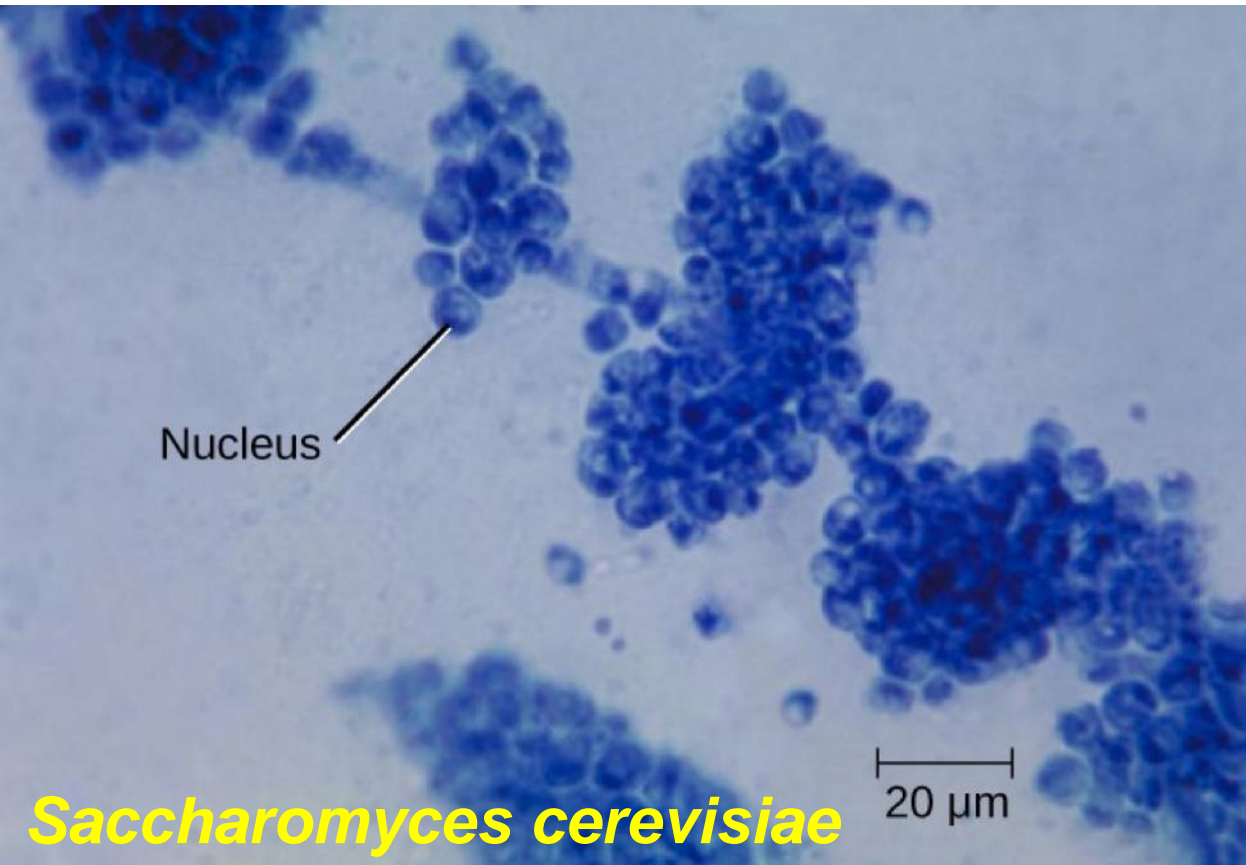


Protozoa

heterotrophic protists (“animal-like”)



Eukaryotes – Fungi



- All are eukaryotic heterotrophs with cell walls made of chitin
- Can be unicellular (yeasts) or multicellular (molds, mushrooms)
- Many are decomposers (saprobes) in nature; some are parasites or pathogens

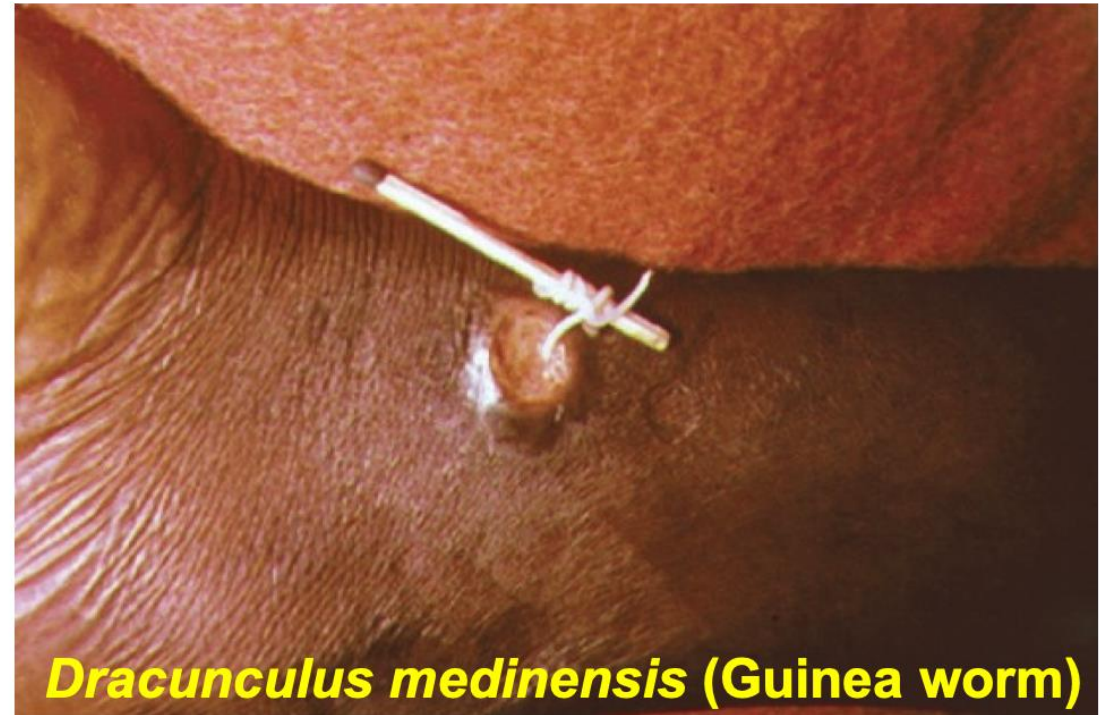
Eukaryotes – Helminths

Parasitic worms in the Animal Kingdom: Multicellular heterotrophs

Flatworms (*Platyhelminthes*)

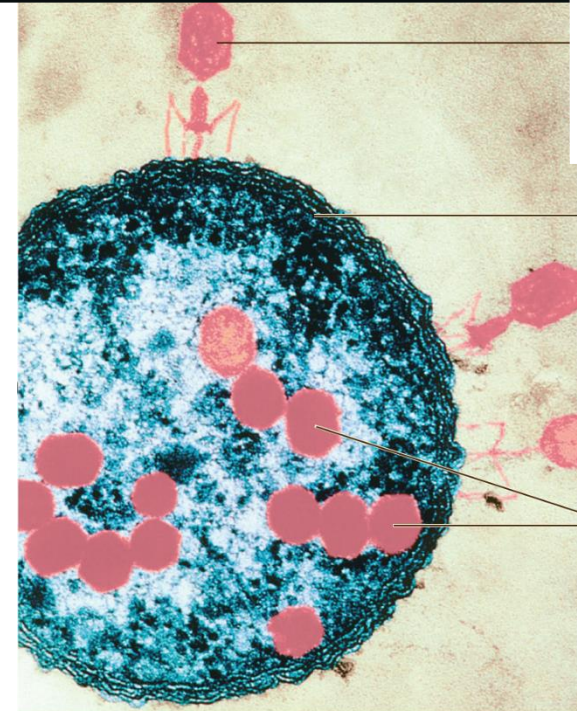
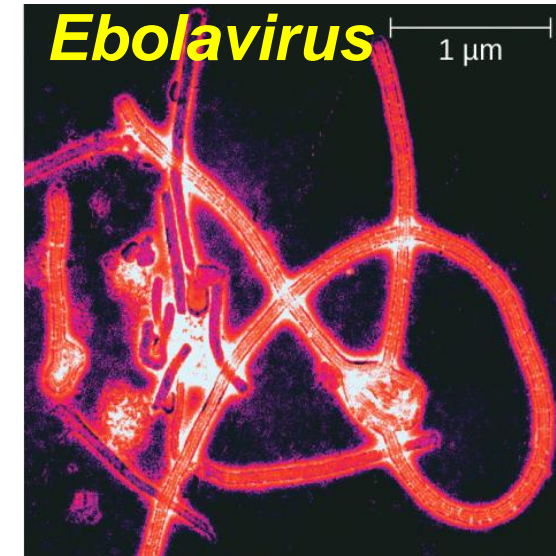
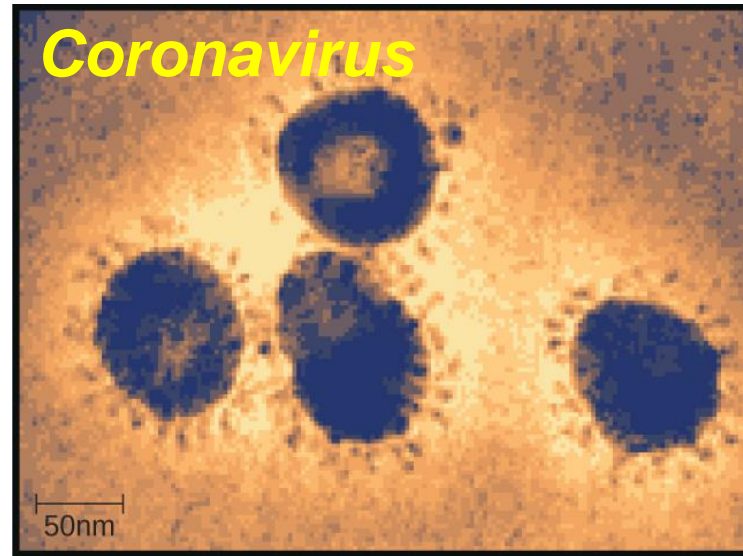


Roundworms (*Nematodes*)



Viruses

- Acellular infectious agents
- Obligate intracellular parasites:
Need a host cell to replicate
- Simple structure with two parts:
 - Protein capsid
 - Genetic material: DNA or RNA
 - Some viruses also have a lipid envelope
- Not considered living organisms



rus

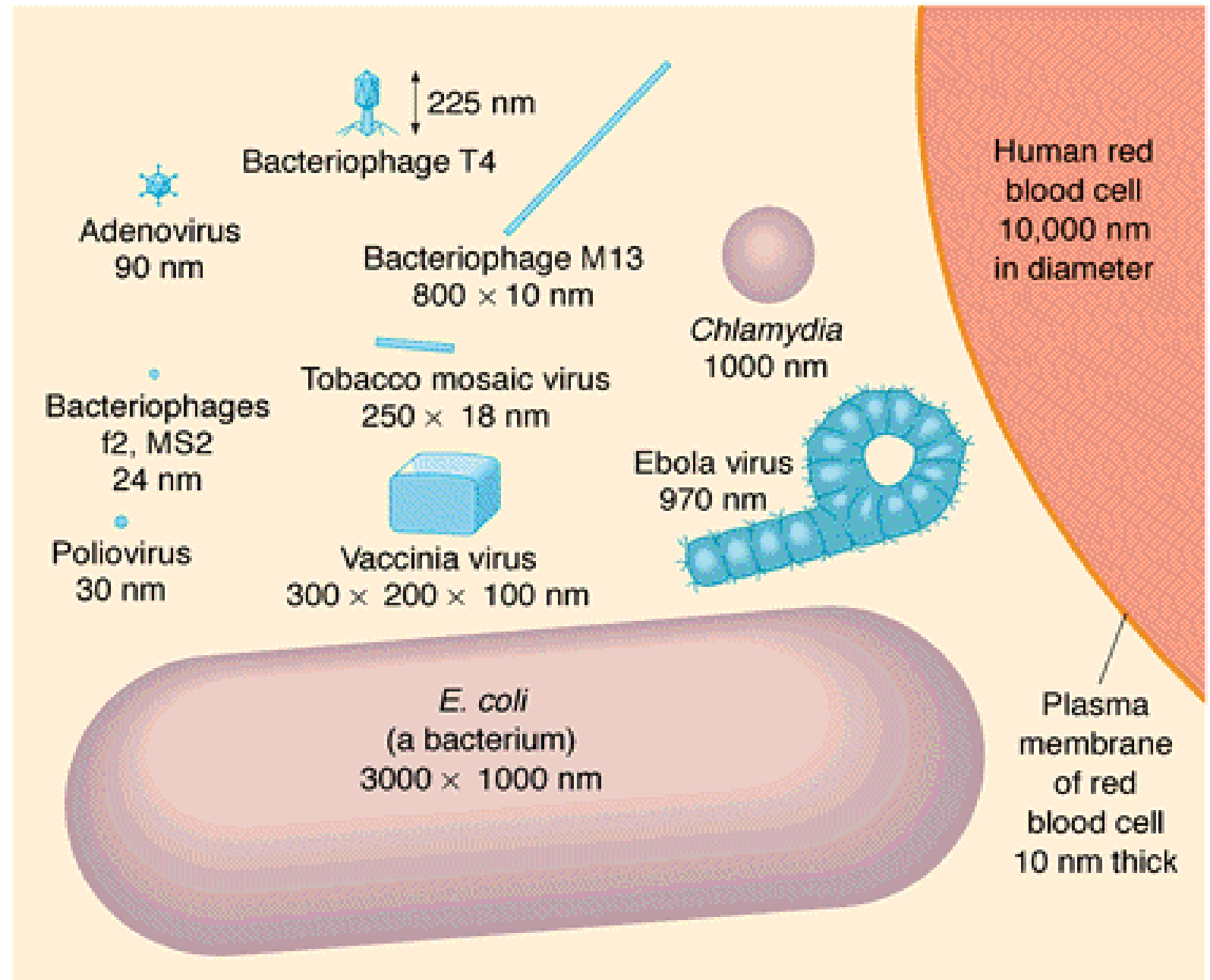
Bacterium

Viruses
assembling
inside cell

Viral
Infection of
Bacterial Cell

TEM 75 nm

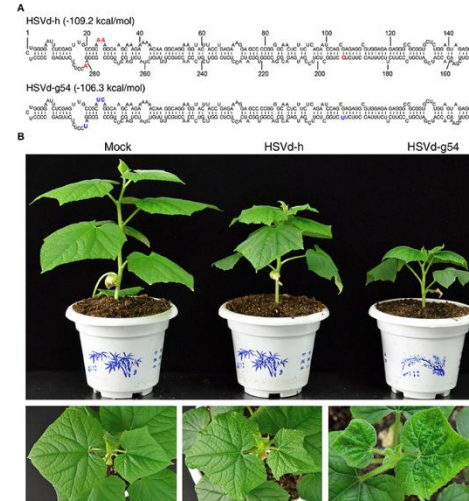
Size Comparison of Different Cells and Viruses



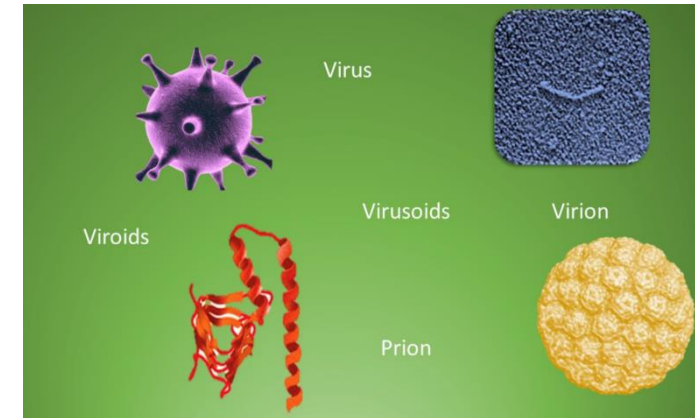
Other Acellular Infectious Agents: Viroids, Virusoids, and Prions

- **Viroids** are infectious RNA molecules that infect plants.
- **Virusoids** are infectious RNA molecules that also require a helper virus to replicate in host cell.
- **Prions** are infectious proteins that cause transmissible spongiform encephalopathies (TSEs), fatal neurological disorders in animals.
 - Mad Cow Disease
 - Scrapie
 - Fatal Familial Insomnia

Cucumber Viroids



Acellular Pathogens



Mad Cow Disease



Key Terms for Chapter 1

- Prokaryote
- Bacteria
- Archaea
- Eukaryote
- Fungi (yeasts, molds, mushrooms)
- Protists
- Algae
- Protozoa
- Helminths (flatworms, roundworms)
- Viruses
- Viroids
- Virusoids
- Prions
- Transmissible Spongiform Encephalopathies (TSEs)
- Hypoxia
- COPD: Chronic Obstructive Pulmonary Disease
- Bacillus, coccus, vibrio, spirochete, spirillum
- Kingdom
- Domain
- Nitrogen fixation
- Saprobe
- Microflora
- Dysbiosis
- Pathogen
- Morphology
- Arrangement
- Heterotroph
- Pandemic
- Fomite
- Decomposer
- Spontaneous generation versus Biogenesis
- Fermentation
- Pasteurization
- Germ Theory of Disease