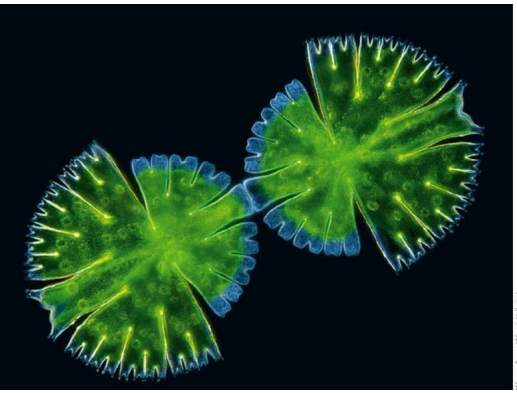
BCH1200
Discovery in Biology

Microbiology



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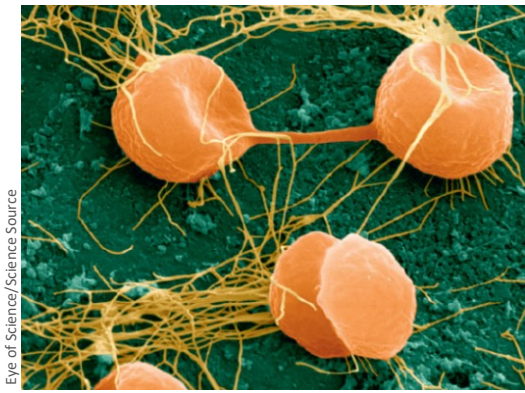
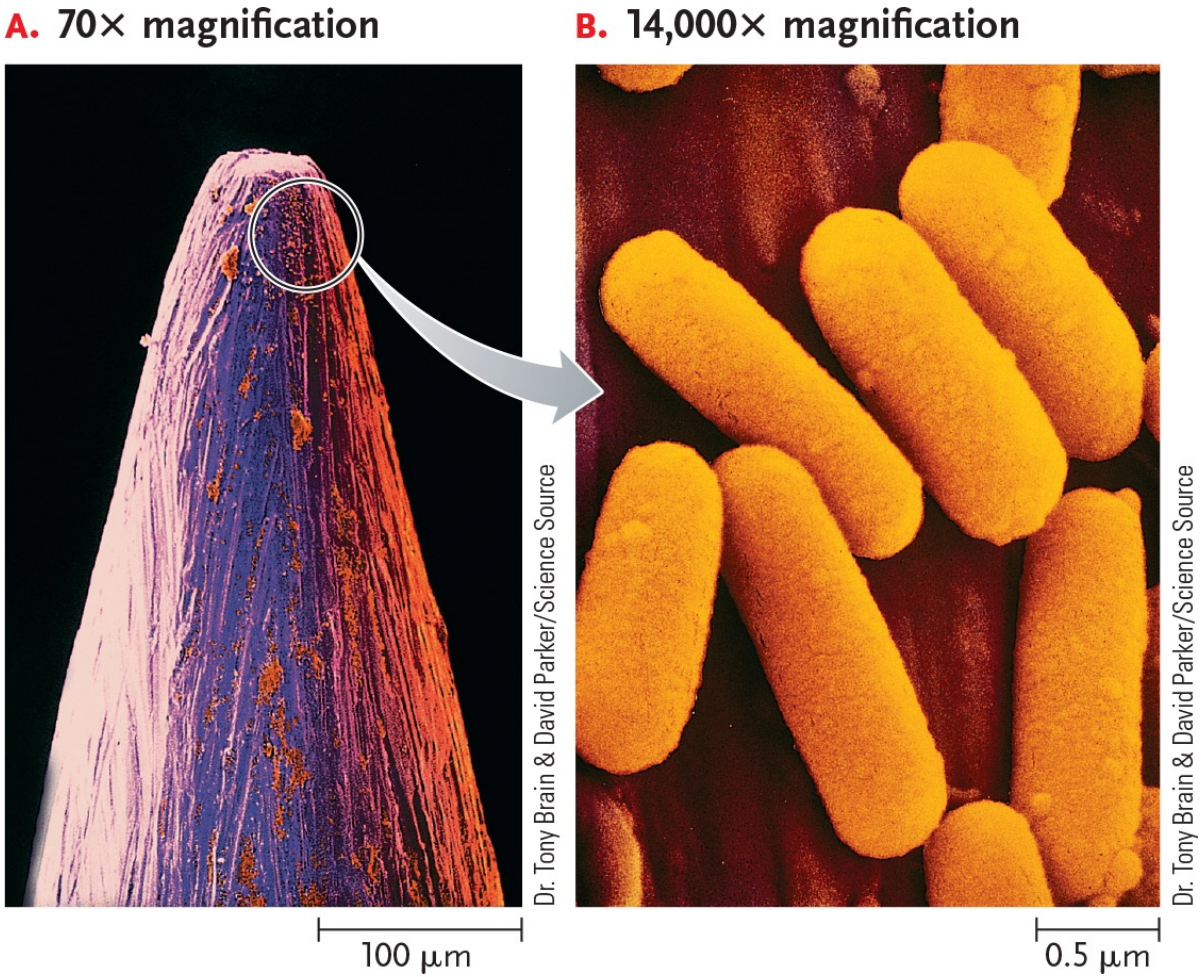


Are you happy to see these fungi??

Fungi have provided many pharmaceutical drugs!

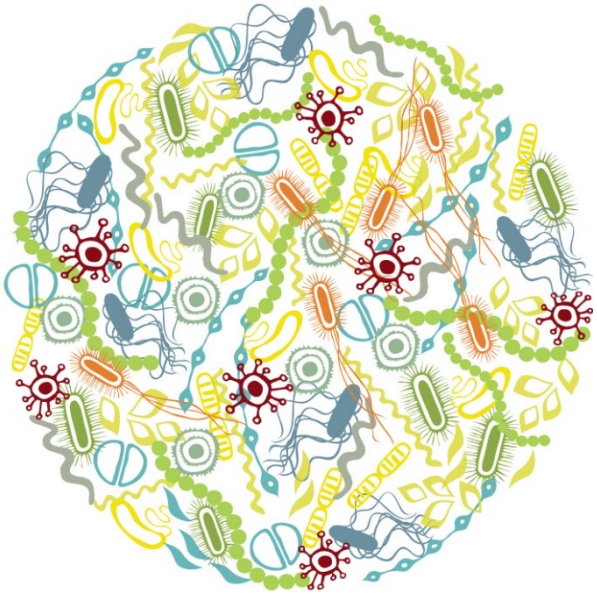
We have a long history with fungi in food productions!

What are these rods?



Content

1. **General features of microbes**
   a) How small are microbes?
   b) Where can you find microbes?
   c) What are their common characteristics?
2. **Different types of microbes**
   a) Viruses
   b) Bacteria
   c) Archaea
   d) Protists
   e) Fungi
3. **Microbial associations**



Intended Learning Outcomes (ILOs)

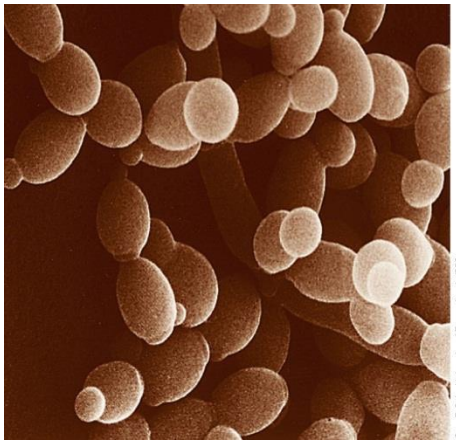
- At the end of this lecture, you should be able to:

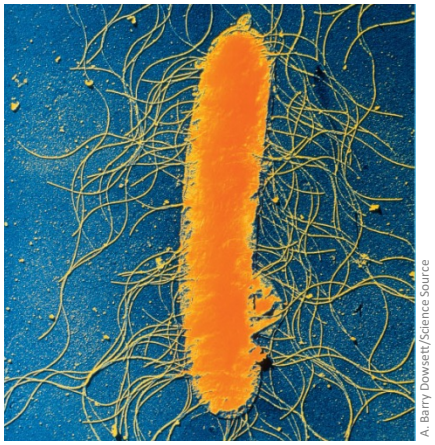
1. describe and **differentiate the major members** of the microbial world.

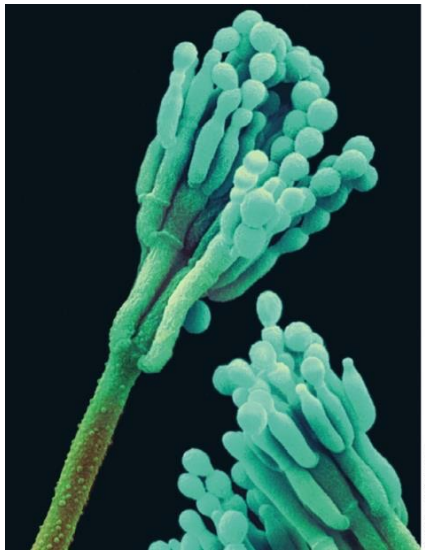
2. apply the knowledge of the basic biology of different groups of microbes and **explain microbial-related events** in our environment

The Microbes: General Features

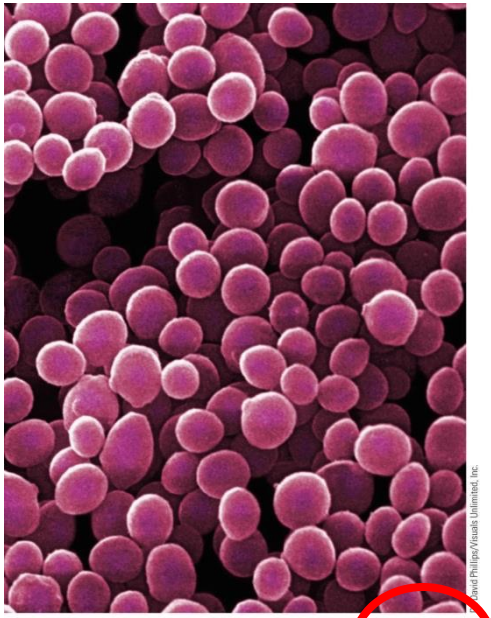
- **Organisms that cannot be seen by our naked eyes**
- Usual range : 0.1 – 1000 µm
- Found everywhere
- The earliest life form
- Characteristics of LIFE
- Harmful AND beneficial





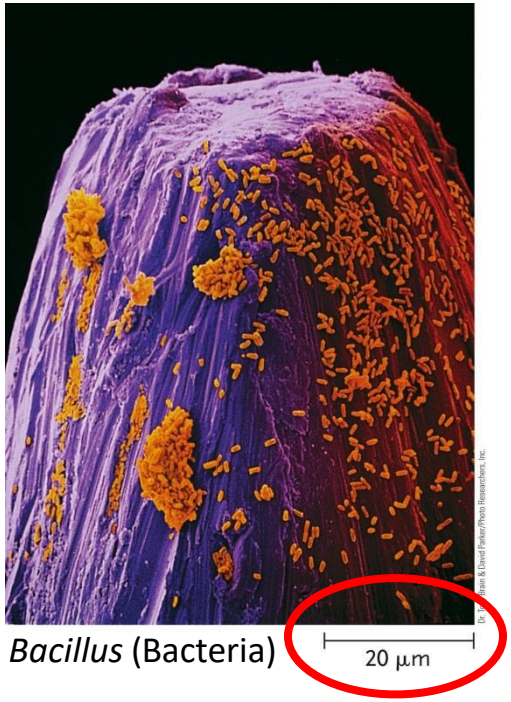


How small are microbes?



Micrococcus (Bacteria)

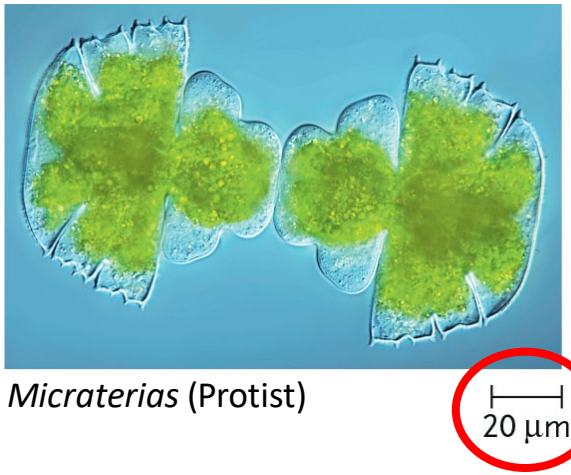
Methanosarcina (Archaea)



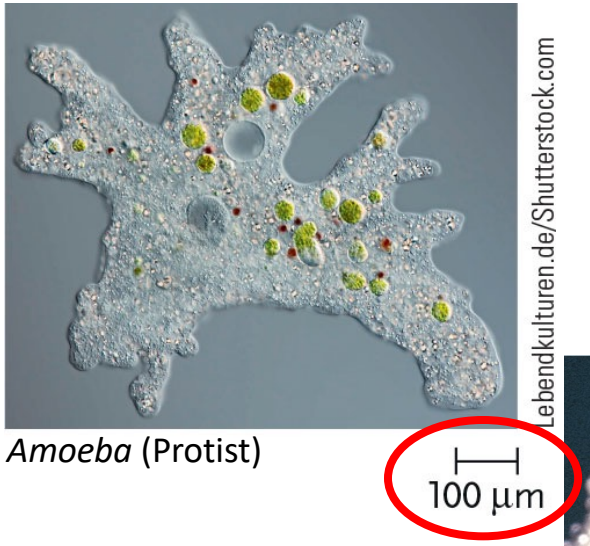
Bacillus (Bacteria)

1 micrometer = ? millimeter

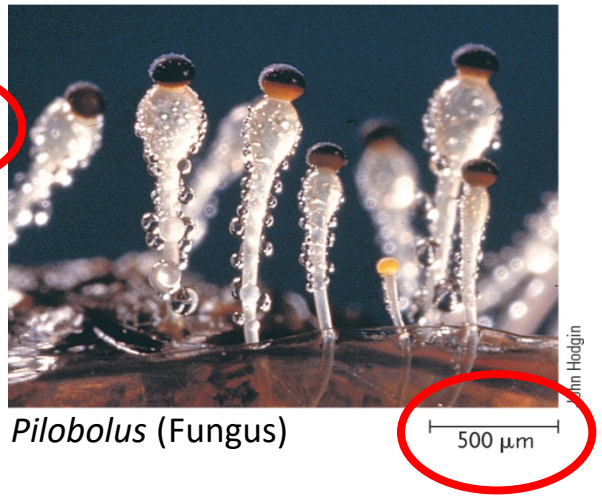
How small are microbes?



Micraterias (Protist)

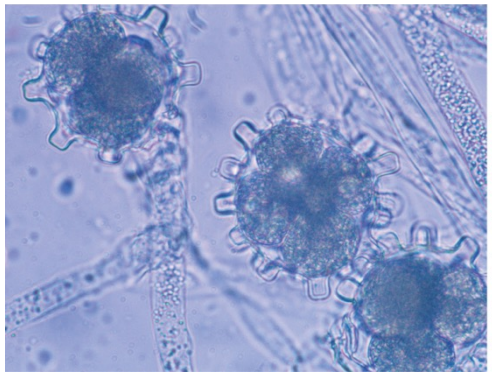


Amoeba (Protist)

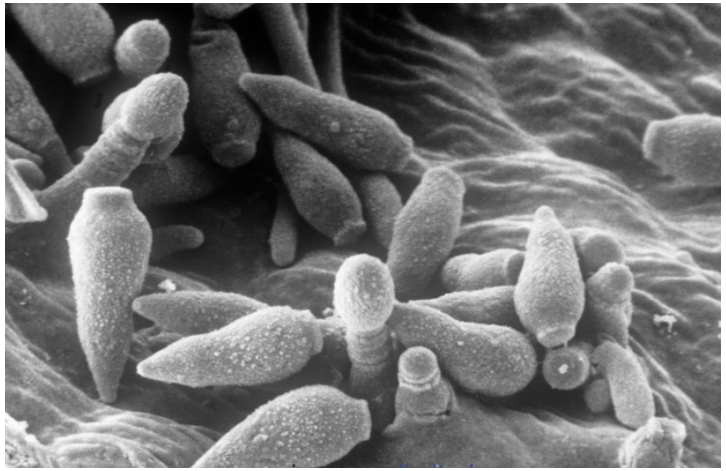


Pilobolus (Fungus)

How small are microbes?

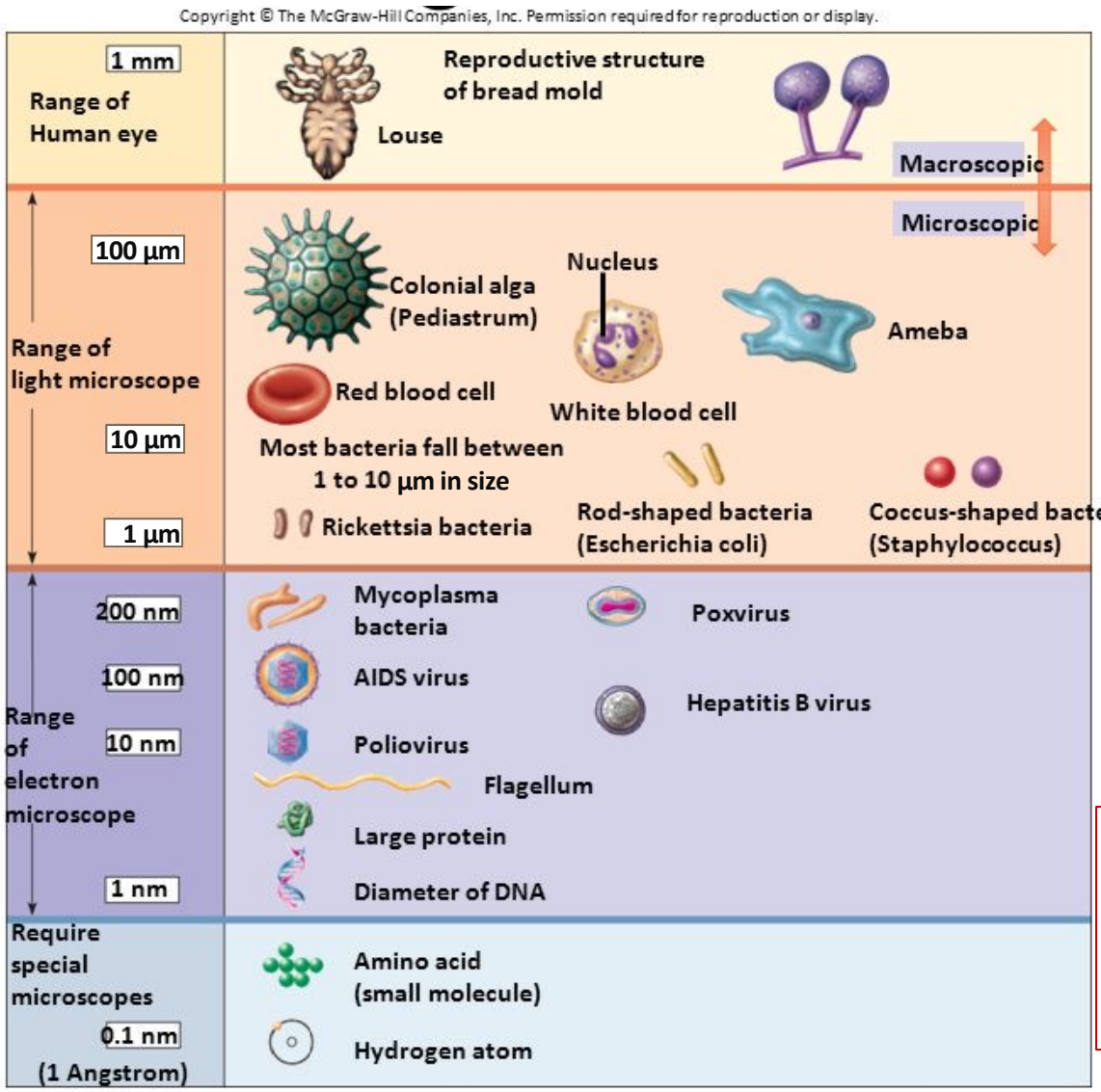


Water mold, a protist infecting fish



Venturia inequalis, a fungus causing apple scab

Comparative size of microbes



Fungi & Protists

Bacteria & Archaea

Viruses

Viruses are normally considered not to be living, but studied in the field of microbiology

Where can you find microbes?

- **Microbes are everywhere!**
  - Air
  - Soil
  - Aquatic systems
  - **On the surface AND inside living organisms**
  - **Extreme habitats** that no other lives can survive
    - e.g. Dead Sea, hot springs

Presence of bacteria in the air

- **Airborne diseases** transmitted through aerosols
  - e.g. Legionnaires' disease, tuberculosis

Presence of fungi in the air

- Different molds release powdery spores that are easily dispersed by air current

A. Sporangia of *Rhizopus stolonifer*

J. D. Cunningham/Visuals Unlimited

Presence of fungi in the air

CFU: colony forming unit

Table 2 Profile of airborne fungi in the air-conditioned offices and outdoor environment of Hong Kong

Fungal genus and species	Indoor ($N=82$)				Outdoor ($N=26$)				I/O ratio
	Distribution (%)		Count[a] (CFU m^{-3})		Distribution (%)		Count[a] (CFU m^{-3})		
	OF	RA	Range	AM (ASD)	OF	RA	Range	AM (ASD)	AM (ASD)
Total	97.6	-	2–92	29(22)	100	-	20–212	94(47)	0.5(0.5)
Arithinium	11.0	3.6	2–20	10(6)	42.3	1.5	2–8	3(2)	0.2(0.8)
Total *Aspergillus*	50.0	28.5	2–70	16(16)	88.5	13.3	2–36	14(9)	1.0(2.1)
A. caespitosus	4.9	0.4	2–4	3(1)	30.8	1.6	2–8	5(3)	0.1(0.5)
A. flavus	9.8	3.8	2–54	11(18)	26.9	1.7	2–16	6(5)	0.2(0.6)[b]
A. japonicus	1.2	0.1	2	2(0)	30.8	2.6	2–18	8(7)	
A. niger	18.3	6.1	2–30	10(8)	42.3	2.9	2–16	7(6)	0.5(1.4)[b]
A. nivens	8.5	2.0	2–20	7(7)	23.1	1.2	2–14	5(5)	

Mui et al. (2010) Building Serv. Eng. Res. Technol. 31, 191-199

Different requirements for growth

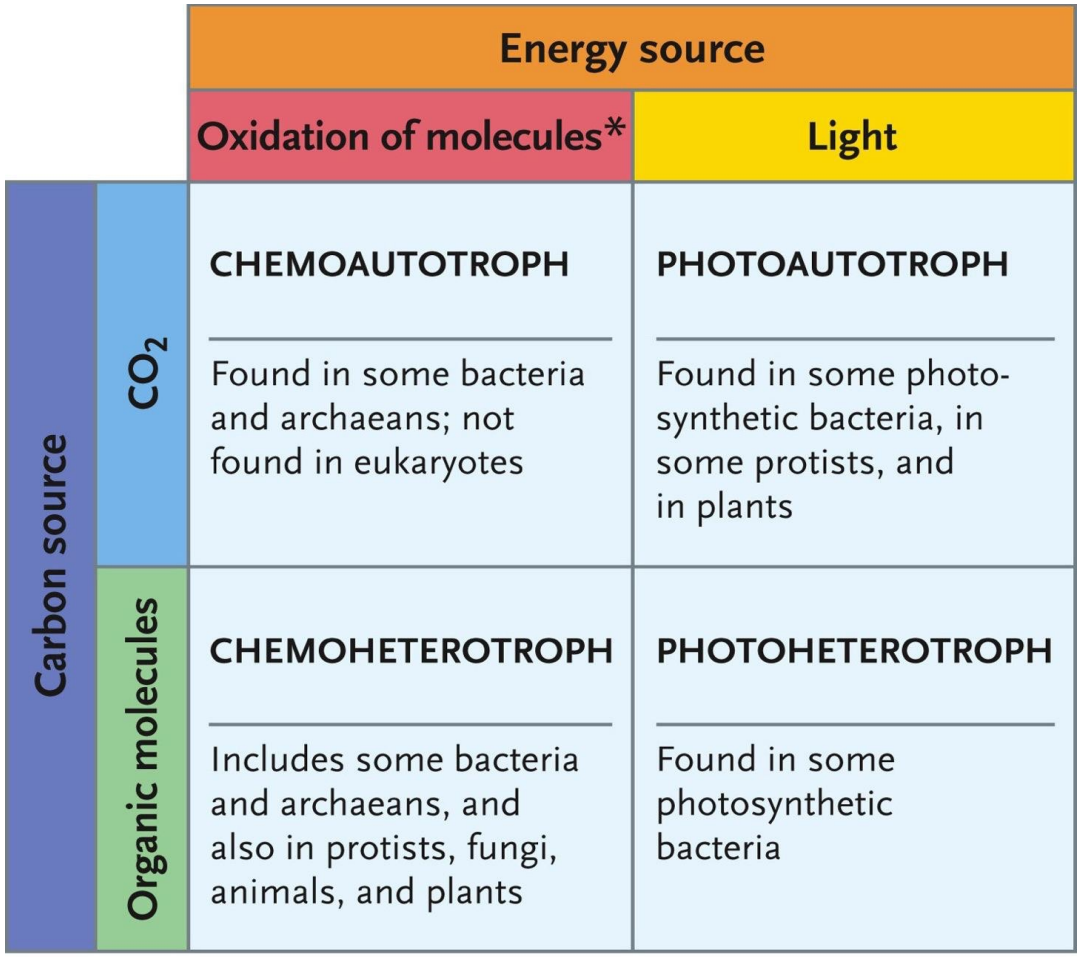
1. Energy & carbon sources
2. Water availability
3. Presence of oxygen
4. Temperature range

Energy and carbon sources

- Two sources of **energy**
  - **Phototrophs** obtain energy from sunlight
  - **Chemotrophs** obtain energy through oxidizing inorganic or organic substances

- Two sources of **carbon**
  - **Autotrophs** obtain carbon from inorganic molecules e.g. CO_2
  - **Heterotrophs** obtain carbon from organic molecules

Mode of nutrition



Carbon source	Energy source: Oxidation of molecules*	Energy source: Light
CO_2	**CHEMOAUTOTROPH** Found in some bacteria and archaeans; not found in eukaryotes	**PHOTOAUTOTROPH** Found in some photosynthetic bacteria, in some protists, and in plants
Organic molecules	**CHEMOHETEROTROPH** Includes some bacteria and archaeans, and also in protists, fungi, animals, and plants	**PHOTOHETEROTROPH** Found in some photosynthetic bacteria

*Inorganic molecules for chemoautotrophs and organic molecules for chemoheterotrophs.

→ Bacteria with the most diverse nutrition mode

Other growth requirements

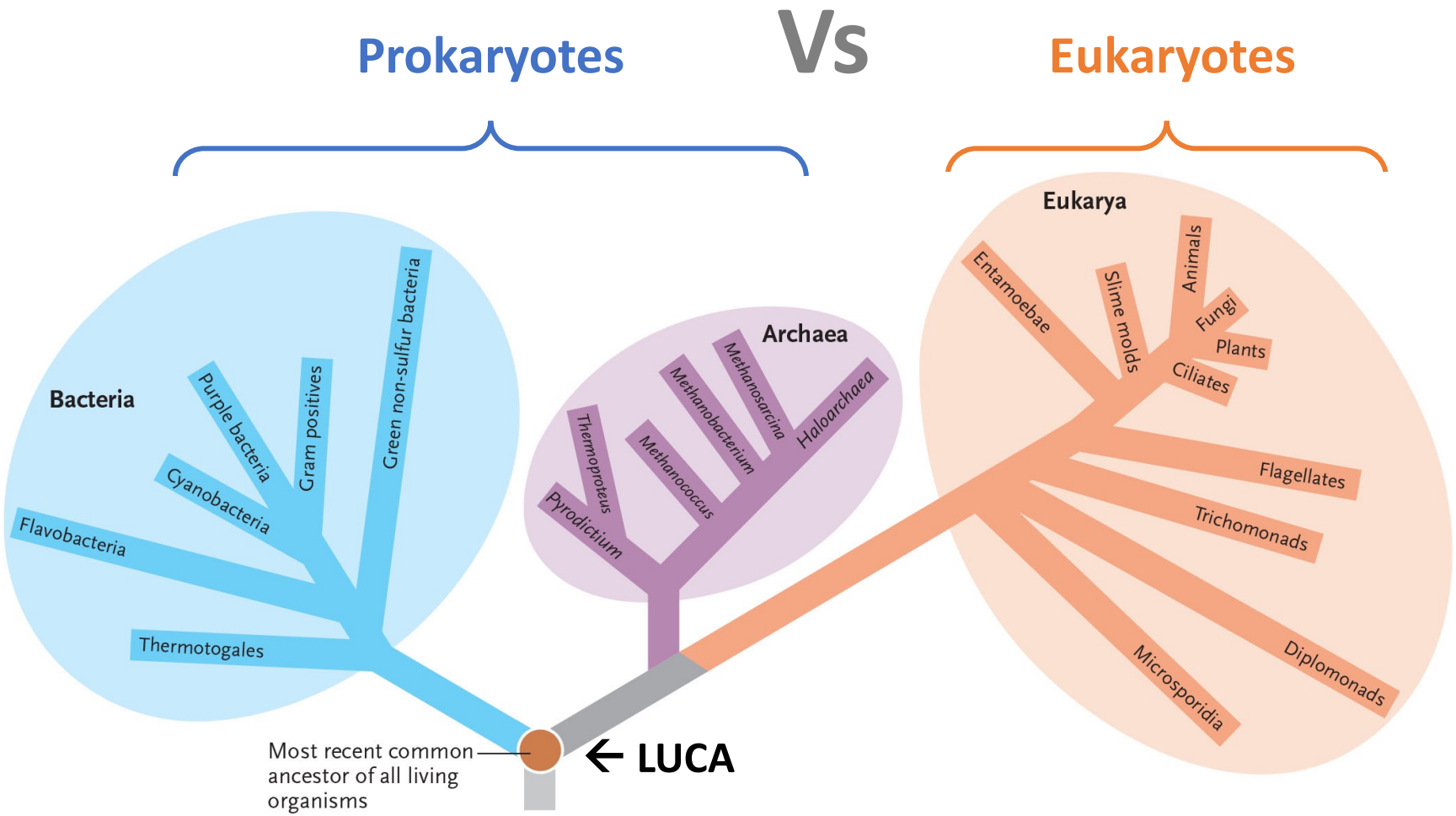
- Water
  - **All organisms require water**
  - Fungi are more tolerant of dryness
- Oxygen
  - **Mostly require oxygen (Aerobes)**
  - Some archaea and bacteria do not need oxygen (**Anaerobes)**, e.g. anaerobic bacterium *Clostridium tetani*
  - **Obligate or facultative?**
- Temperature
  - Mostly at moderate temperature between 20°C to 45°C
  - Many archaea and bacteria tolerate extreme temperatures, e.g. in Arctic oceans and thermal vents

What are their common characteristics?

- Obtain energy from surrounding environment
- Use energy to maintain itself, grow, and reproduce
- Excrete wastes
- Sense and respond to changes in the environment
- Can change (e.g. through genetic mutation) to adapt to environmental changes

Different Types of Microbes

Three domains of life

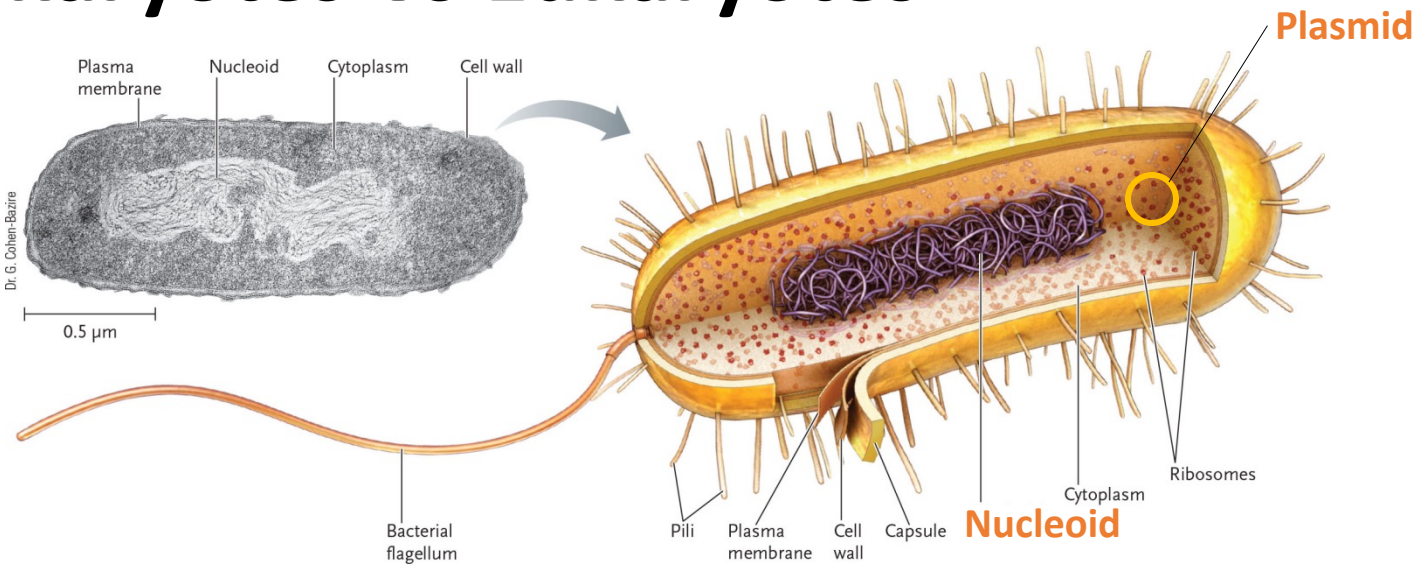


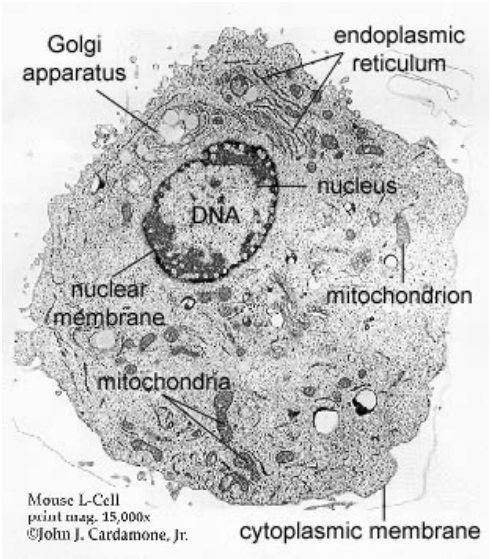
Cengage Learning (2017)

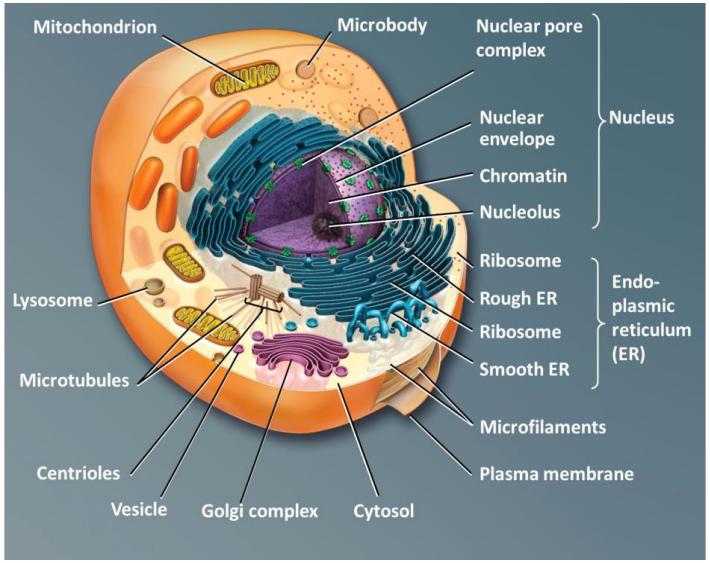
Prokaryotes vs. Eukaryotes

Word	Meaning in Greek
Pro	Before
Eu	True
Karyon	Nucleus

Prokaryotes Vs Eukaryotes

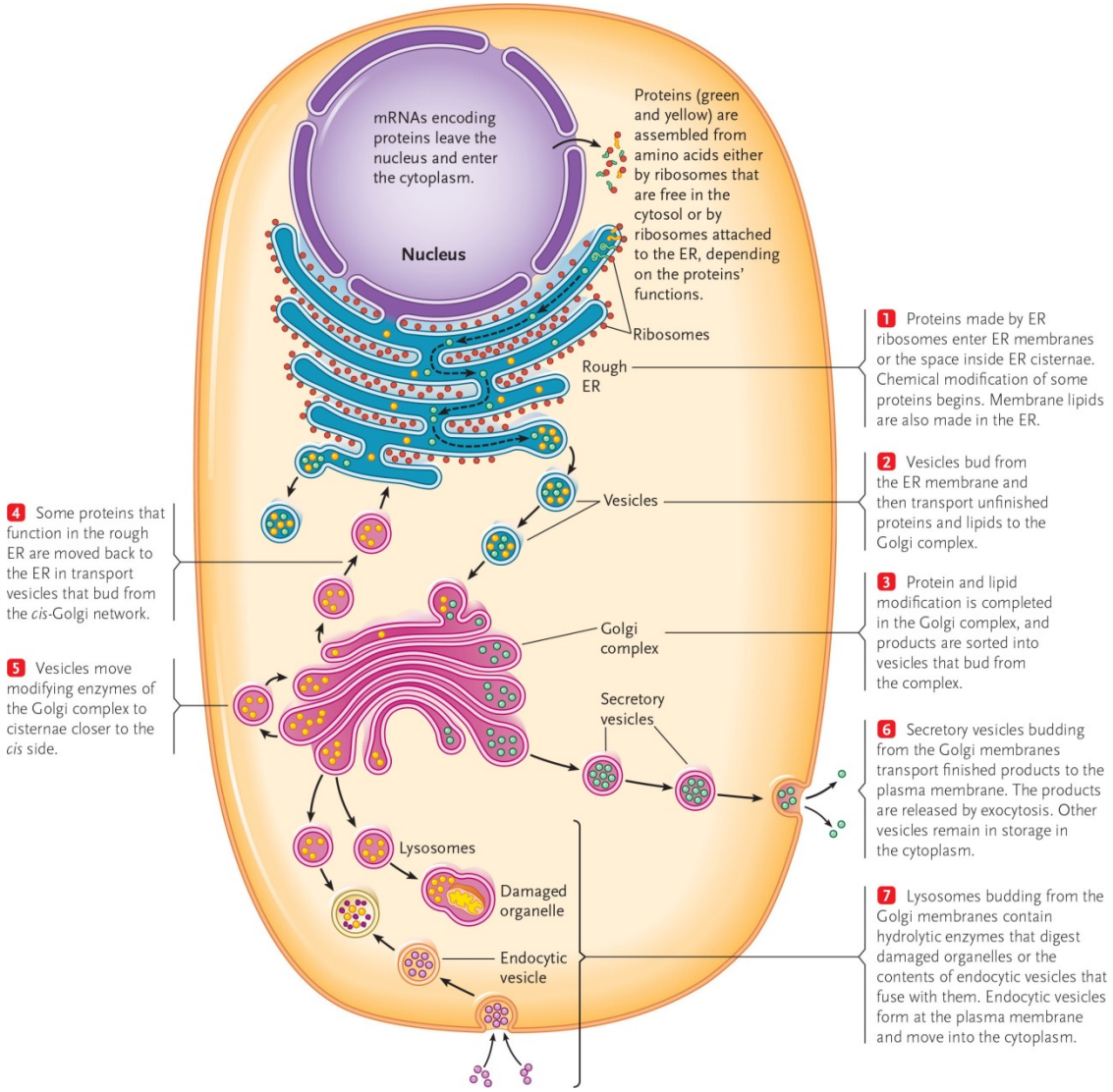






Cengage Learning (2017)

Membrane-bound organelles in eukaryotes



Cengage Learning (2017)

Prokaryotes Vs Eukaryotes: Major differences

	Prokaryotes	Eukaryotes
Cell	Always unicellular	Often multicellular
Cell size	Smaller (usually <5 µm)	Larger (usually >10 µm)
Nucleus and other membrane-bound organelles	Absent	Present
DNA	Mostly single & circular	Multiple linear molecules
Ribosomes	Smaller (70S)	Larger (80S)
Reproduction	Always asexual by binary fission	Asexual or sexual, by mitosis or meiosis
Metabolic diversity	Greater	Less diverse

No niches or ecosystem that prokaryotes are absent

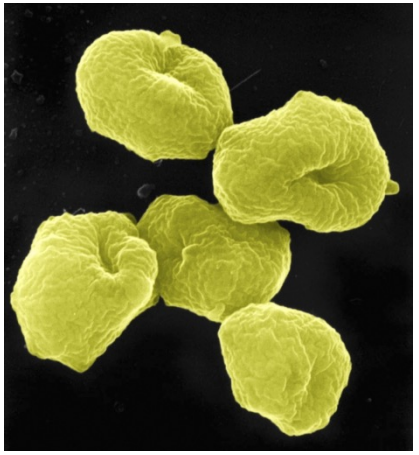
BiologyMad (2018)

5 types of microbes

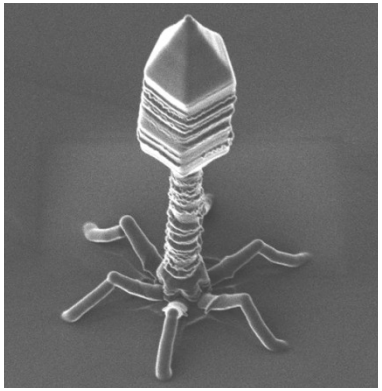
1. **(Viruses)**
2. Prokaryotes: Bacteria
3. Prokaryotes: Archaea
4. Eukaryotes: Protists
5. Eukaryotes: Fungi


Janice Haney Carr

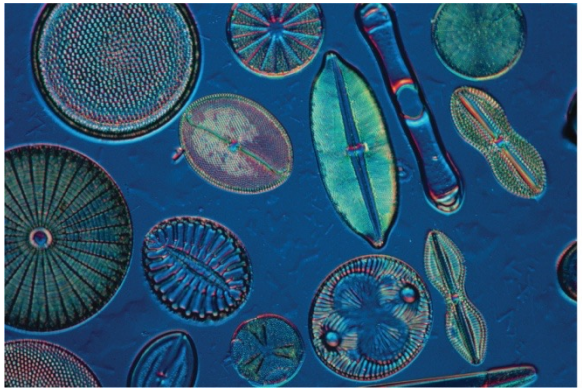
Bacterial cluster


Microbiology Society (2018)

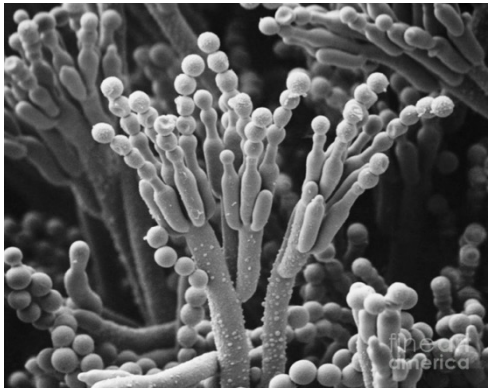
Irregular-shaped archaea


Kometani & Matsui (2005)

Complex virus


Jan Hinsch/Science Source

Diatoms, examples of protist


Biophoto Associations (2014)

Fungal asci with spores

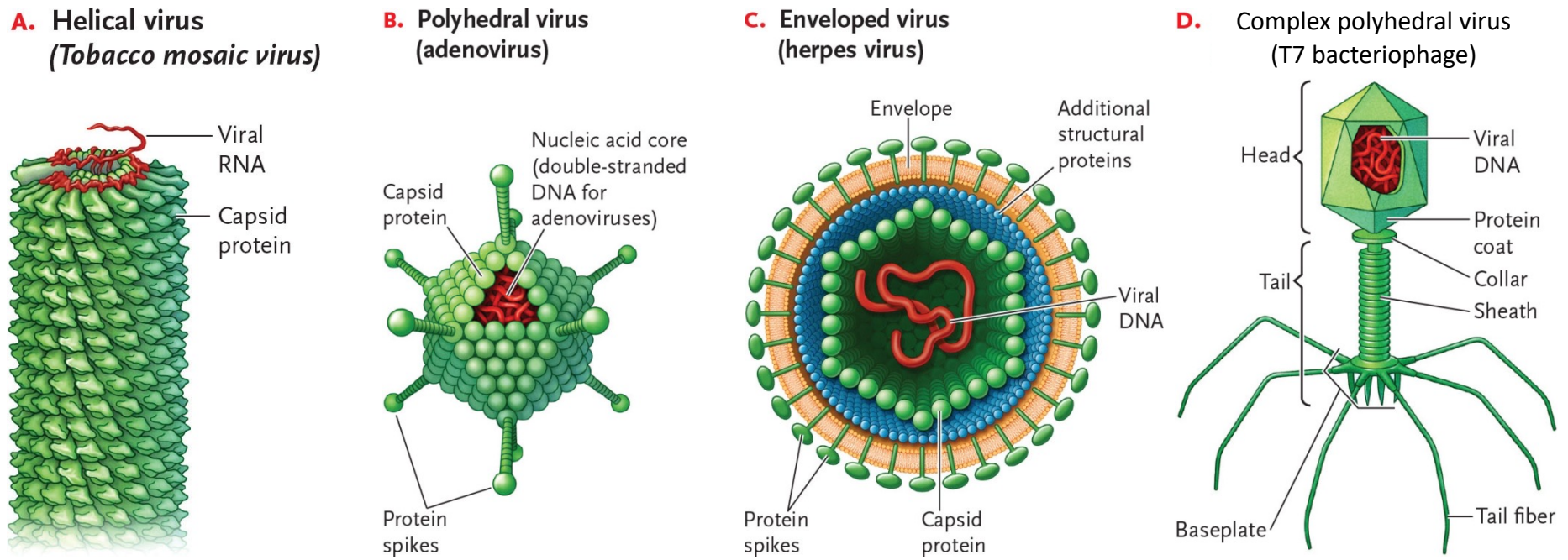
Viruses

- **Biological particle** that infects cells of a living organism
- ds/ss DNA/RNA genome surrounded by protein coat
- Mostly 20 – 400 nm (Vs 200 – 10000 nm for bacteria)

➔ **Living organisms??**

- Similar chemical constituents, BUT:
- **Not made up of cells**
- Do not grow, develop or generate metabolic energy
- Cannot reproduce independently

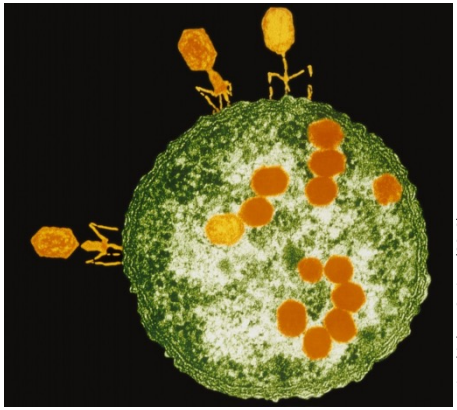
Viruses: Basic structures



- The basic structure of a virus is a particle composed of a viral nucleic acid at the center of the particle and a protein shell called a capsid that surrounds it.
- The size ranges from tens of nanometers for small ones to hundreds of nanometers for large ones.
- A combination of viral nucleic acid and capsid is called a nucleocapsid.

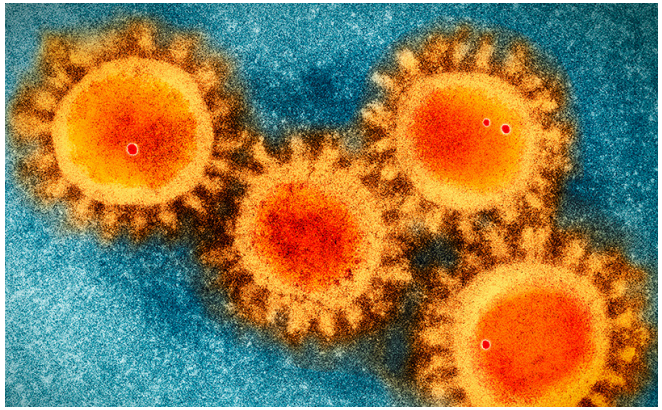
Viruses: Replication within a host

- Replicate ONLY in **living cells**
- Infect bacteria, plants, and animals



T2 bacteriophage

Cucumber mosaic virus



SARS-CoV2 coronavirus

- Take over the host machinery to replicate itself
- Often burst and kill the host

Viruses: All our enemies?

- **Many have detrimental effects**
  - Viral diseases e.g. COVID-19! AIDS, SARS, avian flu, Ebola, Zika, etc.
  - Some help bacteria evade the host's immune system
  - Difficult to treat: **Not cured by antibiotics**

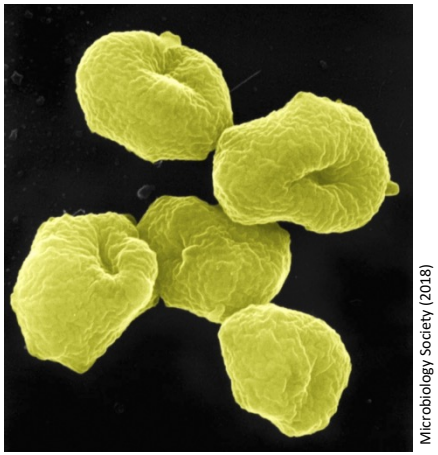
- Beneficial uses??
  - Vaccine production
  - Gene therapy
  - Cancer therapy
  - Provide immunity against bacterial pathogens[1]
  - Render some plants drought or cold tolerant[1]

1) American Society For Microbiology (2015)

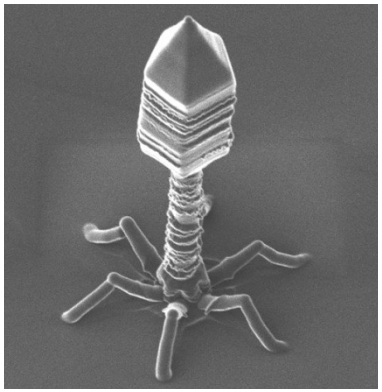
5 types of microbes

1. (Viruses)
2. **Prokaryotes: Bacteria**
3. Prokaryotes: Archaea
4. Eukaryotes: Protists
5. Eukaryotes: Fungi

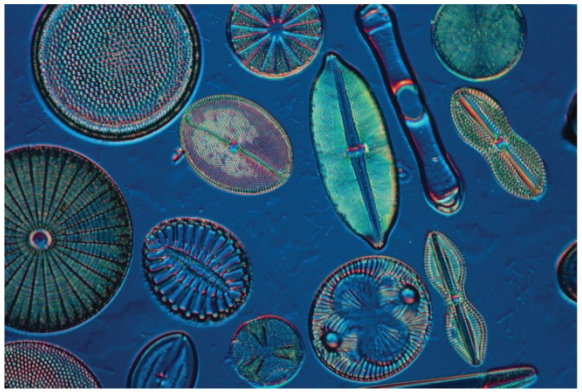
Bacterial cluster



Irregular-shaped archaea



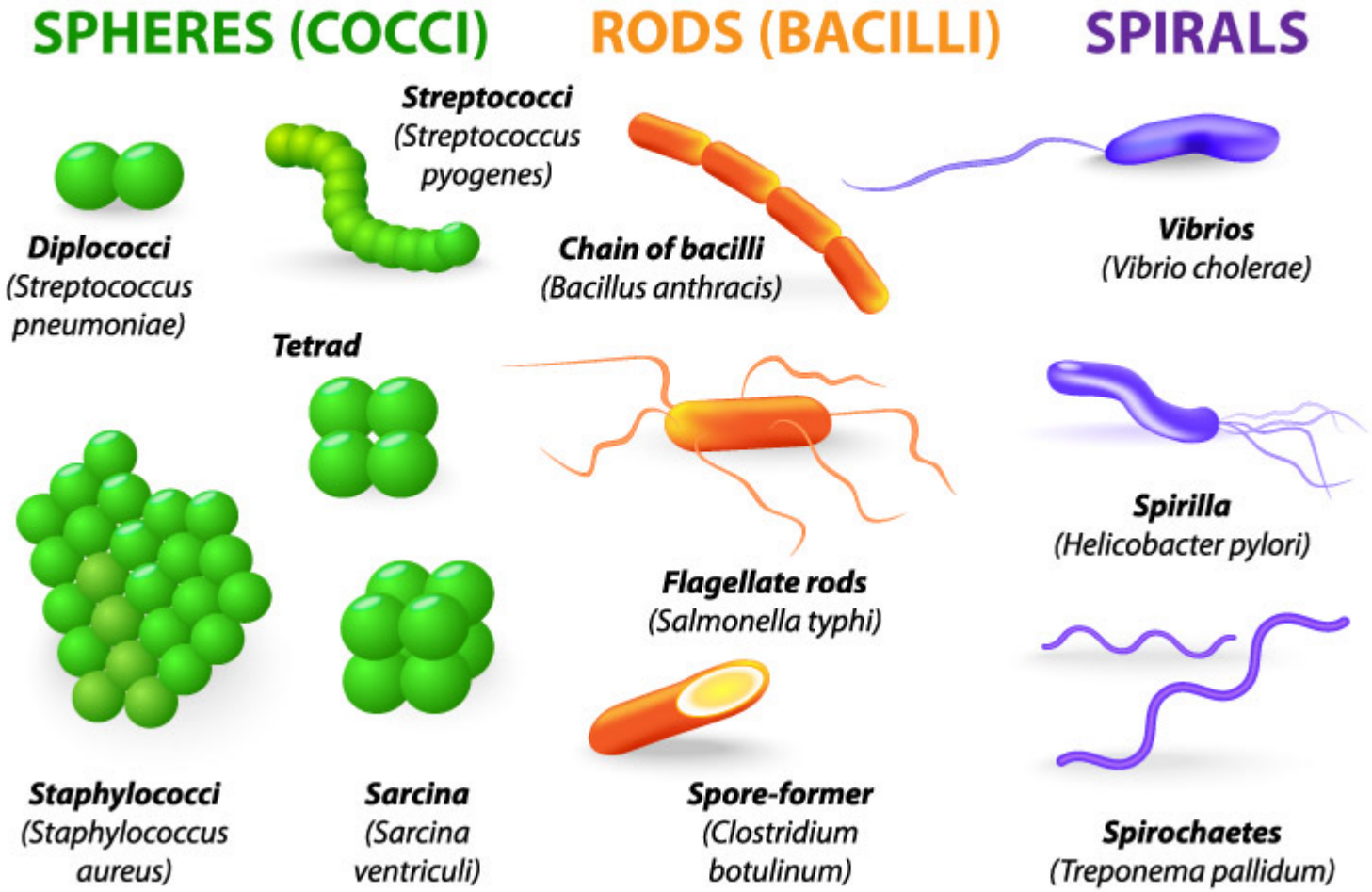
Complex virus



Diatoms, examples of protist

Fungal asci with spores

Bacteria: Common shapes



LaboratoryInfo (2015)

Bacteria: Cocci

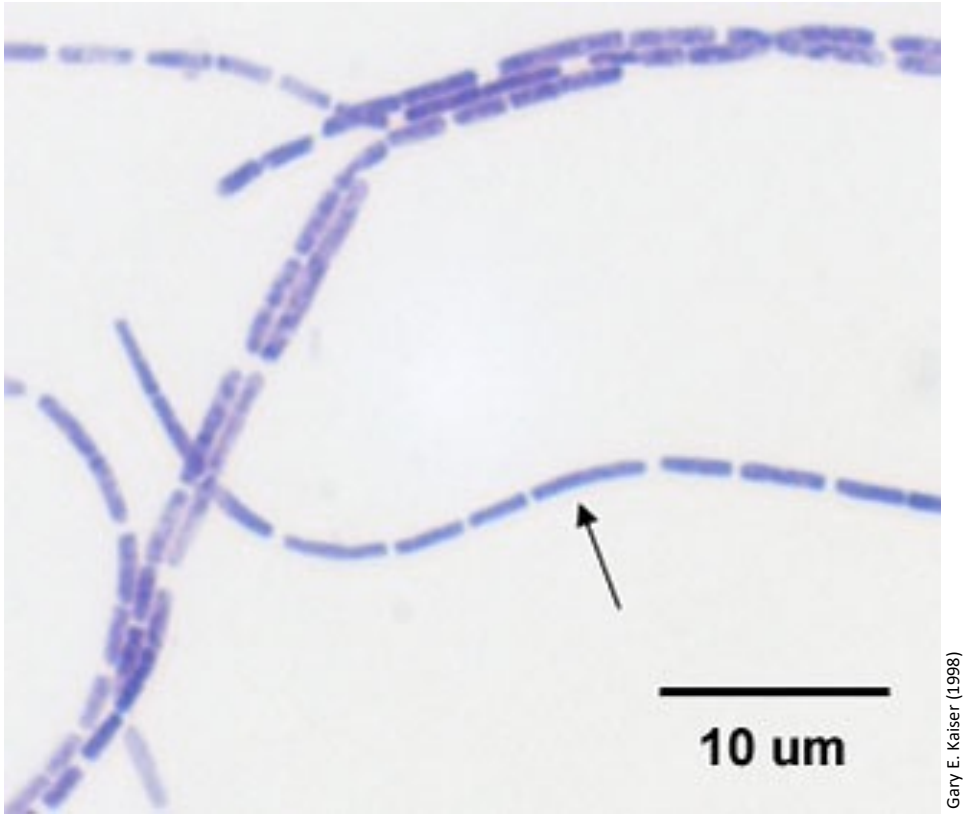
Streptococcus

Micrococcus

Bacteria: Bacilli

Dr. David Phillips/Visuals Unlimited, Inc.

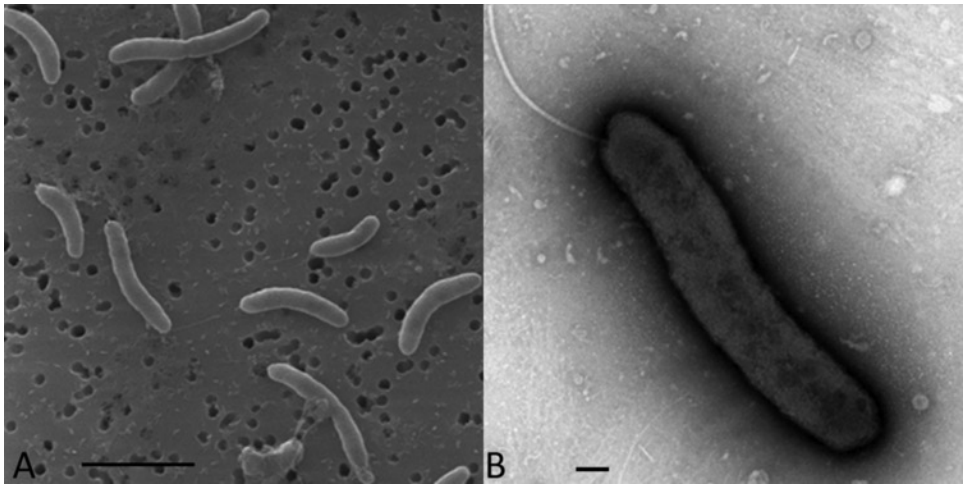
Salmonella



Gary E. Kaiser (1998)

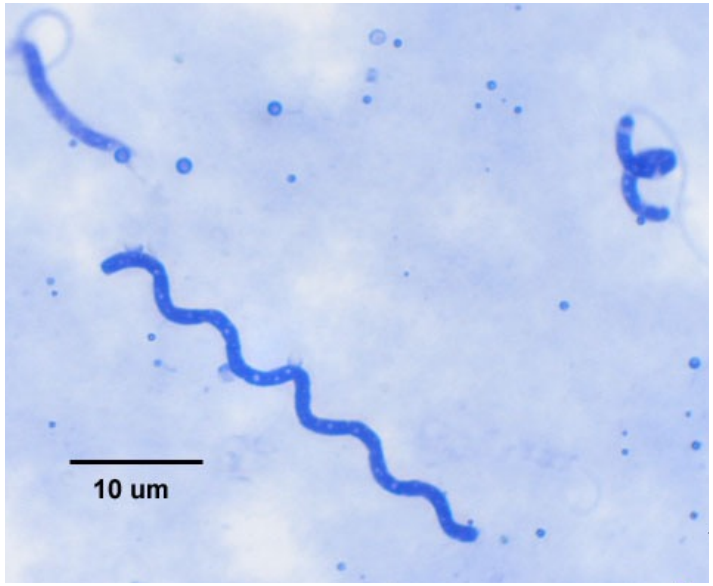
Streptobacillus

Bacteria: Vibrios and spirilla



Kirchberger et al. (2014)

Vibrio metoecus



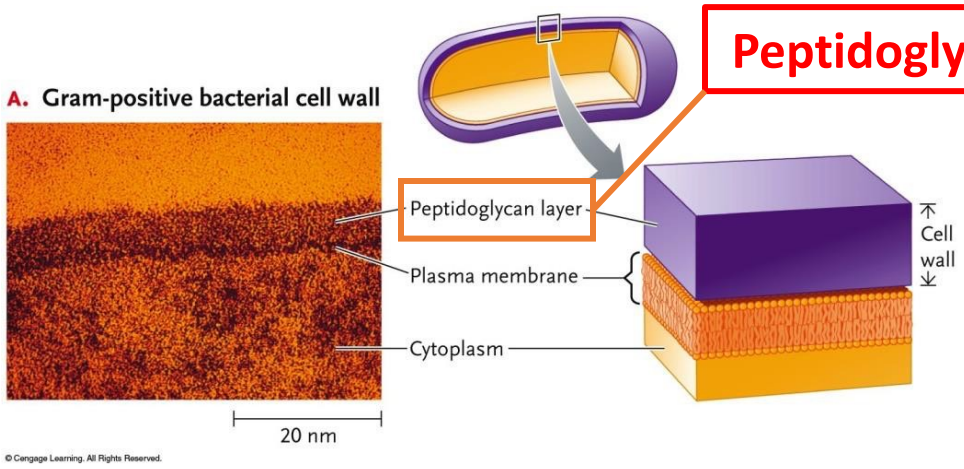
Gary E. Kaiser (2017)

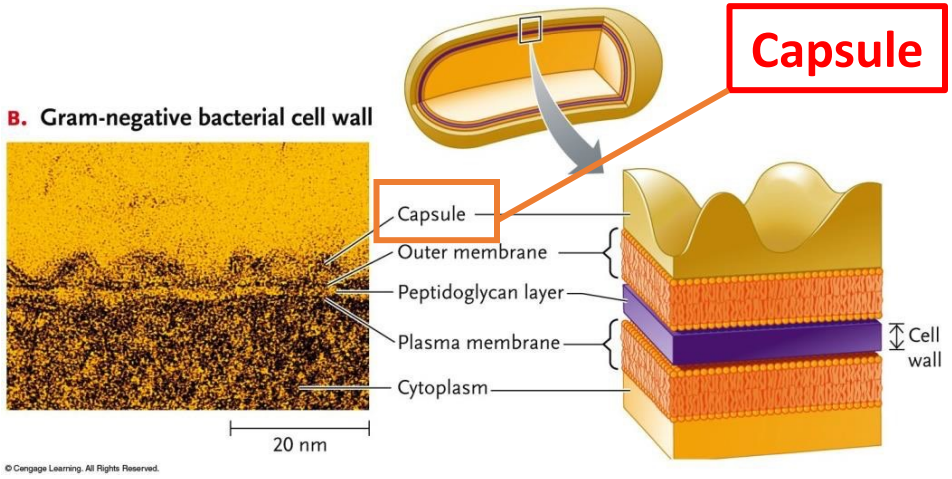
Spirillum

Bacteria: Special features

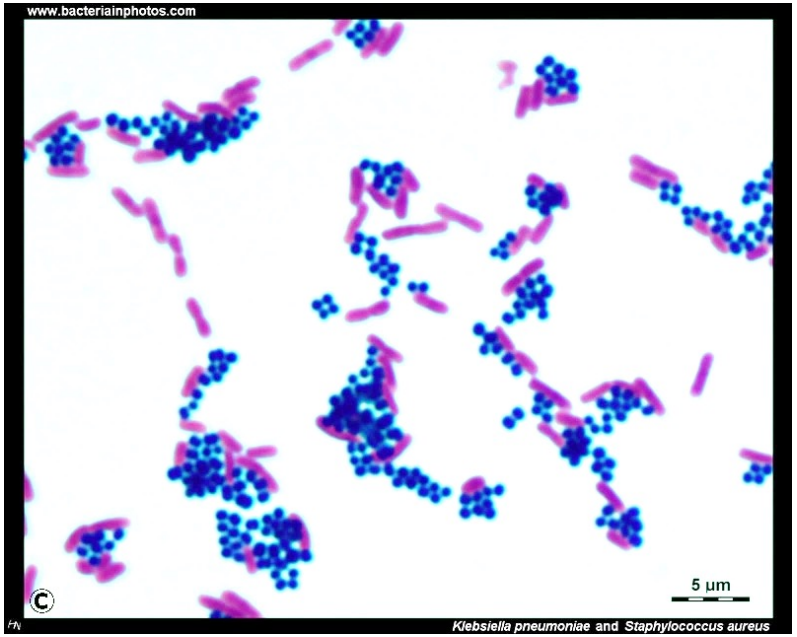
- Various features contribute to the success of bacteria
  - Cell wall
  - Slime layer or capsule
  - Flagella and pili
  - Rapid reproduction
  - Great genetic variability
  - Endospore

Bacteria: Cell wall





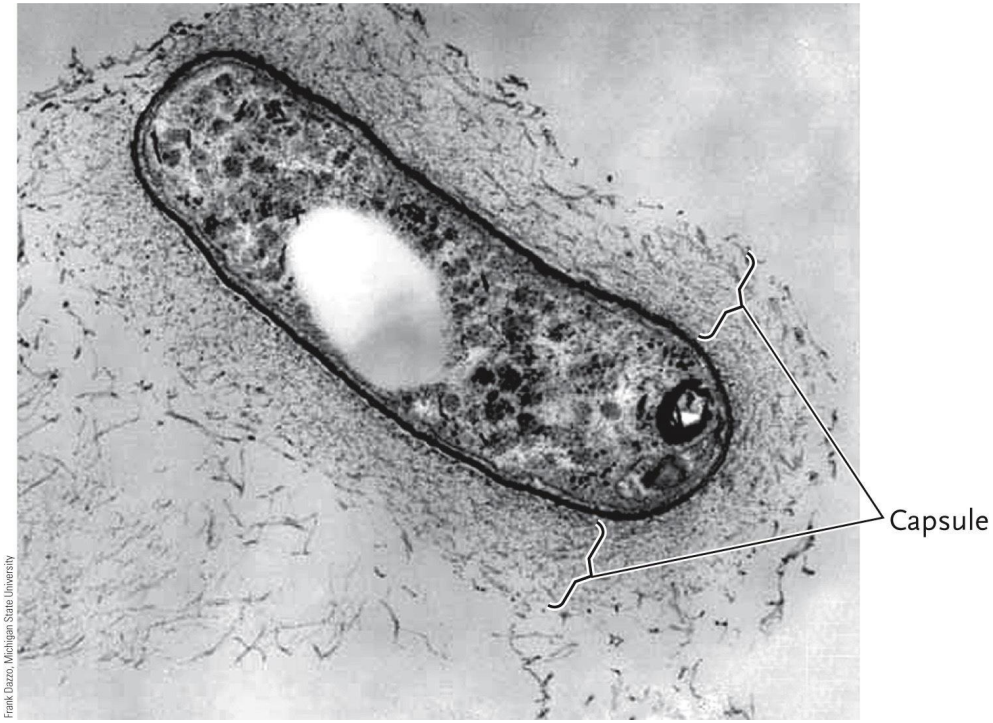
Gram staining



→ Outer membrane: **phospholipids** and **lipopolysaccharide (LPS)**

- Most pathogens are Gram-negative
- Antibiotics are less effective

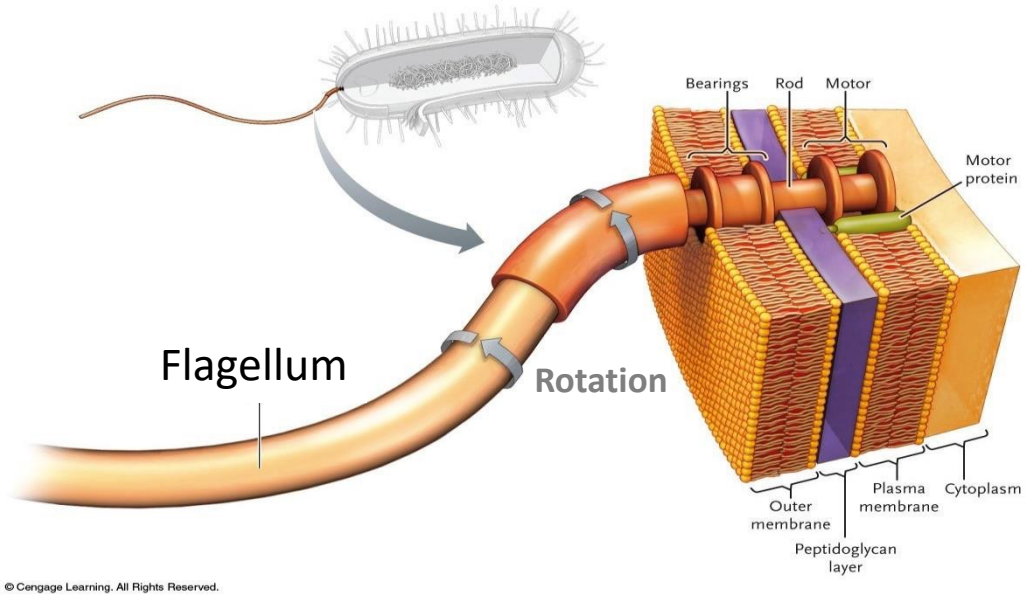
Bacteria: Slime layer or capsule

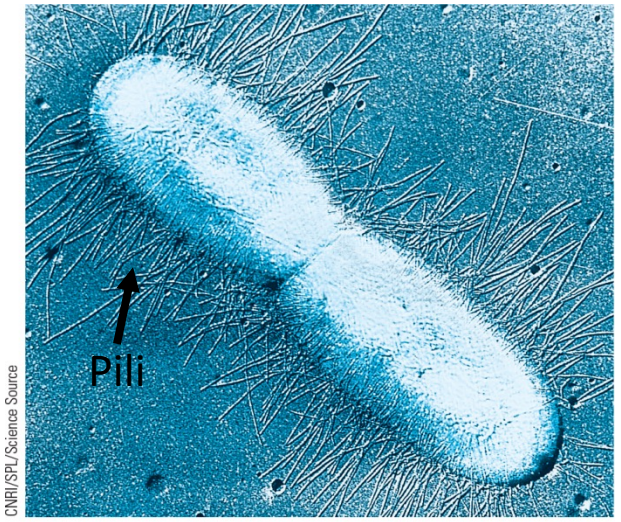


Rhizobium, a Gram-negative soil-dwelling bacterium

- An external layer of **polysaccharides**
- **Protect bacteria** from physical damage, desiccation, antibiotics and immune system in host
- May **facilitate adhesion** to surfaces

Bacteria: Flagella and pili



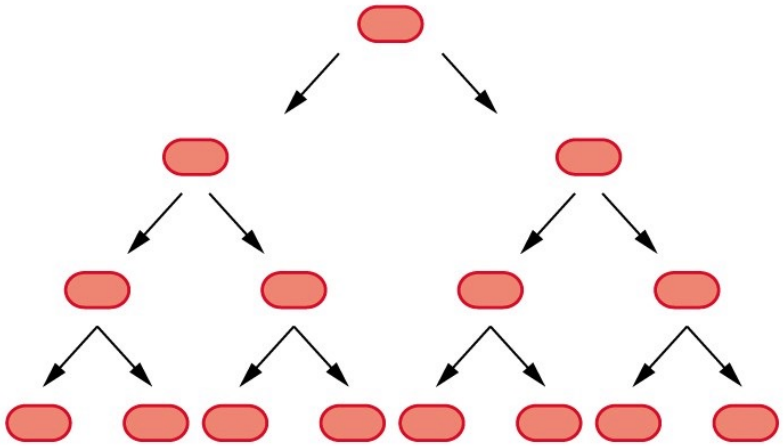


Escherichia coli

- Extensions from cell wall
- **Flagella:** usually longer; for **motility**
- **Pili:** mostly in Gram-negative bacteria; shorter; for **adhesion** and conjugation

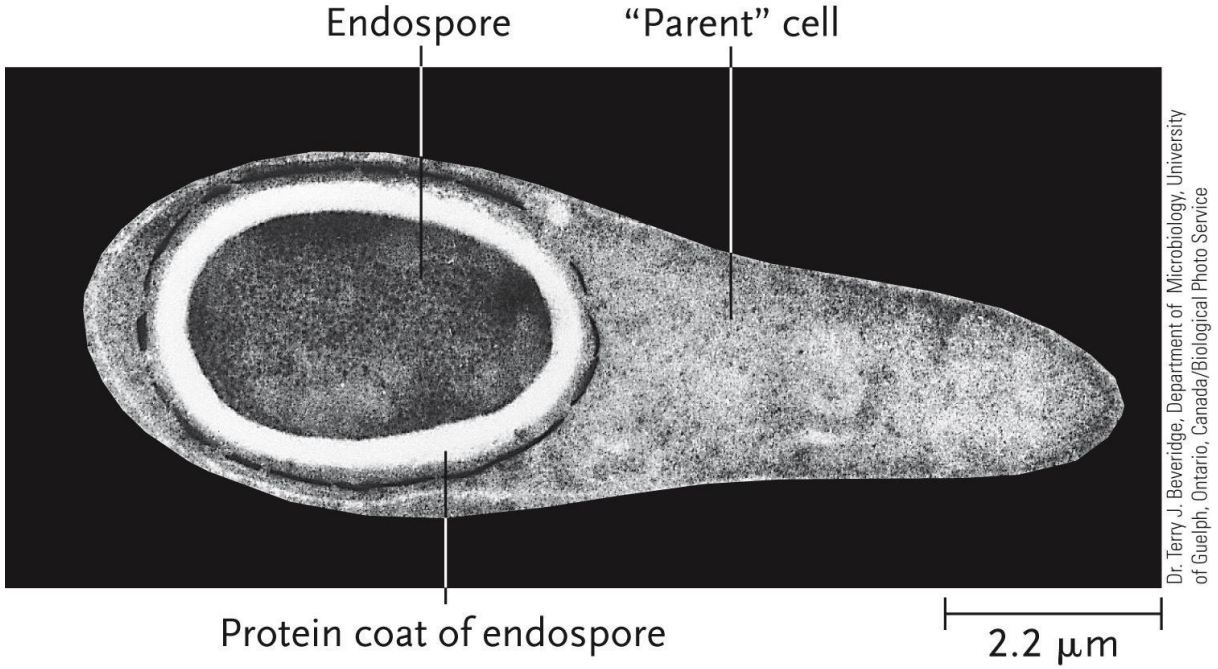
Bacteria: Rapid reproduction

- **Binary fission**: 1 parent cell divides into 2 daughter cells
  - Fastest doubling time: around 10 minutes



- Smaller genome with greater **genetic variability**
  - More spontaneous mutations
  - Acquired genetic changes e.g. **plasmid that confers resistance**

Bacteria: Endospore



- Dormant cell developed under unfavorable conditions
- Metabolically inactive and **highly resistant**

Bacteria: Benefits vs. harm

- **Food production**, e.g. yogurt, pickles, cheeses
- **Food spoilage**

- **Pharmaceutical product synthesis**, e.g. antibiotics, vaccines
- **Diseases and bioweapons**

- **Nutrient recycling**, e.g. nitrogen fixing, sewage treatment, bioremediation of oil spills
- **Environmental issues**, e.g. excessive activities causing hypoxia and killing aquatic organisms

Bacteria: Bioweapon vs. magic drug

- ***Clostridium botulinum***
- Produces an exotoxin, **botulinum**, **the most lethal poison** on Earth
- Blocks transmission of nerve signals and causes **muscle paralysis**
- **Botox injections**
  - Reduce facial wrinkles
  - Treat muscle disorders

Cavallini James/BSIP/Visuals Unlimited, Inc.

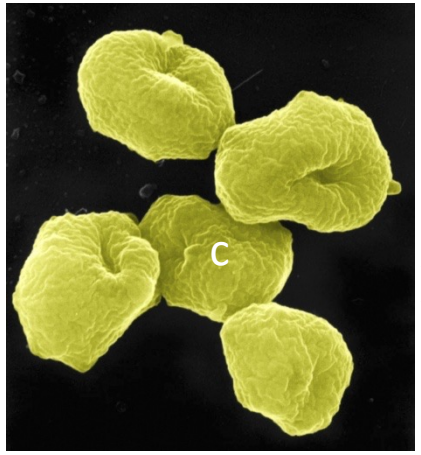
ShutterStocks

5 types of microbes

1. (Viruses)
2. Prokaryotes: Bacteria
3. **Prokaryotes: Archaea**
4. Eukaryotes: Protists
5. Eukaryotes: Fungi

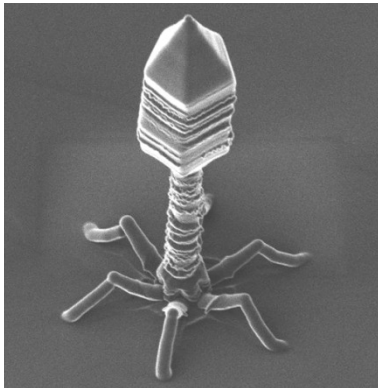

Janice Haney Carr

Bacterial cluster

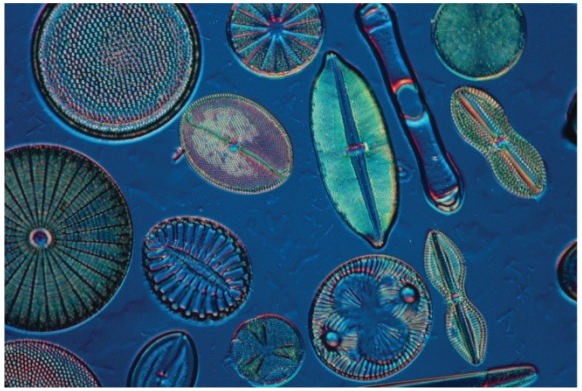


Microbiology Society (2018)

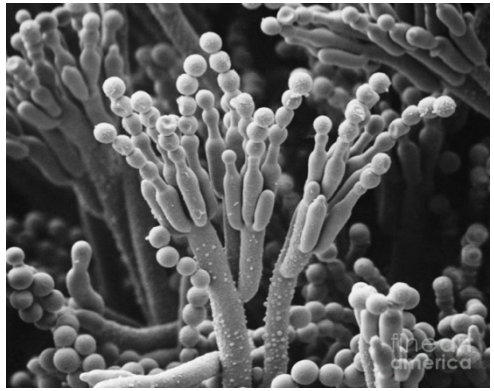
Irregular-shaped archaea


Kometani & Matsui (2005)

Complex virus


Jan Hinsch/Science Source

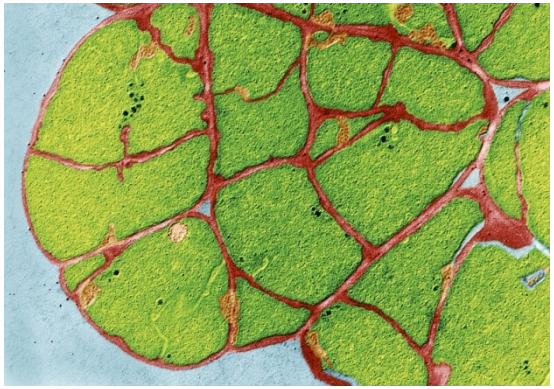
Diatoms, examples of protist


Biophoto Associations (2014)

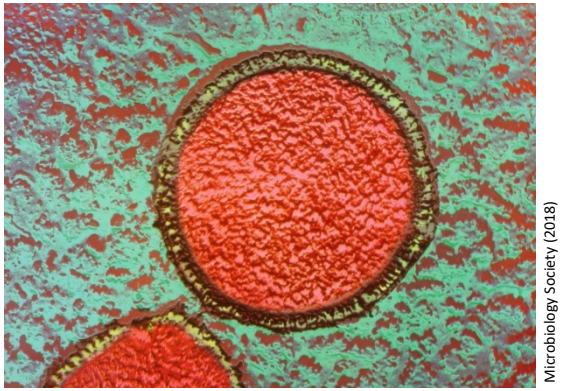
Fungal asci with spores

Archaea

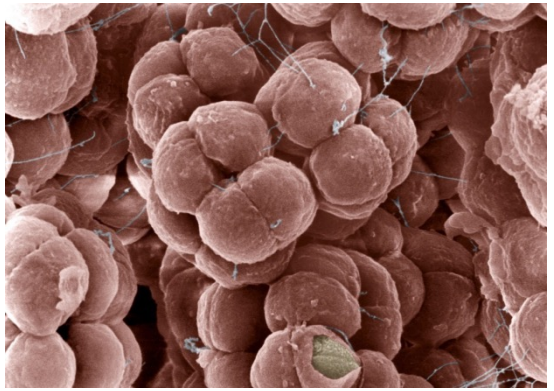
- Many of them are found in extreme environments (**extremophiles**)
- Most are **chemoautotrophs**, some are chemoheterotrophs



Methanosarcina rumen
(Anaerobe in rumen of cattle)



Staphylothermus marinus
(Hyperthermophile in deep ocean hydrothermal vents at 98°C)



Halococcus salifodinae
(Halophile in salt mine)

Archaea: Mixed features

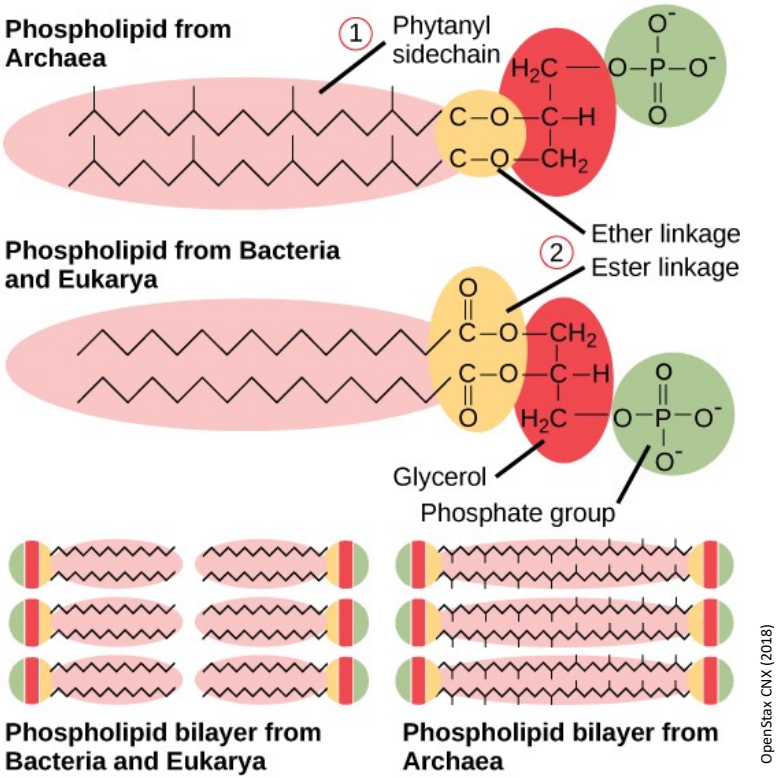
Characteristic	Bacteria	Archaea	Eukarya
DNA arrangement	Single, circular in most, but some linear and/or multiple	Single, circular	Multiple linear molecules
Chromosomal proteins	Prokaryotic histonelike proteins	Five eukaryotic histones	Five eukaryotic histones
Genes arranged in operons	Yes	Yes	No
Nuclear envelope	No	No	Yes
Mitochondria	No	No	Yes
Chloroplasts	No	No	Yes
Peptidoglycans in cell wall	Present	Present but modified, or absent	Absent
Membrane lipids	Unbranched; linked by ester linkages	Branched; linked by ether linkages	Unbranched; linked by ester linkages

Characteristic	Bacteria	Archaea	Eukarya
RNA polymerase	One type	Multiple types	Multiple types
Ribosomal proteins	Prokaryotic	Some prokaryotic, some eukaryotic	Eukaryotic
First amino acid placed in proteins	Formylmethionine	Methionine	Methionine
Aminoacyl–tRNA synthetases	Prokaryotic	Eukaryotic	Eukaryotic
Cell division proteins	Prokaryotic	Prokaryotic	Eukaryotic
Proteins of energy metabolism	Prokaryotic	Prokaryotic	Eukaryotic
Sensitivity to chloramphenicol and streptomycin	Yes	No	No

Archaea: Unique features

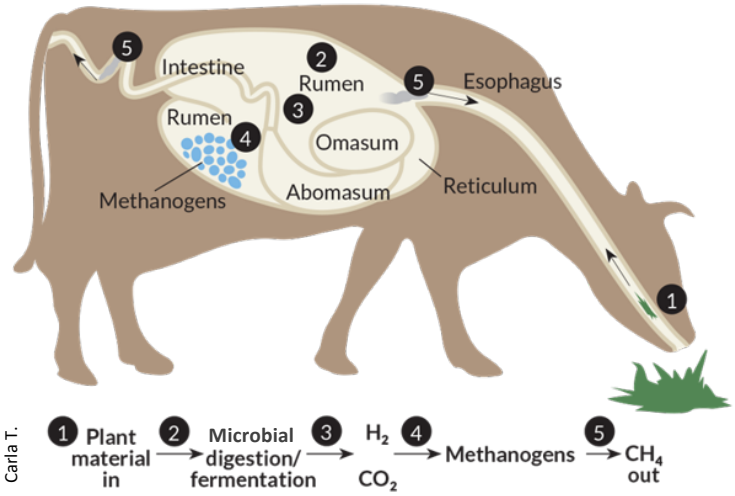
- Plasma membrane
  - Branched sidechain
  - Ether bond between hydrocarbon chains and glycerol
- Cell wall
  - Peptidoglycans with different components and bonding, OR
  - Proteins or polysaccharides instead of peptidoglycan

➔ Greater resistant to disruption



Archaea: Methanogens

- **Produce methane** as a metabolic byproduct in anoxic conditions



- Waste treatment coupled with biogas production[2]
- **Potential human pathogens** e.g. *Methanobrevibacter oralis* associated with tooth infection[3]

2) Scherer et al. (2000) Water Sci. Technol. 41, 83-91; 3) Vianna et al. (2006) J. Clin. Microbiol. 44,1274-1282

5 types of microbes

1. (Viruses)
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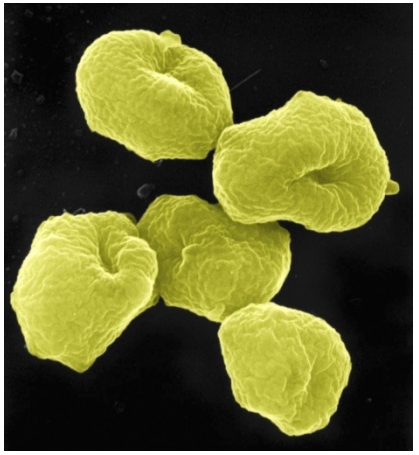
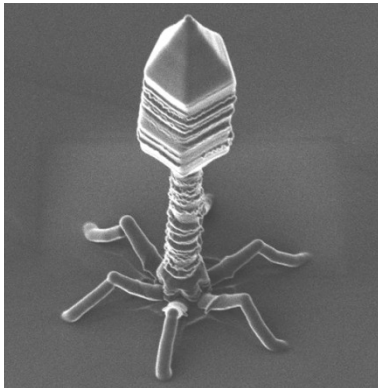
Janice Haney Carr

Bacterial cluster


Microbiology Society (2018)

Irregular-shaped archaea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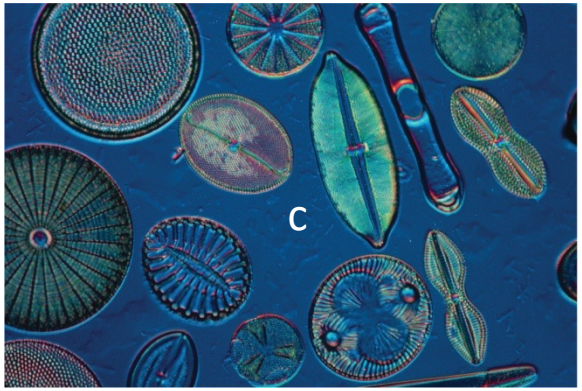
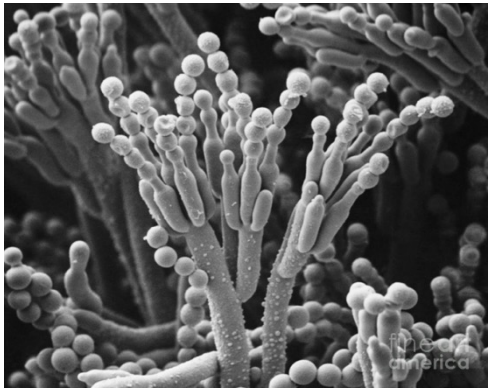


Jan Hinsch/Science Source

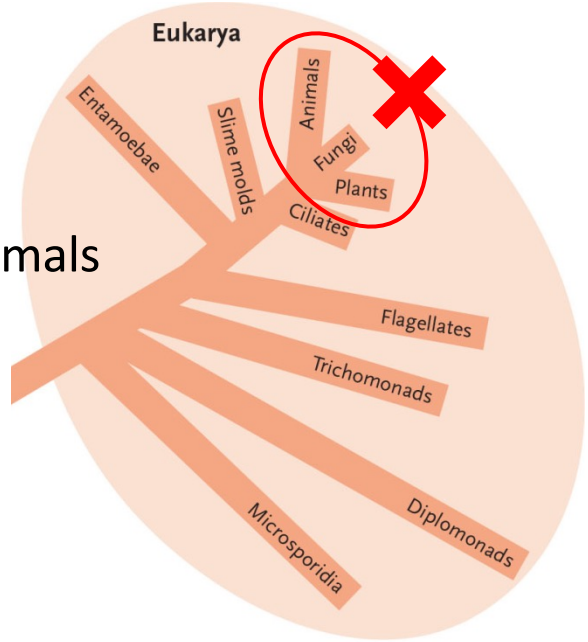
Diatoms, examples of protist


Biophoto Associations (2014)

Fungal asci with spores

Protists

- All eukaryotes **EXCEPT** kingdom Animalia, Fungi and Plantae
- Distinctive features:
  - Lack highly differentiated structures
  - Extracellular support protein different from animals
  - Cell wall components different from fungi
- **Extremely diverse** in structure, metabolism, reproduction and habitat



Types of protists

- Protozoa – animal-like unicellular heterotrophs that eat other organisms
  - e.g. amoeba, plasmodium (parasites that cause malaria)

- Algae – plant-like autotrophs that contain chloroplasts for photosynthesis to make their own food
  - e.g. red tide, seaweed

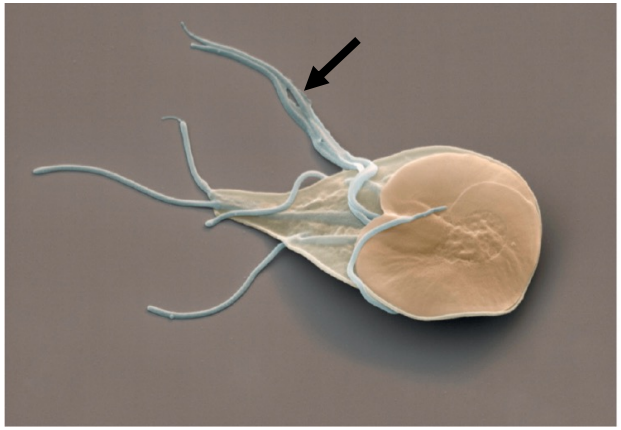
- Fungus-like protists – decompose dead organisms for food, do not have chitin in their cell wall
  - e.g. slime mold

Protists: Locomotion

Cilia

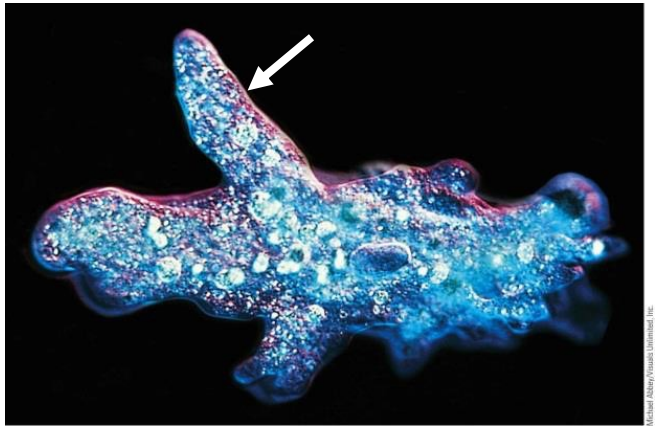
Paramecium, a ciliate

Flagella



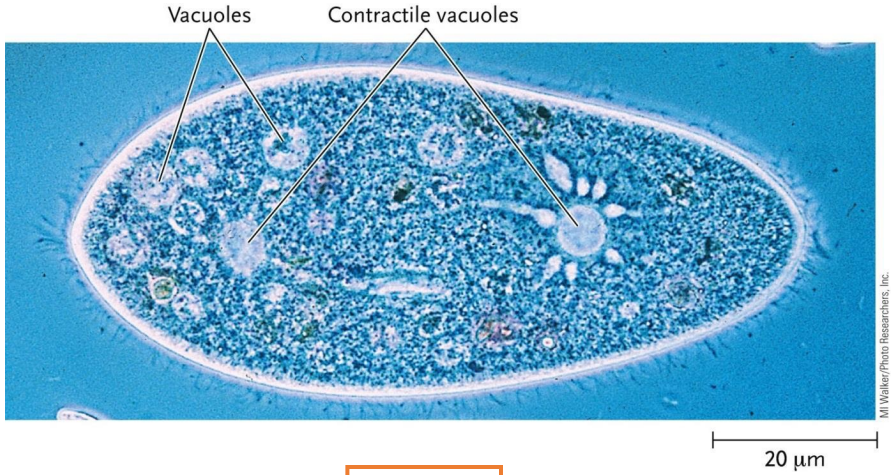
Giardia lamblia, a mammalian parasite

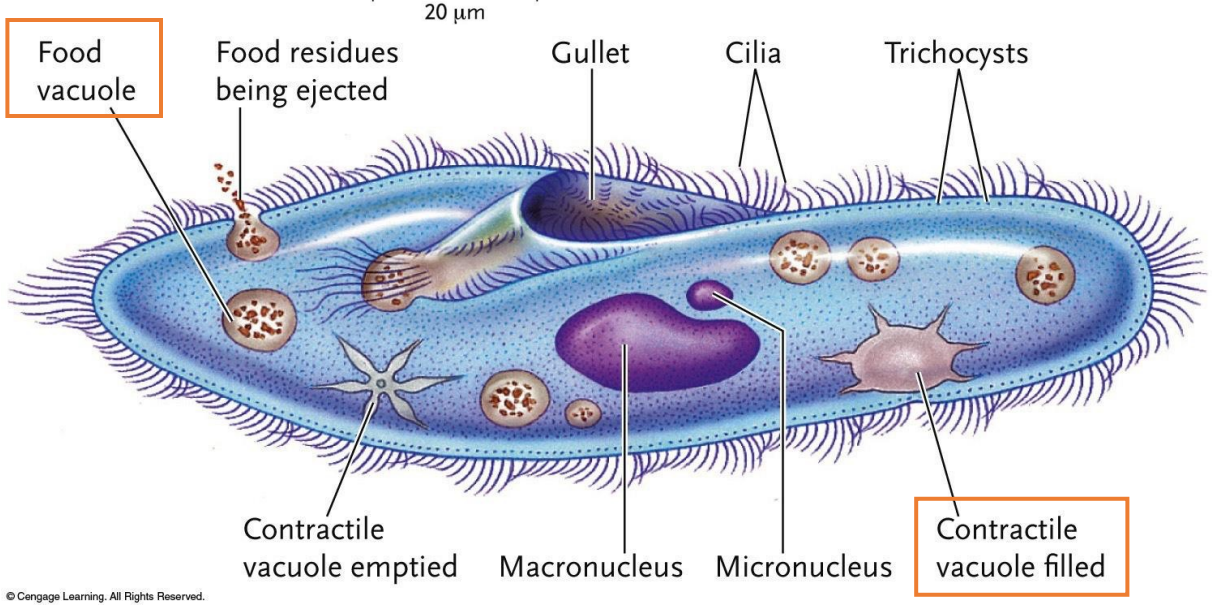
Pseudopodia



Amoeba proteus, an amoeba

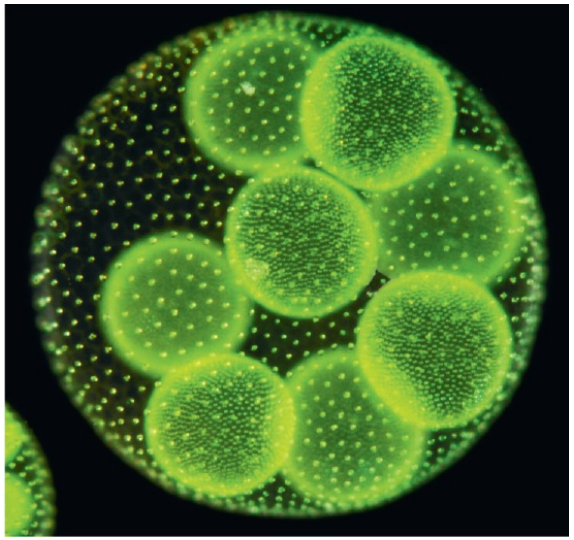
Protists: Special features





Protists: Nutrition

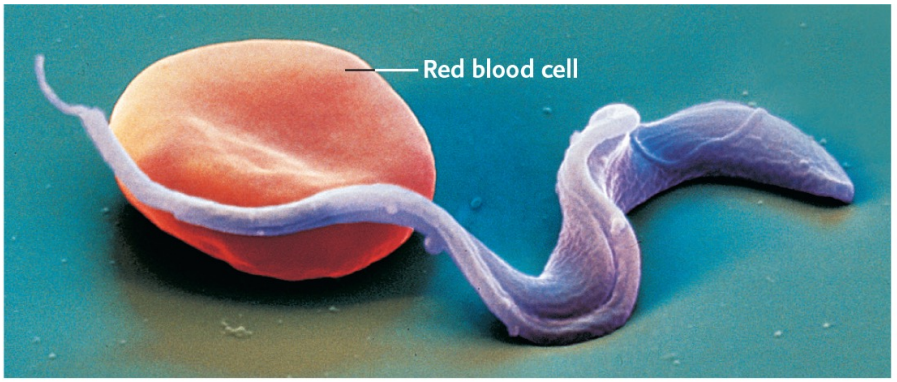
Autotrophy



Lebendkulturen.de/Shutterstock.com

Volvox, a colonial green alga

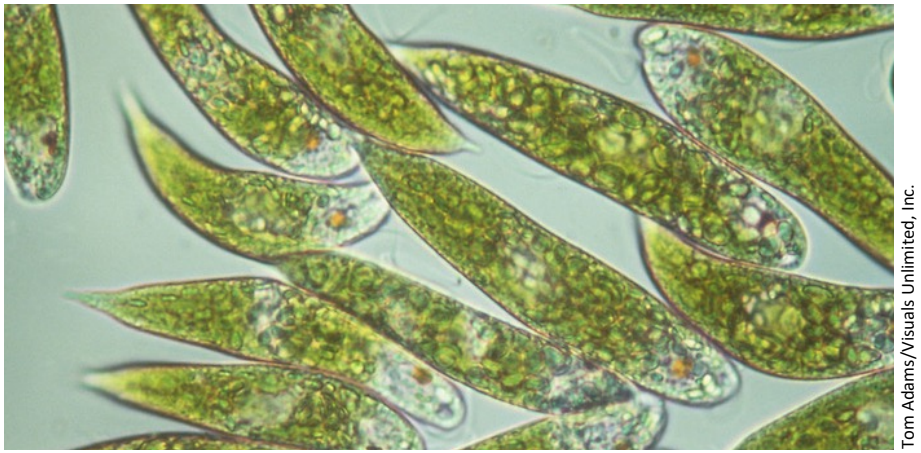
Heterotrophy



Oliver Meckes/Science Source

Trypanosoma brucei, an animal parasite

Mixotrophy



Tom Adams/Visuals Unlimited, Inc.

Euglena

Protists: Habitat

- All protists live in **aquatic habitats**
  - Within host organisms
  - Moist surfaces e.g. soil, wood
  - Aquatic systems e.g. oceans, lakes, streams

Slime mold

Sharnoff/Visuals Unlimited, Inc.

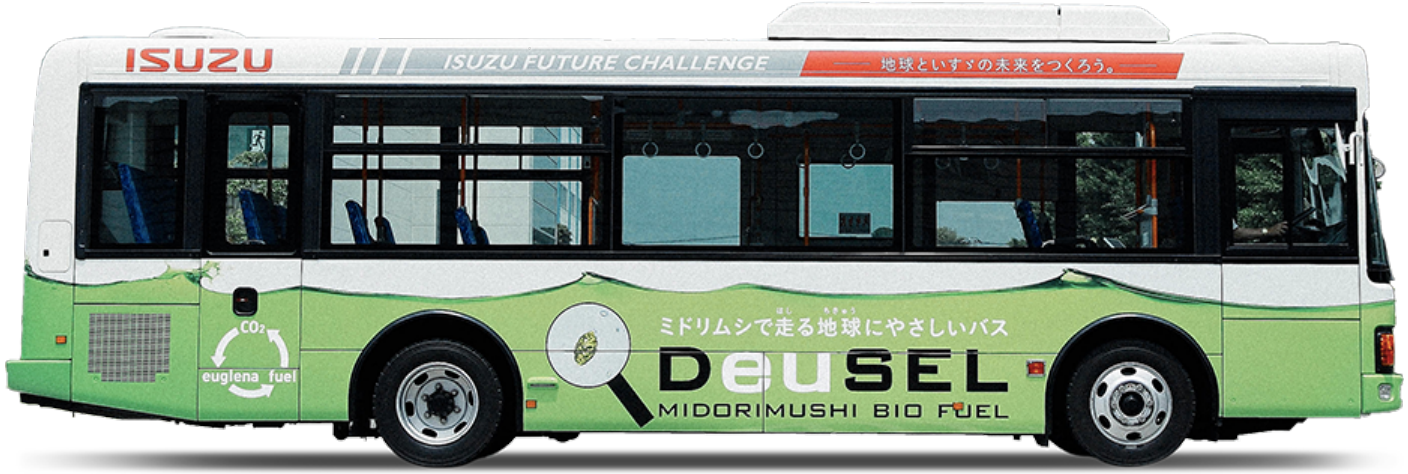
Foram

Courtesy of Allen W. H. Be and David A. Caron

Red algae

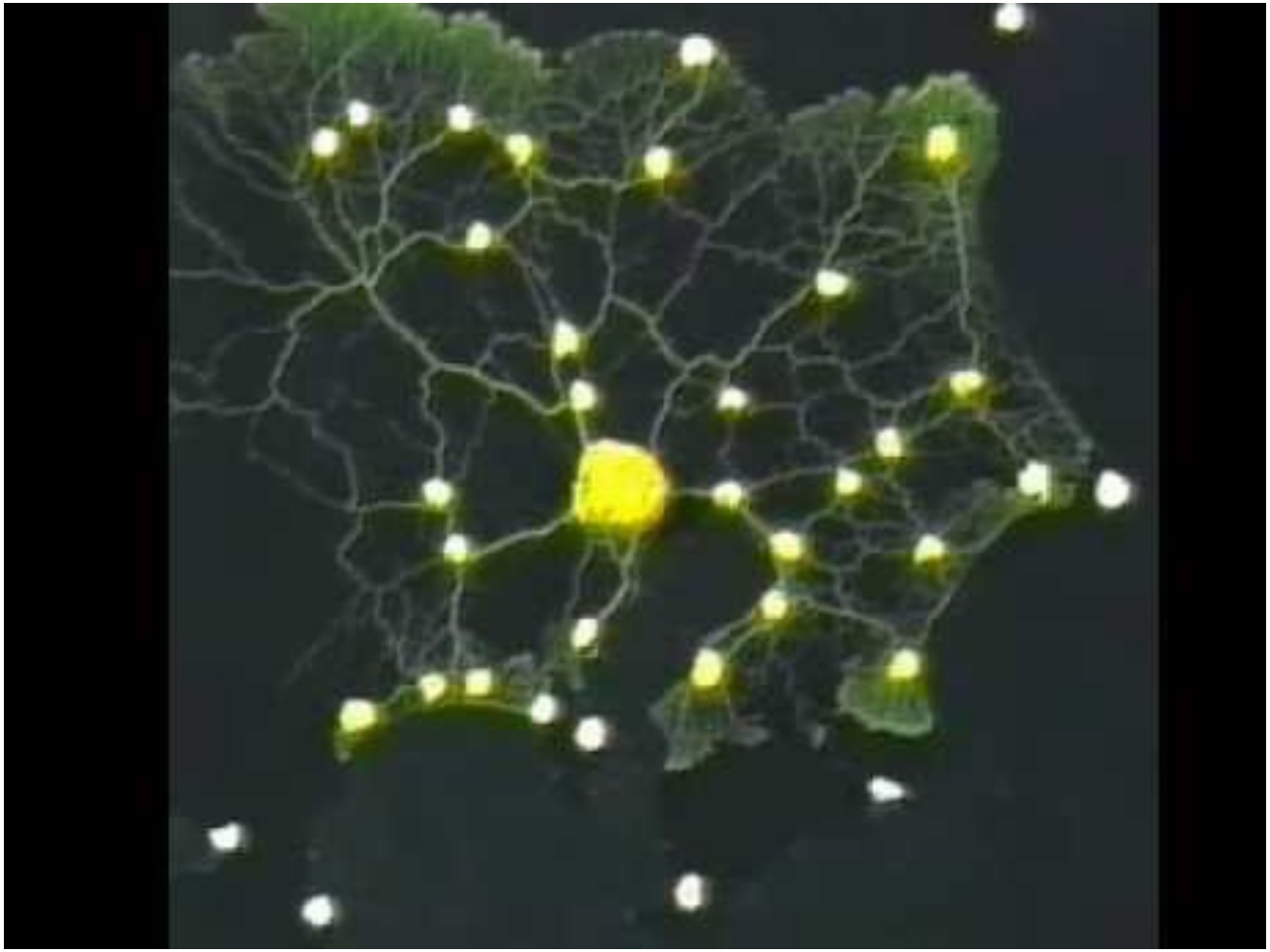
Alison Young

Application of Euglena



https://www.euglena.jp/

Using slime mold to devise a railway map of the Tokyo area



https://www.youtube.com/watch?v=GwKuFREOgmo

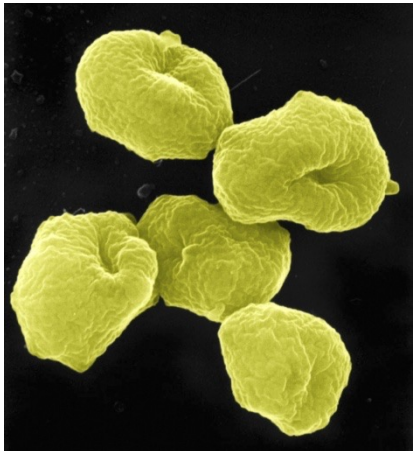
slime mold is more efficient than Japanese graduate students in finding the shortest route through a maze (they “collaborate” by fanning out in the form of a network to explore all possible paths); and is as good as or better than humans at devising maps for railway systems in Great Britain and Japan.

5 types of microbes

1. (Viruses)
2. Prokaryotes: Bacteria
3. Prokaryotes: Archaea
4. Eukaryotes: Protists
5. **Eukaryotes: Fungi**


Janice Haney Carr

Bacterial cluster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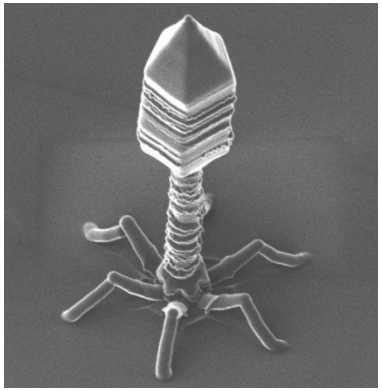
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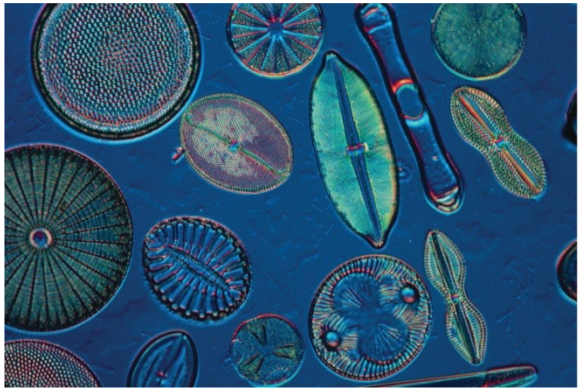
Jan Hinsch/Science Source

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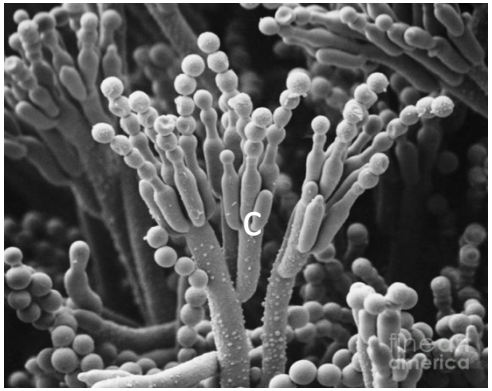

Biophoto Associations (2014)

Fungal asci with spores

Fungi: Not all are microscopic…

Honey mushroom: The biggest individual covers 8.8 km^2 in eastern Oregon, U.S.

Fungi: General features

- Ubiquitous in air, soil, aquatic systems, but mostly terrestrial
- All are **heterotrophs**
- **Major decomposer** of organic matters, especially for wood
- **Rigid cell wall** made of **chitin**

Wood-ear fungus

Mushroom Medium (2017)

Fly agaric mushroom

Jane Burton/Bruce Coleman Ltd.

Shelf fungus

Black truffle

Northwest Wild Foods (2015)

Morel

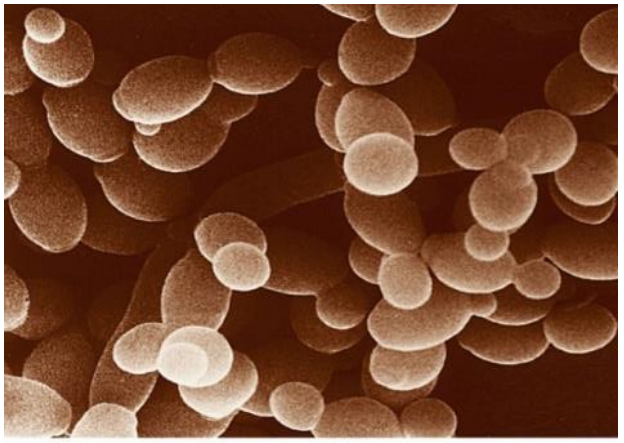
Fungi: Basic body forms

- **Single-celled yeast** e.g. baker's yeast *Saccharomyces cerevisiae*

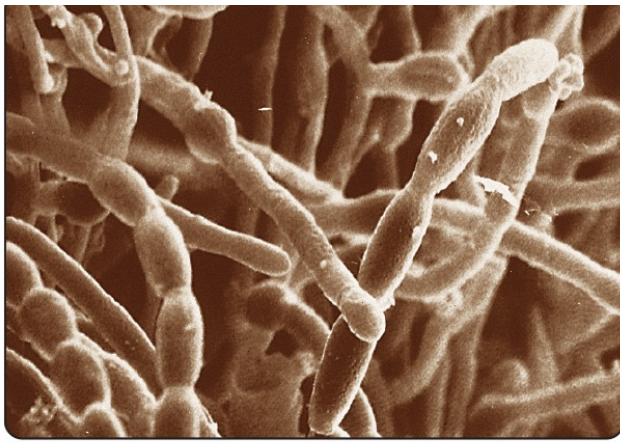
- **Multicellular form** comprised of **mycelia** (combination of **hyphae**) e.g. bread mold *Rhizopus stolonifer*

- Some alternate between two forms at different life stages

Yeast cells



Gary T. Cole, University of Texas, Austin/BPS



Gary T. Cole, University of Texas, Austin/BPS

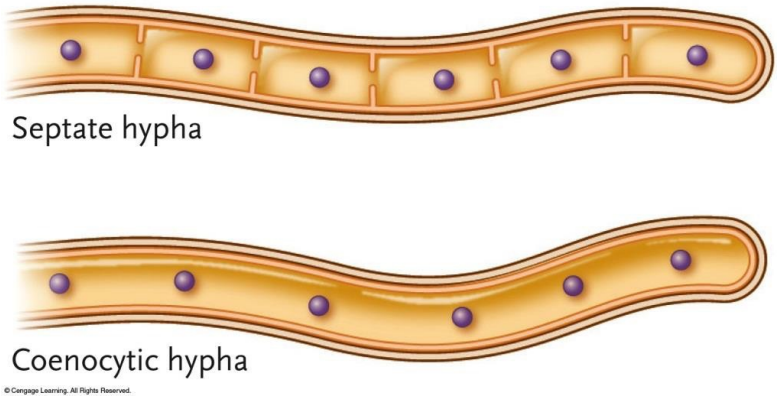
Fungal hyphae

Fungi: Growth pattern

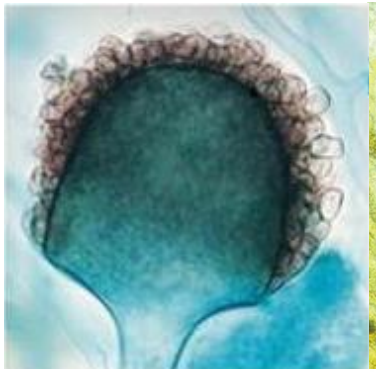
- Yeast cells grow by **budding or binary fission**

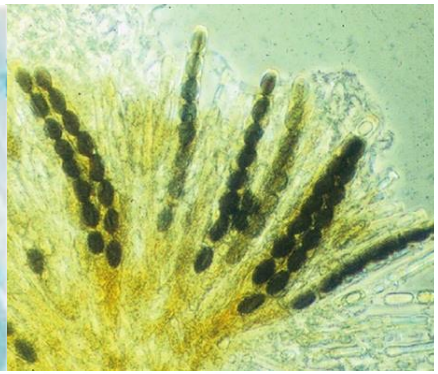
Baker's yeast cells *(Saccharomyces cerevisiae)*

- Hyphal filaments grow at the tip (i.e. **apical growth**)
  - With or without cross walls (**septa**)
  - Septa with pores to allow cytoplasmic streaming

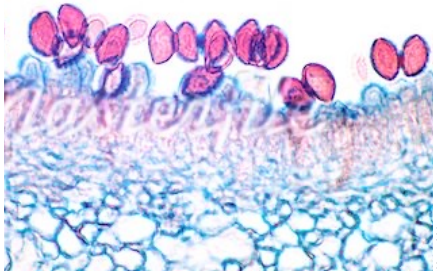


Fungi: Reproduction


North Carolina State University, Department of Plant Pathology


Micrograph Ed Reschke

- All reproduce via fungal **spores**
  - Microscopic in size
  - Easily dispersed
  - Can remain dormant for long periods


Ken Wagner

- Most reproduce both **sexually AND asexually**

Phyla: **Chytridiomycota** **Zygomycota** **Glomeromycota** **Ascomycota** **Basidiomycota**


Chytrids


Zygospore fungi


Mycorrhizal fungi


Sac fungi


Rusts, smuts, mushrooms

Sac fungi (Ascomycota)

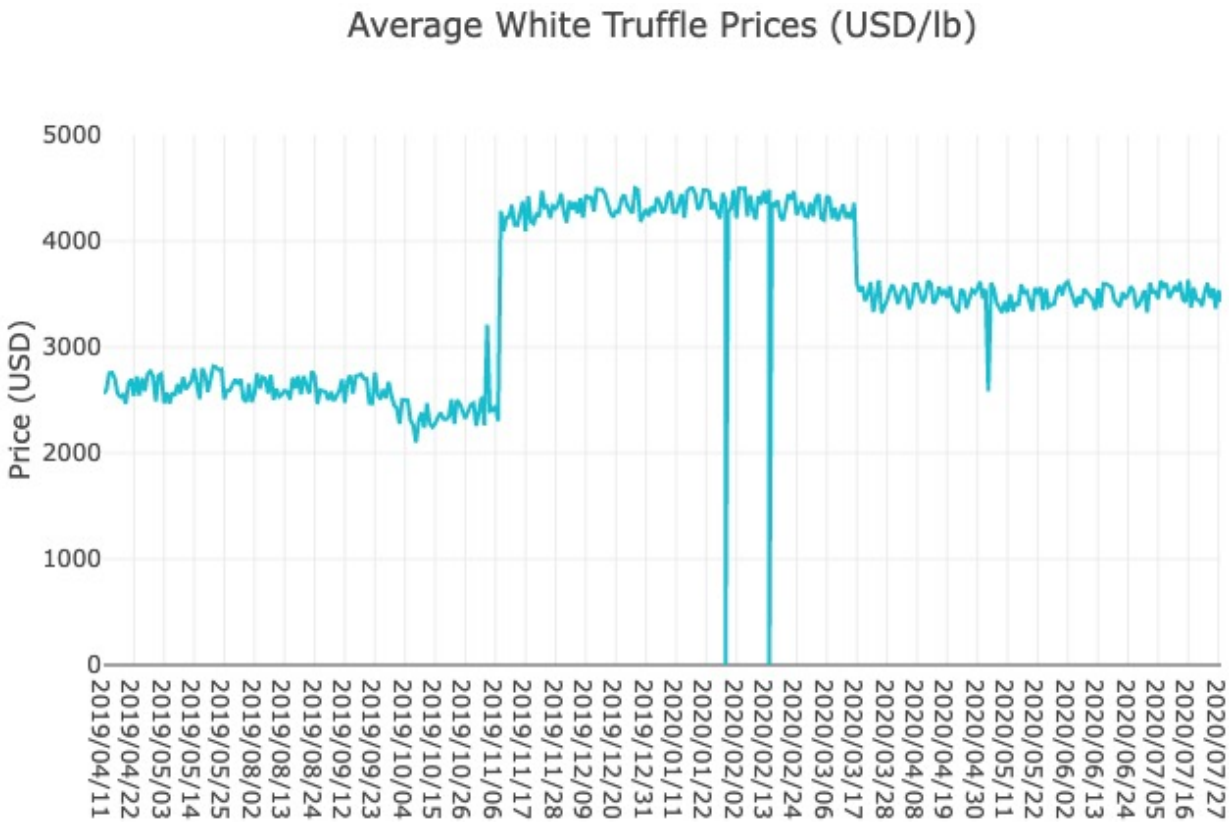
Morchella esculenta (morel)

Tuber magnatum (white truffle)

Some of the most expensive delicacies in the world!

Sac fungi (Ascomycota)

Tuber magnatum (white truffle)



Some of the most expensive delicacies in the world!

Mushrooms (Basidiomycota)

Shelf fungus

Coral fungus

Bird's nest fungus

Stinkhorn

Puffballs

Fungi: Heterotrophic nutrition

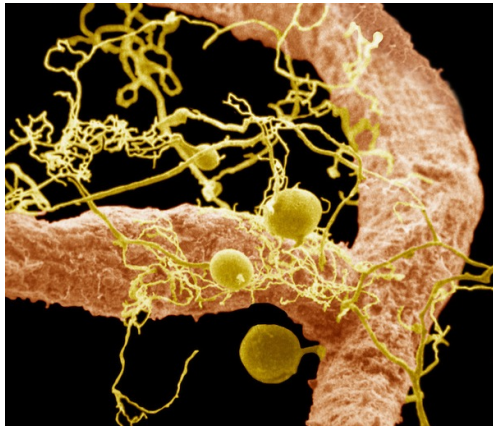
- Secrete hydrolytic enzymes to **digest organic substances extracellularly** before absorption
- From dead organic matters (**saprophytic**) or living hosts (**parasitic** or **mutualistic**)


Nigel Cattlin/Visuals Unlimited, Inc.

Saprophytic bracket fungus turkey tail, *Trametes versicolor*


Ray Coleman/Visuals Unlimited, Inc.

Parasitic powder cap mushrooms, *Asterophoroa lycoperdoides*


Merton Brown/Visuals Unlimited, Inc.

Mycorrhizae

Fungi: Diseases in plants

- Responsible for 80% of plant diseases and 10 – 30% of annual crop losses[4]
- e.g. *Aspergillus flavus* grow on damp grain and peanuts can produce **aflatoxins**, which may **cause cancer**

Purdue University

doc-stock/Visuals Unlimited, Inc.

4) Shuping & Eloff (2017) Afr. J. Tradit. Complement. Altern. Med. 14: 120–127

Fungi: Diseases in animals

- **Mycosis**: Fungal infection in animals, e.g.
  - Ringworm
  - Athlete's foot
  - Farmer's lung

eHome Remedies (2017)

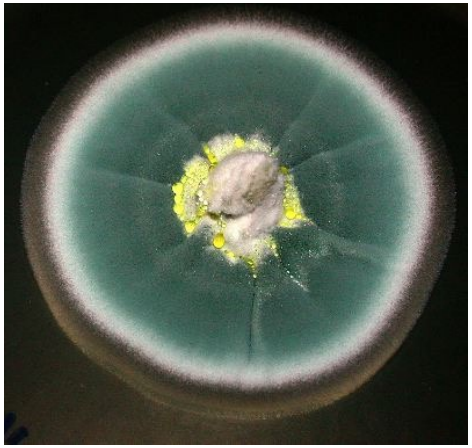
Dermatophytes (Skin fungi)

Melissa Conrad Stöppler/Medicine Net

Fungi: Pharmaceutical uses

- **Antibiotic** e.g. penicillin
- **Chinese medicine** e.g. caterpillar fungus (冬蟲夏草)
- **Immunosuppressant** e.g. cyclosporine

Penicillium chrysogenum



Thomas J. Volk (2003)

Ophiocordyceps sinensis

Gary Lincoff (2012)1

AAAWholesaleCompany 92017)

Fungi: Industrial uses

- **Food industry** e.g. bread, cheese and wine
  - Anaerobic fermentation provides the flavor
  - *e.g. Aspergillus oryzae* for making Japanese sake, soy sauce, and Miso
- **Non-food industry** e.g. leather-making, textile and paper industry

Cheese

Bread

Maurizio Milanesio/Shutterstock.com

Beer and wine

Slawomir Fajer/Shutterstock.com

Østergaard & Olsen (2011) In: Industrial Applications. The Mycota, vol 10. Springer, Berlin, Heidelberg

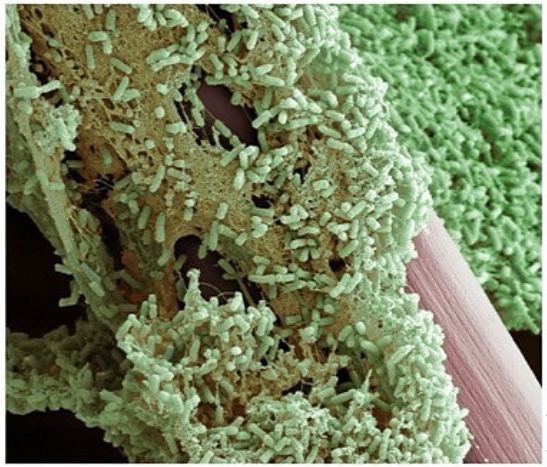
Microbial Associations

Mostly **mutualistic symbiosis** (two or more species living together in close relationship)

Biofilms

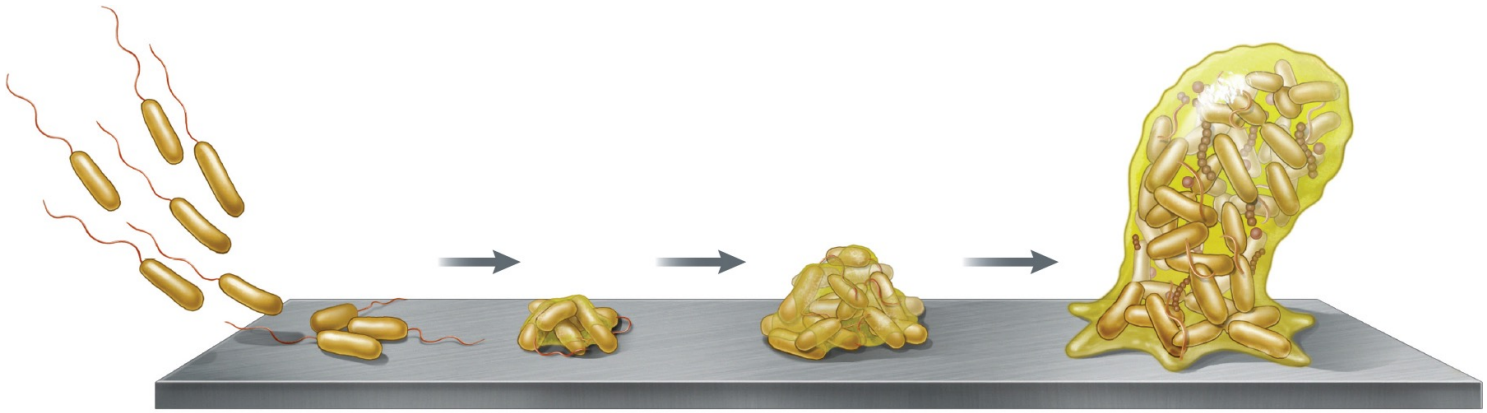
- Microbes, usually bacteria, embedded in matrix
- Found in watery environment
- e.g. dental plaque

Biofilm on a toothbrush bristle



Biofilm on a toothbrush bristle (higher magnification)

BioNinja(2017)



1 A specific environmental signal changes gene expression in free bacteria.

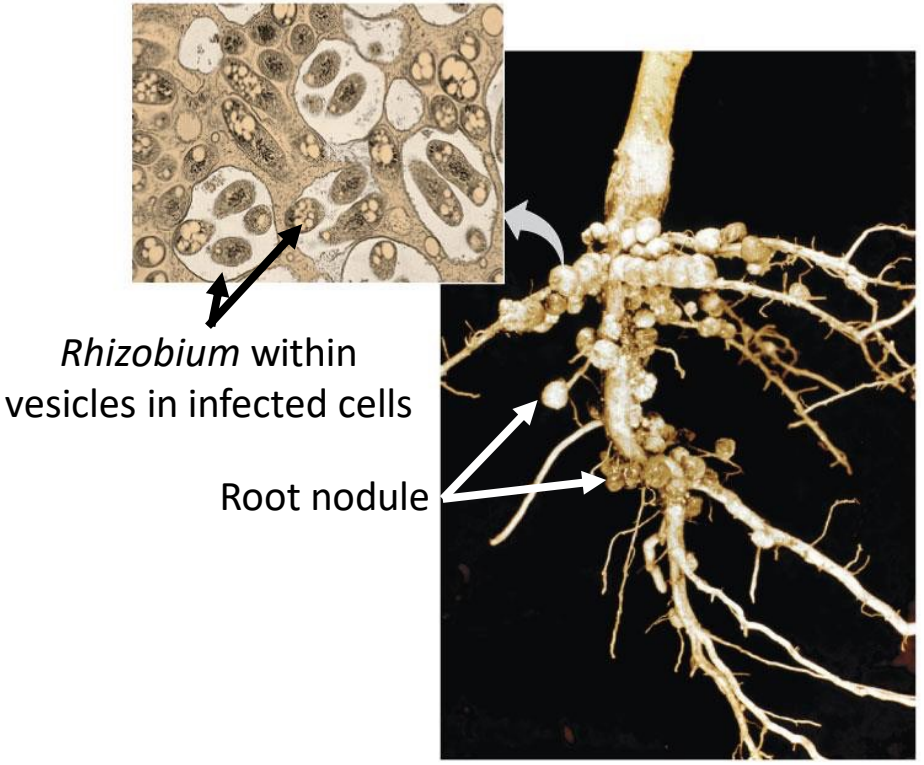
2 Bacteria attach to a surface coated with polysaccharides and glycoproteins, which results in more free bacteria attaching. A monolayer forms.

3 Bacteria attach more firmly to the surface and form small colonies.

4 The bacteria produce an extracellular matrix that enables the biofilm to mature, producing its three-dimensional shape.

Root nodules

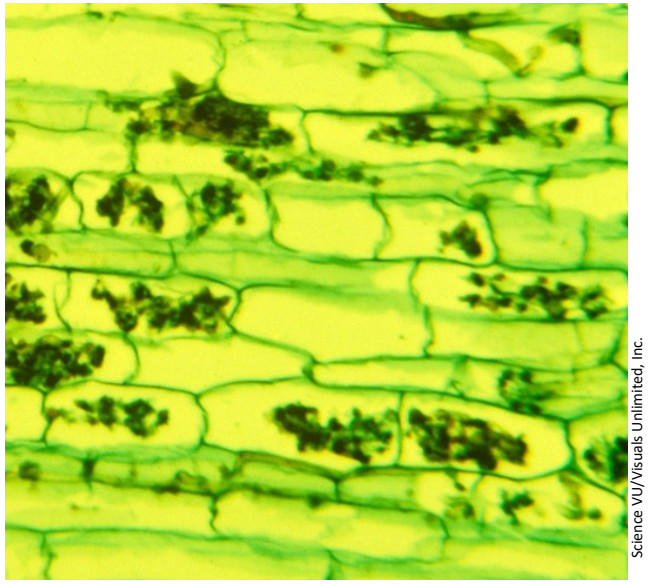
- Nitrogen-fixing bacteria in root of leguminous plants
- Bacteria fix atmospheric nitrogen, whereas plant provides carbon source



Mycorrhizae

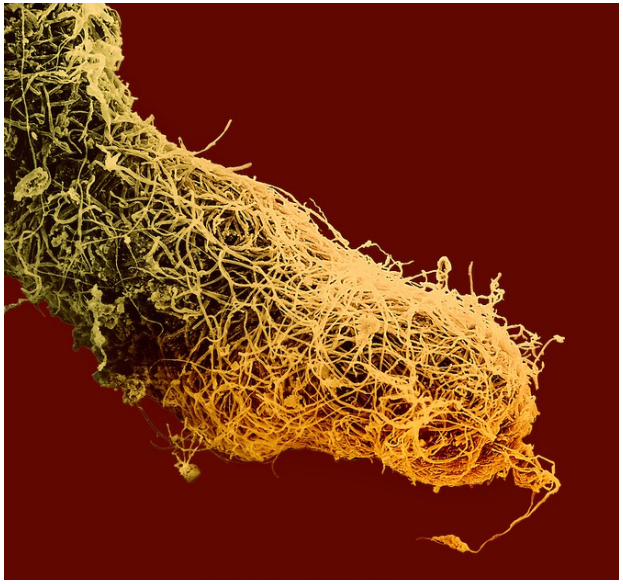
- Fungal hyphae associated with plant root
- Fungi absorb minerals, whereas plant provides carbon source

Endomycorrhizae:
Hyphae penetrating inside root



Science VU/Visuals Unlimited, Inc.

Ectomycorrhizae:
Hyphae surrounding the root



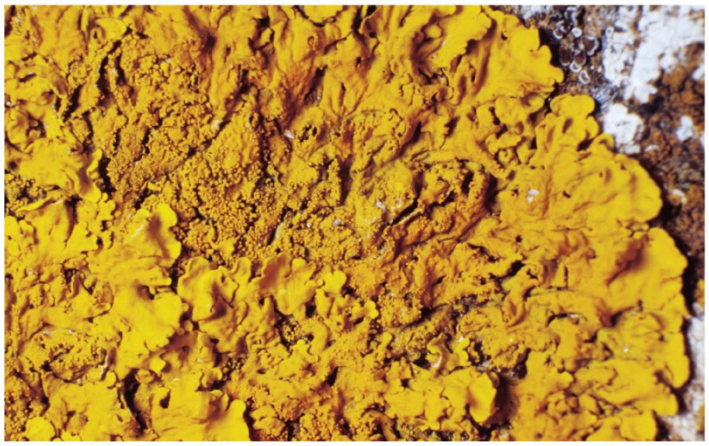
Gerald Van Dyke/Visuals Unlimited, Inc.

Lichens


Henry Lui/Green Power (2017)

- Fungus associated with a photosynthetic partner, e.g. cyanobacteria, green algae
- Fungi (**mycobiont**) absorb minerals and provide shelter, whereas the partner (**photobiont**) capture sunlight for photosynthesis
- Act as **pollution indicator**

C. Crustose lichen


Antonio López Román/AGE Fotostock

D. Branching lichen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Summary

1) Viruses
- Living organisms??
- Reproduction depends on host

2) Bacteria
- Prokaryotes
- Three common cell shapes
- Gram-positive or Gram-negative

3) Archaea
- Prokaryotes with eukaryotic features
- Tolerate extreme environments

4) Protists
- Eukaryotes
- Diverse structures
- Three nutrition modes

5) Fungi
- Eukaryotes
- Two basic body forms
- Three types of heterotrophic nutrition

References) Ch. 4, 17, 26, 27, 30 in *Biology: The Dynamic Science, 4th Ed.*