What is Microbiology?

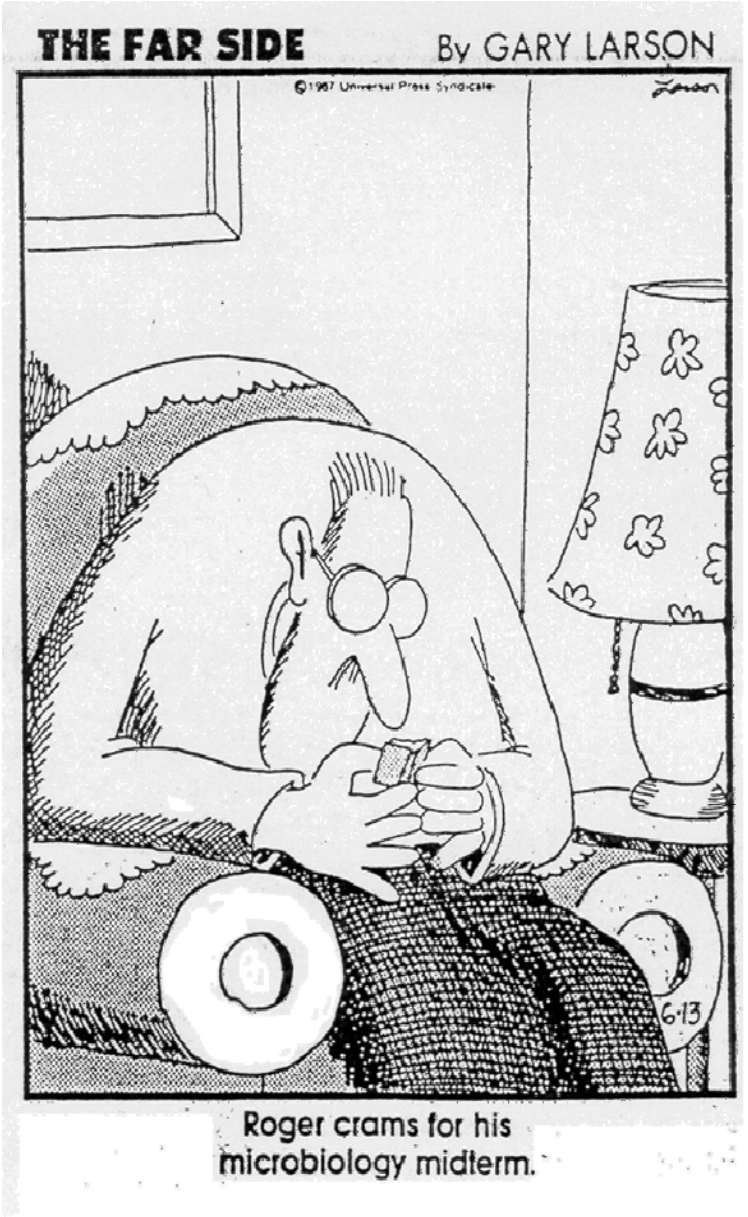
"micro" = small

"bio" = life

"-logy"(logos) = discourse

The study of organisms too small to be seen clearly with the unaided eye.

(e.g. without a microscope)...



What is Microbiology?

A. Classification of microorganisms

B. Types of cells

1. Bacteria
2. Archaea
3. Eukarya

C. Where are microbes and what do they do?

D. What else do microbiologists do?

WHAT IS A MICROORGANISM?

"There is no simple answer to this question. The word 'microorganism' is not the name of a group of related organisms, as are the words 'plants' or 'invertebrates' or 'fish'. The use of the word does, however, indicate that there is something *special* about small organisms; we use no special word to denote large organisms or medium-sized ones.

- Sistrom (1969)

Many organisms are microorganisms

‘Prokaryotes’ = no nucleus

Bacteria	most are beneficial; very few are pathogens
Archaea	no known pathogens; many extremophiles

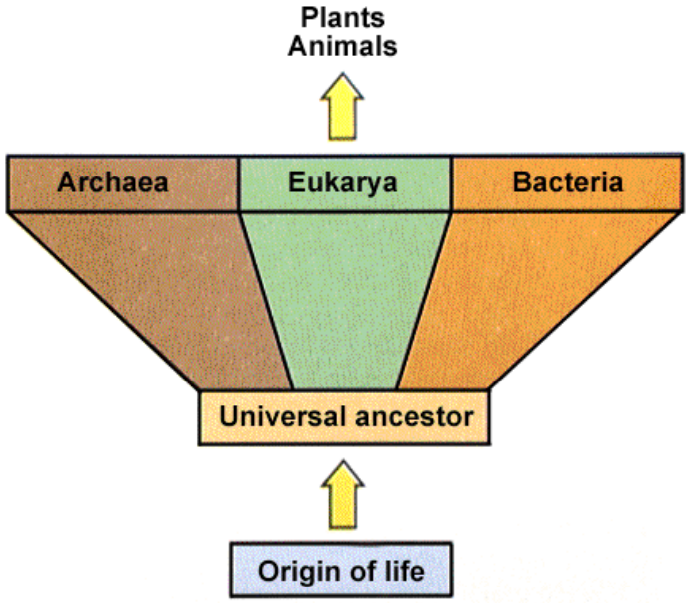
‘Eukaryotes’ = nucleus

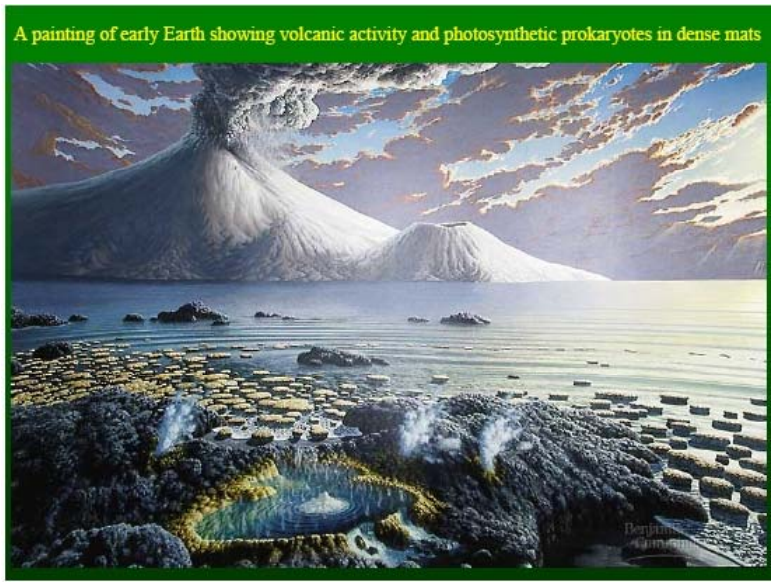
Algae	photosynthetic eukaryotes (autotrophs)
Fungi	heterotrophs; yeasts, molds, mushrooms
Protozoa	single-celled eukaryotes
Nematodes	microscopic unsegmented worms; protostomes, ubiquitous; ~80,000 spp. and ~15,000 are parasitic

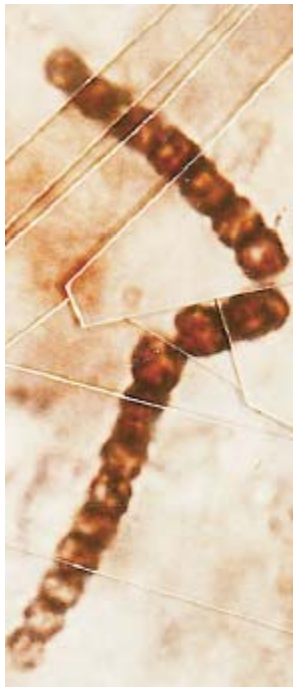
Acellular

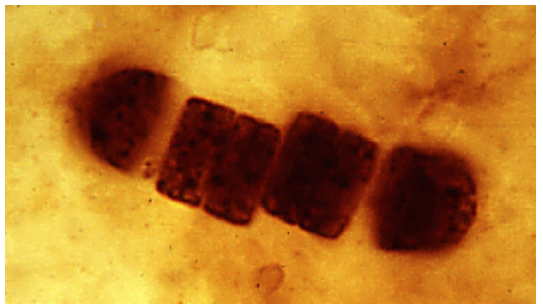
Viruses	nucleic acid (DNA or RNA) surrounded by a protein coat
Viroids	naked nucleic acid only (RNA); infect plants but not animals
Prions	naked protein only: infect animals but not plants

Life was solely microbial for the first 2/3 to 3/4 of Earth's living history







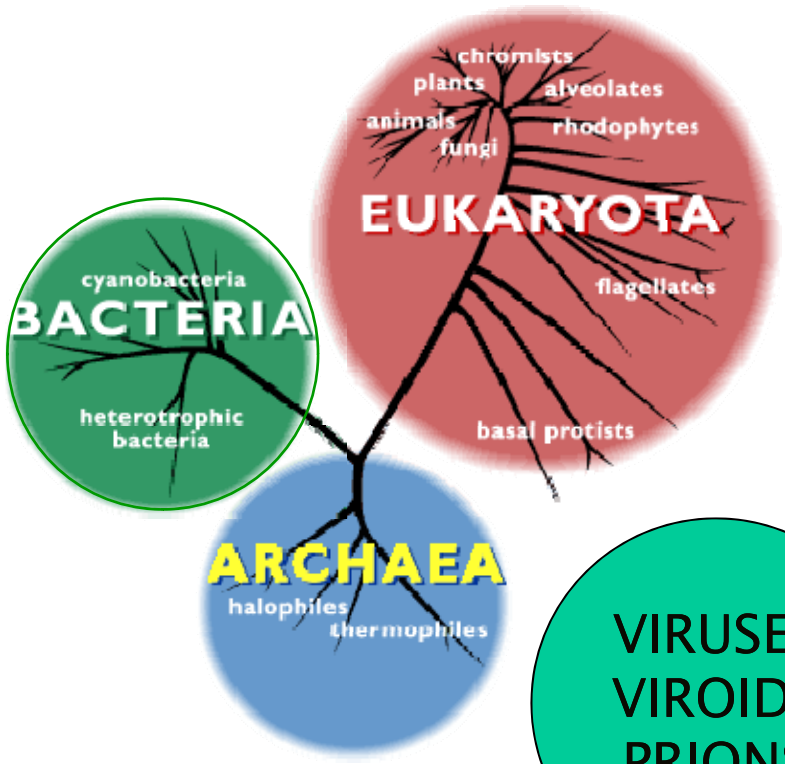


These chert fossils = 2 Gyr old

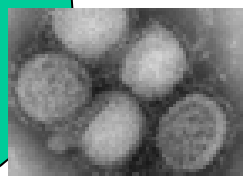
Oldest bacterial fossils = stromatolites, 3.5 billion years (Gyr) old… but not first microbes!

Many organisms are “micro”organisms

Algae, fungi, protozoa, nematodes



VIRUSES
VIROIDS
PRIONS



H1N1 influenza virus

All three domains of life include microbes…
and all three started as microbes.

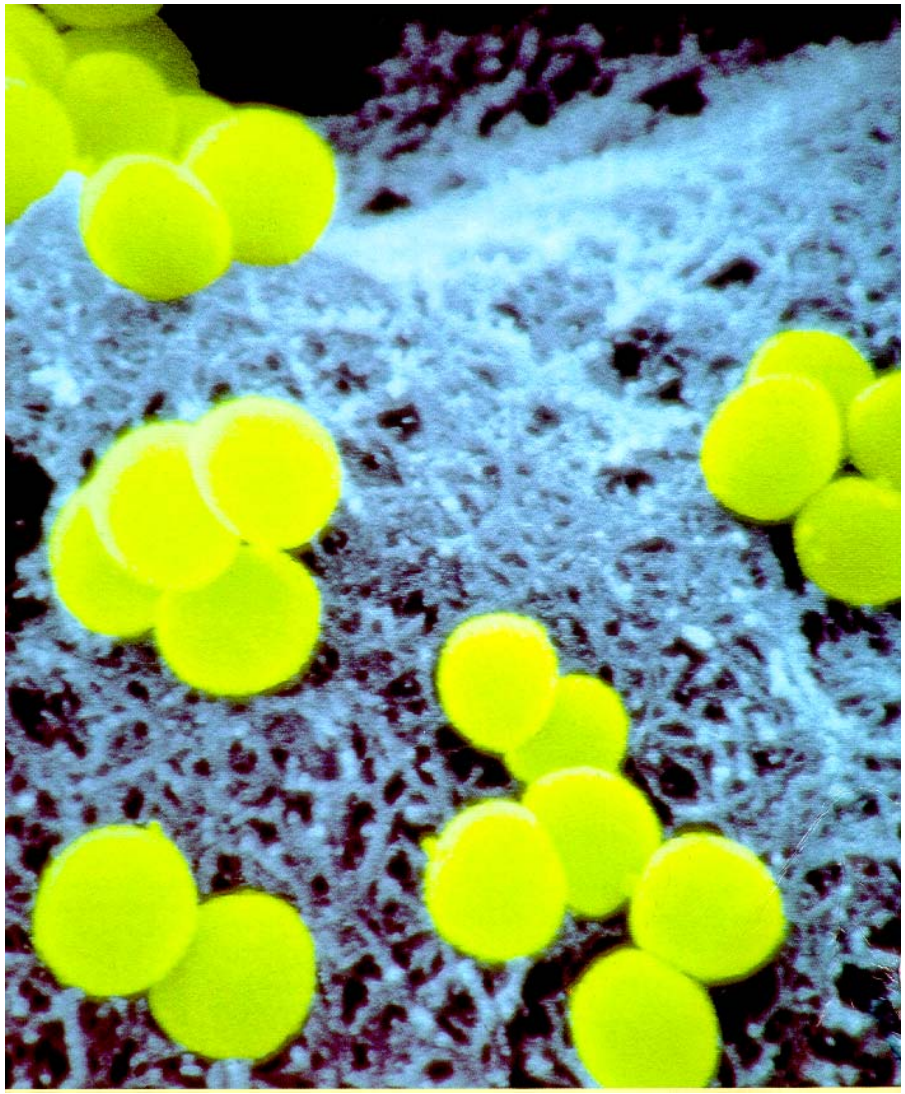
Three Fundamental Kinds of Cells:

Bacteria

- No Nucleus (DNA = “Nucleoid”)
- Mostly circular chromosomes
- No membranous cytoplasmic organelles
- 70S ribosomes – **Less Complex**
- Reproductively haploid
  Asexual reproduction
- Small (usually 1-10 microns)
- Autonomous

Molecular differences from Archaea:

- 4-subunit RNA polymerase
- Peptidoglycan cell wall
- Ester-linked fatty acid membrane lipids
- You’ll learn others later



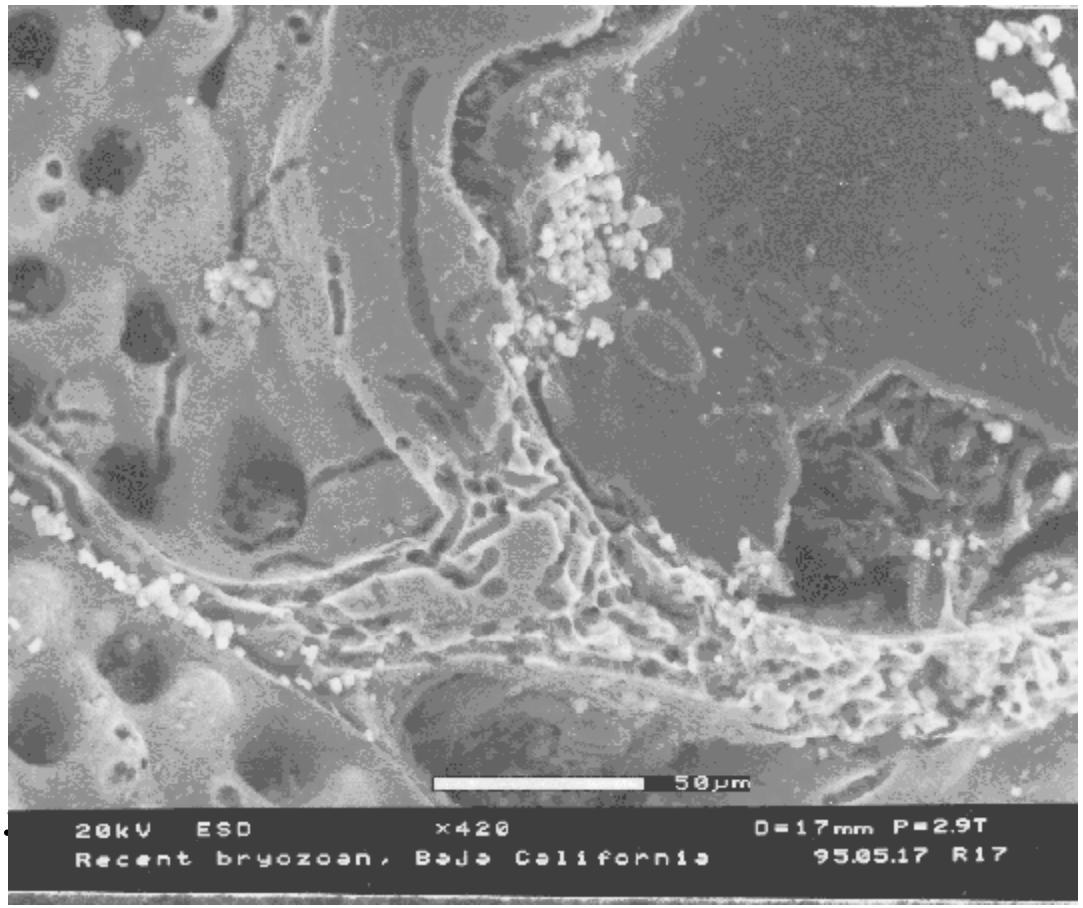
Three Fundamental Kinds of Cells:

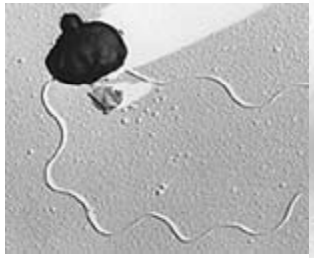
Archaea

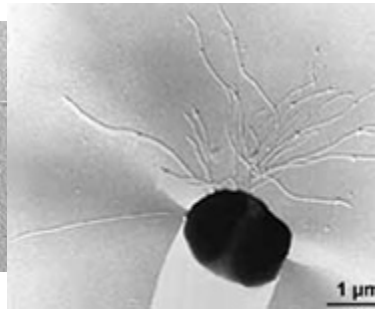
- No Nucleus (DNA = “Nucleoid”)
- Mostly circular chromosomes
- No membranous cytoplasmic organelles
- 70S ribosomes – **More Complex**
- Reproductively haploid
  Asexual reproduction
- Small (usually 1-10 microns)
- Autonomous

Molecular differences from Bacteria.

- 8-subunit RNA polymerase
- Non-peptidoglycan cell wall
- Ether-linked isoprenoid cell membrane lipids
- You’ll learn others later

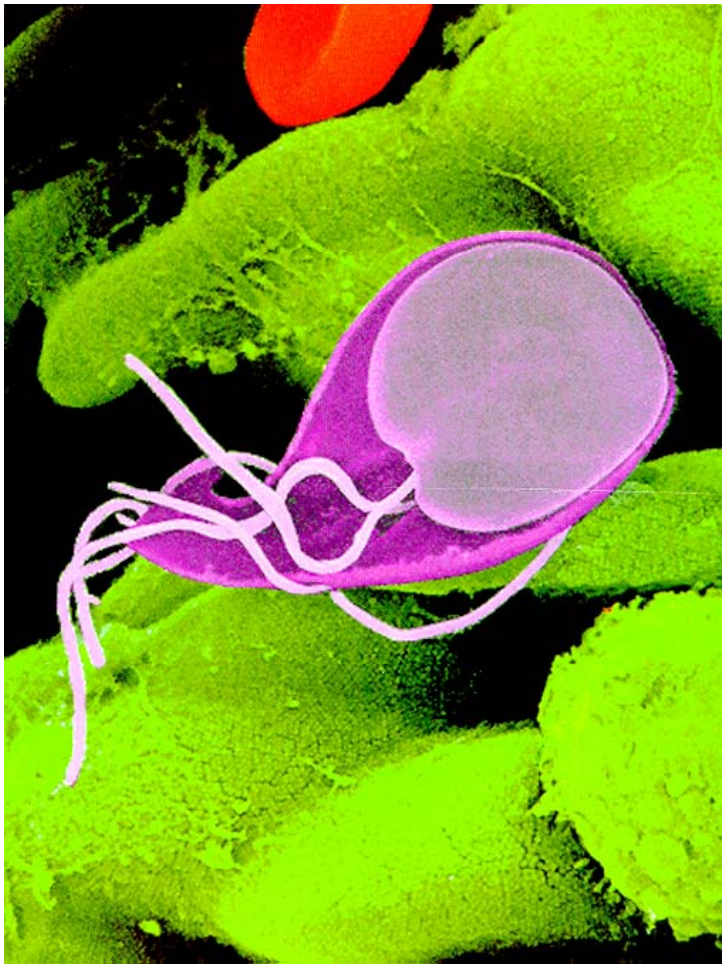






Three Fundamental Kinds of Cells:

Eukaryotic



- Nucleated
- Mostly linear chromosomes
- Membranous organelles
  (mitochondria, chloroplasts, Golgi apparatus, endoplasmic reticulum)
- 80S ribosomes – **Most Complex**
- Reproductively diploid
  sexual reproduction
- Large (usually 8-10 microns)
- *Usually* multicellular

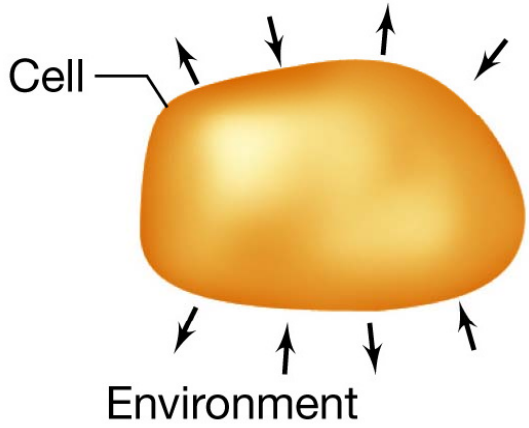
What are the characteristics that define a cell?

-metabolism
-reproduction
-communication
-evolution
-movement
-differentiation

Hallmarks of cellular life

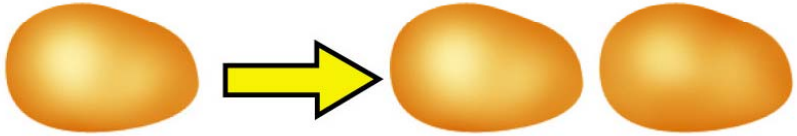
1. Metabolism

Uptake of chemicals from the environment, their transformation within the cell, and elimination of wastes into the environment. The cell is thus an *open* system.



2. Reproduction (growth)

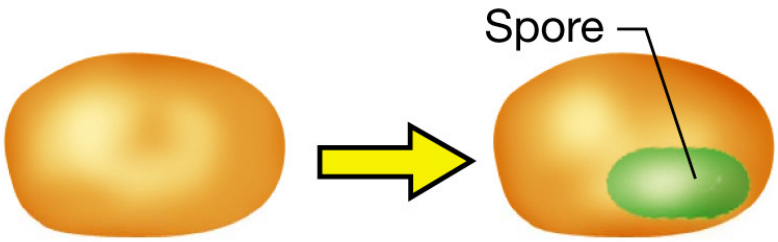
Chemicals from the environment are turned into new cells under the direction of preexisting cells.



Hallmarks of cellular life

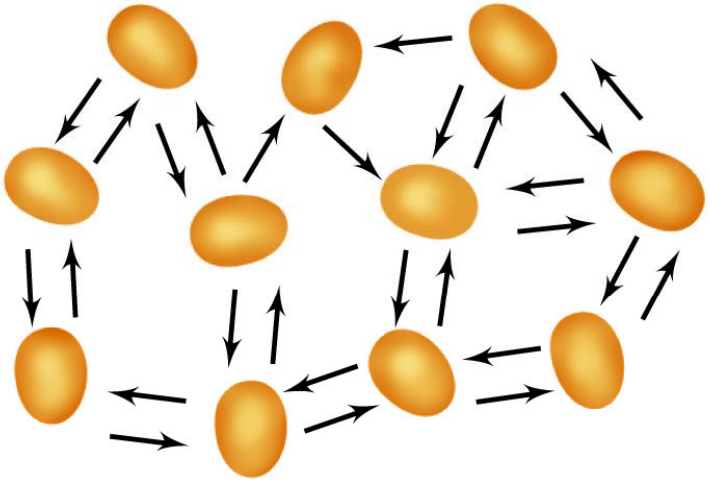
3. Differentiation

Formation of a new cell structure such as a spore, usually as part of a cellular *life cycle*.



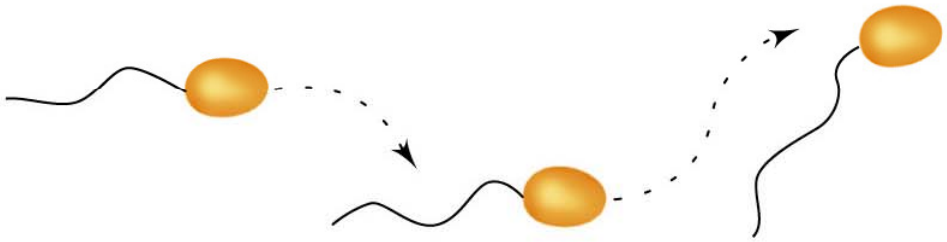
4. Communication

Cells *communicate* or *interact* primarily by means of chemicals that are released or taken up.

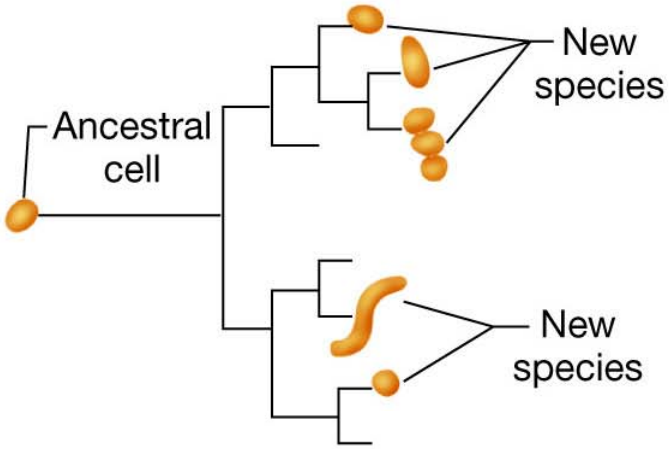


Hallmarks of cellular life

5. Movement
Living organisms are often capable of self-propulsion.



6. Evolution
Cells *evolve* to display new biological properties. Phylogenetic trees show the evolutionary relationships between cells.



WHY STUDY MICROBIOLOGY?

"The role of the infinitely small is infinitely large."

- Louis Pasteur (1862)

WE ARE NOT ALONE!

"We are outnumbered. The average human contains about 10 trillion cells. On that average human are about 10 times as many microorganisms, or 100 trillion cells...As long as they stay in balance and where they belong, [they] do us no harm…In fact, many of them provide some important services to us. [But] most are opportunists, who if given the opportunity of increasing growth or invading new territory, will cause infection."

- Sullivan (1989)

Why study microbes?

1. To understand the rest of life!

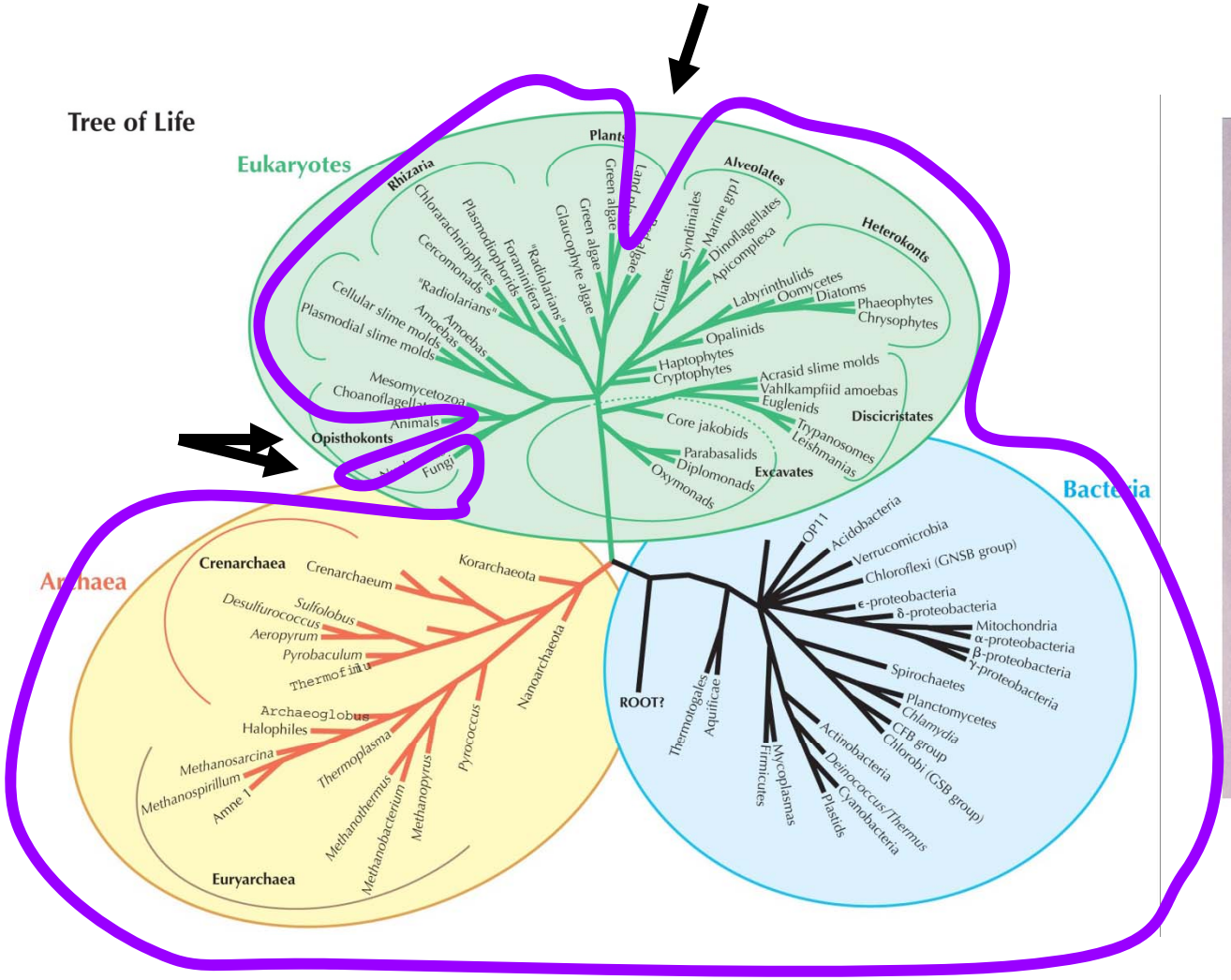
- ***microbes must solve the same basic life problems as multicellular organisms (e.g. replication, DNA repair, nutrient uptake, etc.)***
- **microbes are "low maintenance" in the lab – they don't eat as many bananas as monkeys (or do they?)...**
- **all three domains of life include microbes**

2. To understand our biosphere (geosphere and atmosphere).

- **Microbes are the major players in biosphere homeostasis**

The Earth's biodiversity is 99% microbial.

There are an estimated 5×10^{30} bacterial cells on Earth.



http://archive.niees.ac.uk/talks/egenomics_2006/kowalchuk.ppt

Population densities of microbial populations in different environments

	MOs per gram or per mL*	OTUs per gram or per mL
Typical soil:	~10^9	350-6300
Typical fresh water:	~10^6 to 10^7	?
Open ocean:	~10^5	1000-3300

**Density of H_2O = 1g/mL*

Density does not predict diversity (# of taxa in a community)
Which soil do you think has the most diverse community?

OTUs/g

Native grassland soil
Native Alaskan soil
Agricultural soil
Heavy metal-contaminated soil

Prokaryotes: The unseen majority

Whitman et al., 1998 PNAS

Table 5. Number and biomass of prokaryotes in the world

Environment	No. of prokaryotic cells, $\times 10^{28}$	Pg of C in prokaryotes*
Aquatic habitats	12	2.2
Oceanic subsurface	355	303
Soil	26	26
Terrestrial subsurface	25–250	22–215
Total	415–640	353–546

*Calculated as described in the text.

Rate of turnover controversial:
Cells divide 1X/yr? 1X/100 years?

Pg = Petagram or 10^{15}grams

Subsurface: up to 10 km below surface

Prokaryotes: The unseen majority

Whitman et al., 1998 PNAS

	Total C (Pg)	Total N (Pg)	Total P (Pg)
Plants:	560	12-20	1-2
Prokaryotes:	350-550	70-120	7-12

Take Home Message: Bacteria contain 60 to 100% the cellular carbon of all plants along with ~10x the N and P of plants!

Historical Perspective of Microbiology

1. Ancient History: (pre-1660's)
   - The Age of Sanitation

2. Early History: (1660's to 1850's)
   - The Age of Discovery

3. Microbiology's Renaissance: (1850's to 1920's)
   - The Age of Diagnoses

4. Modern History: (1920's to Present)
   - The Age of Biotechnology

Ancient History: (pre-1660's) - The Age of Sanitation

- Early civilizations (e.g., Crete, India, Pakistan, and Scotland) showed signs of using toilets and sewers dating back as far as 2800 BC.
- The first cities to use Water Pipes made of clay were in the Indus Valley of India around 2700 BC and in the palace of Knossos on Crete around 2000 BC. Metal pipes were used in Egypt as far back as 2450 BC.
- The Romans in 315 AD had public lavatories where people routinely socialized and conducted business. Rome also built elaborate aqueducts and public fountains and had an appointed water commissioner who was responsible for seeing that the water supply was kept clean. Lead was commonly used for Roman pipes and the subsequent fall of the Roman empire has been related by some to this practice.
- The Chinese as early as 589 AD produced toilet paper, while Europeans were still using moss and hay.

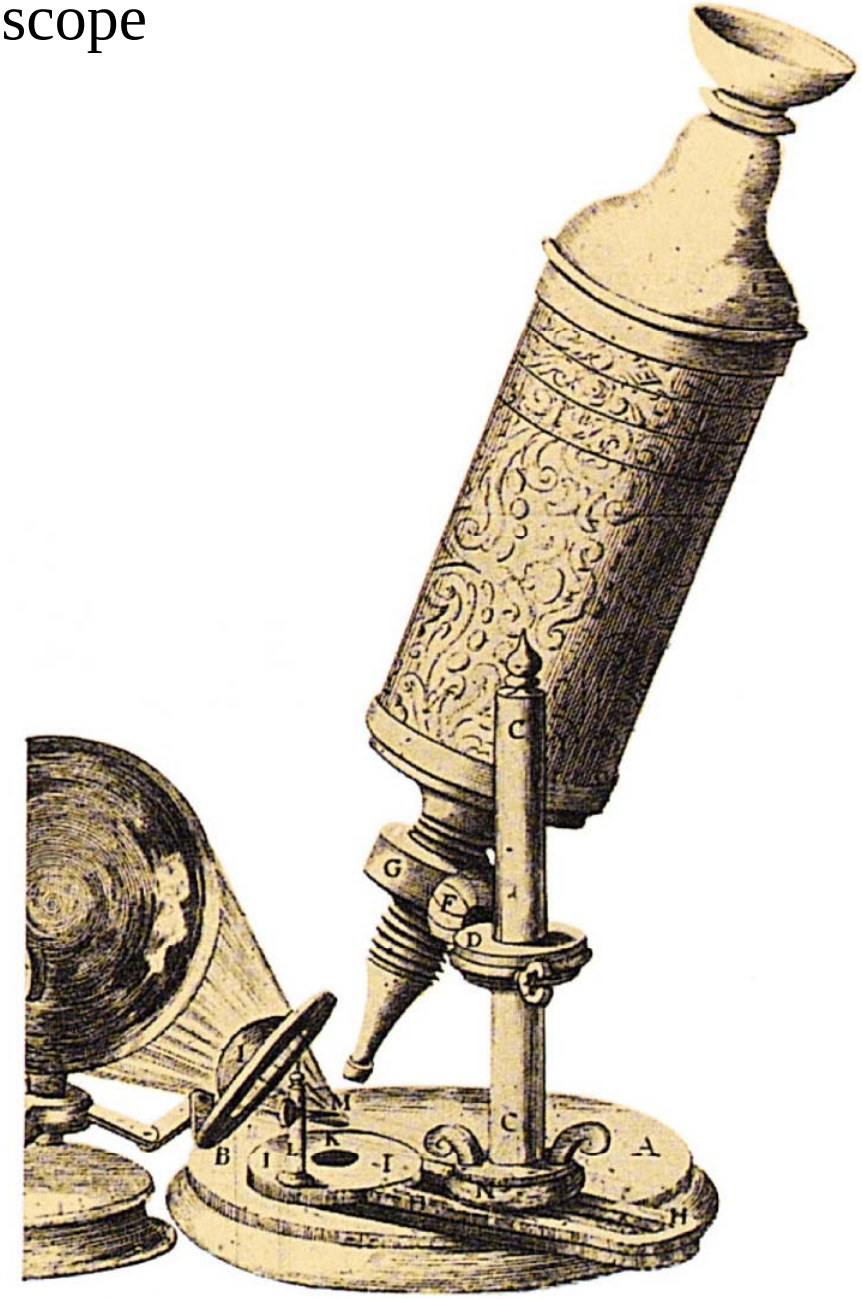
Roman Aqueduct: Sanitation Age

Early History: (1660's to 1850's) - The Age of Discovery

- 1665: **Robert Hooke –** The first person to report seeing MO's under a microscope. He saw the cellular structure of plants and fungi, but his lens were apparently too poor to "see" bacteria.
- 1668: **Francesco Redi** – The first serious attack on the idea of spontaneous generation was made. Redi's experiment proved maggots are not spontaneously produced in rotten meat.
- 1676: **Anton van Leeuwenhoek –** The first to see and describe bacteria and their characteristic morphology. Publishes his drawings of "wee animalcules." Classic example of serendipity, he originally wanting better magnification to judge the quality of cloth.
- Takes 175 years before any major advancements are made:

  1. Technology of producing better microscopes and chemistry.
  2. Leeuwenhoek did not allow others to reproduce and verify his results.
  3. The nature of contagious disease is still paramount.
  4. The question of spontaneous generation lingers.

Robert Hooke’s microscope



(a)

Able to see Mold

(b)

Francesco Redi

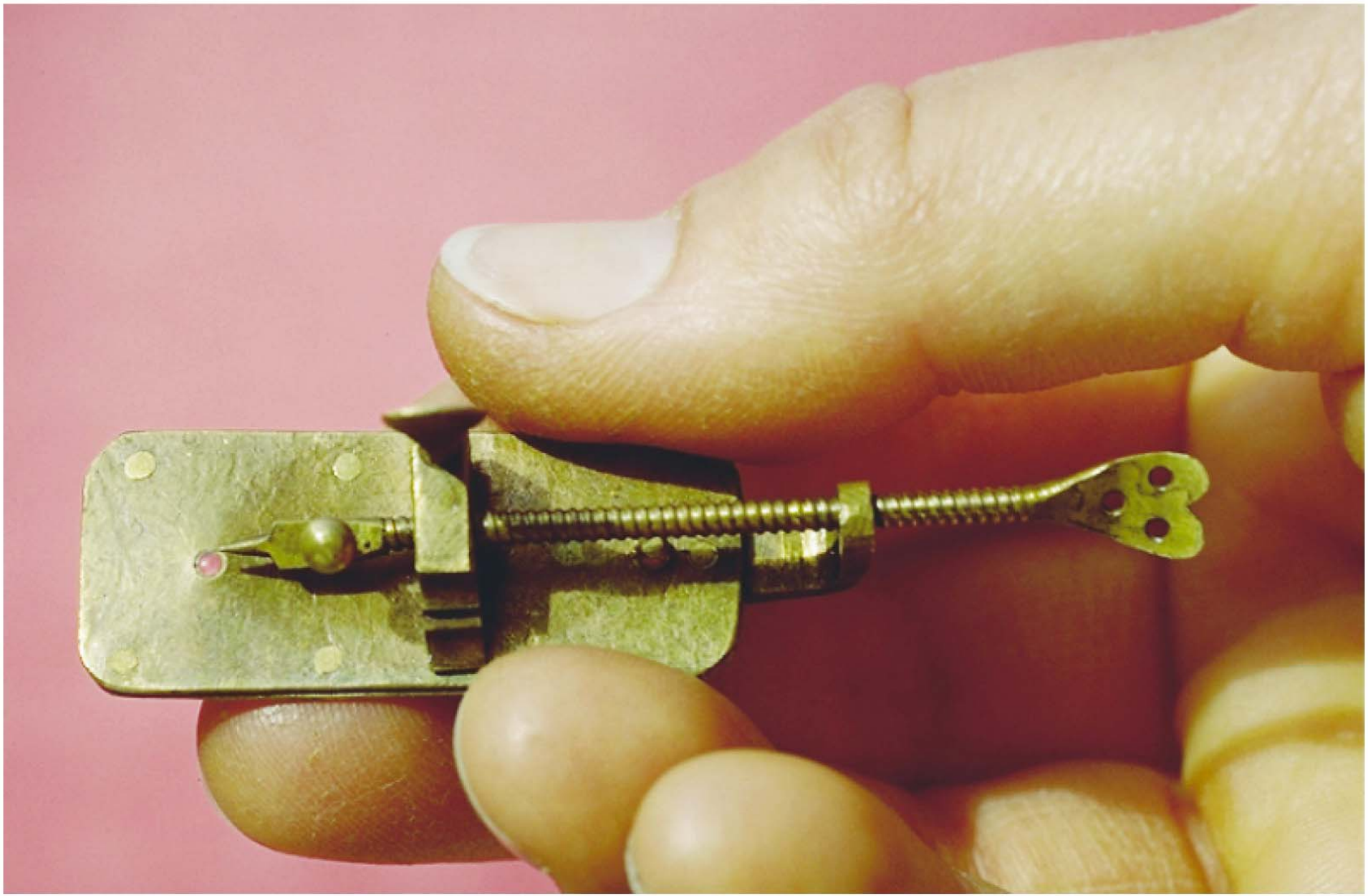
Showed that maggots came from flys.

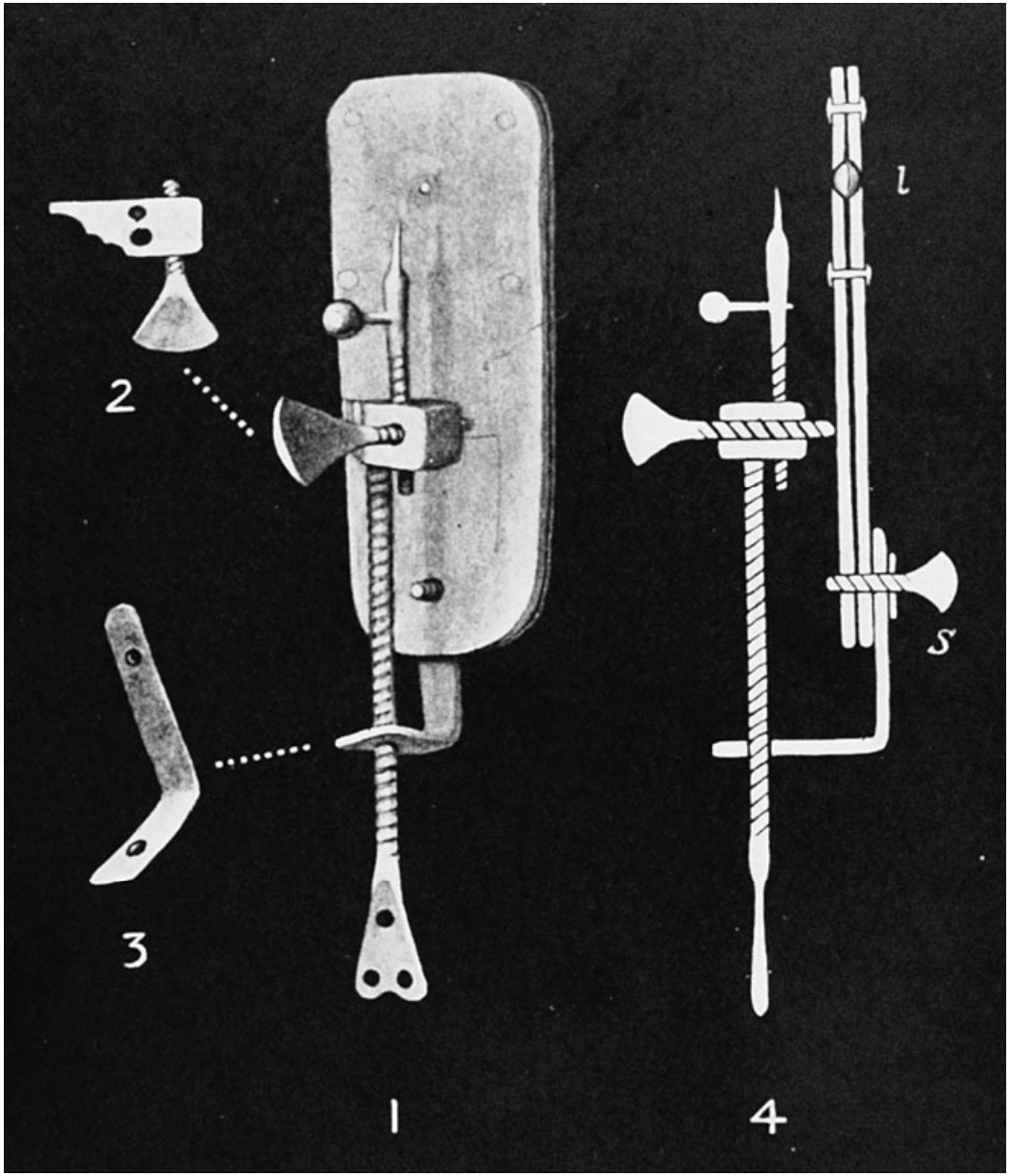
ANTONIUS A LEEUWENHOEK.

Regiæ Societatis Londinensis

membrum.

Verkolje vinx: *I. C. Bleu fe*

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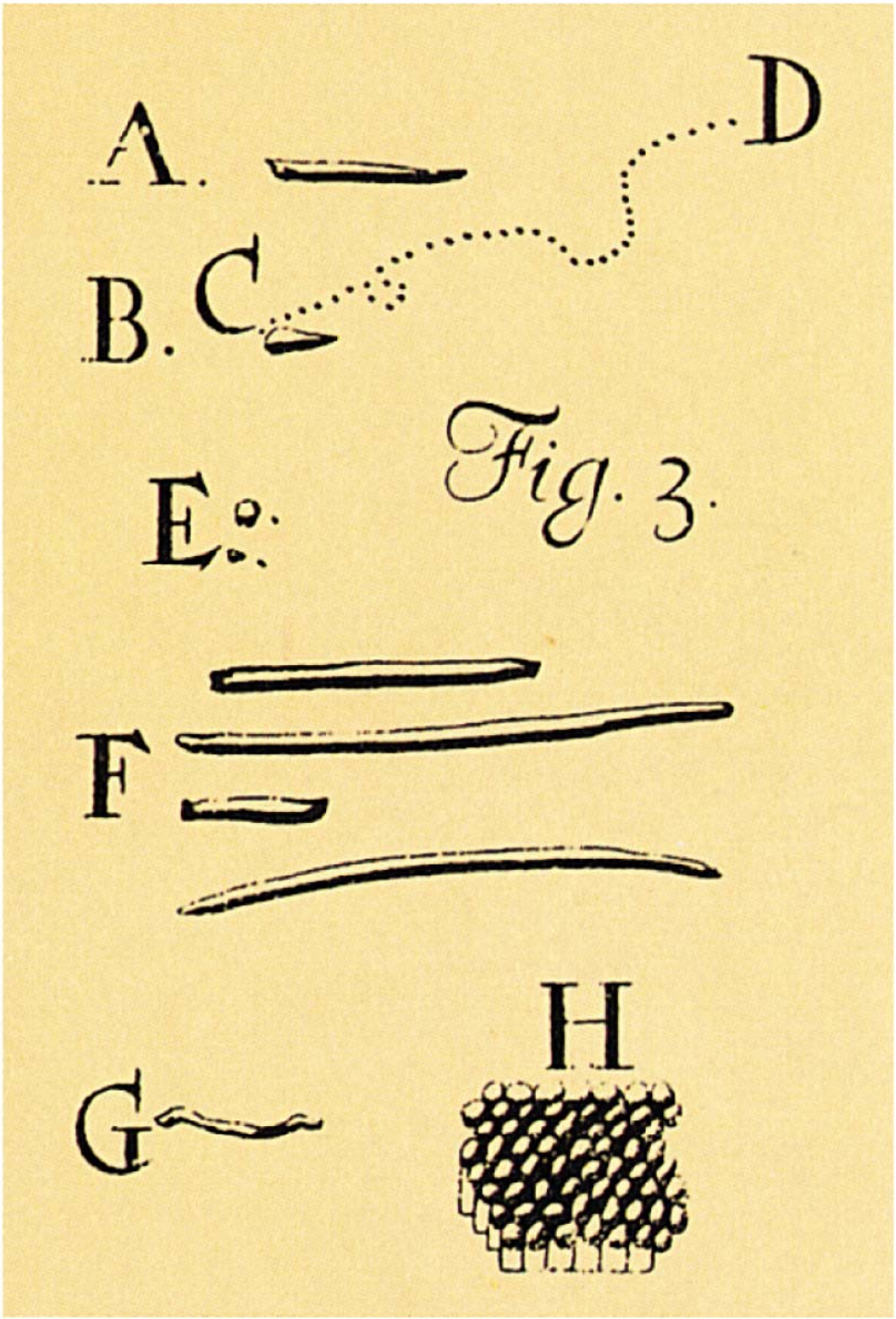
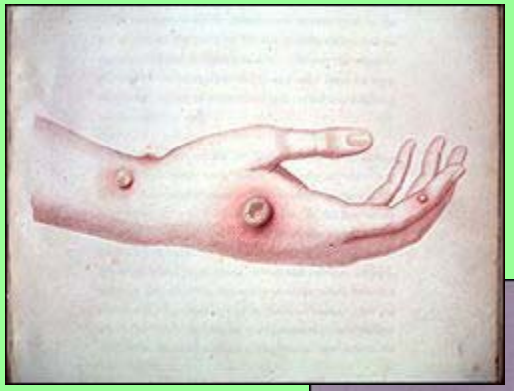


Fig. 3.

Early History: (1660's to 1850's) - The Age of Discovery

- 1798: **Edward Jenner** introduces the concepts of vaccination using cowpox material to prevent small pox, unfortunately many questions left unanswered.
- Late 1840's: **Ignaz Semmelweis** reduces infant mortality in hospitals but many think he is nuts.....no germ theory yet!
- 1804-1806: The Lewis and Clark Expedition.

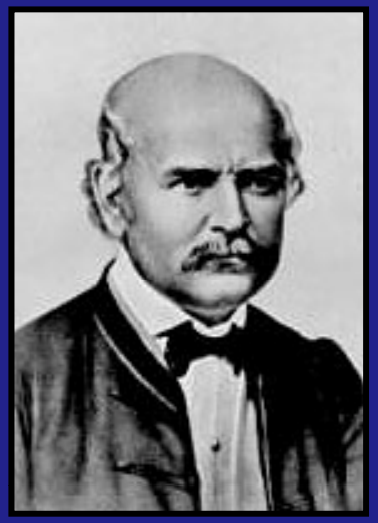
Edward Jenner



Variolation to Vaccination

- Variolation, immunization against smallpox, was a common practice before vaccination was common. This worked because the patient was exposed to a weak strain of smallpox, which did not kill, yet provided immunity to the disease.
- Edward Jenner discovered that cowpox could protect against smallpox, with a much lower incidence of complications than variolation.
- Pasteur actually coined the term vaccination to describe the technique.

Ignaz Semmelweis: aseptic technique to halt germ spread (1818-1865)



http://www.m-ww.de/persoenlichkeiten/semmelweis.html

Childbed fever:

- endometrium infection by Group A *Streptococcus*

Spread by med students but not midwives

Wash hands frequently:

- Reduced death rate from 18.3 to 1.3% in one year

Irony:

Semmelweis died of *Streptococcus* infection in mental hospital after getting tricked to enter.

Microbiology's Renaissance: (1850's to 1920's) - The Age of Diagnoses

- 1859: **Louis Pasteur** settles the question of spontaneous generation once and for all with "simple" experiments using swan necked flasks. Microbiology becomes a truly scientific discipline as MO's are now known to have the same fundamental properties as other living organisms, aka Germ Theory.

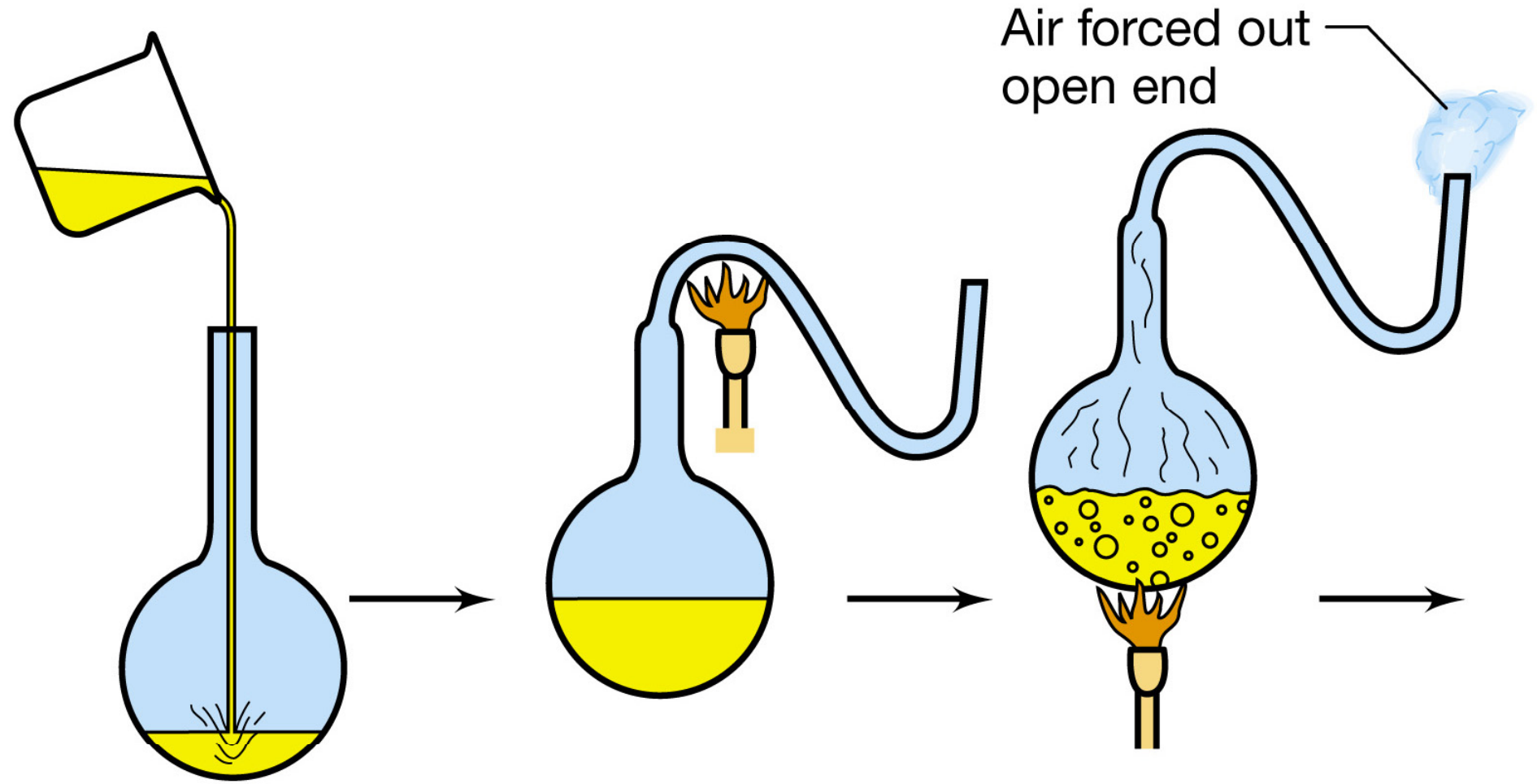
- He contributed to the development of the first vaccines for the immunization against rabies, anthrax, and chicken cholera. He described the scientific basis for fermentation, wine-making, and the brewing of beer. And don't forget Pasteurization, which was originally used to prevent Napoleon's sailors from mutiny and the production of canned food for his armies!

- 1859: Charles Darwin publishes the Origin of the species.

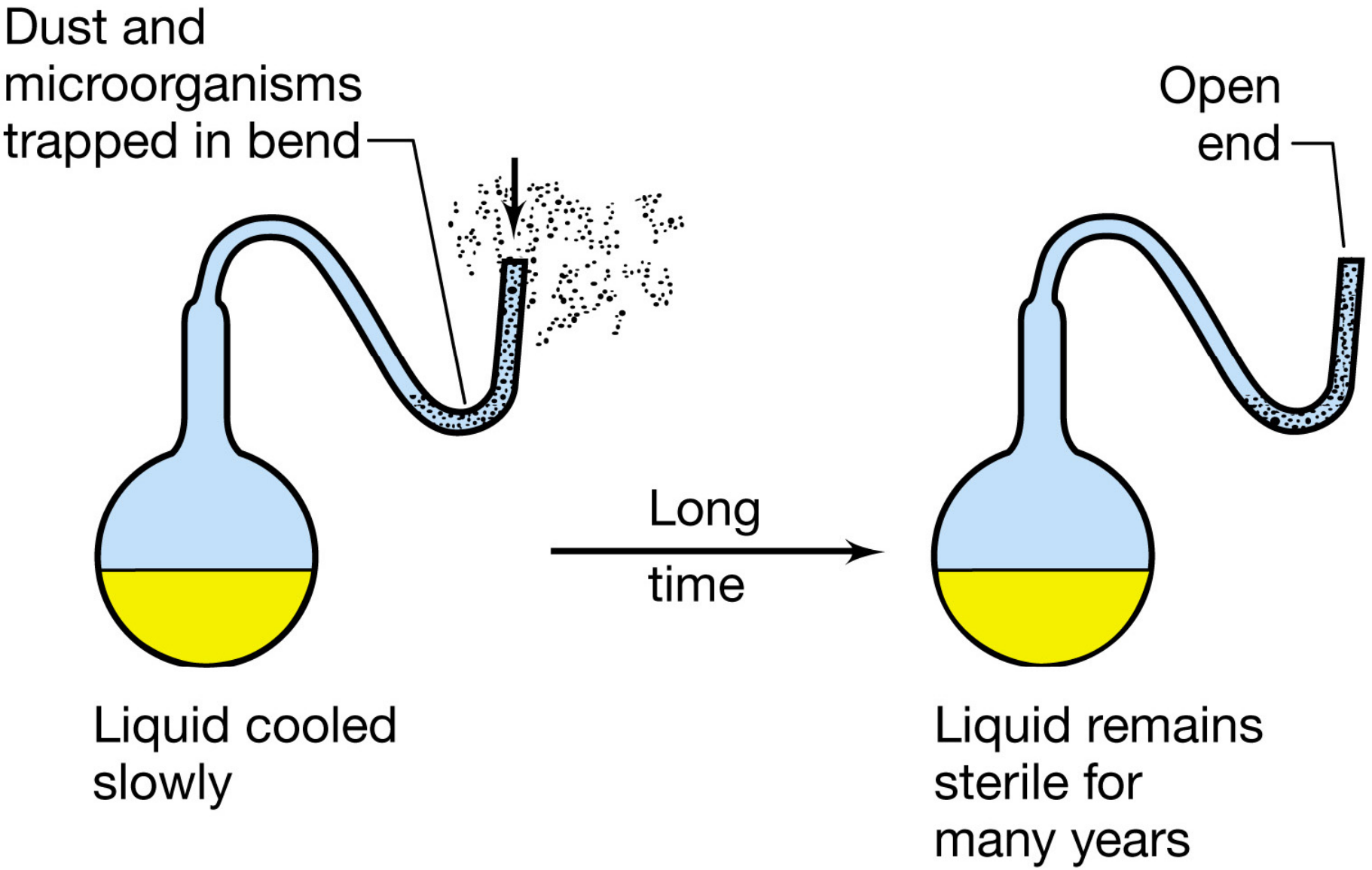
- 1867: **Joseph Lister** – Revolutionized medicine by introducing practices to limit the exposure to infectious MO's during surgery. Developed antiseptic methods for preventing infection using phenol (toxic!) to treat wounds.

Louis Pasteur

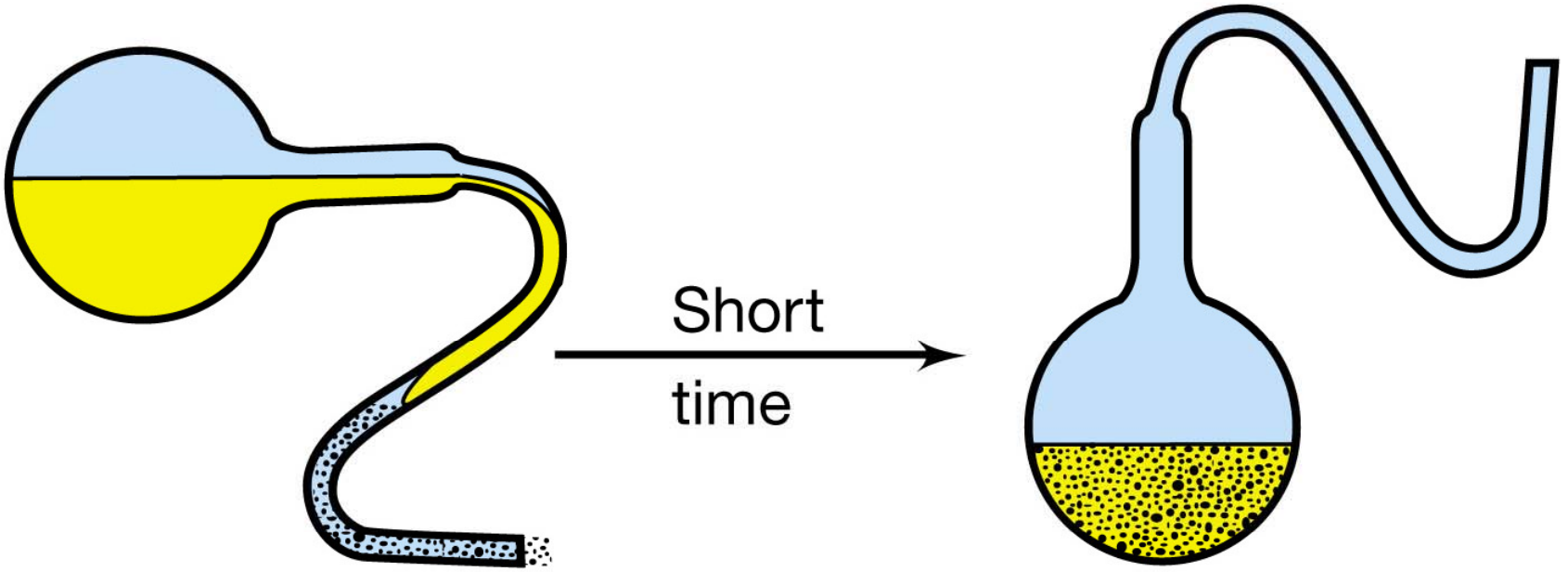
Pasteur’s swan-necked flasks



Pasteur's swan-necked flasks



Pasteur’s swan-necked flasks



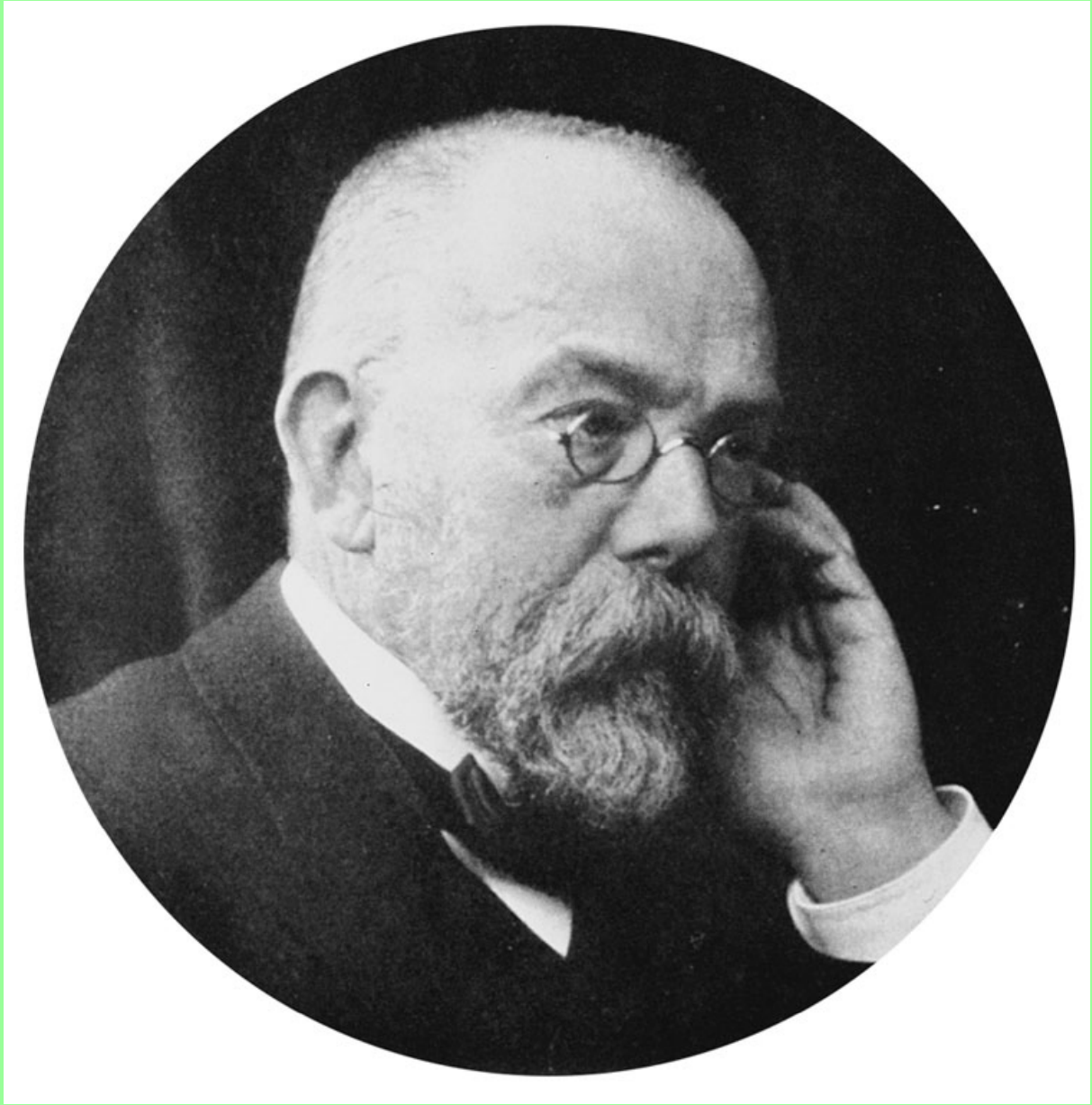
(c) Flask tipped so microorganism-laden dust contacts sterile liquid

Microorganisms grow in liquid

Joseph Lister is known as the founder of antiseptic surgery.

Microbiology’s Renaissance: (1850's to 1920's) - The Age of Diagnoses

- 1876: **Robert Koch –** Established the relationship between MO’s and infectious disease. Determined Koch’s postulates. Discovered causative agent for anthrax, tuberculosis, and cholera. His discoveries, in combination with those of Pasteur, established the **Germ Theory** of disease.
- 1881: **Paul Ehrlich** (working in Koch’s lab) introduces vital staining with methylene blue and the visualization of bacteria is greatly improved. Later credited for early work with chemotherapy (chemicals to treat disease).
- 1882: **Walter Hesse (and wife Fannie) –** uses Agar as solid growth medium.
- 1884: **Hans Christian Gram –** develops a differential staining method, which exploits the difference between two basic variations in cell wall structure and is still essential in the classification of bacteria.
- 1884: Mark Twain writes Huckleberry Finn. Koch’s Postulates are published.
- 1887: **Richard Petri** – describes the utility of the Petri dish.



Robert Koch

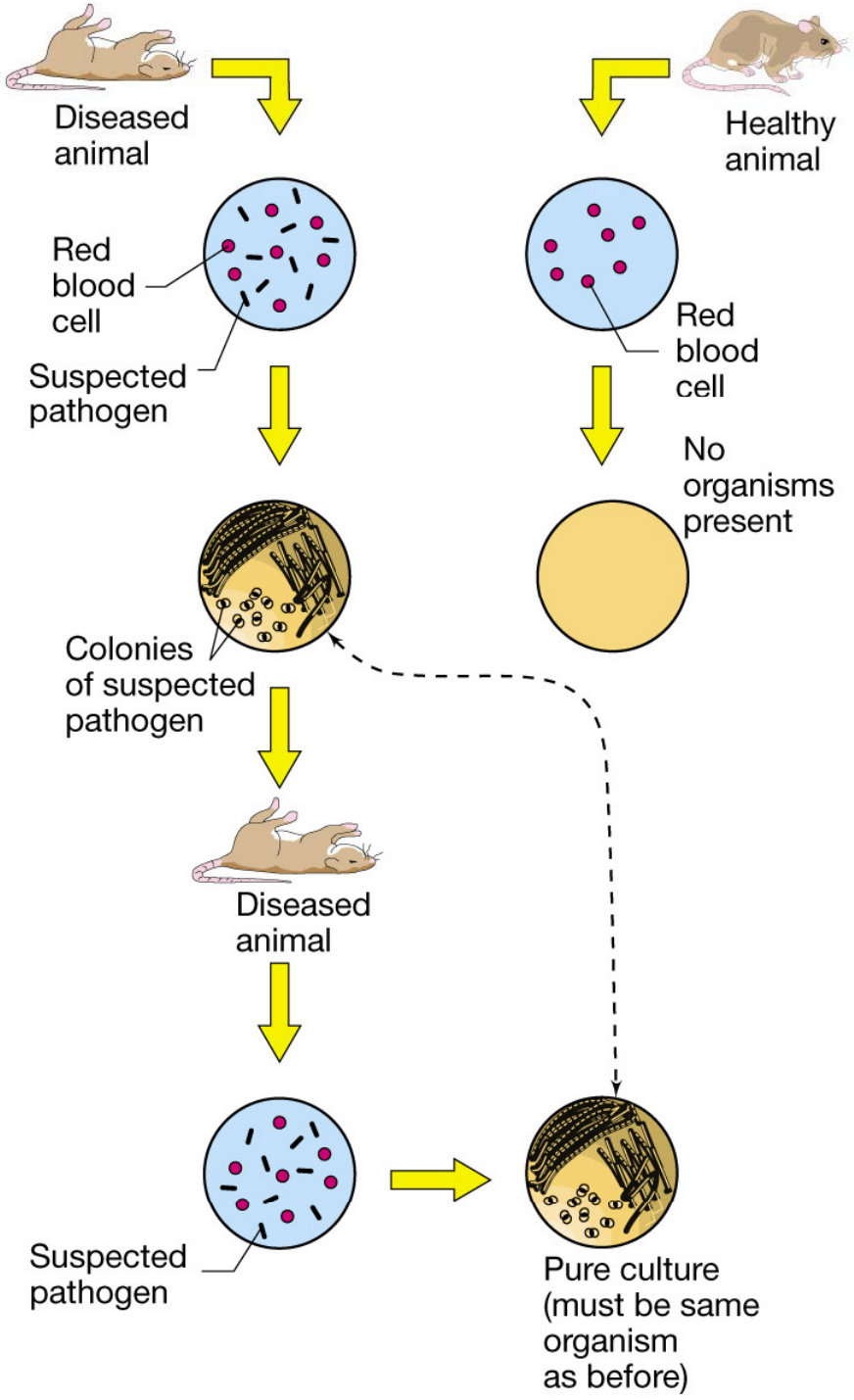
Koch's Postulates:

(1) The suspected pathogenic organism should be present in all cases of disease and absent from healthy animals.

(2) The suspected organism should be grown in pure culture.

(3) Cells from a pure culture of the suspected organism should cause disease in a healthy animal.

(4) The organism should be reisolated and shown to be the same as the original.



Four questions that drove early microbiology

1. What is the origin of life (does spontaneous generation occur)?

2. Fermentation: Why does wine go bad (acidic)? What causes fermentation?

3. What causes contagious disease?

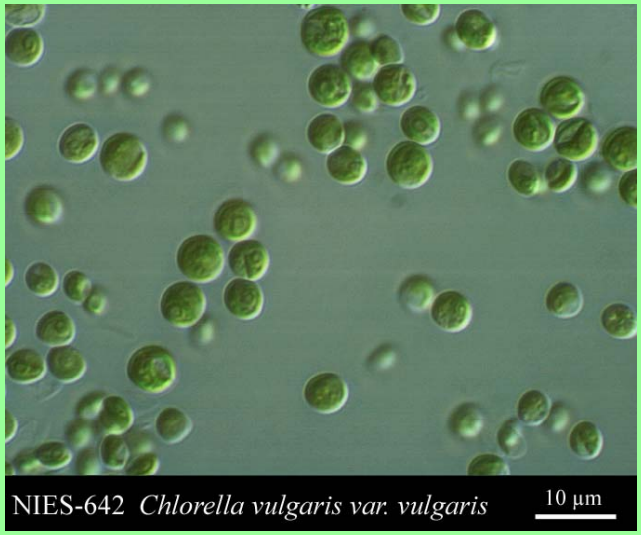
4. OK, microbes cause disease (germ theory).
   How do we prevent and treat disease?

Microbiology's Renaissance: (1850's to 1920's) - The Age of Diagnoses

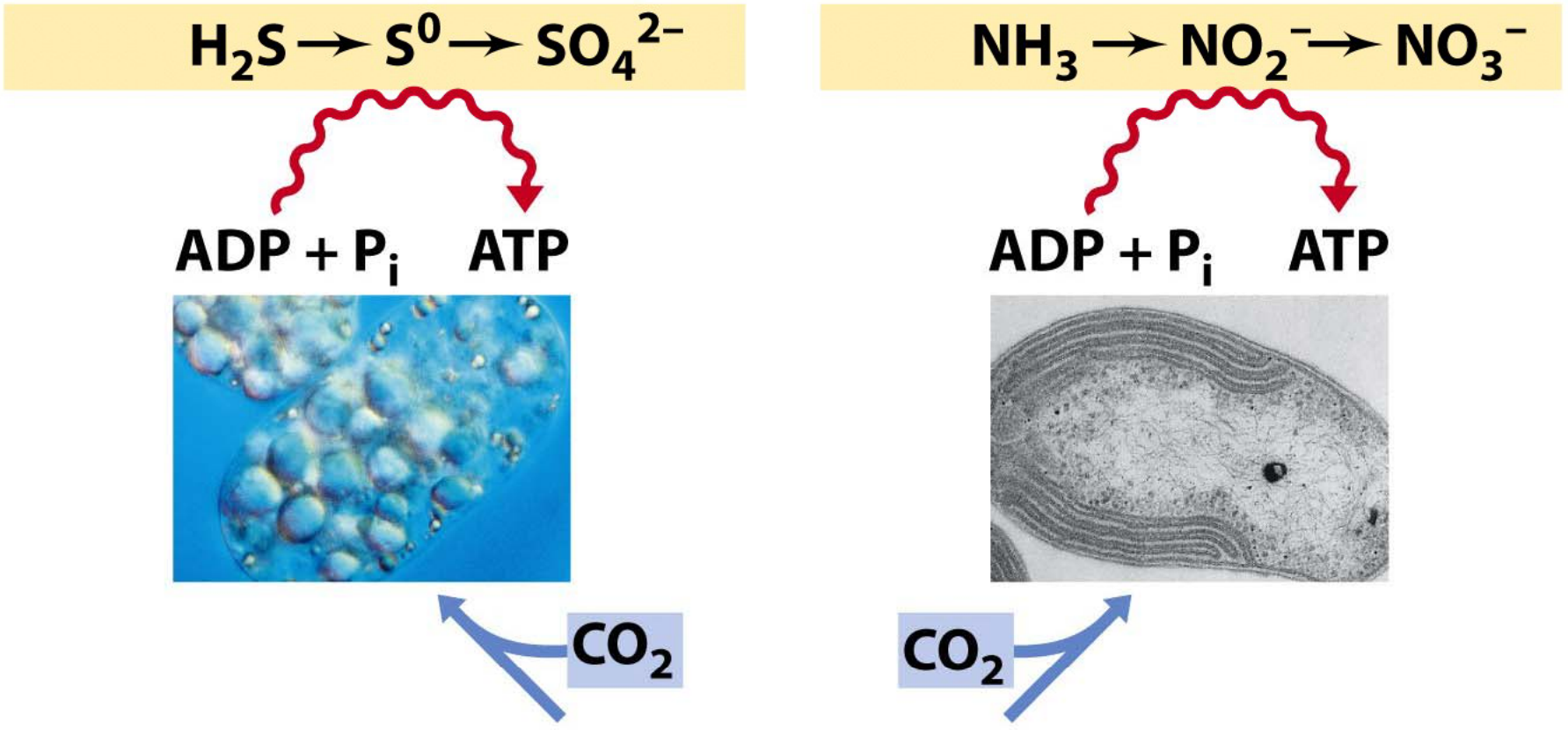
- 1889-91: **Sergei Winogradsky and Martinus Beijerinck –** cofounders of microbial ecology, each made significant discoveries concerning microbial transformations of inorganic compounds aka **chemolithotrophy**. First to develop ideas in biogeochemical cycling on a global scale.
- Winogradsky isolated and described nitrifying bacteria NH_4+ to NO_2- and NO_3- (cations to anions) and other redox reactions including S and Fe and anaerobic N-fixing bacteria.
- Famous for Winogradsky column used to study anaerobic photosynthesis.
- Beijerinck established enrichment culture techniques for the isolation of pure cultures. Isolated anaerobic sulfate reducing bacteria and symbiotic and non-symbiotic aerobic N-fixing bacteria.
- Famous for the statement: "Everything is everywhere, the environment selects."

Sergei Winogradsky

Martinus Beijerinck



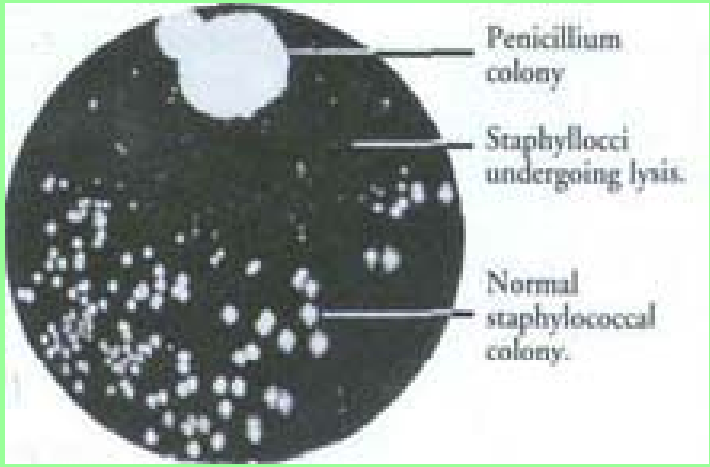
Chemolithotrophy



Chemoautotrophy

Modern History: (1920's to Present) - The Age of Biotechnology

- 1929: **Alexander Fleming** discovers penicillin. An antibiotic produced by a fungus that inhibits bacterial growth.
- 1928: **Fred Griffith** – transforms *Streptococcus pneumoniae*.
- 1933: Invention of the electron microscope.
- 1937: First division of living organisms into prokaryotes and eukaryotes.
- 1940s: **Beadle and Tatum** – One gene-one enzyme hypothesis.
- 1941: **Oswald Avery** – DNA is the genetic material.
- 1953: **Watson and Crick** – DNA structure as double helix.
- 1960s: **Jacob and Monod** – Operon theory, control over enzyme expression.
- 1969: First Man on the Moon – Apollo 11, Neil Armstrong and Buzz Aldrin.
- 1977: **Fred Sanger** – DNA sequencing techniques. Discoveries of both *Archaea* and hydrothermal vents with the submersible Alvin happen this year too.



In 1928, **Alexander Fleming**, a microbiologist working at St. Mary's Hospital in London discovered penicillin. Initially due to purification difficulties and the substance's instability he dismissed the substance as a laboratory curiosity. In 1939, Drs. Howard Florey and Ernst Chain working at Oxford, used freeze drying to stabilize pure penicillin. Using the freeze dried formulation they were able to carry out successful trials, demonstrating the antibiotic's effectiveness. Fleming, Florey and Chain shared the 1945 Nobel prize in medicine for this work.

Modern History: (1920's to Present) - The Age of Biotechnology

- **1980's:**

Genetic manipulation and cloning (PCR).
AIDS and causative agent HIV.
Ribozymes or catalytic RNAs.
RNAs used historical documents – Molecular phylogeny reshapes biological systematics to 3 domains of life.

- **1990's:**

GEMs or genetically engineered microorganisms.
Prions or specific protein pathogens.
Dolly the sheep.
Full genome sequences.

- **2000's:**

Ed DeLong's contributions to marine microbiology.
Craig Venter's environmental genome shotgun sequencing.
What's next???

Archaeoglobus fulgidus Genome

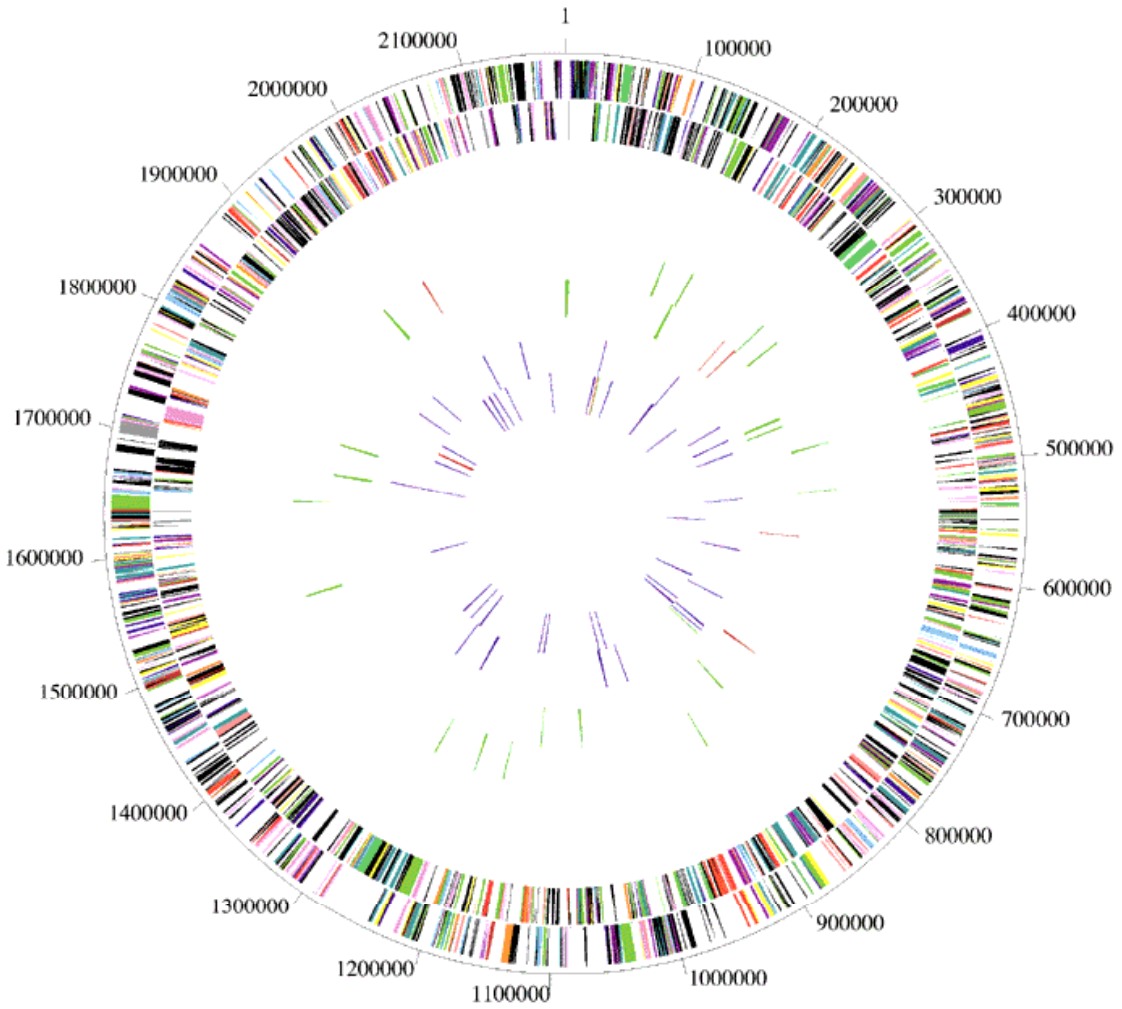
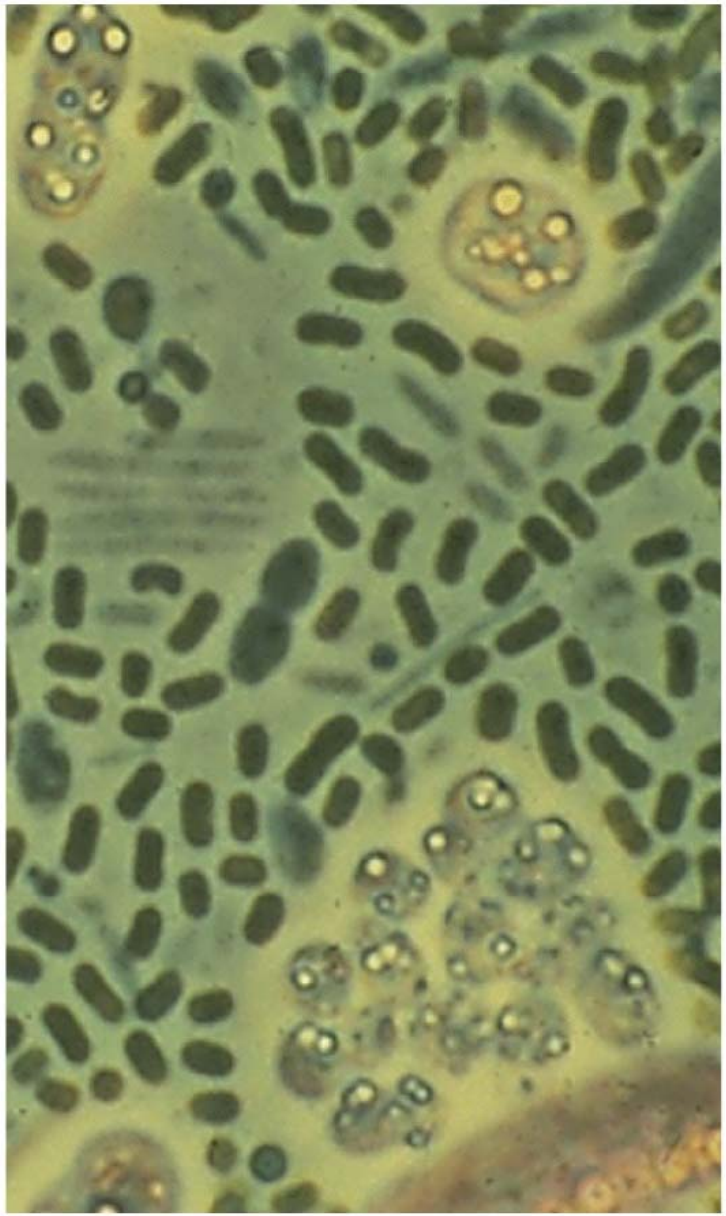
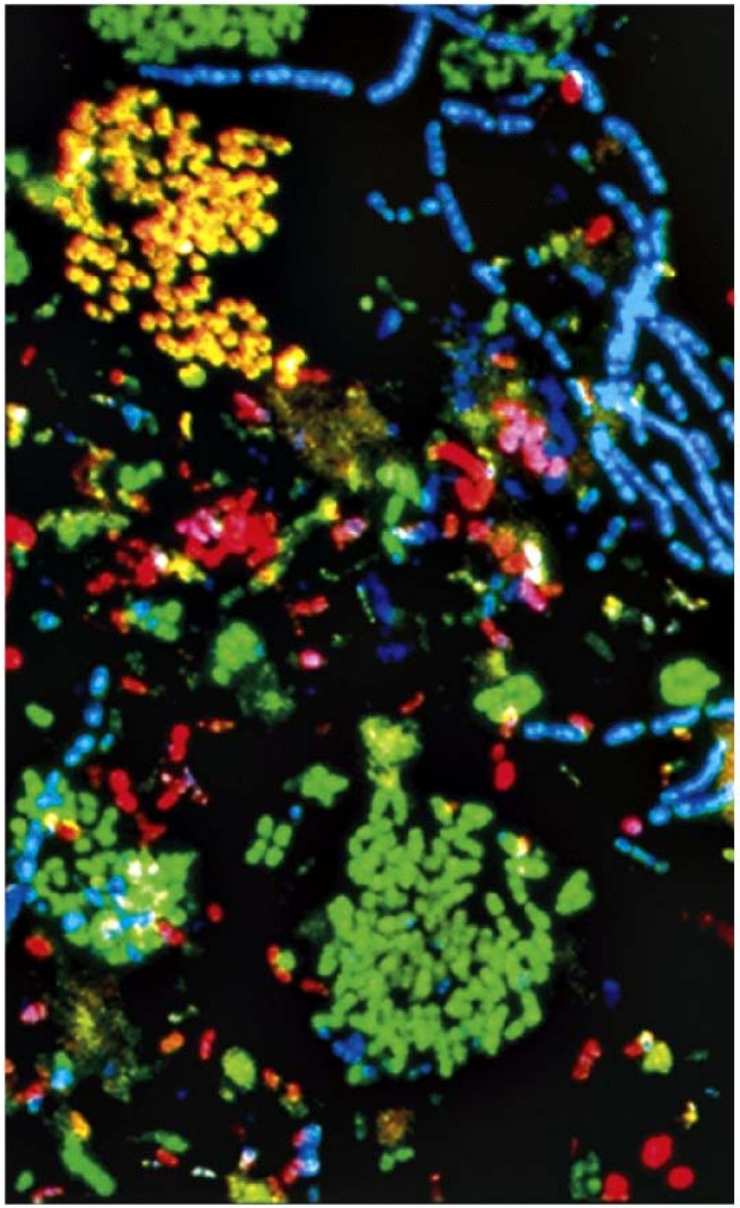


Figure Legend:
A circular representation of the *A. fulgidus* genome illustrating the location of each predicted coding region as well as selected features of the genome. Outer concentric circle: predicted coding regions on the + strand classified as to role. Second concentric circle: predicted coding regions on the - strand. Third and fourth concentric circles: IS elements (red) and repeats (blue) on the + and - strand, respectively. Fifth and sixth concentric circles: tRNAs (blue), rRNAs (red) and small stable RNAs (green) on the + and - strand, respectively.

Improvements in microscopy





Proteorhodopsin phototrophy in the ocean

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† These authors contributed equally to this work

Proteorhodopsin[1], a retinal-containing integral membrane protein that functions as a light-driven proton pump, was discovered in the genome of an uncultivated marine bacterium; however, the prevalence, expression and genetic variability of this protein in native marine microbial populations remain unknown. Here we report that photoactive proteorhodopsin is present in oceanic surface waters. We also provide evidence of an extensive family of globally distributed proteorhodopsin variants. The protein pigments comprising this rhodopsin family seem to be spectrally tuned to different habitats—absorbing light at different wavelengths in accordance with light available in the environment. Together, our data suggest that proteorhodopsin-based phototrophy is a globally significant oceanic microbial process.

From Nature, 2001

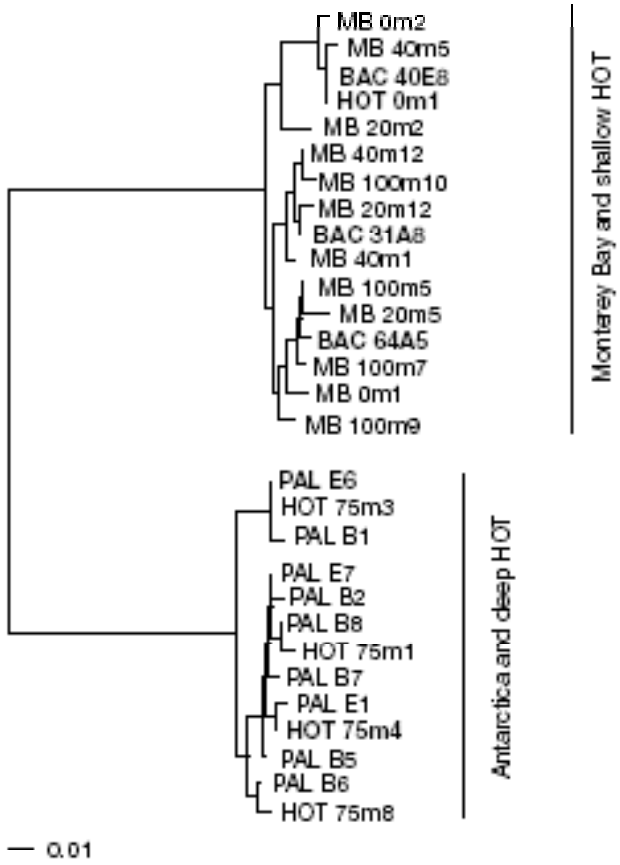

Figure 3 Phylogenetic analysis of the inferred amino-acid sequence of cloned proteorhodopsin genes. Distance analysis of 220 positions was used to calculate the tree by neighbour-joining using the PaupSearch program of the Wisconsin Package version 10.0 (Genetics Computer Group; Madison, Wisconsin). *H. salinarum* bacteriorhodopsin was used as an outgroup, and is not shown. Scale bar represents number of substitutions per site. Bold names indicate the proteorhodopsins that were spectrally characterized in this study.

Take Home Messages:

May the real “bacteriorhodopsin” Please stand up!

Major new way to make ATP in the ocean.

Two distinct “flavors” or evolutionary trajectories.

Environmental Genome Shotgun Sequencing of the Sargasso Sea

J. Craig Venter,[1]* Karin Remington,[1]John F. Heidelberg,[3] Aaron L. Halpern,[2] Doug Rusch,[2] Jonathan A. Eisen,[3] Dongying Wu,[3] Ian Paulsen,[3] Karen E. Nelson,[3] William Nelson,[3] Derrick E. Fouts,[3] Samuel Levy,[2] Anthony H. Knap,[6] Michael W. Lomas,[6] Ken Nealson,[5] Owen White,[3] Jeremy Peterson,[3] Jeff Hoffman,[1] Rachel Parsons,[6] Holly Baden-Tillson,[1] Cynthia Pfannkoch,[1] Yu-Hui Rogers,[4] Hamilton O. Smith[1]

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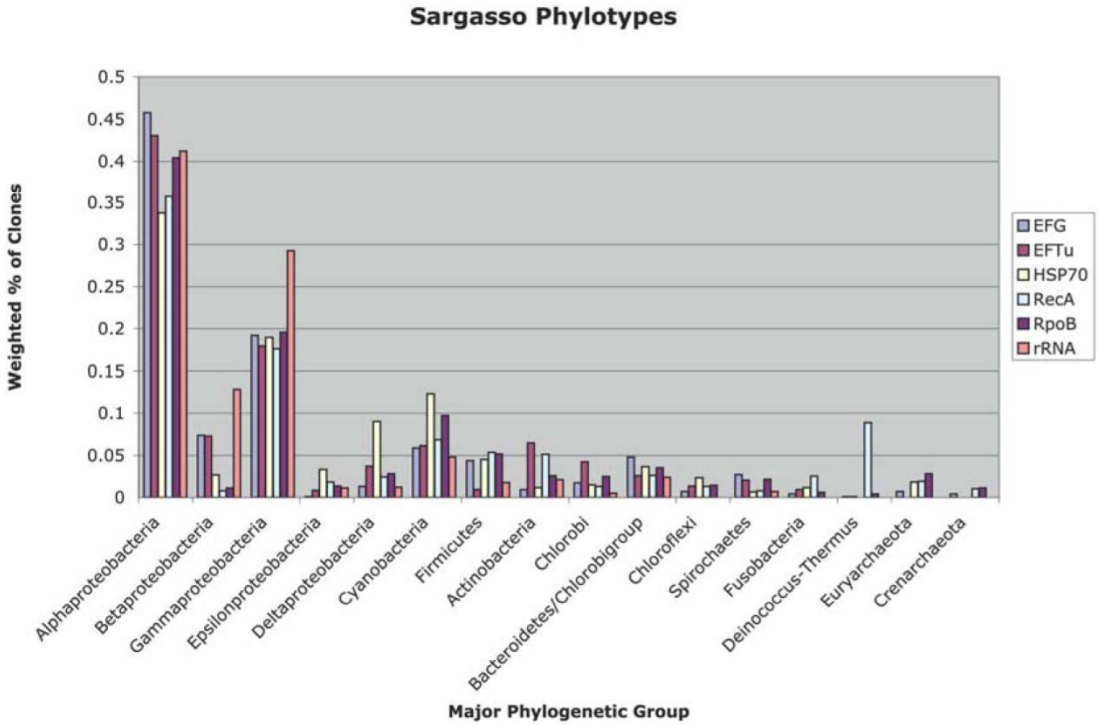
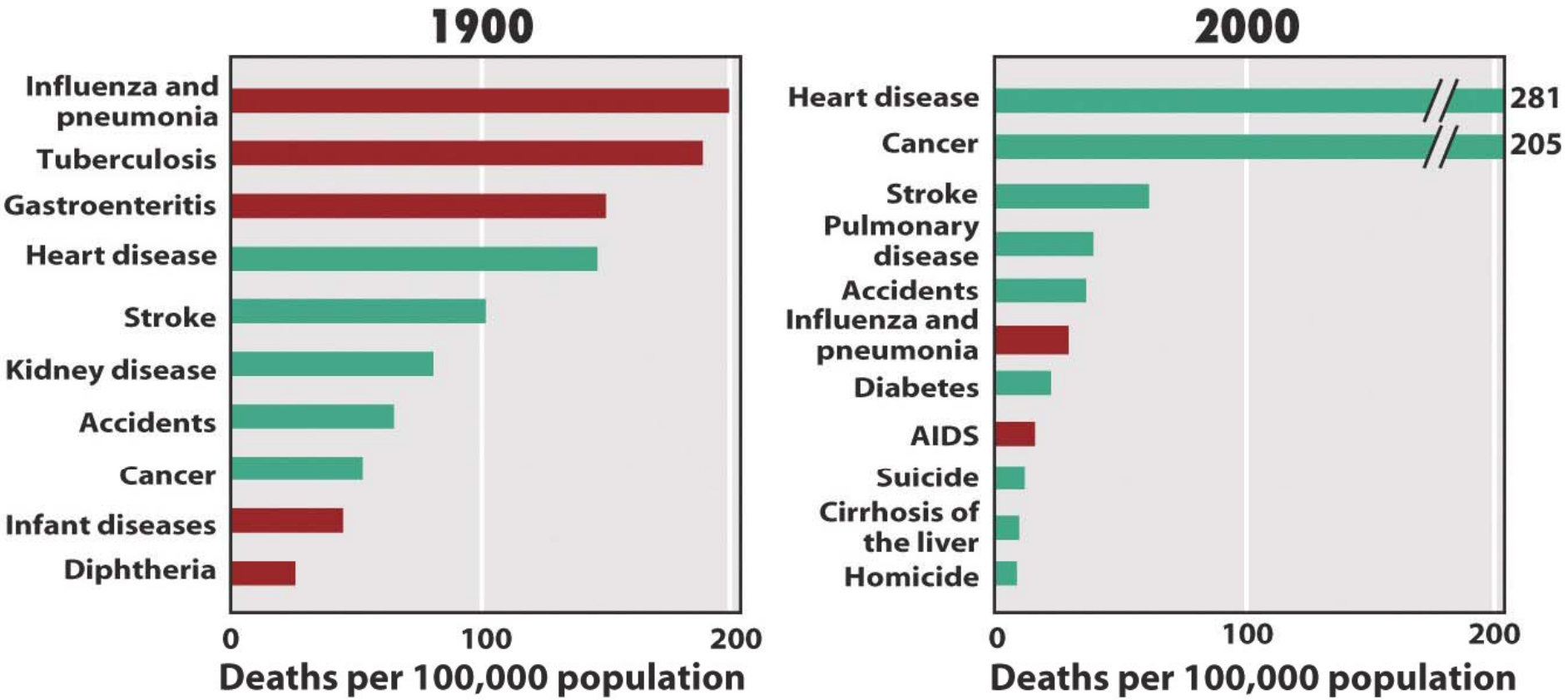
We have applied "whole genome shotgun sequencing" to microbial populations collected *en mass* on tangential flow and impact filters from sea water samples collected from the Sargasso Sea near Bermuda. A total of 1.045 billion basepairs of non-redundant sequence was generated, annotated and analyzed to elucidate the gene content, and diversity and relative abundance of the organisms within these environmental samples. These data are estimated to derive from at least 1800 genomic species based on sequence relatedness, including 148 novel bacterial phylotypes. We have identified over 1.2 million new genes represented in these samples, including more than 782 new rhodopsin-like photoreceptors. Variation in species present and stoichiometry suggests substantial oceanic microbial diversity.



From Nature, 2004

Comparative death rates over the last century in terms of top 10 lists

Key:
Green are non-microbial diseases,
Red are microbial diseases.


1900
Influenza and pneumonia
Tuberculosis
Gastroenteritis
Heart disease
Stroke
Kidney disease
Accidents
Cancer
Infant diseases
Diphtheria
0
100
200
Deaths per 100,000 population
2000
Heart disease
281
Cancer
205
Stroke
Pulmonary disease
Accidents
Influenza and pneumonia
Diabetes
AIDS
Suicide
Cirrhosis of the liver
Homicide
0
100
200
Deaths per 100,000 population

“The microbes will have the last word.”

- Louis Pasteur