Microbiology: A Systems Approach, 2nd ed.

Chapter 1:

The Main Themes of Microbiology

Chapter 1

Topics

- The Scope of Microbiology
- Impact of Microorganisms
- Human use of Microorganisms
- Infectious diseases and the human condition
- The General Characteristics of Microorganisms
- History of Microbiology
- Systematics (Taxonomy) and Evolution

1.1 The Scope of Microbiology

- **Microbiology**: The study of living things too small to be seen without magnification
  - **Microorganisms** or **microbes** - microscopic organisms
  - Commonly called “germs, bugs, viruses, agents…” but not all terms are accurate.
  - Not all cause disease (most of them are benign)
  - Many of them are useful or even essential for human life

Major Groups of Microorganisms

- **Bacteria**, **Archaea**, **Algae**, **Protozoa**, **Helminthes**, and **Fungi**
- **Viruses**- non-cellular, parasitic, protein-coated genetic elements that can infect all living things, including other microorganisms (most microbiologists do not consider viruses "microorganisms" but "pathogens")

Branches of Microbiology

- Agricultural microbiology
- Biotechnology
- Food, dairy, and aquatic microbiology
- Genetic engineering and recombinant DNA technology
- Immunology
- Public health microbiology and epidemiology
- Many, many more

Emerging Areas of Microbiology

- Emerging Pathogens
- Marine microbiology
- Geo-microbiology
- Astro- (Exo)-microbiology

Importance of Microbiology

- First cellular organisms were bacteria
- Primary production and decomposition as part of global biogeochemical cycles
- Human use of microorganisms
- Importance for human health
- Infectious diseases

1.2 The Impact of Microbes on Earth: Small Organisms with a Giant Effect

- Microorganisms have a profound influence on all aspects of the earth and its residents

- Bacterial-like organisms in the fossil record as far back as 3.8 billion years ago (**prokaryotes**- "organisms without a true nucleus")

- ~2 billion years ago, **eukaryotes** ("organisms with a true nucleus") emerged

Bacteria appeared approximately 3.8 billion years ago.

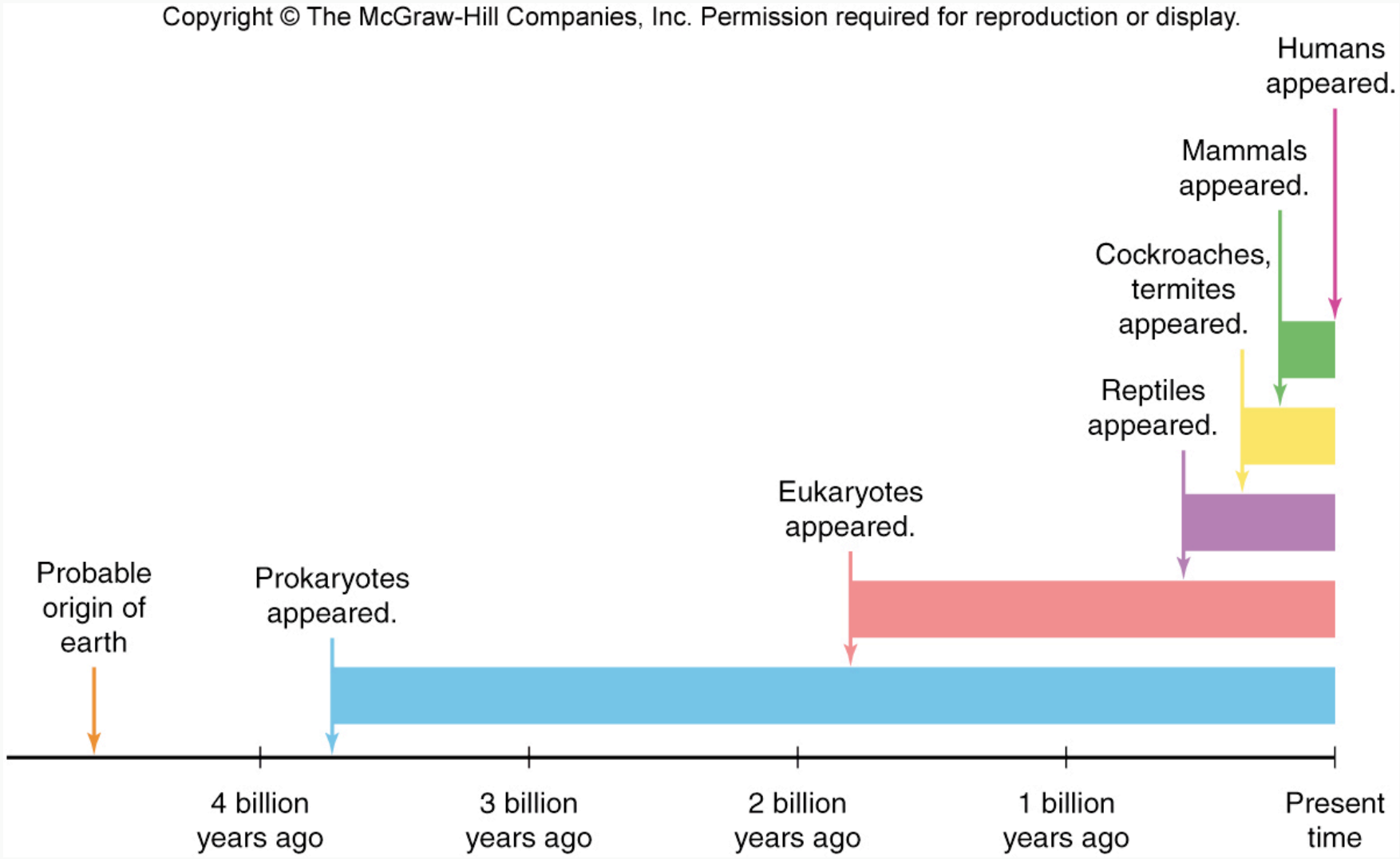


Fig. 1.1 Evolutionary timeline

Ubiquity of Microorganisms

- Found nearly everywhere
- Occur in large numbers
- Live in places many other organisms cannot

(a) (b)

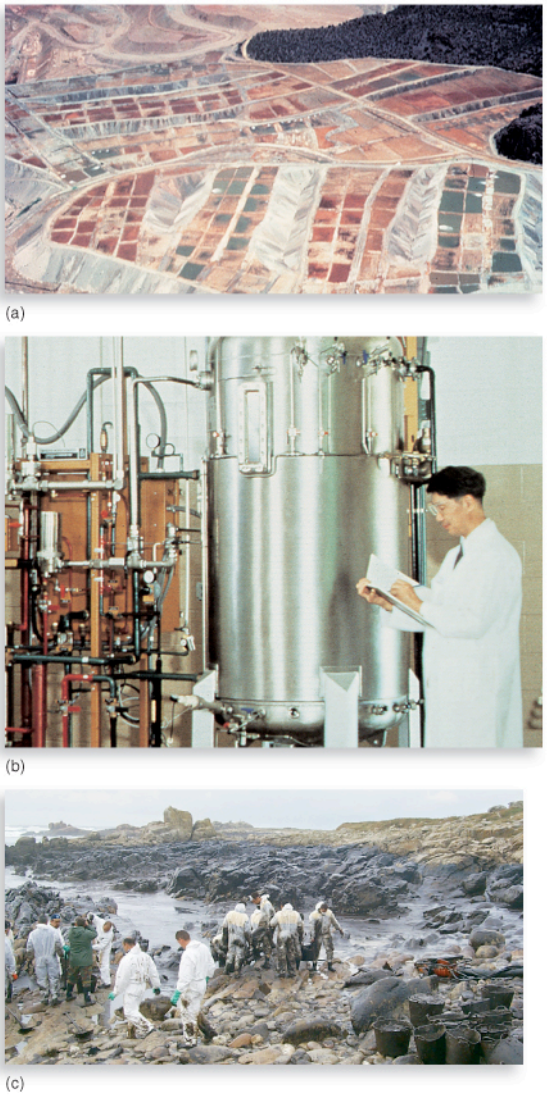
Figure 1.2

Microbial Involvement in Energy and Nutrient Flow

- Bacteria conducted **photosynthesis** before plants appeared
  - Anoxygenic photosynthesis
  - Oxygenic photosynthesis
    - account for >50% of the earth's oxygen
- Biological **decomposition** and nutrient recycling

1.3 Human Use of Microorganisms

- Humans have been using microorganisms for thousands of years
  - Baker's and brewer's yeast
  - Cheeses & other dairy products
  - Moldy bread on wounds



(a) (b) (c)

Figure 1.3: Microbial leaching, fermentation, oil biodegradation

Biotechnology & Bioremediation

- **Biotechnology**- when humans manipulate (micro)organisms to make products in an industrial setting
  - **Genetic engineering**- create new products and "genetically modified organisms" (GMOs)
  - **Recombinant DNA technology**- technology used to engineer GMOs capable of synthesizing desirable proteins
    (i.e. medicines, hormones, and enzymes)

- **Bioremediation** - activity of microbes in the environment helping to restore stability or clean up toxic pollutants
  - Oil spills
  - Chemical spills
  - Water and sewage treatment

1.4 Infectious Diseases and the Human Condition

- **Pathogens** - disease-causing "agents"

TABLE 1.1 Top Causes of Death—All Diseases

United States	No. of Deaths	Worldwide	No. of Deaths
1. Heart disease	725,000	1. Heart disease	11.1 million
2. Cancer	550,000	2. Cancer	7.1 million
3. Stroke	167,000	3. Stroke	5.5 million
4. Chronic lower-respiratory disease	124,000	4. Respiratory infections*	3.9 million
5. Unintentional injury (accidents)	97,000	5. Chronic lower-respiratory disease	3.6 million
6. Diabetes	68,000	6. Accidents	3.5 million
7. Influenza and pneumonia	63,000	7. HIV/AIDS	2.9 million
8. Alzheimer's disease	45,000	8. Perinatal conditions	2.5 million
9. Kidney problems	35,000	9. Diarrheal diseases	2.0 million
10. Septicemia (bloodstream infection)	30,000	10. Tuberculosis	1.6 million

*Diseases in red are those most clearly caused by microorganisms.

Source: Data adapted from The World Health Report 2002 (World Health Organization).

The most common infectious diseases worldwide.

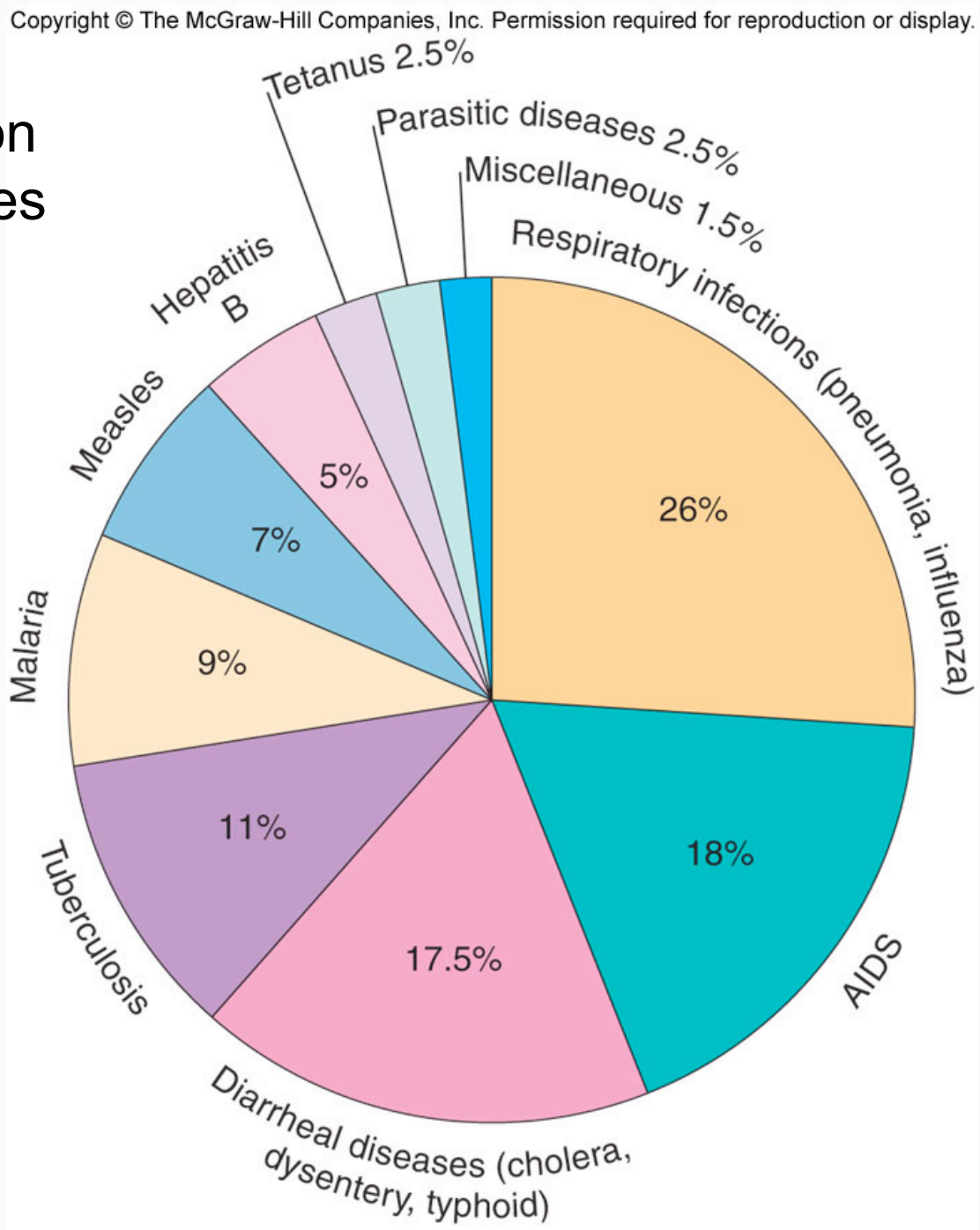


Figure 1.4

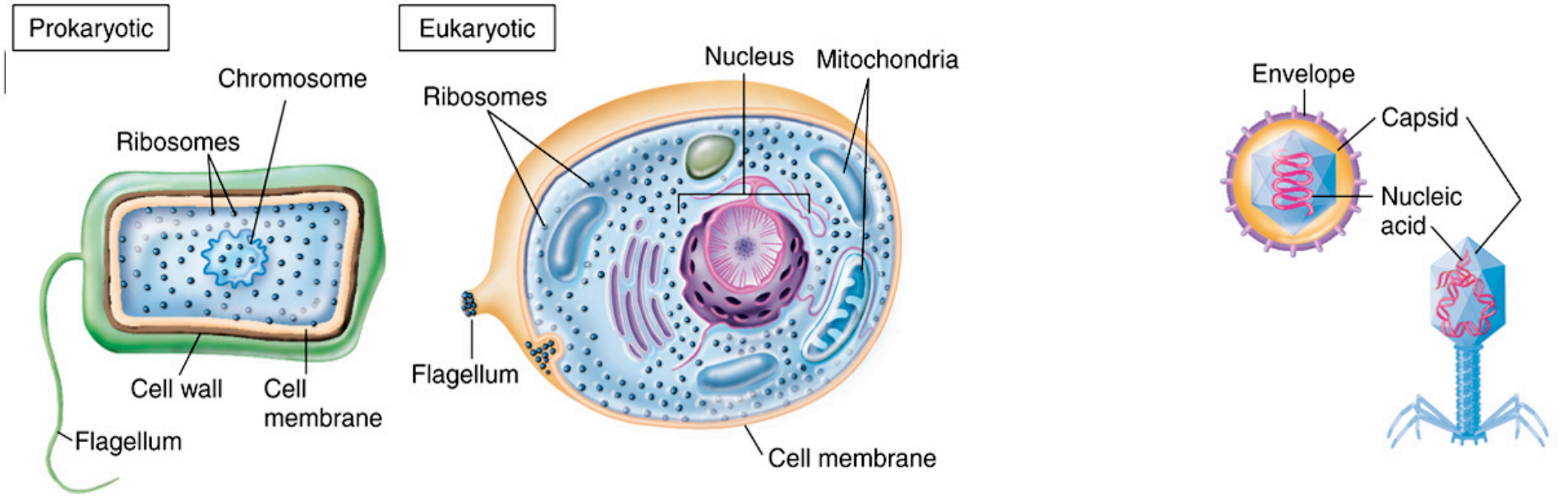
Worldwide Infectious Diseases

- Increasing number of emerging diseases (SARS, AIDS, hepatitis C, viral encephalitis)
- Other diseases previously not linked to microorganisms now are: gastric ulcers, certain cancers, schizophrenia, multiple sclerosis, obsessive compulsive disorder, coronary artery disease …. and the list is growing ….
- Increasing number of drug-resistant strains of disease-causing bacteria

1.5 The General Characteristics of Microorganisms

- Cellular Organization
  - "Prokaryotic" vs. "eukaryotic" cells
    - Prokaryotic (bacterial and archaeal) cells are about 10 times smaller than eukaryotic cells
    - Prokaryotic cells lack many cell structures such as double membrane-bound **organelles**
    - All prokaryotes are microorganisms, but only some eukaryotes are

There is a difference between the cell structure of a prokaryote and eukaryote. Viruses are neither but are considered particles.



(a) Cell Types

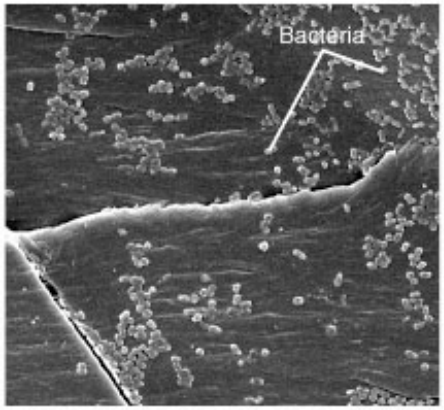
Microbial cells are of the small, relatively simple procaryotic variety (left) or the larger, more complex eucaryotic type (right). (Not to scale)

(b) Virus Types

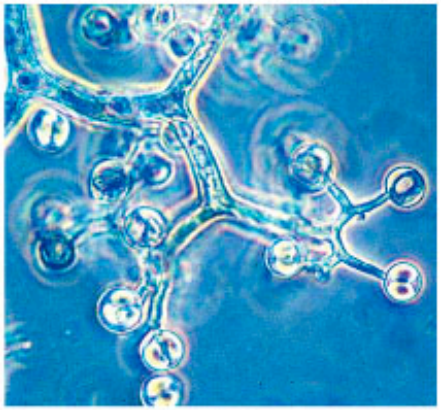
Viruses are tiny particles, not cells, that consist of genetic material surrounded by a protective covering. Shown here are a human virus (top) and bacterial virus (bottom). (Not to scale)

Fig. 1.5 Cell structure

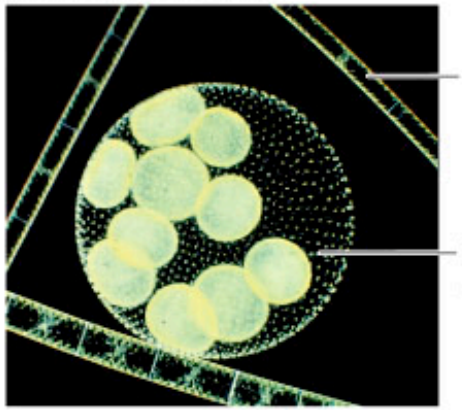
There are six main types of microbes:
1.) Bacterium or Archaeon, 2.) Fungus, 3.) Alga, 4.) Virus, 5.) Protozoon (Protozoan), 6.) Helminth.



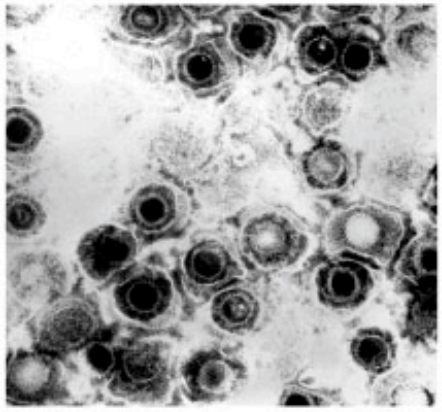
Bacterium: *E. coli*



Fungus: *Thamnidium*



Algae: *Volvox* and *Spirogyra*



Virus: *Herpes simplex*

Protozoan: *Vorticella*

Helminth: Head (scolex) of *Taenia solium*

Fig. 1.6 The six types of microorganisms

Viruses

- Are NOT independently living cellular organisms
- Much simpler than cells- basically a small amount of DNA **or** RNA wrapped in protein and sometimes by a additional lipid membrane
- Individuals are called a **virus particle** or **virion**
- Depend on the infected cell's machinery to multiply and disperse

Microorganisms vary in **size** - 1µm to 200 nm.

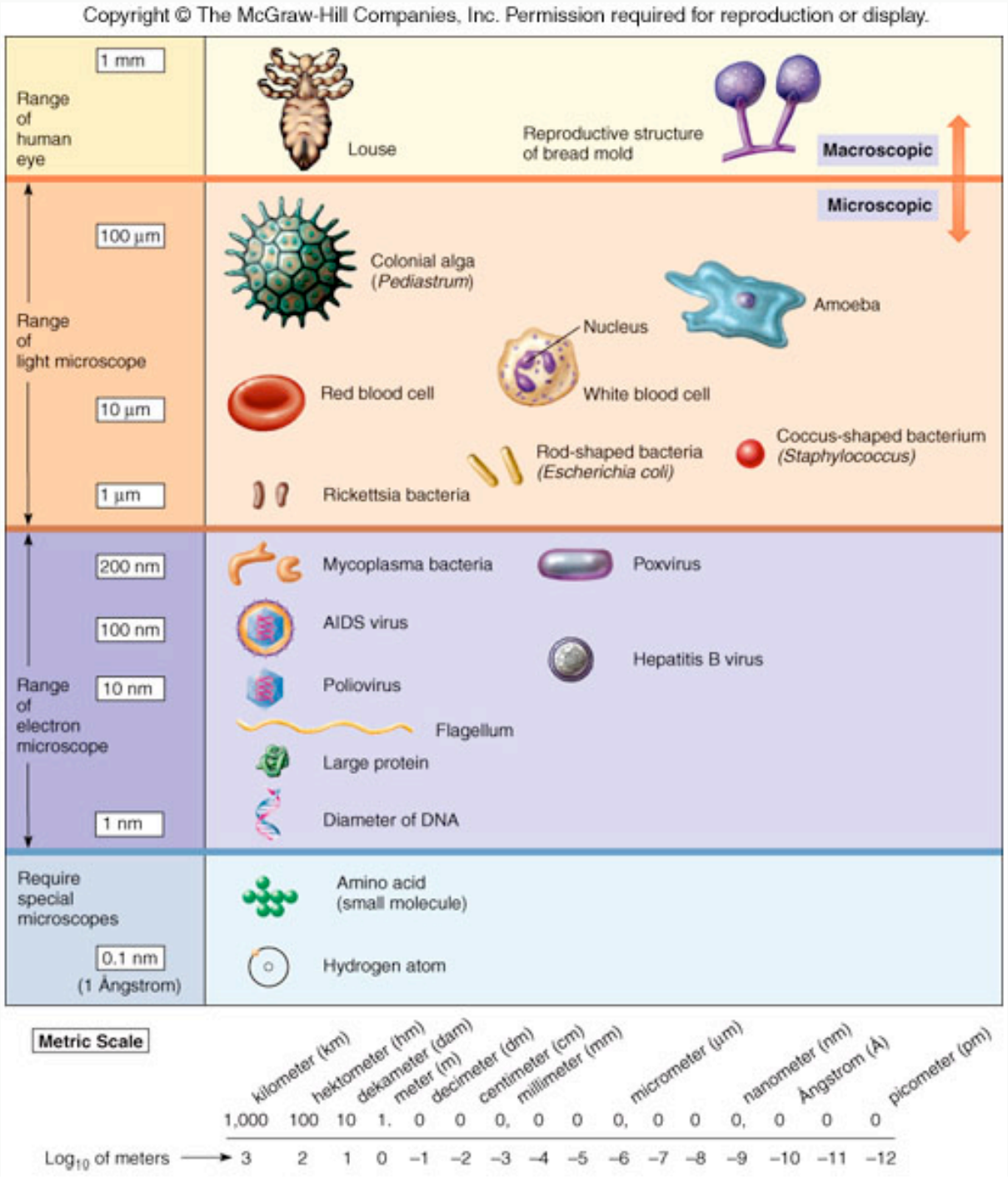


Fig. 1.7
The size of things

Lifestyles of Microorganisms

- Majority of microorganisms lives a free existence called "free-living" (in soil, water, rocks, for example) or as "saprophytes (saprotrophs)"

- Some are **parasites** (mooching off goodies from living beings, but can live freely), some of these are opportunistic pathogens

- Fewer are obligate parasites (exo- or endo-parasitic), some of these are pathogens

Lifestyles of Microorganisms

What are the sources of

- Energy,
- Reductant and
- Carbon?

How do cells dispose of the harvested electrons

- Fermentation
- Respiration

1.6 The Historical Foundations of Microbiology

- Key to the study of microorganisms was the development of the **microscope**
- Earliest record of microbes was from the work of **Robert Hooke** in the 1660s
- The most detailed observations of microbes was possible only after **Antonie van Leeuwenhoek** created the single-lens **microscope**, further perfected by Ernst Abbé abd Carl Zeiss

  (~late 19th century)
  - Leeuwehoek is known as the father of bacteriology & protozoology

Microorganisms were first observed by Antonie van Leeuwenhoek, using a primitive microscope.

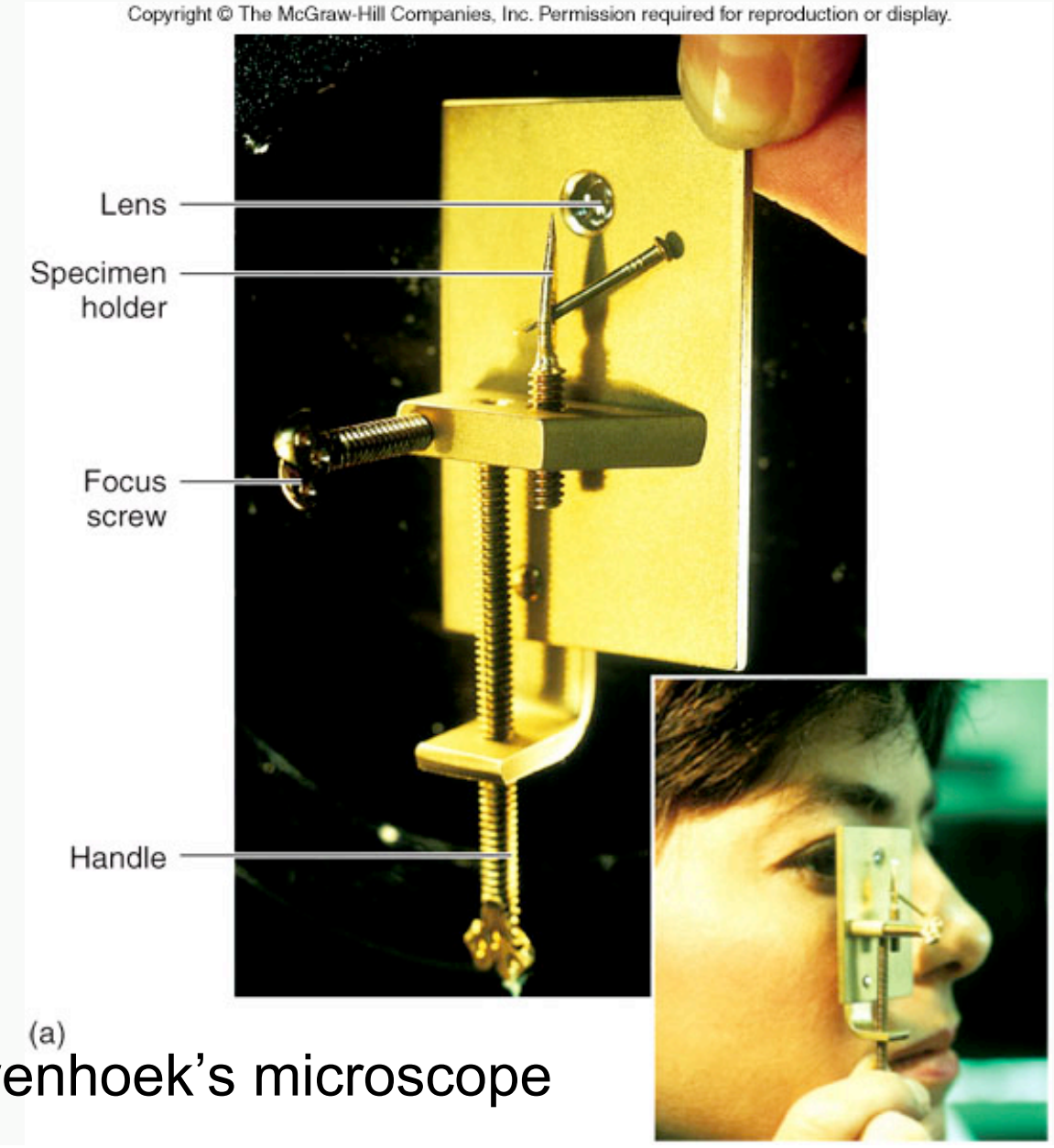


Fig. 1.9 Leeuwenhoek's microscope

History of Microbiology

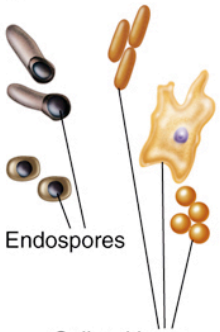
- Scientific Method
- Spores and sterilization
- Spontaneous generation
- Aseptic technique
- Germ theory

Establishment of the **Scientific Method**

- Early scientists tended to explain natural phenomena by a mixture of belief, superstition, and argument
- During the 1600s, true scientific thinking developed
- This led to the development of the **scientific method**
  - Formulate a **hypothesis**
  - Most use the **deductive approach** to apply the scientific method
  - Experimentation, analysis, and testing ==> conclusions
  - Results either support or refute the hypothesis
- Hypotheses can eventually become theories
- Theories can eventually become laws or principles

Hypothesis → **Predictions** → **Testing** → **Theory/Principle**

Bacterial endospores are the most resistant structures of life on earth.



(a)

If hypothesis is true, endospores can survive extreme conditions such as:

Compare endospore formers to non-endospore-forming microbes.

	Survival of endospore former	Survival of non-endospore former
• temperature (boiling)	+	−/+*
• radiation (ultraviolet)	+	−
• lack of water (drying)	+	−/+
• chemicals (disinfectants)	+	−/+

*Only 1 out of 4 cell types survives.

Additional tests show that endospores have thick coverings and protective features and that endospores are known to survive over millions of years.

Endospores are the only structures of life consistently capable of surviving a wide range of destructive environmental conditions. In order to sterilize, endospores must be eliminated.

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Hypothesis → **Predictions** → **Tests/Results** → **Theory**

Tiny, rod-shaped objects from a billion-year-old Martian meteor are microorganisms.

- Objects will be within expected size range of bacteria.
- Objects will contain carbon and other elements in an expected ratio.
- They will occur in samples from Mars but not in rocks from other planets.

- Supportive findings are that the objects appear to be dividing and occur in colonies, not randomly.
- They contain more carbon than surrounding minerals.
- Microbiologists say that objects are too small to be cells.
- Tests show similar crystals are common in geologic samples that are not possibly microbial.
- Chemical tests indicate objects are the result of heat.

Tests give contradictory results. Continued testing of other rocks and samples from Mars' surface are ongoing.

? **Modify**

? **Discard**

- Results are too contradictory to rise to this level.
- Mars projects will continue to examine the Martian landscape for signs of life. See Insight 1.3.

(b)

Figure 1.10

The Development of Medical Microbiology

- The Discovery of Spores and Sterilization
  - **Louis Pasteur-** worked with infusions in the mid-1800s
  - **John Tyndall-** showed evidence that some microbes have very high heat resistance and are difficult to destroy
  - **Ferdinand Cohn-** spores and sterilization
- The Development of Aseptic Techniques
  - Physicians and scientist began to suspect that microorganisms could cause disease
  - **Joseph Lister-** introduced **aseptic technique**

Spores and sterilization

- Some “microbes” in dust and air were resistant to high heat.
- Spores were later identified.
- The term “sterile” was introduced, which meant completely eliminating all life forms from objects or materials.

Spontaneous generation

Early belief that some forms of life could arise from vital forces present in nonliving or decomposing matter. (flies from manure, etc)

Louis Pasteur showed microbes caused fermentation & spoilage, and disproved spontaneous generation.

Fig. 1.11 Louis Pasteur

Aseptic technique

Ignaz Semmelweis, a Hungarian "OB/GYN" established link between "infection" and diseases after labor.

Joseph Lister an English Army Surgeon first introduced the technique in order to reduce microbes in a medical setting and prevent wound infections.

Germ theory of disease

Many diseases are caused by the growth of microbes in the body and not by sins, bad character, or poverty, etc.

- Robert Koch was the first to clearly show the **causal** relationship between bacteria as causal agents and disease in infected animals (including humans).

Robert Koch verified the Germ theory (Koch's postulates).

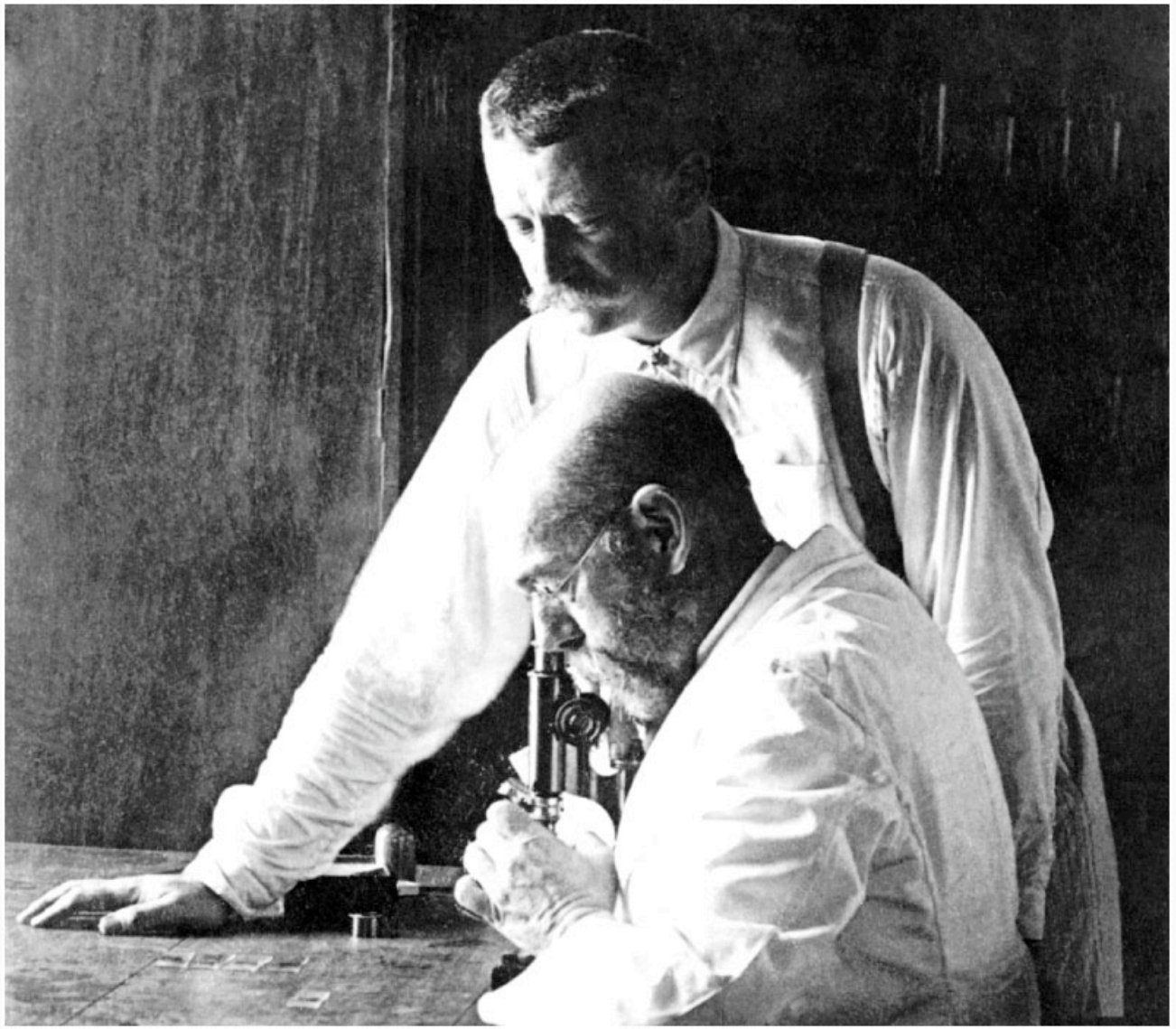

Fig. 1.12 Robert Koch

1.7 Taxonomy: Naming, Classifying, and Identifying Microorganisms

- **Microbial nomenclature**- naming microorganisms
- **Taxonomy**- classifying living things

  originated over 250 years ago with the work of Carl von Linné
- **Identification**- discovering, comparing and recording the traits of organisms so they can be named and classified
- Levels of Classification

Nomenclature

- Binomial (scientific) nomenclature
- **Genus** – *Bacillus,* always capitalized
- **species** - *subtilis*, lowercase
- Both italicized or underlined
  - *Bacillus subtilis (B. subtilis)*

Levels of Classification

- Domain
- Kingdom
- Phylum or Division
- Class
- Order
- Family
- *Genus*
- *species*

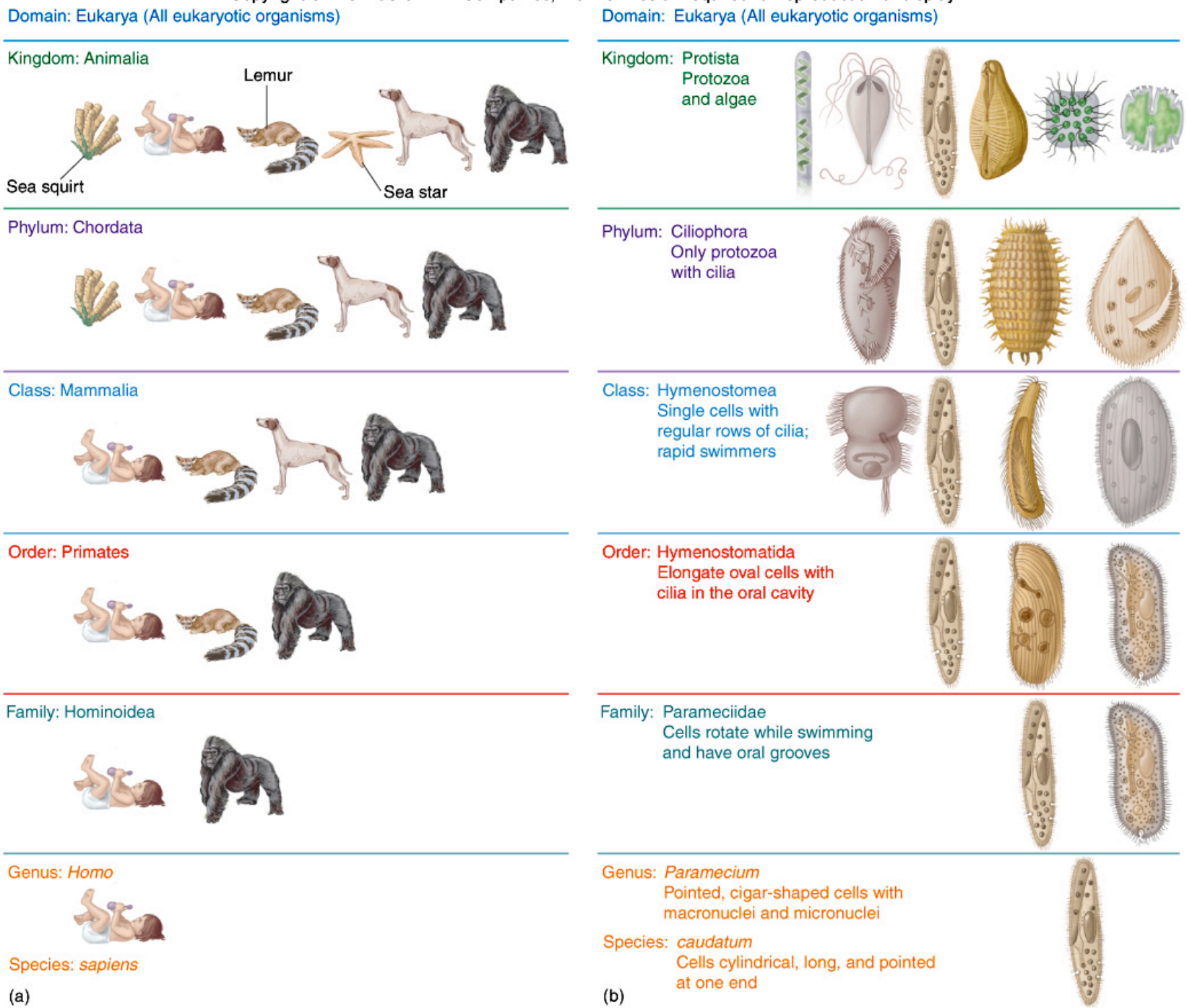

Figure 1.12

Identification

- The process of discovering, comparing and recording the phenetic (physical, biochemical) and genetic traits of organisms, thereby, placing them in a taxonomic scheme.

The five-kingdom system became the standard until molecular biology techniques were used to develop the Domain system.

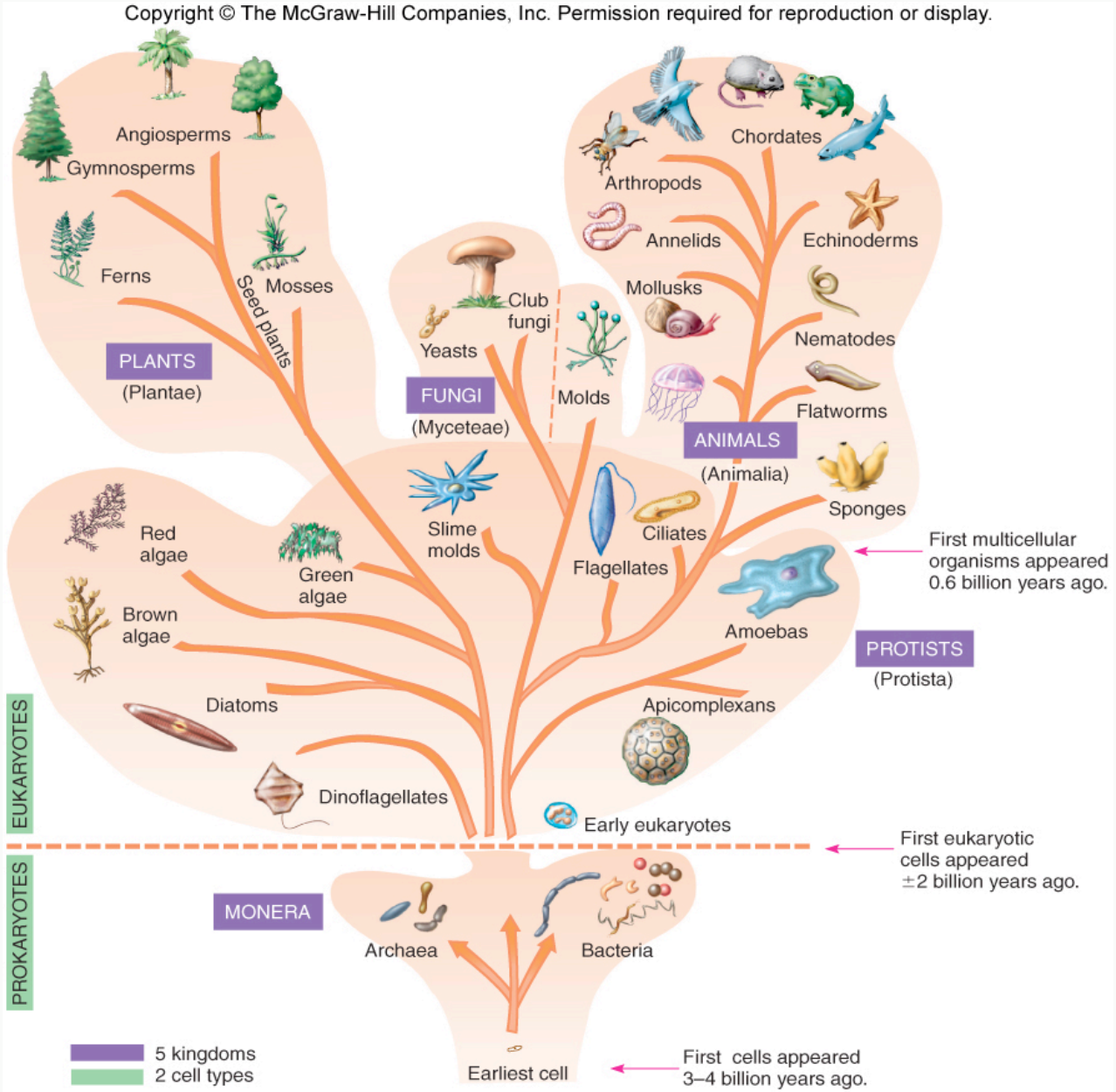

Fig. 1.14 Traditional Margulis-Whittaker system of classification

Subdivisions or Kingdoms

- Protista (protists)
- Fungi
- Plantae (plants)
- Animalia (animals)

The Origin and Evolution of Microorganisms

- **Phylogeny**- the degree of relatedness by descent between groups of living things
- Based on the process of **evolution**- hereditary information in living things changes gradually through time; these changes result in structural and functional changes through many generations
  - Two preconceptions:
    - All new species originate from preexisting species
    - Closely related organisms have similar features because they evolved from a common ancestor
- Phylogeny usually represented by a tree- showing the divergent nature of evolution

Evolution

- Classification schemes allow for a universal tree of life “phylogenetic tree”.
- Living things change gradually over millions of years
- Changes favoring survival are retained & less beneficial changes are lost.

Domains

- Domain system proposed later than the Five-kingdom system

- **Bacteria** - true bacteria, peptidoglycan
- **Archaea** - odd “bacteria” originally believed to only live in extreme environments
  (high salt, heat, etc)
- **Eukarya-** have a nucleus, & organelles

The Domain system was developed by Dr. Carl Woese. The basis of this system is the ssu rRNA sequence information.

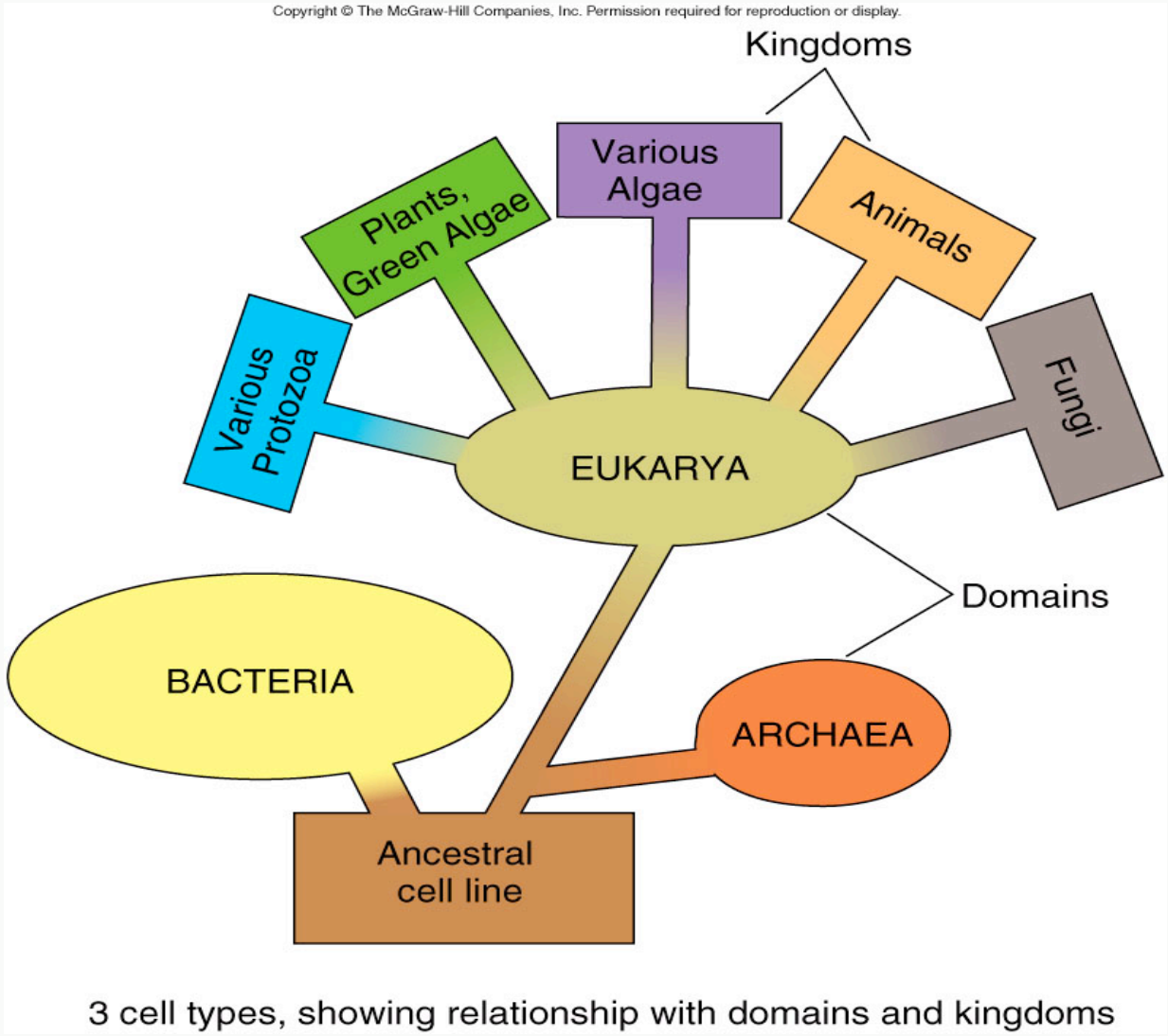

Fig. 1.15 The Woese system - universal tree of life