Johns Hopkins Engineering

Molecular Biology

Types of Cells and Their Properties

JOHNS HOPKINS
WHITING SCHOOL
of ENGINEERING

Outline

- Types of cells and their properties
  - Domains
  - Limits on size
  - Organization

All Organisms Are Bacteria, Archaea, or Eukaryotes

- With advancements in microscopes, biologists recognized two types of cells
- The simpler type is characteristic of bacteria (**prokaryotes**) and the more complex type characteristic of plants, animals, fungi, algae and protozoa **(eukaryotes)**
- The main distinction between the two cells types is the membrane-bound nucleus of eukaryotic cells

A changing view of prokaryotes

- The term *prokaryote* though, does not adequately describe all non-nucleated cells
  - Similarity of a gross structural feature is not necessarily evidence of relatedness (e.g. lack of nucleus)

- Comparative genetic analysis of ribosomal RNA (rRNA), shows that prokaryotic cells can be divided into the widely divergent **bacteria** and **archaea**

- *Bacteria and archaea are as divergent from one another as are humans and bacteria*

Three domains

- Biologists now recognize three domains, the **archaea**, **bacteria** and **eukarya** (*eukaryotes)*
- There are shared characteristics among cells of each of the domains, bacteria, archaea and eukarya

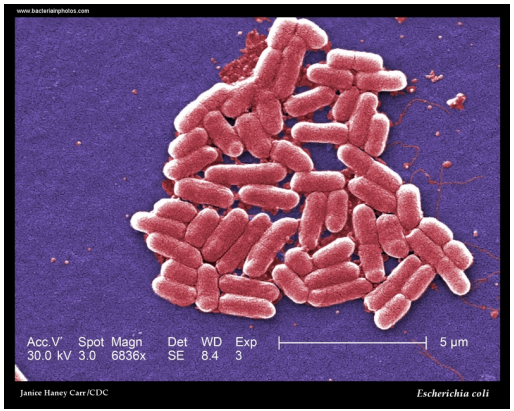
Phylogenetic Tree of Life

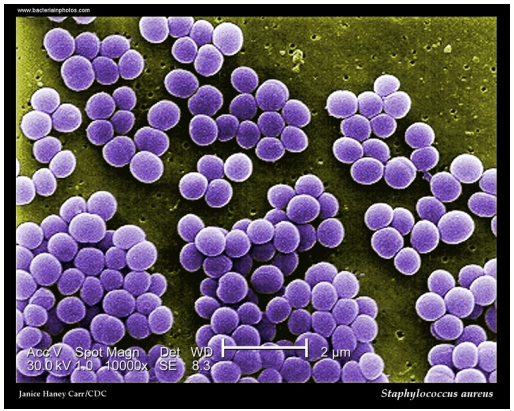
Bacteria

- Includes most of the commonly encountered single-celled, non-nucleated organisms traditionally called bacteria

- Examples include:
  - *Escherichia coli*
  - *Pseudomonas aeruginosa*
  - *Streptococcus pylori*

In a normal, healthy human, bacterial cells outnumber human cells ~10:1.

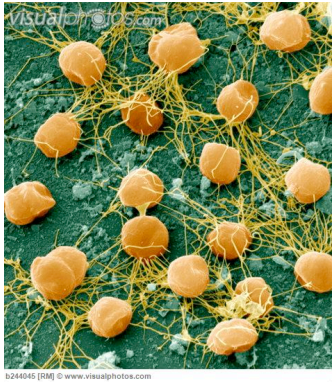




Credit: bacteriainphotos.com

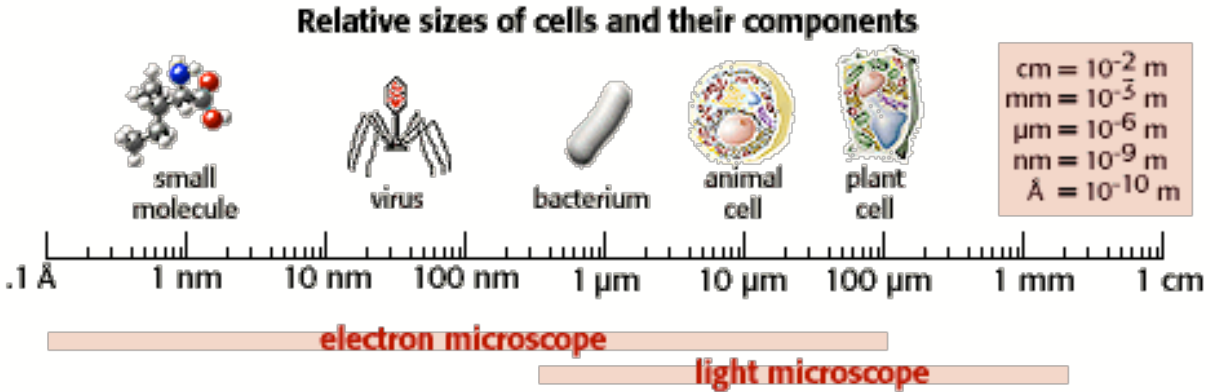
Archaea

- Archaea were originally called *archebacteria* before they were discovered to be so different from bacteria
- They include many species that live in extreme habitats and have diverse metabolic strategies
- Types of archaea include:
  - *methanogens* - obtain energy from hydrogen and convert CO_2 into methane
  - *halophiles* - occupy extremely salty environments
  - *thermacidophiles* - thrive in acidic hot springs
- They are considered to have descended from a common ancestor that also gave rise to eukaryotes long after diverging from bacteria



Cell Sizes

- Cells come in various sizes and shapes,
  - Example: bacteria (1um) vs. nerve cell (1 meter)
- Despite the extremes, different types of cells generally fall into predictable size ranges: bacteria, 1-5 μm; animal cells, 10 - 100 μm
- ***Cells are usually very small, but why?***



http://www.biology.arizona.edu

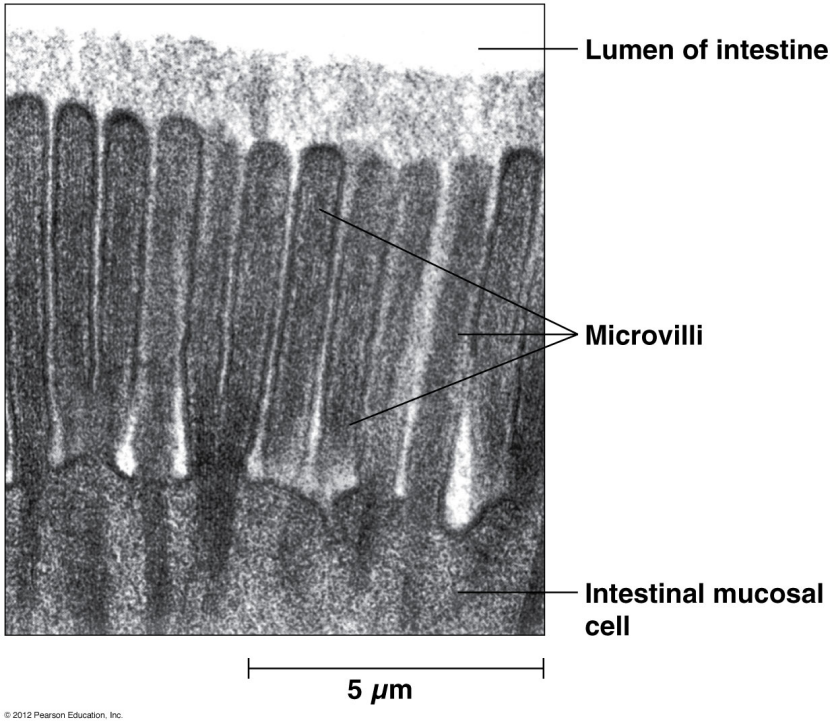
There are three main limitations on cell size

1. The need to maintain an adequate surface area to volume ratio
    - Cell surface area is important to allow exchanges between the cell and its surrounding environment
    - The cell's volume determines the amount of exchange that must take place, across the available surface area
    - Larger cells have proportionately smaller surface areas
    - Beyond a certain threshold a large cell would not have a large enough surface area to allow for intake of enough nutrients and release of enough wastes

Cells specialized for absorption

- Cells that are specialized for absorption have characteristics to maximize surface area/volume ratio

- e.g., cells lining the small intestine have *microvilli,* fingerlike projections that increase the surface area

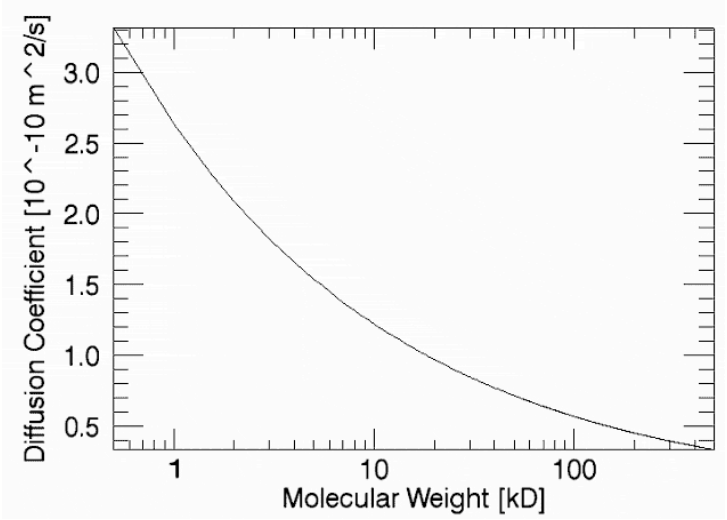


2. Diffusion rates of molecules

- Many molecules move through the cell by **diffusion**, the unassisted movement of a substance from a region of high concentration to a region of low concentration

- The rate of diffusion of molecules decreases as the size of the molecule increases, so the limitation is most important for macromolecules like proteins and nucleic acids

- Eukaryotic cells can avoid the problem of slow diffusion rates by using **carrier proteins or vesicles**



http://book.bionumbers.org/what-are-the-time-scales-for-diffusion-in-cells/

3. The Need for Adequate Local Concentrations of Essential Substances

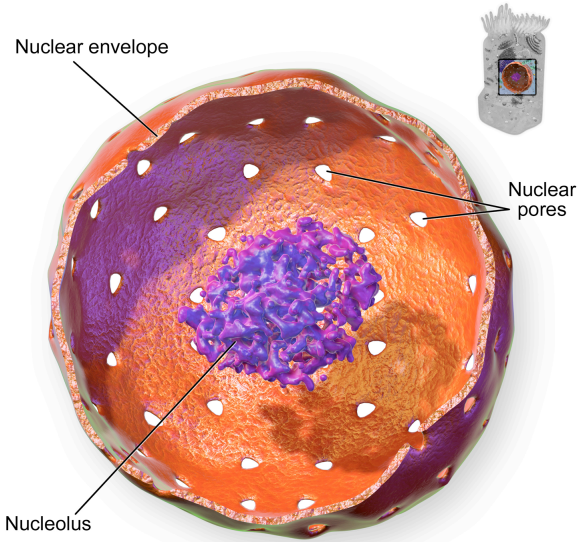
- For a reaction to occur, the appropriate reactants must collide with and bind to a particular enzyme or molecule
- The frequency of such collisions is greatly increased by higher concentrations of enzymes and reactants
- As cell size increases, the number of molecules increase proportionately with volume

Eukaryotic Cells Use Organelles to Compartmentalize Cellular Function

- Cells maintain necessary local reactant concentrations by **compartmentalization** of activities within specific regions (i.e. organelles)
- Most eukaryotic cells have a variety of **organelles**, membrane-bounded compartments that are specialized for specific functions
  - e.g. cells in a plant leaf have most of the materials needed for photosynthesis compartmentalized into structures called *chloroplasts*

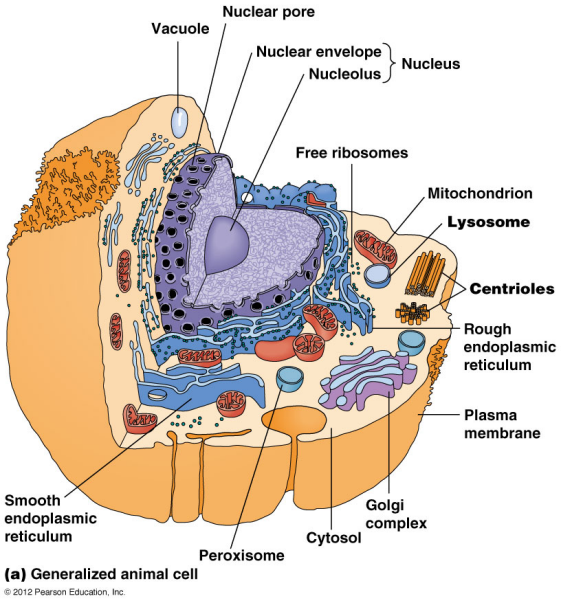
Nucleus

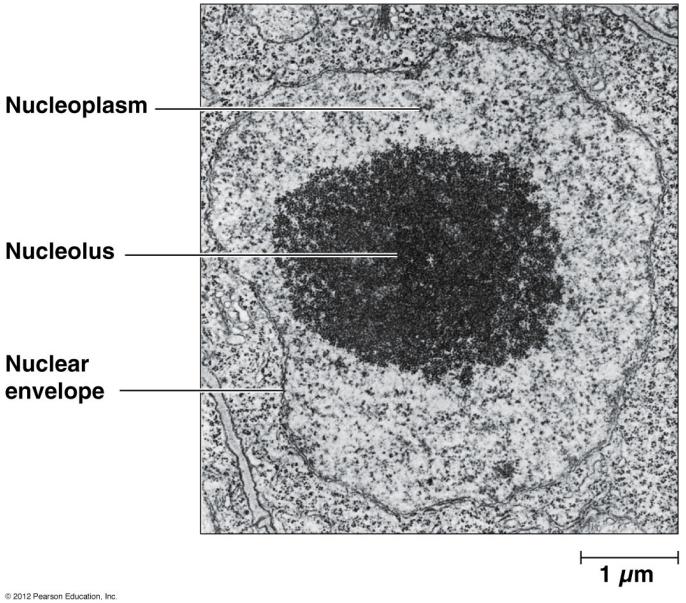
- A **eukaryotic cell** has a true, membrane bounded nucleus
- The nucleus also includes the *nucleolus*, the site of ribosomal RNA synthesis and ribosome assembly



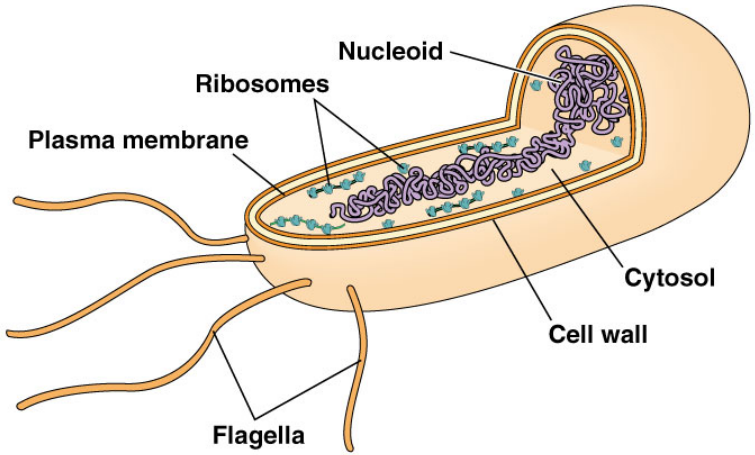
Nucleus

Credit: Wikipedia

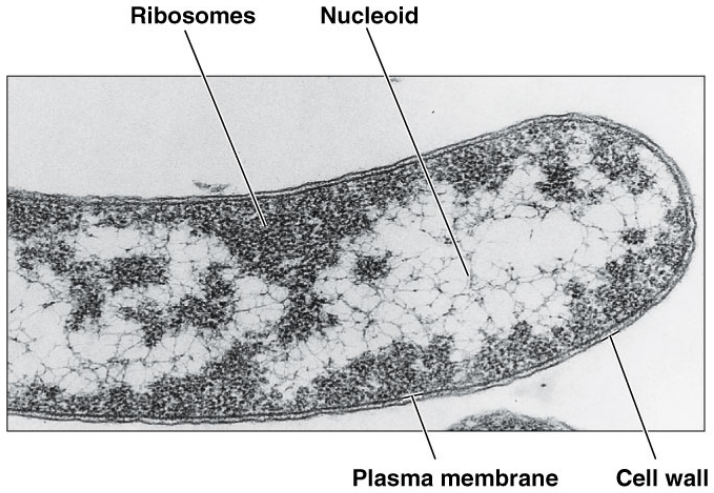




Eukaryotic DNA exists in the cells as multiple linear molecules that are complexed with large amounts of *histone* proteins.



(a)



(b)

Bacterial DNA is typically a circular molecule associated with few proteins.

Organization of DNA - comparison

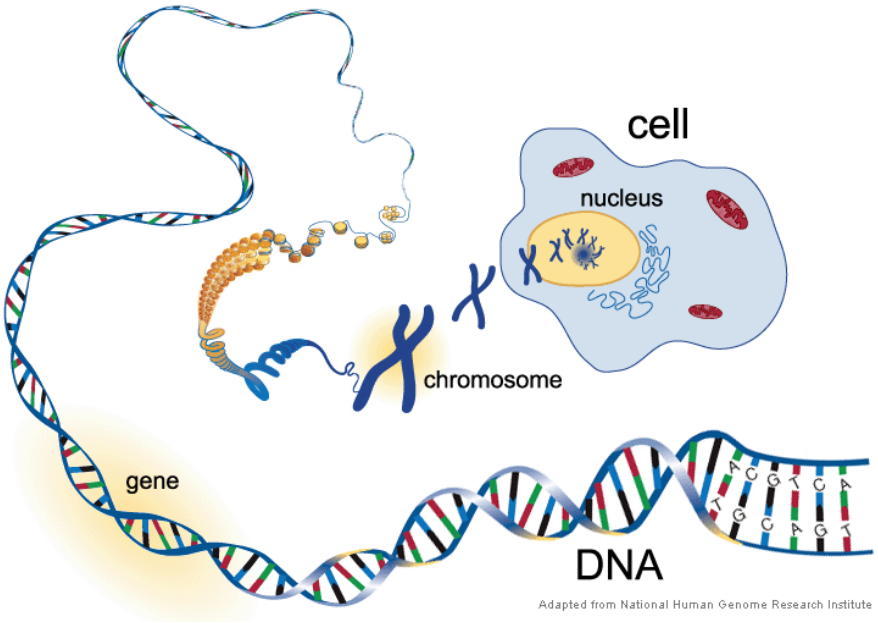
- *Eukaryotic DNA is organized into linear molecules complexed with large amounts of proteins called histones*
- *Bacterial DNA is present in the cell as a circular molecule associated with few proteins*
- Archaeal DNA is circular and complexes with proteins similar to eukaryotic histone proteins

DNA packaging

- The circular DNA of bacteria or archaea is much longer than the cell itself and so must be folded and packed tightly, equivalent to packing about 60 feet of thread into a thimble
- Most eukaryotic cells have more than 1000 times more DNA than prokaryotes, yet encode only 5-10 times more proteins
  - Human genome, ~ 97% DNA is non-coding
  - Bacteria, 1-2% DNA is non-coding
- The excess noncoding DNA has been referred to as junk DNA but is now shown to have important functions in gene regulation (e.g. regulation of the protein-coding genes)

Chromosomes

- The problem of DNA packaging is solved among eukaryotes by organizing the DNA into **chromosomes**



Genetic information

- Prokaryotes and eukaryotes differ in how genetic information is allocated to daughter cells upon division
- Bacterial and archaeal cells replicate their DNA and divide by *binary fission* with one molecule of the replicated DNA and the cytoplasm going into each daughter cell
- Eukaryotic cells replicate DNA and then distribute their chromosomes into daughter cells by *mitosis* and *meiosis*, followed by *cytokinesis*, division of the cytoplasm

Summary

- Three domains of life: prokaryotes, eukaryotes, archaea
- Limits on cell size
- Introduction to organelles