1. Introduction to Cell Biology

LECTURES 2-3

BIO 1140 – Introduction to Cell Biology

TABLE OF CONTENTS

READINGS

PRIMARY READINGS

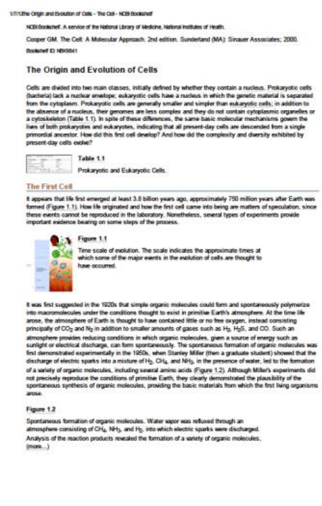
- Chapter 2 (except 2.5)
- Chapter 3
- Purple pages F-52 to F-56

SUPPLEMENTARY READINGS

- Eukaryotes vs. prokaryotes [Ch. 2.2 and 2.3; also Ch. 20]
- Viruses, viroids and prions [Ch. 21]
- Eukaryotic diversity – protists, fungi, plants and animals [scan Ch. 22-26; see in particular the "characteristics" summaries in the Review sections, i.e. 22.2, 23.1, 24.1, 25.1]
- Basic cell structures – cell wall, plasma membrane, non-membrane bound organelles (e.g. cytoskeleton, ribosomes), membrane-bound organelles (e.g. nucleus, endoplasmic reticulum, Golgi complex, lysosomes, peroxisomes, vacuole, vesicles, mitochondria, chloroplasts) [Ch. 2.2-2.4]
    - see also below "The Origin and Evolution of Cells" – section titled "Eukaryotic Cells"
- The cell theory [Ch. 2 Why it matters]
- The endosymbiosis theory [Ch. 3]

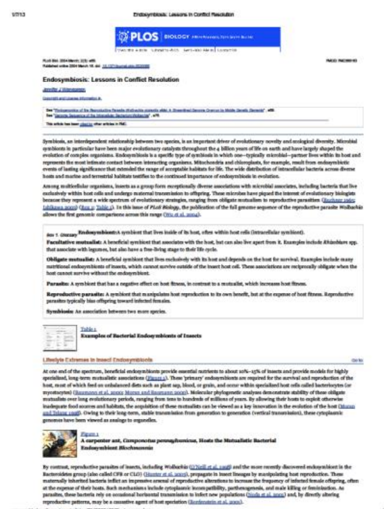
"The Universal Features of Cells on Earth"

Sections: Full Article



"The Origin and Evolution of Cells"

Sections: Full Article



"Endosymbiosis: Lessons in Conflict Resolution" (OPTIONAL)

Sections: Full Article

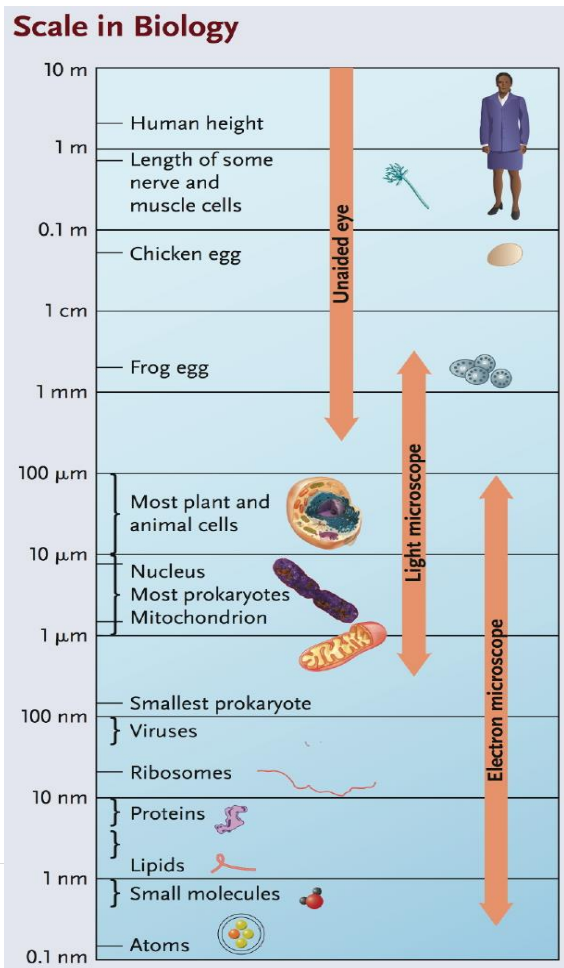
CELL THEORY

WHAT IS A CELL?

- The fundamental unit of life, and every organism consists of cells or is itself a single cell.
- Defining characteristics:
  - Living, interact with other cells
  - Self-regulating
  - Membrane composed of proteins and lipid
  - Organelles structured onto cytoskeleton floating in cytoplasm
  - Genetic information
  - Metabolic processes
  - Adaptable
  - Reproduces by mitosis or meiosis (in gametes)
- All these ideas were formalized in the 1800's as the Cell Theory:
  - I. All organisms consist of one or more cells
  - II. The cell is the basic unit of structure for all organisms (Theodor Schwann,1839 (Matthias Schleiden, 1838)
  - III. All cells arise only from pre-existing cells (i.e. the cell is the basic unit of reproduction) (Rudolf Virchow, 1855)

CAN ONE SPEAK OF "THE CELL"?

- The cell has enormous **diversity:** form, function and size
  - Simple to complex shape
  - Usually very small but can be large too (ostrich egg)
  - Cells can vary in size from microscopic to up to 1m long (giraffe skeletal neurons)
  - Some cells have basic, general functions others are highly specialized (hormones, info transmission, signalling)
- However, all cells have similar basic chemistry (**unity**)
  - **we can therefore more or less refer to them all as a cell**
    - similar metabolism (ATP)
    - chemical composition same
    - use of DNA for genetic information
    - all cells stem from common ancestor

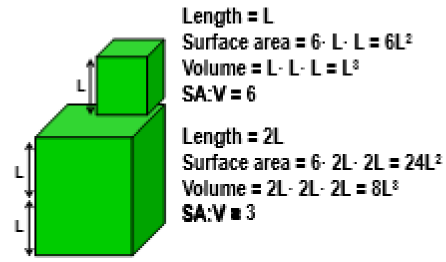


SIZE MATTERS!

- Size matters!
  - Units relevant to cell biology
    - 1 µm = 10-6 m
    - 1 nm = 10-9 m
  - Cells are small
    - 'typical' prokaryote 1 – 5 µm
    - 'typical' eukaryote 10 – 30 µm

Ribosome diameter	30 nm
Nucleus diameter	0.006 um
Mitochondrion length	3 um
Giraffe axon length	1×10^6 µm
Microfilament diameter	3×10^{-6} m

- **SA: V ratio**
  - if surface area and volume ratio not well met, then cell will die
  - volume of a cell determines the amount of chemical activity that can take place within it
  - surface area determines the amount of substances that can be exchanged between the inside of the cell and the outside environment (nutrients must constantly y enter, wastes must leave—past a certain point increasing the diameter of a cell gives a SA inadequate to maintain nutrient-waste exchange for its entire volume
  - increase in cell size causes decrease ratio of SA:V, because we have larger cell volume but small SA
  - large cell requires lots of nutrients but surface area over which they can enter is not adequate
  - therefore, large organisms are not made of a large single cell, but rather lots of small cells
  - some cells develop surface folds to increase, or use projections such as microvilli



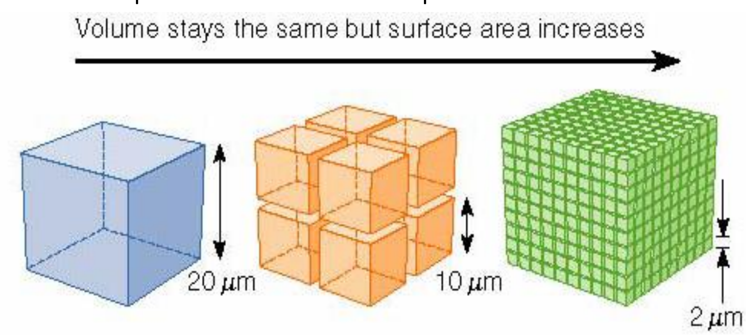
(see Fig. 2.5)

- **Rates of Diffusion**
  - The larger the cell, the longer the rate of diffusion across it
  - Cell has to move across nutrients/substrates/waste out of the cell or to diff parts inside cell, so the larger the cell, the longer it takes to do this

Time to 95% equilibration of O_2 by diffusion

X	time
0.1 mm	0.067s
1 mm	6.7 s
1 cm	10.9 min
1 m	78 d

- **Synthetic Machinery**
  - cell must either bring in substrates and synthesize them for reaction to occur
  - simply cannot produce enough or bring in enough substrates for reactions to occur due to such large volume in proportion to smaller surface area in large cells]
  - difficult to maintain adequate concentrations of required substances if cell is too large



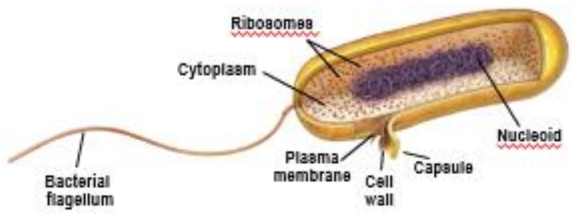
Length of one side	20 µm	10 µm	2 µm
Total surface area (height x width x number of sides x number of cubes)	2400 µm^2	4800 µm^2	24,000 µm^2
Total volume (length x width x height x number of cubes)	8000 µm^3	8000 µm^3	8000 µm^3
Surface area to volume ratio (surface area ÷ volume)	0.3	0.6	3.0

PROKARYOTES VS. EUKARYOTES

- Prokaryotic and eukaryotic cells differ in their solutions to the problem of size

PROKARYOTES

- **They stay small to fight the issue of SA: V and diffusion**
- Characteristics
  - **NO NUCLEUS:** free floating genetic material in the cytoplasm located in nucleoid region
  - very small and simple: 1-5 um, 3 shapes: rod, spherical and spiral
  - yet they are diverse;
  - structure: simple, cell wall for rigidity, no organelles, ribosomes, free floating nucleoid (not membrane bound), ribosomes, flagellum for locomotion



Model Organism: E. coli

- Full name: Escherichia coli
- Know more about it than any other organism in the world
  - Full DNA sequence of the genome has been deciphered – all 4400 genes
- Easy to use in lab
  - Divides every 20 minutes
  - clone of 1 billion cells grown in 10mL of medium in a matter of hours
  - Minimal equipment required; besides a little culture held at 37 degrees Celsius

2 Groups:

Bacteria	Archea
• **i.e. Escherichia coli (E. coli) is model organism**	• older, ancestral • **extremophiles**: adapted to very challenging and unusual environments: • thermophiles (hot) • halophiles (salty) • acidophiles (digestive system, very acidic)

EUKARYOTES

- They use compartmentalization via membranes to fight off SA: V problem
  - we can concentrate substrates in specific areas, at smaller volumes at locations dedicated to certain synthetic processes, so substrate not required in large concentration throughout whole cell, but in just one area of cell
  - reduce diffusion distances
  - projections of the membrane to increase SA (villi)
  - **allows them to achieve larger size than prokaryotes**
- **They also use transport systems to fight off the slower diffusion rates problem**
  - Transport using vesicles provided by the Golgi structure; membranous system

Eukaryotes: Model Organisms of Each Group

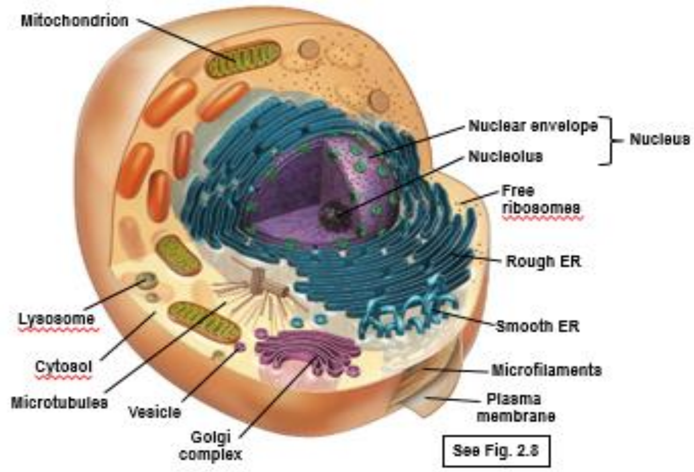
- **PROTIST**
  - none
- **FUNGI**

- **Yeast (**Saccharomyces cerevisiae)
  - first complete eukaryotic genome to be sequenced
  - small easily grown and shows all characteristics of larger complex fungi
  - Researchers can alter any of the yeast genes to test their function and introduce genes or DNA from other organisms for testing/cloning.
  - Often called the "eukaryotic E.Coli. (E.Coli is the model prokaryotic organism and the most extensively studied organism)

- **PLANTS**:
  - **Thale cress** (Arabidopsis thaliana),
    - easily grown, small, quickly reach reproductive stage
    - requires only damp soil, basic nutrients and artificial light
    - first complete plant genome to be sequenced
- **ANIMALS**:
  - **Fruit Flies** (Drosophilia melanogaster)
    - Drosophilia = "dew lover"
    - Model organism for genetics, easily varied by genes and separated, phenotypes easily visible (i.e. red eyes, wing shape, etc.)
    - discovery of sex-linked genes and sex linkage, chromosome map
    - ease of culturing:
      - grown at 25 degrees
      - females lays several hundred eggs at once, produce adults in 10 days
      - breed within 10-12 hours
      - easy to distinguish between male and female with the unaided eye
      - easy to manipulate genes,
      - close relationship to humans in terms of genes (human diseases genes have fruit fly counterparts)
  - **Nematode** (Caenorhabditis elegans) "the worm"
    - Has exactly 959 cells (simple organism) and each reproductive process of the cell has been mapped out.
    - Small size
    - Easy to raise thousands because they feed on bacteria like E.Coli
    - Can be frozen indefinitely
    - Transparent; cell divisions and cell movements in living worm is observable
    - Research on nematode is relevant to larger more complex organisms (such as vertebrates)
  - **Zebra Fish** (Danio rerio)
    - have external fertilization so eggs are easily monitored also because the eggs are transparent, so all stages of the embryonic development are clear and visible, rapid changes due to short lifestyle, easily breed-able every day, not seasonal , hatches in 48 hours, requires only 28 degree temp,
    - Are also small so easily stored, large number of offspring at a time
    - Zebra fish can grow new heart cells (figure out how to transfer this characteristic to humans!)
  - **Mouse** (Mus musculus):
    - Shows many of the same characteristics that humans shows, easily stored and tested on, 3 month reproduction time
    - enables mammalian experimentation on a small, inexpensive scale
    - used in cancer, genetics and immunology research
    - very similar to human

STRUCTURE OF EUKARYOTIC CELL (ORGANELLES)

- **Major Structural Features**
  - Plasma Membrane
  - Nucleus (membrane bound)
  - Membrane bound organelles
- **Cytosol vs. Cytoplasm**
  - **Cytosol:** aqueous solution in which organelles are suspended
  - **Cytoplasm:** includes cytosol and everything found in it
  - Cytosol is **same** in eukaryotic and prokaryotic.
  - Cytoplasm **differs** between eukaryotic and prokaryotic



NON-MEMBRANE BOUND ORGANELLES

- same function in both prokaryote and eukaryote

Cytoskeleton

- microfilaments, microtubules and intermediate filaments
  - -roles: support and structure, transport system, movement of cell
  - classic cytoskeleton as defined here not present in prokaryotic cells (i.e. doesn't have microtubules, microfilaments, and intermediate filaments)
    - the transport role played by these filaments allow growth of eukaryotic cells to larger sizes

Ribosomes

- Protein-synthesis
- Eukaryotic larger and structurally more complex, more subunits than prokaryotic ribosomes
  - Yet both serve same function

MEMBRANE-BOUND ORGANELLES

Nucleus

- not in prokaryotes
- ribosome bits synthesized within nucleus (nucleolus)
- genetic material found here (eukaryotic in form of chromosomes and DNA **protein** complexes and are linear, housed within double membrane structure (nucleus), ribosomal subunits synthesized in nucleolus and migrate to cytosol via the nuclear pores (holes in nuclear membrane), where they become ribosomes
- between cell divisions distinct chromosomes less obvious (massed as chromatin)

Endoplasmic Reticulum

- Outer membrane of nucleus continuous with endoplasmic reticulum
- Tubular membranes and cisternae
- 2 types:
  - **Rough**: **–** ribosomes, for membrane protein and secreted protein synthesis

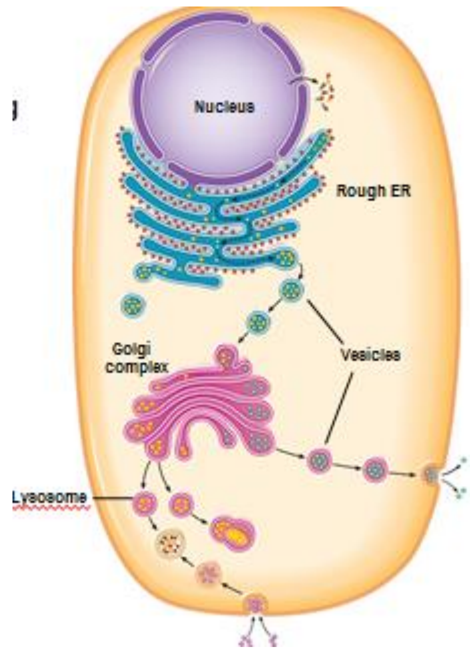
  - **Smooth**: – for lipid (become part of membrane) and steroid synthesis, detoxification, lacks ribosomes

    - Ex. Cells with lots of smooth E.R
      - Steroid synthesis (fat derived hormones)

        - Liver (detoxification of toxic compounds)
- Destination of proteins made on E.R→ Golgi complex

Golgi complex

- stack of flattened vesicles
- sorting, modification and packaging of proteins
- could be inserted into membrane, become lysosome, peroxisome or as a vehicle for transport
- receiving side from ER = *cis* face
- they are moved to the *trans* face where they are sorted and packaged for release



Vesicles

- Transport among organelles and/or to plasma membrane
- Become part of membrane after doing endocytosis/exocytosis

Lysosomes, peroxisomes

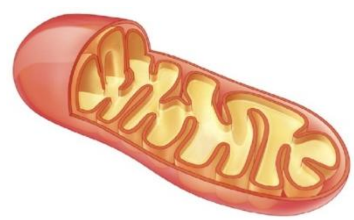
- Contain hydrolases, catalases
- Digestion of complex molecules
- Found in animals, not in plants

Vacuole

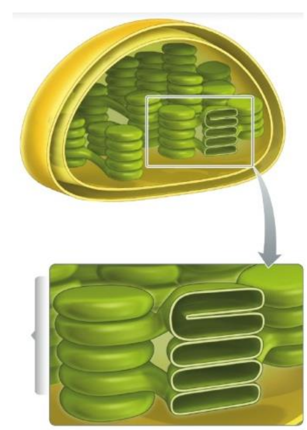
- Smaller in animal cells, large in plants
- Temporary storage
- Turgor pressure in plant cells
    - Central vacuole fills with water and pushes contents of the cell against the cell wall, giving a stiffer cell, insufficient cells leads to no turgor pressure and resulting cell is softer (plant wilts)

Mitochondrion

- ~2 µm
- Double membrane, cristae (folds)
    - Cristae hold the proteins responsible for ATP synthesis
    - Inner mitochondrial matrix surrounded by the membranes



- Oxidative metabolism yielding ATP
- Circular **mDNA** (naked DNA chromosome)
- Reproduce by fission indicating that they were once individual cells on their own
- Take chemical energy and turn into ATP via cellular respiration
- Contain own ribosomes for protein synthesis (ribosomes are smaller and contain fewer subunits)



Chloroplast

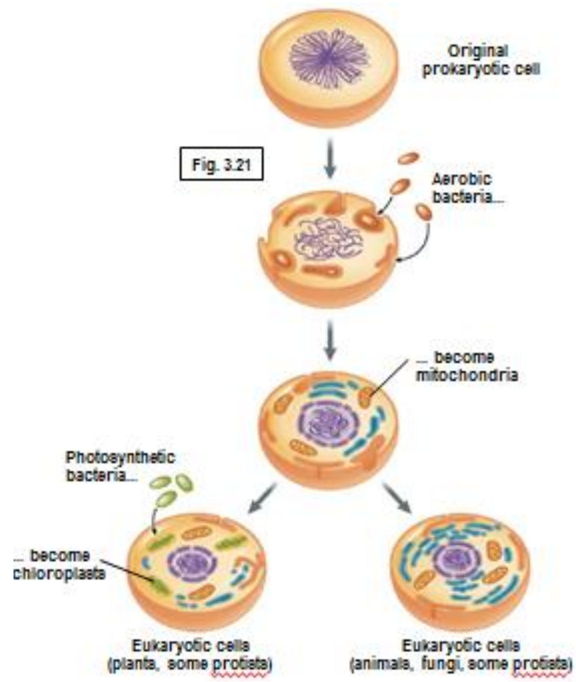
- ~5 µm
- Double membrane + thylakoids
    - Thylakoids: flattened disks which house chlorophyll
- Conversion of light energy to chemical energy (complex carbohydrates)
- Circular **cpDNA**
- Reproduce by fission (naked DNA chromosome)

Cells cannot create their own mitochondria and chloroplasts. They come only from previous cells.

Characteristics very similar to bacterial characteristics.

MITOCHONDRIA	CHLOROPLAST	COMMON
-Around 2 microns. -Inner membrane highly folded to anchor proteins involved in ATP synthesis through oxidative metabolism. -Own genetic: **mDNA.**	-Around 5 microns. -Layers of sacs called thylakoids in the double membrane filled with chloropgyll, which absorb light energy and convert it into chemical energy (carbohydrates). -Own genetic: **cpDNA.**	-Both relatively large and bounded by double membrane. -Both have their own types of DNA, circular chromosome with naked proteins. -Both have smaller ribosomes than the ones in cytoplasm, used to synthesize their own proteins. -Both reproduce by binary fission, from pre-existing mitochondrion chloroplasts.

Endosymbiont Theory



- **<u>Mitochondria from incorporation of aerobic prokaryote</u>**
- **<u>Chloroplast from (later) incorporation of cyanobacteria</u>**
- **Evidence to support this theory?**
  - Fossil Record
  - Similarities between mitochondria and chloroplasts
  - Started out as free living bacteria that were incorporated into a large bacterial cell
- An original prokaryotic cell one day engulfed aerobic bacteria, and the aerobic bacteria started living inside the larger bacterial cell for mutual benefit:
  - **Mutual benefit:** aerobic bacteria has stable safe environment
    - The larger host cell benefit from the more efficient metabolic pathways provided by aerobic bacteria
    - Over time aerobic bacteria turned into mitochondria
- Similar event occurred in which a photosynthetic bacterium was incorporated (cyanobacteria)
- Split in lineage with one lineage acquiring photosynthetic bacterium (plant cells) with the other half having only mitochondria (animal cells)
- **<u>Present day examples of endosymbiosis</u>**
  - Symbiotic animals containing green **photobionts (e.g. some sponges, *Hydra*, the salamander *Ambystoma maculatum*)**
    - solar-powered sea slugs (kleptoplasty in *Elysia chlorotica*)
    - Baby sea slugs are brown, acquire green color once they feed on algae and steal the chloroplasts from it (kleptoplasty)
    - These chloroplasts go into the intestines of the sea slug, the branching of the intestines throughout the body give green appearance
    - Once chloroplasts in place, it survives solely on photosynthesis