Unit 2
The Cellular Basis of Life
2A. Basic Cell Structure and Function
2B. Viruses
2C. Membranes and Cell Transport
2D. Energy and Metabolism
2E. How Cells Harvest Energy
2F. Photosynthesis
2G. Cell Communication

Module 2A
Basic Cell Structure and Function
- Cells are the basic units of life. Therefore, an understanding of cells is essential for an understanding of living organisms.
- In this module, we will take an introductory look at the structure and function of living cells.

Objective # 1
Describe the general plan of cellular organization common to all cells.

Objective 1
- In 1655, the English scientist Robert Hooke coined the term “cellulae” for the small box-like structures he saw while examining a thin slice of cork under a microscope.
- A few years later, a Dutchman named Anton van Leeuwenhoek observed and described numerous living cells.

Onion Cells
Further study has shown that all cells have the following basic structure:
- A thin, flexible plasma membrane surrounds the entire cell.
- The interior is filled with a semi-fluid material called the cytoplasm.
- Also inside are specialized structures called organelles and the cell’s genetic material.
Objective # 2

List and explain the 3 principles of the cell theory.

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Objective 2

- In 1838 – 1839, the German scientists Schleiden and Schwann, proposed the first 2 principles of the cell theory:
  - All organisms are composed of one or more cells.
- Cells are the basic units of life.

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Objective 2

- About 15 years later, the German physician Rudolf Virchow proposed the third and final principle of the cell theory:
  - All cells arise from pre-existing cells.
- This is now qualified with “under the current conditions on earth”.

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Objective # 3

Describe some factors that act to limit cell size.

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Objective 3

- Why are cells so small?
  - Because a cell usually has only 1 or 2 sets of genetic instructions, there is a limit to the volume of cytoplasm that can be effectively controlled.
  - Methods used to transport materials and information inside the cell are efficient over short distances only.
  - Problem with surface-to-volume ratio.
Objective 3
- Assuming constant shape, as an object gets bigger what happens to its surface area?
- What happens to its volume?
- What happens to its surface-to-volume ratio?
  - The S/V ratio decreases because volume increases at a faster rate than surface area.

The ratio of Surface Area to Volume gets smaller as this cell gets larger

<table>
<thead>
<tr>
<th>Cell radius (r)</th>
<th>1 unit</th>
<th>10 unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface area ($4\pi r^2$)</td>
<td>12.57 unit$^2$</td>
<td>1257 unit$^2$</td>
</tr>
<tr>
<td>Volume ($\pi r^3$)</td>
<td>4.189 unit$^3$</td>
<td>4189 unit$^3$</td>
</tr>
<tr>
<td>Surface Area/Volume</td>
<td>3</td>
<td>0.3</td>
</tr>
</tbody>
</table>

Objective 3
- Why is decreasing S/V ratio a problem?
- In order to survive, a cell must exchange materials with its environment. Cell volume determines the amount of materials that must be exchanged, while surface area limits how fast exchange can occur. In other words, as cells get larger the need for materials increases faster than the ability to absorb them.

Objective 3
- How have organisms become larger in spite of these problems?
  - At first, simple cells simply got larger. Average eukaryotic cell is 1,000 X larger in volume than average prokaryotic cell. Eventually, limits to size of individual cells were reached.

Objective 3
- Coenocytic organisms – sac of cytoplasm continued to increase in size but became multinucleate and evolved thin, flat shapes or long, narrow shapes to increase S/V ratio. E.g. some protists, fungi

Objective 3
- Colonial organisms – instead of one large mass of cytoplasm, body was divided into many small, similar cells, each with its own nucleus. E.g. some protists
- Multicellular organisms – similar to colonial except cells became specialized to carry out specific functions. E.g. plants, animals
Objective # 4

Describe the structure of a typical prokaryotic cell.

Objective # 5

Describe the structure of a typical eukaryotic cell.
Nucleus
- Repository of the genetic information
- Most eukaryotic cells possess a single nucleus
- Nucleolus – region where ribosomal RNA synthesis takes place
- Nuclear envelope
  - 2 phospholipid bilayers
  - Nuclear pores – control passage in and out
- In eukaryotes, the DNA is divided into multiple linear chromosomes
  - Chromatin is chromosomes plus protein

Ribosomes
- Cell’s protein synthesis machinery
- Found in all cell types in all 3 domains
- Ribosomal RNA (rRNA)-protein complex
- Protein synthesis also requires messenger RNA (mRNA) and transfer RNA (tRNA)
- Ribosomes may be free in cytoplasm or associated with internal membranes

Endomembrane System
- A system of membranes that run through the cytoplasm and divide the cell into compartments where different cellular functions occur
- Present in eukaryotic cells only
- Components of the endomembrane system include: the endoplasmic reticulum, the Golgi, lysosomes, microbodies, vacuoles, and vesicles
**Endoplasmic reticulum**
- Rough endoplasmic reticulum (RER)
  - Attachment of ribosomes to the membrane gives a rough appearance
  - Synthesis of proteins to be secreted, sent to lysosomes or plasma membrane
- Smooth endoplasmic reticulum (SER)
  - Relatively few bound ribosomes
  - Variety of functions – synthesis, store Ca^{2+}, detoxification
- Ratio of RER to SER depends on cell’s function

**Golgi apparatus**
- Flattened stacks of interconnected membranes (Golgi bodies)
- Functions in packaging and distribution of molecules synthesized at one location and used at another within the cell or even outside of it
- Cis and trans faces
- Vesicles transport molecules to destination

**Lysosomes**
- Membrane-bound sacs that contain digestive enzymes
- Arise from the Golgi apparatus
- Enzymes catalyze the breakdown of macromolecules
- Destroy cells or foreign matter that the cell has engulfed by phagocytosis
**Microbodies**

- Variety of enzyme-bearing, membrane-enclosed vesicles
- One type are peroxisomes
  - Contain enzymes involved in the oxidation of fatty acids
  - $\text{H}_2\text{O}_2$ produced as by-product – rendered harmless by catalase

**Vacuoles**

- Membrane-bounded sacs that carry out various functions depending on the cell type
- There are different types of vacuoles:
  - Central vacuole in plant cells
  - Contractile vacuole of some protists
  - Storage vacuoles

**Mitochondria**

- Found in all types of eukaryotic cells
- Bound by membranes
  - Outer membrane
  - Intermembrane space
  - Inner membrane has cristae
  - Matrix
- On the surface of the inner membrane, and also embedded within it, are proteins that carry out oxidative metabolism
- Have their own DNA
Chloroplasts
- Organelles present in cells of plants and some other eukaryotes
- Contain chlorophyll for photosynthesis
- Surrounded by 2 membranes
- Thylakoids are membranous sacs within the inner membrane
  - Grana are stacks of thylakoids
- Have their own DNA

Be able to describe the structure and function of a chloroplast:

Endosymbiosis
- This theory proposes that some eukaryotic organelles evolved by a symbiosis between two cells that were each free-living
- One cell, a prokaryote, was engulfed by and became part of a larger cell, which was the precursor of modern eukaryotes
- Organelles that probably arose by endosymbiosis include mitochondria and chloroplasts

Some eukaryotic organelles evolved through the process of endosymbiosis:

Cytoskeleton
- A network of protein fibers and tubes found in all eukaryotic cells
  - Supports the shape of the cell
  - Keeps organelles in fixed locations
- Dynamic system – constantly forming and disassembling

3 Components of the Cytoskeleton
- Microfilaments (actin filaments)
  - Two protein chains loosely twined together
  - Movements like contraction, crawling, “pinching”
- Microtubules
  - Largest of the cytoskeletal elements
  - Dimers of α- and β-tubulin subunits
  - Facilitate movement of cell and materials within cell
- Intermediate filaments
  - Between the size of actin filaments and microtubules
  - Very stable – usually not broken down
Be able to describe the structure and function of the 3 components of the cytoskeleton:

**Centrosome**
- Region containing a pair of centrioles
- Centrioles function as microtubule-organizing centers. They can initiate the assembly of new microtubules.
- Animal cells and most protists have centrioles
- Plants and fungi usually lack centrioles

A pair of centrioles. Each centriole is composed of 9 triplets of microtubules:

**Cell Movement**
- Essentially all cell motion is tied to the movement of actin filaments, microtubules, or both
- Some cells crawl using actin microfilaments
- Eukaryotic flagella and cilia have 9 + 2 arrangement of microtubules
  - Not like prokaryotic flagella

Be able to describe the structure and function of a eukaryotic flagellum. Cilia have a similar structure, except they are shorter and more numerous.

A green algal cell with numerous flagella and a paramecium covered with cilia
Eukaryotic cell walls
- Plants, fungi, and many protists
- Different from prokaryote
- Prokaryotes - peptidoglycan
- Plants and protists - cellulose
- Fungi – chitin
- Plants – primary and secondary cell walls

Extracellular matrix (ECM)
- Animal cells lack cell walls
- Secrete an elaborate mixture of glycoproteins into the space around them
- Collagen may be abundant
- Form a protective layer over the cell surface
- Integrins link ECM to cell’s cytoskeleton

Objective # 6
Describe the similarities and differences between prokaryotic and eukaryotic cells.
Objective 6

<table>
<thead>
<tr>
<th>Prokaryotes</th>
<th>Eukaryotes</th>
</tr>
</thead>
<tbody>
<tr>
<td>organisms</td>
<td></td>
</tr>
<tr>
<td>monera (bacteria)</td>
<td>all other organisms</td>
</tr>
<tr>
<td>size</td>
<td></td>
</tr>
<tr>
<td>very small (1 – 5 µm)</td>
<td>much larger (10 – 100 µm)</td>
</tr>
<tr>
<td>complexity</td>
<td></td>
</tr>
<tr>
<td>relatively simple</td>
<td>more complex</td>
</tr>
<tr>
<td>cell wall</td>
<td></td>
</tr>
<tr>
<td>usually present (contains peptidoglycan)</td>
<td>sometimes present (lacks peptidoglycan)</td>
</tr>
</tbody>
</table>

Objective 6

<table>
<thead>
<tr>
<th>Prokaryotes</th>
<th>Eukaryotes</th>
</tr>
</thead>
<tbody>
<tr>
<td>plasma membrane</td>
<td>always present</td>
</tr>
<tr>
<td>internal membranes</td>
<td>may contain infoldings of the plasma membrane but usually lack internal membranes</td>
</tr>
<tr>
<td>complexity</td>
<td></td>
</tr>
<tr>
<td>relatively simple</td>
<td>more complex</td>
</tr>
</tbody>
</table>

Objective 6

<table>
<thead>
<tr>
<th>Prokaryotes</th>
<th>Eukaryotes</th>
</tr>
</thead>
<tbody>
<tr>
<td>membrane-bound organelles</td>
<td>present</td>
</tr>
<tr>
<td>ribosomes</td>
<td>larger and may be bound to ER</td>
</tr>
<tr>
<td>cytoskeleton</td>
<td>present</td>
</tr>
<tr>
<td>flagella</td>
<td>microtubules; bend</td>
</tr>
</tbody>
</table>

Objective 6

<table>
<thead>
<tr>
<th>Prokaryotes</th>
<th>Eukaryotes</th>
</tr>
</thead>
<tbody>
<tr>
<td>structure of genetic material</td>
<td>single, naked, circular DNA molecule</td>
</tr>
<tr>
<td>location of genetic material</td>
<td>in an area of the cytoplasm called the nucleoid</td>
</tr>
</tbody>
</table>

Objective # 7

Name and describe the types of surface markers that give cells identity.

Objective 7

- Cell surface markers allow the cells of a multicellular organism to recognize each other and to distinguish “self” from “non-self.”
- In this section, we will examine 2 types of cell surface markers:
  - Glycolipids
  - MHC proteins
Objective 7

- Glycolipids:
  - Are lipids embedded in the plasma membrane with carbohydrate groups attached
  - Allow cells that are part of the same tissue to recognize each other and form intimate connections to better coordinate their functions.

Objective 7

- MHC proteins:
  - Are proteins embedded in the surface of the plasma membrane.
  - Allow cells of the immune system to distinguish foreign cells from the body’s own cells so they can mount an attack against any foreign cells.

Objective # 8

Explain what cell junctions are, and discuss the following types of cell junctions:

- a) tight junction
- b) anchoring junction
- c) communicating junction

Objective 8

- Cell junctions refer to long-lasting or permanent connections between adjacent cells.
- We will examine 3 types of cell junctions:

Objective 8a

- a) Tight junctions connect cells into sheets. Because these junctions form a tight seal between cells, in order to cross the sheet, substances must pass through the cells, they cannot pass between the cells.
Objective 8b

b) Anchoring junctions attach the cytoskeleton of a cell to the matrix surrounding the cell, or to the cytoskeleton of an adjacent cell.

Objective 8c

c) Communicating junctions link the cytoplasms of 2 cells together, permitting the controlled passage of small molecules or ions between them. In animals, these junctions are called gap junctions; in plants they are called plasmodesmata.

Table 4.4

<table>
<thead>
<tr>
<th>TABLE 4.4</th>
<th>Cell-to-Cell Connections and Cell Identity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of Junction</td>
<td>Structure</td>
</tr>
<tr>
<td>Surface junction</td>
<td>Tightly bound transmembrane proteins and filaments</td>
</tr>
<tr>
<td>Tight junction</td>
<td>Tightly bound transmembrane proteins</td>
</tr>
<tr>
<td>Ankylin junction (seam junction)</td>
<td>Intermediate filaments and desmosome</td>
</tr>
<tr>
<td>Gap junction (desmosome)</td>
<td>Communicates between cells</td>
</tr>
<tr>
<td>Gap junction (plasmodesma)</td>
<td>Communicates between cells</td>
</tr>
</tbody>
</table>