

AP BIOLOGY

**UNIT 2**

# Cell Structure and Function



**10–13%**  
AP EXAM WEIGHTING



**~11–13**  
CLASS PERIODS

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The icon consists of a white circle containing a blue square with the letters 'AP' in white. Below the square is a blue horizontal line with two short vertical bars extending downwards from its center, resembling a computer monitor or a stylized 'I'.

Remember to go to **AP Classroom** to assign students the online **Personal Progress Check** for this unit.

Whether assigned as homework or completed in class, the **Personal Progress Check** provides each student with immediate feedback related to this unit's topic and skills.

### **Personal Progress Check 2**

**Multiple-choice: ~30 questions**

**Free-response: 2 questions**

- Interpreting and Evaluating Experimental Results (partial)
- Analyze Model or Visual Representation (partial)

# Cell Structure and Function



## Developing Understanding

### BIG IDEA 1

#### Evolution **EVO**

- Defend the origin of eukaryotic cells.

### BIG IDEA 2

#### Energetics **ENE**

- How do the mechanisms for transport across membranes support energy conservation?
- What are the advantages and disadvantages of cellular compartmentalization?

### BIG IDEA 4

#### Systems

#### Interactions **SYI**

- How are living systems affected by the presence or absence of subcellular components?

The cell is the basic unit of life. Cells contribute to the organization of life and provide the environment in which organelles function. Organelles in turn provide compartmentalization and organize cellular products for dispersal and waste for disposal. Cells have membranes that allow them to establish and maintain an internal environment. These membranes also control the exchange of material with the cell's external environment—an important, foundational concept. The maintenance of the internal and external conditions of a cell is called homeostasis. Student understanding of these concepts will be necessary in later units when the focus of instruction shifts to cellular products and by-products and when students learn why cellular exchange of energy and materials matters.

## Building Science Practices

1.A 1.B 6.B 4.A 6.E.b 6.E.a 5.A.d

A solid understanding of the origin and function of organelles is the foundation for understanding cell biology. Students should explain the relationships between structure and function of organelles and cellular components on the subcellular and cellular levels.

Understanding biological systems frequently requires students to select the data necessary to solve a problem and use them to perform the appropriate calculations with correct units while showing their work and linking the results to a biological process. Students should gain proficiency in describing the characteristics of data given in a diagram, graph, or data table and identify patterns or trends in the data.

Selecting and creating the appropriate type of graph for a set of data are critical skills for communicating data that students should begin to master in this unit. Students should routinely practice analyzing different types of data, both hypothetical and those they collect, to identify patterns, connect variables, and perform statistical analysis.

## Preparing for the AP Exam

On the exam, students frequently can correctly identify an organelle but fail to accurately describe its function. Students should be able to explain the relationships between structure and function on both the subcellular and cellular level. Avoid using catchy analogies (e.g., cell city) and food-based models because on the exam students tend to write about the analogy without demonstrating an understanding of its underlying concept using appropriate terminology.

The graphing skills learned in this unit are important. Students should be able to label the independent and dependent variables *with units*, correctly plot data points with appropriate scaling, and correctly represent the data in question. For instance, a line graph should be used for continuous data and a bar graph for categorical data. Students often fail to earn points because they draw error bars incorrectly and fail to use them to draw conclusions about the significance of the data.

## UNIT AT A GLANCE

Enduring Understanding	Topic	Suggested Skill	Class Periods
			~11–13 CLASS PERIODS
SYI-1	<b>2.1 Cell Structure: Subcellular Components</b>	<b>1.A</b> Describe biological concepts and/or processes.	
	<b>2.2 Cell Structure and Function</b>	<b>6.A</b> Make a scientific claim.	
ENE-1	<b>2.3 Cell Size</b>	<b>2.D.a</b> Represent relationships within biological models, including mathematical models. <b>5.A.d</b> Perform mathematical calculations, including ratios.	
	<b>2.4 Plasma Membranes</b>	<b>2.A</b> Describe characteristics of a biological concept, process, or model represented visually.	
ENE-2	<b>2.5 Membrane Permeability</b>	<b>3.D</b> Make observations or collect data from representations of laboratory setups or results. <b>5.D.b</b> Use data to evaluate a hypothesis (or prediction), including supporting or refuting the alternative hypothesis.	
	<b>2.6 Membrane Transport</b>	<b>3.E.b</b> Propose a new/next investigation based on an evaluation of the design/methods.	
	<b>2.7 Facilitated Diffusion</b>	<b>6.E.b</b> Predict the causes or effects of a change in, or disruption to, one or more components in a biological system based on a visual representation of a biological concept, process, or model.	
	<b>2.8 Tonicity and Osmoregulation</b>	<b>4.A</b> Construct a graph, plot, or chart.	
	<b>2.9 Mechanisms of Transport</b>	<b>1.B</b> Explain biological concepts and/or processes.	
	<b>2.10 Cell Compartmentalization</b>	<b>6.E.a</b> Predict the causes or effects of a change in, or disruption to, one or more components in a biological system based on a biological concepts or processes.	
	<b>2.11 Origins of Cell Compartmentalization</b>	<b>6.B</b> Support a claim with evidence from biological principles, concepts, processes, and/or data.	



Go to [AP Classroom](#) to assign the **Personal Progress Check** for Unit 2. Review the results in class to identify and address any student misunderstandings.

## SAMPLE INSTRUCTIONAL ACTIVITIES

The sample activities on this page are intended to give you ideas of ways to incorporate varied instructional approaches in the teaching of this course. You do not need to use these activities or approaches and are free to alter or edit them in any way you choose. The following examples were developed in partnership with teachers from the AP community to share ways that they approach teaching some of the topics in this unit. Please refer to the Instructional Approaches section beginning on p. 171 for more examples of activities and strategies.

Activity	Topic	Sample Activity
1	2.1	<p><b>Ask the Expert</b></p> <p>Students can be divided into groups and each group assigned a subcellular component to study. Students then rotate through the expert stations to learn about the subcellular components required for this topic.</p>
2	2.3	<p><b>Misconception Check</b></p> <p>Students can take agar cubes of different sizes that are soaked in phenolphthalein and soak them in vinegar. The students can measure how long it takes for the cubes to become clear as the vinegar diffuses into the cubes. Students will find that the smaller cubes become clear before the larger cubes and can use their observations to determine how cell size affects cell function.</p>
3	2.4	<p><b>One-Minute Essay</b></p> <p>Before teaching the topic, have students read a case study about osmosis and answer questions (either those given with the case study or those you create) about the scenario. Ask students to draw what they think is occurring on the cellular level. Then, teach the topic in the way that best fits your classroom. Once students have demonstrated an understanding of the topic, have them revisit their answers to the questions in the case study as well as their drawings.</p>



### Unit Planning Notes

Use the following space to plan your approach to the unit. Consider how you want to pace your course and your methods of instruction and assessment.

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## SUGGESTED SKILL

 Concept Explanation

## 1.A

Describe biological concepts and/or processes.



## ILLUSTRATIVE EXAMPLE

- Glycosylation and other chemical modifications of proteins that take place within the Golgi and determine protein function or targeting

## TOPIC 2.1

# Cell Structure: Subcellular Components

## Required Course Content

### ENDURING UNDERSTANDING

**SYI-1**

Living systems are organized in a hierarchy of structural levels that interact.

### LEARNING OBJECTIVE

**SYI-1.D**

Describe the structure and/or function of subcellular components and organelles.

### ESSENTIAL KNOWLEDGE

**SYI-1.D.1**

Ribosomes comprise ribosomal RNA (rRNA) and protein. Ribosomes synthesize protein according to mRNA sequence.

**SYI-1.D.2**

Ribosomes are found in all forms of life, reflecting the common ancestry of all known life.

**SYI-1.D.3**

Endoplasmic reticulum (ER) occurs in two forms—smooth and rough. Rough ER is associated with membrane-bound ribosomes—

- a. Rough ER compartmentalizes the cell.
- b. Smooth ER functions include detoxification and lipid synthesis.

**EXCLUSION STATEMENT**—*Specific functions of smooth ER in specialized cells are beyond the scope of the course and the AP Exam.*

**SYI-1.D.4**

The Golgi complex is a membrane-bound structure that consists of a series of flattened membrane sacs—

- a. Functions of the Golgi include the correct folding and chemical modification of newly synthesized proteins and packaging for protein trafficking.

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## LEARNING OBJECTIVE

### SYI-1.D

Describe the structure and/or function of subcellular components and organelles.

## ESSENTIAL KNOWLEDGE

**✖ EXCLUSION STATEMENT**—*The role of the Golgi in the synthesis of specific phospholipids and the packaging of specific enzymes for lysosomes, peroxisomes, and secretory vesicles are beyond the scope of the course and the AP Exam.*

- b. Mitochondria have a double membrane. The outer membrane is smooth, but the inner membrane is highly convoluted, forming folds.
- c. Lysosomes are membrane-enclosed sacs that contain hydrolytic enzymes.
- d. A vacuole is a membrane-bound sac that plays many and differing roles. In plants, a specialized large vacuole serves multiple functions.
- e. Chloroplasts are specialized organelles that are found in photosynthetic algae and plants. Chloroplasts have a double outer membrane.

## SUGGESTED SKILL

 Argumentation

6.A

Make a scientific claim.

## TOPIC 2.2

# Cell Structure and Function

## Required Course Content

### ENDURING UNDERSTANDING

**SYI-1**

Living systems are organized in a hierarchy of structural levels that interact.

### LEARNING OBJECTIVE

**SYI-1.E**

Explain how subcellular components and organelles contribute to the function of the cell.

**SYI-1.F**

Describe the structural features of a cell that allow organisms to capture, store, and use energy.

### ESSENTIAL KNOWLEDGE

**SYI-1.E.1**

Organelles and subcellular structures, and the interactions among them, support cellular function—

- Endoplasmic reticulum provides mechanical support, carries out protein synthesis on membrane-bound ribosomes, and plays a role in intracellular transport.
- Mitochondrial double membrane provides compartments for different metabolic reactions.
- Lysosomes contain hydrolytic enzymes, which are important in intracellular digestion, the recycling of a cell's organic materials, and programmed cell death (apoptosis).
- Vacuoles have many roles, including storage and release of macromolecules and cellular waste products. In plants, it aids in retention of water for turgor pressure.

**SYI-1.F.1**

The folding of the inner membrane increases the surface area, which allows for more ATP to be synthesized.

**SYI-1.F.2**

Within the chloroplast are thylakoids and the stroma.

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## LEARNING OBJECTIVE

### SYI-1.F

Describe the structural features of a cell that allow organisms to capture, store, and use energy.

## ESSENTIAL KNOWLEDGE

### SYI-1.F.3

The thylakoids are organized in stacks, called grana.

### SYI-1.F.4

Membranes contain chlorophyll pigments and electron transport proteins that comprise the photosystems.

### SYI-1.F.5

The light-dependent reactions of photosynthesis occur in the grana.

### SYI-1.F.6

The stroma is the fluid within the inner chloroplast membrane and outside of the thylakoid.

### SYI-1.F.7

The carbon fixation (Calvin-Benson cycle) reactions of photosynthesis occur in the stroma.


### SYI-1.F.8

The Krebs cycle (citric acid cycle) reactions occur in the matrix of the mitochondria.

### SYI-1.F.9


Electron transport and ATP synthesis occur on the inner mitochondrial membrane.

**SUGGESTED SKILLS**

 *Statistical Tests and Data Analysis*

**5.A.d**

Perform mathematical calculations, including ratios.

 *Visual Representations*

**2.D.a**

Represent relationships within biological models, including mathematical models.



**ILLUSTRATIVE EXAMPLES**  
**SA/V Ratios and Exchange**

- Root hair cells
- Guard cells
- Gut epithelial cells

**ILLUSTRATIVE EXAMPLES**

- Vacuoles
- Cilia
- Stomata

## TOPIC 2.3

# Cell Size

### Required Course Content

#### ENDURING UNDERSTANDING

**ENE-1**

The highly complex organization of living systems requires constant input of energy and the exchange of macromolecules.

#### LEARNING OBJECTIVE

**ENE-1.B**

Explain the effect of surface area-to-volume ratios on the exchange of materials between cells or organisms and the environment.

#### ESSENTIAL KNOWLEDGE

**ENE-1.B.1**

Surface area-to-volume ratios affect the ability of a biological system to obtain necessary resources, eliminate waste products, acquire or dissipate thermal energy, and otherwise exchange chemicals and energy with the environment.

#### RELEVANT EQUATIONS

Volume of a Sphere:  $V = \frac{4}{3} \pi r^3$

Volume of a Cube:  $V = s^3$

Volume of a Rectangular Solid:  $V = lwh$

Volume of a Cylinder:  $V = \pi r^2 h$

Surface Area of a Sphere:  $SA = 4\pi r^2$

Surface Area of a Cube:  $SA = 6s^2$

Surface Area of a Rectangular Solid:  
 $SA = 2lh + 2lw + 2wh$

Surface Area of a Cylinder:  $SA = 2\pi rh + 2\pi r^2$

$r$  = radius

$l$  = length

$h$  = height

$w$  = width

$s$  = length of one side of a cube

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## LEARNING OBJECTIVE

### ENE-1.B

Explain the effect of surface area-to-volume ratios on the exchange of materials between cells or organisms and the environment.

### ENE-1.C

Explain how specialized structures and strategies are used for the efficient exchange of molecules to the environment.

## ESSENTIAL KNOWLEDGE

### ENE-1.B.2


The surface area of the plasma membrane must be large enough to adequately exchange materials—

- These limitations can restrict cell size and shape. Smaller cells typically have a higher surface area-to-volume ratio and more efficient exchange of materials with the environment.
- As cells increase in volume, the relative surface area decreases and the demand for internal resources increases.
- More complex cellular structures (e.g., membrane folds) are necessary to adequately exchange materials with the environment.
- As organisms increase in size, their surface area-to-volume ratio decreases, affecting properties like rate of heat exchange with the environment.

### ENE-1.C.1

Organisms have evolved highly efficient strategies to obtain nutrients and eliminate wastes. Cells and organisms use specialized exchange surfaces to obtain and release molecules from or into the surrounding environment.

## SUGGESTED SKILL

 Visual  
Representations

## 2.A

Describe characteristics of a biological concept, process, or model represented visually.

## TOPIC 2.4

# Plasma Membranes

### Required Course Content

#### ENDURING UNDERSTANDING

**ENE-2**

Cells have membranes that allow them to establish and maintain internal environments that are different from their external environments.

#### LEARNING OBJECTIVE

**ENE-2.A**

Describe the roles of each of the components of the cell membrane in maintaining the internal environment of the cell.

**ENE-2.B**

Describe the Fluid Mosaic Model of cell membranes.

#### ESSENTIAL KNOWLEDGE

**ENE-2.A.1**

Phospholipids have both hydrophilic and hydrophobic regions. The hydrophilic phosphate regions of the phospholipids are oriented toward the aqueous external or internal environments, while the hydrophobic fatty acid regions face each other within the interior of the membrane.

**ENE-2.A.2**

Embedded proteins can be hydrophilic, with charged and polar side groups, or hydrophobic, with nonpolar side groups.


**ENE-2.B.1**

Cell membranes consist of a structural framework of phospholipid molecules that is embedded with proteins, steroids (such as cholesterol in eukaryotes), glycoproteins, and glycolipids that can flow around the surface of the cell within the membrane.

## TOPIC 2.5


## Membrane Permeability

## SUGGESTED SKILL

 *Questions and Methods*

**3.D**

Make observations or collect data from representations of laboratory setups or results.

 *Statistical Tests and Data Analysis*

**5.D.b**

Use data to evaluate a hypothesis (or prediction), including supporting or refuting the alternative hypothesis.

## Required Course Content

## ENDURING UNDERSTANDING

**ENE-2**

Cells have membranes that allow them to establish and maintain internal environments that are different from their external environments.

## LEARNING OBJECTIVE

**ENE-2.C**

Explain how the structure of biological membranes influences selective permeability.

**ENE-2.D**

Describe the role of the cell wall in maintaining cell structure and function.

## ESSENTIAL KNOWLEDGE

**ENE-2.C.1**

The structure of cell membranes results in selective permeability.

**ENE-2.C.2**

Cell membranes separate the internal environment of the cell from the external environment.

**ENE-2.C.3**

Selective permeability is a direct consequence of membrane structure, as described by the fluid mosaic model.

**ENE-2.C.4**

Small nonpolar molecules, including  $N_2$ ,  $O_2$ , and  $CO_2$ , freely pass across the membrane. Hydrophilic substances, such as large polar molecules and ions, move across the membrane through embedded channel and transport proteins.

**ENE-2.C.5**

Polar uncharged molecules, including  $H_2O$ , pass through the membrane in small amounts.


**ENE-2.D.1**

Cell walls provide a structural boundary, as well as a permeability barrier for some substances to the internal environments.

**ENE-2.D.2**

Cell walls of plants, prokaryotes, and fungi are composed of complex carbohydrates.

## SUGGESTED SKILL

 Questions and Methods

## 3.E.b

Propose a new/next investigation based on an evaluation of the design/methods.

## TOPIC 2.6

## Membrane Transport

## Required Course Content

## ENDURING UNDERSTANDING

## ENE-2

Cells have membranes that allow them to establish and maintain internal environments that are different from their external environments.

## LEARNING OBJECTIVE

## ENE-2.E

Describe the mechanisms that organisms use to maintain solute and water balance.

## ENE-2.F

Describe the mechanisms that organisms use to transport large molecules across the plasma membrane.

## ESSENTIAL KNOWLEDGE

## ENE-2.E.1

Passive transport is the net movement of molecules from high concentration to low concentration without the direct input of metabolic energy.

## ENE-2.E.2

Passive transport plays a primary role in the import of materials and the export of wastes.

## ENE-2.E.3

Active transport requires the direct input of energy to move molecules from regions of low concentration to regions of high concentration.

## ENE-2.F.1

The selective permeability of membranes allows for the formation of concentration gradients of solutes across the membrane.

## ENE-2.F.2

The processes of endocytosis and exocytosis require energy to move large molecules into and out of cells—

- a. In exocytosis, internal vesicles fuse with the plasma membrane and secrete large macromolecules out of the cell.
- b. In endocytosis, the cell takes in macromolecules and particulate matter by forming new vesicles derived from the plasma membrane.

## TOPIC 2.7

# Facilitated Diffusion

**SUGGESTED SKILL**
 *Argumentation*
**6.E.b**

Predict the causes or effects of a change in, or disruption to, one or more components in a biological system based on a visual representation of a biological concept, process, or model.

## Required Course Content

### ENDURING UNDERSTANDING

**ENE-2**

Cells have membranes that allow them to establish and maintain internal environments that are different from their external environments.

### LEARNING OBJECTIVE

**ENE-2.G**

Explain how the structure of a molecule affects its ability to pass through the plasma membrane.

### ESSENTIAL KNOWLEDGE

**ENE-2.G.1**

Membrane proteins are required for facilitated diffusion of charged and large polar molecules through a membrane—

- Large quantities of water pass through aquaporins.
- Charged ions, including  $\text{Na}^+$  and  $\text{K}^+$ , require channel proteins to move through the membrane.
- Membranes may become polarized by movement of ions across the membrane.

**ENE-2.G.2**

Membrane proteins are necessary for active transport.


**ENE-2.G.3**

Metabolic energy (such as from ATP) is required for active transport of molecules and/or ions across the membrane and to establish and maintain concentration gradients.

**ENE-2.G.4**

The  $\text{Na}^+/\text{K}^+$  ATPase contributes to the maintenance of the membrane potential.

**SUGGESTED SKILL**

 *Representing and Describing Data*

**4.A**

Construct a graph, plot, or chart.



**AVAILABLE RESOURCES**

- Classroom Resources > [Investigation 4: Diffusion and Osmosis](#)
- Classroom Resources > [Visualizing Information](#)

**ILLUSTRATIVE EXAMPLES**

- Contractile vacuole in protists
- Central vacuoles in plant cells

# TOPIC 2.8

## Tonicity and Osmoregulation

### Required Course Content

#### ENDURING UNDERSTANDING

**ENE-2**

Cells have membranes that allow them to establish and maintain internal environments that are different from their external environments.

#### LEARNING OBJECTIVE

**ENE-2.H**

Explain how concentration gradients affect the movement of molecules across membranes.

#### ESSENTIAL KNOWLEDGE

**ENE-2.H.1**

External environments can be hypotonic, hypertonic or isotonic to internal environments of cells—

- Water moves by osmosis from areas of high water potential/low osmolarity/low solute concentration to areas of low water potential/high osmolarity/high solute concentration.

#### RELEVANT EQUATION

Water Potential:

$$\Psi = \Psi_p + \Psi_s$$

$\Psi_p$  = pressure potential

$\Psi_s$  = solute potential

**ENE-2.I**

Explain how osmoregulatory mechanisms contribute to the health and survival of organisms.

**ENE-2.I.1**

Growth and homeostasis are maintained by the constant movement of molecules across membranes.

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## LEARNING OBJECTIVE

### ENE-2.1

Explain how osmoregulatory mechanisms contribute to the health and survival of organisms.

## ESSENTIAL KNOWLEDGE

### ENE-2.1.2

Osmoregulation maintains water balance and allows organisms to control their internal solute composition/water potential.

### SOLUTE POTENTIAL OF A SOLUTION

$$\Psi_s = -iCRT$$

where:

$i$  = ionization constant

$C$  = molar concentration

$R$  = pressure constant

$$\left( R = 0.0831 \frac{L \cdot \text{bars}}{\text{mol} \cdot K} \right)$$

$T$  = temperature in Kelvin ( $^{\circ}\text{C} + 273$ )

## SUGGESTED SKILL

 *Concept Explanation***1.B**

Explain biological concepts and/or processes.

## TOPIC 2.9

# Mechanisms of Transport

## Required Course Content

### ENDURING UNDERSTANDING

**ENE-2**

Cells have membranes that allow them to establish and maintain internal environments that are different from their external environments.

### LEARNING OBJECTIVE

**ENE-2.J**

Describe the processes that allow ions and other molecules to move across membranes.

### ESSENTIAL KNOWLEDGE

**ENE-2.J.1**

A variety of processes allow for the movement of ions and other molecules across membranes, including passive and active transport, endocytosis and exocytosis.

## TOPIC 2.10

# Compartmentalization

## SUGGESTED SKILL

 Argumentation**6.E.a**

Predict the causes or effects of a change in, or disruption to, one or more components in a biological system based on biological concepts or processes.

## Required Course Content

### ENDURING UNDERSTANDING

**ENE-2**

Cells have membranes that allow them to establish and maintain internal environments that are different from their external environments.

### LEARNING OBJECTIVE

**ENE-2.K**

Describe the membrane-bound structures of the eukaryotic cell.

**ENE-2.L**

Explain how internal membranes and membrane-bound organelles contribute to compartmentalization of eukaryotic cell functions.

### ESSENTIAL KNOWLEDGE

**ENE-2.K.1**

Membranes and membrane-bound organelles in eukaryotic cells compartmentalize intracellular metabolic processes and specific enzymatic reactions.

**ENE-2.L.1**

Internal membranes facilitate cellular processes by minimizing competing interactions and by increasing surface areas where reactions can occur.

**SUGGESTED SKILL** *Argumentation***6.B**

Support a claim with evidence from biological principles, concepts, processes, and/or data.

**TOPIC 2.11**

# Origins of Cell Compartmentalization

## Required Course Content

### ENDURING UNDERSTANDING

**EVO-1**

Evolution is characterized by a change in the genetic makeup of a population over time and is supported by multiple lines of evidence.

### LEARNING OBJECTIVE

**EVO-1.A**

Describe similarities and/or differences in compartmentalization between prokaryotic and eukaryotic cells.

**EVO-1.B**

Describe the relationship between the functions of endosymbiotic organelles and their free-living ancestral counterparts.

### ESSENTIAL KNOWLEDGE

**EVO-1.A.1**

Membrane-bound organelles evolved from once free-living prokaryotic cells via endosymbiosis.

**EVO-1.A.2**

Prokaryotes generally lack internal membrane-bound organelles but have internal regions with specialized structures and functions.

**EVO-1.A.3**

Eukaryotic cells maintain internal membranes that partition the cell into specialized regions.

**EVO-1.B.1**

Membrane-bound organelles evolved from previously free-living prokaryotic cells via endosymbiosis.