Unit 1 Big Ideas

Biological systems are governed by chemical principles.

The structure of molecules determines how they interact, and these interactions explain biological function at every level, from enzymes and membranes to ecosystems.

In Unit 1, students must be able to:

- Explain how molecular structure leads to function
- Use chemical principles to predict biological outcomes
- Connect microscopic interactions to macroscopic biological effects

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1.1 Water Structure and Polarity（结构层面）

Molecular Structure of Water

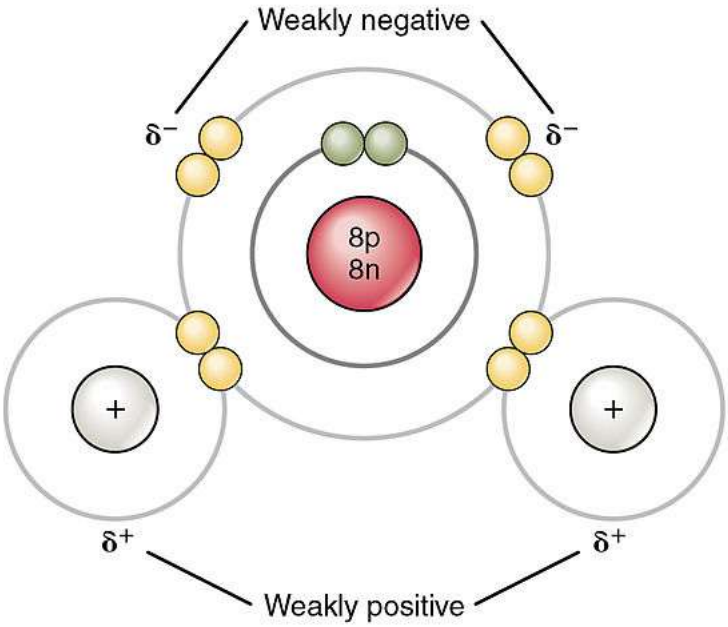
A water molecule (H_2O) consists of:

- One oxygen atom
- Two hydrogen atoms
- Covalent bonds formed by shared electrons

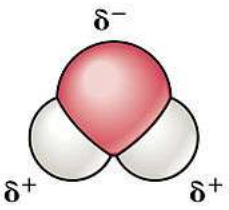
Oxygen is more electronegative than hydrogen, meaning it attracts shared electrons more strongly.

As a result:

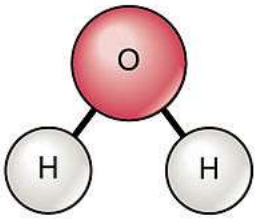
- Oxygen develops a partial negative charge ($\delta-$)
- Hydrogen develops partial positive charges ($\delta+$)



(a) Planetary model of a water molecule



(b) Three-dimensional model of a water molecule



(c) Structural formula for water molecule

This unequal charge distribution makes water a polar molecule.

AP 核心逻辑：
polarity → intermolecular attraction → biological properties

1.2 Hydrogen Bonding（机制层面）

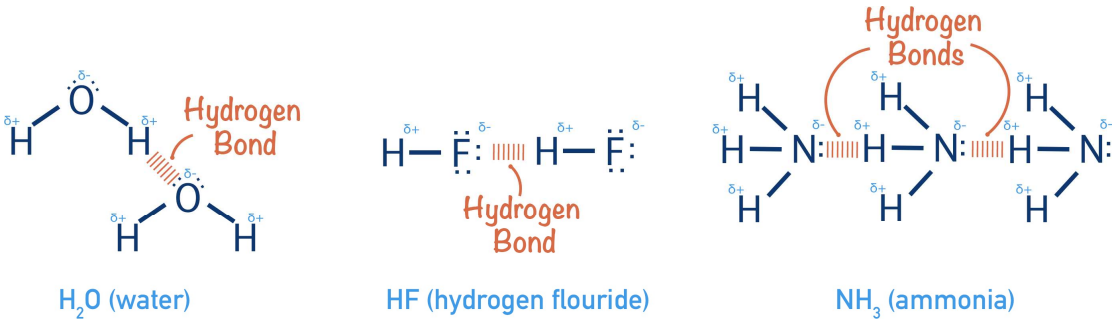
What is a Hydrogen Bond?

A hydrogen bond is a weak intermolecular attraction between:

- A partially positive hydrogen atom
- And a partially negative atom (usually oxygen or nitrogen)

Hydrogen bonds are:

- Not covalent
- Individually weak
- Collectively strong when many are present



Why Hydrogen Bonds Matter

In water, hydrogen bonding:

- Links water molecules together
- Creates a dynamic network
- Constantly breaks and reforms

This explains nearly all of water's life-supporting properties.

1.3 Properties of Water and Biological Significance（AP 必考核心）

Cohesion

Cohesion is the attraction between water molecules due to hydrogen bonding.

Biological significance:

- Maintains continuous columns of water in plant xylem
- Allows water transport against gravity

Adhesion

Adhesion is the attraction between water and other polar surfaces.

Biological significance:

- Helps water cling to cell walls
- Assists transpiration in plants

AP 常考对比点：
Cohesion = water–water
Adhesion = water–surface

Surface Tension

Surface tension results from cohesive forces at the surface of water.

Biological significance:

- Allows insects to walk on water
- Maintains integrity of water surfaces

High Specific Heat

Specific heat is the amount of energy required to raise temperature.

Water has a high specific heat because:

- Hydrogen bonds absorb heat before breaking

Biological significance:

- Buffers organisms from rapid temperature change
- Stabilizes internal body temperature
- Moderates Earth's climate

Heat of Vaporization

Heat of vaporization is the energy required to convert liquid to gas.

Water has a high heat of vaporization, meaning:

- Large amounts of energy are required for evaporation

Property	Attributes	Significance
Thermal	Extensive hydrogen bonding means water can absorb a lot of heat before changing state	Water is an excellent coolant (e.g. sweat) Water is a good medium for metabolic reactions (absorbs heat from exothermic reactions)
Cohesive	Dipolarity means water will stick to other water molecules (via H-bonds)	Water has a high surface tension, allowing small organisms to move on its surface (e.g. Basilisk lizard)
Adhesive	Dipolarity means water will stick to surfaces that are polar or charged	Water can move via capillary action against gravity (e.g. water can move up the xylem via transpiration)
Solvent	Dipolarity means water can dissolve molecules that are polar or charged	Water is a good transport medium (e.g. the blood system can transport soluble materials in its plasma)
Density	Water is less dense as a solid than as a liquid (maximum density ~ 4°C)	Ice floats on water (prevents oceans from freezing as ice layer prevents exposure to cold temperatures)
Transparency	Water is transparent to visible spectrum	Aquatic plants can undergo photosynthesis

Biological significance:

- Evaporative cooling (sweating, transpiration)
- Prevents overheating

1.4 Density of Ice and Aquatic Life

When water freezes:

- Hydrogen bonds form a rigid lattice
- Molecules spread farther apart

As a result:

- Ice is less dense than liquid water
- Ice floats

Biological importance:

- Ice insulates water below
- Aquatic organisms survive in cold environments

1.5 pH, Acids, and Bases（FRQ 高频）

pH Scale

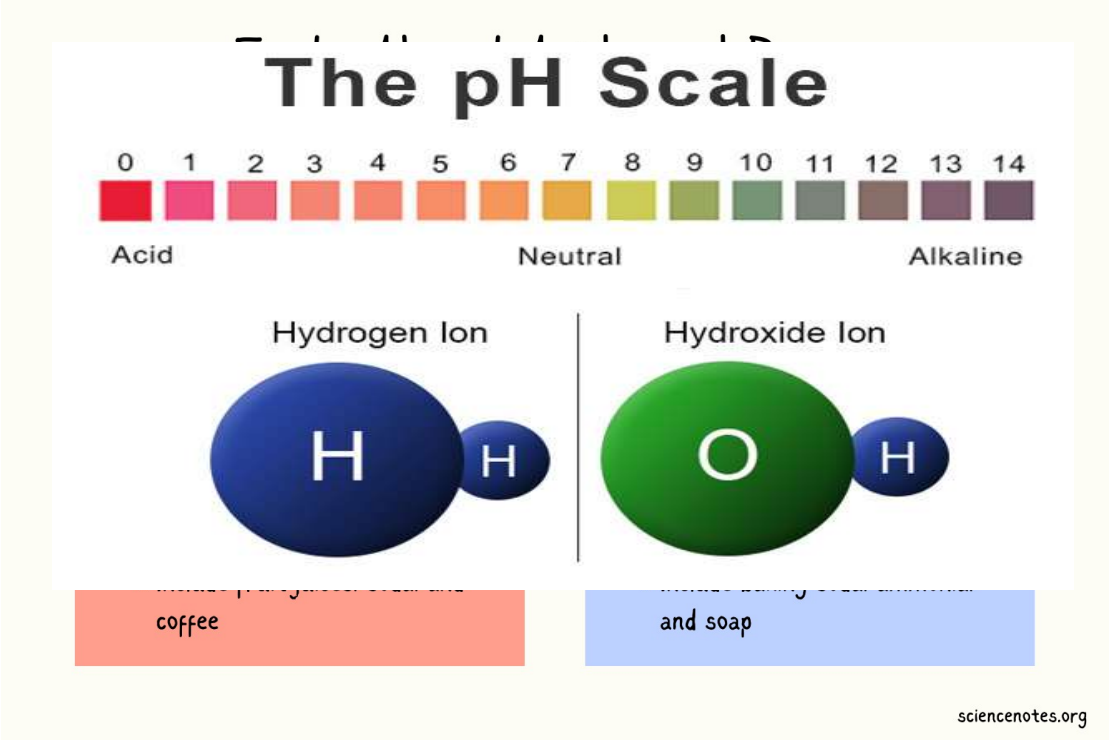
pH measures the concentration of hydrogen ions (H^+).

- Scale ranges from 0–14
- pH is logarithmic

- Each whole number represents a 10× change in H^+ concentration

Acids and Bases

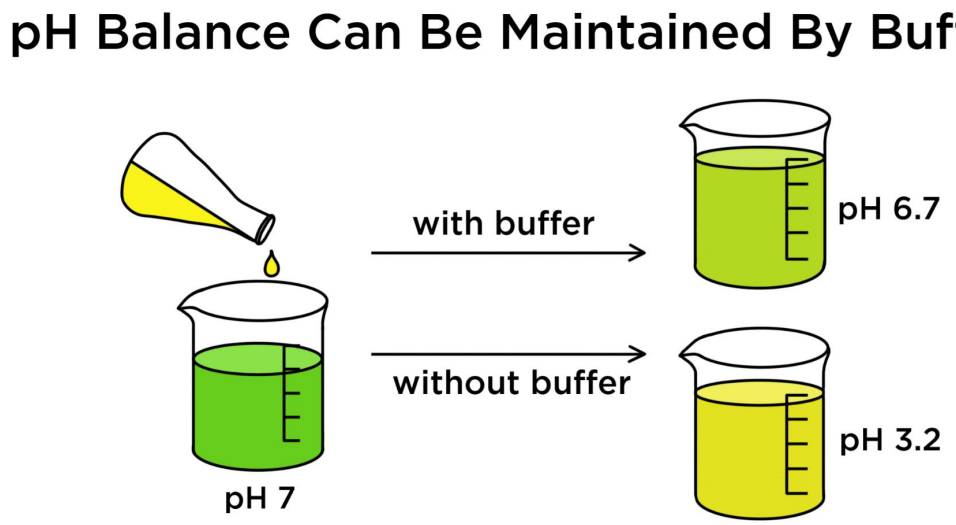
- Acid: donates H^+
- Base: accepts H^+ or releases OH^-



1.6 Buffers and Homeostasis（AP 实验重点）

Buffers are substances that resist changes in pH by:

- Accepting excess H^+
- Donating H^+ when levels drop



Biological importance:

- Maintain enzyme structure
- Keep blood pH stable (~7.4)

AP 常考推理题：
If a buffer is added, the pH will change less than without the buffer.

1.7 Carbon Chemistry（结构 → 多样性）

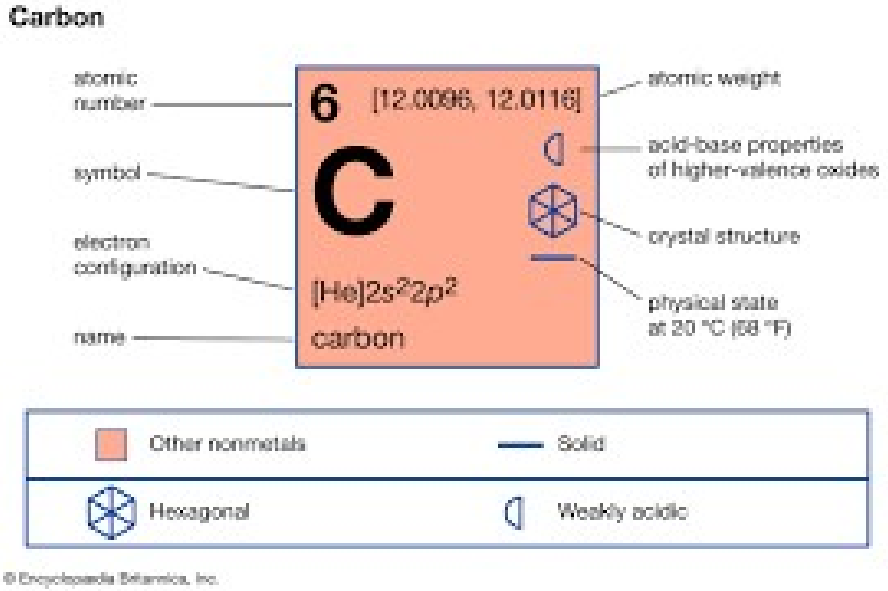
Carbon is uniquely suited for life because it:

- Has four valence electrons
- Forms four covalent bonds
- Creates chains, rings, and complex structures

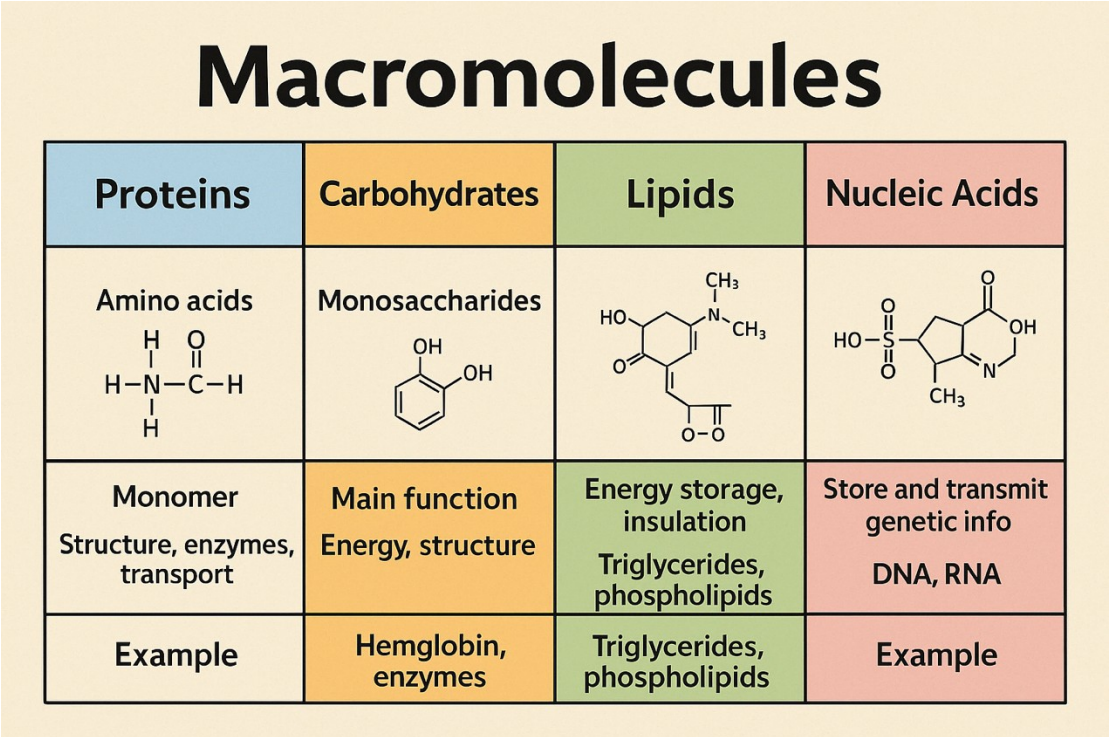
This allows:

- Structural diversity

- Molecular complexity
- Stable biological macromolecules



1.8 Biological Macromolecules（全面展开）

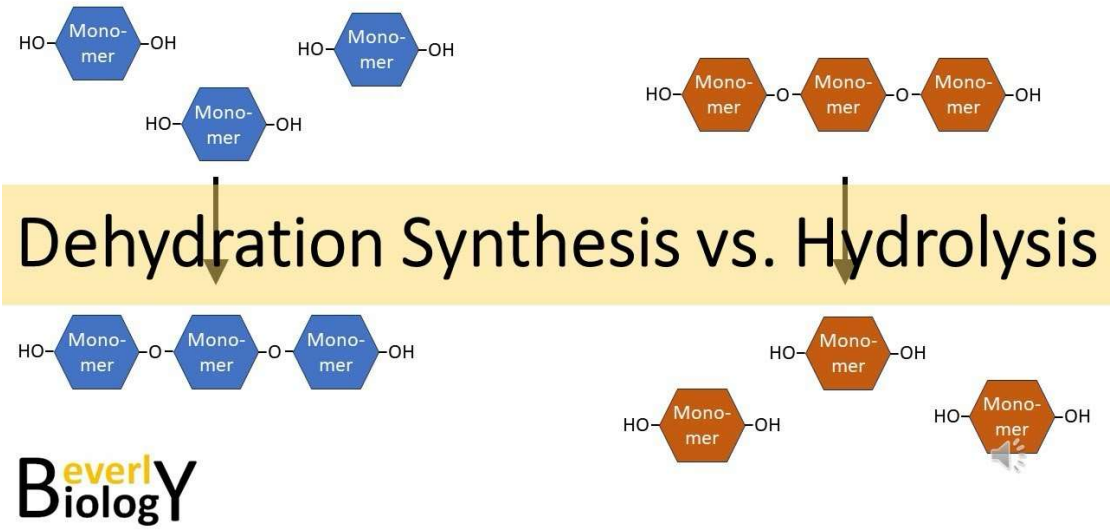


Dehydration Synthesis

- Forms covalent bonds
- Removes water
- Builds polymers

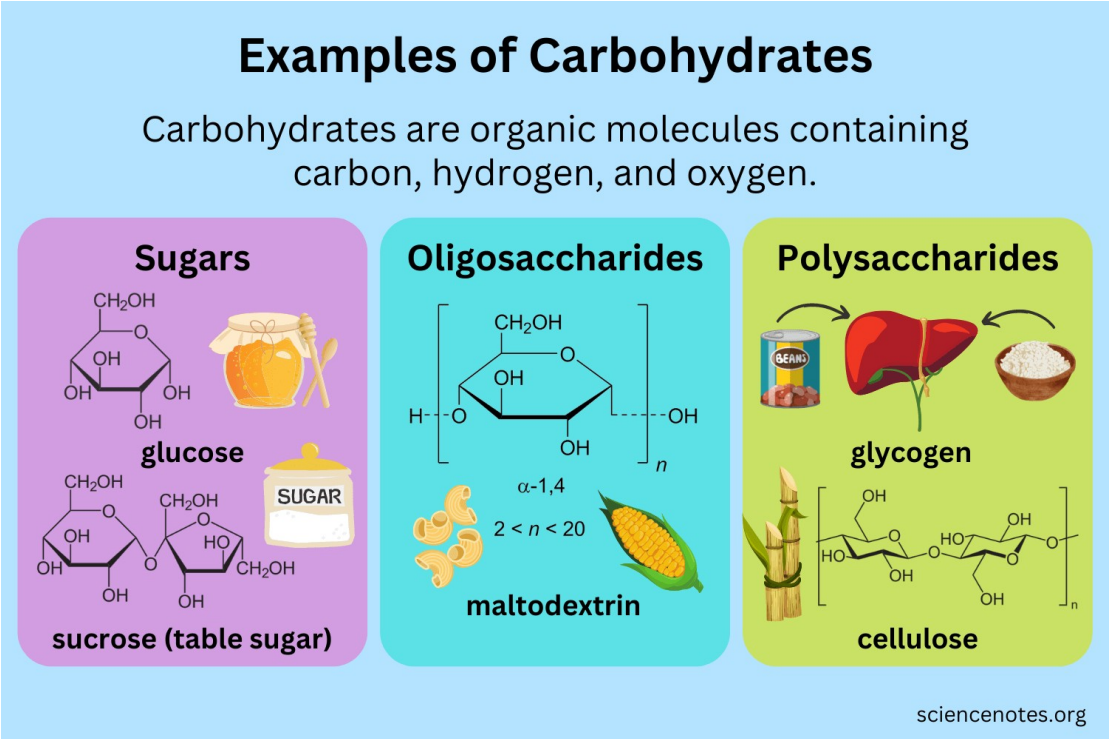
Hydrolysis

- Breaks covalent bonds
- Adds water
- Breaks polymers into monomers



Carbohydrates

- Monomer: monosaccharide
- Polymer: polysaccharide
- Function: energy and structure



Examples:

- Glucose (energy)
- Starch (plant storage)
- Glycogen (animal storage)
- Cellulose (cell walls)

Lipids

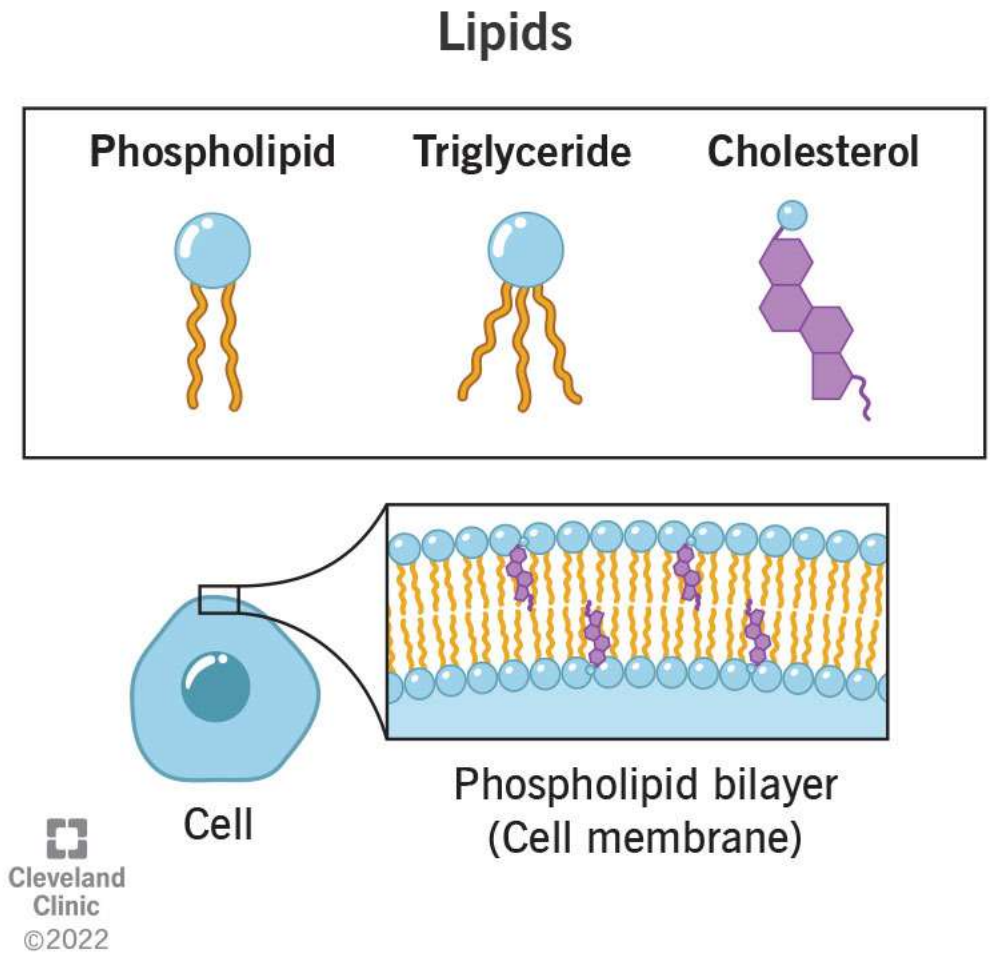
- Hydrophobic
- Not true polymers

Functions:

- Energy storage
- Membrane structure
- Hormones

Types:

- Fats (saturated vs unsaturated)
- Phospholipids (amphipathic)
- Steroids (cholesterol)

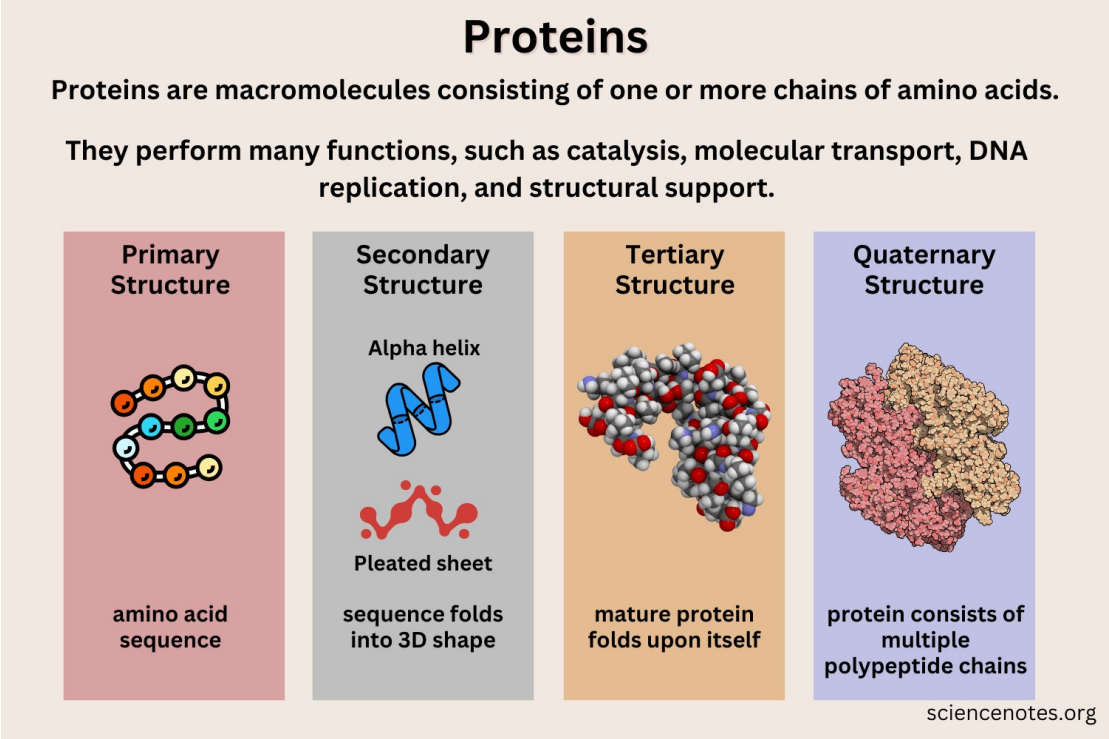


Proteins（AP 最爱）

- Monomer: amino acid
- R group determines properties

Levels of structure:

1. Primary
2. Secondary
3. Tertiary
4. Quaternary



Denaturation occurs when:

- Temperature
- pH
- Ionic conditions

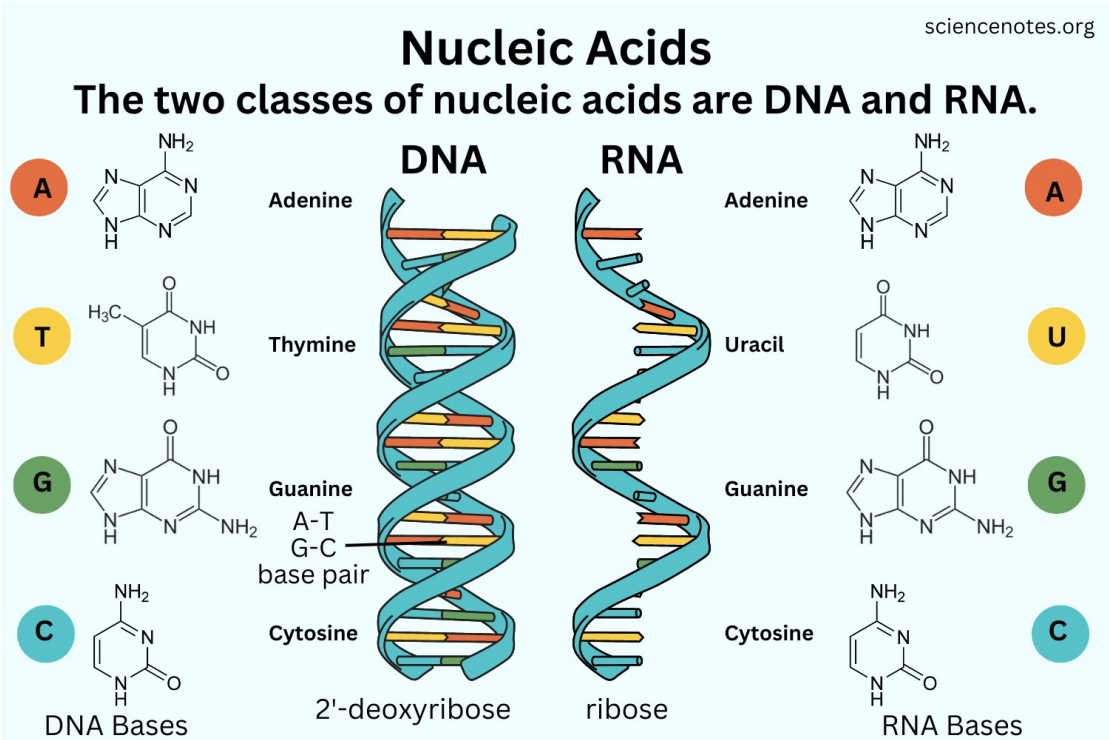
Nucleic Acids

- Monomer: nucleotide
- DNA: stores genetic information
- RNA: expresses genetic information

Base pairing:

- A–T

- C–G



1.9 Enzymes（Unit 1 终点，必考）

Enzymes are biological catalysts that:

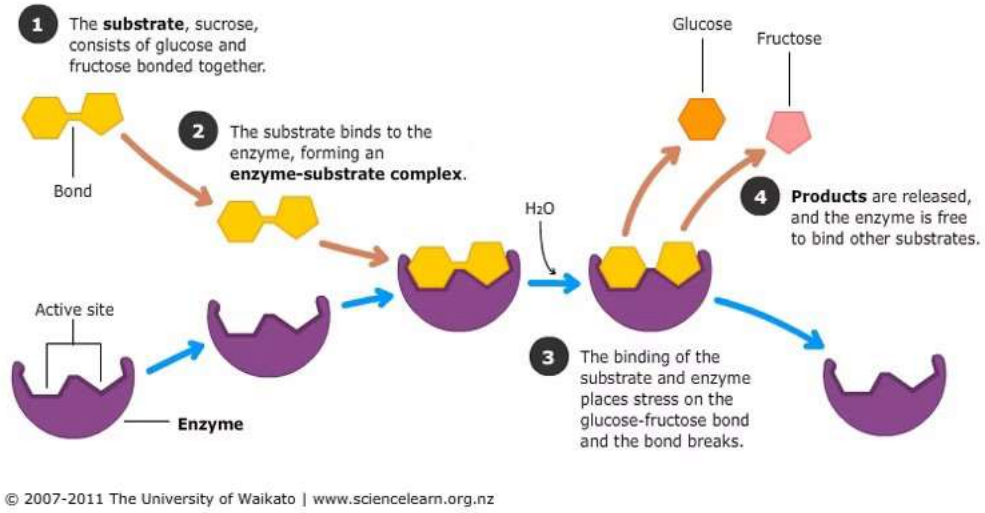
- Lower activation energy
- Increase reaction rate
- Are not consumed

Key concepts:

- Active site
- Substrate specificity
- Induced fit model

Factors affecting enzyme activity:

- Temperature
- pH
- Substrate concentration
- Inhibitors



Unit 1 总结（FRQ 结尾句可直接用）

The chemical properties of water and carbon-based molecules explain how biological systems function.

Changes in molecular interactions can alter structure, disrupt function, and affect homeostasis at all levels of life.

AP Biology – Unit 2: Cell Structure and Function

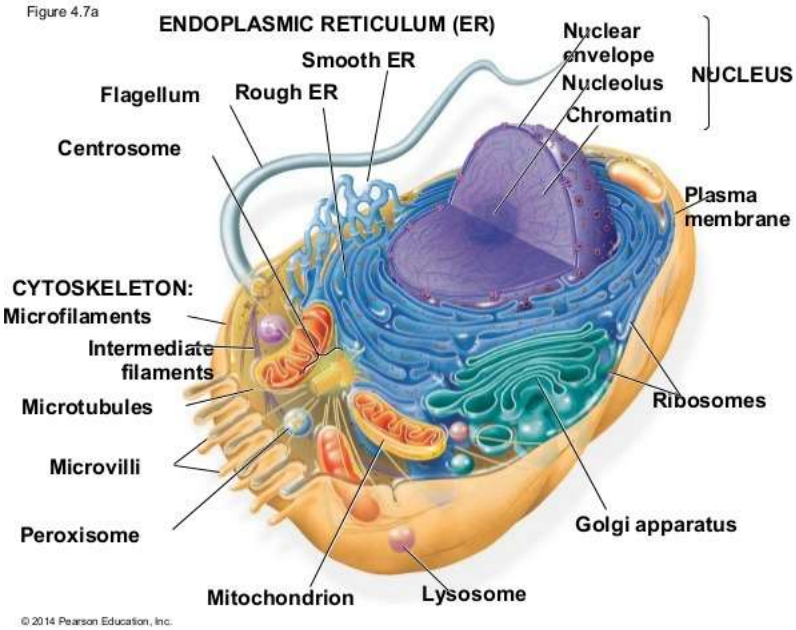
Unit 2 Big Ideas（AP 官方核心）

Cells are the basic units of life.

The structure of cellular components determines their function, and the organization of membranes and organelles allows cells to maintain homeostasis, exchange materials, and carry out life processes efficiently.

In Unit 2, students must be able to:

- Compare prokaryotic and eukaryotic cells
- Explain how membrane structure controls transport
- Connect organelle structure to function



- Use surface area–to–volume ratio to explain limits on cell size

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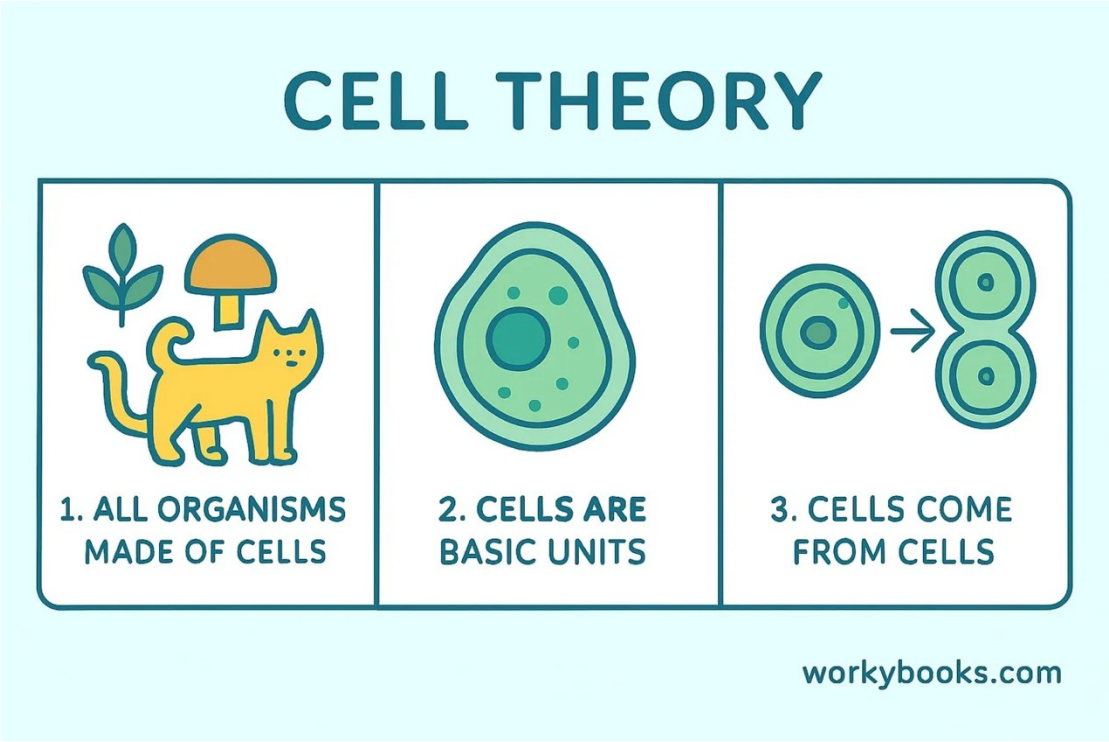
2.1 Cell Theory（基础但常被忽略）

Core Principles

Cell theory states that:

1. All living organisms are composed of one or more cells
2. The cell is the basic unit of structure and function
3. All cells arise from pre-existing cells

AP 理解点：



Cell theory emphasizes continuity of life and rules out spontaneous generation.

2.2 Prokaryotic vs. Eukaryotic Cells（高频对比）

Prokaryotic Cells

- No membrane-bound nucleus
- DNA located in the nucleoid region
- No membrane-bound organelles
- Smaller and simpler

Examples:

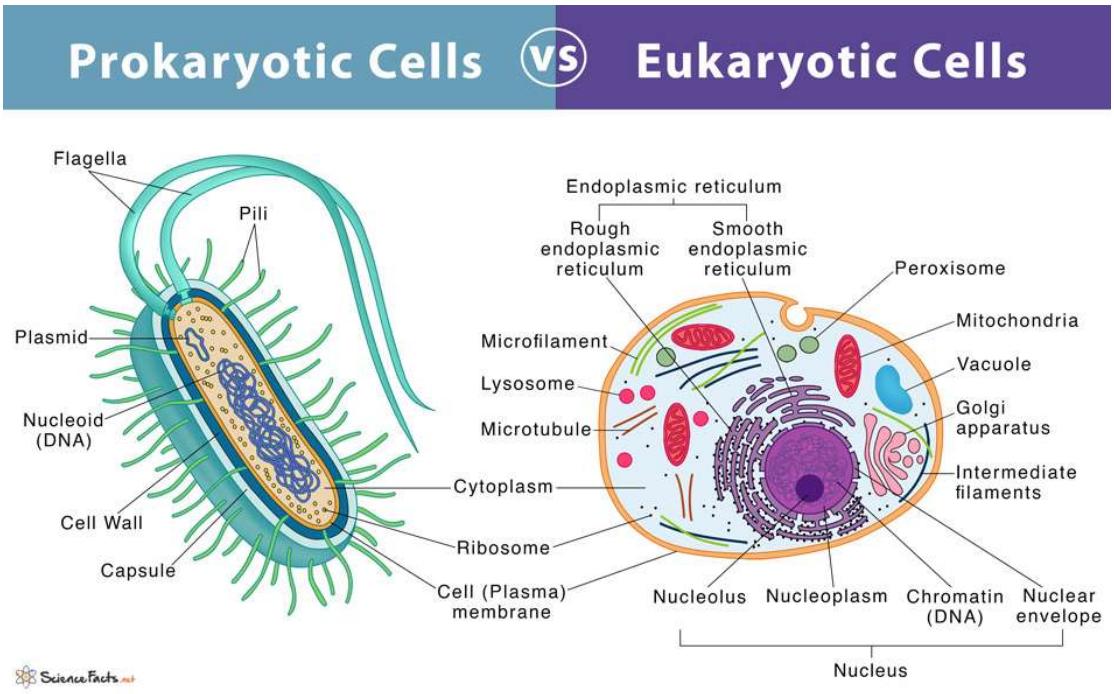
- Bacteria
- Archaea

Eukaryotic Cells

- True nucleus enclosed by nuclear membrane
- Membrane-bound organelles
- Larger and more complex

Examples:

- Animal cells
- Plant cells
- Fungi
- Protists



AP 常考点：
Prokaryotes do have ribosomes and plasma membranes, even though they lack organelles.

2.3 Plasma Membrane Structure（Unit 2 核心）

Fluid Mosaic Model

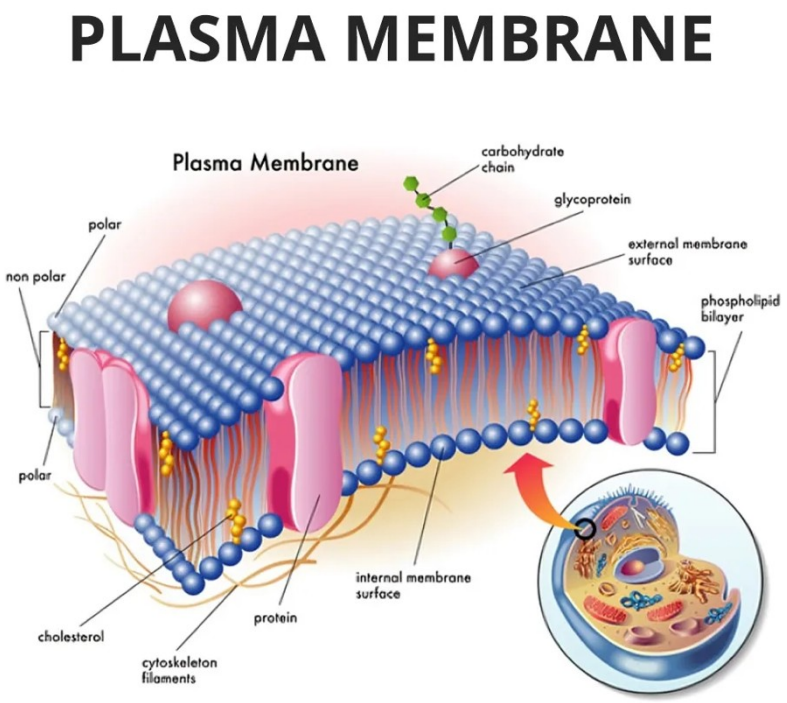
The plasma membrane is described as a fluid mosaic because:

- Phospholipids move laterally (fluid)
- Proteins are embedded throughout (mosaic)

Phospholipid Bilayer

Each phospholipid has:

- Hydrophilic phosphate head
- Hydrophobic fatty acid tails



In water:

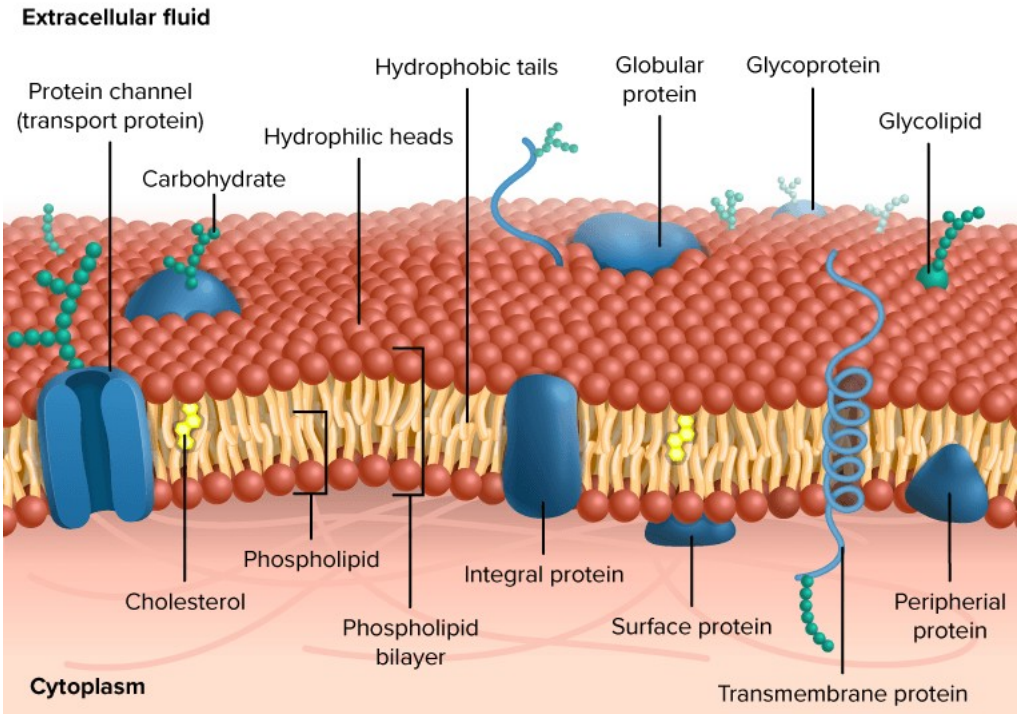
- Heads face outward
- Tails face inward

This creates a selectively permeable barrier.

2.4 Membrane Proteins（结构 → 功能）

Types of membrane proteins:

- Transport proteins (channels, carriers)
- Receptor proteins
- Enzymatic proteins
- Cell recognition proteins



- Adhesion proteins

AP 推理重点：

Changing membrane protein structure will affect transport, signaling, or recognition.

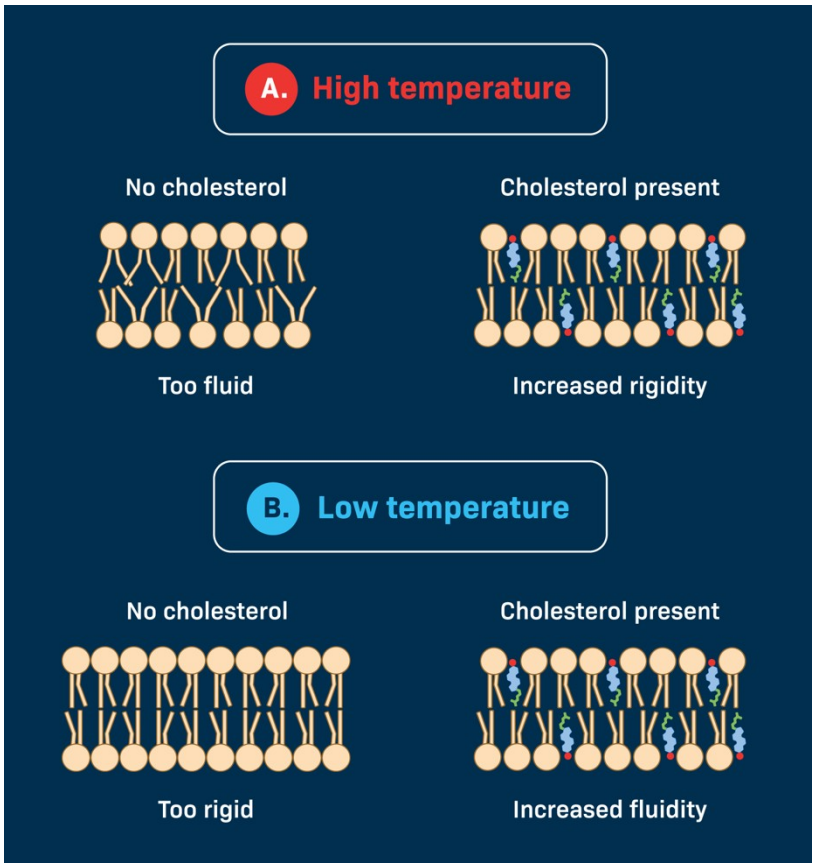
2.5 Membrane Fluidity

Membrane fluidity depends on:

- Temperature
- Cholesterol
- Fatty acid saturation

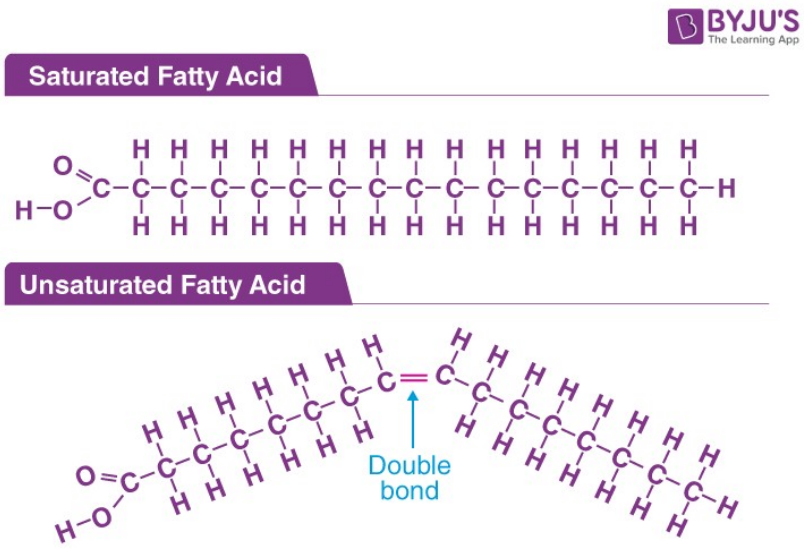
Cholesterol

- In animal cells
- Maintains membrane stability
- Prevents membrane from becoming too rigid or too fluid



Fatty Acids

- Unsaturated fats increase fluidity



- Saturated fats decrease fluidity

2.6 Passive Transport（不消耗能量）

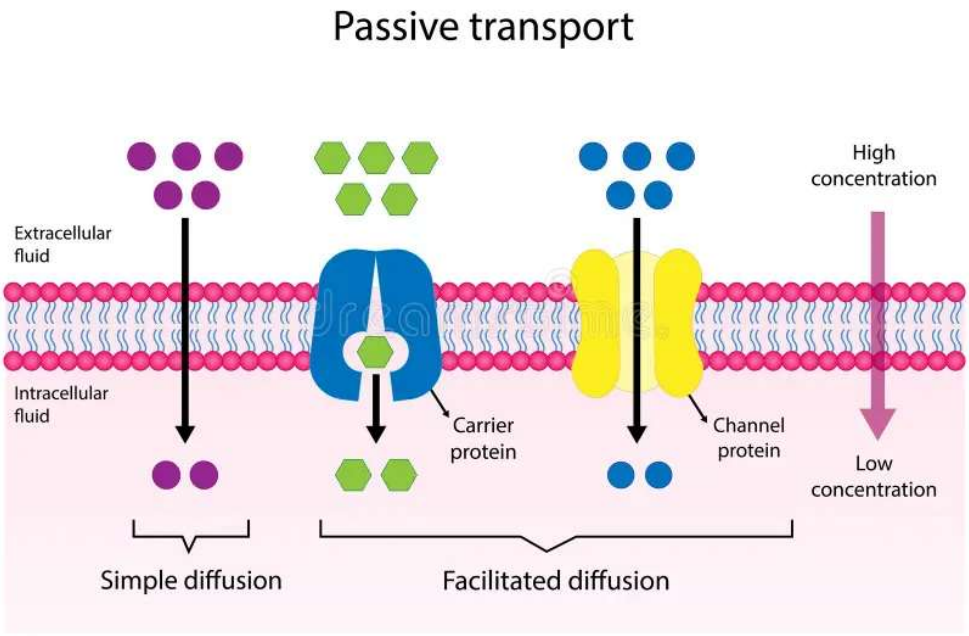
Diffusion

Movement of molecules from high to low concentration.

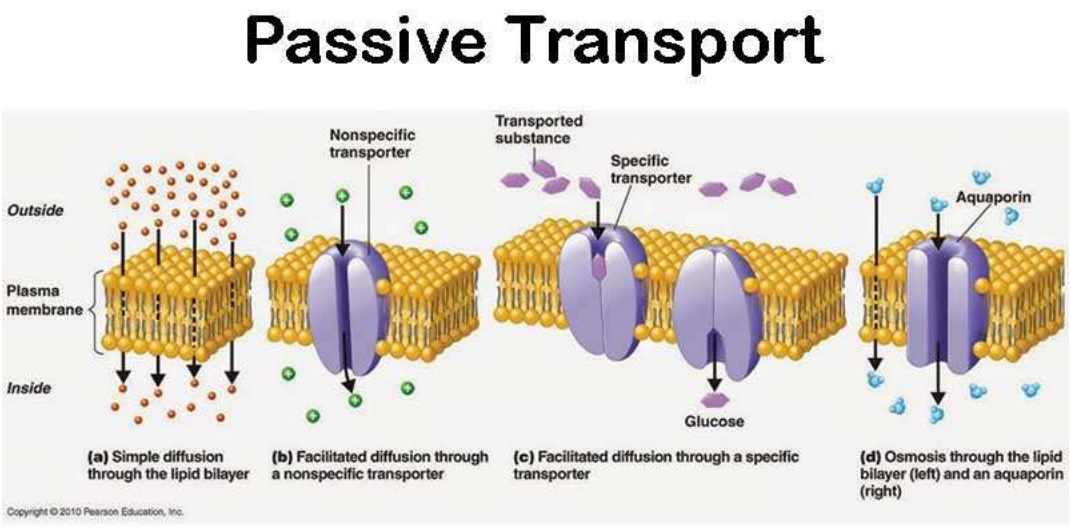
Facilitated Diffusion

- Requires transport proteins
- Still moves down concentration gradient

- No ATP required



Osmosis



Diffusion of water across a selectively permeable membrane.

2.7 Tonicity（AP 实验重点）

Isotonic

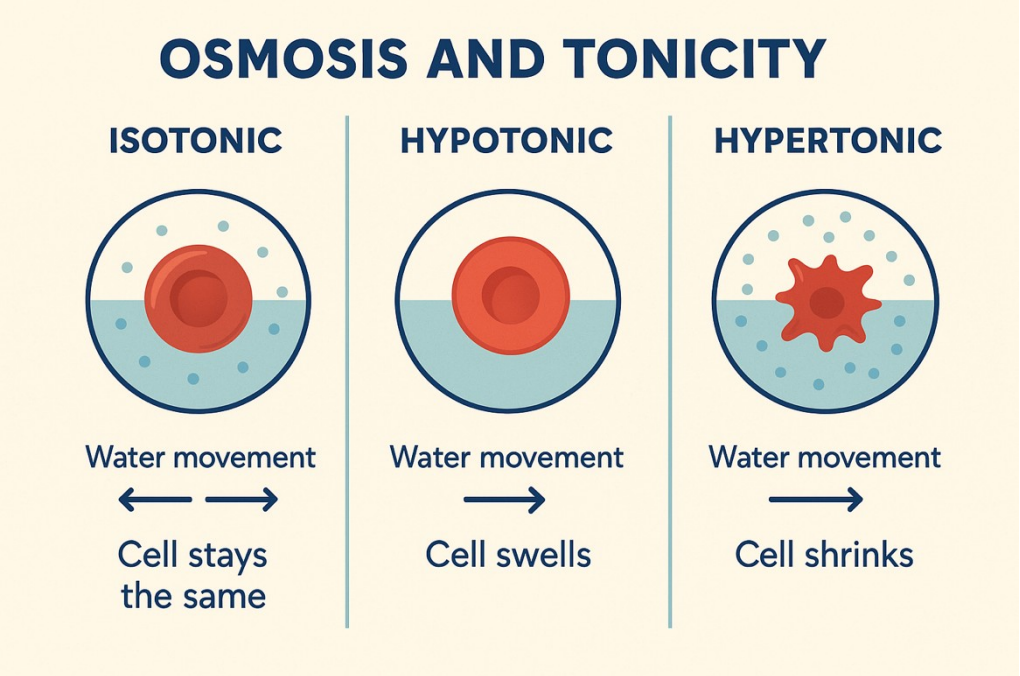
- Equal solute concentration
- No net water movement

Hypertonic

- Higher solute concentration outside cell
- Water leaves cell

Hypotonic

- Lower solute concentration outside cell
- Water enters cell



Plant Cells vs Animal Cells

- Animal cells may lyse
- Plant cells become turgid (cell wall prevents bursting)

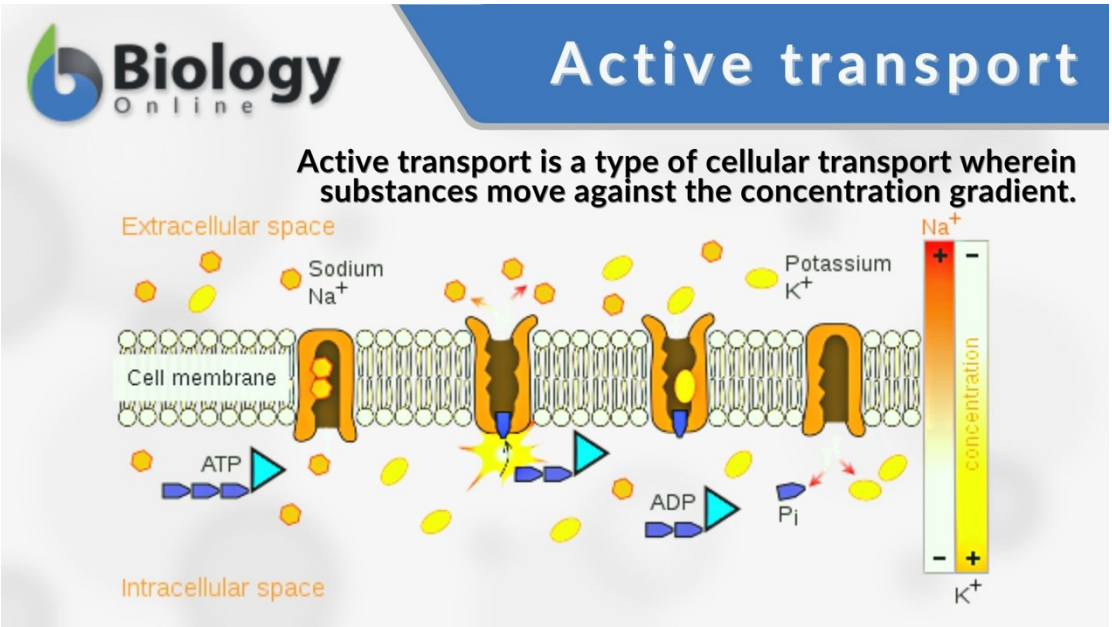
2.8 Active Transport（需要能量）

Active transport:

- Moves substances against concentration gradient
- Requires ATP
- Uses carrier proteins

Sodium–Potassium Pump

- Pumps Na^+ out
- Pumps K^+ in
- Maintains electrochemical gradients



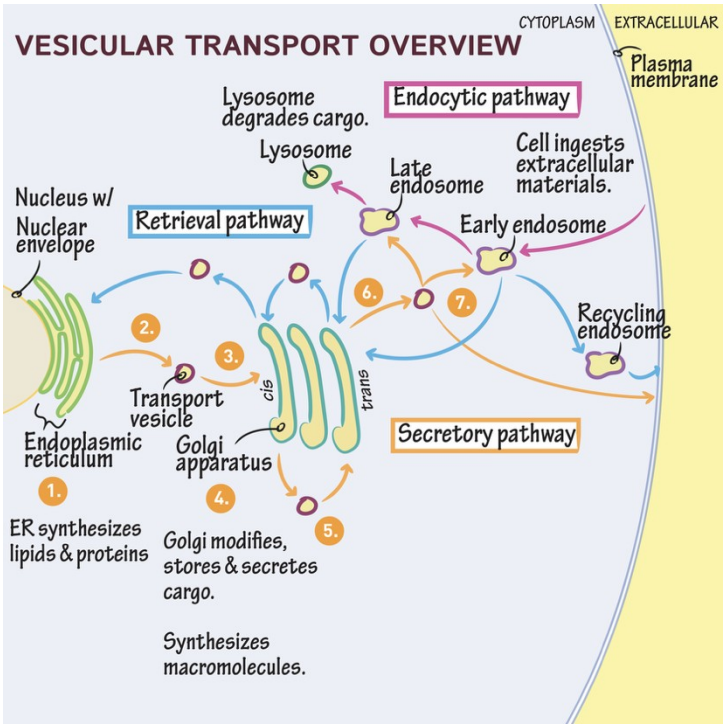
2.9 Vesicular Transport

Endocytosis

- Phagocytosis (solids)
- Pinocytosis (liquids)
- Receptor-mediated endocytosis

Exocytosis

- Vesicles fuse with membrane
- Materials released outside cell



2.10 Eukaryotic Organelles（结构 → 功能）

Nucleus

- Stores DNA
- Controls gene expression
- Nuclear pores regulate transport

Ribosomes

- Protein synthesis
- Free vs bound ribosomes make different destinations, not different proteins

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Endoplasmic Reticulum

- Rough ER: protein synthesis
- Smooth ER: lipid synthesis, detoxification, calcium storage

Golgi Apparatus

- Modifies proteins
- Sorts and ships to correct destinations

Lysosomes

- Digest macromolecules
- Recycle organelles
- Maintain acidic environment

Mitochondria

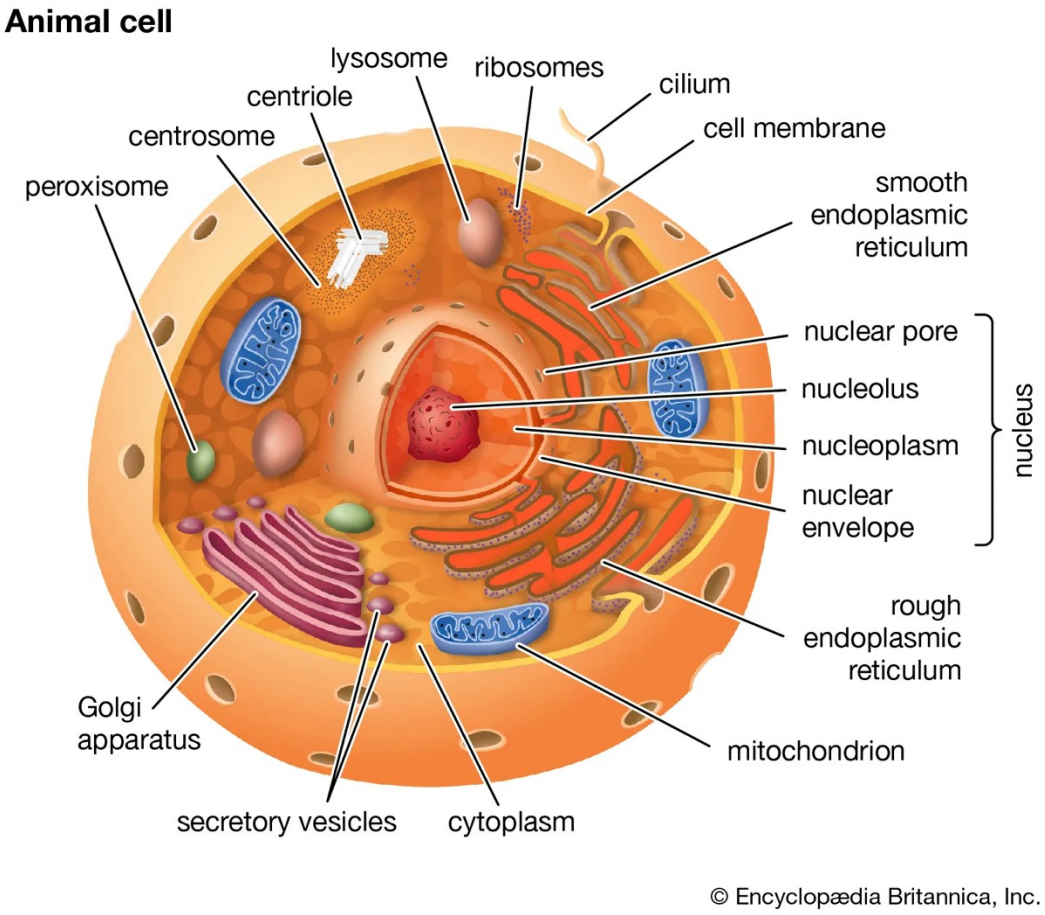
- Site of cellular respiration
- Double membrane
- Own DNA (endosymbiotic theory)

Chloroplasts (Plants)

- Photosynthesis
- Thylakoids and stroma
- Also have own DNA

Cytoskeleton

- Microtubules
- Microfilaments
- Intermediate filaments



Functions:

- Shape
- Movement
- Transport

2.11 Cell Surface Area–to–Volume Ratio（FRQ 高频）

As a cell grows:

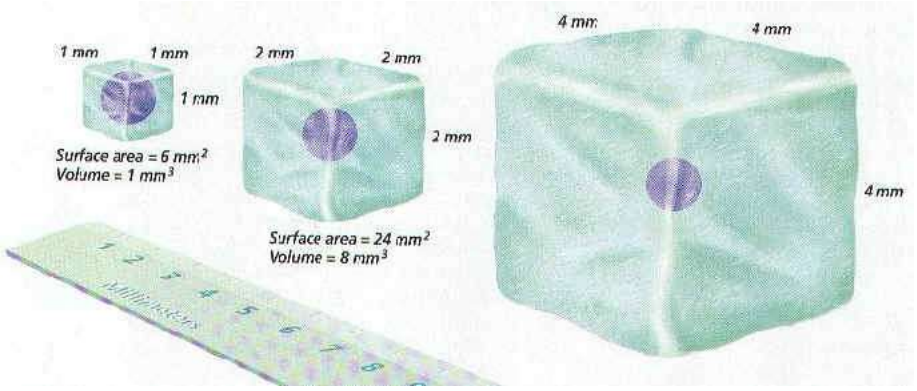
- Volume increases faster than surface area

Consequences:

- Reduced efficiency of exchange
- Limits maximum cell size

Cells adapt by:

- Remaining small
- Flattening
- Developing folds (microvilli)



Unit 2 Summary（FRQ 结尾可用）

The structure of cellular membranes and organelles determines their function.

Efficient transport and compartmentalization allow cells to maintain homeostasis and carry out complex processes essential for life.

AP Biology – Unit 3: Cellular Energetics

Unit 3 Big Ideas（AP 官方核心）

Living systems require a constant input of energy to maintain organization and carry out biological processes.

Energy is transferred and transformed through metabolic pathways, and these pathways are governed by the laws of thermodynamics.

In Unit 3, students must be able to:

- Explain how energy flows through biological systems
- Describe how ATP couples exergonic and endergonic reactions
- Analyze the mechanisms of photosynthesis and cellular respiration
- Interpret experimental data related to energy transformations

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3.1 Energy and the Laws of Thermodynamics

Energy

Energy is the capacity to do work or cause change.

Forms of energy relevant to biology:

- Chemical energy
- Kinetic energy
- Potential energy

First Law of Thermodynamics

Energy cannot be created or destroyed, only transformed.

Biological implication:

- Energy entering ecosystems (sunlight) is transformed, not recycled

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Second Law of Thermodynamics

Every energy transfer increases entropy (disorder) in the universe.

Biological implication:

- Cells require constant energy input to maintain order
- Living systems increase entropy in their surroundings

AP 推理重点：
Local order in cells does not violate the second law because total entropy still increases.

3.2 Free Energy (Gibbs Free Energy)

Gibbs free energy (G) measures the amount of energy available to do work.

- $\Delta G < 0 \rightarrow$ exergonic (spontaneous)
- $\Delta G > 0 \rightarrow$ endergonic (non-spontaneous)

Cells drive endergonic reactions by coupling them to exergonic reactions.

3.3 ATP and Energy Coupling

ATP Structure

ATP consists of:

- Adenine
- Ribose
- Three phosphate groups

Energy is stored in the bonds between phosphate groups.

ATP Hydrolysis

ATP → ADP + Pi + energy

Energy released is used to:

- Drive endergonic reactions
- Power active transport
- Support cellular movement

AP 常考误区：
Energy is not stored in ATP itself, but released when phosphate bonds are broken.

3.4 Enzymes and Metabolic Pathways（延伸 Unit 1）

Enzymes:

- Lower activation energy
- Do not change ΔG
- Are highly specific

Metabolic pathways:

- Series of enzyme-catalyzed reactions
- Each step is regulated

3.5 Photosynthesis Overview

Photosynthesis converts light energy into chemical energy.

Overall equation:

$6\ CO_2 + 6\ H_2O + \text{light} \rightarrow C_6H_{12}O_6 + 6\ O_2$

Occurs in chloroplasts of plant cells and algae.

3.6 Light Reactions（机制级）

Location

- Thylakoid membranes

Key Inputs

- Light
- Water
- ADP + Pi

- $NADP^+$

Key Outputs

- ATP
- NADPH
- Oxygen (O_2)

Photosystems

- Photosystem II (PSII)
- Photosystem I (PSI)

Light excites electrons, which:

- Move through an electron transport chain
- Create a proton gradient

Chemiosmosis

- Proton gradient drives ATP synthase
- ATP produced by photophosphorylation

AP 高频考点：
Oxygen comes from water, not carbon dioxide.

3.7 Calvin Cycle（光不直接参与）

Location

- Stroma of chloroplast

Three Phases

1. Carbon fixation (RuBisCO)
2. Reduction
3. Regeneration of RuBP

Role of ATP and NADPH

- ATP provides energy
- NADPH provides reducing power

3.8 Photorespiration and Environmental Effects

RuBisCO can bind:

- CO_2 (desired)
- O_2 (undesired)

Photorespiration:

- Wastes energy
- Reduces sugar production

Adaptations:

- C_4 plants
- CAM plants

3.9 Cellular Respiration Overview

Cellular respiration converts glucose into usable energy (ATP).

Overall equation:

$C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O + \text{energy}$

Occurs in both prokaryotic and eukaryotic cells.

3.10 Glycolysis

Location

- Cytoplasm

Key Features

- Does not require oxygen
- Produces 2 ATP (net)
- Produces NADH and pyruvate

3.11 Pyruvate Oxidation and Krebs Cycle

Pyruvate Oxidation

- Pyruvate converted to Acetyl-CoA
- CO_2 released
- NADH produced

Krebs (Citric Acid) Cycle

- Occurs in mitochondrial matrix
- Produces:

- NADH
- $FADH_2$
- ATP
- CO_2

3.12 Electron Transport Chain and Oxidative Phosphorylation

Electron Transport Chain

- Located in inner mitochondrial membrane
- Electrons passed through protein complexes
- Protons pumped into intermembrane space

Chemiosmosis (Respiration)

- Proton gradient drives ATP synthase
- Oxygen is final electron acceptor
- Water is produced

AP 实验重点：
Without oxygen, ETC stops because electrons cannot be accepted.

3.13 Fermentation

Occurs when oxygen is absent.

Types:

- Lactic acid fermentation
- Alcoholic fermentation

Purpose:

- Regenerate NAD^+
- Allow glycolysis to continue

Unit 3 Summary（FRQ 结尾可直接用）

Energy transformation in biological systems follows the laws of thermodynamics.

Through photosynthesis and cellular respiration, cells capture, store, and release energy to maintain organization and drive life processes.

AP Biology – Unit 4: Cell Communication and Cell Cycle

Unit 4 Big Ideas（AP 官方核心）

Cells must communicate to coordinate functions in multicellular organisms and to respond to environmental changes. These signals control processes like growth, immune response, metabolism, and reproduction. Cells also follow a regulated cell cycle, and failure of regulation can lead to uncontrolled division (cancer).

In Unit 4, students must be able to:

- Explain how cells use signals to produce specific responses
- Describe the steps of signal transduction and predict outcomes of changes
- Compare mitosis and meiosis (connection to Unit 5)
- Explain how cell cycle regulation prevents uncontrolled division

---

4.1 Cell Communication Overview

Cell communication is essential for:

- Homeostasis (blood sugar control, temperature regulation)
- Development (cell differentiation, pattern formation)
- Immune defense (identifying pathogens)
- Response to environment (light, stress, nutrients)

Cells communicate using chemical signals (ligands) that bind to receptors.

A signal can cause:

- Changes in gene expression
- Activation/inactivation of enzymes
- Opening/closing ion channels

- Cytoskeleton changes
- Apoptosis (programmed cell death)

4.2 Types of Cell Signaling（AP 常考分类）

1) Autocrine signaling

- Cell signals itself
- Common in immune signaling and cancer cells

2) Paracrine signaling

- Local signals to nearby cells
- Example: growth factors, neurotransmitters (at synapses)

3) Endocrine signaling

- Long-distance signals via bloodstream
- Example: insulin, epinephrine

4) Direct contact signaling (Juxtacrine)

- Membrane-bound signal binds receptor on adjacent cell
- Example: embryonic development pathways

4.3 Signal Transduction Pathway – The 3 Main Steps（必背）

Step 1: Reception

A signaling molecule (ligand) binds to a receptor.

Receptors can be:

- Cell-surface receptors (for hydrophilic signals)
- Intracellular receptors (for hydrophobic signals)

Step 2: Transduction

Signal is converted into a series of intracellular steps, often involving:

- Protein phosphorylation cascades
- Second messengers (cAMP, Ca^{2+}, IP_3)
- Kinases and phosphatases

Step 3: Response

The cell carries out a response:

- Changes in gene expression
- Changes in enzyme activity
- Cytoskeleton rearrangement
- Secretion of molecules

AP 核心推理：
Same signal → different responses in different cells, because cells express different receptors and proteins.

4.4 Receptor Types and How They Work

A) G-Protein Coupled Receptors (GPCRs)

- Large family of receptors

- Ligand binds → receptor changes shape
- Activates G-protein (GDP → GTP)
- G-protein activates an enzyme or channel → triggers response

AP common idea:

- Amplification: one receptor activates many downstream molecules

---

B) Receptor Tyrosine Kinases (RTKs)

- Important in growth and development
- Ligand binds → receptors dimerize
- Autophosphorylation on tyrosine residues
- Activates multiple signaling pathways

AP connection:

- Mutations in RTKs are common in cancer

C) Ligand-Gated Ion Channels

- Channel opens when ligand binds
- Ions move down gradient
- Changes membrane potential
- Common in neuron signaling

D) Intracellular Receptors (Steroid hormones)

- Ligand is hydrophobic, crosses membrane
- Receptor–ligand complex enters nucleus
- Acts as transcription factor → changes gene expression

Example:

- Testosterone, estrogen, cortisol

4.5 Signal Amplification and Specificity

Amplification

A small signal can cause a large response because:

- One receptor activates many proteins
- Kinase cascades multiply the signal
- Second messengers spread quickly

Specificity

Cells respond differently because of:

- Different receptors
- Different signal transduction proteins
- Different transcription factors
- Different gene targets

4.6 Feedback in Cell Signaling（控制与稳定）

Negative feedback

- Reduces output to stabilize system
- Example: insulin lowers blood glucose; less glucose reduces insulin release

Positive feedback

- Increases output to intensify response
- Example: blood clotting cascade

4.7 The Cell Cycle Overview

The cell cycle includes:

1. Interphase (G1, S, G2)
2. M phase (mitosis + cytokinesis)

Interphase

- G1: growth, normal function
- S: DNA replication
- G2: preparation for division

M phase

- Mitosis: division of nucleus
- Cytokinesis: division of cytoplasm

4.8 Mitosis（机制级拆解）

Purpose of mitosis:

- Growth
- Repair
- Asexual reproduction (some organisms)

Mitosis produces:

- 2 genetically identical diploid cells (in most animals)

Stages

Prophase

- Chromatin condenses → chromosomes visible
- Spindle forms
- Nuclear envelope breaks down

Metaphase

- Chromosomes line up at metaphase plate
- Spindle fibers attach to kinetochores

Anaphase

- Sister chromatids separate
- Pulled to opposite poles

Telophase

- Nuclear envelopes reform
- Chromosomes decondense

Cytokinesis

- Animals: cleavage furrow
- Plants: cell plate

4.9 Cell Cycle Regulation（AP 超级重点）

Cell cycle is controlled by:

- Cyclins
- Cyclin-dependent kinases (CDKs)

Cyclins regulate CDKs by:

- Binding to them
- Activating them at specific checkpoints

Major checkpoints

- G1 checkpoint (restriction point): go/no-go; checks cell size, nutrients, DNA damage
- G2 checkpoint: checks DNA replication completion
- M checkpoint (spindle checkpoint): ensures chromosomes attached correctly

AP 必考推理：
If a checkpoint fails, cells may divide with damaged DNA → mutations → cancer risk.

4.10 Cancer and Uncontrolled Cell Division

Cancer results when mutations affect:

- Proto-oncogenes (become oncogenes)
- Tumor suppressor genes (loss of function)

Proto-oncogenes

Normal function: promote cell cycle progression

Mutation: overactive → uncontrolled division

Example concept:

- growth factor receptors stuck “on”

Tumor suppressor genes

Normal function: inhibit cell cycle, repair DNA, trigger apoptosis

Mutation: loss of inhibition

Example:

- p53 protein (“guardian of the genome”)

4.11 Apoptosis（程序性死亡）

Apoptosis is controlled cell death that is important for:

- Development (removing webbing between fingers)
- Removing damaged cells
- Preventing cancer

Failure of apoptosis can lead to:

- accumulation of abnormal cells
- tumor formation

4.12 AP Exam Skills – What they actually test

Common MCQ patterns

- Identify step in pathway: reception vs transduction vs response
- Predict effect of mutation:
  - receptor cannot bind ligand
  - kinase is inactive
  - second messenger is blocked
- Interpret graph of signaling intensity over time

Common FRQ expectations

Your answers should show:

- clear cause → effect logic
- correct vocabulary (ligand, receptor, phosphorylation, transcription factor)
- a specific predicted outcome

FRQ sentence patterns that score well:

- “Binding of the ligand changes the receptor shape, which activates…”
- “The signal is amplified through a phosphorylation cascade, leading to…”
- “If the receptor is mutated, the cell will not respond because…”

Unit 4 Summary（高分结尾）

Cells communicate through receptor-mediated signaling pathways that include reception, transduction, and response. These pathways allow coordinated biological activity and homeostasis. The cell cycle is tightly regulated by cyclins, CDKs, and checkpoints, and disruption of these controls can result in cancer. Apoptosis serves as an additional mechanism to remove damaged cells and maintain organismal integrity.

AP Biology – Unit 5: Heredity

Unit 5 Big Ideas（AP 官方核心）

Heredity explains how genetic information is transmitted from parents to offspring.

The behavior of chromosomes during meiosis generates genetic variation, and patterns of inheritance can be predicted using probability and statistical reasoning.

Students must be able to:

- Explain how meiosis produces genetic diversity
- Predict inheritance patterns using probability
- Distinguish between different modes of inheritance
- Use chi-square analysis to evaluate genetic data

5.1 Meiosis Overview（AP 超高频）

Purpose of Meiosis

Meiosis produces:

- Haploid (n) gametes
- Cells with genetic variation

This is essential for:

- Sexual reproduction
- Maintaining chromosome number across generations

5.2 Stages of Meiosis（机制级拆解）

Meiosis I（Reduction Division）

- Homologous chromosomes separate
- Chromosome number is halved (2n → n)

Prophase I

- Homologous chromosomes pair (synapsis)
- Crossing over occurs at chiasmata
- Genetic material is exchanged

AP 必考点：
Crossing over increases genetic variation by producing recombinant chromosomes.

Metaphase I

- Homologous pairs align randomly at metaphase plate
- Basis of independent assortment

Anaphase I

- Homologous chromosomes separate
- Sister chromatids remain attached

Telophase I & Cytokinesis

- Two haploid cells formed

Meiosis II（类似有丝分裂）

- Sister chromatids separate
- Produces four haploid cells

5.3 Sources of Genetic Variation（必背三点）

1. Independent assortment
    - Random alignment of homologous pairs
2. Crossing over
    - Exchange of DNA during Prophase I
3. Random fertilization
    - Any sperm can fertilize any egg

5.4 Mendelian Genetics

Mendel’s Experiments

Gregor Mendel studied inheritance using pea plants.

Key principles:

- Traits are controlled by genes
- Each gene has alleles
- Alleles segregate during gamete formation

Law of Segregation

Each organism has two alleles per gene, which separate during meiosis.

Law of Independent Assortment

Genes for different traits assort independently (if on different chromosomes or far apart).

AP 常考限制条件：
Linked genes do not assort independently.

5.5 Punnett Squares and Probability

Punnett squares:

- Predict genotype ratios
- Predict phenotype ratios

Probability Rules

- Product rule: probability of two independent events both occurring
- Sum rule: probability of either event occurring

5.6 Extensions of Mendelian Genetics（AP 爱考）

Incomplete Dominance

- Heterozygote has intermediate phenotype
- Example: red × white → pink

Codominance

- Both alleles fully expressed
- Example: AB blood type

Multiple Alleles

- More than two alleles exist in population
- Example: ABO blood group

5.7 Epistasis（高分理解点）

Epistasis occurs when:

- One gene masks the expression of another

Example:

- Labrador coat color (pigment vs deposition)

AP 推理题常见：
Identify gene interactions based on phenotype ratios.

5.8 Linked Genes and Recombination

Linked Genes

- Located close together on same chromosome
- Tend to be inherited together

Recombination Frequency

- Indicates distance between genes
- Used to create genetic maps

5.9 Sex-Linked Inheritance

X-linked Traits

- More common in males
- Males are hemizygous (XY)

Examples:

- Hemophilia
- Color blindness

5.10 Chromosomal Errors（AP 高频）

Nondisjunction

- Failure of chromosomes to separate
- Results in abnormal chromosome number

Examples:

- Trisomy 21 (Down syndrome)

5.11 Pedigrees

Pedigrees track inheritance across generations.

Used to determine:

- Autosomal vs sex-linked
- Dominant vs recessive

5.12 Chi-Square Analysis（AP FRQ 常考）

Chi-square tests whether observed results differ significantly from expected results.

Formula:

$\chi^2 = \Sigma ((\text{observed} - \text{expected})^2 / \text{expected})$

Interpretation:

- High p-value → results likely due to chance
- Low p-value → results unlikely due to chance

5.13 AP Exam Skills

Common MCQ Traps

- Confusing meiosis I with meiosis II
- Forgetting that crossing over occurs only in Prophase I
- Assuming independent assortment applies to linked genes

FRQ Sentence Starters

- “Independent assortment during meiosis contributes to variation because…”
- “Crossing over produces recombinant chromosomes by…”
- “The chi-square test supports the hypothesis because…”

Unit 5 Summary（FRQ 结尾可用）

Meiosis generates genetic diversity through independent assortment, crossing over, and random fertilization. Mendelian and non-Mendelian inheritance patterns can be predicted using probability and evaluated using statistical analysis.

AP Biology – Unit 6: Gene Expression and Regulation

Unit 6 Big Ideas（AP 官方核心）

Genetic information flows from DNA → RNA → Protein.

Cells regulate gene expression to respond to environmental conditions, conserve energy, and support development.

Although all cells contain the same DNA, differences in gene expression lead to different cell types and functions.

Students must be able to:

- Explain how DNA stores information and is replicated
- Describe transcription and translation in detail
- Analyze how gene expression is regulated in prokaryotes and eukaryotes
- Predict the effects of mutations on gene products and phenotype

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6.1 DNA Structure（结构 → 功能）

Chemical Structure of DNA

DNA is a double-stranded nucleic acid composed of nucleotides.

Each nucleotide contains:

- A deoxyribose sugar
- A phosphate group
- A nitrogenous base (A, T, C, or G)

Double Helix

DNA strands:

- Are antiparallel (5′ → 3′ and 3′ → 5′)
- Are held together by hydrogen bonds between complementary bases:
  - A–T (2 hydrogen bonds)
  - C–G (3 hydrogen bonds)

AP 推理重点：
More C–G base pairs increase DNA stability due to additional hydrogen bonds.

6.2 DNA Replication（机制级）

Semi-Conservative Replication

Each new DNA molecule consists of:

- One original (parental) strand
- One newly synthesized strand

Replication Enzymes

- Helicase: unwinds the DNA helix
- Single-strand binding proteins: stabilize separated strands
- Topoisomerase: relieves supercoiling
- DNA polymerase: adds nucleotides to the 3′ end
- Primase: synthesizes RNA primers
- DNA ligase: joins Okazaki fragments

Leading vs Lagging Strand

- Leading strand: synthesized continuously

- Lagging strand: synthesized discontinuously as Okazaki fragments

AP 常考点：
DNA polymerase can only add nucleotides in the 5′ → 3′ direction.

6.3 DNA Repair and Telomeres

DNA Repair Mechanisms

Cells repair DNA damage using:

- Proofreading by DNA polymerase
- Mismatch repair enzymes
- Nucleotide excision repair

Telomeres

- Repetitive DNA sequences at chromosome ends
- Protect genes from erosion during replication
- Shorten with each cell division

Telomerase:

- Extends telomeres
- Active in germ cells and cancer cells

6.4 Transcription（DNA → RNA）

Overview

Transcription synthesizes RNA using DNA as a template.

Occurs in:

- Nucleus (eukaryotes)
- Cytoplasm (prokaryotes)

Stages of Transcription

Initiation

- RNA polymerase binds to promoter
- TATA box helps locate start site (eukaryotes)

Elongation

- RNA polymerase moves along DNA
- RNA synthesized 5′ → 3′

Termination

- RNA polymerase detaches
- RNA transcript released

6.5 RNA Processing（Eukaryotes only）

Pre-mRNA is modified to form mature mRNA.

Key Modifications

- 5′ cap: protects RNA and aids ribosome binding
- Poly-A tail: increases stability
- RNA splicing: introns removed, exons joined

Alternative Splicing

- Different combinations of exons
- Allows one gene to produce multiple proteins

6.6 Translation（RNA → Protein）

Genetic Code

- Triplet code (codons)
- Redundant but not ambiguous
- Start codon: AUG
- Stop codons: UAA, UAG, UGA

Translation Stages

Initiation

- Ribosome binds mRNA
- tRNA with methionine binds start codon

Elongation

- Amino acids added via peptide bonds
- Ribosome moves along mRNA

Termination

- Stop codon reached
- Polypeptide released

---

tRNA and Ribosomes

- tRNA carries amino acids
- Anticodon pairs with codon
- Ribosomes have A, P, and E sites

6.7 Protein Folding and Modification

Proteins become functional after:

- Folding into correct 3D shape
- Post-translational modifications

Examples:

- Addition of carbohydrates (glycoproteins)
- Phosphorylation
- Cleavage

6.8 Mutations（AP 高频）

Types of Mutations

- Point mutations (substitution)
- Insertions and deletions (frameshift)

Effects

- Silent mutation: no change in amino acid

- Missense mutation: different amino acid
- Nonsense mutation: premature stop codon

AP 推理点：
Frameshift mutations usually have more severe effects than substitutions.

6.9 Regulation of Gene Expression – Prokaryotes

Operon Model

An operon consists of:

- Promoter
- Operator
- Structural genes
- Regulatory gene

Lac Operon

- Inducible operon
- Lactose present → genes expressed
- Glucose presence reduces transcription (catabolite repression)

Trp Operon

- Repressible operon
- Tryptophan present → transcription stops

6.10 Regulation of Gene Expression – Eukaryotes

Regulation occurs at multiple levels:

- Chromatin modification
- Transcriptional control
- Post-transcriptional control
- Translational control
- Post-translational control

Epigenetics

- DNA methylation
- Histone modification

These changes:

- Affect gene expression
- Do not change DNA sequence
- Can be inherited

6.11 Cell Differentiation and Development

- All cells have same genome
- Different genes are expressed
- Controlled by transcription factors and signaling pathways

6.12 AP Exam Skills

Common MCQ Traps

- Confusing transcription with translation
- Forgetting RNA uses uracil instead of thymine
- Ignoring RNA processing in eukaryotes

FRQ Sentence Starters

- “Gene expression is regulated by…”

- “A frameshift mutation alters the reading frame by…”
- “Alternative splicing allows…”

Unit 6 Summary（FRQ 结尾可用）

Genetic information is stored in DNA, expressed through transcription and translation, and regulated at multiple levels. Regulation of gene expression allows cells to respond to environmental changes and differentiate into specialized cell types.

AP Biology – Unit 7: Natural Selection（极致细节满分版）

Unit 7 Big Ideas（AP 官方核心）

Evolution explains the diversity and unity of life.

Populations evolve over generations through natural selection, which acts on heritable variation and results in adaptations that increase reproductive success in a specific environment.

Students must be able to:

- Explain the mechanism of natural selection
- Distinguish microevolutionary processes
- Apply and interpret the Hardy–Weinberg model
- Analyze evidence for evolution
- Interpret phylogenetic trees to infer relationships

7.1 What Is Evolution?（定义与层级）

Evolution is a change in the genetic composition (allele frequencies) of a population over time.

Key clarifications (AP 常考）：

- Evolution occurs in populations, not individuals
- Individuals are selected, but populations evolve
- Natural selection acts on phenotypes, but evolution is measured by genotypes/alleles

---

7.2 Sources of Genetic Variation（选择的原材料）

Natural selection requires heritable variation. Major sources include:

1. Mutation
    - Ultimate source of new alleles
    - Random with respect to fitness
2. Sexual reproduction
    - Independent assortment
    - Crossing over
    - Random fertilization

AP 推理重点：
Selection does not create variation; it filters existing variation.

7.3 Mechanism of Natural Selection（四步机制，必背）

Natural selection occurs when all four conditions are met:

1. Variation exists within a population
2. Overproduction of offspring occurs
3. Differential survival and reproduction
4. Traits are heritable

Result:

- Individuals with advantageous traits leave more offspring
- Alleles associated with those traits increase in frequency

7.4 Fitness and Adaptation（高频概念）

Fitness

Fitness is a measure of reproductive success, not strength or size.

- Depends on environment
- Context-specific

Adaptation

An adaptation is a heritable trait that increases fitness in a specific environment.

AP 易错点：
Traits do not evolve “because organisms need them.”

7.5 Types of Natural Selection

Directional Selection

- One extreme phenotype favored
- Mean shifts over time

Example:

- Antibiotic resistance in bacteria

Stabilizing Selection

- Intermediate phenotype favored
- Reduces variation

Example:

- Human birth weight

Disruptive Selection

- Both extremes favored
- Can lead to speciation

Example:

- Different beak sizes in birds with two food sources

7.6 Other Mechanisms of Evolution（非选择）

Genetic Drift

Random change in allele frequencies, especially in small populations.

Forms:

- Bottleneck effect
- Founder effect

Consequences:

- Reduced genetic diversity
- Loss of rare alleles

Gene Flow

Movement of alleles between populations via migration.

Effects:

- Reduces differences between populations
- Can introduce new alleles

7.7 Hardy–Weinberg Equilibrium（AP 核心模型）

Hardy–Weinberg describes a non-evolving population.

Conditions

1. Large population
2. No mutation
3. No migration
4. Random mating
5. No natural selection

Equations

- $p + q = 1$
- $p^2 + 2pq + q^2 = 1$

Where:

- p = frequency of dominant allele
- q = frequency of recessive allele

AP 推理技能

If any condition is violated → population is evolving.

7.8 Evidence for Evolution（证据链）

Fossil Record

- Shows change over time
- Transitional forms

Comparative Anatomy

- Homologous structures: common ancestry
- Analogous structures: convergent evolution
- Vestigial structures: reduced function

Comparative Embryology

- Similar early development indicates shared ancestry

Molecular Evidence

- DNA and protein sequence similarity
- Greater similarity → closer relationship

7.9 Speciation（物种形成）

Speciation occurs when reproductive isolation evolves.

Prezygotic Barriers

- Temporal
- Behavioral

- Mechanical
- Gametic

Postzygotic Barriers

- Reduced hybrid viability
- Reduced hybrid fertility
- Hybrid breakdown

Allopatric Speciation

- Geographic isolation
- Genetic divergence over time

Sympatric Speciation

- Occurs without geographic separation
- Often involves polyploidy (plants)

7.10 Phylogenetic Trees（读图必考）

Phylogenetic trees represent evolutionary relationships, not time unless stated.

Key rules:

- Nodes = common ancestors
- Closer nodes = closer relationship
- Rotation around a node does not change relationships

AP 易错点：
Species at the “end” are not more evolved.

7.11 Evolution in Response to Environmental Change

Examples:

- Antibiotic resistance
- Pesticide resistance
- Climate-driven selection

AP 核心推理：
Resistance arises from pre-existing variation, not exposure.

7.12 AP Exam Skills

Common MCQ Traps

- Confusing genetic drift with selection
- Thinking selection acts on genes directly
- Misinterpreting Hardy–Weinberg assumptions

FRQ Sentence Starters

- “Natural selection occurs because individuals with…”
- “A deviation from Hardy–Weinberg equilibrium indicates…”
- “The phylogenetic tree suggests that…”

Unit 7 Summary（FRQ 结尾可用）

Evolution is the change in allele frequencies within populations over time. Natural selection acts on heritable variation to produce adaptations, while additional mechanisms such as genetic drift and gene flow also shape evolutionary outcomes.

AP Biology – Unit 8: Ecology

Unit 8 Big Ideas（AP 官方核心）

Ecology examines how organisms interact with each other and with their environment.

Energy flows through ecosystems, while matter is recycled.

Population dynamics, community interactions, and ecosystem stability are shaped by biotic and abiotic factors, including human activity.

Students must be able to:

- Trace energy flow through ecosystems
- Explain nutrient cycles
- Analyze population growth models
- Evaluate species interactions
- Predict ecosystem responses to disturbances and human impacts

---

8.1 Ecology Levels of Organization（基础但必考）

Ecology can be studied at multiple levels:

1. Organism – individual living thing
2. Population – members of same species in same area
3. Community – all populations in an area
4. Ecosystem – community + abiotic factors
5. Biome – large geographic region with similar climate
6. Biosphere – all ecosystems on Earth

AP 易错点：
Energy flows across levels, but matter cycles within and among them.

8.2 Energy Flow Through Ecosystems（核心机制）

Energy Enters as Sunlight

- Primary source of energy for most ecosystems
- Captured by primary producers through photosynthesis

Trophic Levels

1. Primary producers (autotrophs)
2. Primary consumers (herbivores)
3. Secondary consumers
4. Tertiary consumers
5. Decomposers (bacteria, fungi)

10% Rule

Only about 10% of energy is transferred to the next trophic level.

Reasons for energy loss:

- Heat (respiration)
- Waste
- Uneaten biomass

AP 推理重点：
Energy pyramids always decrease upward because energy is lost as heat.

8.3 Food Chains and Food Webs

Food Chain

Linear sequence of energy transfer.

Food Web

Complex network of feeding relationships.

Food webs:

- Are more stable
- Provide alternative energy pathways

8.4 Primary Productivity

Gross Primary Productivity (GPP)

Total energy captured by producers.

Net Primary Productivity (NPP)

Energy available to consumers after respiration.

Formula:

NPP = GPP − Respiration

8.5 Nutrient Cycles（物质循环）

Unlike energy, matter is recycled.

Carbon Cycle

Key processes:

- Photosynthesis
- Respiration
- Decomposition
- Combustion

Human impact:

- Burning fossil fuels increases atmospheric CO_2

Nitrogen Cycle（FRQ 高频）

Key steps:

- Nitrogen fixation
- Nitrification
- Assimilation
- Ammonification
- Denitrification

AP 推理重点：
Plants cannot use atmospheric N_2 directly.

Phosphorus Cycle

- No gaseous phase
- Cycles through rock and soil
- Often limiting in ecosystems

8.6 Population Ecology

Population Density

Number of individuals per unit area.

Population Growth Models

Exponential Growth

- Unlimited resources
- J-shaped curve

Equation:

$dN/dt = rN$

Logistic Growth

- Limited resources
- S-shaped curve
- Carrying capacity (K)

AP 常考点：
When N approaches K, growth rate slows.

8.7 Regulation of Population Size

Density-Dependent Factors

- Competition
- Predation
- Disease
- Parasitism

Density-Independent Factors

- Natural disasters
- Climate events
- Human disturbance

8.8 Community Ecology

Species Interactions

Competition

- Both species harmed
- Limits population size

Predation

- Predator benefits
- Prey harmed

Herbivory

- Similar to predation but prey survives

Symbiosis

- Mutualism (+/+)
- Commensalism (+/0)
- Parasitism (+/−)

8.9 Keystone Species and Trophic Cascades

Keystone Species

Species with disproportionately large impact on ecosystem structure.

Removal leads to:

- Loss of biodiversity
- Trophic cascades

Example:

- Sea otters controlling sea urchins

8.10 Ecological Succession

Primary Succession

- Occurs on bare rock
- No soil present

Secondary Succession

- Soil remains
- Faster recovery

8.11 Ecosystem Stability and Disturbance

Ecosystem stability depends on:

- Species diversity
- Redundancy in food webs

Disturbances can be:

- Natural (fires, storms)
- Human-caused (deforestation)

8.12 Human Impacts on Ecosystems（必考）

Major impacts:

- Climate change
- Habitat destruction
- Pollution
- Invasive species
- Overexploitation

Effects:

- Reduced biodiversity
- Altered nutrient cycles
- Disrupted food webs

8.13 Conservation Biology

Goals:

- Preserve biodiversity
- Maintain ecosystem services
- Promote sustainability

Strategies:

- Habitat protection
- Restoration
- Sustainable resource use

8.14 AP Exam Skills

Common MCQ Traps

- Thinking energy cycles
- Confusing trophic levels
- Misreading population graphs

FRQ Sentence Starters

- “Energy decreases at higher trophic levels because…”
- “Nitrogen fixation is necessary because…”
- “Human activity alters ecosystems by…”

Unit 8 Summary（FRQ 结尾可用）

Ecological systems are shaped by energy flow, nutrient cycling, species interactions, and population dynamics. Human activities can disrupt these processes, but conservation strategies can help maintain ecosystem stability and biodiversity.