

Unit 6: Gene Expression and Regulation

Unit 6 covers DNA and RNA structure, replication, transcription, translation, gene regulation, mutations, and biotechnology. CED topics 6.1 through 6.8.

AP Biology

Gene Expression and Regulation

About 15 minutes to read

How to use this guide

Read it in order the first time because the topics build on each other. The structure of DNA explains how it is copied, the copy explains how it is transcribed, the transcript explains how it is translated, and the whole sequence explains what gene regulation actually controls. Exam questions usually give a change at one step, a mutation or a blocked enzyme, and ask what happens downstream.

After the first read, use the trap boxes and the tables to review the distinctions that exam questions test most often. Finish with the practice questions, then complete the recall check on the last page out loud and note any items you cannot explain yet.

What this unit covers. This is the central dogma unit. It describes how DNA becomes protein and how cells control the process. The ideas connect directly to heredity in Unit 5 and to evolution in Unit 7, because mutations are the raw material that natural selection acts on. Biotechnology questions draw on every topic here, so the details in this unit pay off in several places on the exam.

6.1 DNA and RNA Structure

DNA stores genetic information and passes it to subsequent generations. Some viruses store their genetic information in RNA instead. In cells, the genetic material is carried on **chromosomes**. Prokaryotes typically have one circular chromosome. Eukaryotes typically have multiple linear chromosomes, and the DNA is condensed by wrapping around **histone** proteins. **Plasmids** are small extra circles of DNA found in prokaryotes and eukaryotes, separate from the main chromosome.

The bases fall into two shape families. **Purines**, adenine and guanine, have a double-ring structure. **Pyrimidines**, cytosine, thymine, and uracil, have a single-ring structure. **Base pairing** is strict. A purine always pairs with a pyrimidine. Adenine pairs with thymine in DNA and with uracil in RNA. Guanine pairs with cytosine. This pairing pattern is conserved through evolution, which is why the same rules work in every organism you will meet on the exam.

FEATURE	DNA	RNA
Strands	Double-stranded helix	Usually single-stranded
Sugar	Deoxyribose	Ribose
Bases	Adenine, thymine, guanine, cytosine	Adenine, uracil, guanine, cytosine
Main job	Long-term storage of genetic information	Carrying out the instructions, in several forms

Trap. Uracil replaces thymine in RNA, but the pairing logic does not change. Adenine still pairs with a pyrimidine, so A pairs with U the same way A pairs with T. Questions that ask for an RNA sequence from a DNA template are testing whether you swap in U without disturbing the rest of the pattern.

6.2 Replication

DNA replication copies the genetic information so it can be transmitted when cells divide. New DNA is synthesized in the 5' to 3' direction, and replication is **semiconservative**. Each new DNA molecule keeps one original template strand and gains one newly built complementary strand.

The course names five enzymes, and these are the only replication enzymes the exam requires.

Helicase unwinds the two strands. **Topoisomerase** relaxes the supercoiling that builds up in front of the replication fork. **DNA polymerase** synthesizes the new strands, but it cannot start on its own. It needs a short **RNA primer**, which **primase** synthesizes, to begin, and it builds continuously on the **leading strand** and in fragments on the **lagging strand**. **Ligase** joins those lagging-strand fragments into one piece. Enzymes beyond these five are beyond AP scope, so do not spend time memorizing additional names.

Trap. DNA polymerase always builds in the 5' to 3' direction on both strands. The leading and lagging strands do not differ in direction. They differ in continuity, because the two template strands run antiparallel and the fork only opens one way. Questions that offer a 3' to 5' synthesis direction are testing whether you hold that line.

6.3 Transcription and RNA Processing

Transcription copies one template strand of DNA into RNA. **RNA polymerase** reads the template strand in the 3' to 5' direction and builds the new **mRNA** molecule in the 5' to 3' direction. That mRNA then carries the information from the DNA in the nucleus to the ribosome in the cytoplasm.

In eukaryotes, the raw transcript is edited before it leaves the nucleus. A **5' cap** (a modified guanine nucleotide) is added to help the ribosome recognize the message. A **poly-A tail** is added to make the mRNA more stable. **Introns**, the non-coding segments, are cut out, and **exons**, the coding segments, are spliced together into the mature message. **Alternative splicing** keeps different combinations of exons, so one gene can produce several different mature mRNAs.

Trap. Introns are removed and exons are kept. The names help. Exons are expressed, introns are intervening. Alternative splicing changes which exons are kept, never the DNA sequence of the gene itself.

Trap. Transcription and replication use opposite reading directions on paper but the same building direction. RNA polymerase reads the template 3' to 5' and synthesizes 5' to 3'. If a question gives a template strand, read it 3' to 5' and write the RNA 5' to 3' with U in place of T.

6.4 Translation

Translation builds a **polypeptide**, a chain of amino acids, from the mRNA message. It happens on ribosomes in the cytoplasm of both prokaryotes and eukaryotes, and on the surface of the rough ER in eukaryotes. In prokaryotes, translation can begin while the mRNA is still being transcribed. The mRNA is read in triplets called **codons**. Translation starts at the **start codon** AUG, which codes for methionine, and ends at a **stop codon**, which releases the finished protein.

RNA TYPE	JOB IN TRANSLATION
mRNA	Carries the codon sequence from the nucleus to the ribosome
tRNA	Binds a specific amino acid. Its anticodon base pairs with the mRNA codon and the amino acid is added to the growing chain
rRNA	Forms the functional core of the ribosome itself

The **genetic code** is the set of rules matching each codon to an amino acid, read from a codon chart. Many amino acids are coded by more than one codon, and nearly all living organisms use the same code. That universality is evidence for common ancestry. **Retroviruses** run the flow backward, from RNA to DNA. Their enzyme **reverse transcriptase** copies the viral RNA genome into DNA, which integrates into the host genome and is then transcribed and translated to assemble new viruses.

Trap. The codon is on the mRNA and the anticodon is on the tRNA. Questions swap the two, or ask which molecule carries the anticodon, and the swap is the whole test.

6.5 Regulation of Gene Expression

Cells control transcription through **regulatory sequences**, stretches of DNA that interact with regulatory proteins. Some genes show **constitutive expression** and stay on continuously. An **inducible gene** is expressed only when specific conditions induce it. In prokaryotes, an **operon** groups several genes under one coordinately regulated system, inducible or repressible. In eukaryotes, groups of genes can be influenced by the same **transcription factors** so their expression is coordinated, and the induction of transcription factors during development produces sequential gene expression.

Epigenetic change modifies DNA or histones reversibly to affect expression without changing the DNA sequence. **Cell differentiation** follows from this control. A cell phenotype is determined by which genes are expressed and at what levels, so differentiation means expressing the genes for tissue-specific proteins.

Trap. Operons are a prokaryote structure. If a question describes an operon in a eukaryotic cell, that detail alone makes the statement wrong. Eukaryotes coordinate genes with shared transcription factors instead.

Trap. Epigenetic changes do not alter the DNA sequence. Methylation or histone modification can silence a gene completely while the sequence stays identical. Any answer choice that calls an epigenetic change a mutation confuses regulation with sequence alteration.

6.6 Gene Expression and Cell Specialization

Transcription starts where **RNA polymerase** and transcription factors bind the **promoter**, a DNA sequence that can sit upstream or downstream of the transcription start site. An **enhancer** is a separate DNA sequence where transcription factors bind to affect how much expression occurs. A **negative regulatory molecule** binds DNA and blocks transcription. **Small regulatory RNAs** also have roles in regulating gene expression.

Differential gene expression is the result. Different cells express different sets of genes, producing different cell products and functions, which is what creates phenotypic differences among cells and among organisms.

Trap. The promoter is the binding site where transcription initiates. The enhancer influences the level of expression but is not the start site. Questions that describe transcription factors binding far from the start site and boosting output are describing an enhancer, not a promoter.

6.7 Mutations

A **mutation** is an alteration in a DNA sequence. It can change the type or amount of protein produced and therefore the phenotype. Whether a mutation is beneficial, detrimental, or neutral depends on the environmental context, and mutations are a source of genetic variation. **Mutagens** such as radiation and reactive chemicals can cause random mutations, as can errors in DNA replication or repair.

MUTATION TYPE	WHAT HAPPENS	TYPICAL EFFECT
Point mutation	One nucleotide is substituted for another	Depends on the new codon
Silent mutation	A substitution that does not change the amino acid	No effect on the protein sequence
Nonsense mutation	A substitution that creates a premature stop codon	Shortened, usually nonfunctional protein
Frameshift mutation	Nucleotides are inserted or deleted, shifting the reading frame	Alters every codon downstream
Aneuploidy	Chromosome number changes, often from nondisjunction	New phenotypes, often developmental disorders
Chromosomal alteration	Chromosome structure is altered	Genetic disorders

Bacteria also gain variation without mutation. **Transformation** is the uptake of DNA from the environment. **Transduction** is the transfer of DNA by viruses. **Conjugation** is the direct cell-to-cell transfer of DNA. **Transposition** moves DNA segments within and between DNA molecules. Viruses gain variation another way: when two related viruses infect the same host cell, **viral recombination** can combine their genetic information, increasing genetic variation. Specific named disorders and their mutations are beyond AP scope, so learn the categories, not individual disease cases.

Trap. A frameshift requires an insertion or deletion. A single-nucleotide substitution can never cause a frameshift, no matter how damaging it is. If the question says one base was swapped, the answer stays in the point mutation family.

Trap. Transformation, transduction, and conjugation are three different delivery routes. Transformation takes up free DNA from the surroundings, transduction uses a virus as the carrier, and conjugation passes DNA directly from cell to cell. The question usually names the carrier, and the carrier names the process.

6.8 Biotechnology

Genetic engineering covers the techniques used to analyze and manipulate DNA and RNA. The exam requires what each technique accomplishes, not the step-by-step details of how it is performed.

TECHNIQUE	WHAT IT DOES
PCR	Amplifies DNA fragments. The DNA is denatured, primers anneal to the original strands, and new DNA is extended, producing many copies
Gel electrophoresis	Separates DNA fragments by size and charge
DNA sequencing	Determines the order of nucleotides in a DNA molecule
DNA fingerprint	A DNA pattern from sequencing or electrophoresis used to compare samples
Bacterial transformation	A laboratory technique that introduces foreign DNA into bacterial cells

These tools are applied to identify organisms, perform phylogenetic analysis, identify individuals forensically, create genetically modified organisms including transgenic animals, and clone DNA fragments for propagation. Those applications are illustrative examples, so understand how each technique could be used without memorizing any single case.

Trap. PCR makes copies, electrophoresis separates, sequencing reads the order. Questions deliberately hand you the wrong tool for the job, such as sequencing when the task needs amplification. Match the verb in the question stem, copy, separate, or read, to the technique before looking at the options.

Practice Questions

Original questions written for this guide in the style of the AP exam. Answers and explanations are on the next page, so complete the questions before checking them.

- 1.** A bacterial cell with DNA labeled by a heavy isotope replicates once in medium containing only normal light nucleotides. Each of the two resulting DNA molecules contains
 - A. one heavy strand and one light strand
 - B. one fully heavy molecule and one fully light molecule
 - C. two strands that are each half heavy and half light
 - D. two light strands

- 2.** Which statement about DNA synthesis on the lagging strand is accurate?
 - A. DNA polymerase builds it continuously in the 5' to 3' direction
 - B. It is built in fragments that ligase joins together
 - C. It requires no RNA primer to begin synthesis
 - D. DNA polymerase builds it in the 3' to 5' direction

- 3.** A DNA template strand segment reads 3'-TAC-GGA-5'. The mRNA transcribed from this segment reads
 - A. 5'-AUG-CCU-3'
 - B. 5'-UAC-GGA-3'
 - C. 3'-AUG-CCU-5'
 - D. 5'-ATG-CCT-3'

- 4.** A eukaryotic gene contains five exons. Alternative splicing of its primary transcript can produce
 - A. different mature mRNAs from the same gene
 - B. permanent changes to the DNA sequence of the gene
 - C. the same protein in every cell type
 - D. removal of exons from the chromosome

- 5.** A bacterial operon controlling genes for nutrient breakdown is switched off until the nutrient appears in the environment, at which point transcription begins. This operon is best described as
- A. constitutively expressed
 - B. an inducible system
 - C. regulated by alternative splicing
 - D. silenced by a frameshift mutation
- 6.** Two cells from the same organism have identical DNA sequences, but a histone modification causes one cell to express a gene that the other does not express. This difference is best described as
- A. a point mutation
 - B. an epigenetic change
 - C. aneuploidy
 - D. a chromosomal alteration
- 7.** A single-nucleotide substitution changes a codon that specified an amino acid into a stop codon. This mutation is best classified as
- A. a silent mutation
 - B. a frameshift mutation
 - C. a nonsense mutation
 - D. transduction
- 8.** A forensic scientist has only a trace amount of DNA from a sample and needs many identical copies before analysis can begin. The appropriate technique is
- A. gel electrophoresis
 - B. DNA sequencing
 - C. PCR
 - D. bacterial transformation

Answer Key

- 1. A.** Semiconservative replication keeps one original strand in each new molecule, so each daughter has one heavy template strand and one light new strand. B describes conservative replication, C describes dispersive replication, and D ignores that the template strands are retained.
- 2. B.** The lagging strand is built discontinuously in fragments because the fork opens in only one direction, and ligase joins them. A describes the leading strand, C is wrong because DNA polymerase needs an RNA primer on both strands, and D reverses the synthesis direction, which is 5' to 3' everywhere.
- 3. A.** RNA polymerase reads the template 3' to 5' and builds 5' to 3', pairing A with U. TAC becomes AUG and GGA becomes CCU. B copies the template directly without transcribing, C writes the product in the wrong direction, and D leaves thymine in an RNA molecule.
- 4. A.** Alternative splicing retains different combinations of exons, so one gene yields multiple mature mRNAs. B confuses splicing with mutation, C is the opposite of what splicing allows, and D mistakes transcript editing for a change to the chromosome.
- 5. B.** A system that stays off until a specific condition turns it on is inducible. A is the opposite, always on. C happens in eukaryotes during RNA processing, not in bacterial operons. D invents a mutation the stem never mentions.
- 6. B.** A histone modification that changes expression without changing the sequence is an epigenetic change. A requires a sequence alteration, which the stem rules out. C changes chromosome number and D changes chromosome structure, neither of which occurred here.
- 7. C.** A substitution that creates a premature stop codon is a nonsense mutation. A would leave the amino acid unchanged, B requires an insertion or deletion that shifts the frame, and D is a viral gene transfer process, not a mutation type at all.
- 8. C.** PCR amplifies a small DNA sample into many copies through denaturing, primer annealing, and extension. A separates fragments by size but copies nothing, B reads nucleotide order but does not amplify, and D inserts foreign DNA into bacteria rather than copying a sample.

When you check your answers, note which distinction each miss came from. Make a flashcard for that distinction and drill it spaced out over the next few days instead of rereading the whole section. If you missed one of these questions, the same distinction is worth practicing again in Rycal, where the Gene Expression and Regulation deck has flashcards for it and more practice questions use the same kinds of traps.

One-Page Recall Check

Say each answer out loud before you look back, and mark the ones you cannot finish. Anything you cannot say out loud yet belongs in your flashcard deck. In Rycal, add those items to the Gene Expression and Regulation deck and let spaced review bring them back over the next few days.

- State the base-pairing rules for DNA, then for RNA.
- Name the five replication enzymes and give one job for each.
- Explain why the lagging strand is built in fragments while the leading strand is not.
- Describe the direction RNA polymerase reads and the direction it builds.
- List the three eukaryotic mRNA processing steps and what each accomplishes.
- Distinguish an intron from an exon.
- Explain how alternative splicing produces protein variety without new genes.
- Match mRNA, tRNA, and rRNA to their roles in translation.
- Explain why a nearly universal genetic code supports common ancestry.
- Describe the flow of genetic information in a retrovirus.
- Distinguish constitutive expression from an inducible gene.
- Explain what an operon is and in which organisms operons are found.
- Distinguish a promoter from an enhancer.
- Explain how two cells with identical DNA end up as different cell types.
- Distinguish point, silent, nonsense, and frameshift mutations.
- Name the three routes of horizontal gene transfer in bacteria and how they differ.
- Distinguish PCR, gel electrophoresis, and DNA sequencing by what each accomplishes.

Where to go next. Turn every missed item above into flashcards and drill them spaced out over several days rather than in one sitting. In Rycal, open the Gene Expression and Regulation deck under AP Biology. The deck covers the terms in this guide, and its practice questions target the same traps named here. If you have a test date, add it in the Test Planner. You can also start your next review with a Brain Dump, then check what you missed against this guide.

Key terms for this unit

DNA, chromosome, histone, plasmid, purine, pyrimidine, base pairing, DNA replication, semiconservative replication, helicase, topoisomerase, primase, DNA polymerase, RNA primer, leading strand, lagging strand, ligase, mRNA, tRNA, rRNA, transcription, RNA polymerase, poly-A tail, 5' cap, intron, exon, alternative splicing, translation, codon, start codon, stop codon, genetic code, polypeptide, retrovirus, reverse transcriptase, viral recombination, regulatory sequence, constitutive expression, inducible gene, epigenetic change, cell differentiation, transcription factor, operon, coordinately regulated genes, promoter, enhancer, negative regulatory molecule, differential gene expression, small regulatory RNA, mutation, point mutation, frameshift mutation, nonsense mutation, silent mutation, mutagen, aneuploidy, chromosomal alteration, transformation, transduction, conjugation, transposition, mutation examples, genetic engineering, gel electrophoresis, PCR, bacterial transformation, DNA sequencing, DNA fingerprint, biotechnology applications.