

Unit 5: Heredity

Unit 5 covers meiosis, the sources of genetic variation, Mendel's laws of inheritance, non-Mendelian patterns, and how the environment shapes phenotype. CED topics 5.1 through 5.5.

AP Biology

Heredity

About 12 minutes to read

How to use this guide

Read it in order the first time because the topics build on each other. Meiosis comes first because every genetics topic in this unit depends on what chromosomes do during gamete formation. Mendel's laws describe the inheritance patterns, and the non-Mendelian section describes where those patterns break down. The unit closes with the environment, which can change what genes actually produce.

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 is worth. Unit 5 carries 8 to 11 percent of the AP Biology exam. The chromosome mechanics here return in Unit 6, where gene expression builds on how chromosomes behave, and the genetic variation produced in this unit is the raw material for natural selection in Unit 7.

5.1 Meiosis

Meiosis is the cell division that produces **gametes**, the reproductive cells. It starts with one diploid cell, copies the DNA once, then divides twice. The result is four haploid cells, each genetically different from the parent cell and from each other.

Most body cells are **diploid**. They carry two full sets of chromosomes, one set from each parent. Gametes are **haploid**. They carry a single set. When two gametes fuse at fertilization, the diploid number is restored in the zygote.

Chromosomes come in **homologous** pairs. Each pair holds one chromosome from the mother and one from the father. The two chromosomes of a pair look alike and carry genes for the same traits, but they may carry different alleles of those genes.

Meiosis I

Meiosis I is the first division, and it is the one that makes the cells haploid. In prophase I, homologous chromosomes pair up along their lengths. This pairing is **synapsis**, and at the points where the paired chromosomes touch, **chiasmata** can form. Crossing over happens at these points and is covered in the next section. In metaphase I, the homologous pairs line up together at the **metaphase plate**, the midline of the cell. In anaphase I, the homologous chromosomes separate and move to opposite poles while the sister chromatids stay attached to each other. Telophase I ends with two haploid daughter cells.

Meiosis II

Meiosis II is the second division, and no DNA is copied between the two divisions. In metaphase II, the chromosomes line up at the metaphase plate with their **kinetochores**, the attachment structures on each chromatid, connected to spindle microtubules reaching from the poles. In anaphase II, the sister chromatids finally separate and move apart. The division ends with four haploid cells, each carrying one unduplicated chromatid from every original chromosome.

FEATURE	MEIOSIS I	MEIOSIS II
What separates	Homologous chromosomes	Sister chromatids
Prophase	Synapsis and crossing over occur	No synapsis, no crossing over
Metaphase	Homologous pairs align at the plate	Single chromosomes align at the plate
Anaphase	Homologs separate, chromatids stay together	Chromatids separate
Result	Two haploid cells	Four haploid cells

Trap. In anaphase I, homologous chromosomes separate. Sister chromatids do not separate until anaphase II. When a question asks what pulls apart in anaphase I and you answer chromatids, you are describing the wrong division.

Trap. Haploid means one full set of chromosomes, not half a chromosome. After meiosis I the two cells are already haploid, even though each chromosome still consists of two joined chromatids.

5.2 Meiosis and Genetic Diversity

Sexual reproduction shuffles genes in three separate steps, and the exam tests each one by name.

Crossing over happens in prophase I. Non-sister chromatids of homologous chromosomes exchange segments of genetic material. The chromatids that result carry new combinations of alleles that neither parent chromosome had. This recombination is the first source of diversity.

Random assortment happens in metaphase I. Each homologous pair lines up at the metaphase plate independently of every other pair. Which chromosome of each pair goes to which pole is a matter of chance, so every gamete receives a random mix of maternal and paternal chromosomes. With n chromosome pairs, the number of possible combinations is two raised to the n th power.

Fertilization adds the third shuffle. Two haploid gametes fuse, the diploid number is restored, and the zygote carries a new combination of alleles from two parents.

When separation fails

Nondisjunction is the incorrect separation of chromosomes during meiosis. Homologous chromosomes can fail to separate in meiosis I, or sister chromatids can fail to separate in meiosis II. Either mistake produces gametes that are no longer haploid. They carry too many or too few chromosomes, and any zygote formed from them carries an abnormal chromosome number.

Trap. Crossing over and random assortment both increase diversity, but they happen at different steps. Crossing over is prophase I, an exchange between chromatids. Random assortment is metaphase I, the independent lining up of whole homologous pairs.

Mitosis vs. meiosis

FEATURE	MITOSIS	MEIOSIS
Purpose	Growth and repair	Gamete formation
Divisions	One	Two
Daughter cells	Two diploid cells, genetically identical	Four haploid cells, genetically unique
Synapsis and crossing over	Do not occur	Occur in prophase I
Homologs separate	Never; chromatids separate	In anaphase I

5.3 Mendelian Genetics

An **allele** is a version of a gene. Mendel's **law of segregation** states that the two alleles of a gene separate during gamete formation, so each gamete ends up with one allele or the other. His **law of independent assortment** states that genes on different chromosomes are sorted into gametes independently of each other. The first law explains why a heterozygous parent passes each allele to about half its gametes. The second explains why the inheritance of one trait does not drag another trait along with it, as long as the genes sit on different chromosomes.

The vocabulary of crosses

Genotype is the set of alleles an organism carries for one or more genes. **Phenotype** is the observable expression of those alleles, the trait you can actually see or measure. **Homozygous** means two identical alleles for a gene. **Heterozygous** means two different alleles. A **dominant allele** shows its phenotype even when paired with a different allele. A **recessive allele** is masked whenever the dominant allele is present, and its phenotype appears only in the homozygous recessive genotype.

CROSS	WHAT IT ANALYZES	WHAT IT REVEALS
Monohybrid cross	One gene, two alleles	Whether alleles behave as dominant or recessive
Dihybrid cross	Two genes at once	Whether the genes assort independently
Test cross	Unknown genotype crossed with a homozygous recessive individual	The unknown genotype, from the offspring phenotypes

Trap. Dominant describes what happens when two different alleles meet. It says nothing about how common the allele is in a population. A dominant allele can be rare and a recessive allele can be widespread.

Trap. A test cross works only because the partner is homozygous recessive. Every allele the recessive parent contributes is known, so each offspring phenotype directly reveals which allele the unknown parent contributed.

5.3 Mendelian Genetics, continued

Reading Punnett squares and pedigrees

A **Punnett square** is a diagram that predicts the genotypes and phenotypes of offspring from a cross. Each box is one possible combination, and the ratios across the boxes are probabilities. They describe what to expect across many offspring, not what any single offspring must be.

A **pedigree** is a family-tree chart used to work out patterns of inheritance. From a pedigree you can judge whether a trait looks autosomal or sex-linked and whether the allele behaves as dominant or recessive. A trait that appears in every generation and passes from an affected parent to about half the children points to dominance. A trait that skips generations and appears in children of unaffected parents points to recessiveness.

Working a dihybrid cross

When two individuals heterozygous for two genes on different chromosomes are crossed, the gametes carry every combination of the two genes in equal numbers. That is the law of independent assortment in action. The classic phenotypic result is a 9:3:3:1 ratio, with nine showing both dominant traits, three and three showing one dominant trait each, and one showing both recessive traits. If the genes were on the same chromosome, the ratio would break down because the genes would travel together.

Testing ratios with probability and chi-square

Two tools turn predicted ratios into testable claims. The **rules of probability** handle the math of crosses: if two outcomes are mutually exclusive, the probability of either is the sum, $P(A \text{ or } B) = P(A) + P(B)$; if two events are independent, the probability of both is the product, $P(A \text{ and } B) = P(A) \times P(B)$. The **chi-square test** checks whether observed offspring ratios differ statistically from the ratios Mendel's laws predict. It starts with a **null hypothesis**, usually that the observed ratios match the predicted ones, and ends with a decision to reject it or fail to reject it.

Trap. The law of segregation is about the two alleles of one gene parting in gamete formation. The law of independent assortment is about different genes being sorted independently. Questions that ask which law a scenario shows are testing whether you keep one-gene and two-gene situations apart.

5.4 Non-Mendelian Genetics

Many traits do not follow Mendel's simple dominant-recessive pattern. The exam tests four departures by name, plus three related concepts.

When the heterozygote looks different

Codominance expresses the phenotypes of both alleles at once, so the heterozygote looks different from either homozygote. Both alleles show up side by side rather than one masking the other.

Incomplete dominance blends the two alleles, so the heterozygote phenotype falls between the two homozygotes instead of showing either one fully.

PATTERN	HETEROZYGOTE PHENOTYPE
Complete dominance	Shows the dominant phenotype only
Incomplete dominance	Intermediate, a blend of both homozygotes
Codominance	Shows both alleles fully, side by side

Trap. Codominance is not a blend. If the heterozygote shows patches, spots, or both traits distinctly, both alleles are being expressed and the pattern is codominance. A smooth intermediate is incomplete dominance.

Linked genes and mapping

Genetic linkage describes genes located on the same chromosome. They tend to segregate together during meiosis, which violates the law of independent assortment. But crossing over in prophase I can separate linked genes, and it does so more often when the genes sit farther apart. **Genetic mapping** uses that relationship. The percentage of recombinant offspring becomes the map distance in map units, so a 7 percent recombination frequency means the genes sit about 7 map units apart.

5.4 Non-Mendelian Genetics, continued

Sex-linked traits

Sex-linked traits come from genes on the X or Y chromosome, and their inheritance patterns can often be read straight from a pedigree. Because males carry only one X chromosome, a recessive allele on the X shows its phenotype in a male whenever it is present. That is why X-linked recessive traits appear more often in males. An affected son must have received the allele from his mother, since his single X comes from her.

One gene, many effects, and DNA outside the nucleus

Pleiotropy is the expression of a single gene producing multiple traits or effects. Those traits travel together because they come from the same gene, so they do not assort independently.

Non-nuclear inheritance involves DNA in chloroplasts or mitochondria, and it does not follow Mendel's rules. In animals these organelles are usually transmitted by the egg, and in plants by the ovule, so the traits are typically inherited from the mother regardless of the father's genotype.

Trap. Linked genes and sex-linked genes answer different questions. Linked means two genes sit on the same chromosome. Sex-linked means a gene sits on a sex chromosome. A gene can be both at once, but the terms are not interchangeable.

Trap. In non-nuclear inheritance, look for the maternal pattern. If every child of an affected mother shows the trait and no child of an affected father does, the gene is almost certainly mitochondrial or chloroplast, not nuclear.

5.5 Environmental Effects on Phenotype

Genes do not work in a vacuum. **Phenotypic plasticity** is the ability of one genotype to produce different phenotypes under different environmental conditions. The DNA stays the same. What changes is how the genes are expressed.

The examples run across kingdoms. Human height and weight shift with nutrition. Flower color changes with soil pH. Arctic animals grow different fur with the seasons. In some reptiles, the temperature of the nest determines the sex of the offspring. Increased ultraviolet exposure raises melanin production in skin. In yeast and other fungi, mating type changes pheromone production.

Trap. Plasticity is not mutation and it is not evolution. No allele changes and no new genotype appears. When the environment shifts back, the phenotype can shift back too, because the underlying genotype never changed.

This section connects back to the start of the unit. Meiosis and Mendel explain how genotypes are built and shuffled. Plasticity explains why the same genotype can still look different in different places, which is exactly what natural selection in Unit 7 gets to act on.

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 cell in anaphase I of meiosis is observed under a microscope. Which of the following is occurring?
 - A. Sister chromatids are separating and moving to opposite poles
 - B. Chromosomes are aligning at the metaphase plate
 - C. Homologous chromosomes are separating and moving to opposite poles
 - D. The nuclear envelope is reforming around two haploid nuclei
- 2.** During prophase I of meiosis, segments are exchanged between chromatids of paired homologous chromosomes. Which of the following best describes this event and its result?
 - A. Non-sister chromatids exchange segments, producing recombinant chromatids with new allele combinations
 - B. Sister chromatids exchange segments, producing two identical chromatids
 - C. Homologous chromosomes separate to opposite poles, halving the chromosome number
 - D. Kinetochores attach to spindle microtubules, preparing for chromatid separation
- 3.** A plant with purple flowers could be homozygous dominant or heterozygous, since purple is dominant to white. To determine the plant's genotype, a researcher should cross it with a
 - A. purple-flowered plant of unknown genotype
 - B. purple-flowered plant known to be heterozygous
 - C. white-flowered plant known to be heterozygous
 - D. white-flowered plant, which must be homozygous recessive
- 4.** Two fruit flies heterozygous for two genes on different chromosomes are crossed. The offspring show a 9:3:3:1 phenotypic ratio. This result best illustrates
 - A. the law of segregation
 - B. the law of independent assortment
 - C. genetic linkage
 - D. incomplete dominance

- 5.** In a certain breed of chicken, the alleles for black feathers (B) and white feathers (W) produce a heterozygote with both black and white feathers clearly visible in distinct patches. This inheritance pattern is best described as
- A. incomplete dominance
 - B. complete dominance
 - C. codominance
 - D. pleiotropy
- 6.** A pedigree shows a trait appearing mostly in males. Every affected male has a mother who carries the allele, and the trait never passes directly from father to son. The trait is most likely
- A. X-linked recessive
 - B. autosomal dominant
 - C. autosomal recessive
 - D. mitochondrial
- 7.** Two linked genes show recombinant offspring in 12 percent of the progeny of a test cross. The map distance between the two genes is approximately
- A. 1.2 map units
 - B. 24 map units
 - C. 6 map units
 - D. 12 map units
- 8.** Genetically identical plants grown in acidic soil produce blue flowers, while the same genotype grown in basic soil produces pink flowers. This observation best illustrates
- A. a mutation in the flower-color gene caused by soil pH
 - B. phenotypic plasticity
 - C. independent assortment of flower-color alleles
 - D. nondisjunction during gamete formation

Answer Key

- 1. C.** Anaphase I separates homologous chromosomes while sister chromatids stay attached. A describes anaphase II, where chromatids finally part. B describes metaphase, the lining-up step before separation. D describes telophase, after the chromosomes have already moved.
- 2. A.** Crossing over exchanges segments between non-sister chromatids of homologous chromosomes in prophase I, creating recombinant chromatids. B swaps in sister chromatids, which would produce no new combinations. C describes anaphase I, a later step. D describes kinetochore attachment in metaphase II, a different division entirely.
- 3. D.** Crossing the unknown plant with a homozygous recessive white plant reveals the unknown genotype, because every allele from the white parent is known. A adds no information since both genotypes are unknown. B is the wrong tool: crossing with a known heterozygote cannot cleanly reveal the unknown genotype the way a recessive partner can. C is impossible, since a white-flowered plant showing the recessive phenotype cannot be heterozygous.
- 4. B.** A 9:3:3:1 ratio from a dihybrid cross shows genes on different chromosomes assorting independently. A concerns the two alleles of a single gene separating, which a one-trait cross would test. C is the opposite situation: linked genes travel together and distort the ratio. D concerns the heterozygote phenotype, which says nothing about how two genes sort.
- 5. C.** Distinct patches of both colors mean both alleles are fully expressed side by side, which is codominance. A would produce a blended intermediate color, not patches. B would show only one color in the heterozygote. D describes one gene affecting multiple traits, which is unrelated to how the two feather alleles interact.
- 6. A.** Males show X-linked recessive traits whenever they carry the allele because they have only one X, and each affected son must receive that X from his mother. B and C would affect both sexes more evenly across the pedigree. D would pass from affected mothers to all of their children, not mostly to sons.
- 7. D.** Map distance in map units equals the recombination percentage, so 12 percent means about 12 map units. A misplaces the decimal. B doubles the value for no reason. C invents a number with no basis in the data given.
- 8. B.** One genotype producing different phenotypes in different environments is phenotypic plasticity. The soil changes gene expression, not the DNA. A mistakes an expression change for a mutation. C and D name meiosis concepts that have nothing to do with environmental effects on an already grown plant.

One-Page Recall Check

- Walk through meiosis I and II in order, naming what separates at each anaphase.
- Explain how crossing over and random assortment each increase genetic diversity, and name the meiotic step where each happens.
- Define haploid and diploid, and say which cells of the body are which.
- State Mendel's law of segregation and law of independent assortment in your own words, and say which kind of cross tests each.
- Explain what a test cross reveals and why the partner must be homozygous recessive.
- Distinguish genotype from phenotype, and homozygous from heterozygous.
- Distinguish codominance from incomplete dominance, giving the heterozygote phenotype for each.
- Explain how a recombination frequency becomes a map distance in map units.
- Explain why X-linked recessive traits appear more often in males, using a pedigree argument.
- Name two environmental effects on phenotype from this unit and explain what phenotypic plasticity means.

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 Heredity 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

Meiosis, haploid, diploid, gamete, homologous chromosome, meiosis I, meiosis II, synapsis, chiasma, metaphase plate, kinetochore, crossing over, random assortment, nondisjunction, fertilization, allele, law of segregation, law of independent assortment, monohybrid cross, dihybrid cross, test cross, genotype, phenotype, homozygous, heterozygous, dominant allele, recessive allele, Punnett square, pedigree, genetic linkage, genetic mapping, codominance, incomplete dominance, sex-linked trait, pleiotropy, non-nuclear inheritance, phenotypic plasticity, centromere, cytokinesis, meiotic spindle, mitosis and meiosis, genetic diversity, zygote, map unit, null hypothesis, rules of probability, chi-square test, environmental phenotype examples.

About this guide. Written for Rycal and aligned to the College Board AP Biology course framework, Unit 5, topics 5.1-5.5. All questions and explanations are original Rycal writing. Rycal is independent and is not affiliated with or endorsed by the College Board.